High Energy Gamma-ray Astrophysics with the Fermi Gamma-ray Space Telescope

Stefano Ciprini

1. ASI Science Data Center, Frascati, Roma
2. INAF Roma Observatory

asdc ASI Science Data Center

agenzia spaziale italiana
Italian Space Agency

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

High Energy Astrophysics and Gamma-ray Astronomy

L' Universo e' "IL LABORATORIO" in cui si possono osservare tutte le leggi della natura all'opera, spesso in condizioni limite che non possono essere riprodotte all'interno dei laboratori terrestri

- Applicazione delle leggi note per descrivere fenomeni in condizioni estreme
- Scoperta di nuove leggi della fisica sulla base delle osservazioni sperimentali
- L'osservazione del "laboratorio cosmico" ha lo svantaggio di non poter permettere, nella maggioranza dei casi, la verifica sperimentale e la ripetibilità dell'esperimento, ma in cambio fornisce il vantaggio dell'evoluzione, Per ogni sistema astrofisico e per ogni classe di sorgente ed oggetto l'Universo ci fornisce istantanee di tutte le sue fasi di vita ed evoluzione. L'osservazione del cosmo è intrinsecamente una ricerca scientifica in 4 dimensioni e dinamica.

Nuove leggi della fisica derivate dall' osservazione astronomica:

OSSERVAZIONI

- **Tycho Brahe misura il moto dei pianeti**
- **Leggi di Keplero**
- **Osservazione dello spettro delle stelle (nane bianche)**
- **Formula di Balmer**
- **Perdita di energia per radiazione gravitazionale in sistemi binari**

LEGGI

- **Keplero scopre le leggi del moto dei pianeti**
- **Newton: gravitazione universale**
- **Scoperta della serie di Balmer per l'atomo di idrogeno**
- **Teoria di Bohr dell'atomo**
- **Relativita' generale di Einstein**

"La filosofia e' scritta in questo grandissimo libro che continuamente ci sta aperto innanzi agli occhi (co l'universo) , ma non si puo' intendere se prima non si impara ad intendere la lingua, e conoscer i caratteri, ne' quali e' scritto. Egli e' scritto in lingua matematica, e i caratteri son triangoli, cerchi ed altre figure geometriche, senza i quali mezi e' impossibile a internderne umana parola: senza questi e' un aggirarsi vanamente per un oscuro labirinto"

Galileo Galilei

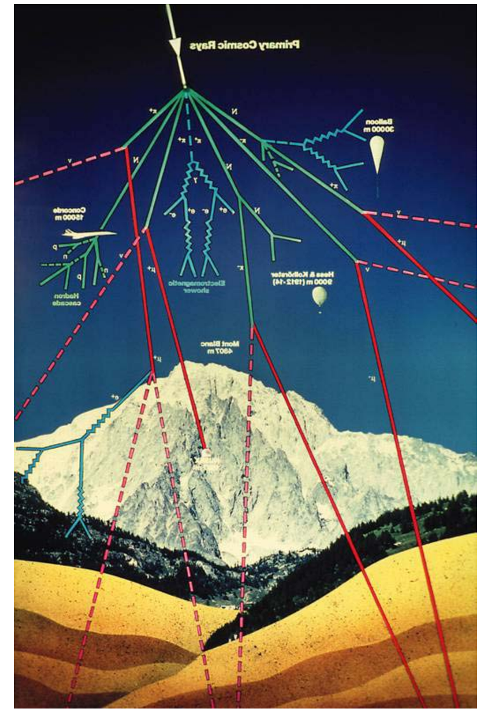
Il Saggiatore 1623

High Energy Astrophysics and Gamma-ray Astronomy

L'Universo ad alta energia e' fatto di particelle

SCOPERTA DELLE PARTICELLE SUB-ATOMICHE

- Maxwell, 1864: Teoria dell'elettromagnetismo
- Hertz, 1884: conferma l'esistenza delle onde elettromagnetiche
- Crookes, 1879: conduzione nei gas (buoni tubi a vuoto - Geissler-) + (alta tensione - Rumhkorff-) "raggi catodici"
- Thomson, 1895: *e/m 2000 volte piu' piccolo che per l'idrogeno* usando un tubo di Crookes con un vuoto ancora migliore
- Rontgen, 1895: raggi X emessi da un tubo di Crookes
- Becquerel, 1896: radioattivita' naturale
- Rutherford, 1898: α, β
- Villard, 1900: γ

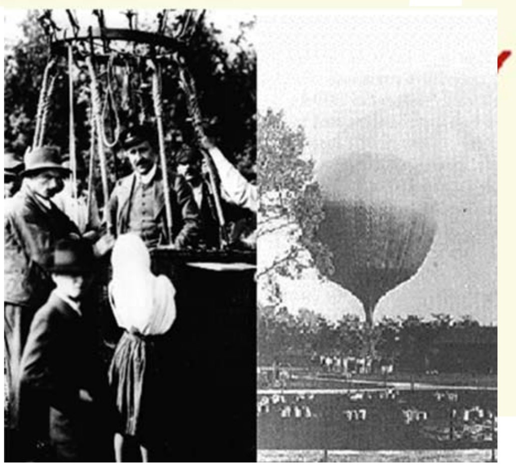


SCOPERTA DEI RAGGI COSMICI

- 1900: gli elettroscopi si scaricano
- Wulf, 1910: ma sulla torre Eiffel durano di piu'! (migliore elettroscopio dell'epoca)
- Hess 1912, Kolhorster, 1914: ma sopra 1,5 Km durano di meno! Radiazione ionizzante che proviene dallo spazio
- Millikan, 1925: li chiama Raggi Cosmici
- Skobeltsyn, 1929: alcune tracce in camera a nebbia sono molto rigide - β secondari dovuti alla radiazione γ di Hess (?)
- Geiger-Muller, 1929: osservazione istantanea delle particelle ionizzanti
- Bothe, Kolhorster, 1929: tecnica della coincidenza (0,01 s) I raggi cosmici sono a) carichi b) penetranti c) energetici (10^{9}-10^{10} eV) -----> non sono γ non sono β, non sono α

High Energy Astrophysics and Gamma-ray Astronomy

- *Cosmic Rays* are subatomic particles and radiation of *extra-terrestrial* origin.
- First discovered in 1912 by Austrian scientist *Victor Hess*, measuring radiation levels aboard a balloon at up to 17,500 feet *(without oxygen!)*
- Hess found increased radiation levels at higher altitudes: named them *Cosmic Radiation*



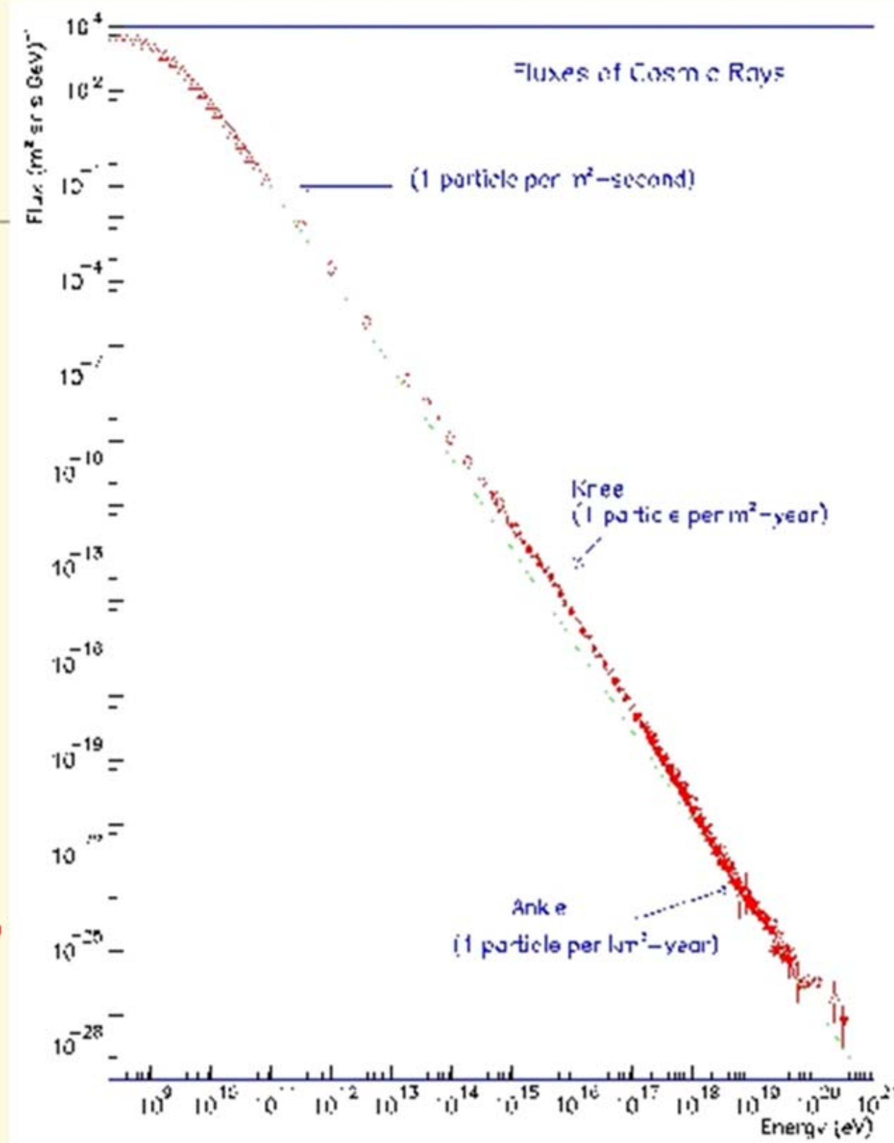
Energy of Cosmic Rays

- Cosmic Rays have been observed with energies at up to ~10^{20} eV:

  (1 eV = energy drop of one electron through a 1 V battery/cell… e.g. a 40 W light bulb uses about 10^{24} eV in one hour)
- The *flux* (rate of particles per unit area) follows a *power law*

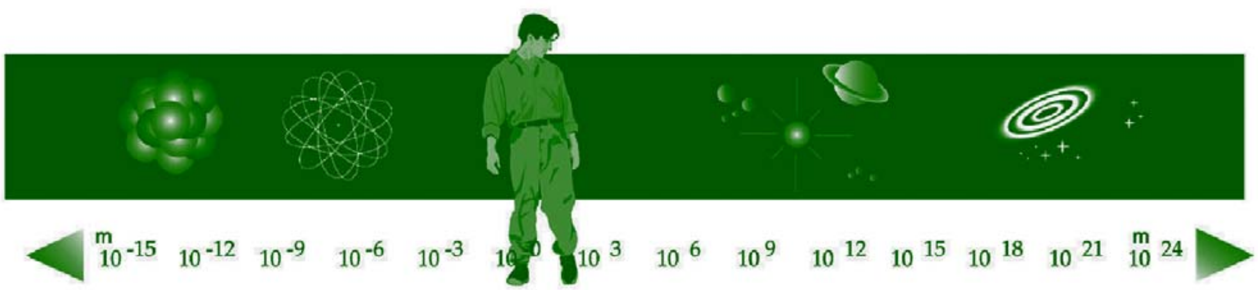
  ~E^{-3}

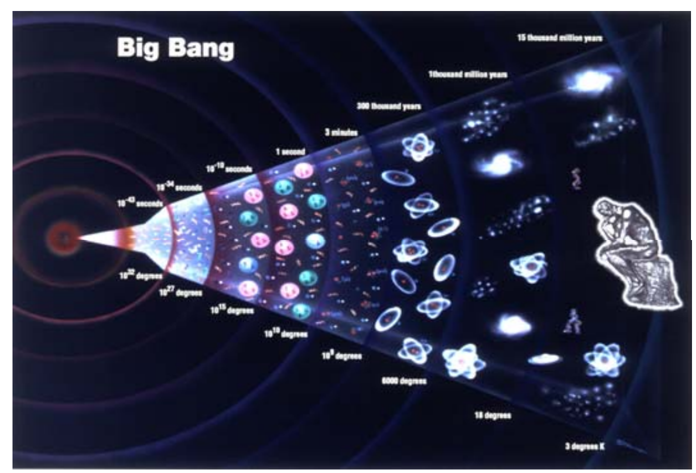
  (very rapidly falling)



SCOPERTA DELLE PARTICELLE ELEMENTARI

- Wilson, 1910: Camera a nebbia, i nuclei hanno massa multipla del protone
- Bothe, Becker 1930, Curie, Joliot 1932: radiazione neutra dalla radioattivita'
- Chadwick: sono dei neutroni
- Anderson, 1930: camera a nebbia, scoperta del positrone (predetto da Dirac)
- Blackett,Occhialini, 1933: camera a nebbia tecnica di coincidenza Geiger, alta statistica di positroni nei RC
- Anderson, 1936: ma ci sono particelle positive e negative piu' penetranti e di massa intermedia (mesoni, massa 20-400 volte la massa dell'elettrone) (Yukawa aveva predetto i pioni)
- Rochester, Butler,1947: camera a nebbia , osservazione decadimenti di K e Λ nei RC, vita media lunga 10^{-8} - 10^{-10} s
- Powell, 1947: pacchi di emulsione Ilford, produzione e decadimento dei π+ e π-
- Manchester Group, 1952 :camera a bolle, scoperta della Ξ^{-} sul Pic du Midi
- Italian Group, 1953: scoperta della Σ
- <u>dal 1953 avvento degli acceleratori per studio particelle elementari</u>





Photons

Photons: Until 1945: Optical Band

THERMAL EMISSION

$\nu_{max} = 10^{11}$ (T/K) Hz

λ_{max} T = 3 10^{6} nm K

$\lambda \sim 300 - 800$ nm

T ~ 3000 - 10000 K

Photons: After 1945 …. Radio band

Long wave: Synchrotron radiation

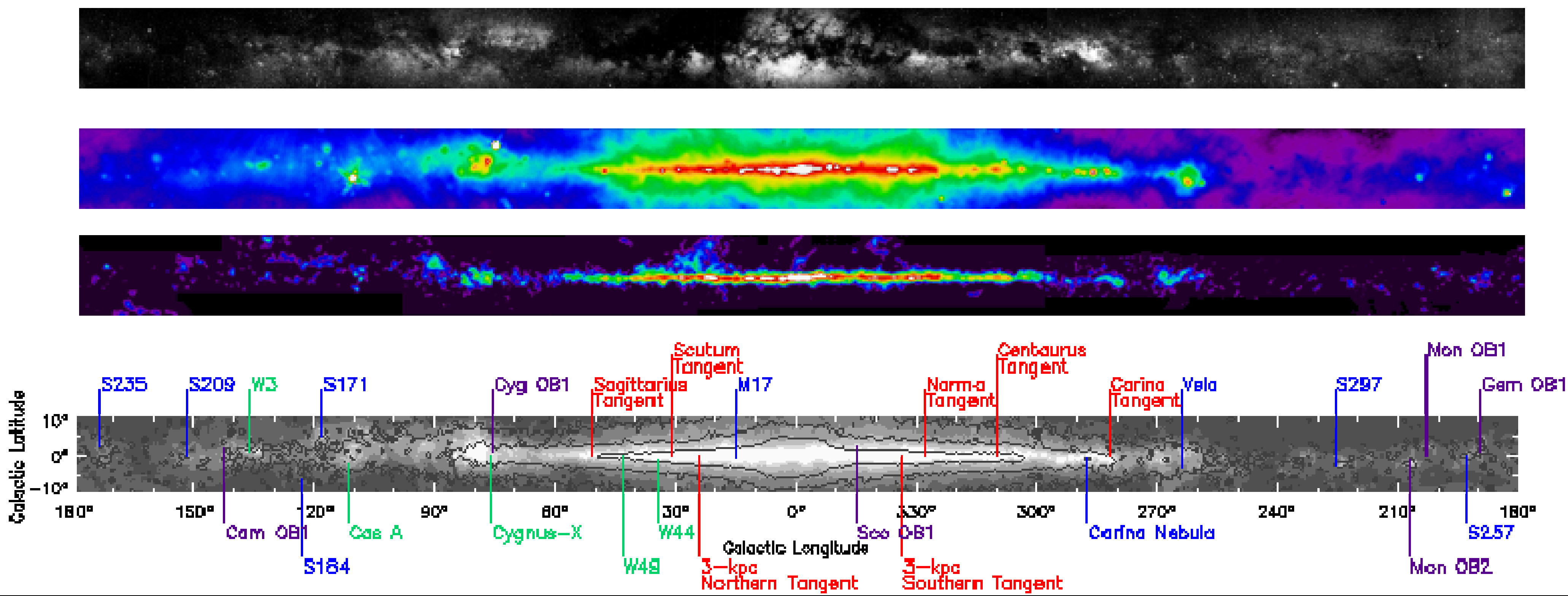
$\lambda \sim 73$ cm

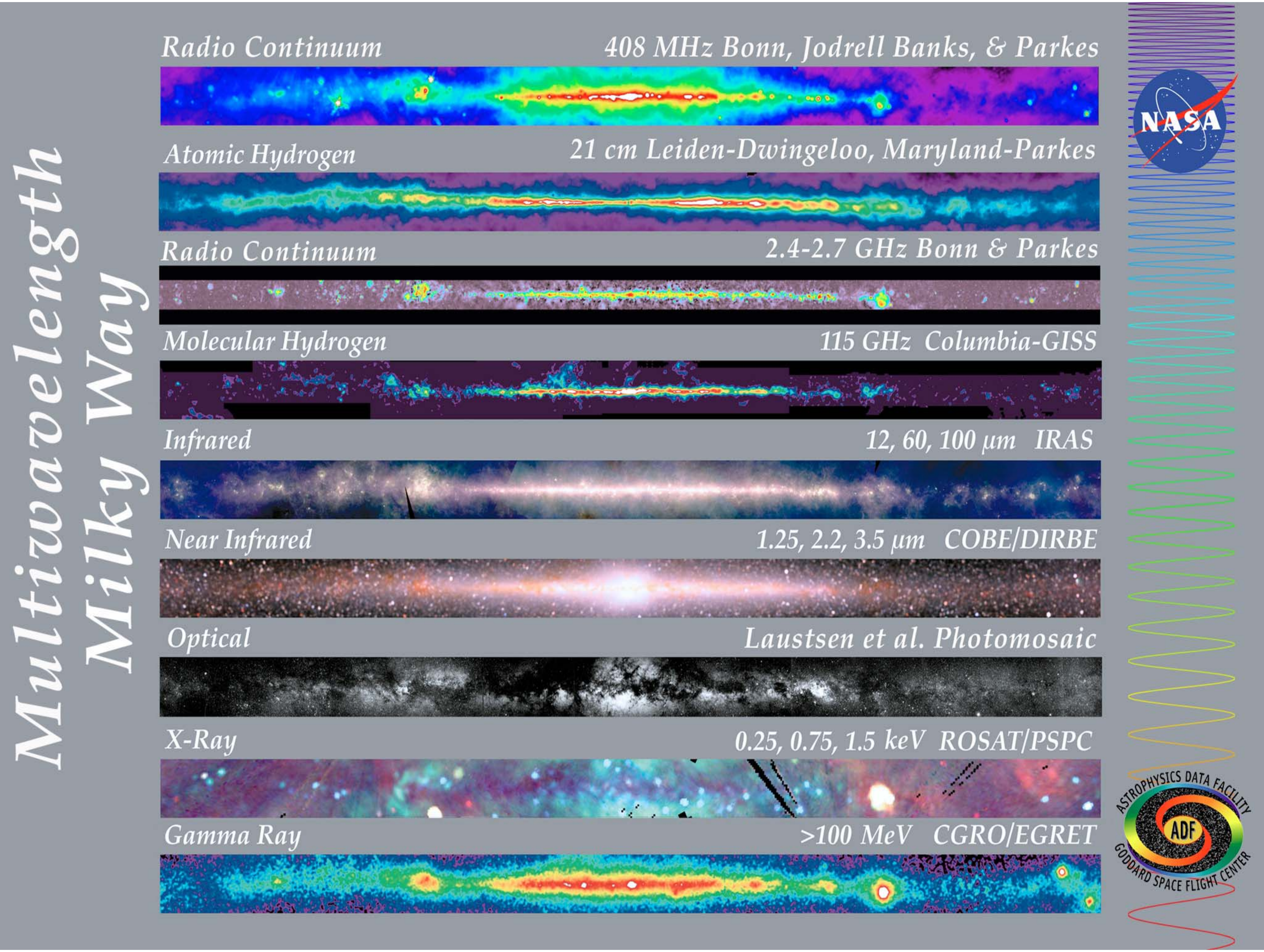
$\nu \sim 408$ MHz

Microwave: Bremstrahlung radiation CBR

$\lambda \sim 5.7$ mm

$\nu \sim 53$ GHz

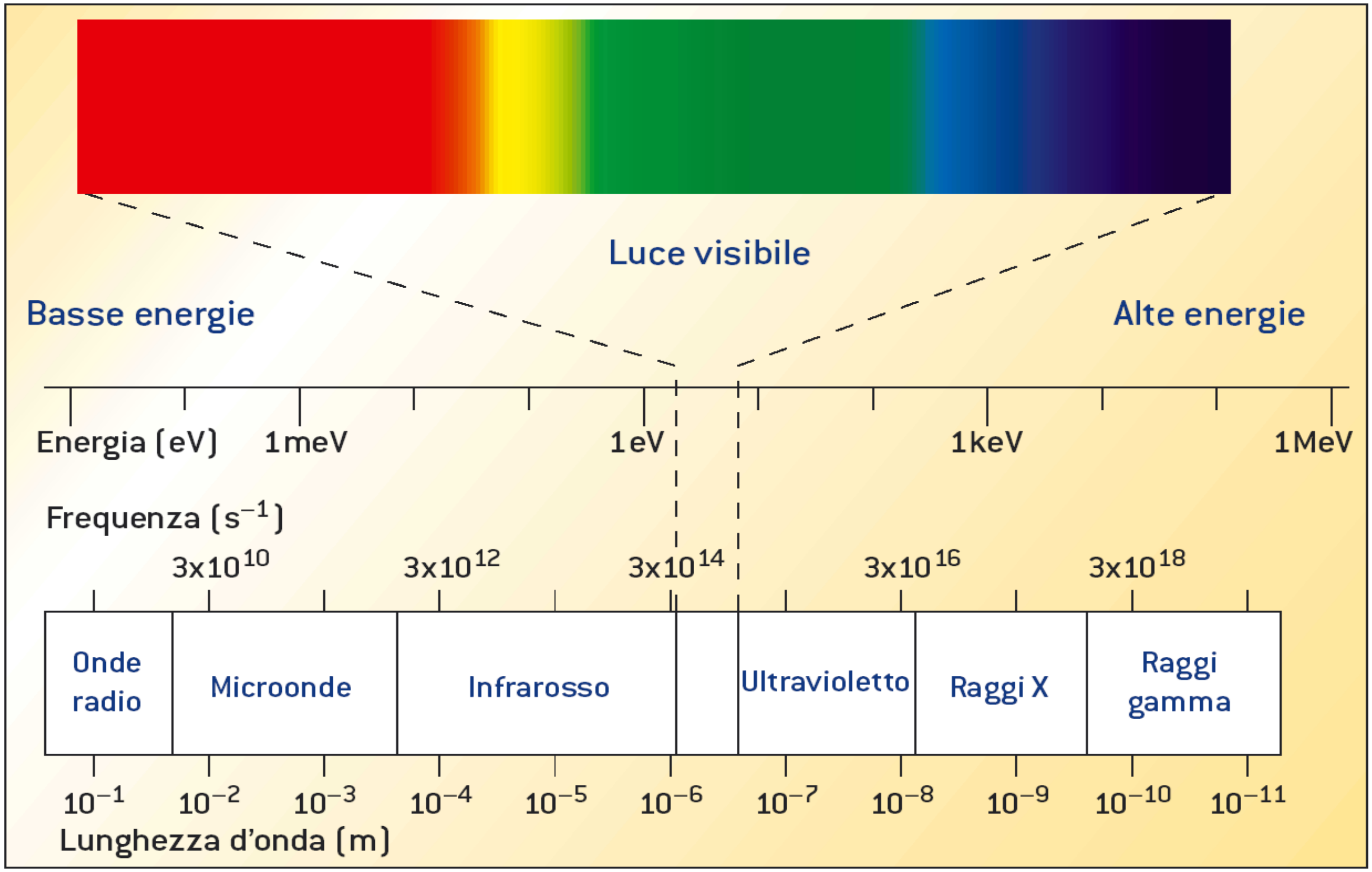



Multiwavelength
Milky Way
Radio Continuum
408 MHz Bonn, Jodrell Banks, & Parkes
Atomic Hydrogen
21 cm Leiden-Dwingeloo, Maryland-Parkes
Radio Continuum
2.4-2.7 GHz Bonn & Parkes
Molecular Hydrogen
115 GHz Columbia-GISS
Infrared
12, 60, 100 μm IRAS
Near Infrared
1.25, 2.2, 3.5 μm COBE/DIRBE
Optical
Laustsen et al. Photomosaic
X-Ray
0.25, 0.75, 1.5 keV ROSAT/PSPC
Gamma Ray
>100 MeV CGRO/EGRET
ASTROPHYSICS DATA FACILITY
ADF
GODDARD SPACE FLIGHT CENTER

What is a gamma-ray?

The term is historical and not descriptive. It refers to a portion of the electro-magnetic spectrum (but they didn't know it at the time the name was invented!):

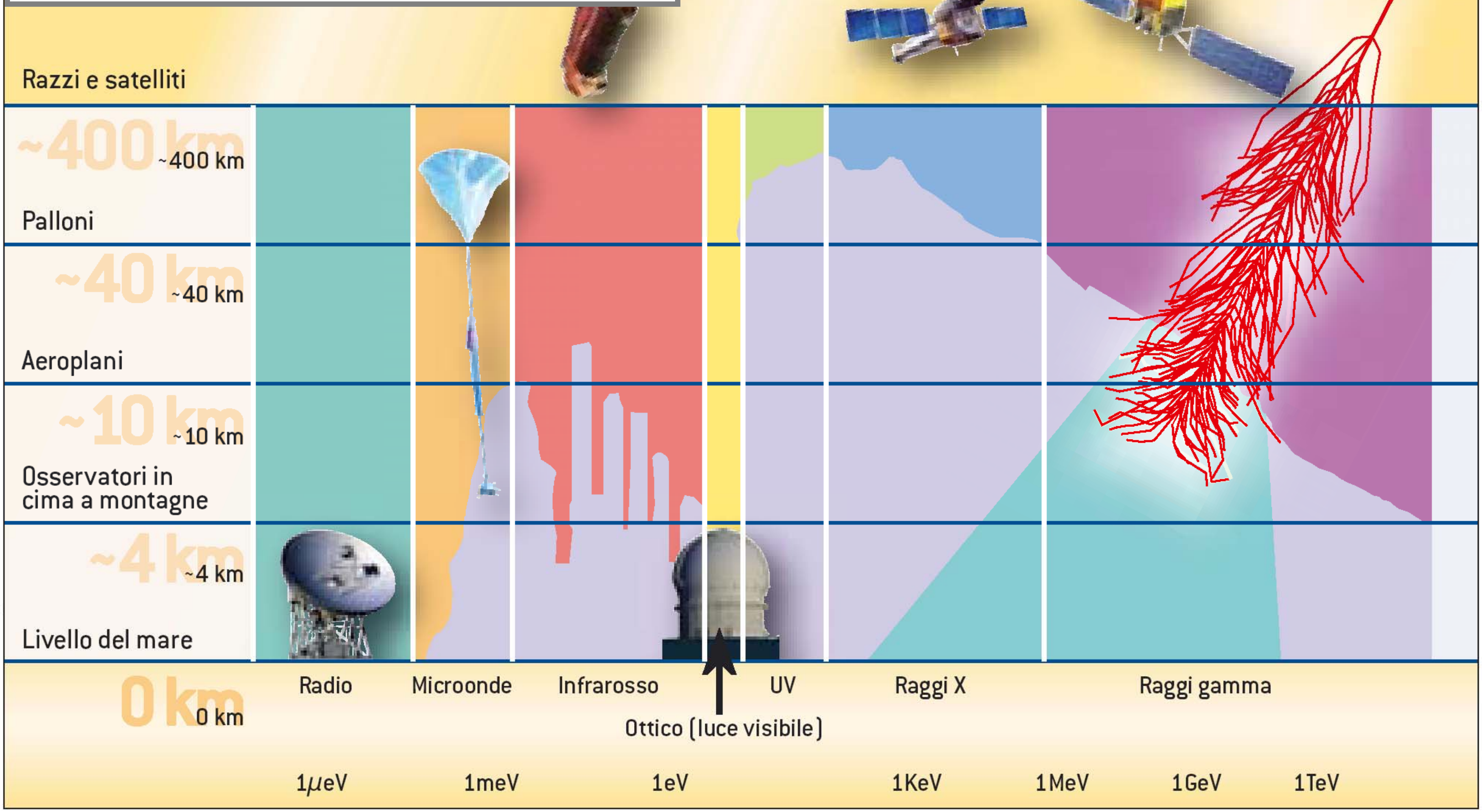
Einstein (1905) light quantum hypothesis: electromagnetic radiation is composed of discrete particles (later called PHOTONS) whose energy is $E=hc/\lambda$, where h is Planck's constant (4.1357×10^{-15} eV s), λ is the wavelength, and $c=3\times10^{8}$ m/s.



Question: why do particle physicists want to build more powerful accelerators?

Radiazione e.m. (multifrequenza) e atmosfera

L'ALTITUDINE FINO ALLA QUALE PENETRA UN FOTONE influenza la scelta degli strumenti da usare per la rivelazione. Mentre le onde radio e la luce visibile sono ben rivelabili a terra, i raggi gamma lo sono solo a energie più alte di una cinquantina di GeV, come sciami elettromagnetici.



Danilo Sossi, su indicazione degli autori

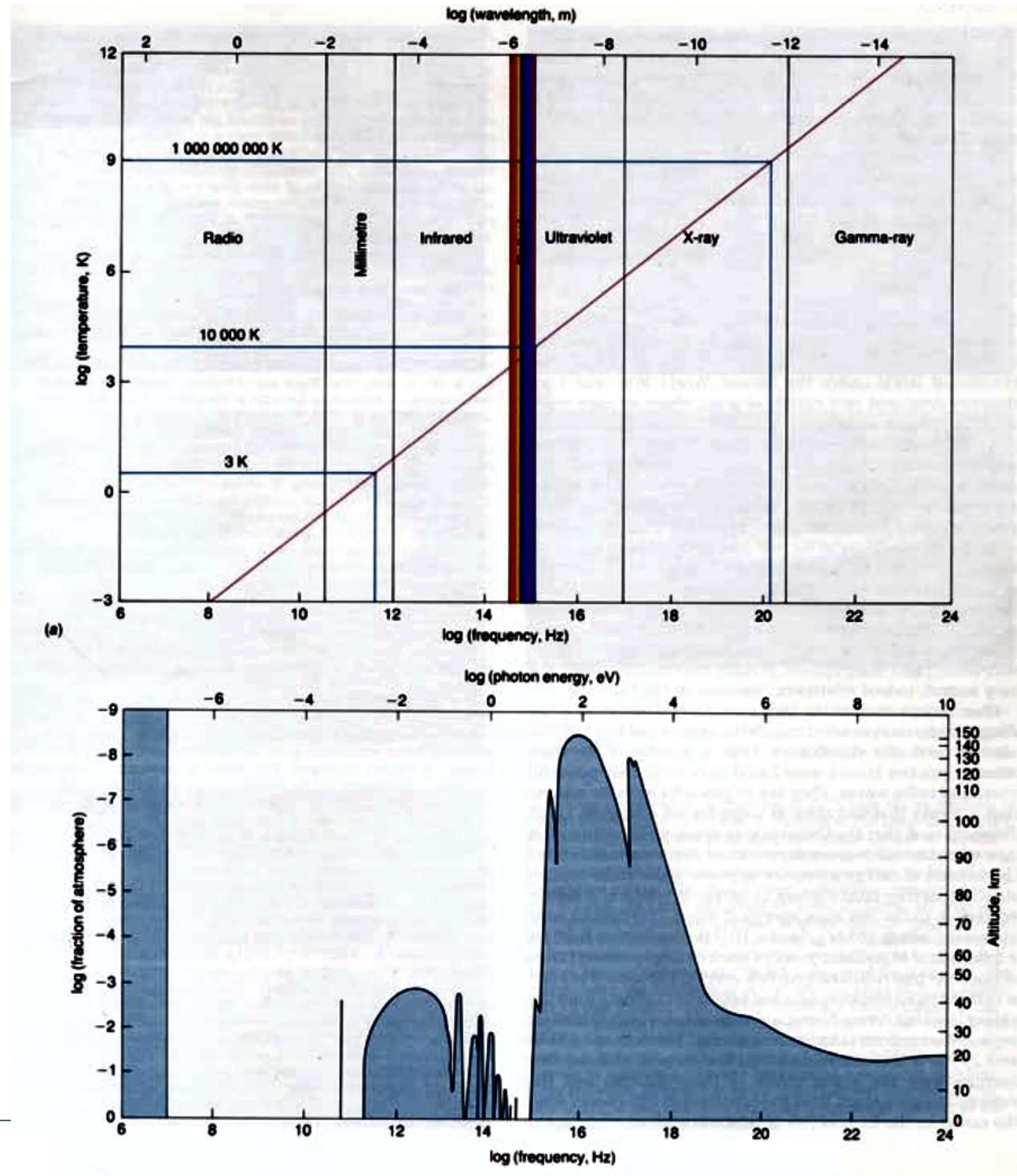
ASI Science Data Center

Radiazione e.m. (multifrequenza) e atmosfera

Gamma ray attenuation

Relation between the temperature of a black body and the frequency at which most of the energy is emitted

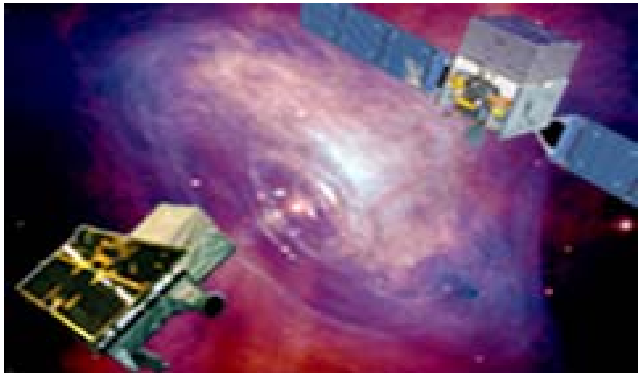
Transparency of the atmosphere for radiation of different wavelengths. The solid line show the height above sea-level at which the atmosphere becomes tranparent.



Why study gamma-rays ?

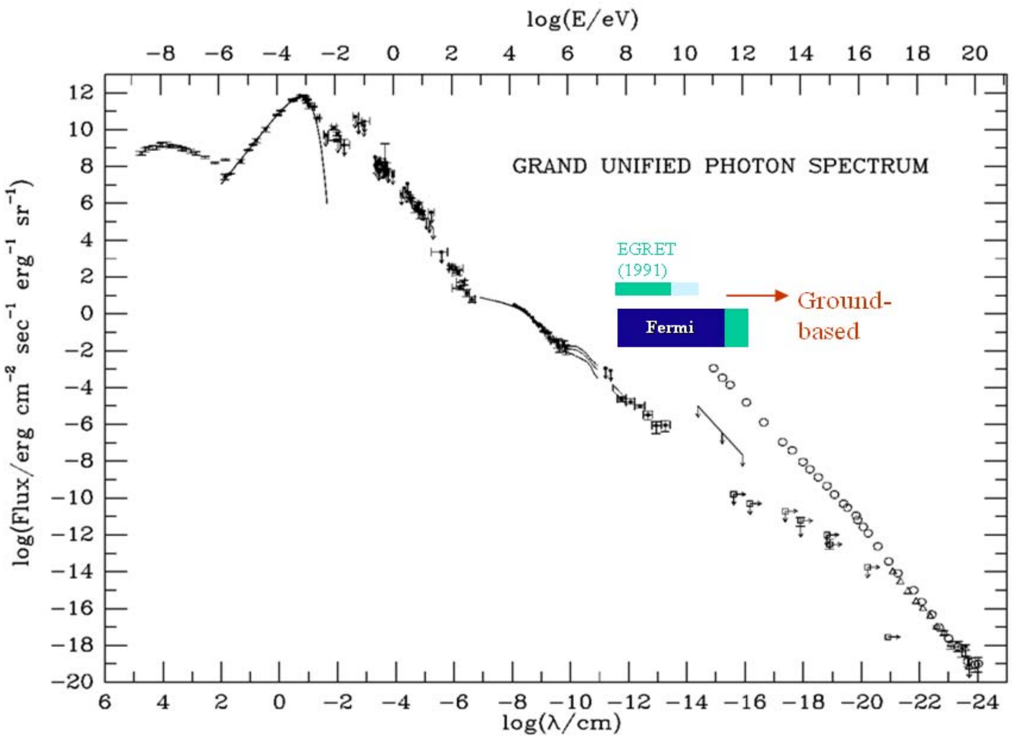
Gamma-rays carry a wealth of information:

- ❑ γ rays do not interact much at their source: they offer a direct view into Nature's largest accelerators.
- ❑ similarly, the Universe is mainly transparent to γ rays: can probe cosmological volumes. Any opacity is energy-dependent (light interacts with light!).
- ❑ conversely, γ rays readily interact in detectors, with a clear signature.
- ❑ γ rays are neutral: no complications due to magnetic fields. Point directly back to sources, etc.



The Flux of Diffuse Extra-Galactic Photons

The Grand Unified Photon Spectrum (GUPS) c.a. 1990, Ressell and Turner



Note:
1 MeV=10^6 eV
1 GeV=10^9 eV
1 TeV=10^{12} eV
1eV=1.6x10^{-19}J

Why study gamma-rays ?

Fermi/GLAST do fundamental science, with a very broad menu that includes:

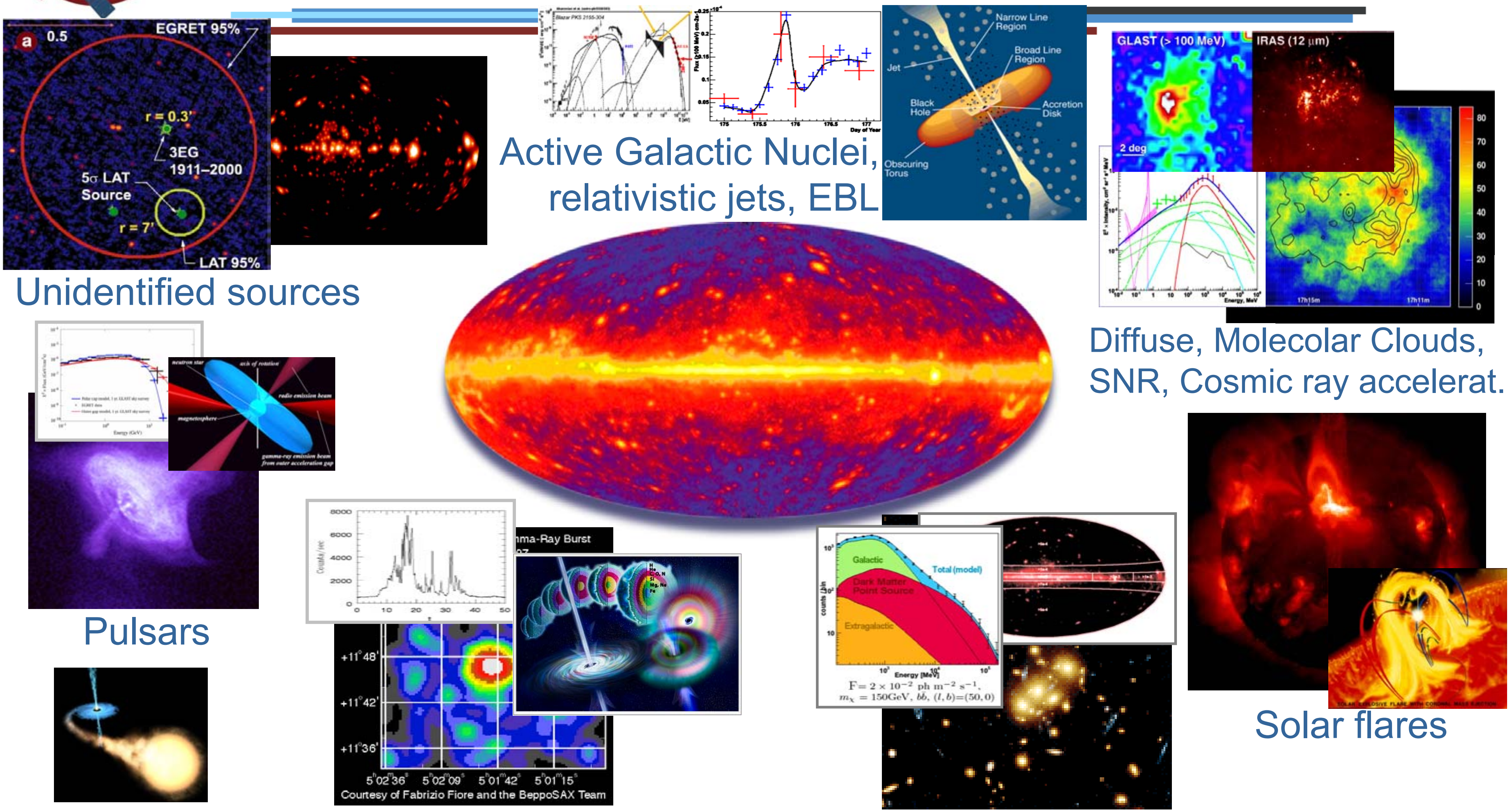
- Systems with supermassive black holes
- Gamma-ray bursts (GRBs)
- Dark Matter
- Solar physics
- Origin of Cosmic Rays
- Probing the era of galaxy formation
- Discovery! Hawking Radiation? Other relics from the Big Bang? – Huge increment in capabilities.

Fermi/GLAST draws the interest of both the the High Energy Particle Physics and High Energy Astrophysics communities.

GLAST Science Topics List

1. Galactic Diffuse Radiation and Emission from Normal Galaxies
2. Gamma-ray Emission from Molecular Clouds
3. Extragalactic Diffuse Radiation and LogN-LogS of Extragalactic Sources
4. Gamma-ray Emission from Plerions
5. Cosmic Ray Acceleration and Gamma-ray Emission from SNR shells
6. High-Energy Emission from Galaxy Clusters
7. Particle Acceleration and Gamma-ray Emission in Pulsars
8. High-Energy Emission from Neutron Stars in Binary Systems
9. Gamma-ray Emission from Blazar AGNs: Emission mechanisms, multiwavelength spectral studies and time variability
10. Luminosity Evolution of AGN Blazars and spectral cutoffs: population and EBL studies
11. High-Energy Gamma-ray Emission from Seyfert and Radio Galaxies
12. Unidentified High-Energy Sources: Population Studies
13. Unidentified High-Energy Sources: Radio/Optical/X-ray identifications
14. High-Energy Emission from Stellar-Mass Galactic Black Hole Candidates
15. The Galactic Center
16. Spectral Searches for Dark Matter
17. Search for Signatures of Quantum Gravity
18. Search for Primordial Black Hole Evaporation
19. Gamma-Ray Bursts: Testing Emission Models
20. Gamma-ray Bursts: Afterglows and Multiwavelength Observations
21. Solar Flares

High energy gamma-ray sky above 100 MeV



Unidentified sources

Active Galactic Nuclei, relativistic jets, EBL

Diffuse, Molecolar Clouds, SNR, Cosmic ray accelerat.

Pulsars

Solar flares

Microquasars

Gamma Ray Bursts

Dark matter, cosmology, particle physics

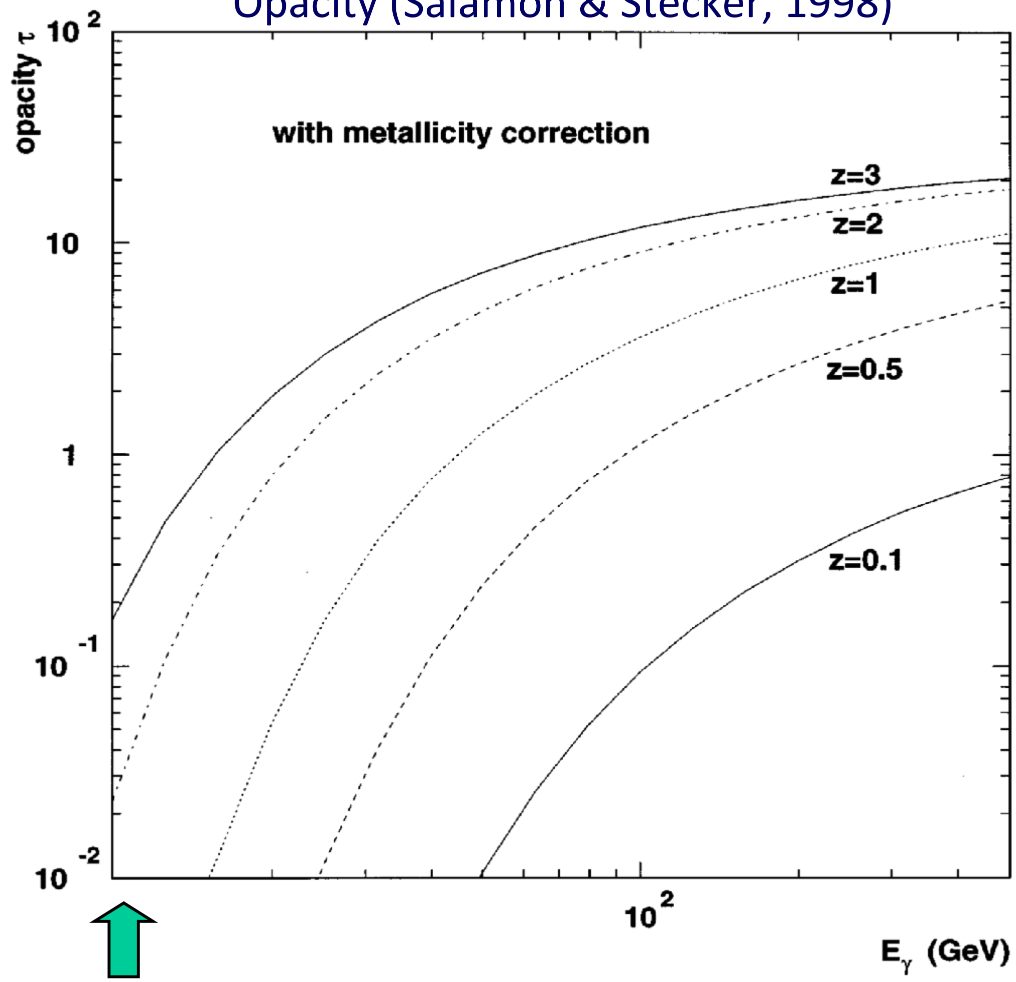
0.01 GeV | 0.1 GeV | 1 GeV | 10 GeV | 100 GeV | 1 TeV

Gamma-rays useful also for Cosmology

Photons with E>10 GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL)

- ❑EBL over cosmological distances is probed by gammas in the 10-100 GeV range.
- ❑In contrast, the TeV-IR attenuation results in a flux that may be limited to more local (or much brighter) sources.
- ❑ A dominant factor in EBL models is the time of galaxy formation -- attenuation measurements can help distinguish models.

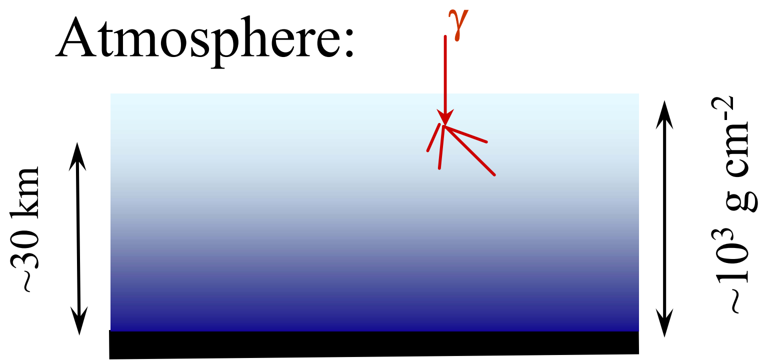
Opacity (Salamon & Stecker, 1998)



No significant attenuation below ~10 GeV.

Gamma-ray Detection and Measurement

Atmosphere:



For E_g < ~ O(100) GeV, must detect above atmosphere (balloons, satellites, rockets)

For E_g > ~ O(100) GeV, information from showers penetrates to the ground (Cherenkov)

Energy loss mechanisms:

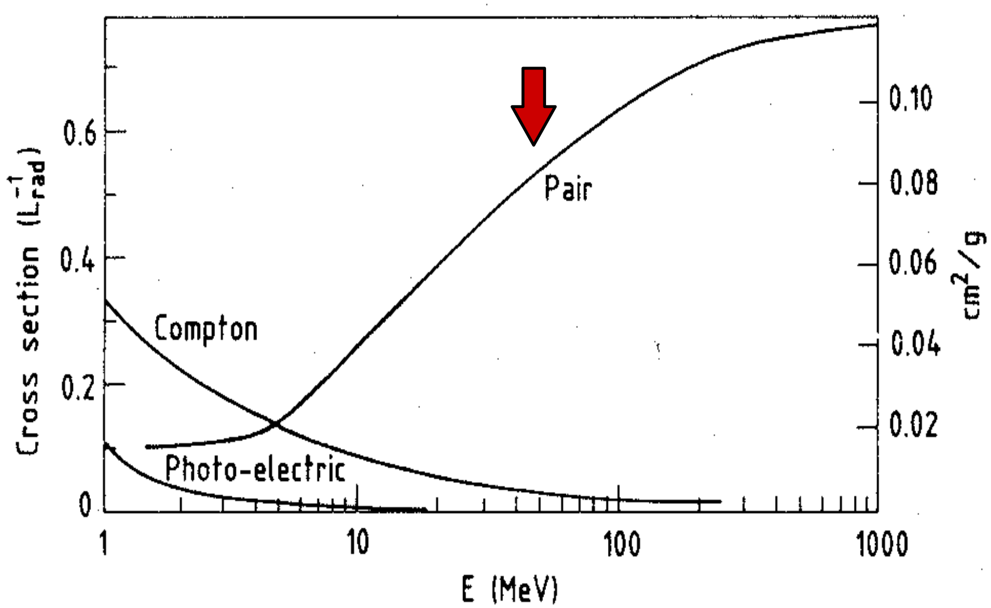
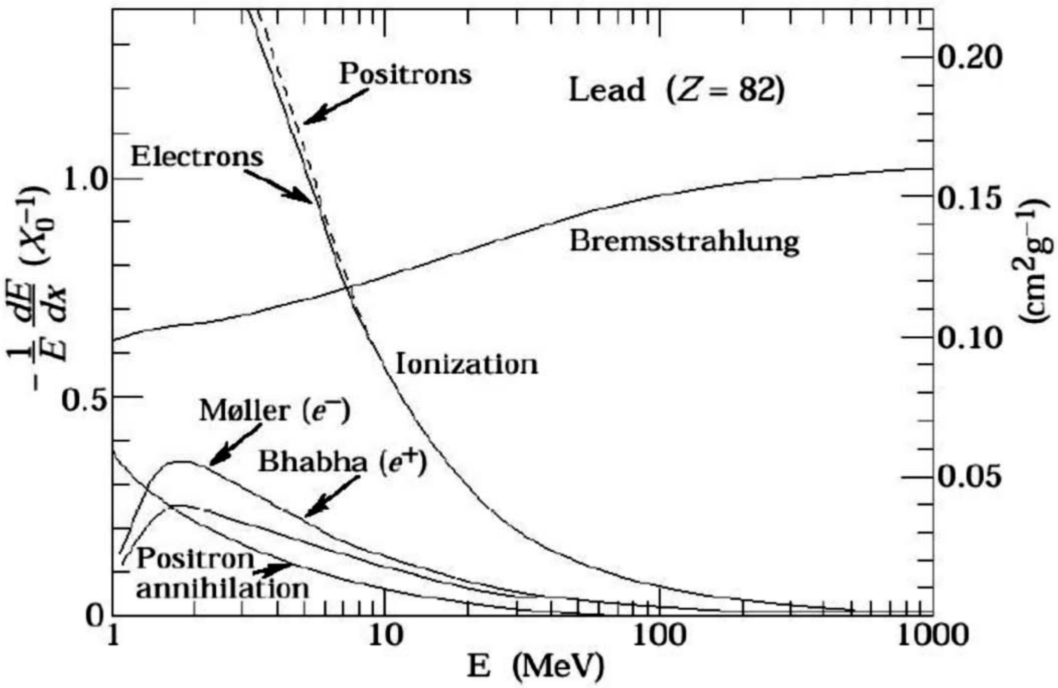


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

$E=mc^2$. If 2x the rest energy of an electron (~0.5 MeV) is available (i.e., if the photon energy is large enough), in the presence of matter the photon can *convert* to an electron-positron pair.

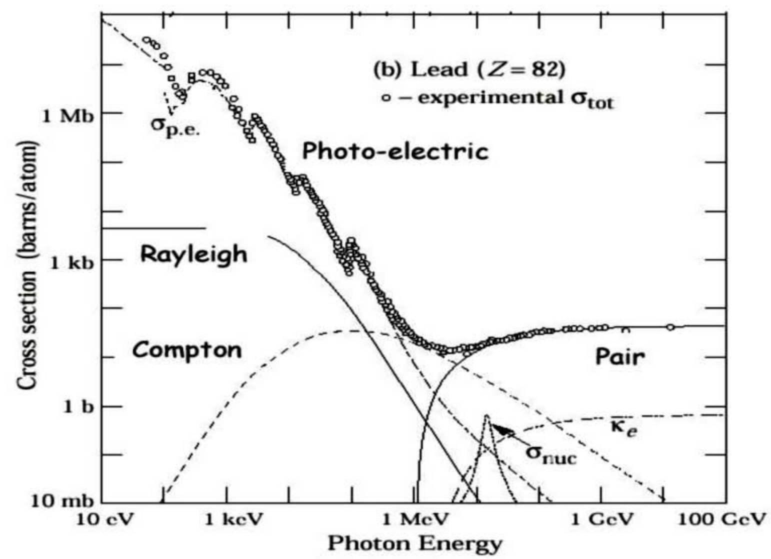
Interaction of electrons and photons with matter

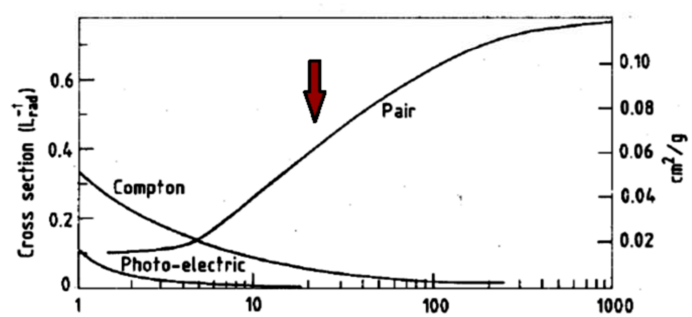
Fractional energy loss for e^+ and e^- in lead



$$\frac{dE}{dx}_{Brems} = -\frac{E}{X_0} \Rightarrow E(x) = e^{-\frac{x}{X_0}}$$

Photon total cross sections

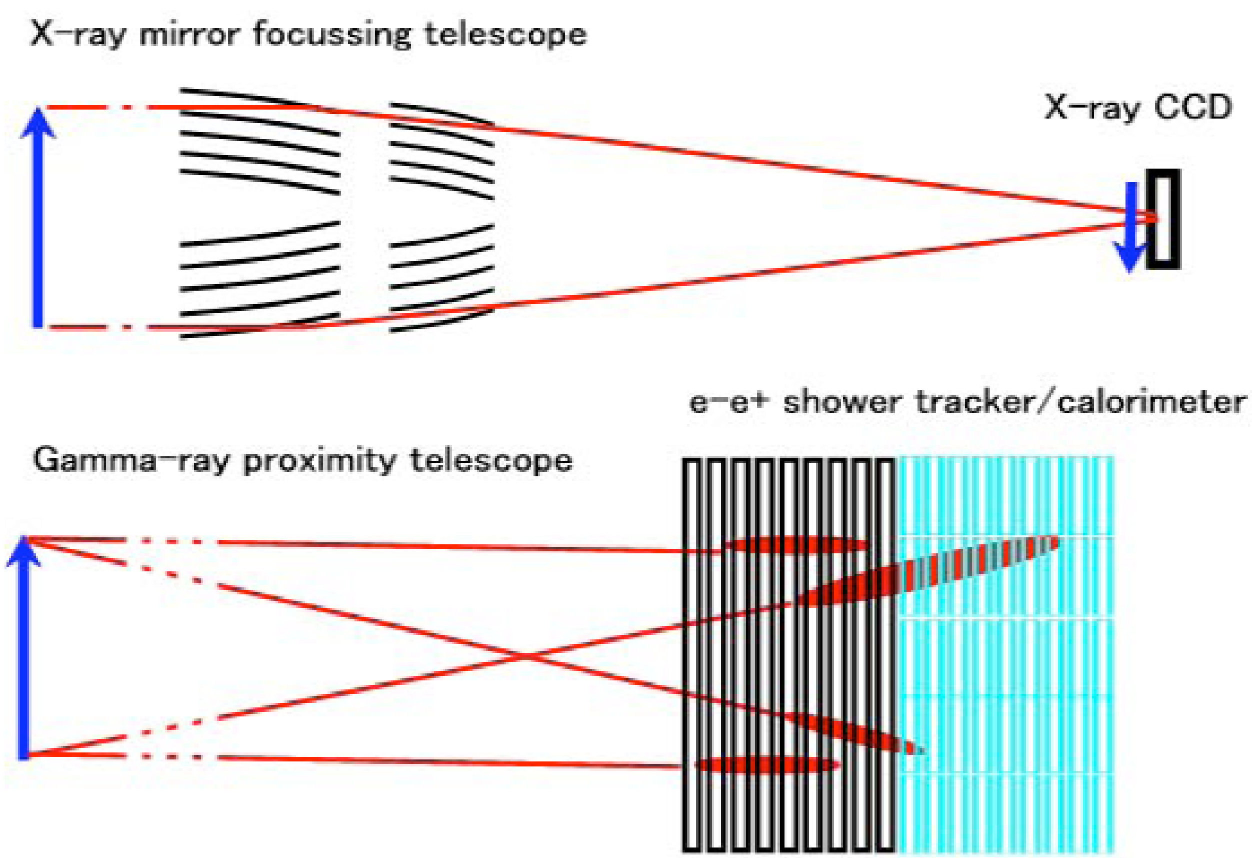




$$\text{Prob. of Int.} = 1 - \exp^{-\frac{7}{9}\frac{x}{X_0}}$$

stefano.ciprini@asdc.asi.it – ASDC Roma

Detector Technology: X-ray vs. Gamma-ray



X-ray (0.5 - 10keV)
Focusing possible

↓

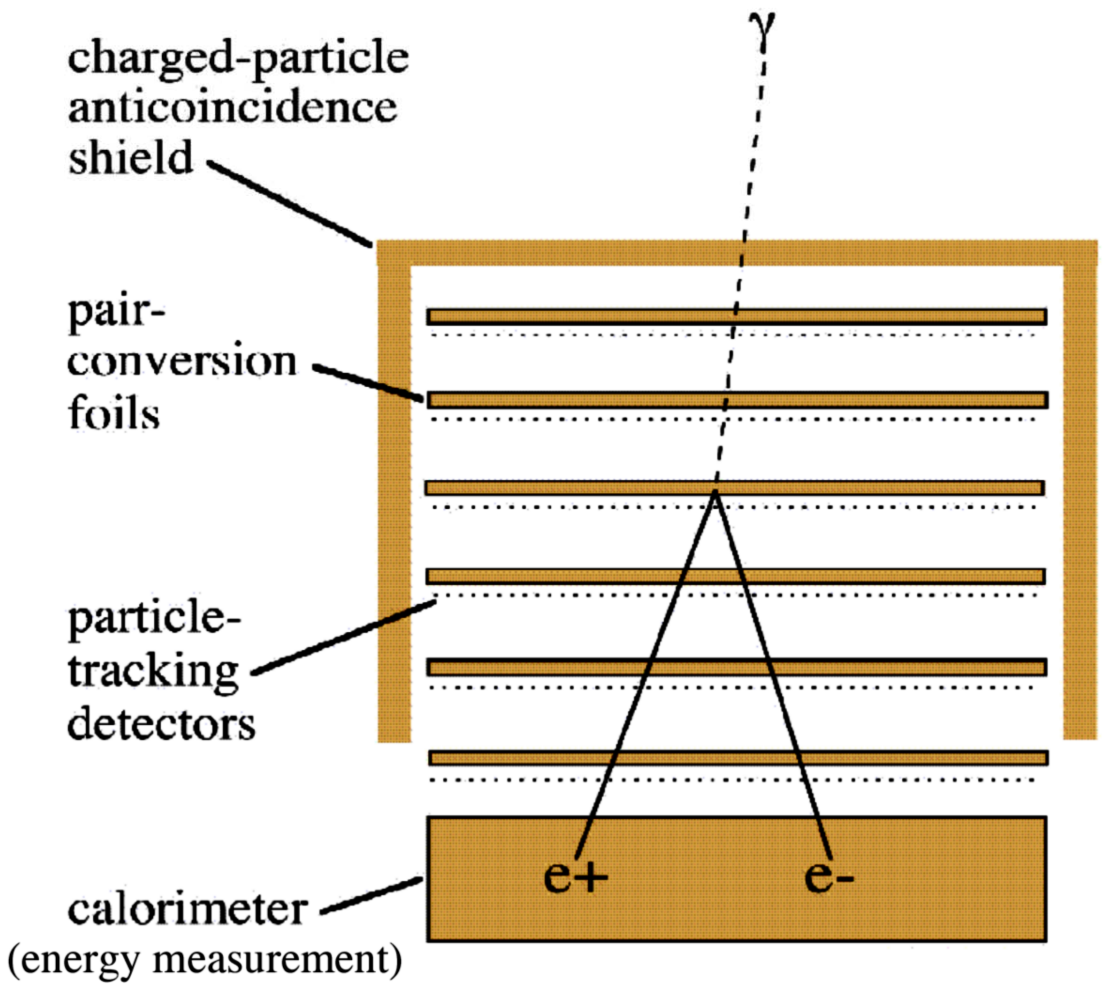
Large effective area
Excellent energy resolution
Very low background
Narrow view

Gamma-ray(0.1-500GeV)
No focusing possible

↓

Wide field of view
Limited effective area
Moderate energy resolution
High background

Elements of a pair-conversion telescope



- photons materialize into matter-antimatter pairs:
  E_γ --> $m_{e+}c^2 + m_{e-}c^2$
- electron and positron carry information about the direction, energy and polarization of the γ-ray

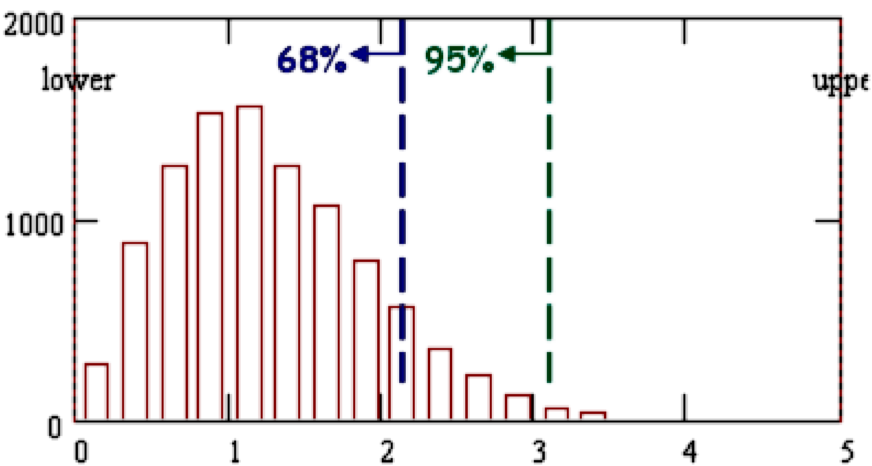
Gamma-ray detection: A_eff and PSF

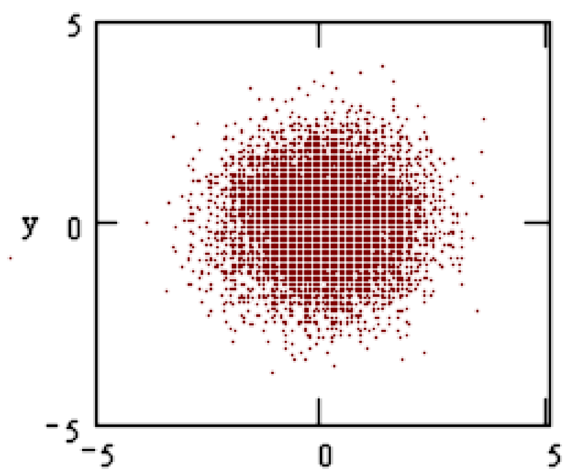
Effective area

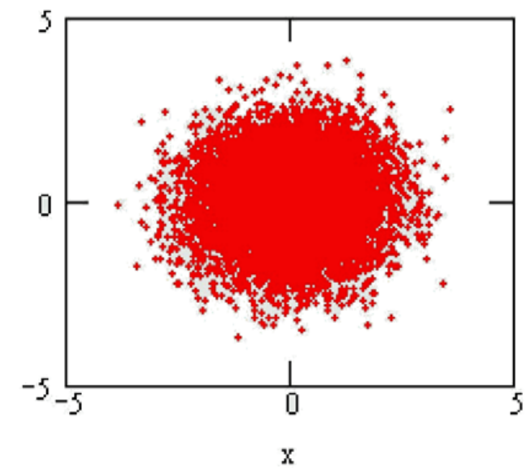
(total geometric acceptance) X (conversion probability) X (all detector and reconstruction efficiencies). Real rate of detecting a signal is (flux) X A_{eff}

Point Spread Function (PSF)

Angular resolution of instrument, after all detector and reconstruction algorithm effects. The 2-dimensional 68% containment is the equivalent of ~1.5σ (1-dimensional error) if purely Gaussian response. The non-Gaussian tail is characterized by the 95% containment, which would be 1.6 times the 68% containment for a perfect Gaussian response.

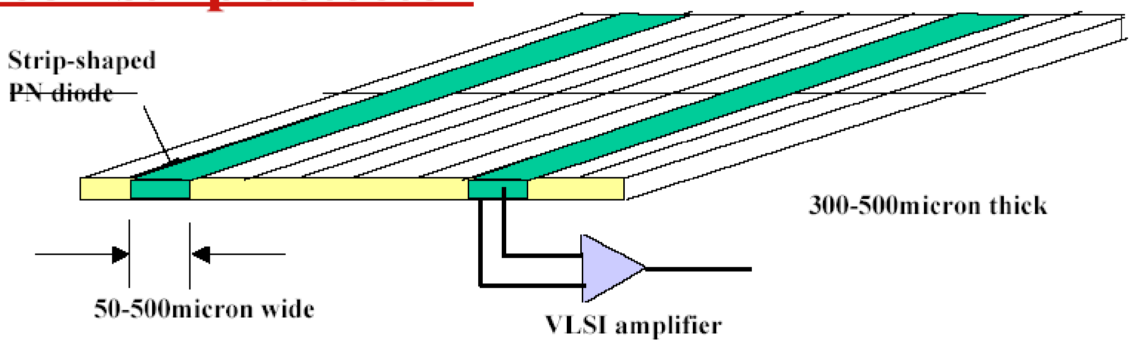


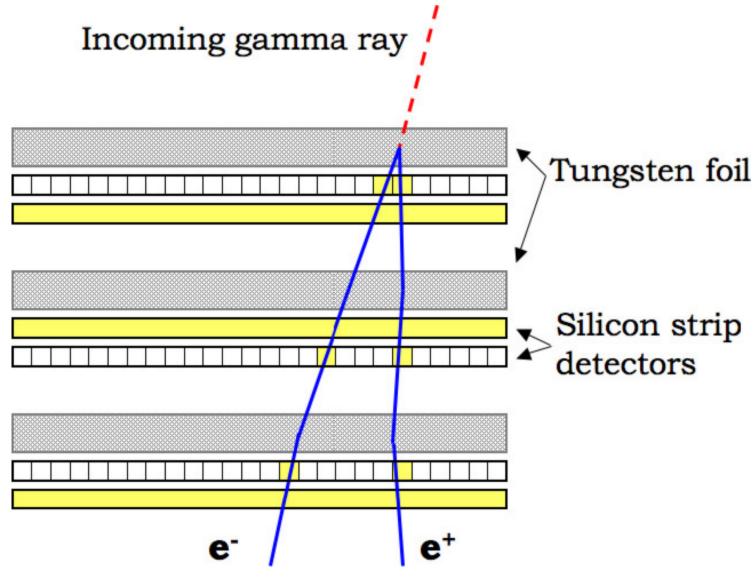




Gamma-ray Detection and Measurement

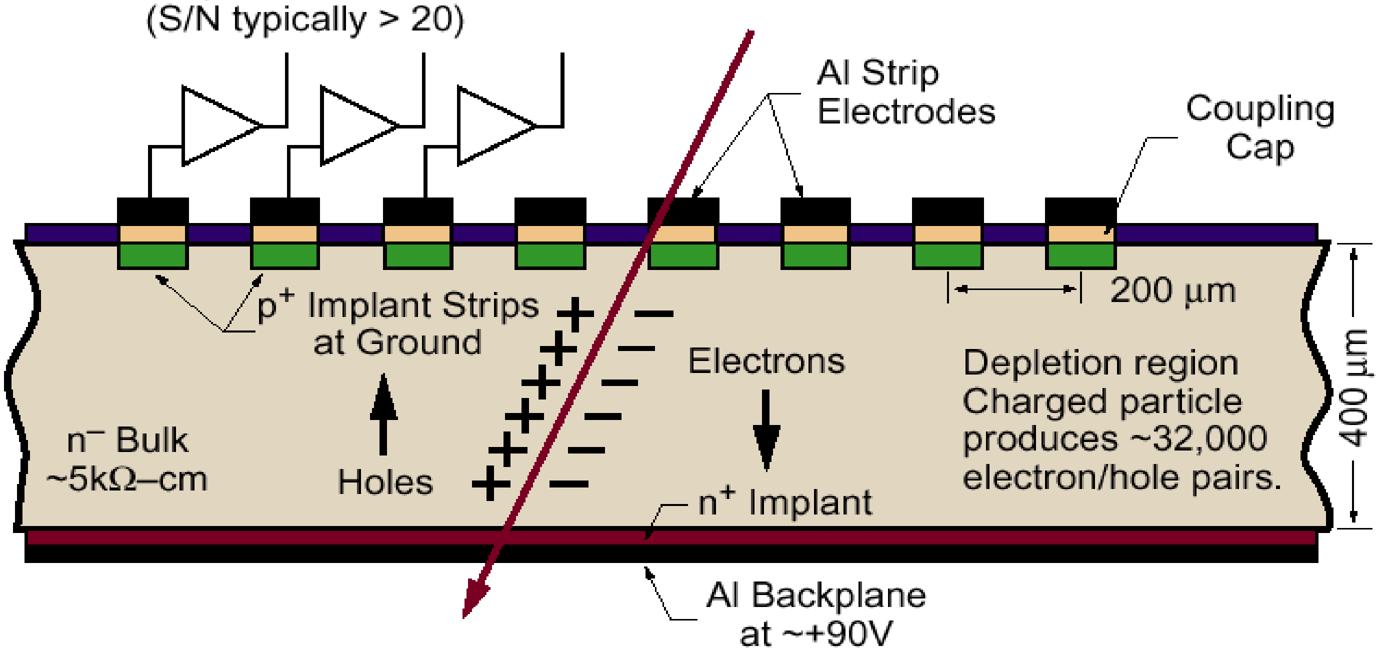
Silicon strip detector





Stable particle tracker that allows micron-level tracking of gamma-rays

VLSI
Low-noise, Low-power
Amplifier/Discriminator
(S/N typically > 20)

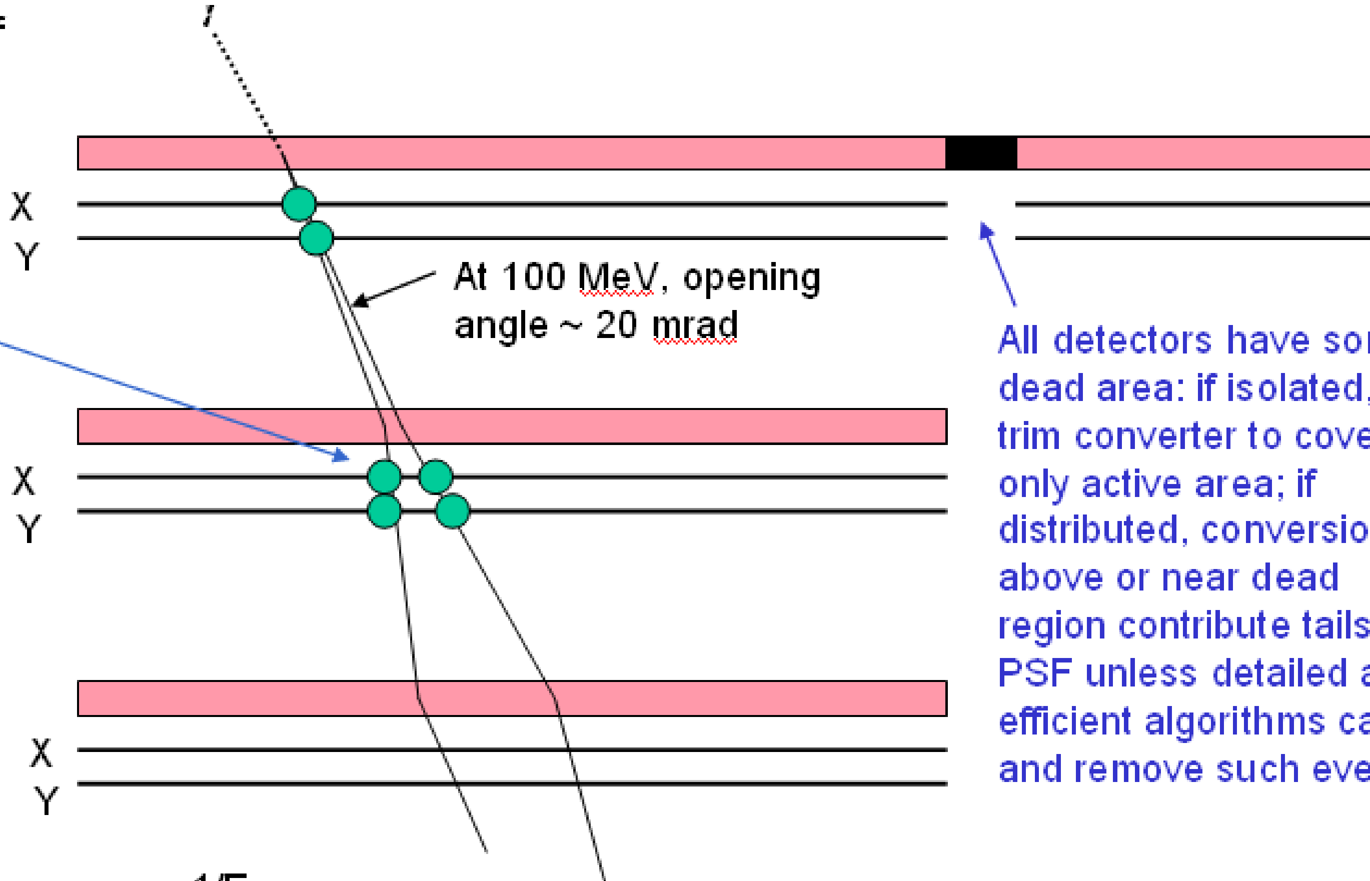


Silicon Strip Detector Principle

Gamma-ray Detection and Measurement

Expanded view of converter-tracker:

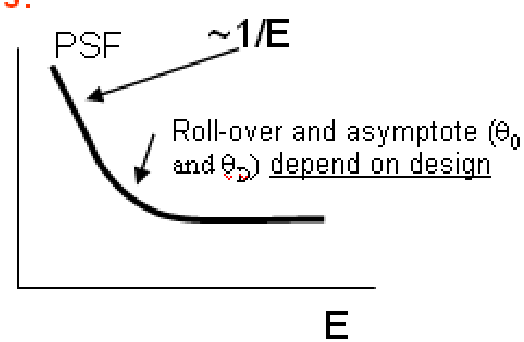
At low energy, measurements at first two layers completely dominate due to multiple scattering-- MUST have all these hits, or suffer factor ~ 2 PSF degradation. If eff = 90%, already only keep $(.9)^4$= 66% of potentially good photons. => <u>want >99% efficiency.</u>



All detectors have some dead area: if isolated, can trim converter to cover only active area; if distributed, conversions above or near dead region contribute tails to PSF unless detailed and efficient algorithms can ID and remove such events.

Low energy PSF completely dominated by multiple scattering effects:
$\theta_0 \sim 2.9$ mrad / E[GeV]
(scales as $(x_0)^{½}$)

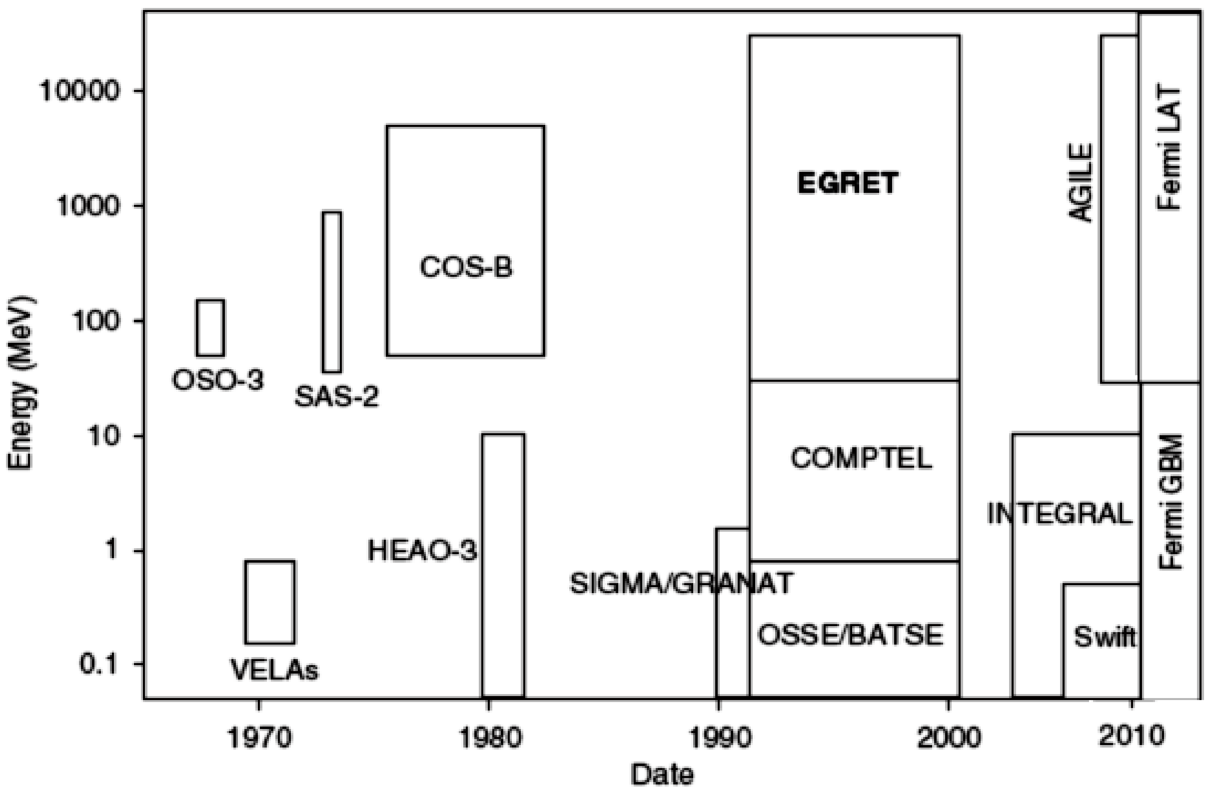
High energy PSF set by hit resolution/plane spacing:
$\theta_D \sim 1.8$ mrad.

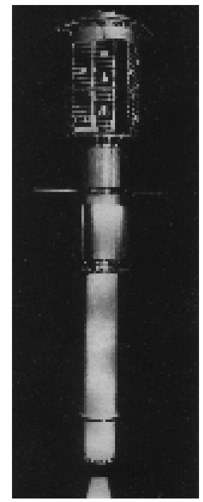


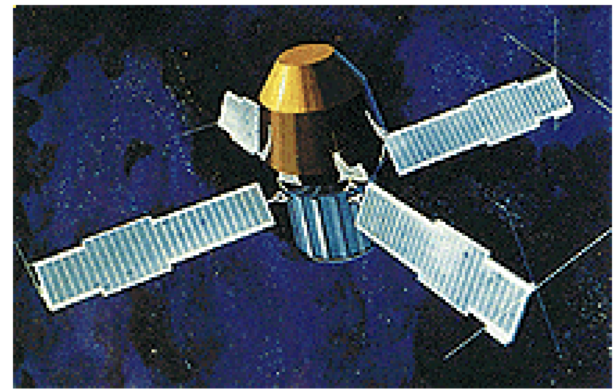
At higher energies, more planes contribute information:

Energy	# significant planes
100 MeV	2
1 GeV	~5
10 GeV	>10

Gamma-ray Astronomy (The Short Story…)







Some space gamma-ray missions, showing energy coverage and the time frame of the mission.

- The first gamma-ray telescope carried into orbit, on the Explorer XI satellite in 1961, picked up fewer than 100 cosmic gamma-ray photons. These appeared to come from all directions in the Universe, implying some sort of uniform "gamma-ray background".
- Additional gamma-ray experiments flew on the OGO, OSO, Vela, and Russian Cosmos series of satellites. However, the first satellite designed as a "dedicated" gamma-ray mission was the second Small Astronomy Satellite (SAS-2) in 1972.

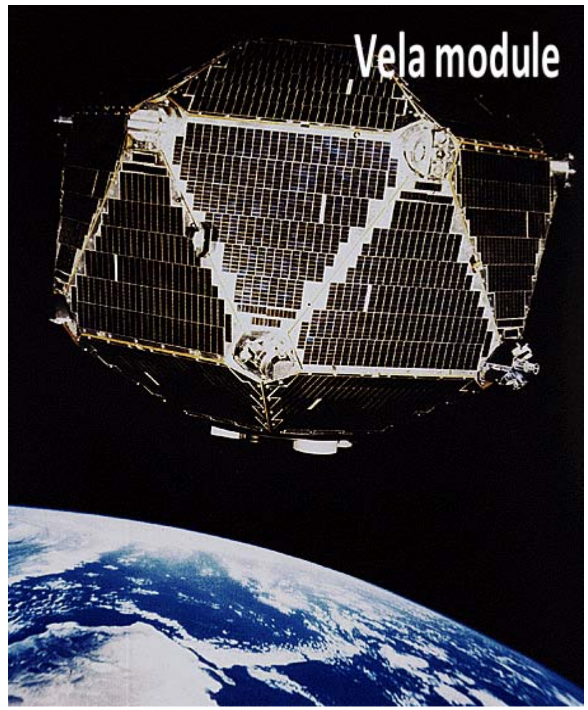
Gamma-ray Astronomy (The Short Story…)

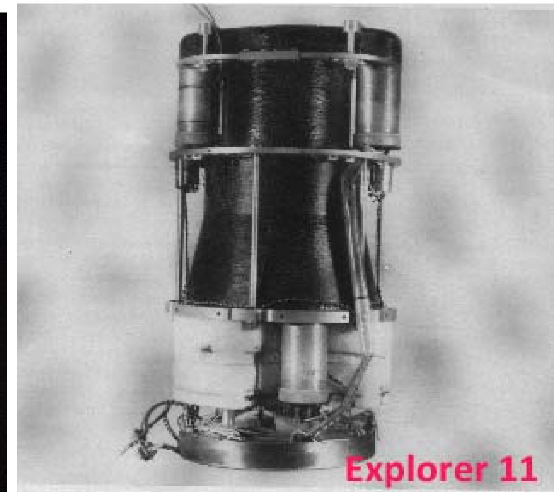
Gamma-ray Bursts:

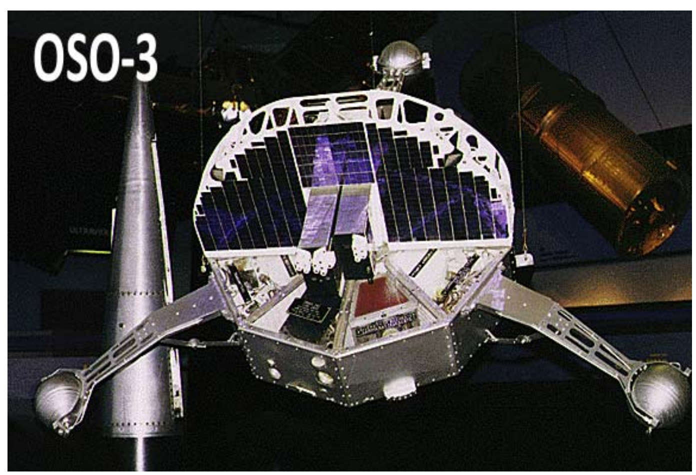
- Vela Program : A Bomb or Not a Bomb? (Vela Program, 1969-1979)
- A few hundred events, a few hundred theories

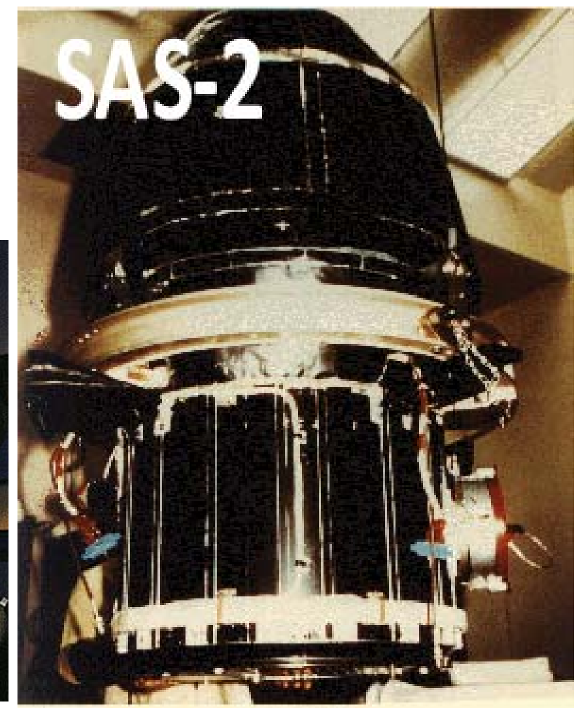
Gamma-ray Sources:

- SAS-2 – discovered 2 pulsars (1972)
- COS-B – about 25 sources (1975-82)
- Most unidentified, but 1 quasar
- Diffuse extra-galactic background



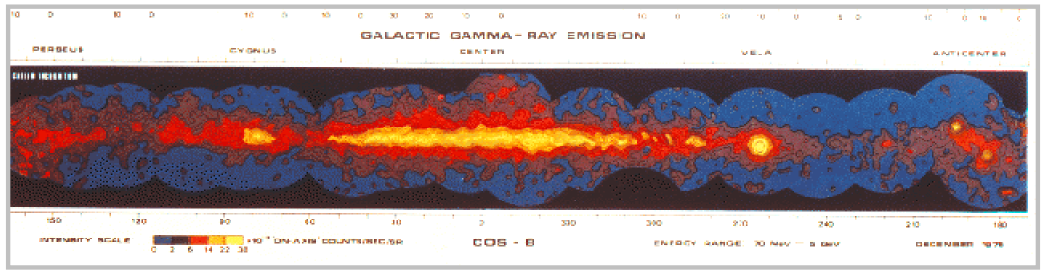






Gamma-ray Astronomy (The Short Story…)

- **Cos-B** è stato il primo satellite per l'osservazione dello spazio (telescopio spaziale astronomico) lanciato dall'Agenzia Spaziale Europea (ESA) il 9 agosto 1975 per lo studio dei raggi gamma galattici e cosmici, in particolare per rispondere ed investigare le sorgenti e gli inspiegati livelli di radiazione gamma scoperti dai primi satelliti americani (come la serie Vela, OSO-3, e sopratutto SAS-2). I contributi scientifici includono il catalogo 2CG contenente circa 25 sorgenti puntiformi di raggi gamma e una mappa della Via lattea. La sonda osservò anche la pulsar Cygnus X-3 e Geminga.

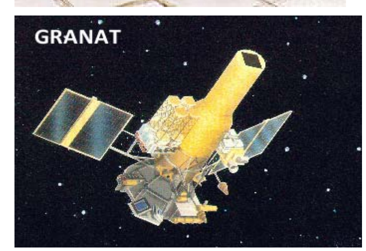


Mission Characteristics

- Lifetime : 9 Aug 1975 - 25 April 1982
- Energy Range : 2 keV - 5 GeV
- Payload : Magnetic-core, wire-matrix, spark chamber gamma-ray detector (~30 MeV-5 GeV), eff. area 50 cm2 at 400 MeV a 2-12 keV proportional counter mounted on the side of the gamma-ray detector

Science Highlights:

- Observations of gamma-ray pulsars, binary systems.
- Gamma-ray map of the Galaxy.
- Detailed observations of the Geminga gamma-ray pulsar.



Gamma-ray Astronomy (The Short Story…): CGRO

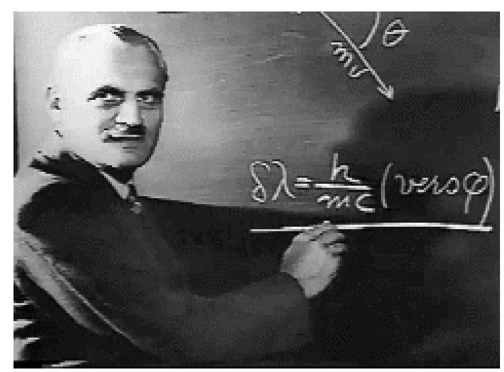
The Compton Gamma-ray Observatory, CGRO, Mission (1991 - 2000)

- The Compton Gamma Ray Observatory was the second of NASA's Great Observatories. Compton, at 17 tons, was the heaviest astrophysical payload ever flown at the time of its launch on April 5, 1991 aboard the space shuttle Atlantis. Compton was safely deorbited and re-entered the Earth's atmosphere on June 4, 2000.
- Compton had four instruments that covered an unprecedented six decades of the electromagnetic spectrum, from 30 keV to 30 GeV. In order of increasing spectral energy coverage, these instruments were the Burst And Transient Source Experiment (BATSE), the Oriented Scintillation Spectrometer Experiment (OSSE), the Imaging Compton Telescope (COMPTEL), and the Energetic Gamma Ray Experiment Telescope (EGRET). For each of the instruments, an improvement in sensitivity of better than a factor of ten was realized over previous missions.

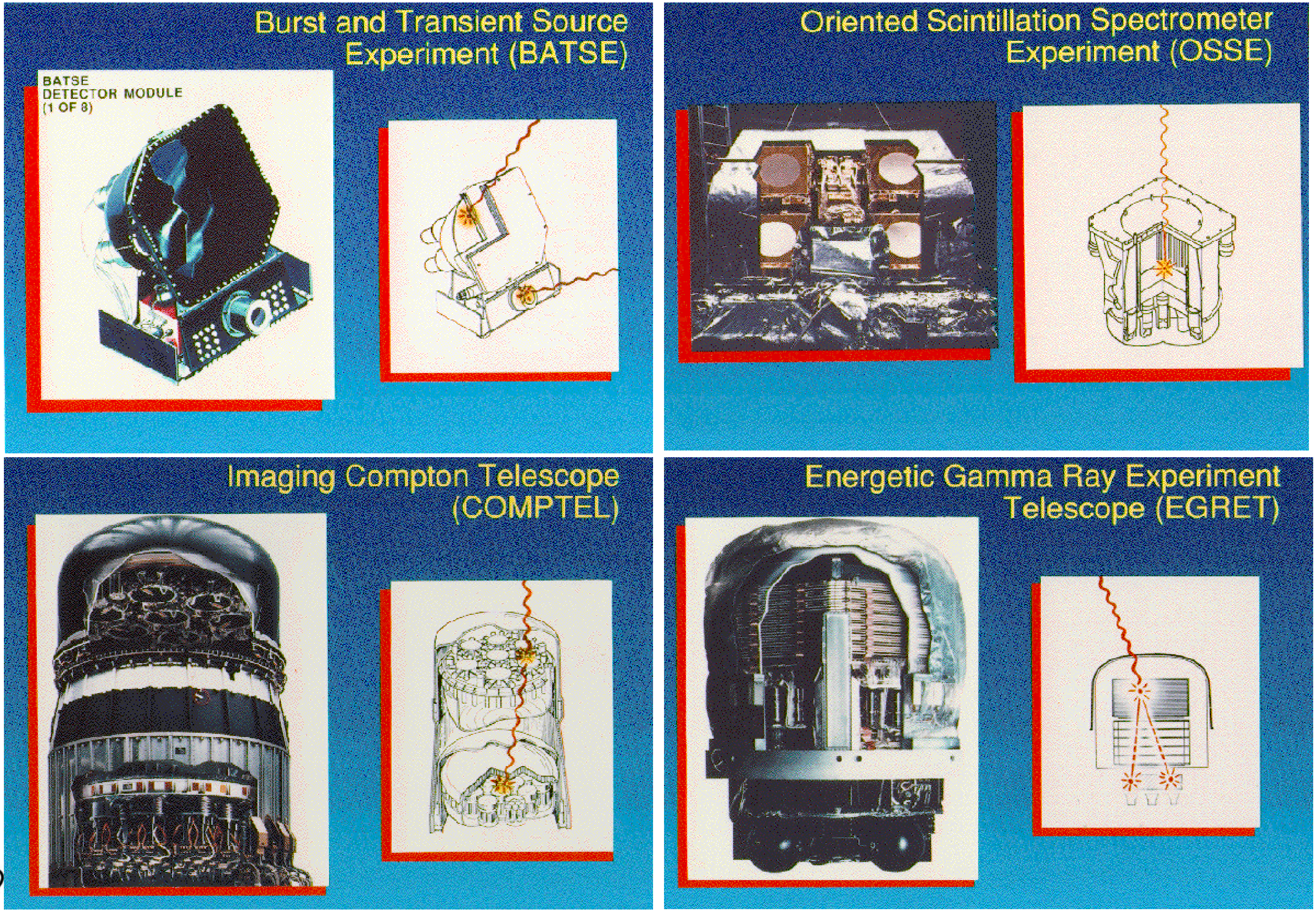
- The Observatory was named in honor of Dr. Arthur Holly Compton, who won the Nobel prize in physics for work on scattering of high-energy photons by electrons - a process which is central to the gamma-ray detection techniques of all four instruments.

Sources of gamma-ray Emission discovered and classified:

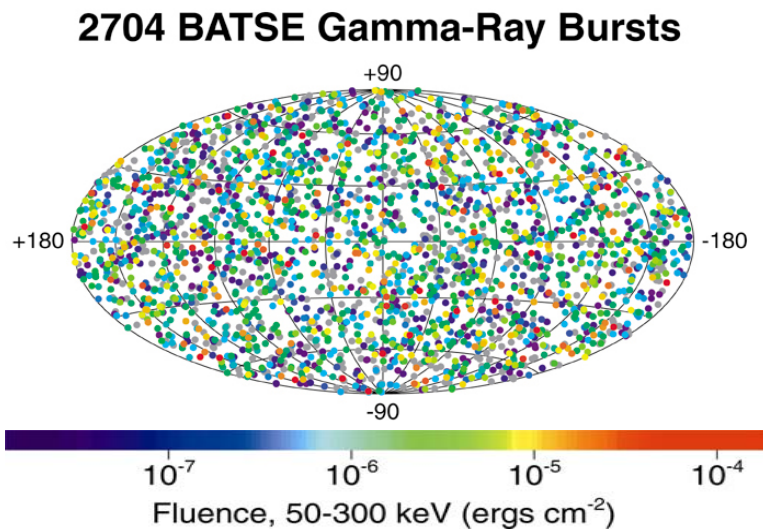
- Black holes
- Active Galaxies
- Pulsars
- Gamma-ray bursts
- Diffuse emission
- Supernovae,
- Unidentified

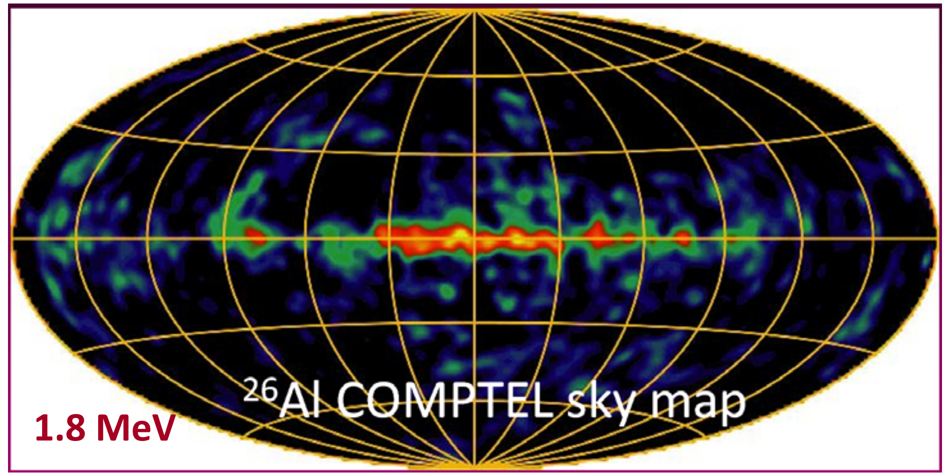


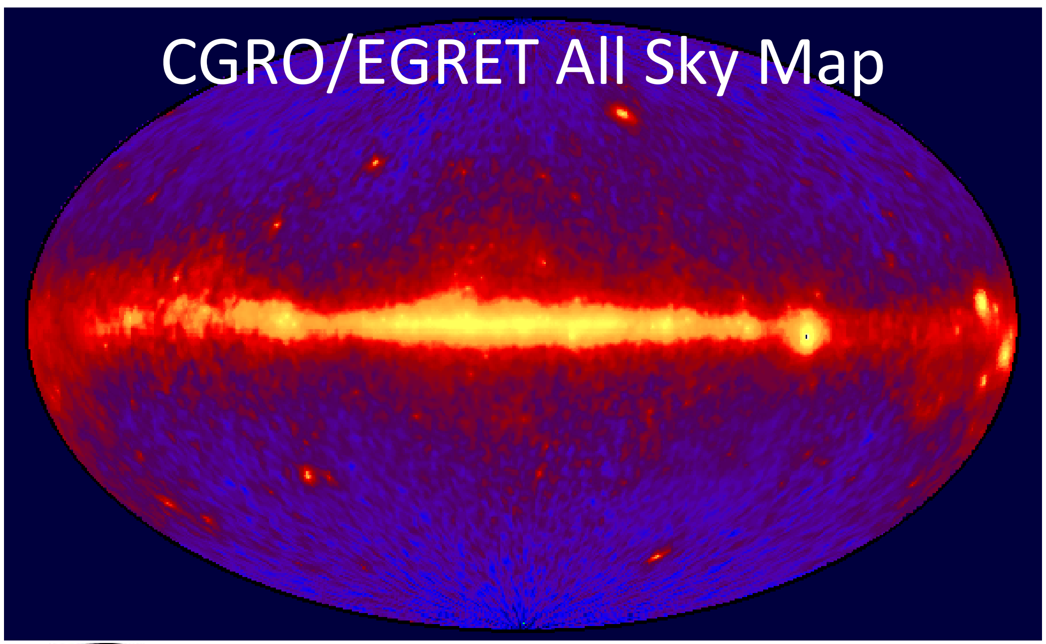
Gamma-ray Astronomy (The Short Story…): CGRO

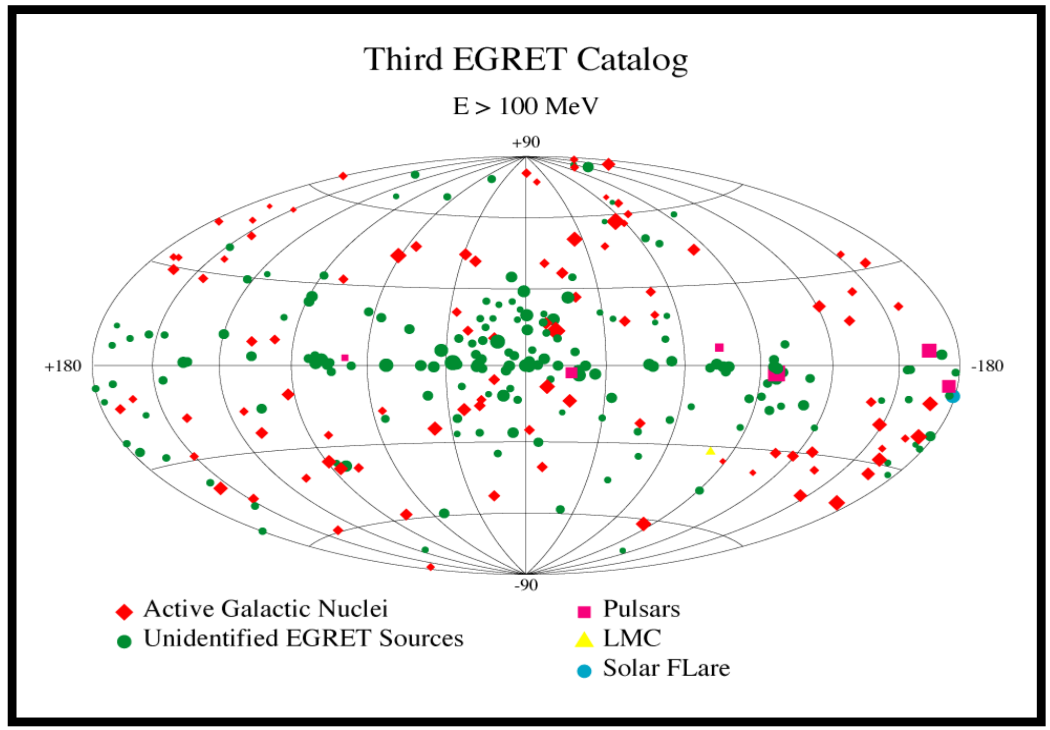


Gamma-ray Astronomy (The Short Story…): CGRO







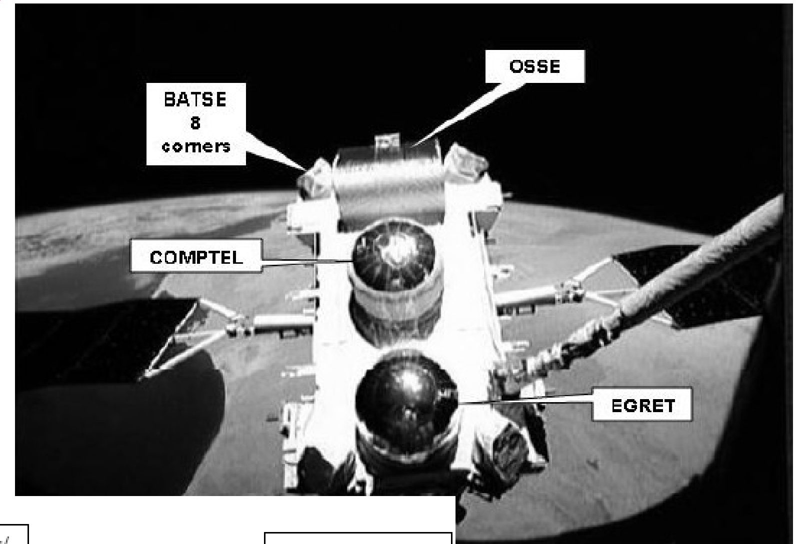


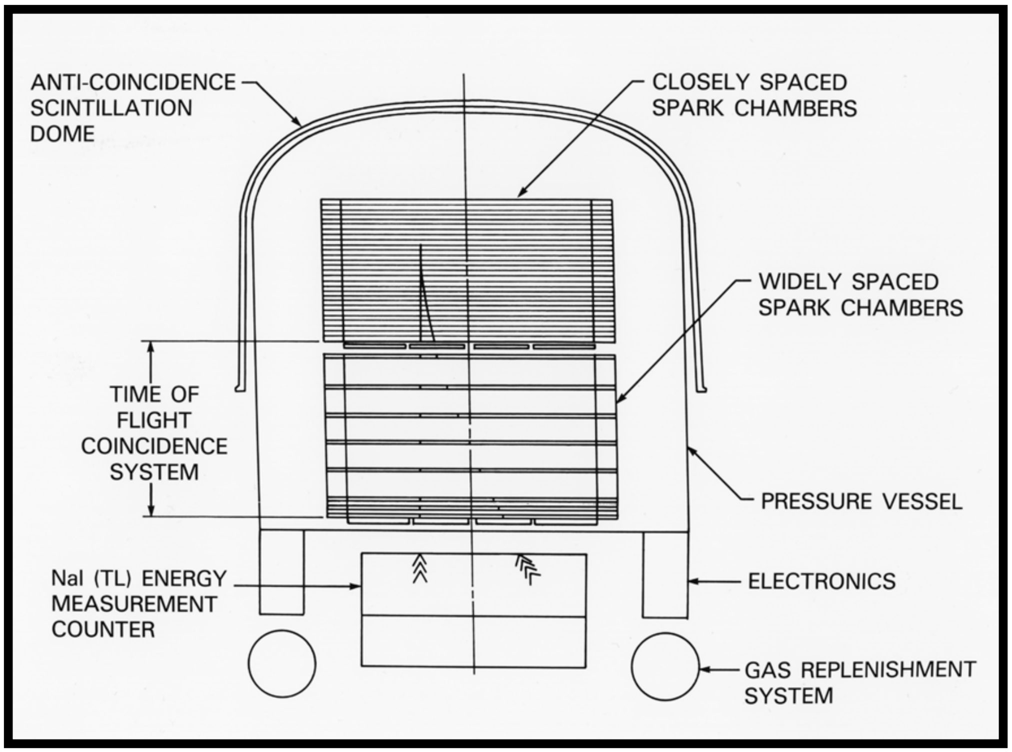
Gamma-ray Astronomy (The Short Story…): CGRO EGRET

- Apr 1991 – Jun 2000
- 30 MeV – 30 GeV
- $\theta_{67\%}=5.85°(100\ \mathrm{MeV}/E)^{0.534}$

Table 1. Performance characteristics of EGRET.

Property	Value
Energy range	20 MeV to 10 GeV
Peak effective area	1500 cm^2 at 500 MeV
Energy resolution	15% FWHM
Off-axis effective area	25% of peak at 30°
Timing accuracy	$<100\ \mu$s absolute





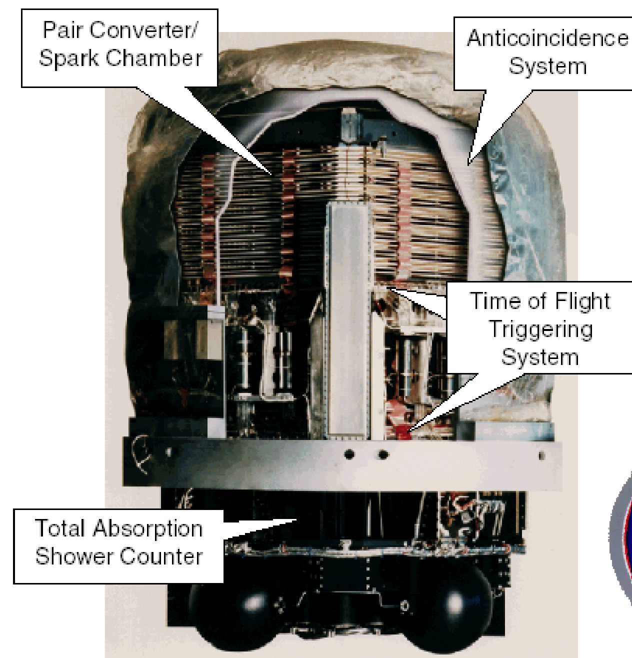
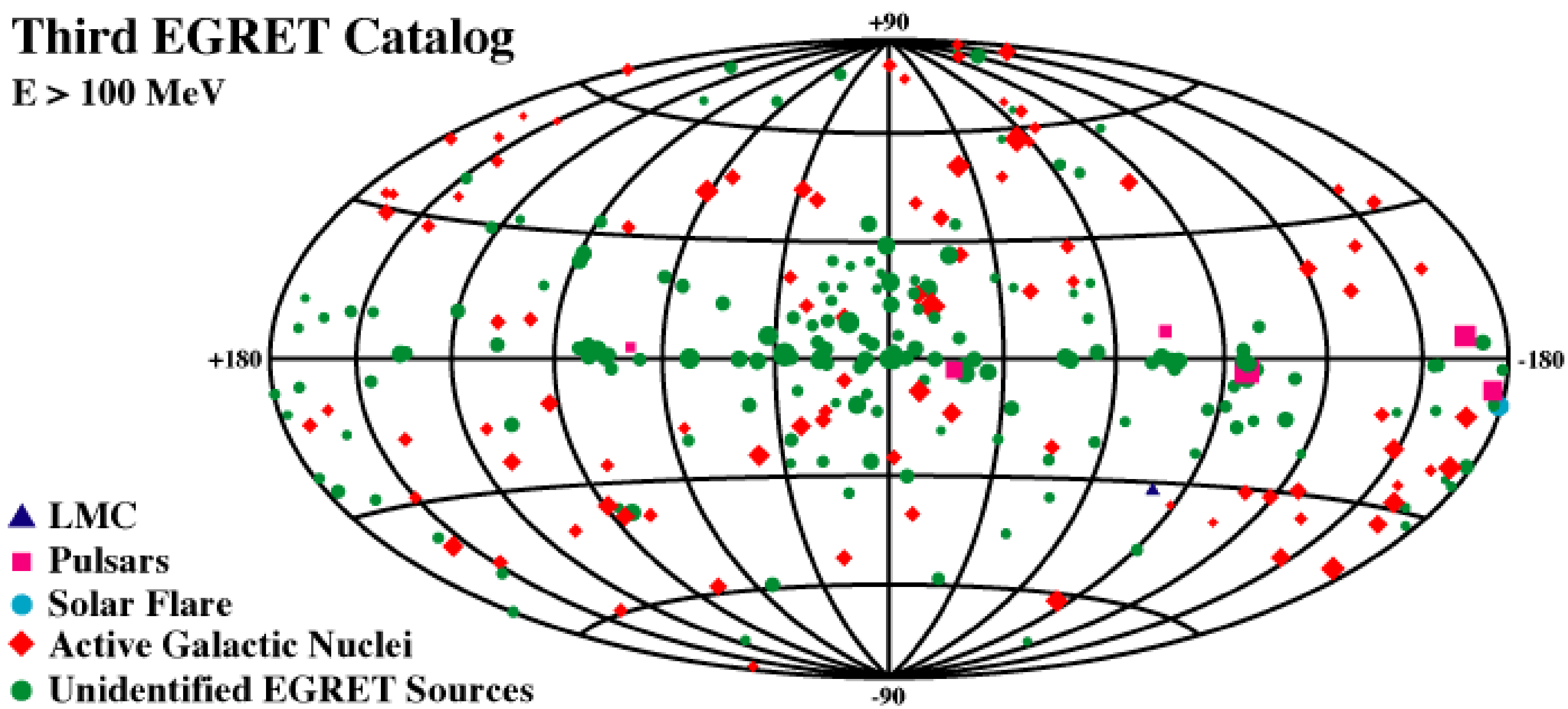


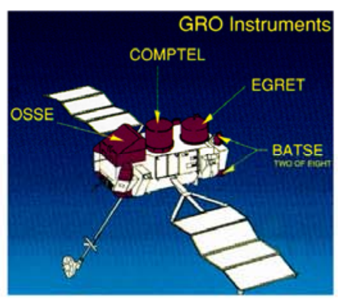
Figure 4. Composite photo showing a cutaway view of EGRET. The major subsystems are identified.

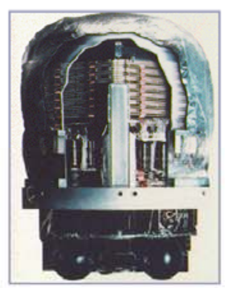
3rd EGRET Catalog

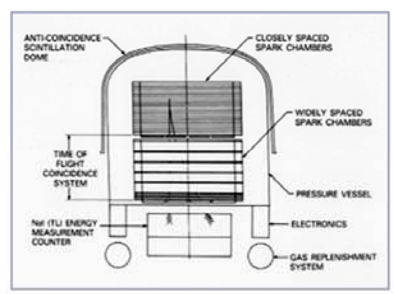
Data from April 5, 1991 to October 3, 1995

CGRO mission 1990-1999



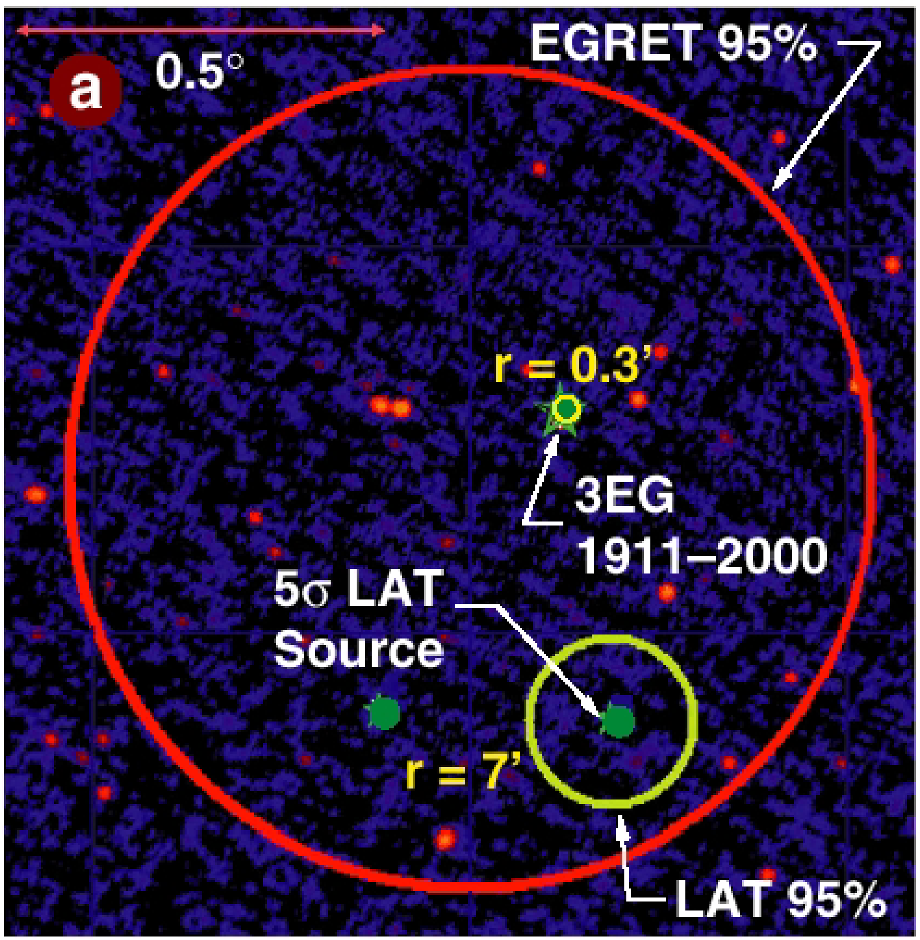






EGRET: Unidentified Sources

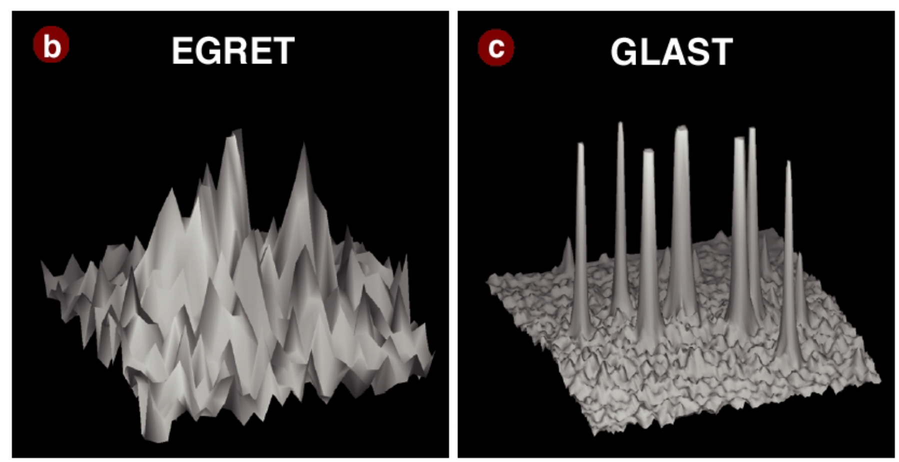
172 of the 271 sources in the EGRET 3rd catalog are "unidentified"



● Rosat or Einstein X-ray Source
● 1.4 GHz VLA Radio Source

EGRET source position error circles are ~0.5°, resulting in counterpart confusion.

GLAST will provide much more accurate positions, with ~30 arcsec - ~5 arcmin localizations, depending on brightness.

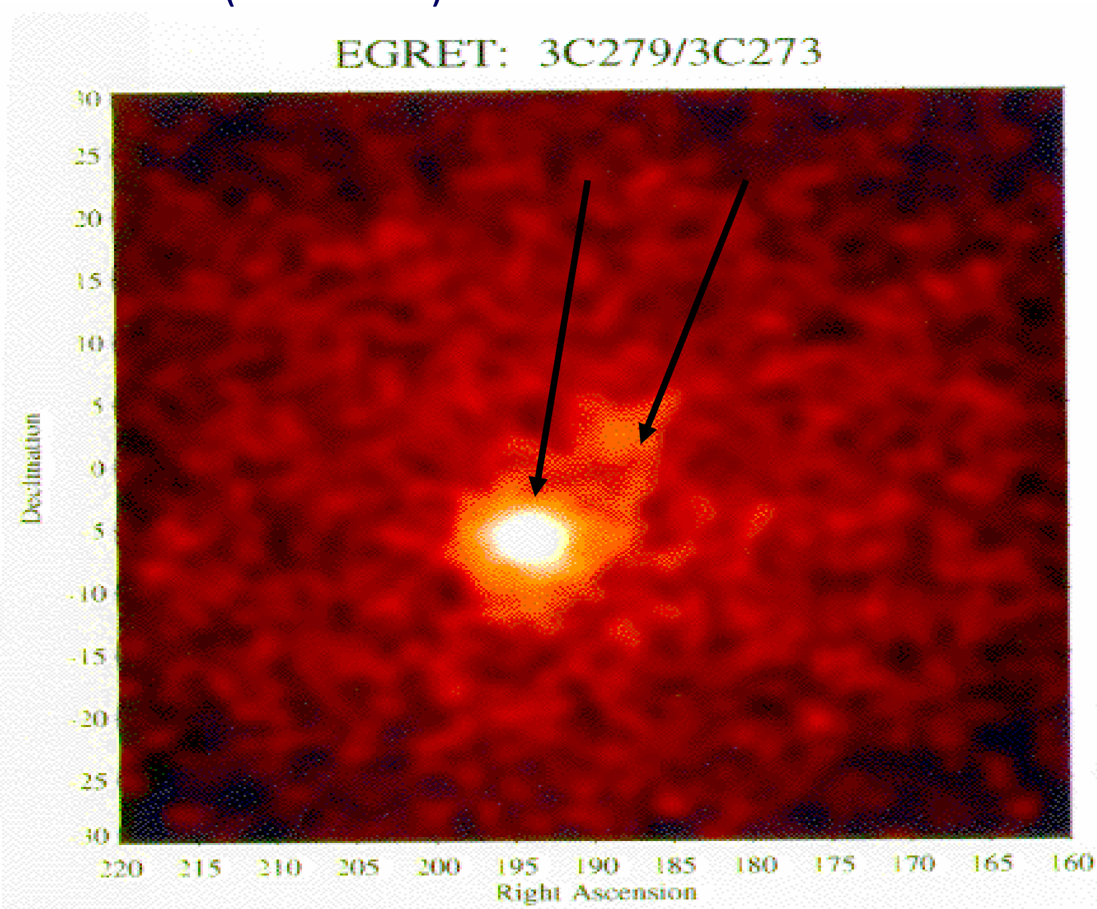


Cygnus region (15x15 deg)

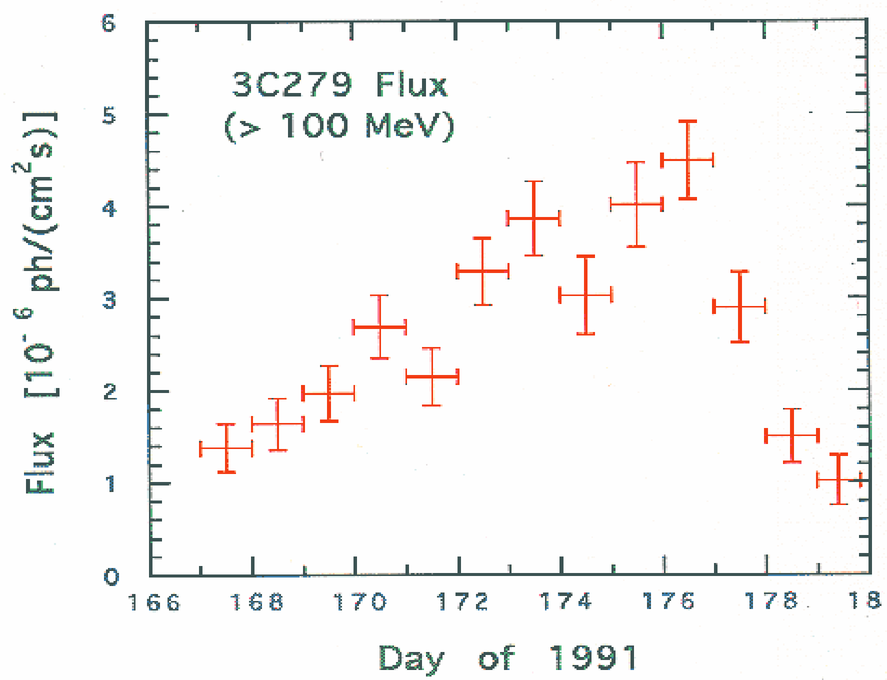
EGRET and 3C279

Prior to EGRET, the only known extra-galactic point source was 3C273; however, when EGRET launched, 3C279 was flaring and was the brightest object in the gamma-ray sky!

EGRET discovery image of gamma-ray blazar 3C279 (z=0.54)
E>100 MeV (June 1991)



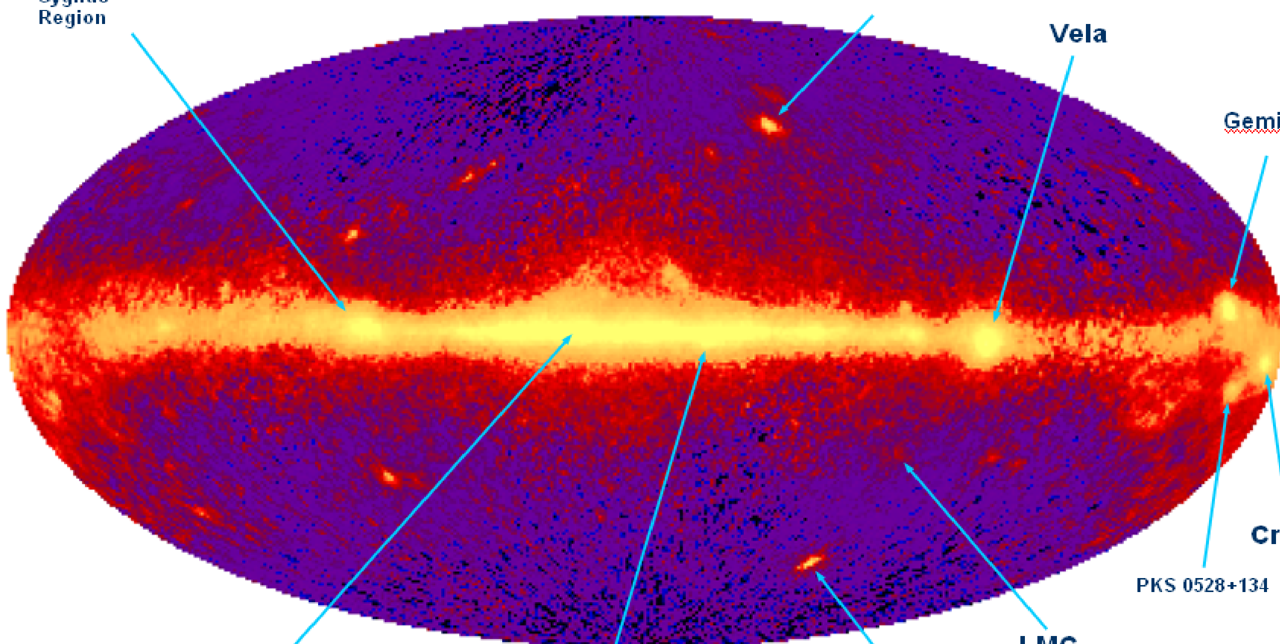
VARIABILITY: EGRET has seen only the tip of the iceberg.



The success of EGRET: probing new territory

SAS-2, COSB (1970's-1980's) exploration phase: established galactic diffuse flux
EGRET (1990's) established field:

- ❑ increased number of ID'd sources by large factor;
- ❑ broadband measurements covering energy range ~20 MeV - ~20 GeV;
- ❑ discovered many yet-unidentified sources;
- ❑ discovered surprisingly large number of Active Galactic Nuclei (AGN);
- ❑ discovered multi-GeV emissions from gamma-ray bursts (GRBs);
- ❑ discovered GeV emissions from the sun



EGRET Data Analysis

EGRET Data Products, and Data Analysis: http://heasarc.gsfc.nasa.gov/docs/cgro/egret/egret_doc.html

There are three areas where it is important to know the instrument performance:

- the point-spread function, or the distribution of the measured fl-ray incident angles as a function of true incident angle
- the sensitive (or effective) area, or the physical area for collecting fl-rays multiplied by the efficiency, as a function of position on the sky at any given time;
- the energy dispersion, or the distribution of measured energy as a function of the true energy.

Point Spread Function - PSF(q)

From the calibration data it is seen that the point-spread function is roughly azimuthally symmetric then:

$$PSF(\theta) = \frac{2\pi}{N} \int_{E=E_{\min}}^{E_{\max}} \int_{E=0}^{\infty} E'^{-\alpha} PSF(\theta, E') EDP(E, E') dE' dE$$

The point-spread function PSF(q) is the integral of the true-energy dependent point-spread function, weighted by the spectrum, integrated over the measured energy band from E min to E max , and integrated over all true energies, weighted by the energy dispersion function. This reflects the fact that there is some probability that a gamma-ray of any given true energy will have a measured energy between E min and E max .

A reasonable approximation to the point-spread width assumes a relatively simple functional form. The half-angle which defines a cone containing ¸ 68% of the gamma-rays from a point on the sky may be taken as

$$\theta_{68} = 5^{0}.85(E/100MeV)^{-0.534}$$

EGRET Data Analysis

Counts – Exposure - Intensity

If a detector has exposure E_T to a source with photon flux F(ph/cm^{2}sec) , then the number of counts N which will be measured is

$$N = FE_T$$

where

$$F(\Delta E) = \int_{\Delta E} I(E)dE$$

ΔE is the energy range being considered and I(E) is the differential flux as a function of energy (ph/cm^{2}secMeV).The differential number of counts that will be detected by EGRET from a source of intensity I(E) is

$$dN = I(E)A(E)dEdt$$

where A(E) is the energy-dependent effective area of the instrument, and dt is the differential unit of time.

Taking into account the energy dispersion of the instrument, the correct expression for the number of counts that will be measured is

$$N(\Delta E;\theta,\phi,m) = T(\theta,\phi,m)\int_{\Delta E} dE' \int_0^{\infty} dE I(E) SAR(E;\theta,\phi,m) EDP(E,E';\theta,\phi,m)$$

$T(\theta,\phi,m)$ = is the amount of instrument livetime spent observing a source at (θ,ϕ)

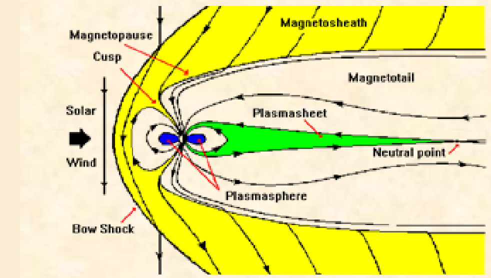
$EDP(E,E';\theta,\phi,m)$ = Prob. of true energy E will be measured with an energy E'

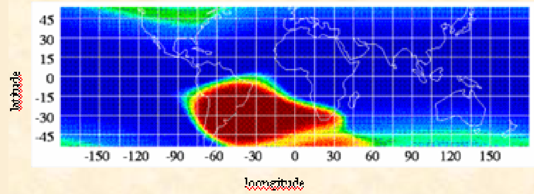
solving for exposure:

$$E_T(\Delta E;\theta,\phi) = \sum_m T(\theta,\phi,m)\overline{SAR}(E;\theta,\phi,m)$$

$$\overline{SAR}(E;\theta,\phi,m) = \frac{N(\Delta E;\theta,\phi,m)}{\int_{\Delta E} dE I(E)}$$ = average effective area of EGRET

$I(E) = I_o E^{\alpha}\ ph\,cm^{-2} s^{-1} MeV^{-1}$ =source photon spectrum $\quad \alpha \approx -2.0$

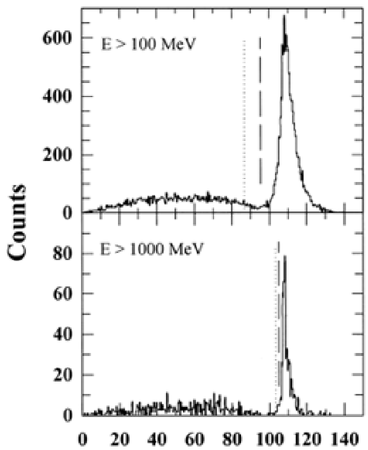




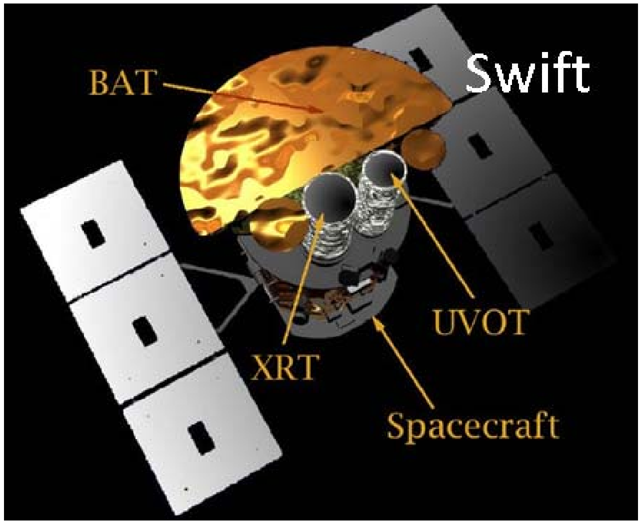
South Atlantic Anomaly Detector (SAAD) aboard the ROSAT spacecraft. It consists of 10 cm^2 of Germanium and served as a particle background monitor.

South Atlantic Anomaly

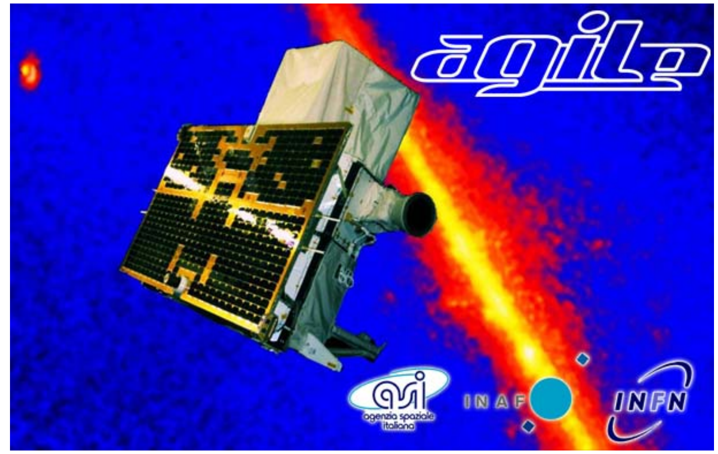
Earth Albedo



Gamma-ray Astronomy (The Short Story…): current space missions

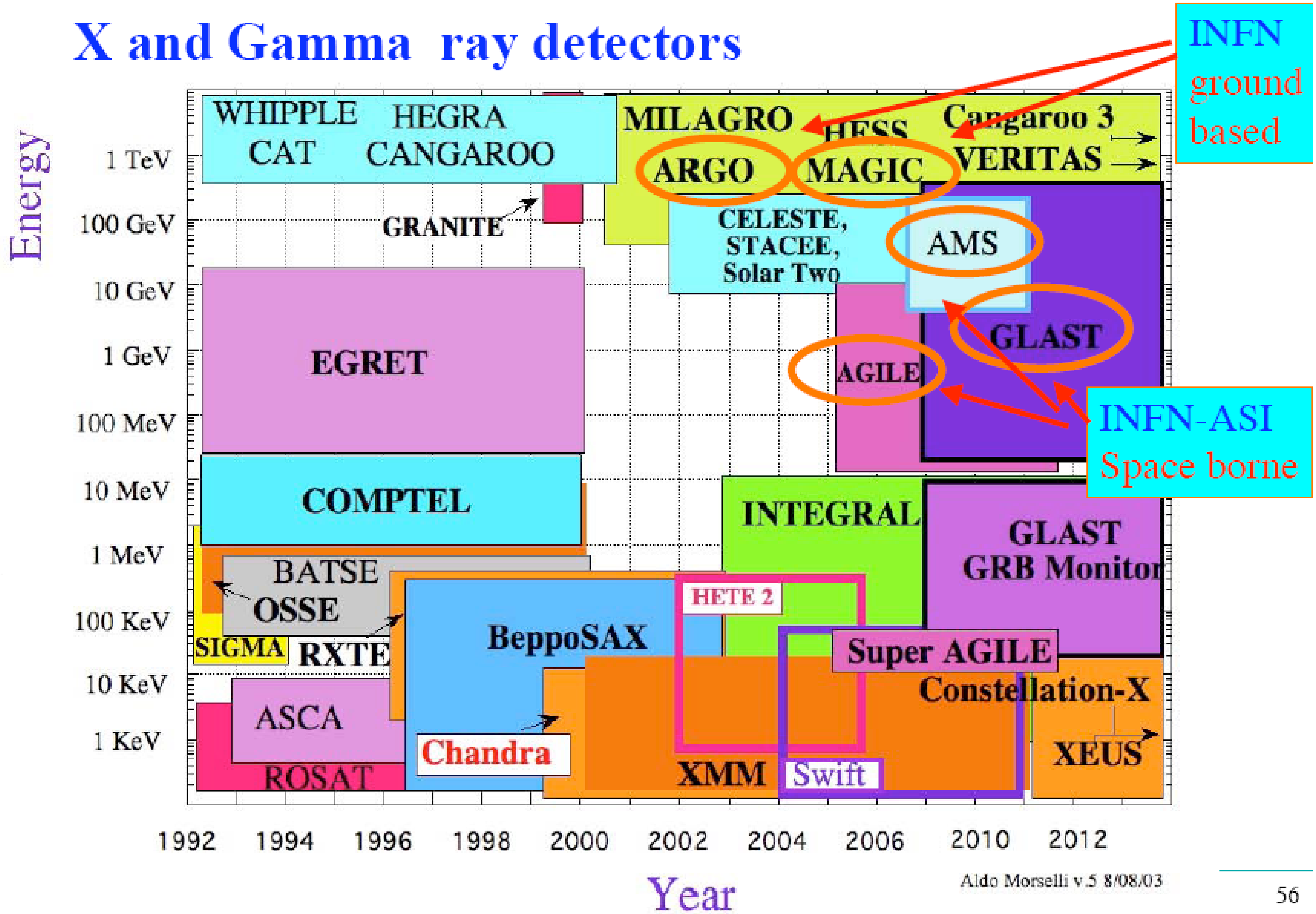


BAT

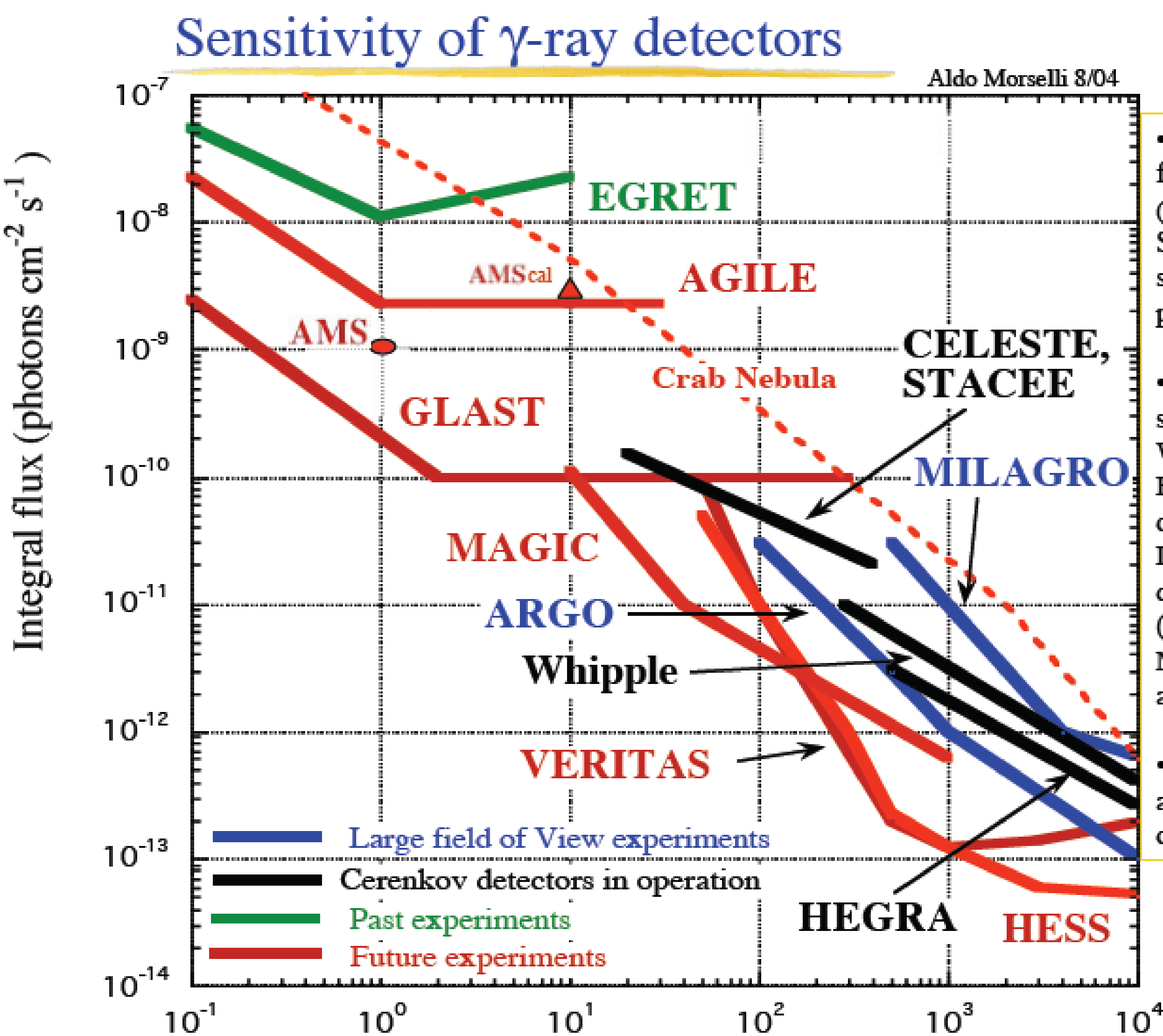


Fermi
Gamma-ray Space Telescope

Recent and ongoing gamma-ray projects

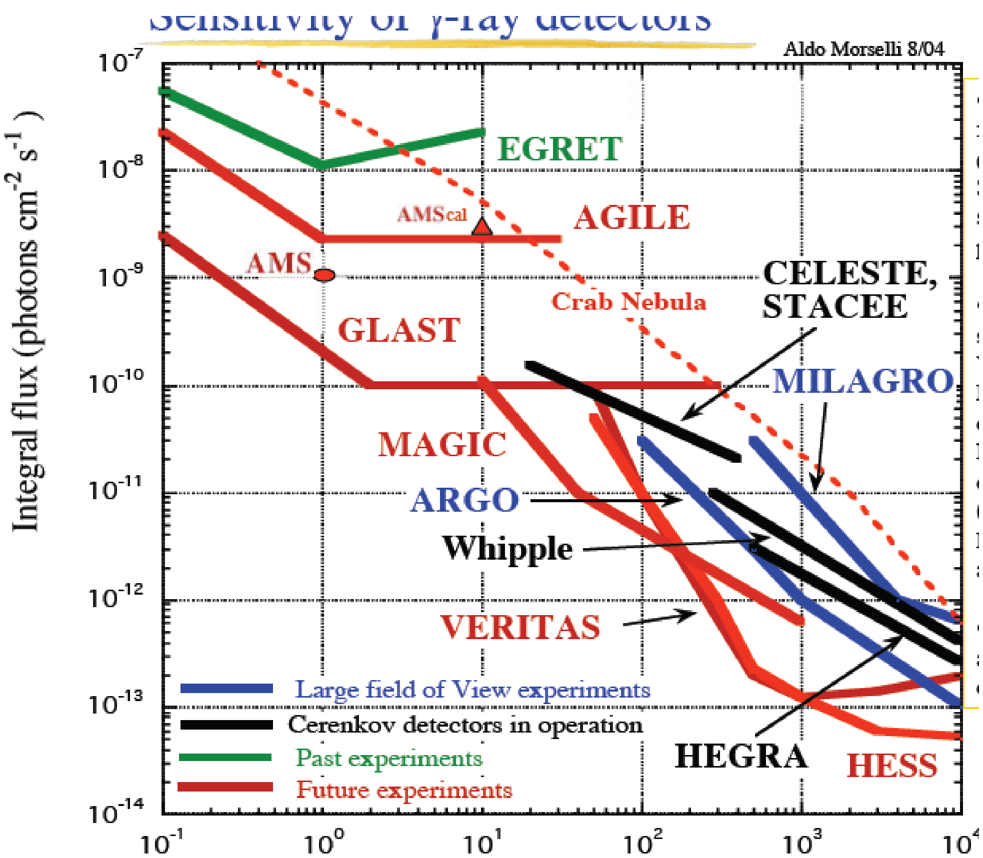


Recent and ongoing gamma-ray projects



- All sensitivities are at 5σ for a high latitude background ($2\ 10^{-5}$ ph cm^{-2} sr^{-1} (100 MeV/E)$^{1.1}$) Source differential photon spectrum is assumed to have a power law index of -2.
- Cerenkov telescopes sensitivities (Veritas, MAGIC, Whipple, Hess, Celeste, Stacee, Hegra) are for 50 hours of observations.
  Large field of view detectors sensitivities (AGILE, GLAST, Milagro, ARGO, AMS are for 1 year of observation.
- MAGIC sensitivity based on the availability of high efficiency PMT's

Unified gamma-ray experiment spectrum



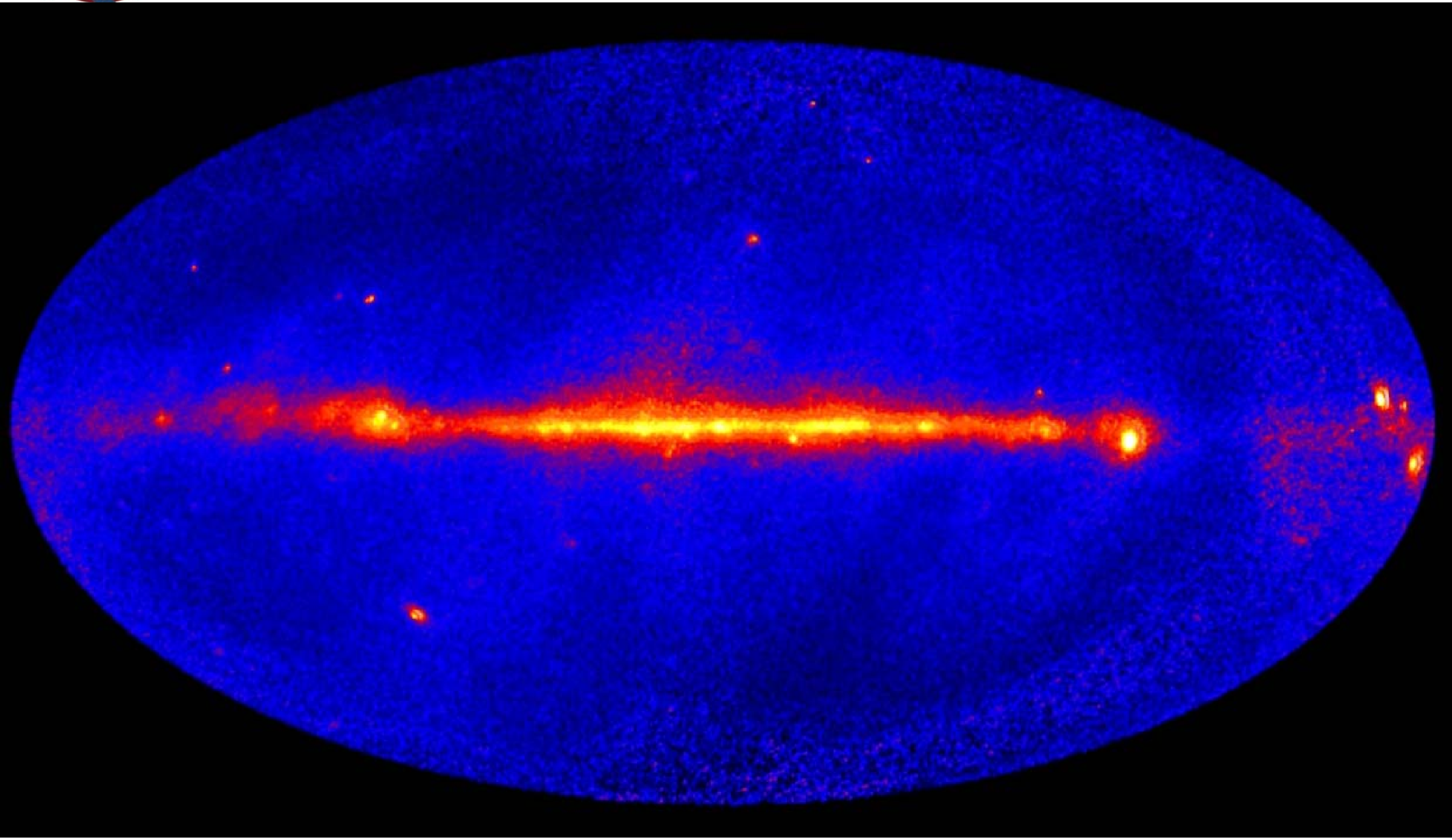
Complementary capabilities

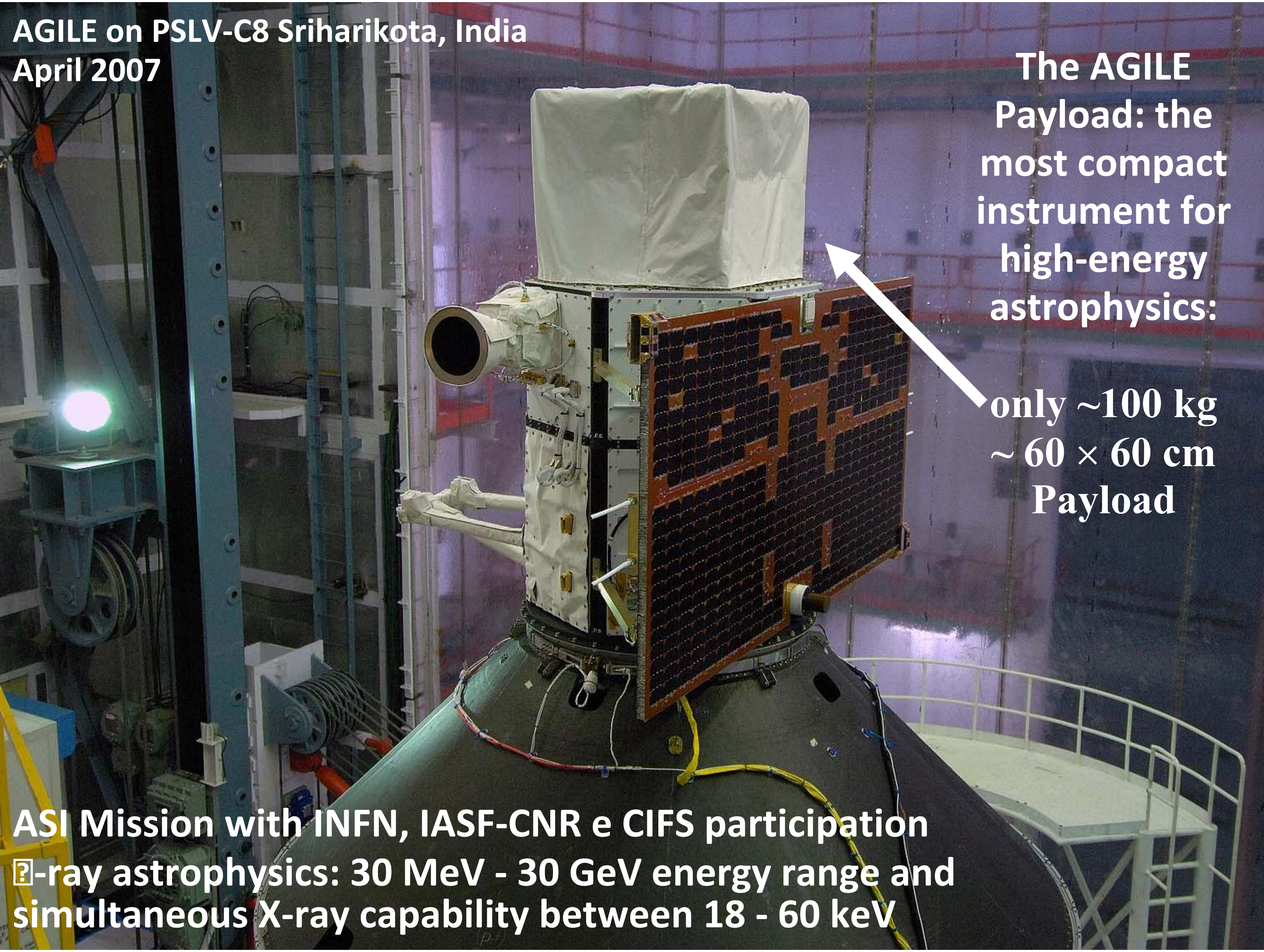
	ground-based*	space-based
angular resolution	good	good
duty cycle	low	excellent
area	**HUGE !**	relatively small
field of view	small	excellent (~20% of sky at any instant)
energy resolution	good	good, w/ small systematic uncertainties

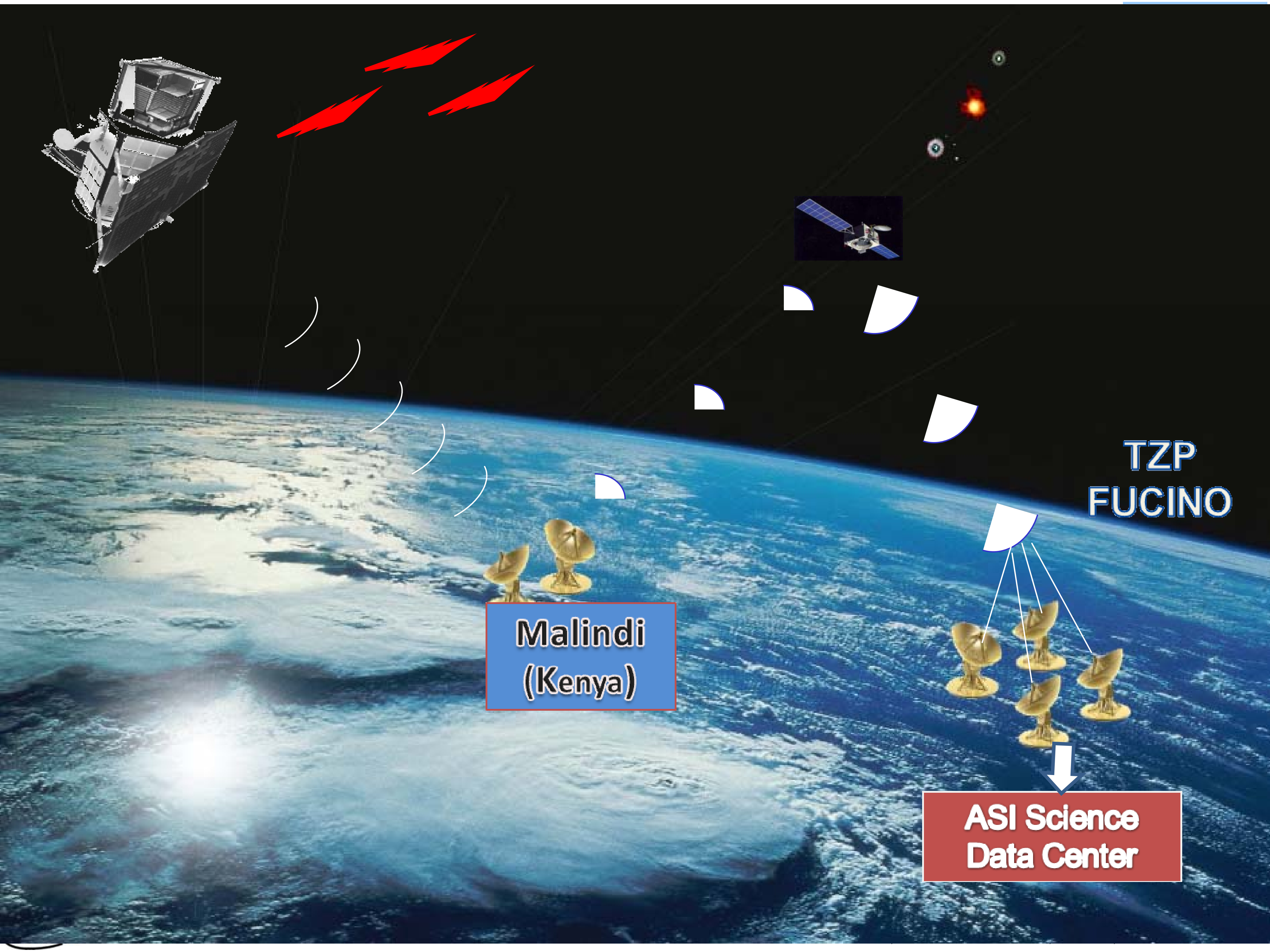
***air shower experiments have excellent duty cycle and FOV, and poorer energy resolution.**

The current new generation of ground-based and space-based experiments are well matched.

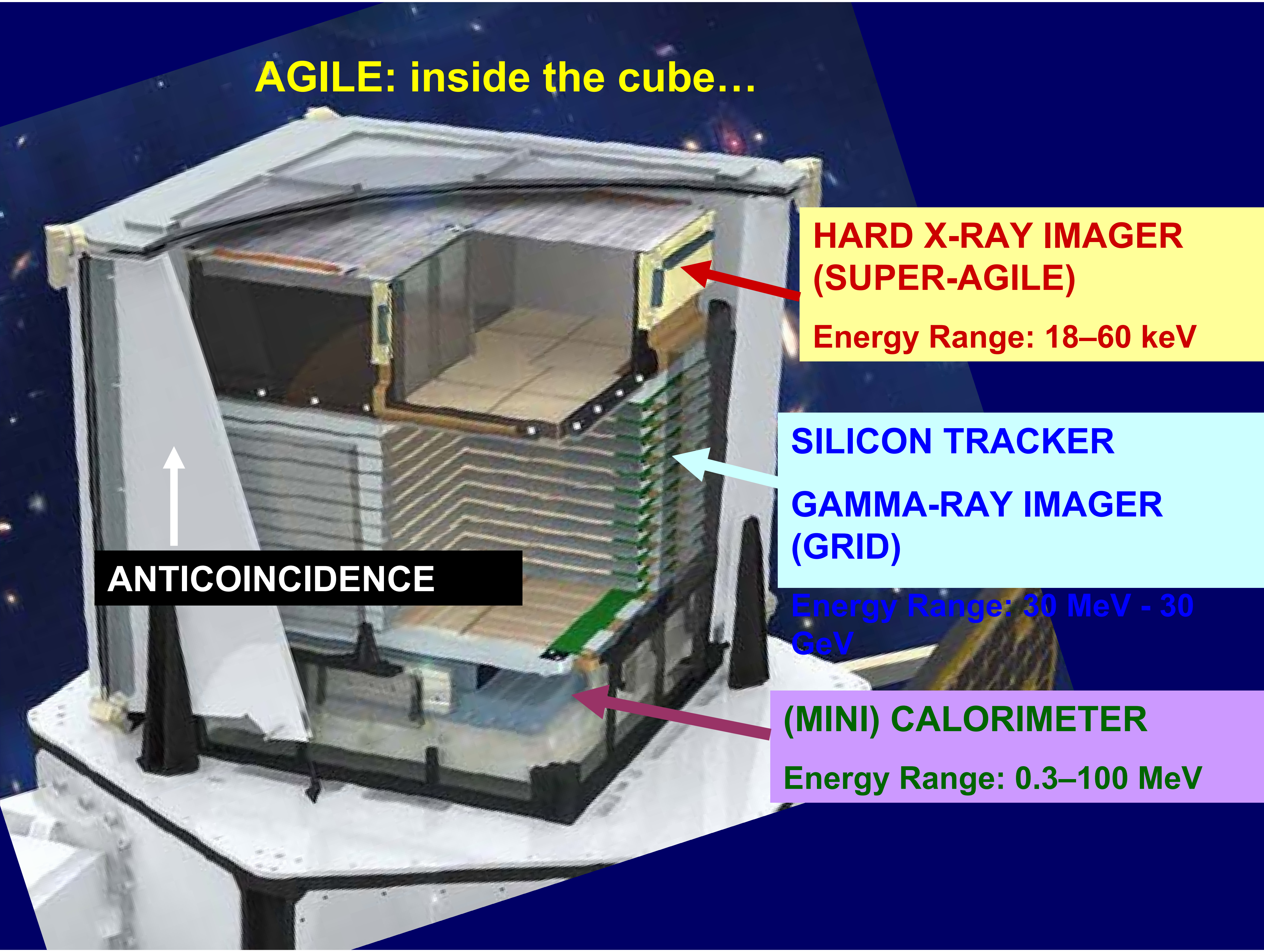
AGILE: 2 years all-sky map




AGILE on PSLV-C8 Sriharikota, India
April 2007
The AGILE Payload: the most compact instrument for high-energy astrophysics:
only ~100 kg
~ 60 × 60 cm
Payload
ASI Mission with INFN, IASF-CNR e CIFS participation
γ-ray astrophysics: 30 MeV - 30 GeV energy range and
simultaneous X-ray capability between 18 - 60 keV


TZP
FUCINO
Malindi
(Kenya)
ASI Science
Data Center

AGILE: inside the cube…



Main topics and AGILE discoveries

- ❑ **Bright gamma-ray blazars (3C 454.3, PKS 1510-089, TX 0716+714, Mrk 421,…)**
- ❑ **Several new pulsars (one millisecond pulsar in the globular cluster M28)**
- ❑ **Discovery of E > 100 MeV emission in PWNs (Vela X) (A. Pellizzoni et al., Science, 2010)**
- ❑ **Discovery of γ-ray transients in the Galaxy**
- ❑ **Colliding Wind Binary gamma-ray emission (η-Car), Microquasar studies (Cygnus X-1 and Cygnus X-3)**
- ❑ **SNRs and origin of cosmic rays (W28) (A. Giuliani et al. A&A 2010)**
- ❑ **GRBs, millisecond triggers, Terrestrial γ-ray Flashes**

- **Carina region: γ-ray detection of the colliding wind massive binary system η-Car with AGILE**

  Tavani et al., ApJ, 698, L142, 2009 (arXiv:0904.2736

- **Cygnus region microquasars:**
  - **AGILE observations of Cygnus X-1 gamma-ray flares**

    Sabatini et al., ApJ 2010, Del Monte et al., A&A 2010

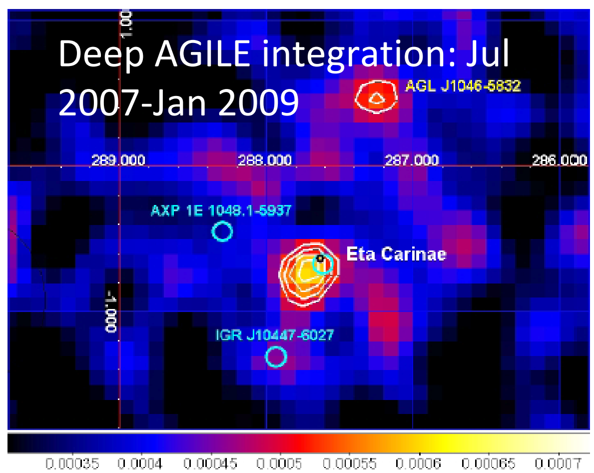
  - **AGILE detects several gamma-ray flares from Cygnus X-3, and also weak persistent emission above 100 MeV**

    Tavani et al., Nature 462, 620, 2009 (arXiv:0910.5344)

- **Detection of Gamma-Ray Emission from the Vela Pulsar Wind Nebula with AGILE**

  Pellizzoni et al., Science 327, 2010

The Eta Carinae region

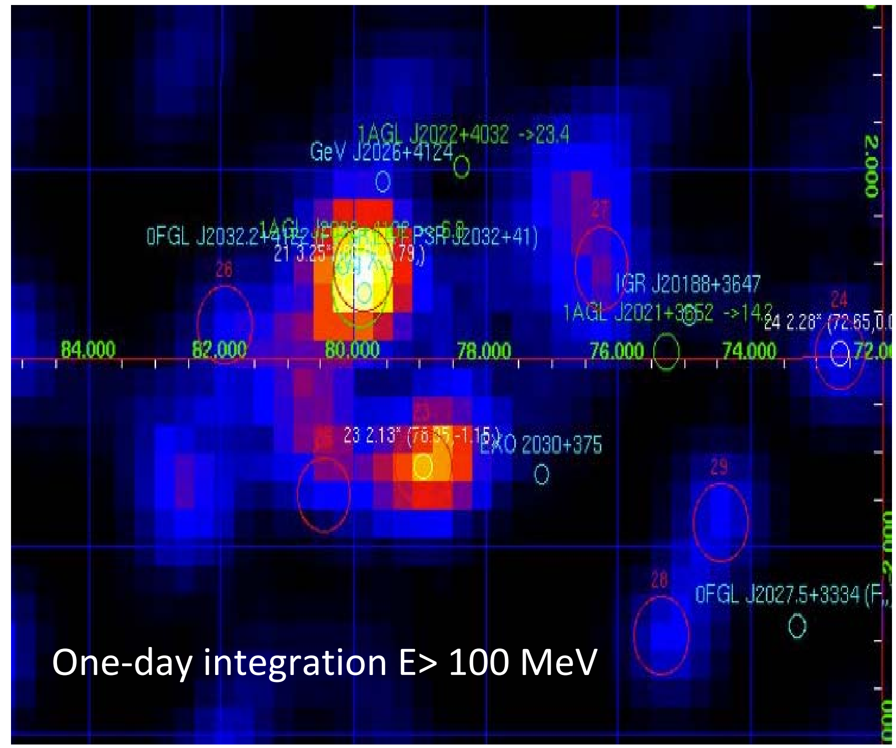


❑ Extensive AGILE observations of the Galactic region hosting the Carina nebula and the colliding wind binary Eta Carinae (η-Car). One flaring episode in Oct 2008.

❑ AGILE result: first detection above 100 MeV of a colliding wind binary system, confirming the efficiency of particle acceleration and the highly non-thermal nature of the strong shock in a CWB.

AGILE and Cygnus X-3

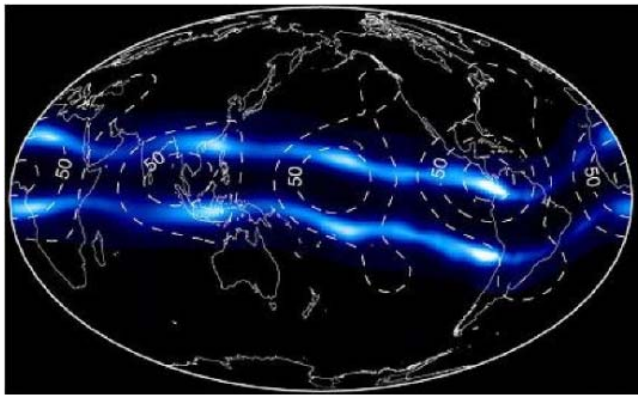
- AGILE detects weak persistent emission above 100 MeV and several gamma-ray flares from Cygnus X-3 microquasar for the first time:
  - 16-17 Apr 2008 (AGILE first gamma-ray detection above 100 MeV!!)
  - 2-3 Nov 2008
  - 11-12 Dec 2008
  - 20-21 Jun 2009
- AGILE discovery of a pattern in the gamma-ray emission: flares are all associated with special CygX-3 radio and X-ray/hard X-ray states
- Gamma-ray flares usually *before* major radio flares !!
- Pattern confirmation: Cyg X-3 gamma-ray flare expected from X-ray/hard X-ray monitoring observed on May 27, 2010 !!!
- Fermi confirmation and 4,8 hours orbital modulation measured!
- Other flaring events: Feb 1, Feb 8 and Mar 26, 2011
- 3 ATel.

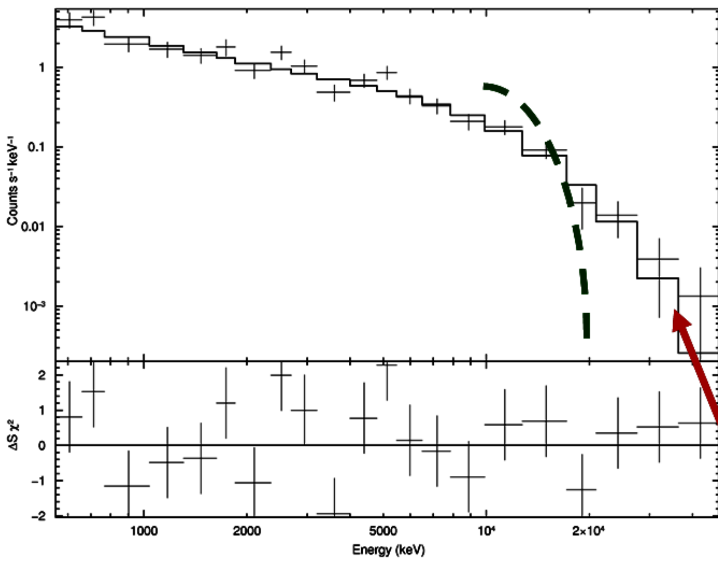


INTEGRAL confirms evidence that Cygnus X-3 has been transitioning to its soft state. Gamma-ray flare (E> 100 MeV) expected: **AGILE and Fermi detection of the expected flare!**

AGILE and TGF

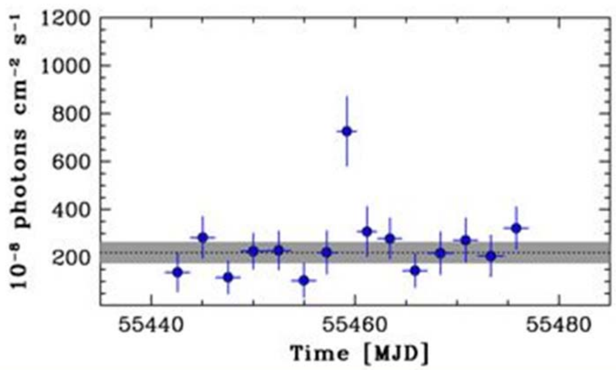
- ❑ Normal lightnings involve a potential difference ~ 500 kVolts
- ❑ **Terrestrial Gamma-Ray Flashes (TGF) involve DV > 100 MVolts !**
- ❑ Models: **Relativistic Runaway Electron Avalanche** (RREA) with relativistic feedback (Dwyer 2008). Bremsstrahlung + Compton scattering
- ❑ RHESSI cumulative spectrum compatible with a production altitude of 15-21 km (just above tropical thunderstorms)
- ❑ **AGILE MCAL: an optimal detector for TGF**
- ❑ MCAL energy range is extended **up to 100 MeV**
- ❑ Efficient trigger at **ms and sub-ms time scale** (the TGF time scale)
- ❑ AGILE **equatorial orbit** at 2.5° inclination is optimal for mapping the equatorial region, where most of the events take place
- ❑ A real-time monitoring and alert system can be implemented for correlation with other meteo resources (work in progress)





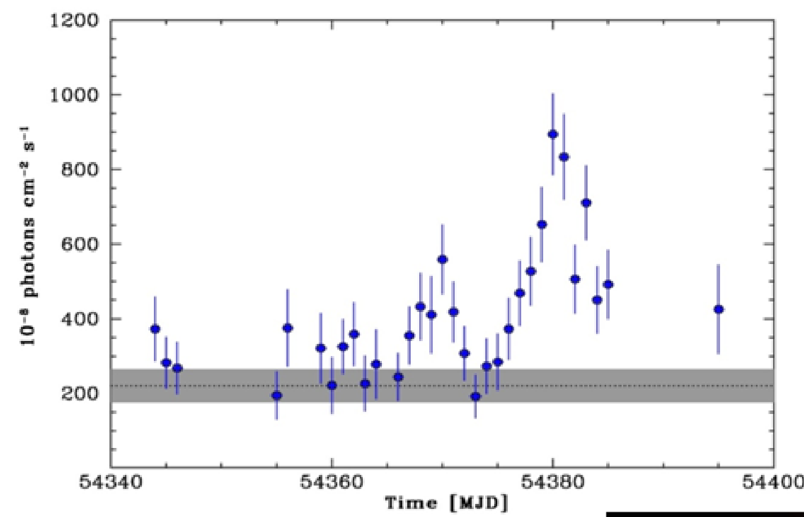
The gamma-ray variable Crab Nebula

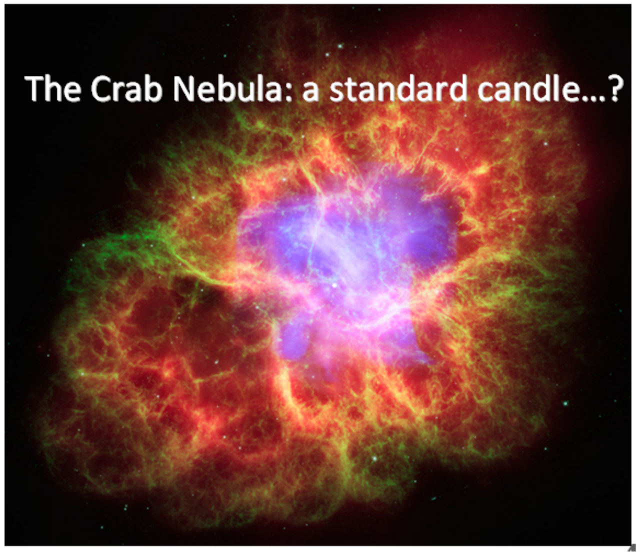
FIRST PUBLIC ANNOUNCEMENT Sept. 22, 2010: AGILE issues the Astronomer's Telegram n. 2855 announcing a gamma-ray flare from the Crab Nebula



***Science Express* (6 January 2011)**

AGILE first detection of a strong gamma-ray flare in Oct. 2007





AGILE DISCOVERY OF THE CRAB NEBULA VARIABILITY IN γ-RAYS

Tavani et al., Science, 331, 736 (2011)

Fermi confirmation:

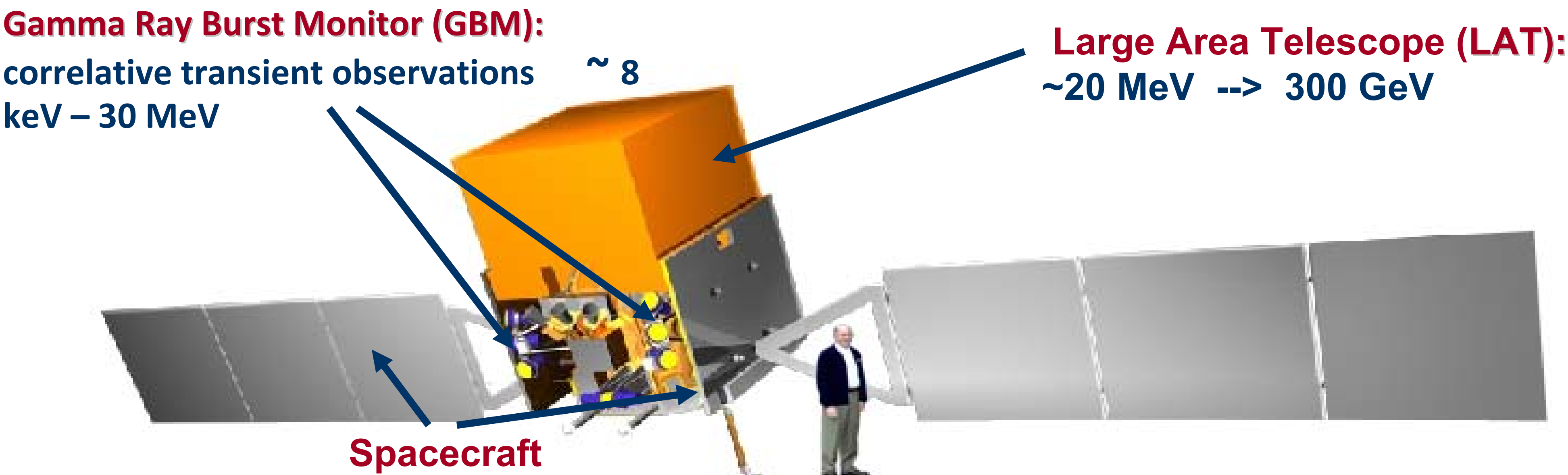
Abdo et al., Science, 331, 739 (2011)

Fermi Gamma-ray Space Telescope

Fermi (formerly GLAST): two Instruments (and two Collaborations):

The Large Area Telescope (LAT)
www-glast.stanford.edu
PI: P. Michelson (Stanford University)
20 MeV - 300 GeV
>2.5 sr FoV

The Burst Monitor (GBM)
f64.nsstc.nasa.gov/gbm/
PI: W.S. Paciesas (NASA/U.Alabama)
Co-PI: J Greiner (MPE)
8 keV – 40 MeV
9.5 sr FoV



www.nasa.gov/fermi - fermi.gsfc.nasa.gov - fgst.slac.stanford.edu

The Fermi LAT Collaboration

US Team Institutions	
SU	Stanford University, Physics Department, GLAST group
SU-HEPL	Hansen Experimental Physics Laboratory
SU-SLAC	Stanford Linear Accelerator Center (SLAC), Kavli Institute for Particle Astrophysics and Cosmology
GSFC	NASA Goddard Space Flight Center, Astrophysics Science Division
NRL	U. S. Naval Research Laboratory, High Energy Space Environment (HESE) branch
OSU	Ohio State University, Physics Department
UCSC	University of California at Santa Cruz, Physics Department
SSU	Sonoma State University, Physics & Astronomy Department, GLAST group, Education and Public Outreach
UW	University of Washington
Denver	University of Denver
Purdue	Purdue University - Calumet

Italian Team Institutions	
ASI	Italian Space Agency
INAF-IASF	Istituto di Astrofisica Spaziale e Fisica Cosmica, Milano, CNR
INFN-Bari	INFN Sezione di Bari
Bari	Università e Politecnico di Bari
Perugia	INFN and University of Perugia
Pisa	INFN and University of Pisa
Rome	INFN and University of Rome 2 (Tor Vergata)
Trieste	INFN and University of Trieste
Udine	INFN and University of Udine

French Team Institutions	
CEA/DAPNIA	Service d'Astrophysique, DAPNIA, CEA Saclay
CESR/CNRS/UPS	Centre d'Étude Spatiale des Rayonnements, Toulouse
IN2P3/LLR	Laboratoire Leprince-Ringuet de l'École Polytechnique
IN2P3/CENBG	Centre d'Études Nucléaires de Bordeaux Gradignan
IN2P3/LPTA	Laboratoire de Physique Théorique et Astroparticules Montpellier

Japanese Team Institutions	
Tokyo Tech	Tokyo Institute of Technology
ISAS	Institute for Space and Astronautical Science
Hiroshima	Hiroshima University

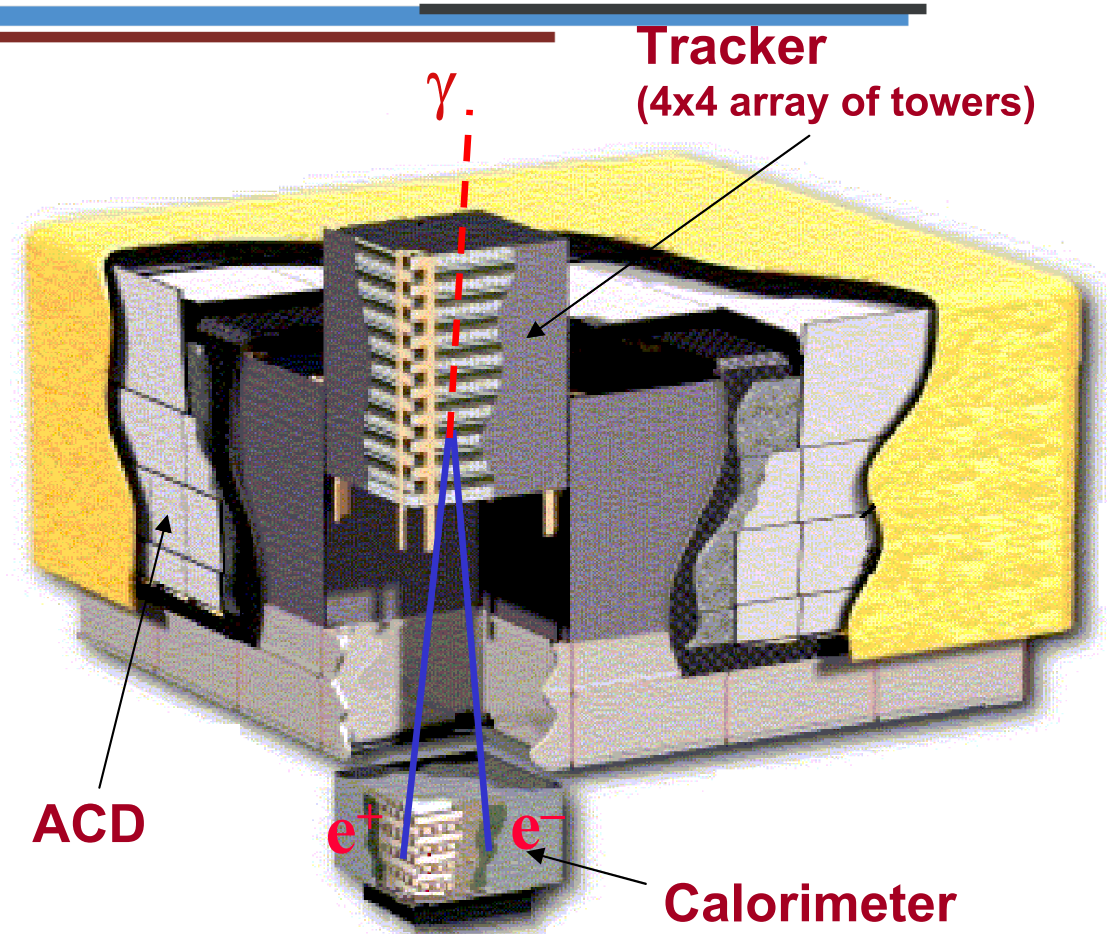
Swedish Team Institutions	
KTH	Royal Institute of Technology
Stockholm	Stockholms Universitet

Cooperation between US NASA and DOE, with key contributions from Institutions and Government Agencies in France, Italy, Japan, and Sweden.

LAT instrument construction managed by the Stanford Linear Accelerator Center (SLAC).

Main Components of the LAT

- **Precision Si-strip Tracker (TKR)**
  18 XY tracking planes with tungsten foil converters. Single-sided silicon strip detectors (228 µm pitch, 900k strips)
  Measures the photon direction; gamma ID.
- **Hodoscopic CsI Calorimeter(CAL) Array**
  of 1536 CsI(Tl) crystals in 8 layers. Measures the photon energy; image the shower.
- **Segmented Anticoincidence Detector (ACD)** 89 plastic scintillator tiles. Rejects background of charged cosmic rays; segmentation mitigates self-veto effects at high energy.
- **Electronics System**
  Includes flexible, robust hardware trigger and software filters.



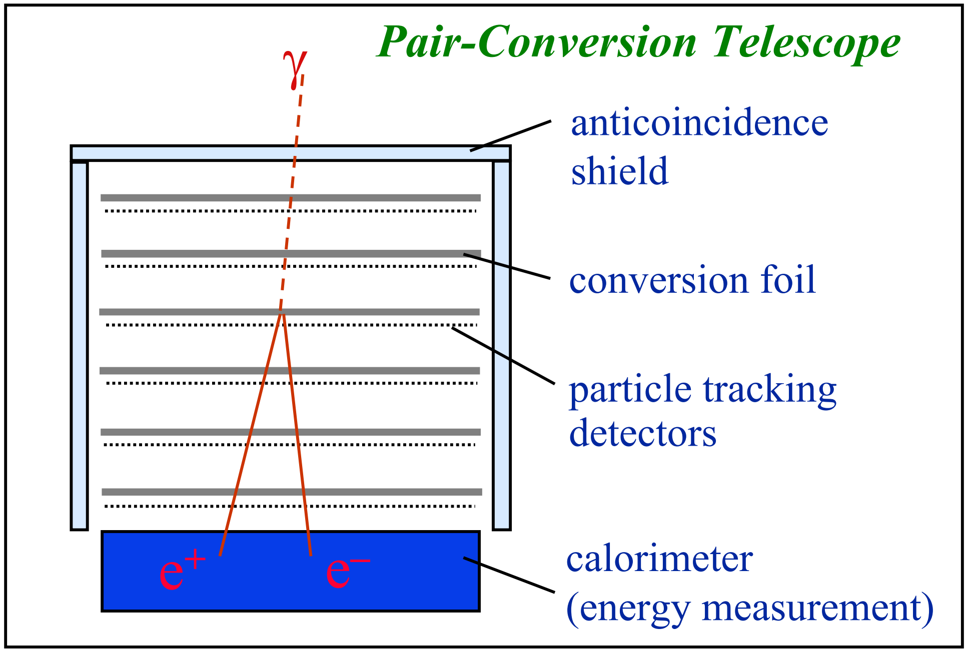
modular - 4x4 array
3ton – 650watts

The systems work together to identify and measure the flux of celestial gamma rays with energy between ~20 MeV and above 300 GeV.

Experimental Technique

Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV):

- photon interactions with matter in GLAST energy range dominated by pair conversion:
  - ➡ determine photon direction
  - ➡ clear signature for background rejection
- limitations on angular resolution (PSF)
  - **low E: multiple scattering => many thin layers**
  - **high E: hit precision & lever arm**



Energy loss mechanisms:

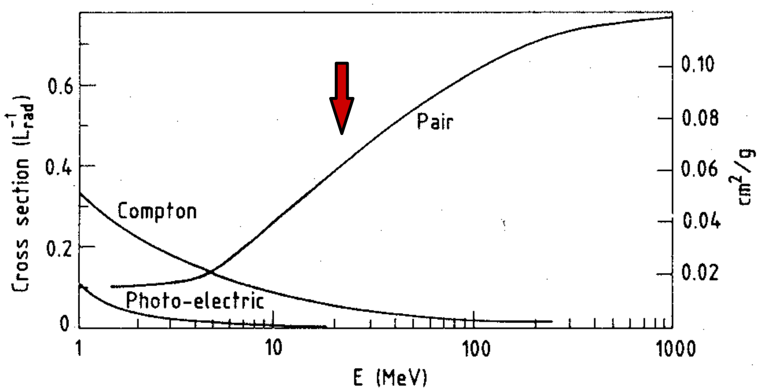
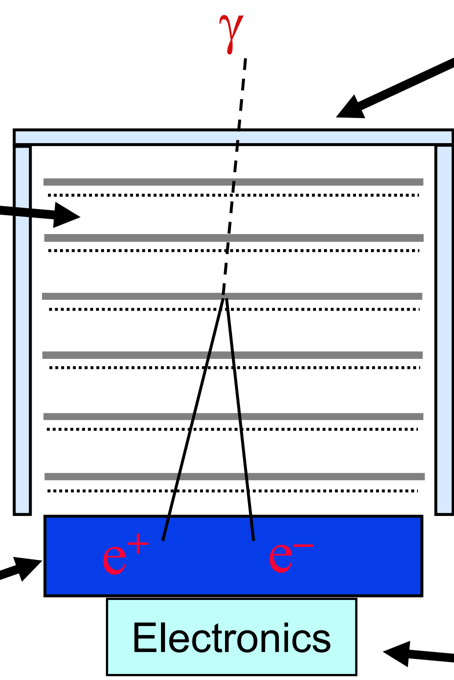


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

- instrument must detect γ-rays with high efficiency and reject the much higher flux (x ~10^4) of background cosmic-rays, etc.;
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful.

Primary Design Impacts of Science Requirements



Background rejection requirements drive the ACD design (and influence the calorimeter and tracker layouts).

Effective area and PSF requirements drive the converter thicknesses and layout. PSF requirements also drive the design of the mechanical support.

Field of view sets the aspect ratio (height/width)

Energy range and energy resolution requirements set thickness of calorimeter

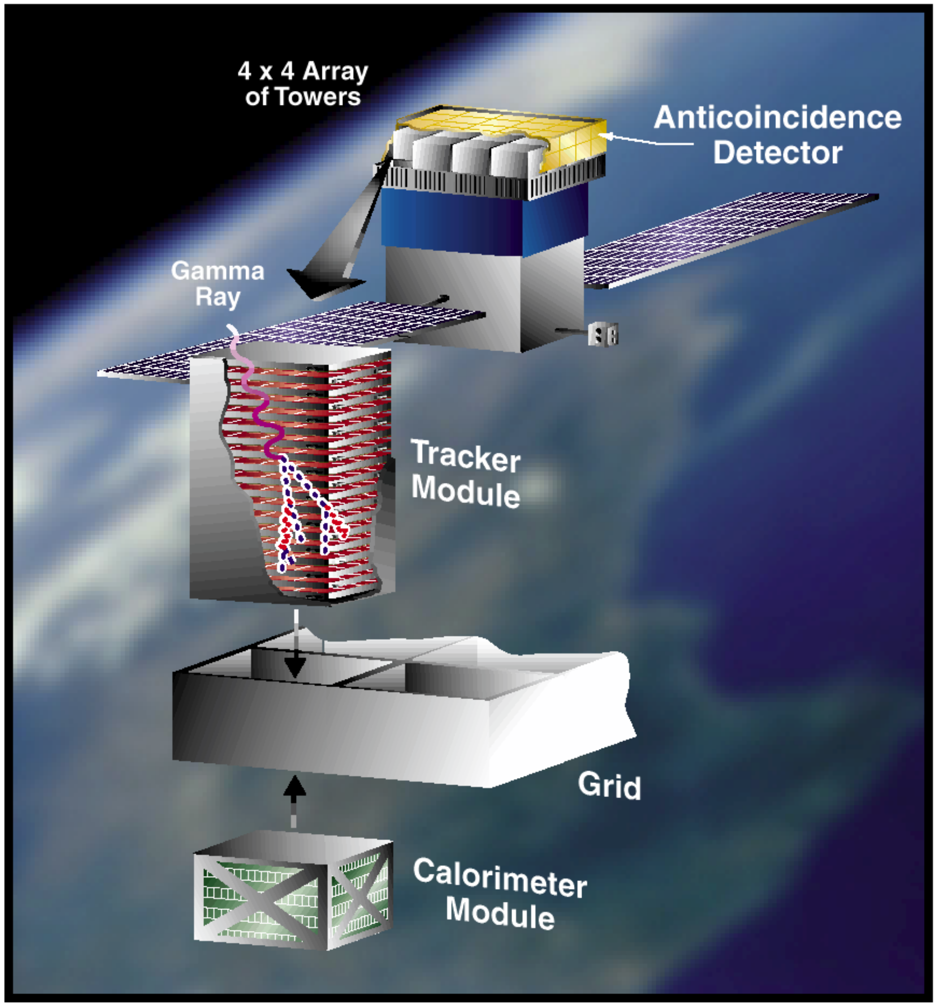
Time accuracy provided by electronics and intrinsic resolution of the sensors.

On-board transient detection requirements, and on-board background rejection to meet telemetry requirements, drive the electronics, processing, flight software, and trigger design.

Instrument life has an impact on detector technology choices.
Derived requirements (source location determination and point source sensitivity) drive the overall system performance.

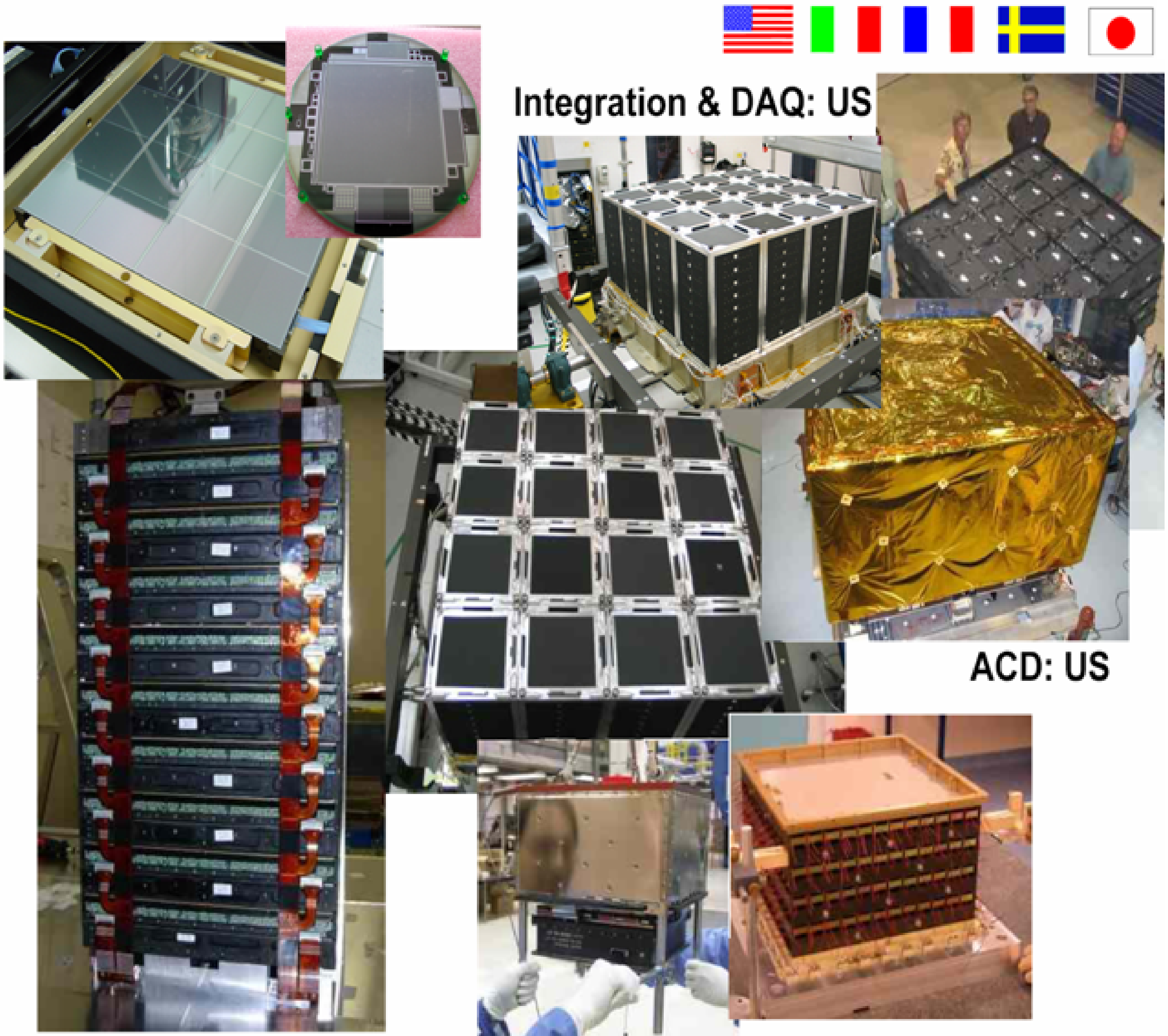
Fermi LAT Instrument Basics

- 4x4 array of identical towers
  Advantages of modular design.
- Precision Si-strip Tracker (TKR)
  Detectors and converters arranged in 18 XY tracking planes. Measure the photon direction.
- Hodoscopic CsI Calorimeter(CAL)
  Segmented array of CsI(Tl) crystals. Measure the photon energy.
- Segmented Anticoincidence Detector (ACD First step in reducing the large background of charged cosmic rays. Segmentation removes self-veto effects at high energy.
- Central Electronics System Includes flexible, highly-efficient, multi-level trigger.



Systems work together to identify and measure the flux of cosmic gamma rays with energy 30 MeV - >300 GeV.

LAT Construction: an International Effort

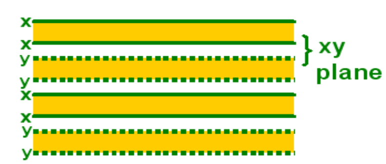


Tracker: US, Italy, Japan

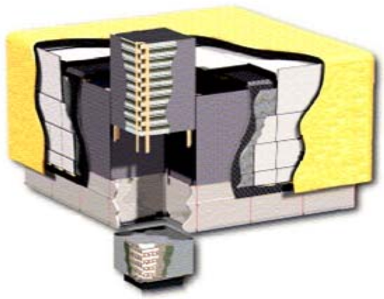
Calorimeter: US, France, Sweden

TRACKER details:

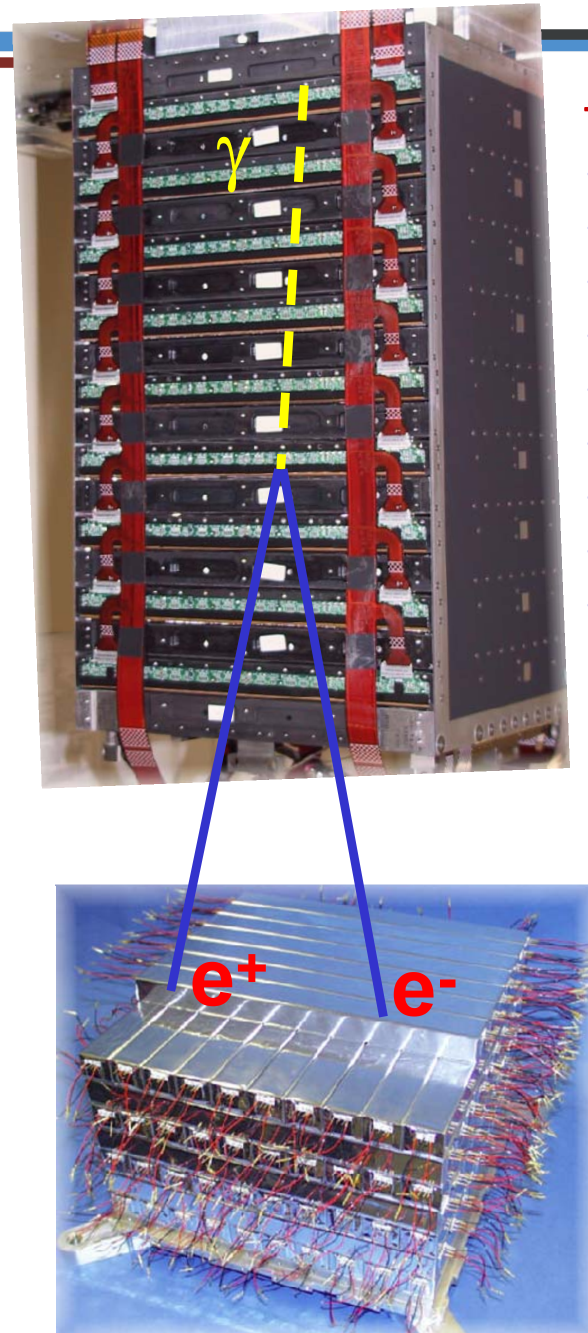
- **16 tower modules**: 37×37cm^2 active cross section/layer
- **83 m^2 of Si**
- **11500 Single Strip Detectors**, ~ 1M channels, strip-pitch: 228μm
- **18 *xy* layers per tower**
  19 "tray" structures, 12 with 3% X_0 W on top, 4 with 18% X_0 W on bottom, 3 with no converter foils. Every tray is rotated by 90° with the previous one: W foils followed by. *x,y* plane of detectors, 2mm gap between *x* and *y* oriented detect.
- Trays stack and align at their corners
- Electronics on sides of trays: minimize gap between towers



Fermi LAT: Tracker, Calorimeter, ACD



Anti-Coincidence (ACD):
- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- **0.9997 detection efficiency**

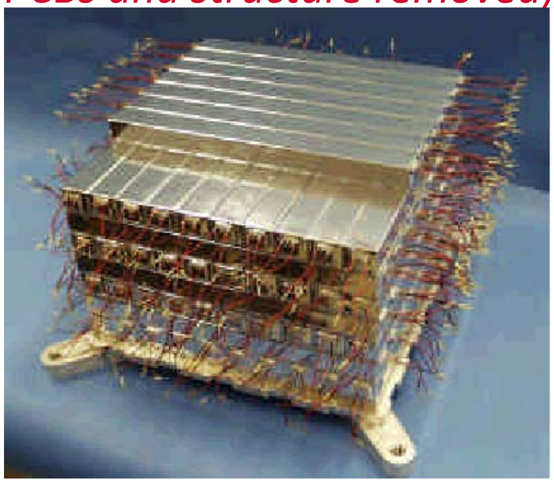


Tracker/Converter (TKR):
- Si-strip detectors
- ~80 m^2 of silicon (total)
- W conversion foils
- **1.5 X0 on-axis**
- 18XY planes
- **~10^6 digital elx chans**
- Highly granular
- High precision tracking
- Average plane PHA

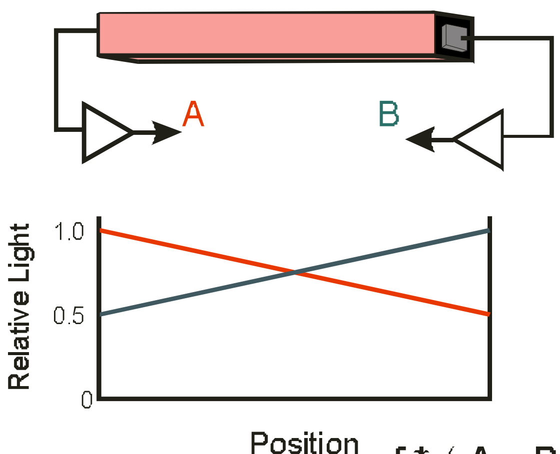
Calorimeter (CAL):
- 1536 CsI(Tl) crystals
- **8.6 X0 on-axis**
- large elx dynamic range (2MeV-60GeV per xtal)
- **Hodoscopic (8x12)**
- Shower profile recon
- leakage correction
- EM vs HAD separation

LAT Calorimeter and ACD

Modular CsI Calorimeter (PCBs and structure removed)



- ❑ **Calorimeter Concept**
  - ❑ Modular design matches GLAST Tower Concept
  - ❑ Hodoscopic Imaging of EM Showers
  - ❑ CsI(Tl) Detectors with long space history
  - ❑ PIN photodiode readout for reliability and compact design
- ❑ **Calorimeter Hodoscopic Design**
  - ❑ 8 layers of 12 CsI blocks in each tower
  - ❑ Custom dual-PIN photodiode on each end
  - ❑ low-power front end electronics supporting large dynamic range ($\sim 10^5$)



$$\text{Position} = 0.5 + \frac{f * (A - B)}{(A + B)}$$

Position Measurement

ACD

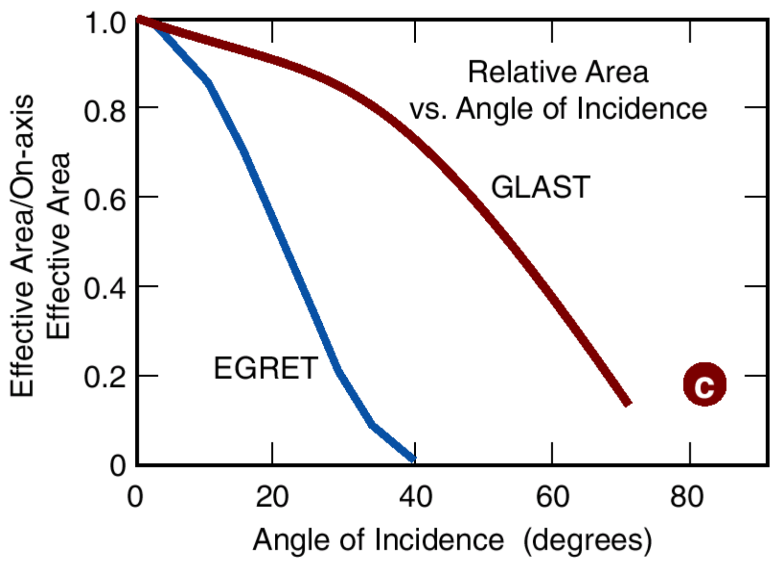
❑ ACD Segmented plastic scintillator with wave-shifting fibers + photomultiplier readout; each segment (tile) has a separate light-tight housing.

❑Separate tile housings provide resistance to accidental puncture by micrometeoroids.

❑Wave-shifting fiber readout provides the best light collection uniformity within the space constraints and minimizes the inert material

❑ACD "hat" covers the top and the sides of the tracker down to the calorimeter, covering the gap between tracker and calorimeter where the grid is located.

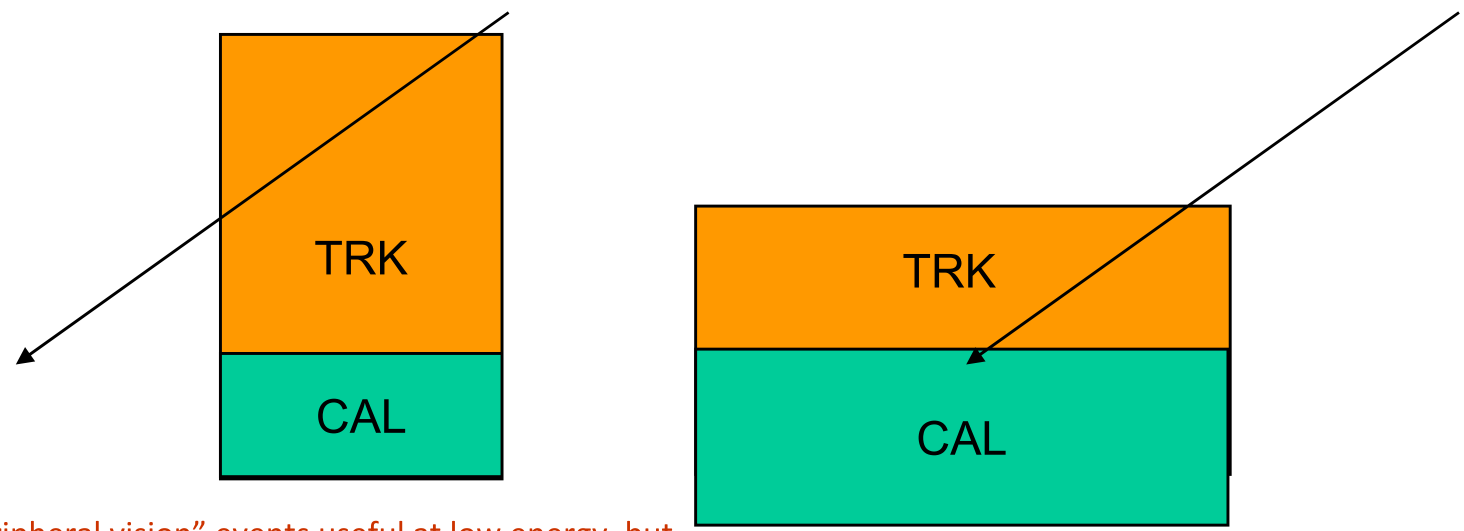
Field of View and Instrument Aspect Ratio



For energy measurement and background rejection, want events to pass through the calorimeter*.

The aspect ratio (Area/Height) then governs the main field of view of the tracker:

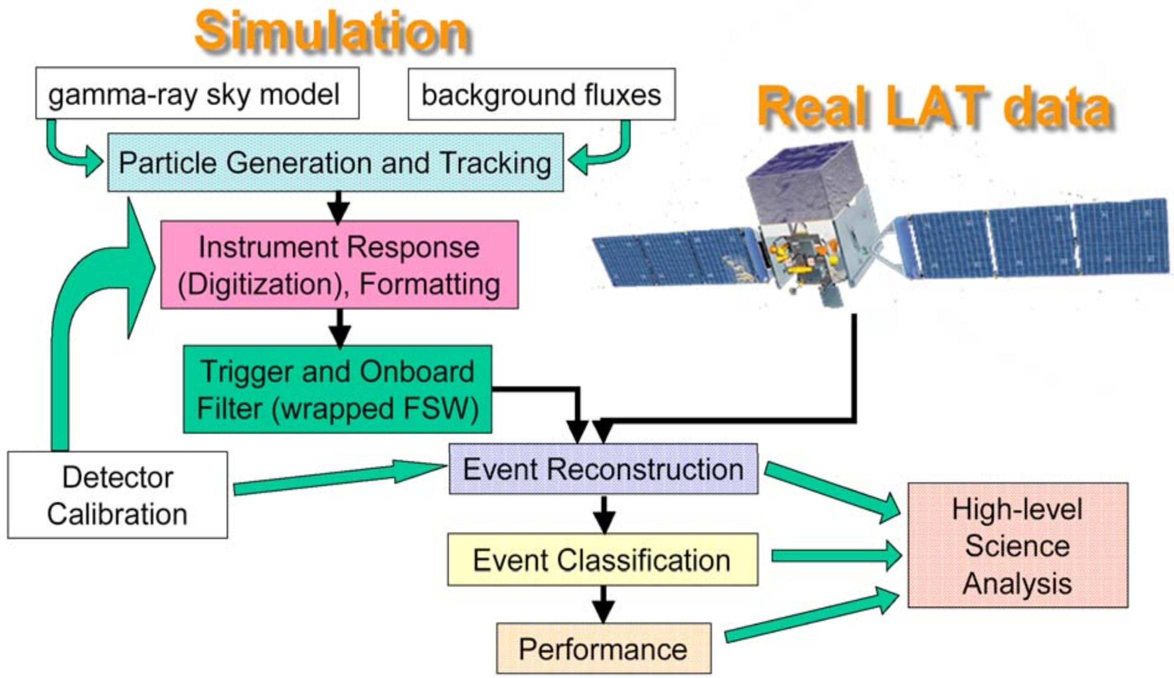
- EGRET had a relatively small aspect ratio
- GLAST has a large aspect ratio

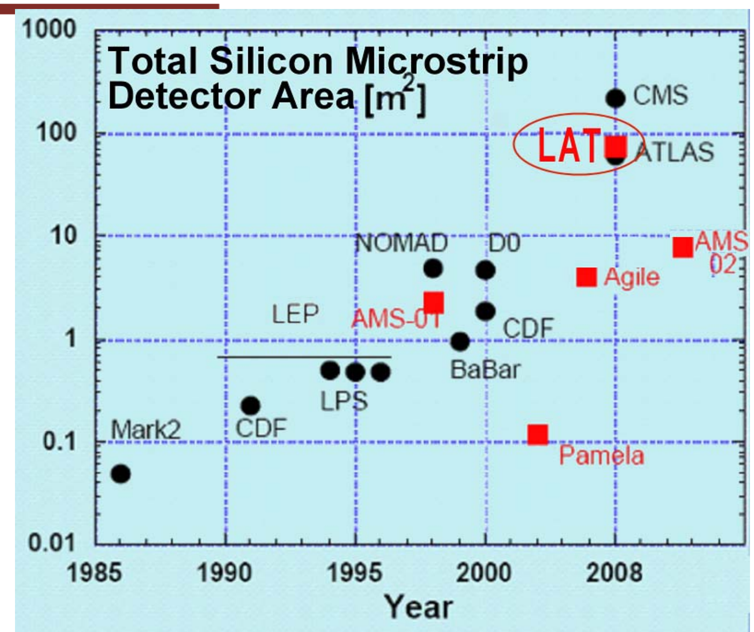


*note: “peripheral vision” events useful at low energy, but are not included in performance calculations.

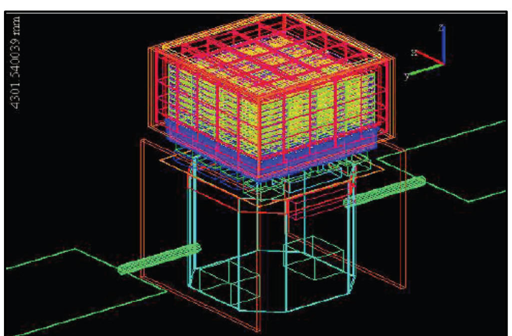
LAT Simulation and Data Analysis

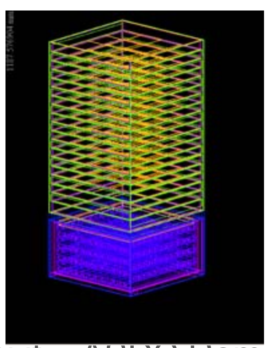
- ❑ Geometry Detail
  - > 500k Volumes, spacecraft details, electronics, gaps, dead material, detector response
- ❑ Geant 4 Interaction Physics
- ❑ Propagation, Full treatment of multiple scattering

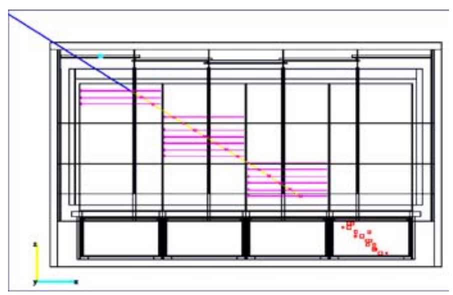




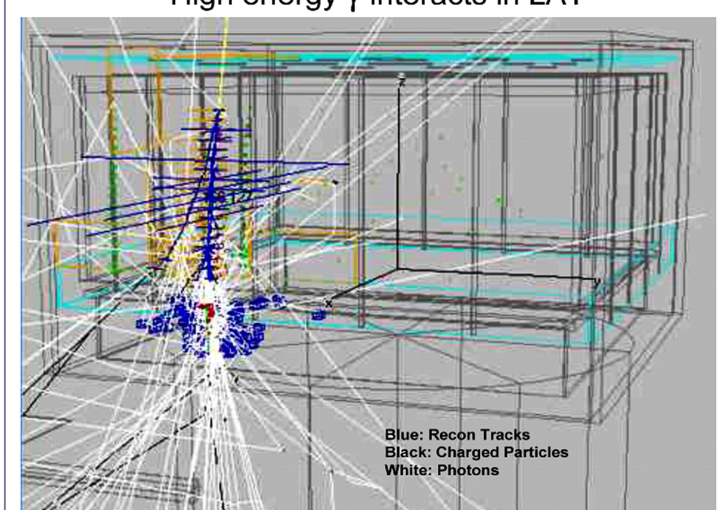
Apart of LHC-CMS, the GLAST-LAT has the larger quantity of silicon strip







High energy γ interacts in LAT

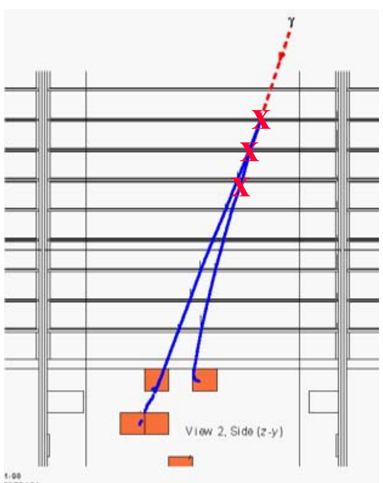


Instrument Triggering and Onboard Data Flow

Level 1 Trigger

Hardware trigger based on special signals from each tower; initiates readout

Function: • "did anything happen?"
• keep as simple as possible



- **TKR 3 *x•y* pair planes in a row**[**]
  workhorse γ trigger

OR

- **CAL:**
  LO – independent check on TKR trigger.
  HI – indicates high energy event ⟶ ground

Upon a L1T, all towers are read out within 20μs

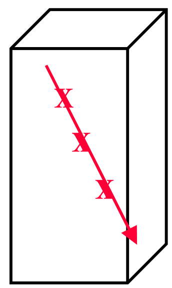
Instrument Total L1T Rate: <5 kHz>

rates are orbit averaged; peak L1T rate is approximately 10 kHz. **L1T rate estimate being revised.**

[**]ACD may be used to throttle this rate, if req.

Level 2 Processing

Function: • reject background efficiently & quickly with loose cuts,
• reduce computing load
• remove any noise triggers



- **tracker hits ~line up**
- **track does not point to hit ACD tile**

L2 was motivated by earlier DAQ design that had one processor per tower. **On-board filtering hierarchy being redesigned.**

Level 3 Processing

L3T: full instrument

Function: reduce data to fit within downlink

- **complete event reconstruction**
- **signal/bkgd tunable, depending on analysis cuts:**
  γ:cosmic-rays ~ 1:~few

Total L3T Rate: <30 Hz>

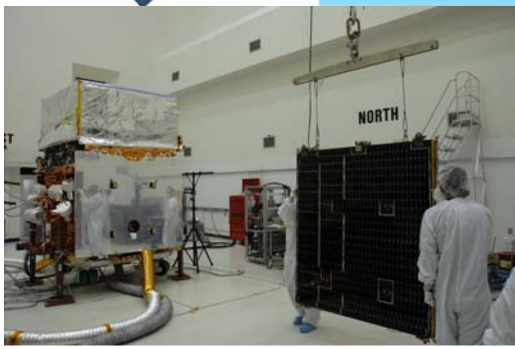
(average event size: ~7 kbits)

On-board science analysis:
transient detection (AGN flares, bursts)

Spacecraft

Fermi Launch

Launch: 2008, June 11
5 year mission life
(goal: 7-10 years)

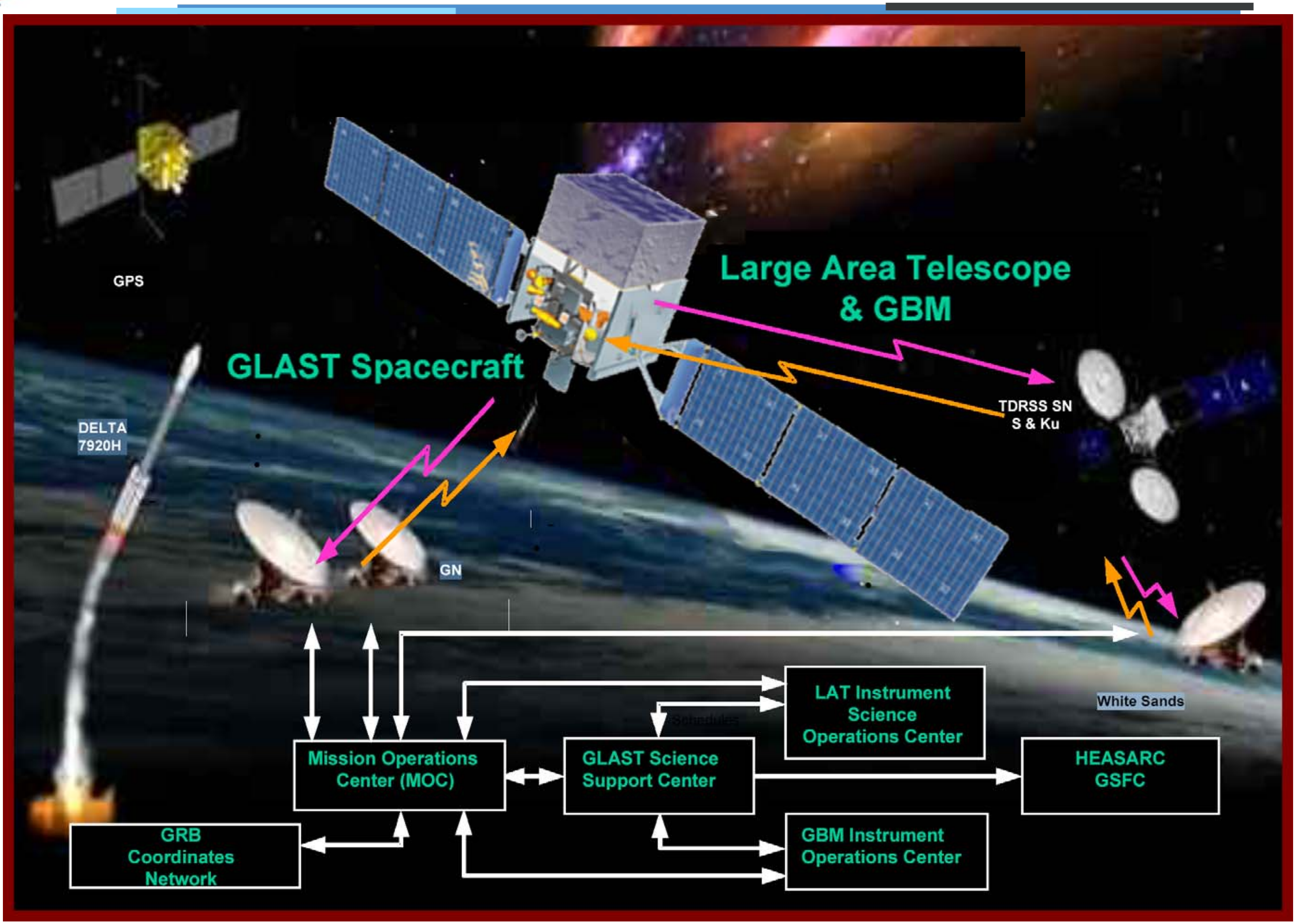


Fermi Launch

Launch from Cape Canaveral Air Station
11-June-2008
at 12:05PM EDT

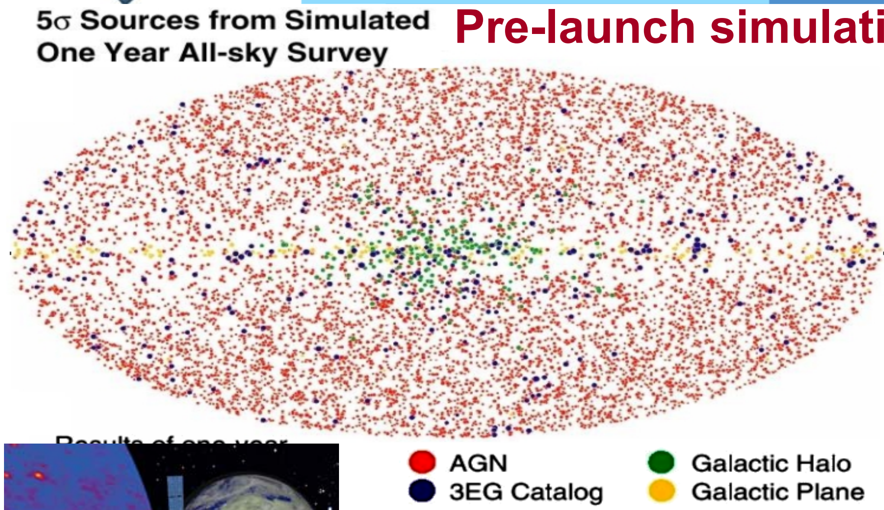
Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

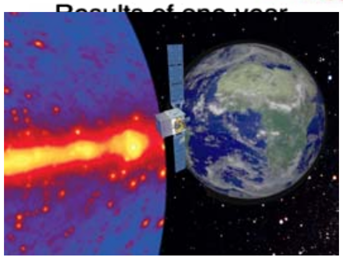
Fermi Mission Elements

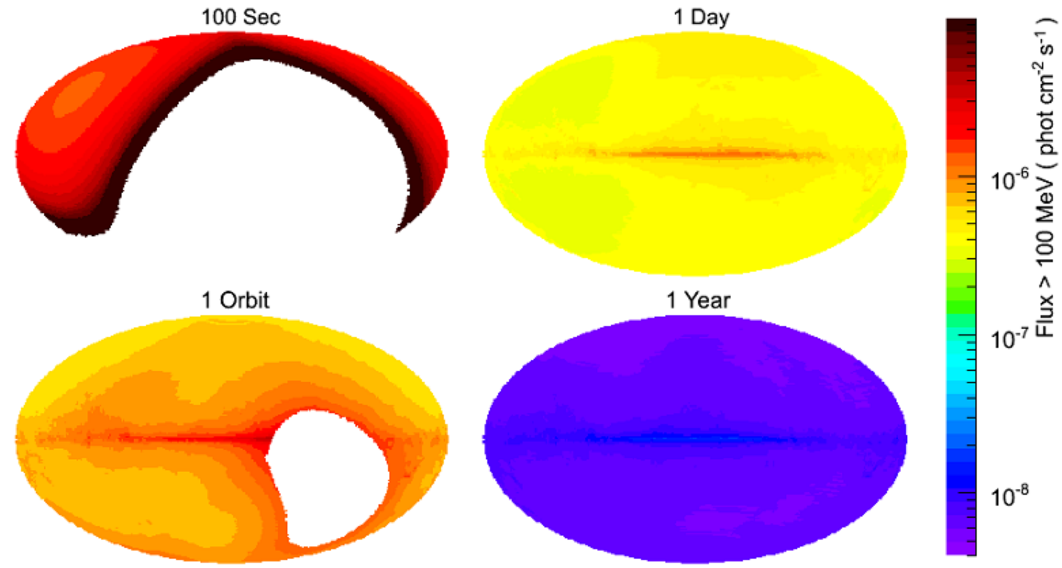


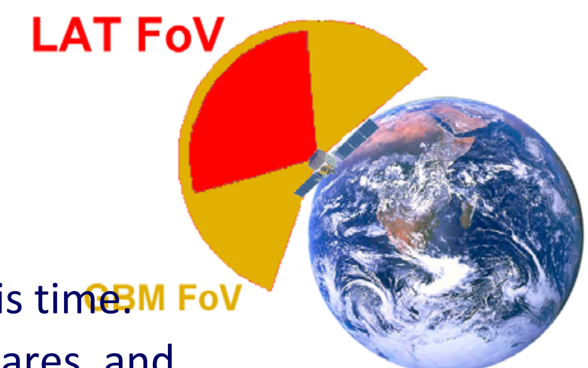
Operating mode: All Sky Scanning Survey

Pre-launch simulation



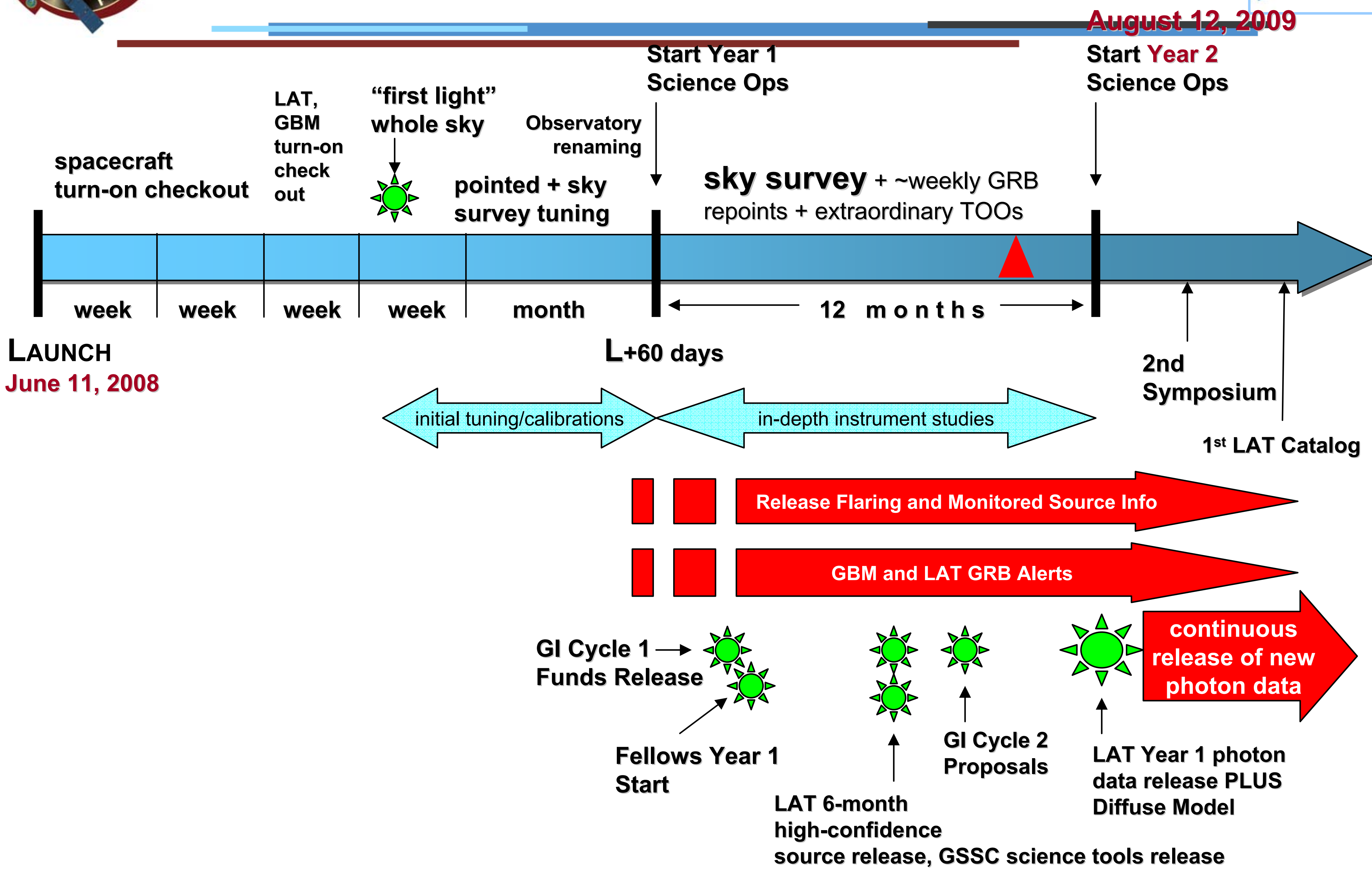






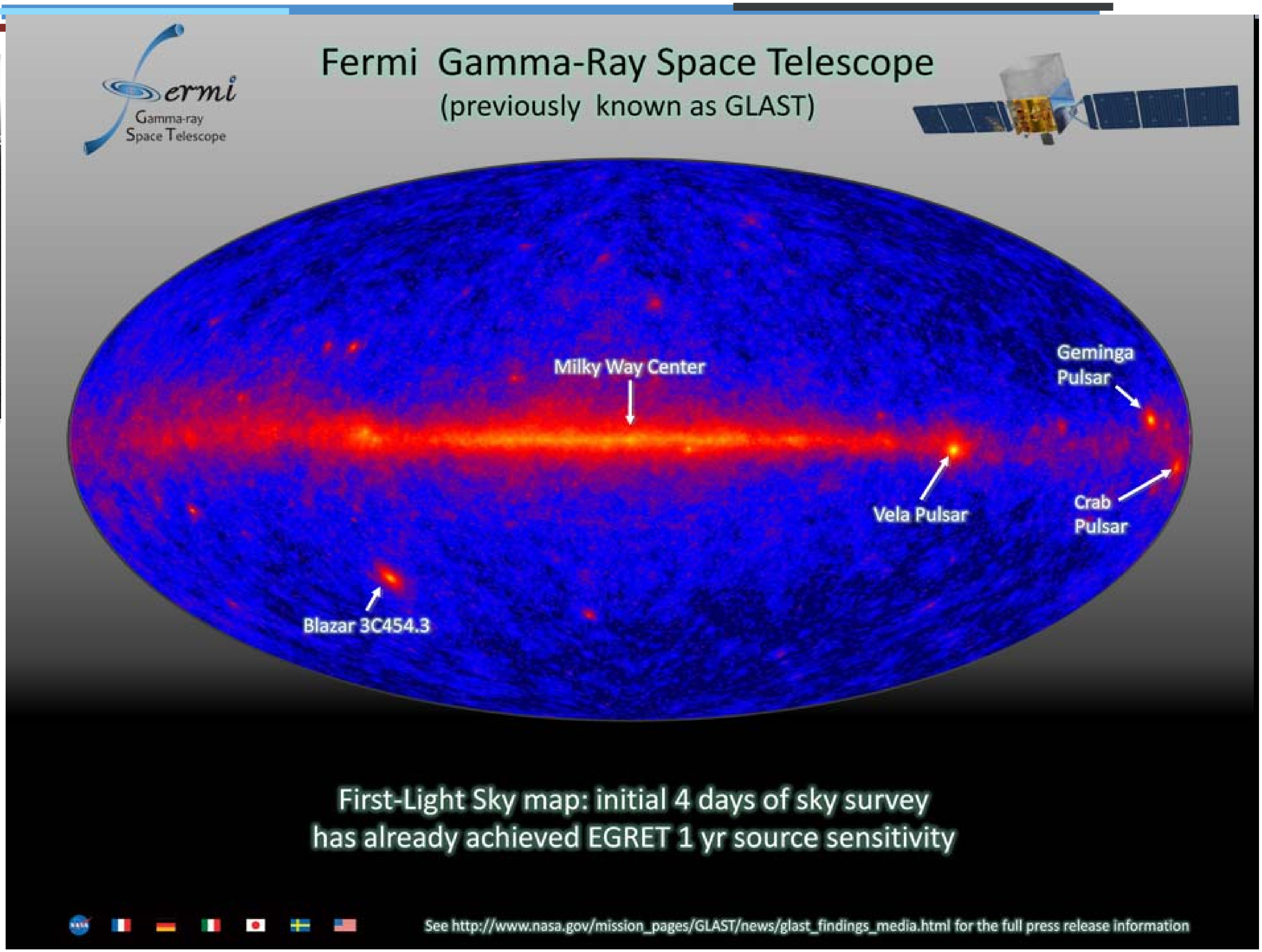
- LAT has a huge field of view >20% of the sky (>2.5 sr)
  Excellent for "catching" GRBs and blazar flares.
- In survey mode, the LAT observes the entire sky every two orbits
  (~3 hours), each point on the sky receives ~30 mins exposure during this time.
- The LAT, as an all-sky hunter and surveyor for high-energy transients, flares, and variability of the restless and violent high-energy Universe, is producing evenly sampled light curves for the brightest gamma-ray sources in the sky.
- Multiwavelength observations joined with the LAT are limited only by the ability to coordinate to other observations in other wavebands.

Year 1 Science Operations Timeline Overview



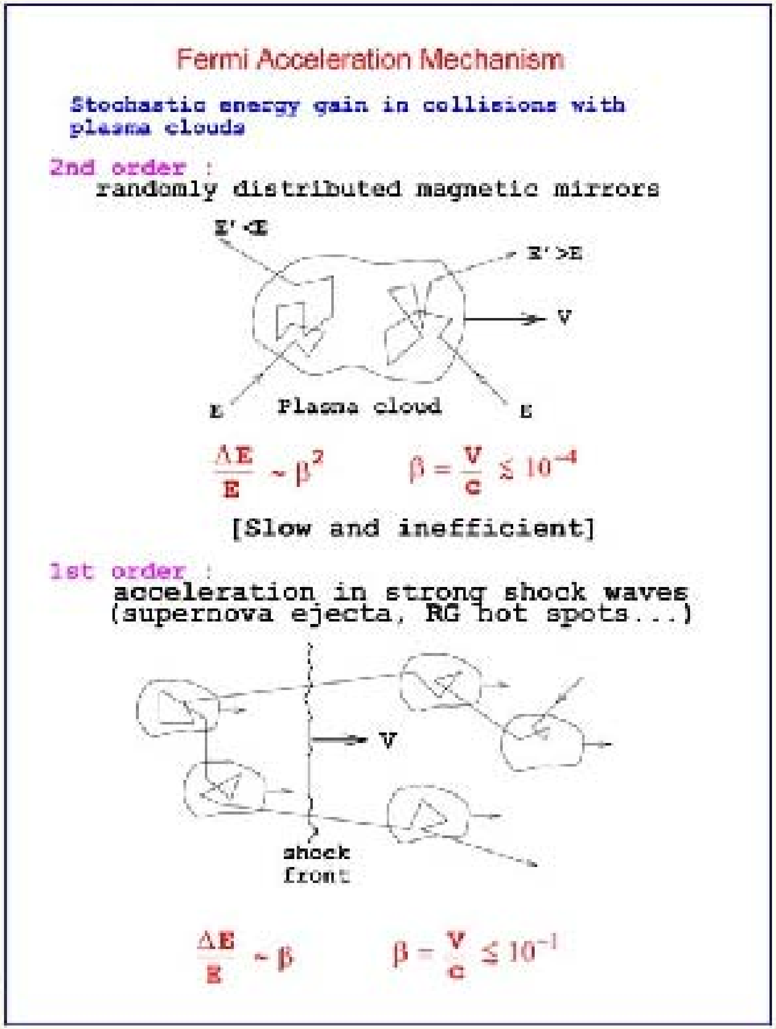
Fermi LAT First light (July 2008)

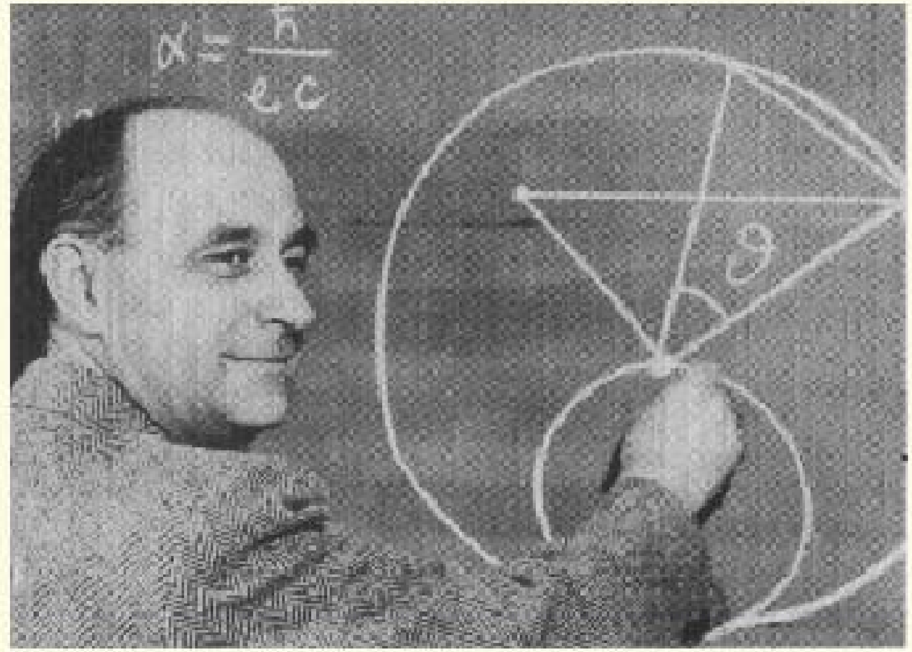
The new name, Fermi Gamma-ray Space Telescope, honors Enrico Fermi (1901-1954), a pioneer in high-energy physics.



Enrico Fermi

Mystery of Ultra-High Energy Cosmic Rays



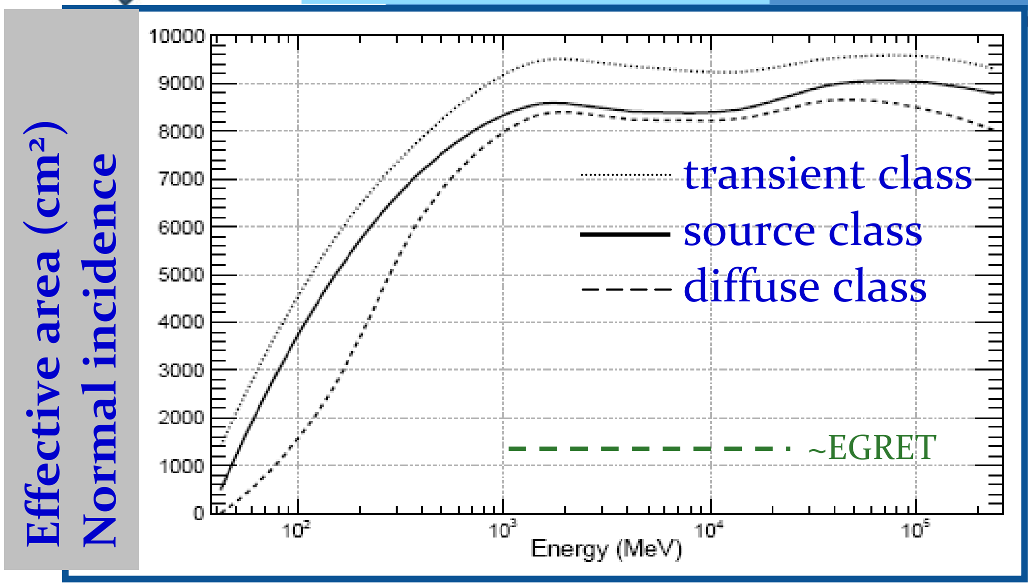


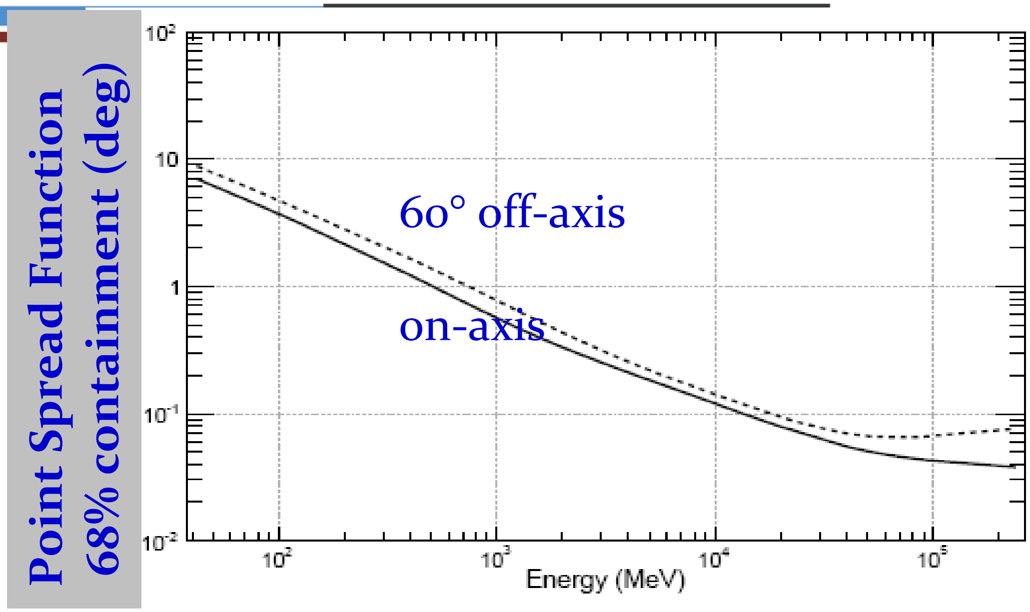
How are they accelerated?

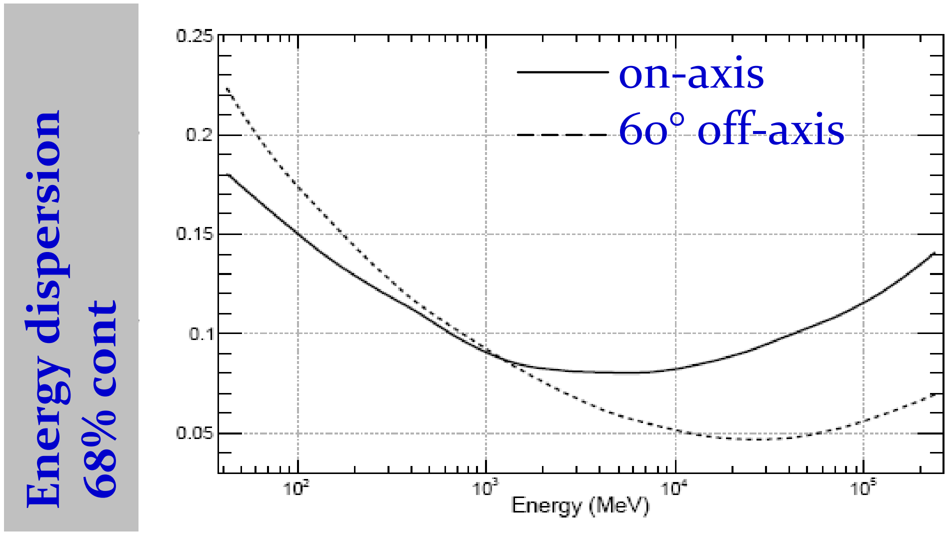
We're not sure…

Some plausible theories based on ideas of ***Enrico Fermi:***

Fermi-LAT Instrument Performance





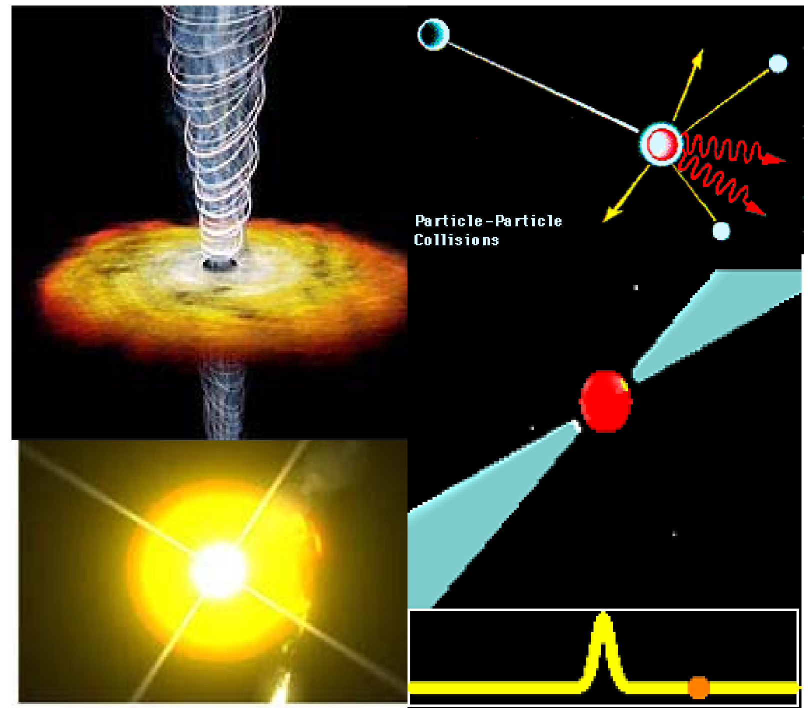


The Large Area Telescope on the Fermi Gamma-ray Space Telescope

Atwood, W. B. et al. 2009, ApJ, 697, 1071

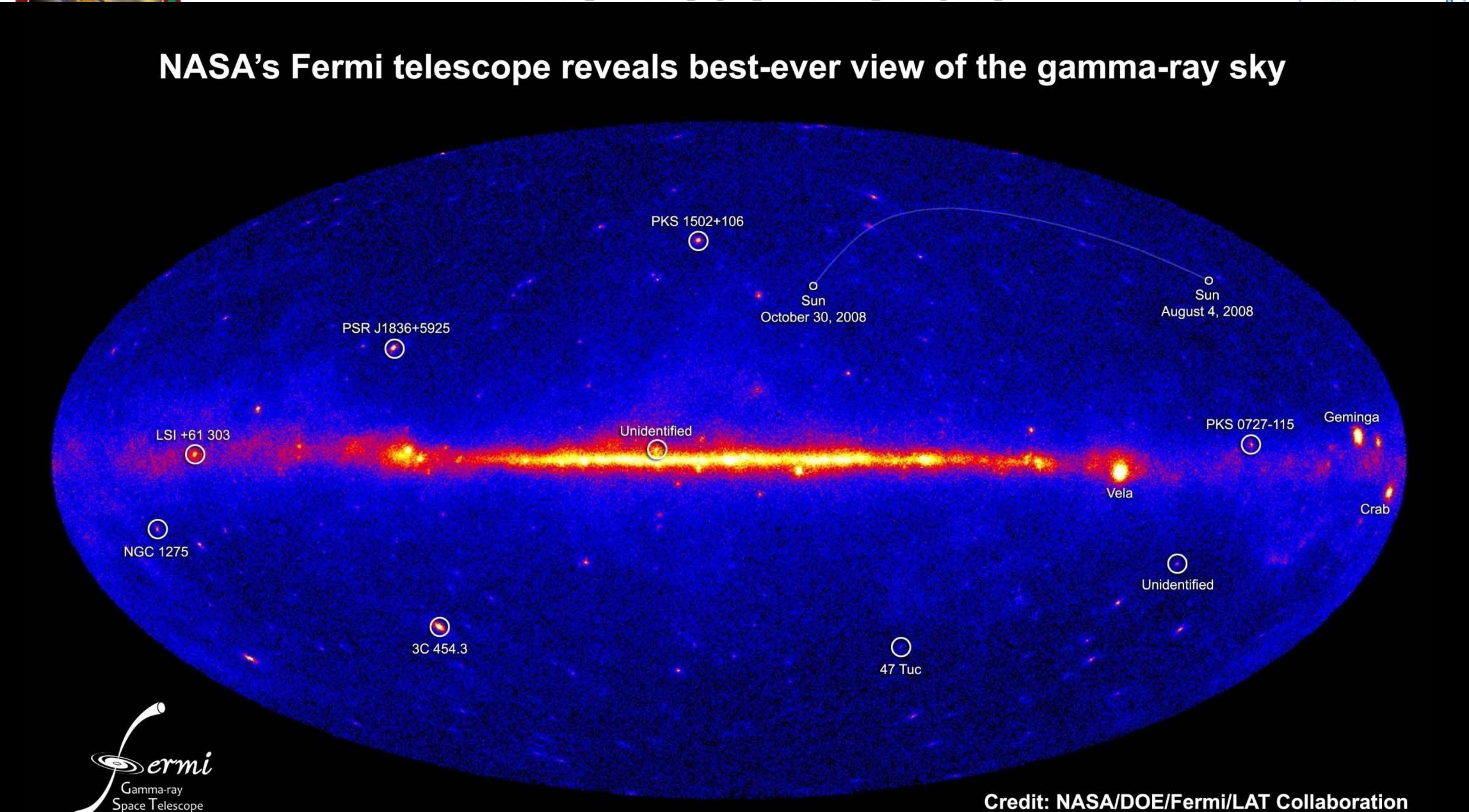
Fermi LAT science program

- Active galactic nuclei (blazars, quasars, radiogalaxies, other types)
- Gamma ray bursts
- Supernova remnants
- Pulsars
- X-ray binaries ad microquasars
- Solar flares and solar system objects
- Normal galaxies, clusters of galaxies
- Unidentified sources/new populations
- Study of diffuse gamma-ray emission
- Cosmic-ray acceleration & propagation
- Study of Extra-galactic background light (EBL)
- Search for Particle Dark matter/ tests of new physics
- Test Quantum Gravity (?)



Draws the interest of both the High Energy Particle Physics and High Energy Astrophysics communities.

The first 3 months



5 top sources within our Galaxy

- the quiet sun (moving in the map)
- LSI +61 303 - a high-mass X-ray binary
- PSR J1836+5925 – a gamma-ray-only pulsar
- 47 Tucanae – a globular cluster of stars
- unidentified, new and variable, 0FGL J1813.5-1248

5 top sources beyond our Galaxy

- NGC 1275 – the Perseus A galaxy
- 3C 454.3 – a wildly flaring blazar
- PKS 1502+106 – a flaring 10.1 billion ly away blazar
- PKS 0727-115 – a quasar
- unidentified known, 0FGL J0614.3-3330

The first 3 months

Public release highlights of the first three months

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- the quiet sun (moving in the map)
- LSI +61 303 - a high-mass X-ray binary
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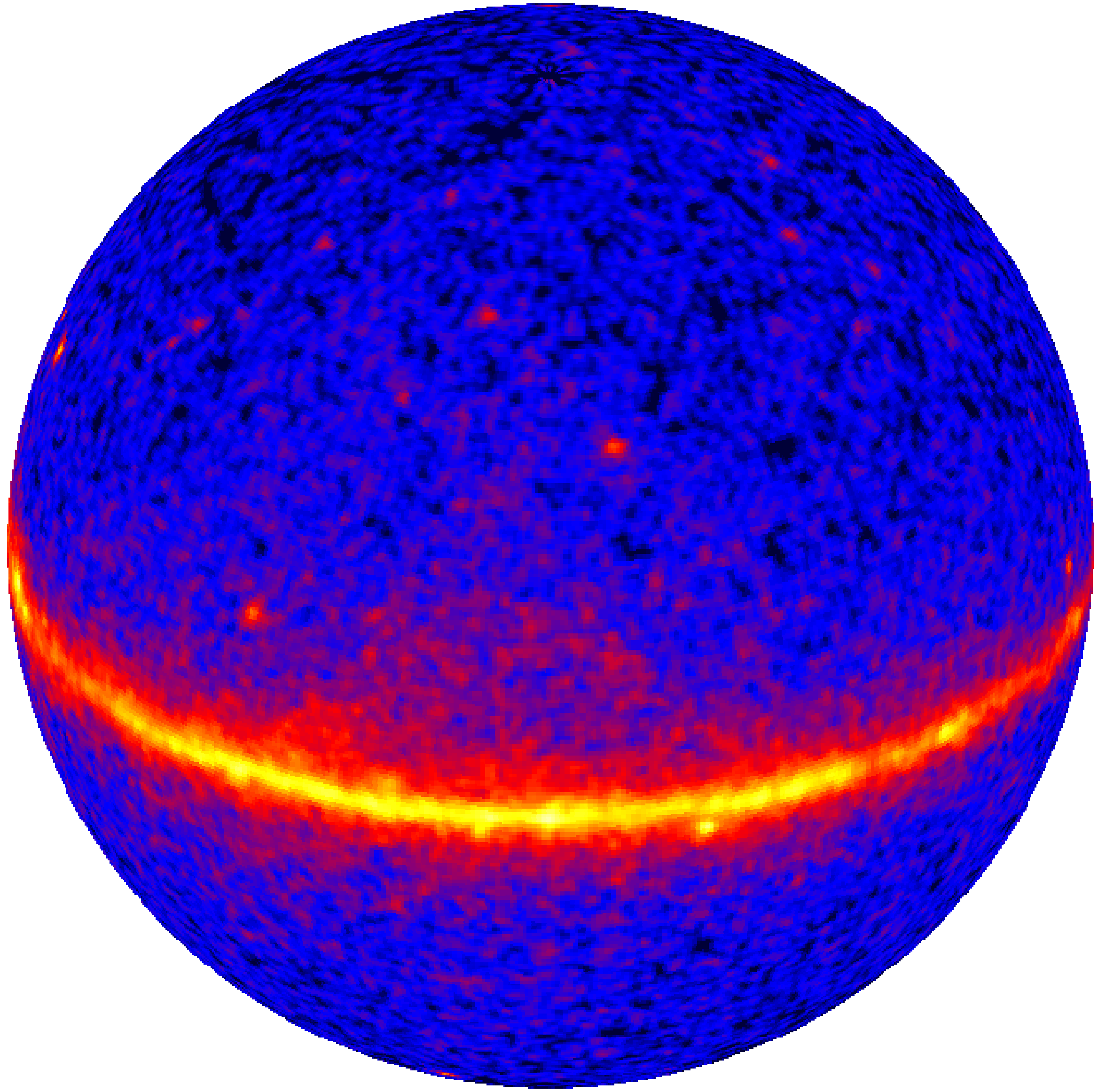
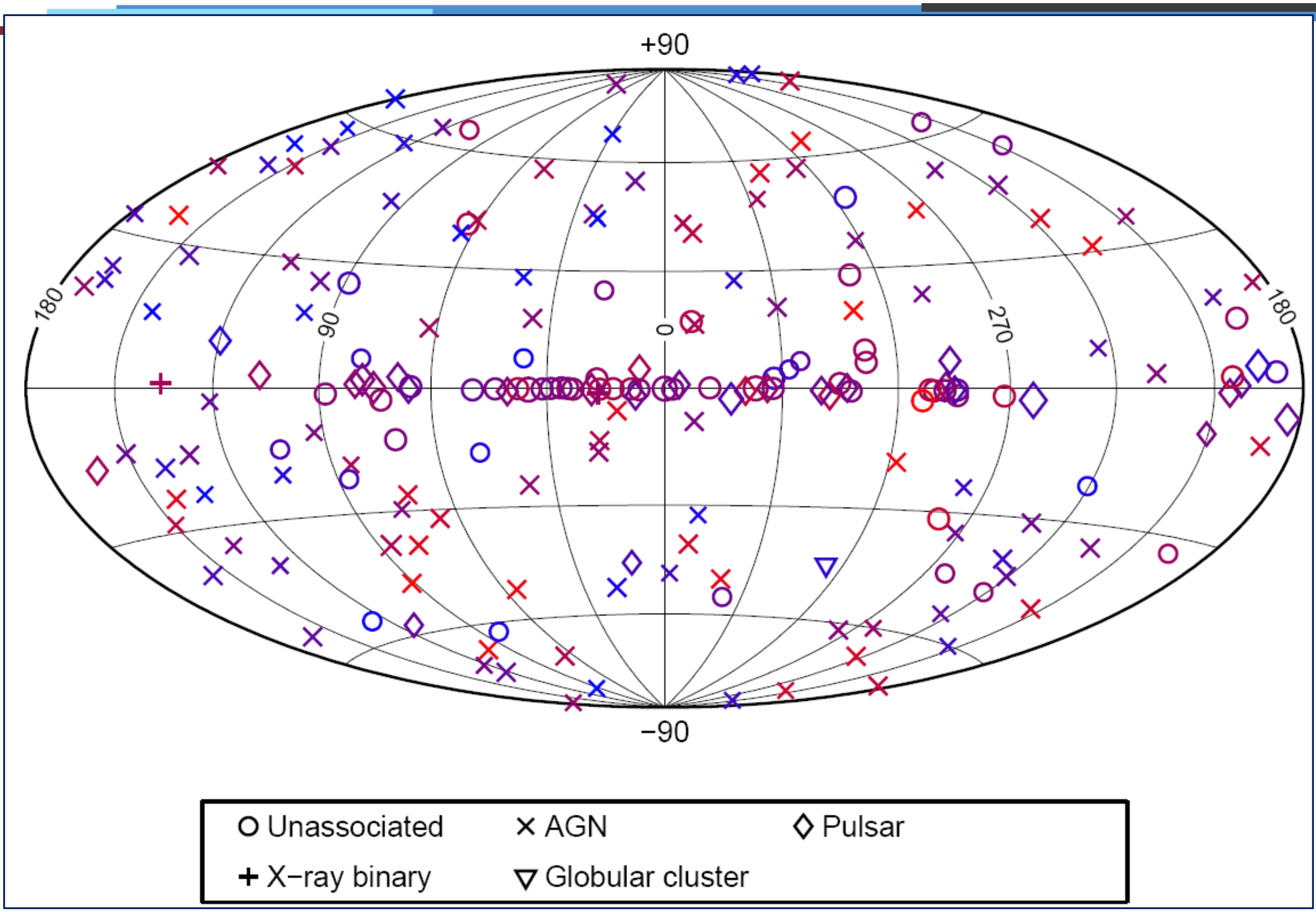


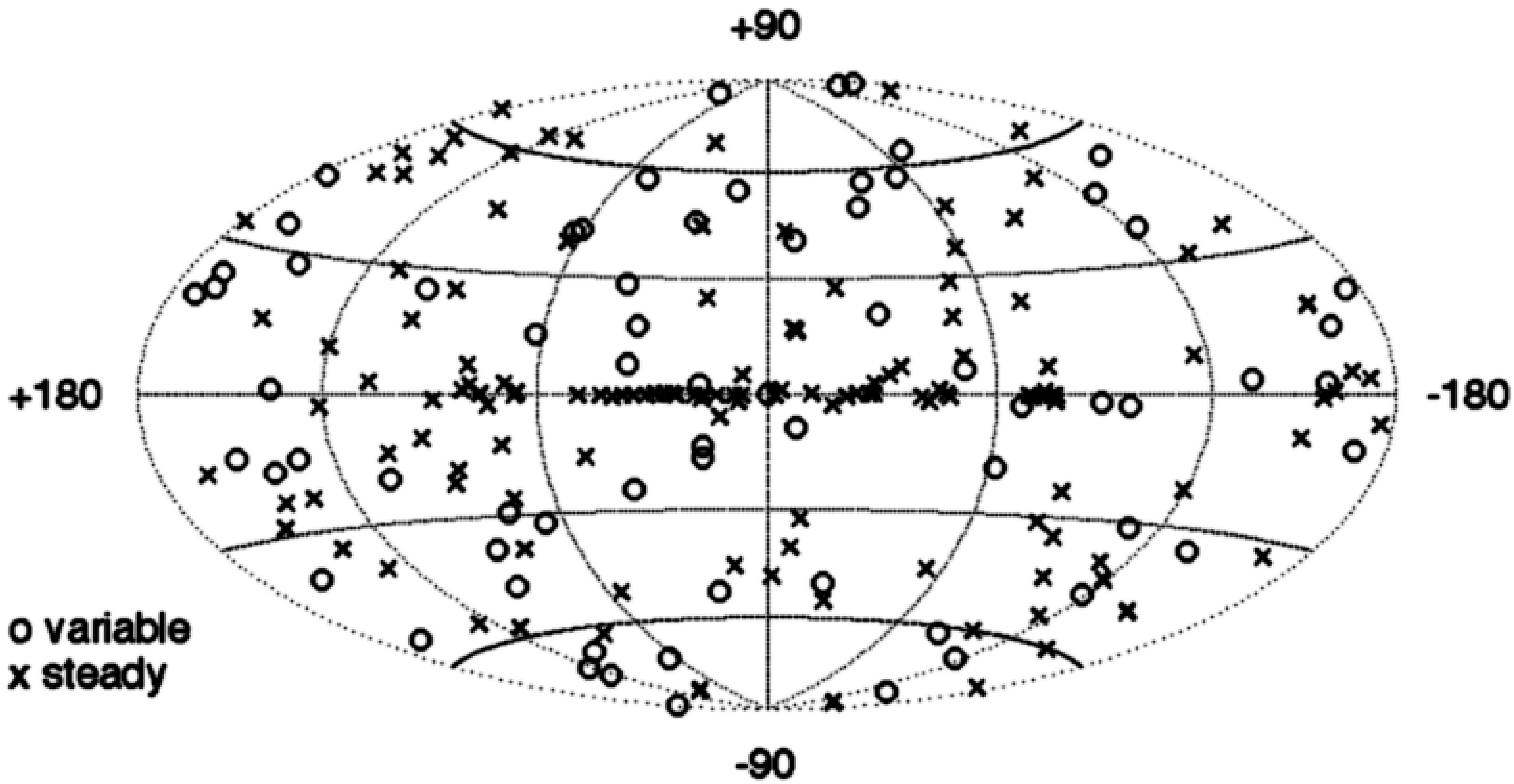
Fermi LAT High Confidence Source List (0FGL)



3 months LAT data – 205 sources with > 10 σ significance. Only 60 associated with EGRET sources – variability!

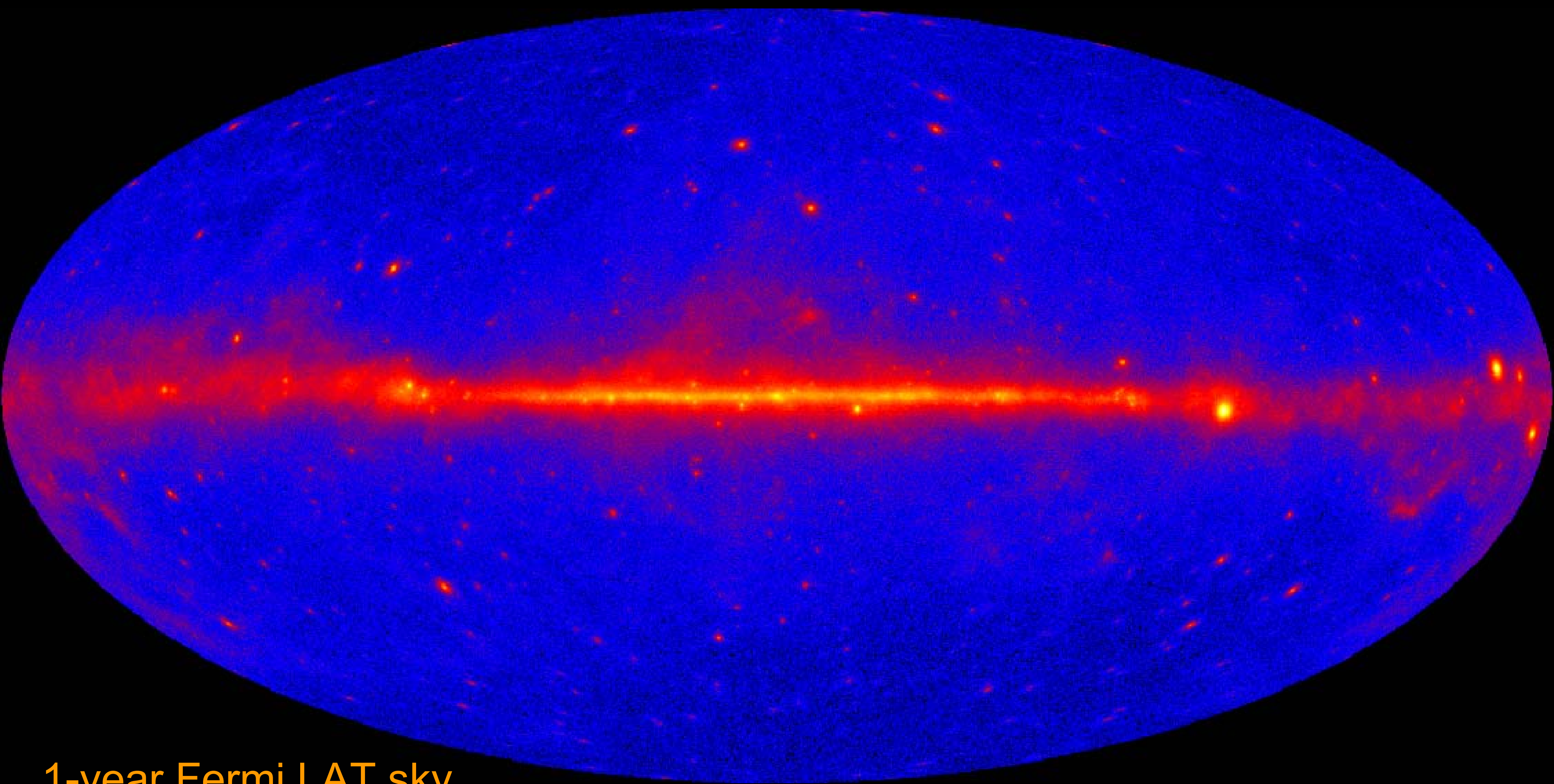
Fermi Large Area Telescope Bright Gamma-ray Source List - 2009, ApJS, 183, 46

Variable sources in the LAT 0FGL List



- **Based on 1 week time scales**
- **68/205 show variability with probability > 99%**
- **Isotropic distribution ⇒ blazars**

The first year of Fermi LAT survey (>1000 sources)

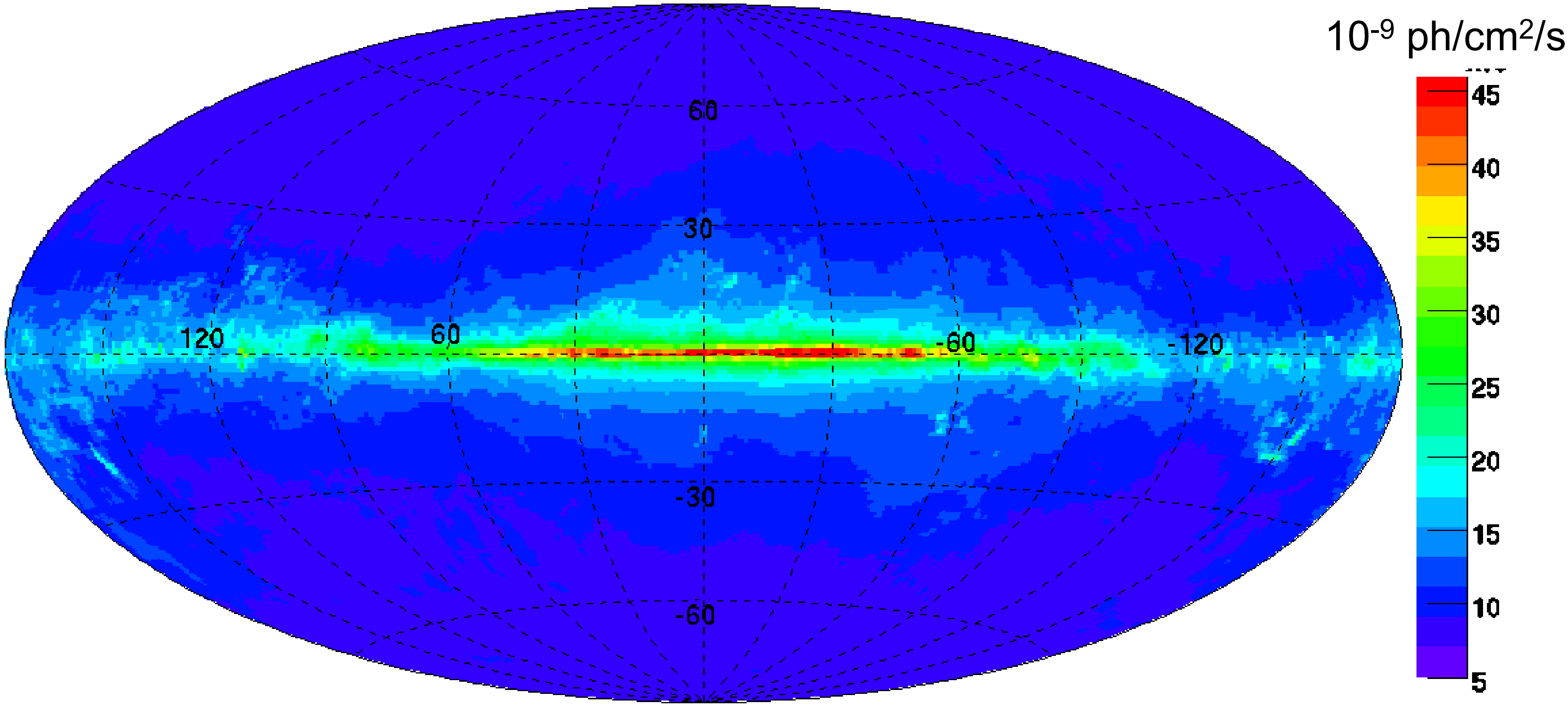


1-year Fermi LAT sky.
E > 200 MeV in
0.3°/pixel

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

1 year sensitivity map

- Structure is mostly that of the interstellar medium
- Below 10^{-8} ph/cm^2/s outside the Galaxy (|b| > 30°)
- Strong dependence on spectral index



Flux > 100 MeV required to reach TS=25 for average $E^{-2.2}$ spectrum

Galactic coordinates, Aitoff projection

The First LAT Catalog (1FGL)

- 11 months of data 100 MeV to 100 GeV, 23.3 Ms livetime
- 10.6 M events over the whole sky
- Improved diffuse model and calibration with respect to 0FGL high-confidence 3-month list
- Very uniform exposure (factor 1.25 between north and south)
- Detection based on integrated data (not on flares)
- Precise localization
- Characterization: spectral, variability
- Association with external catalogs

Content of the LAT source catalog (1FGL)

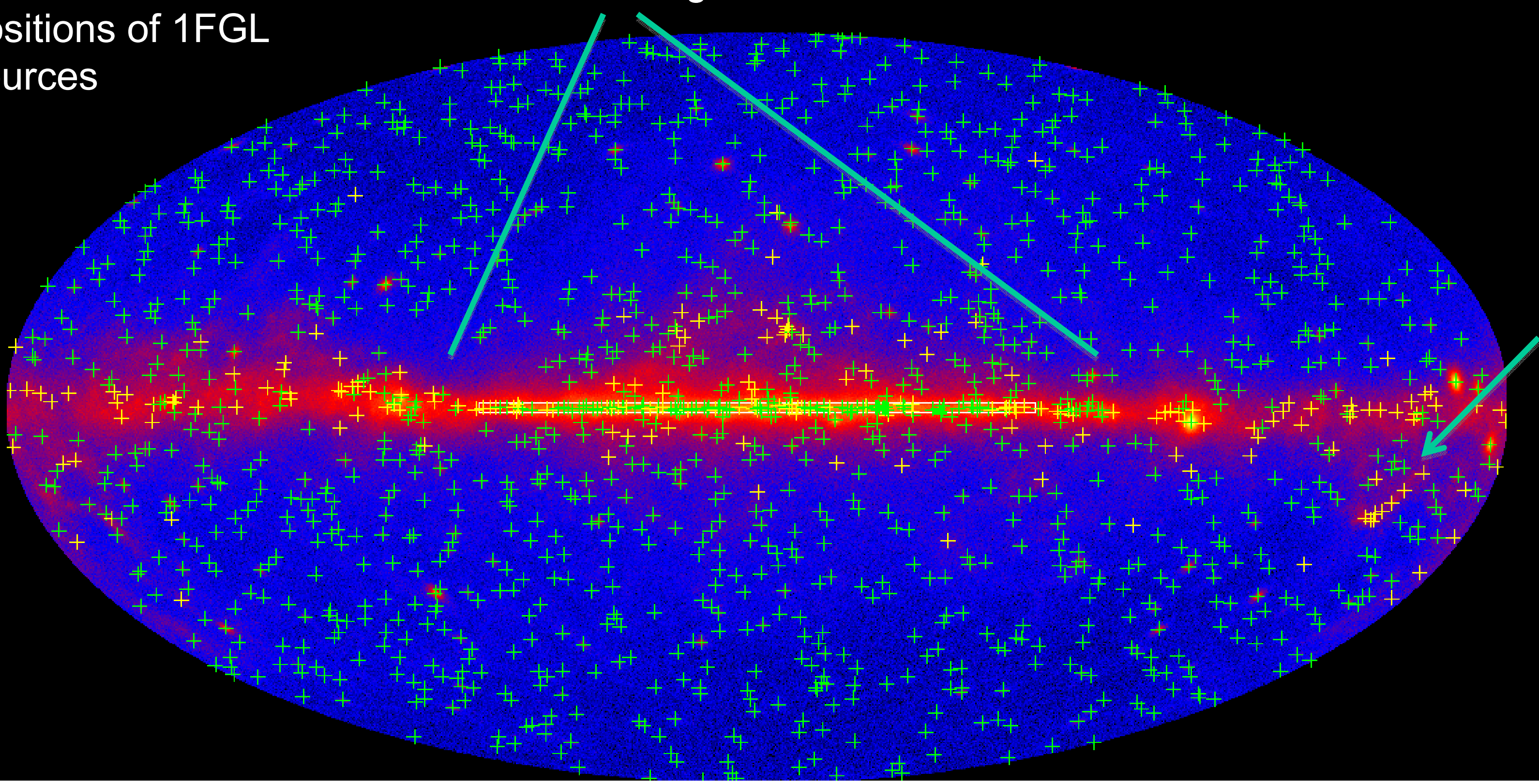
- Source coordinates and error ellipse at 95% confidence
- Source significance and overall spectral index
- Flux in 5 energy bands 0.1 – 0.3 – 1 – 3 – 10 – 100 GeV
- Flux per month, variability index
- Extension flag
- Quality flag: sensitivity to diffuse model, confusion, error ellipse not well defined
- Associations with known sources (external catalogs)

1FGL Analysis Challenges

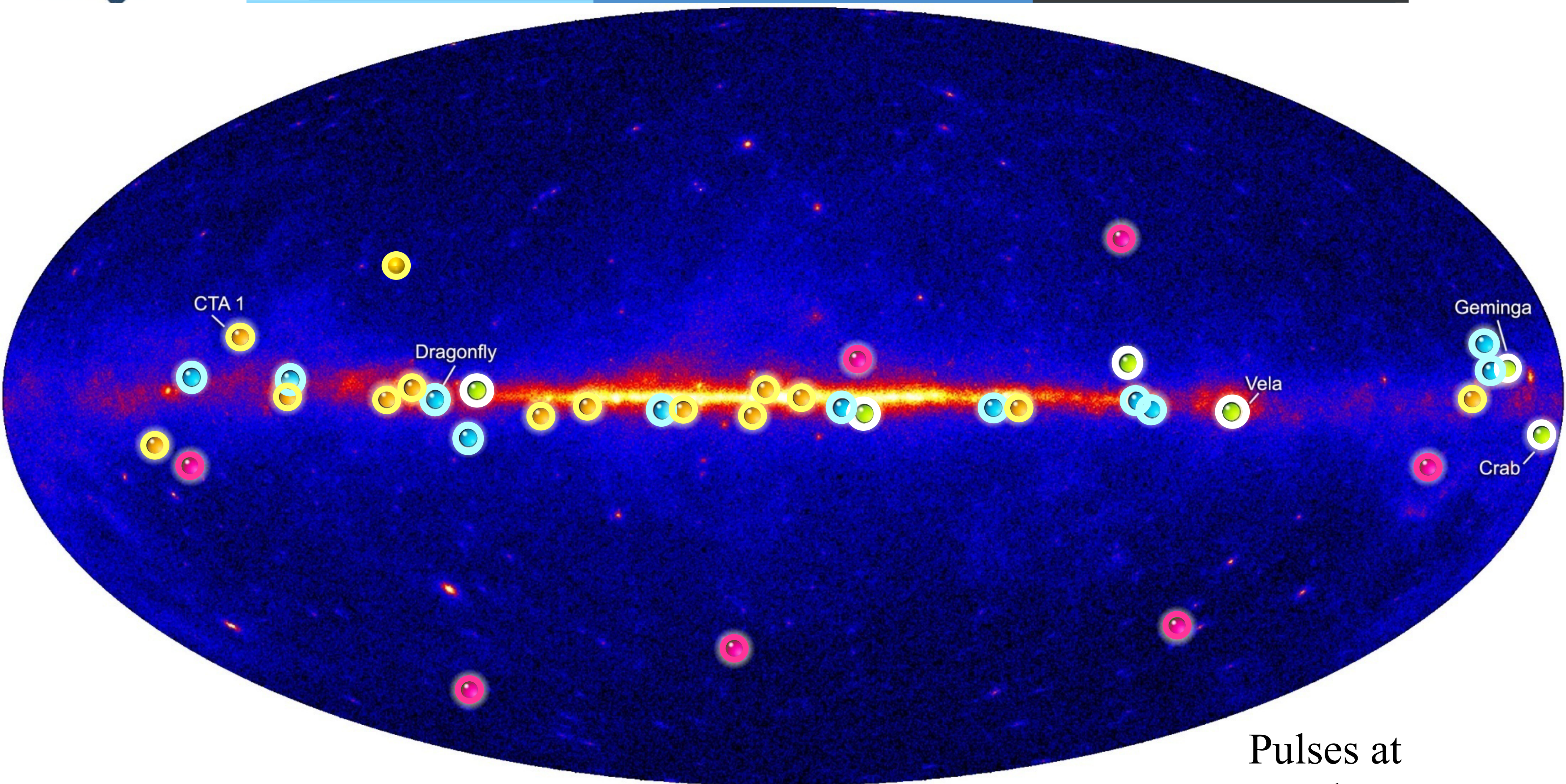
- In the Galactic ridge and toward prominent interstellar clouds, sources are close to each other, are not bright above the background <3 GeV, and the Galactic diffuse model has uncertainties on small scales
- The affected sources (~150) have a special designation, and warnings against using them without detailed analysis. Identified sources are not flagged

1FGL paper

- About 1400 sources above about 4σ significance threshold
- Extends 0FGL to much fainter sources
- Typical 95% error radius is 10arcmin. Absolute accuracy is <1arcmin
- At least 17% of the sources show evidence of 1-month bin scale variability
- About half the sources are associated positionally, mostly with blazars and pulsars
- 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, should be kept in mind for low-latitude and local cloud studies
- The Catalog is an analysis product but also a useful input for many other studies with LAT data



1-year Pulsing gamma-ray Sky

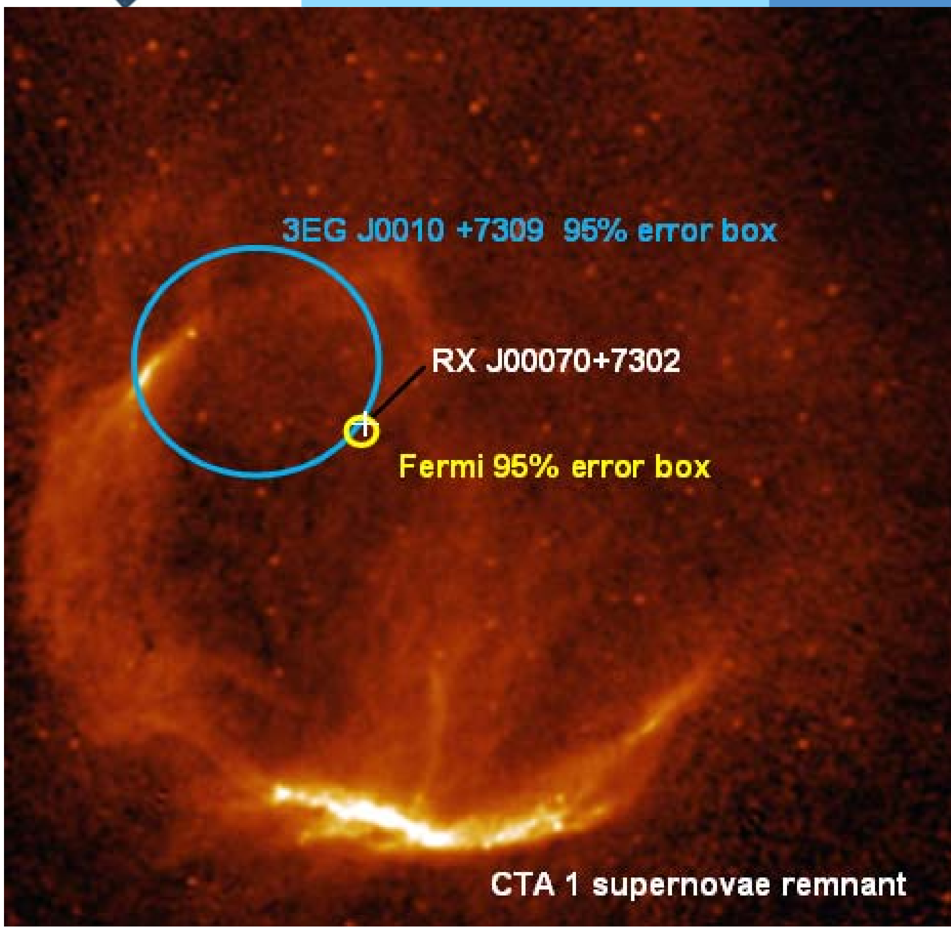


Pulses at
1/10th true rate

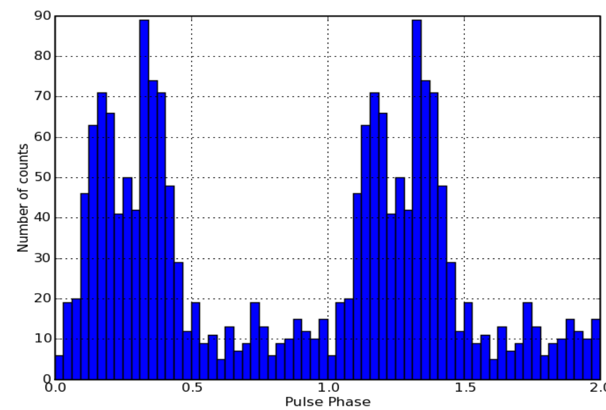
Fermi Pulsar Detections

- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

New pulsars discovered only in gamma-rays



CTA 1 pulsar (2 cycles, P=315.86 ms)

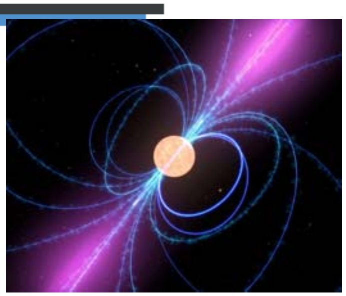


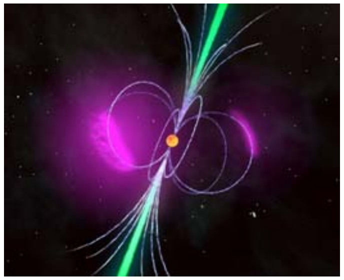
- ❑ γ-ray source at *l,b* = 119.652, 10.468;
- ❑ 95% error circle radius =0.038° contains the ROSAT X-ray source RX J00070+7302, central to the PWN superimposed on the radio map at 1420 MHz.
- ❑ pulsar off-set from center of radio SNR; rough estimate of the lateral speed of the pulsar is ~450 km/s
- ❑ spin-down luminosity ~10^{36} erg s^{-1}, sufficient to supply the PWN with magnetic fields and energetic electrons.

❑ CTA 1 source exhibits all characteristics of a young high-energy pulsar (characteristic age ~1.4 x 10 yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

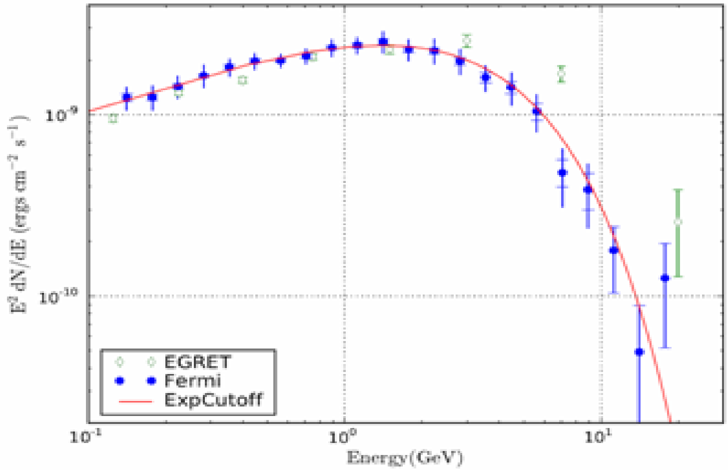
Pulsars Models

- An open question (before Fermi): where do the emission come from?
- Model predictions:
  - "Polar cap" : the emission come form the magnetic poles, where the magnetic fields are higher. The spectrum should roll-off steeply (faster than an exponential cut-off)
  - "Outer Gap": emission comes from particles in region with lower magnetic field (outer magnetosphere): The spectrum has an exponential cut off. Radio beam misaligned w.r.t. the gamma emission.

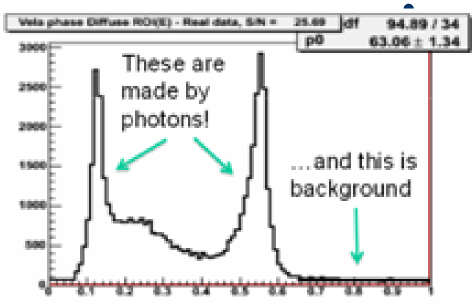




- **Young radio pulsar**
  - Radio ephemerides… knowing the period, we can "fold the data" and look for temporal structures (peaks)
- **Blind Search Pulsars, discovery**
  - We can select a target, and "search for pulsation blindly"… the phase space is very big:
    - Development of new analysis technique ("Time differentiating FFT") made this possible
  - Some of them might not emit in radio
- **Millisecond Pulsars,**
  - Extremely rapidly spinning NS,
  - "Recycled pulsar" through accretion. (accretion increases the rotational speed)
  - Thanks to Fermi, we know that they also emit gamma-rays



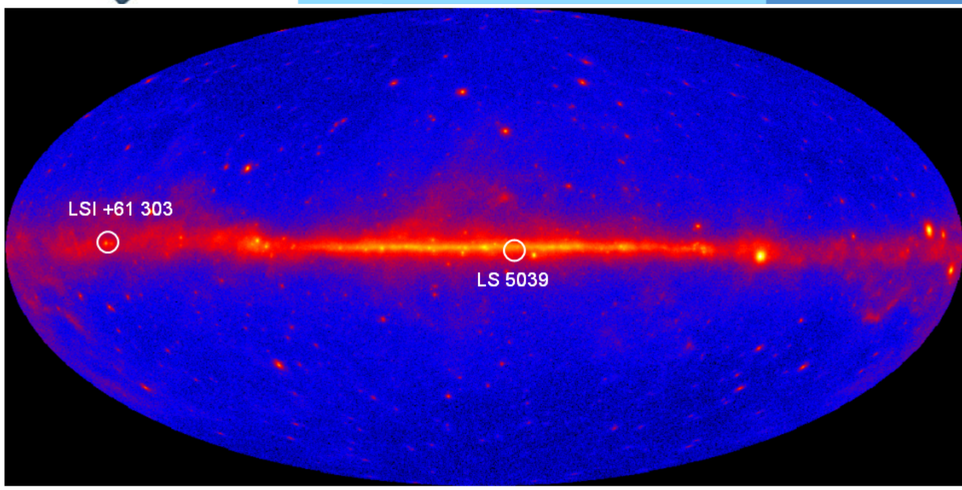
Vela
Abdo, A. A. et al. 2009, ApJ, 696, 1084

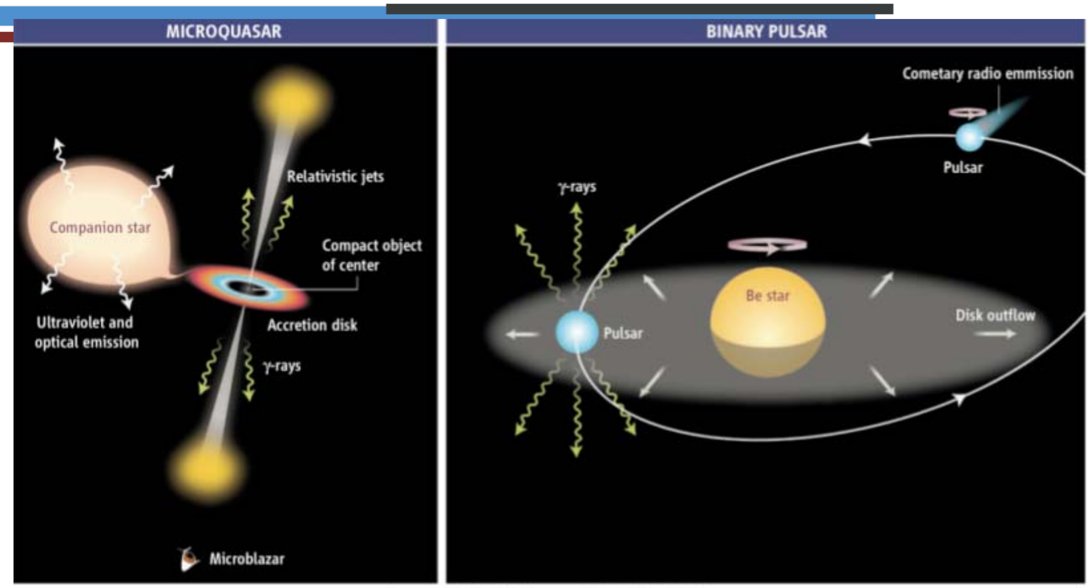


- Evidence of γ-ray emission in the outer magnetopshere (exponential cut-off)
  - Radio and g-ray fan beams separated
  - gamma-ray only PSRs

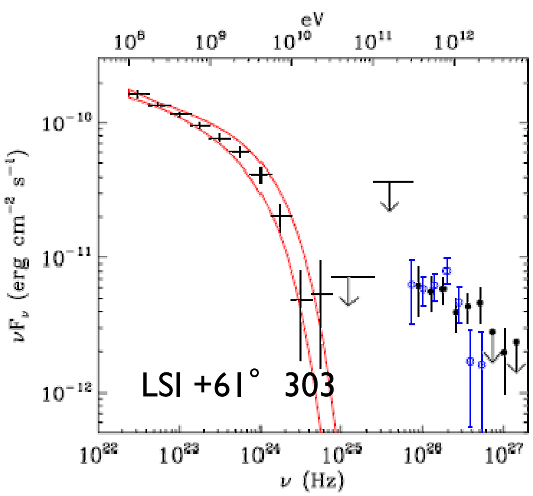
Pure Polar cap model ruled out!

Fermi LAT X-ray/γ-ray) binaries: microquasars or pulsars?

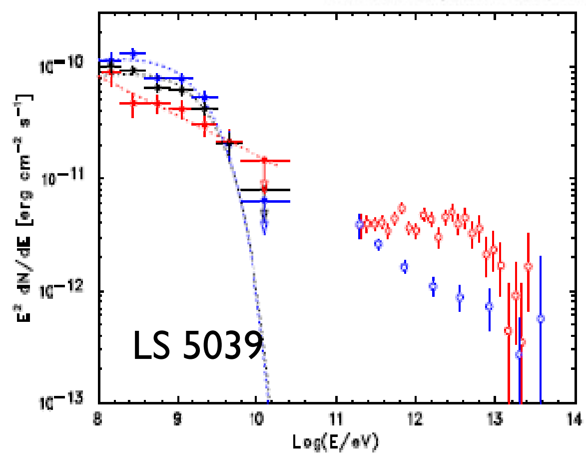




from: Mirabel (Science 309, 714, 2006)



Average spectrum:
Index: 2.21, Cutoff: 6.3 GeV

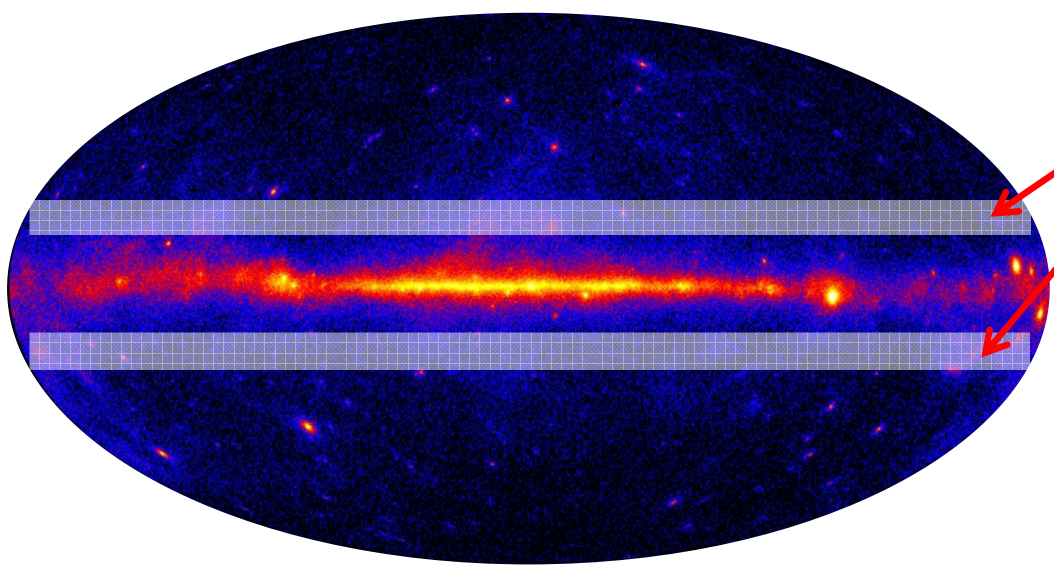


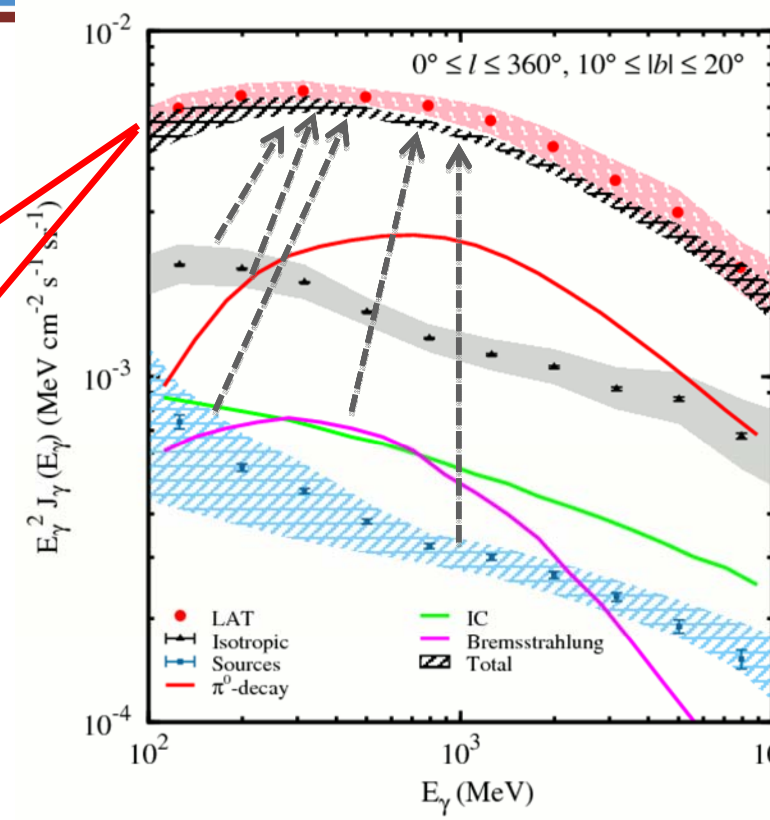
Average spectrum:
Index: 1.9, Cutoff: 2.1 GeV

- Exponential cut-offs are reminiscent of the Fermi pulsar spectra; is this a sign of magnetospheric emission in these systems?
- How to connect to TeV? More than one emission mechanism
- Further investigation required, but the emerging scenario is the binary pulsar

Diffuse Emission: Nailing the EGRET "GeV Excess"

100 MeV – 10 GeV

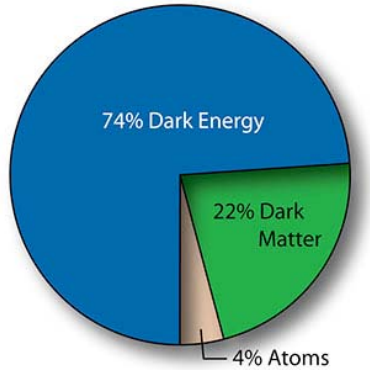




- One mystery from EGRET was that the diffuse emission seemed to have too many high-energy gamma rays
- This "GeV excess" had potentially profound implications for Dark Matter (more later)
- With the LAT one early study was a search for the GeV excess in a 'simple' region of the sky
- Not seen - the diffuse emission was consistent with expectations based on space and balloon-based measurements of cosmic rays

Many places to look for dark matter signals

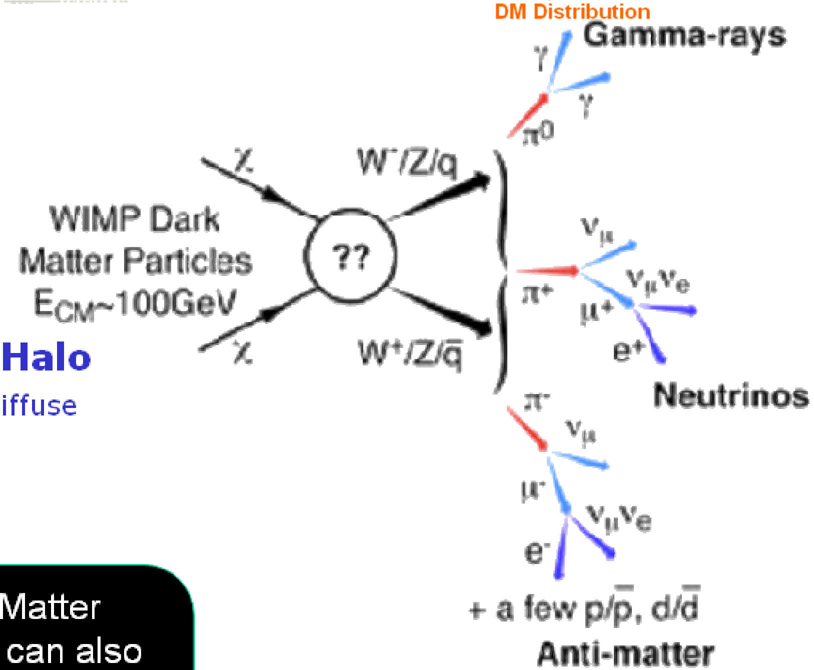
THE KNOWLEDGE OF THE FOREGROUND IS NEEDED TO UNDERSTAND IF SOMETHING IS MISSING…



$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\phi,\theta)=\frac{1}{4\pi}\frac{\langle\sigma_{ann}v\rangle}{2m_\chi^2}\sum_f\frac{dN_\gamma^f}{dE_\gamma}B_f \times \int_{\Delta\Omega(\phi,\theta)} d\Omega' \int_{los}\rho^2\left(\vec{r}\left(l,\theta',\phi'\right)\right)dl$$

Particle Physics

DM Distribution



Gamma-ray indirect emission: **Galactic Center**

Good Statistics but source confusion/diffuse background

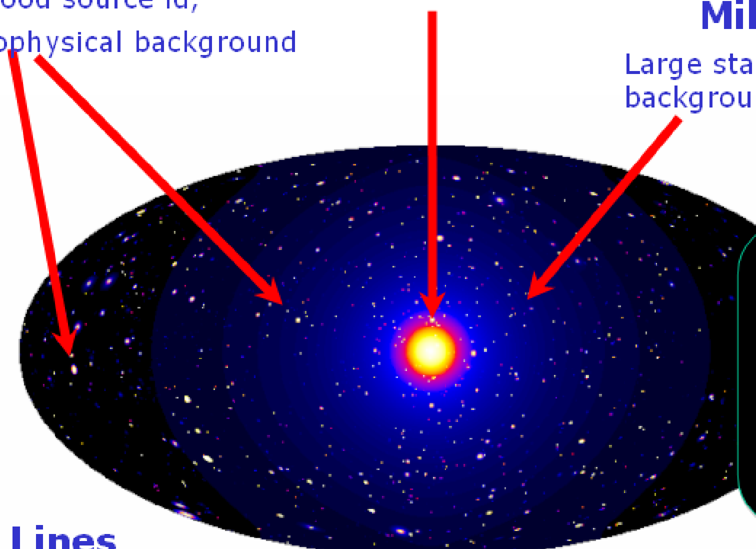
Satellites

Low background and good source id, but low statistics, astrophysical background

Milky Way Halo

Large statistics but diffuse background

All-sky map of simulated gamma ray signal from DM annihilation (Baltz 2006)



Dark Matter sources can also produce features in the local Cosmic Ray Electron spectrum

Decaying or annihilation of DM particles signal can be searched in gamma-rays (and electrons)

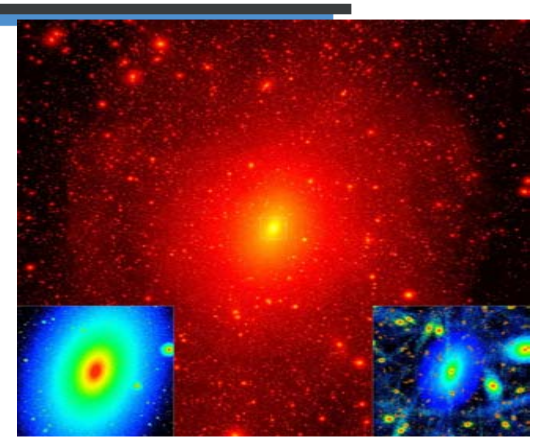
Spectral Lines

No astrophysical uncertainties, good source id, but low sensitivity because of expected small BR

Extra-galactic

Large statistics, but astrophysics, galactic diffuse background

Search for DM Subhalos : Two Kinds



DM substructures: very low background targets for DM searches

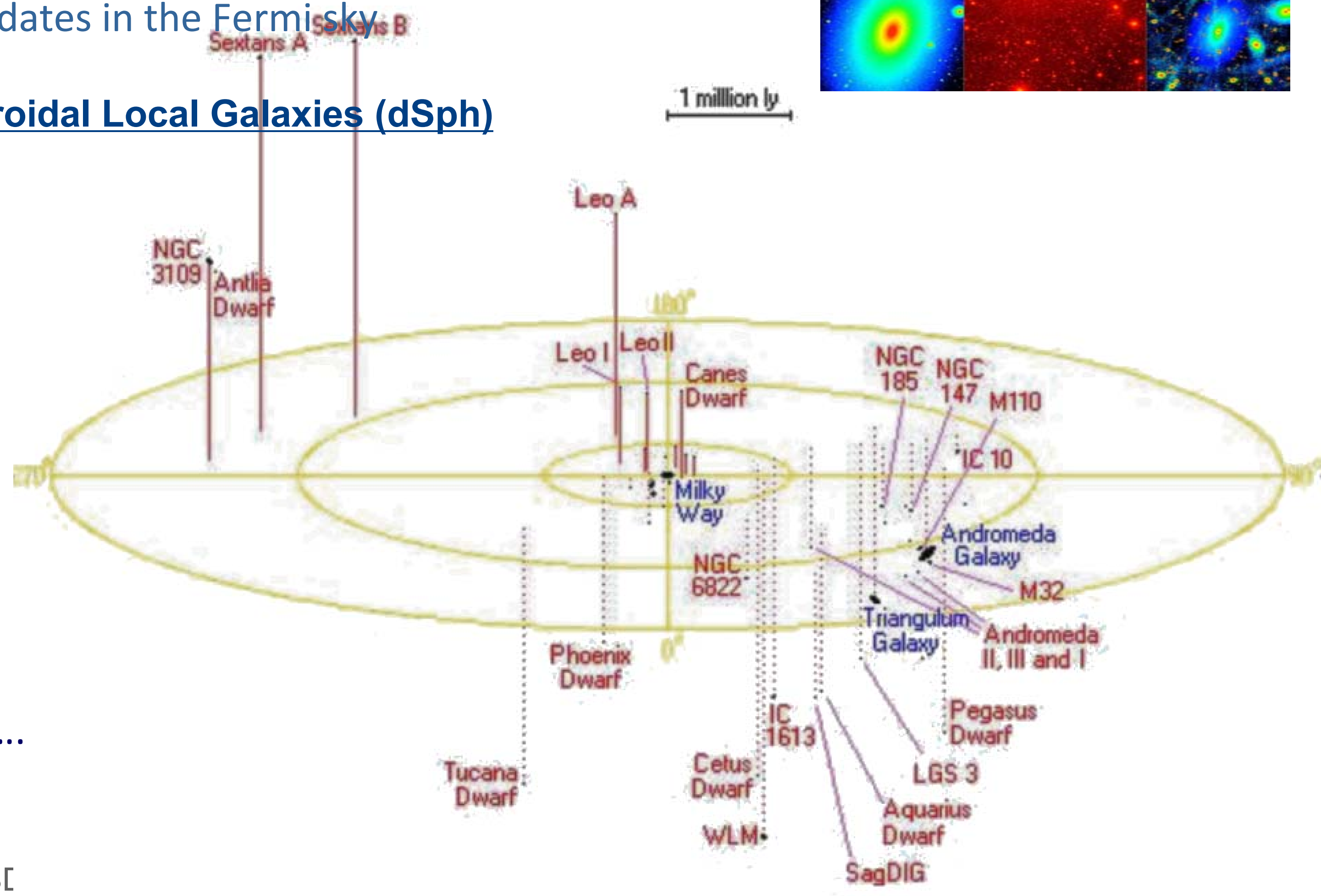
Never before observed DM substructures (DM Satellites)

- Would significantly shine only in radiation produced by DM annihilations or decays
- Blind search for promising candidates in the Fermi sky

Optically observed Dwarf Spheroidal Local Galaxies (dSph)

- Most are expected to be free from other astrophysical gamma ray sources and have low content in dust/gas, very few stars
- Given the distance and the LAT PSF, they are expected to be consistent with pointlike objects

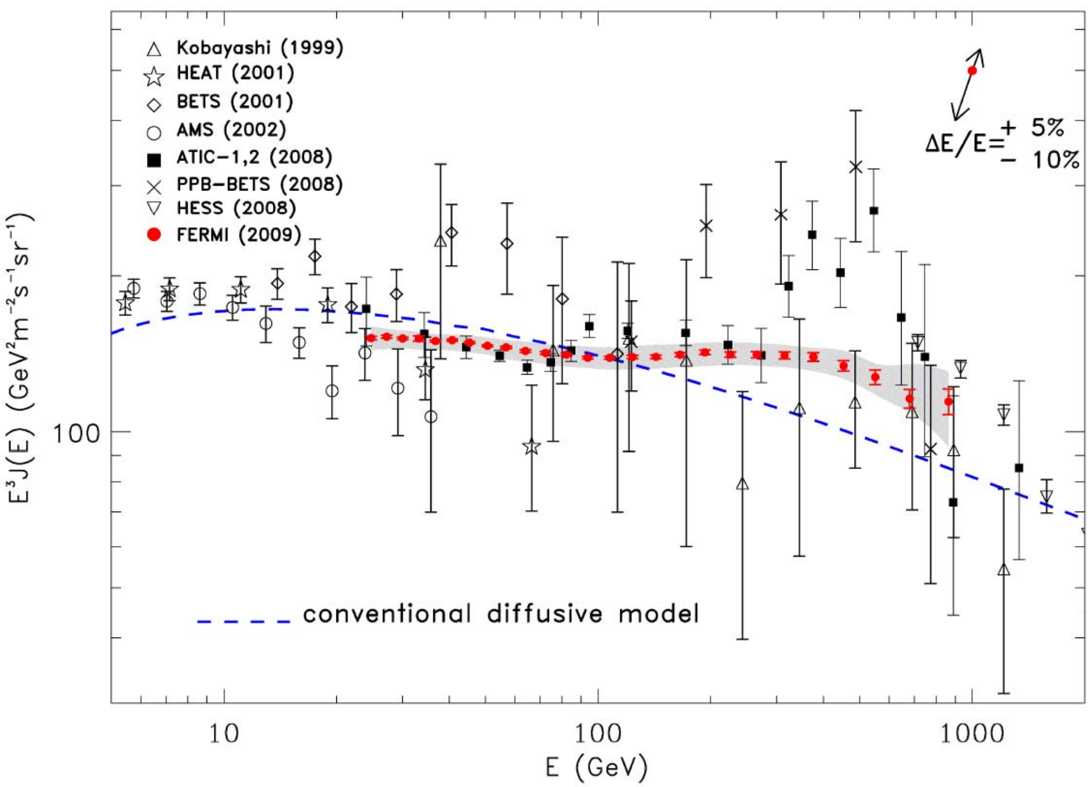
ONLY UPPER LIMITS SO FAR….
Stay tuned!



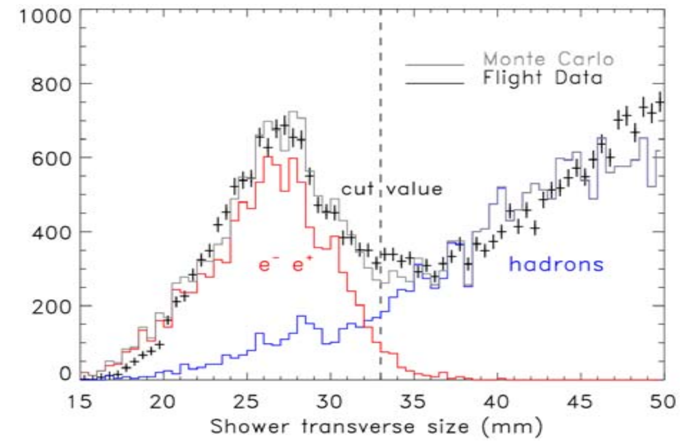
Cosmic electron spectrum measured by the LAT

PRL **102,** 181101 (2009) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 8 MAY 2009

Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope



- ❑ The LAT has great potential to tag electrons in the multi-100GeV range



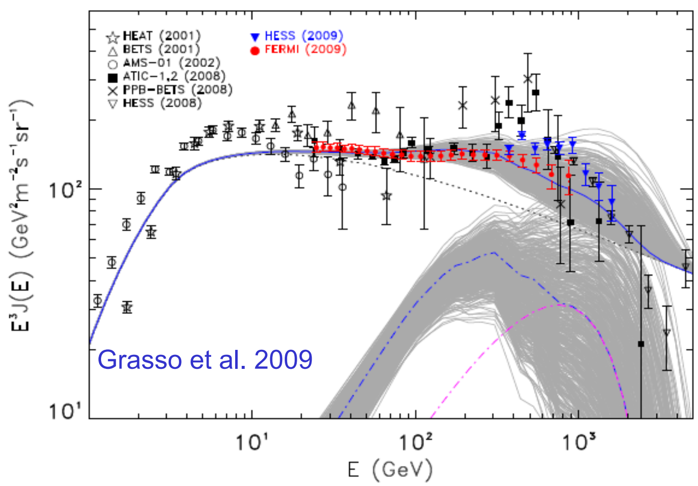
- ❑ The LAT tracks electrons!
- ❑ Local Cosmic Ray electron spectrum measured with high precision:
- ❑ no prominent spectral features between 20 GeV and 1 TeV
- ❑ significantly harder spectrum than inferred from previous measurements (constrain injection spectrum, diffusion and interaction of CR with the matter and radiation)

- High statistics 4.5M events in 6 months: systematics dominate but small wrt existing literature
- Not compatible with pre-Fermi diffusive model: E^{-3} versus $E^{-3.3}$
- No evidence of the dramatic ATIC spectral feature: Conservative statistical+systematic error allow good fit with a simple power law

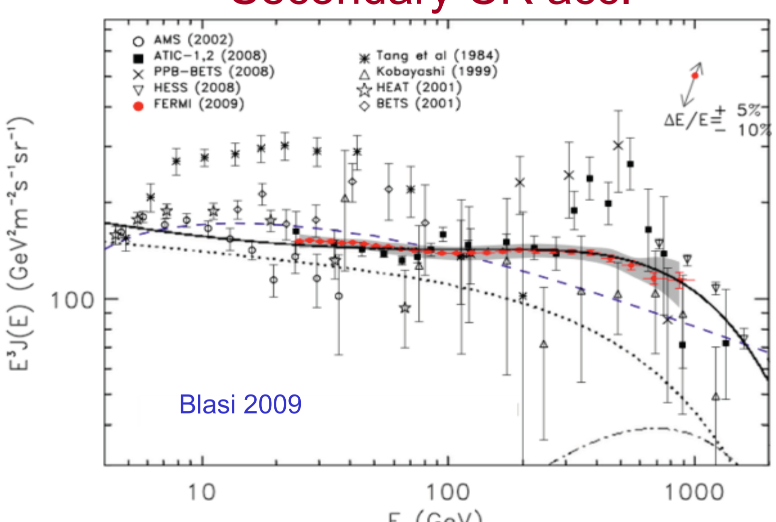
Some possible interpretations

- Several papers already published to explain electron spectrum
  - Together with other observations (positron fraction, diffuse gamma-ray)

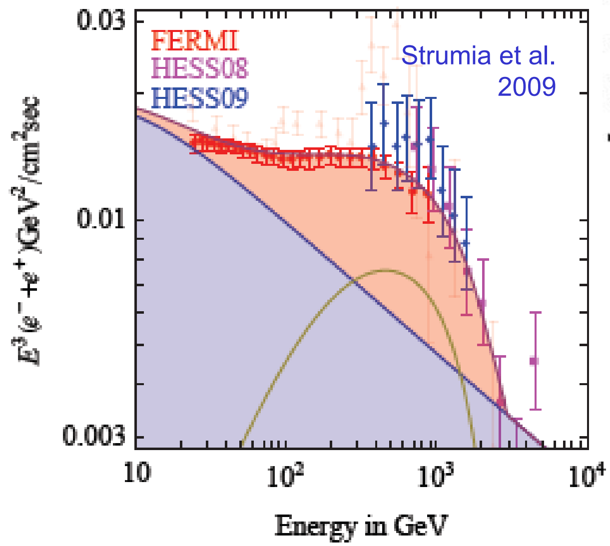
Pulsars



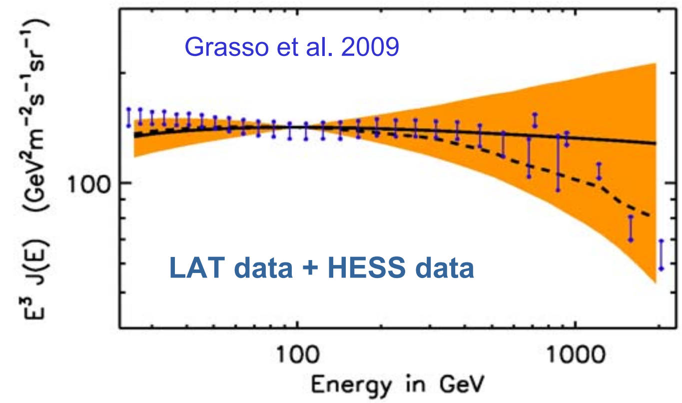
Secondary CR acc.



Dark Matter



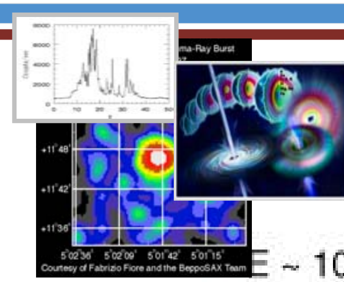
Source stocasticity

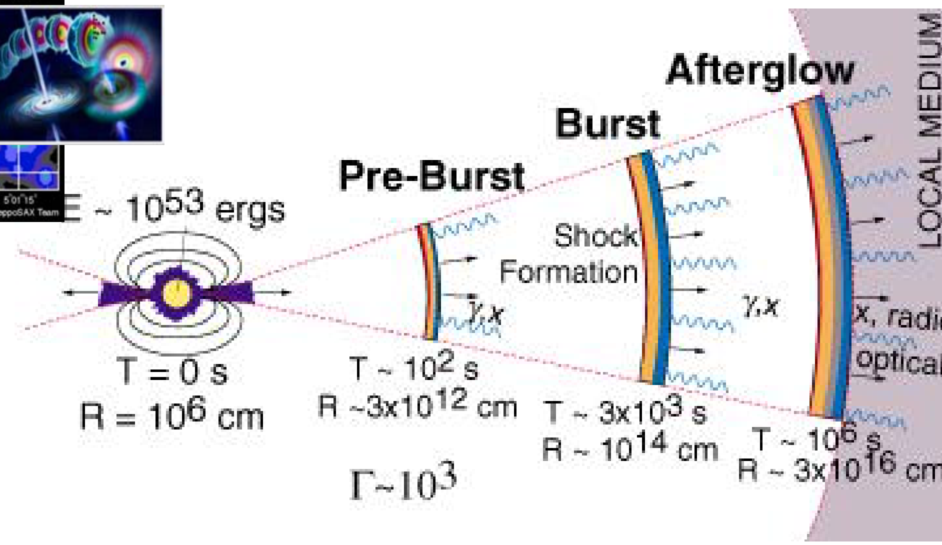


- SNR as electron sources
- Propagation of time-dependent distribution of SNR in the Galaxy (all fluxes normalized at 100GeV) (following Pohl+ Esposito 98; Pohl et al. 03)
- $\Delta\alpha$ = 0.2 equivalent spread on spectral index

Gamma-Ray Bursts

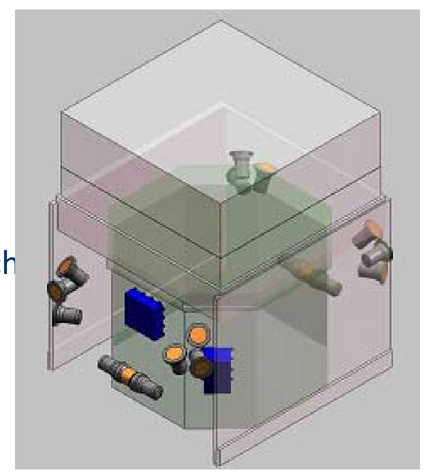
- ❑Rapid flashes of radiation, probably related to the destructive end of massive stars in the early Universe
- ❑Long vs short bursts:
  - ❑do they have the same progenitor?
  - ❑Do they share the same characteristics?
- ❑Physics of “colliding relativistic shells”
- ❑Before Fermi: 7 GRB known above >100 MeV from EGRET and AGILE

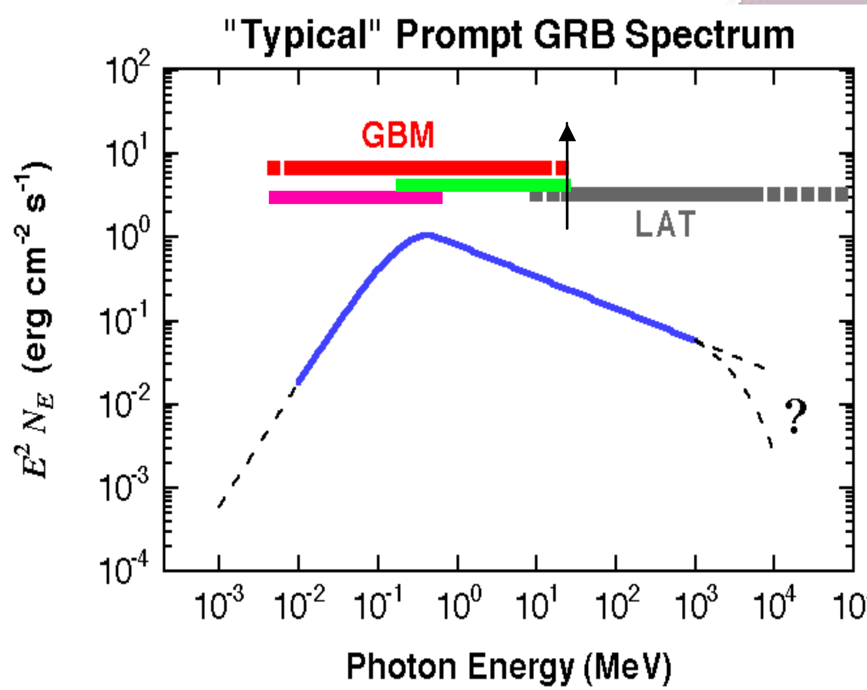




Fermi Gamma-Ray Burst Monitor (GBM)

- ❑ Monitor the entire sky not occulted by the Earth. 200-300 GRB per year (260 the first year)
- ❑ NaI: 8 keV - 1 MeV
- ❑ BGO: 150 keV - 40 MeV
- ❑ GBM Collaboration:
  - ❑ University of Alabama in Huntsville
  - ❑ NASA Marshall Space Flight Center
  - ❑ Max-Planck-Institut für extraterrestrisch Physik
  - ❑ W.S. Paciesas (PI)
  - ❑ J. Greiner (Co-PI)

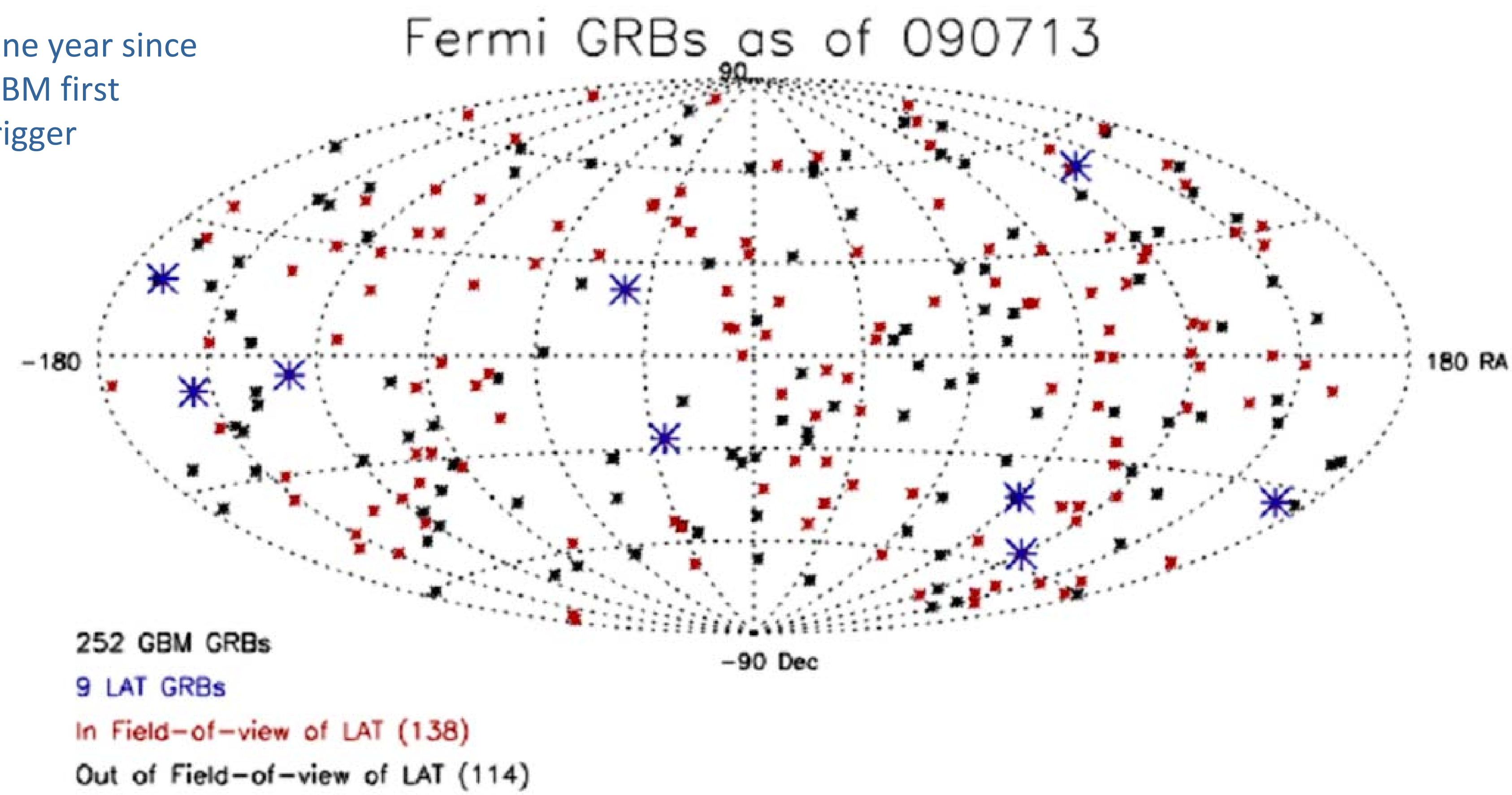




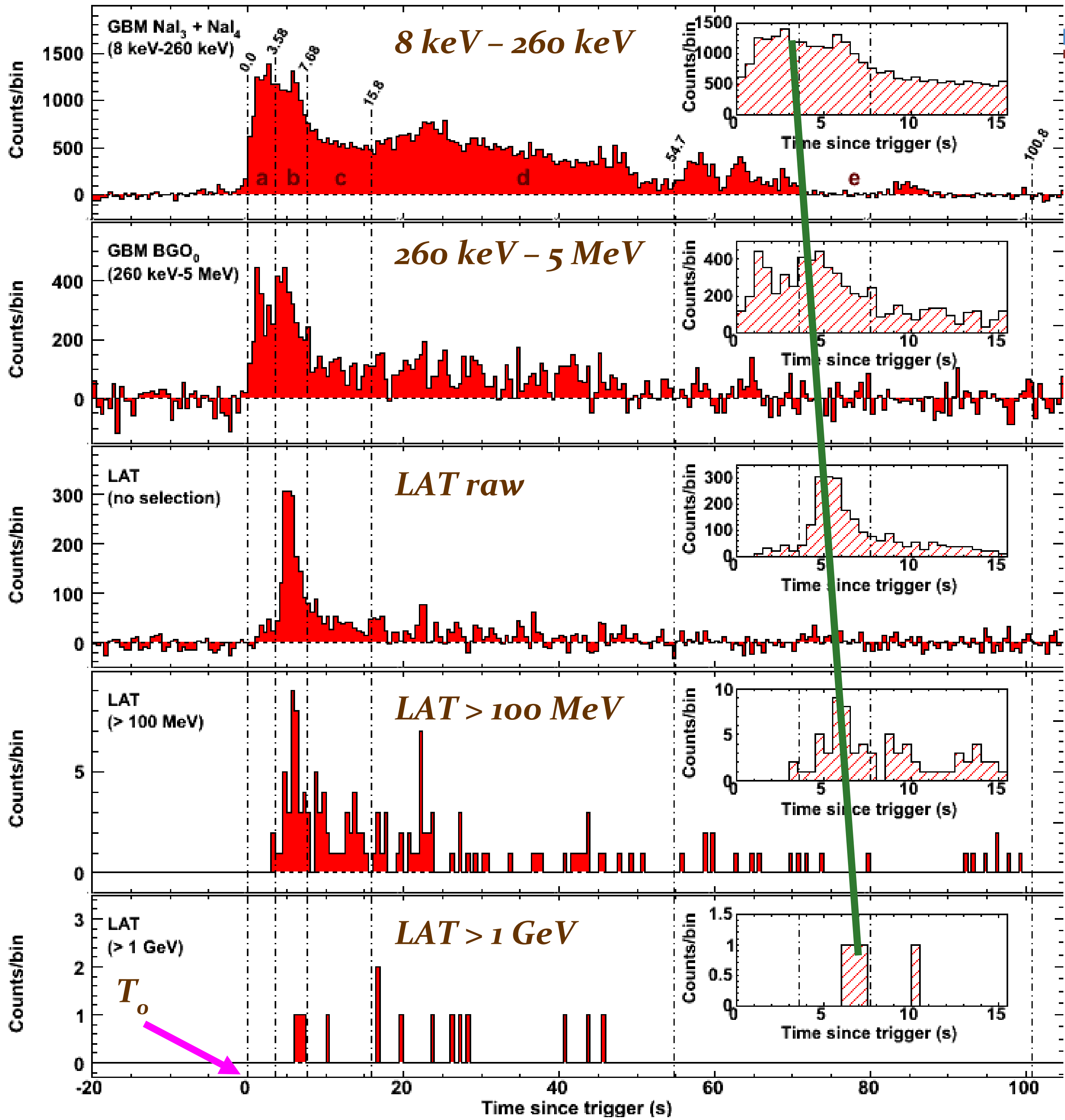
Fermi gamma-ray bursts

- 10 long and 2 short bursts detected by LAT at GeV energies during the first year
  - GRB Catalog paper almost completed
  - Both types of GRB show similar phenomenology at high energies
  - An X-ray telescope (Swift) has detected emissions from the 4 brightest LAT bursts resulting in the determination of the burst redshift/distance.

One year since GBM first trigger



Example of a long burst: GRB 080916C



- First high-energy GRB (>100 MeV) with known redshift
- Largest sample >100 MeV
  - 14 events >1 GeV
  - High energy photon (E = 13.2 GeV after 16.5 s) from GRB

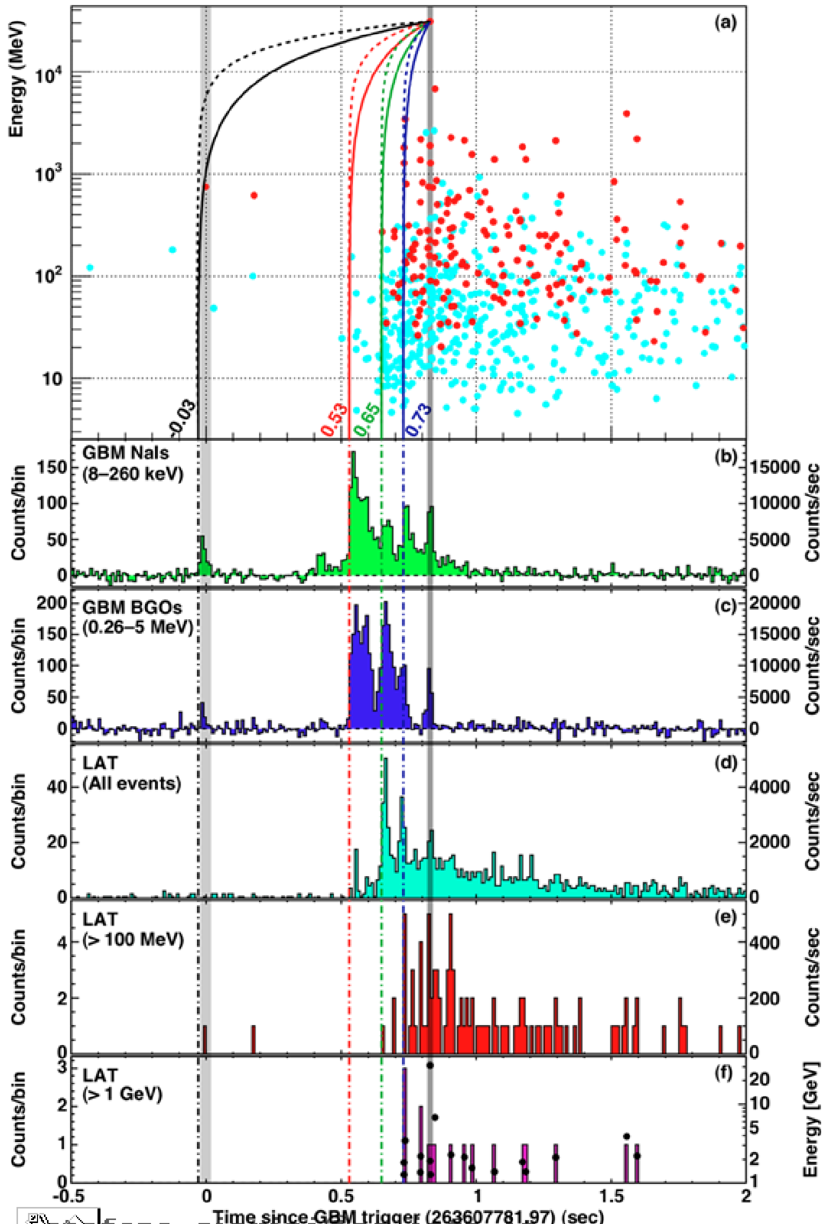
Abdo et al., Science 323, 1688 (2009)

Testing Einstein's Theory of Special Relativity

- The Principle of Invariant Light Speed (Lorentz Invariance) – *Light in vacuum propagates with the speed c (a fixed constant) in terms of any system of inertial coordinates, regardless of the state of motion of the light source and regardless of the photon energy.*
- Consider a race between two photons traveling a very large distance at slightly different speeds. The slower photon will arrive later.
  - To do this we need
    - Distant object (10^9 years light travelling time!)
    - Very bright (GRB can be brighter than the remaining sky)
    - Well defined start time (GRB lasts only few seconds)
- If the dispersion relation depends on energy: we want to make this test at the highest possible photon energies.
  - Some models of quantum gravity predict that space itself might be distorted by effects of quantum gravity (quantum foam).

$$\Delta t = \frac{(1+n)}{2H_0}\frac{E_h^n - E_l^n}{(M_{QG,n}c^2)^n}\int_0^z \frac{(1+z')^n}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}\,dz'$$

GRB 090510



- 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
- Intrinsic delay?
  - Onset LAT-GBM
  - Evolution of the spectrum
- Only conservative assumption!
  - the HE photon is not emitted *before* the LE photons, at different events.

$$M_{qg} > 1.2\ M_{plank}$$

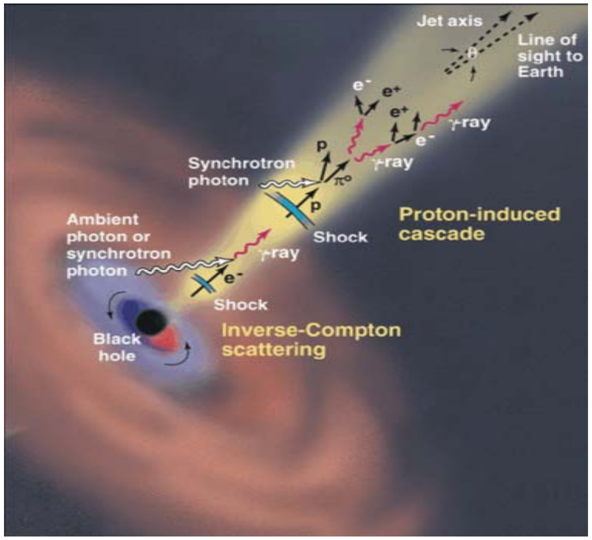
Table 2 | Limits on Lorentz Invariance Violation

#	$t_{start} - T_0$ (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

Active Galactic Nuclei with the Fermi LAT

- Fermi has discovered hundreds of new sources, proving that blazars dominate the extragalactic sky :
  - BL Lac objects (x~20 with respect to EGRET), many being HSPs
  - Flat Spectrum Radio Quasars (x~5 wrt EGRET)
  - majority of TeV AGNs.

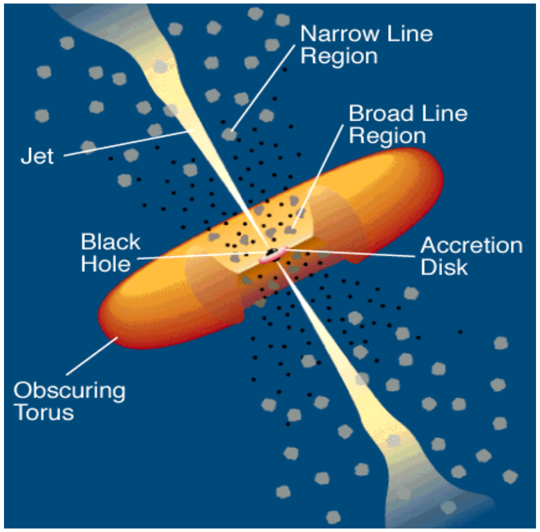
making detailed population studies possible.



- Important spectral properties (correlation of photon index with blazar class, spectral breaks, relative constancy of photon index with flux)

- Variability time scales were observed ranging from sub-day to several months.

- Many multifrequency studies heve been triggered by Fermi observations, providing time-resolved SEDs and interband (radio, optical, X-ray, TeV) temporal correlation.



- The emission of gamma-rays from the lobes of Cen A has been discovered.

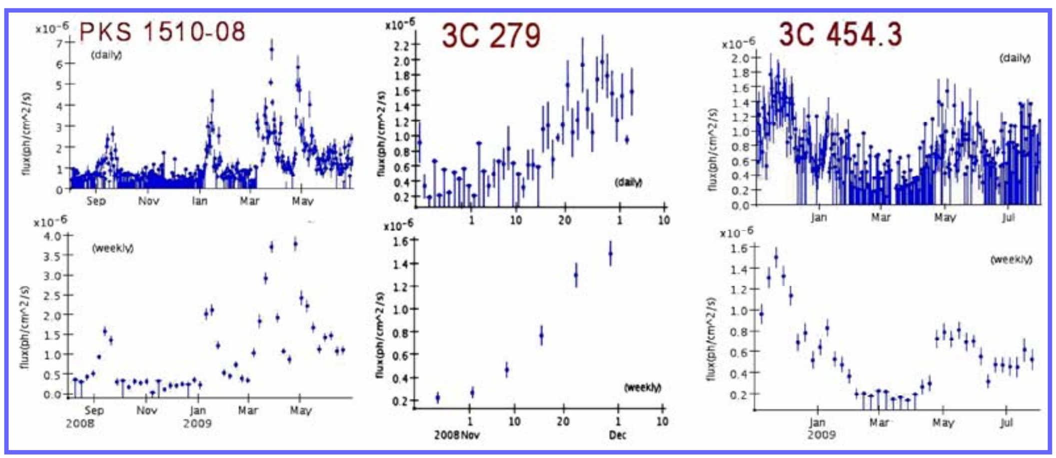
- Many new non-blazars sources have been detected (Radio galaxies, NRLSy1, Cen A giant radio lobes).

- Constraints on EBL opacity have been obtained.

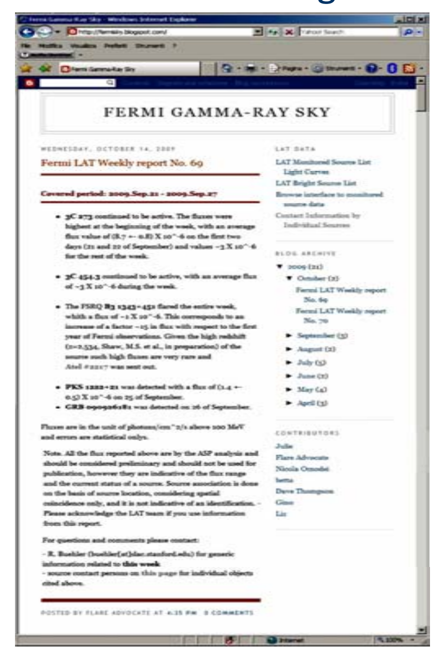
- A lot of novel features and correlations to digest, but ultimately a better understanding of gamma-ray emitting AGNs will emerge.

LAT source monitoring and Flare Advocate activities

- **Automated Science Processing (ASP)**
  - Transient detection: uses source detection (pgwave) to find all point sources in data from each epoch (6hr, day, week)
  - Follow-up monitoring: Runs full likelihood analysis on list from source detection step + “Data Release Plan” (DRP) sources
  - 10^{-6} ph cm^{-2} s^{-1} threshold (daily) for public release of light curves of non-DRP sources
- **Flare Advocates:**
  - LAT scientists mainly from the AGN LAT science group. They examine output from ASP pipeline and perform an outlook and follow-up analyses, produce ATels, compile the Fermi gamma-ray sky public blog, and propose ToOs and multifrequency campaings.
  - ~60 Astronomers Telegrams (ATels): discovery of new gamma-ray blazars, flares from known gamma-ray blazars, a few galactic plane transients

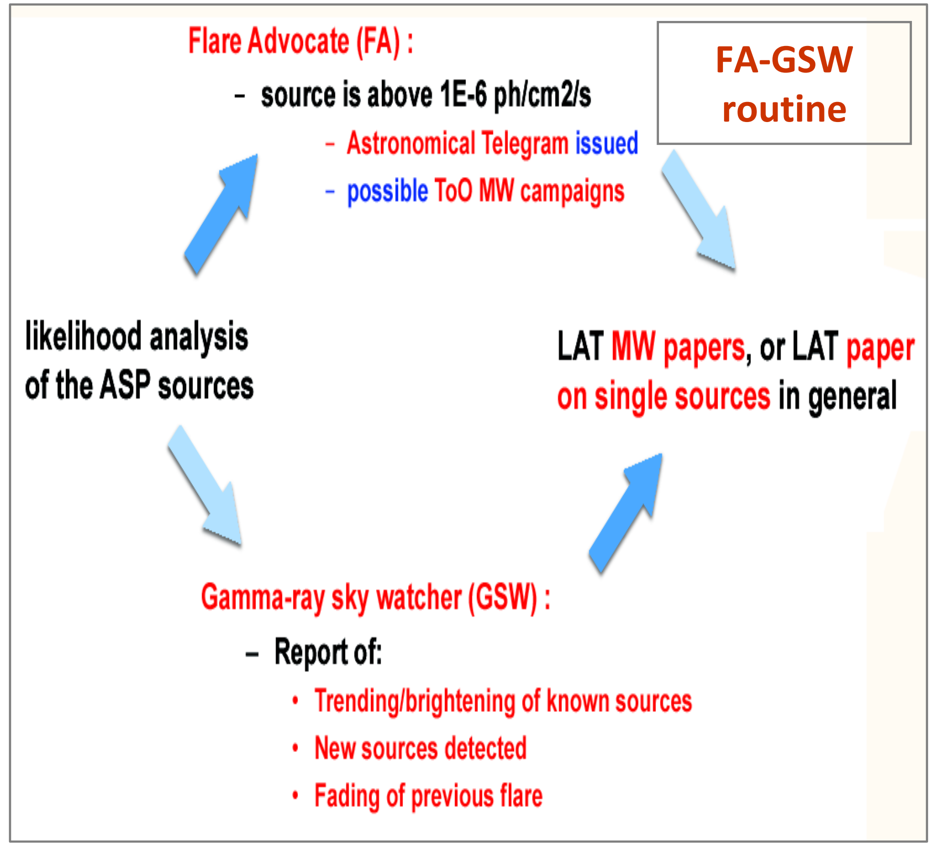


Light curves of blazars produced by the ASP trending monitoring task. These light curves are only a first preliminary and automated quick-look to some LAT sources. The 3 examples reported here shown already different behaviors (rapid pulse flares, monotonic slower trends, irregular oscillations).



The Fermi FA-GSW service

- **Twofold role and work of the FA-GSW:**
  - **Flare Advocate (FA)**: for sources above threshold of 1E-6 ph/cm2/s, or new and interesting; ATels, internal emails to science groups, ToO requests for multifrequency observations, multifrequency campaings, source friendship, papers on flares.
  - **Gamma-ray Sky Watcher (GSW)**: outlook to daily and 6h interval all sky maps and ASP data; daily confluence report with highlights; weekly summary of the shift on the public Fermi sky blog; EVO summaries; looks for 1) flares or slower brightening trends of sources (FA duty), 2) new sources detected (with respect to Catalog list or ASP confirmed sources), 3) outlook and validation of ASP sources, through likelihood check for detection and localization.
- Supply a first and prompt human outlook service to the quicklook automatic science processing (ASP) products and in general to the Fermi LAT gamma-ray sky, day by day.
- Look for flares, transients, pop up of new sources, brightness trends, in general for something of interest/ unusual on short time scales (<1 week).
- Communicate basic and relevant information and news about the LAT to the external community and internal science groups.



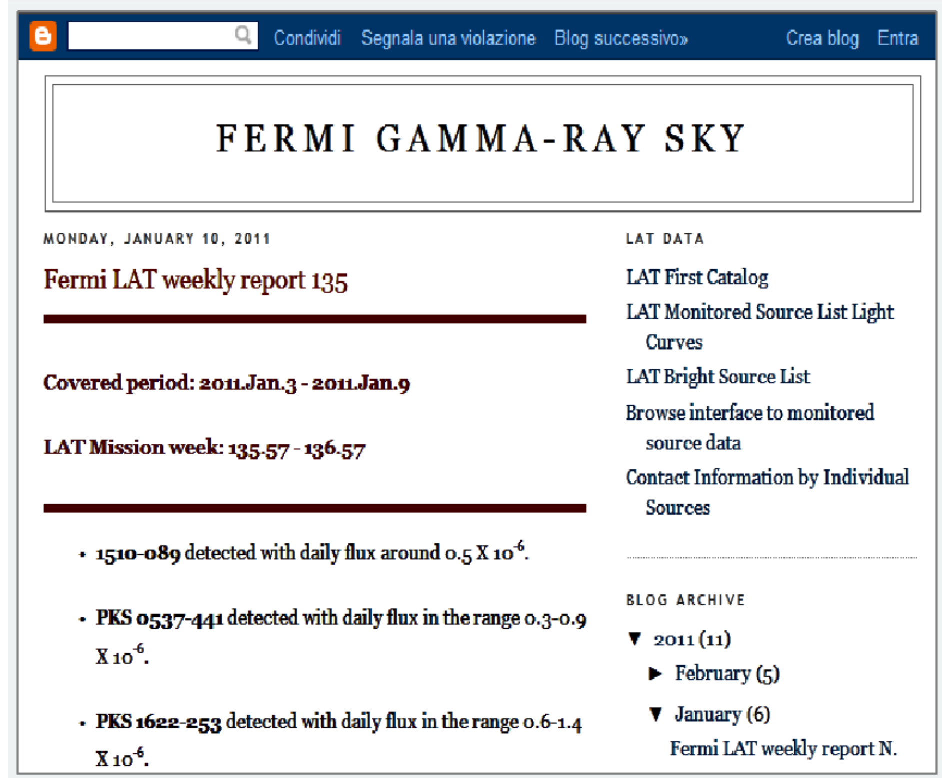
The Fermi FA-GSW service

❑News from the Fermi GeV gamma-ray sky:
http://fermisky.blogspot.com

❑ ATels (159 Fermi-LAT ATels in about 3 Years):
http://www.astronomerstelegram.org

❑ Contact information for individual flaring sources
https://confluence.slac.stanford.edu/x/tRNEAw

❑ Fermi LAT multiwavelength coordinating group
https://confluence.slac.stanford.edu/x/YQw


Condividi Segnala una violazione Blog successivo» Crea blog Entra

FERMI GAMMA-RAY SKY

MONDAY, JANUARY 10, 2011

Fermi LAT weekly report 135

Covered period: 2011.Jan.3 - 2011.Jan.9

LAT Mission week: 135.57 - 136.57

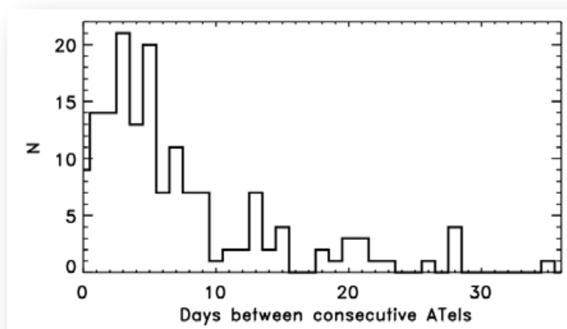
- 1510-089 detected with daily flux around 0.5 X 10^{-6}.
- PKS 0537-441 detected with daily flux in the range 0.3-0.9 X 10^{-6}.
- PKS 1622-253 detected with daily flux in the range 0.6-1.4 X 10^{-6}.

LAT DATA

LAT First Catalog
LAT Monitored Source List Light Curves
LAT Bright Source List
Browse interface to monitored source data
Contact Information by Individual Sources

BLOG ARCHIVE

▼ 2011 (11)
► February (5)
▼ January (6)
Fermi LAT weekly report N.



Average rate of Fermi LAT ATels:
in 2011 = 1 Atel per 6.5 days
in 2010 = 1 Atel per 5.8 days
in 2009 = 1 Atel per 8.5 days
in 2008 = 1 Atel per 11.2 days

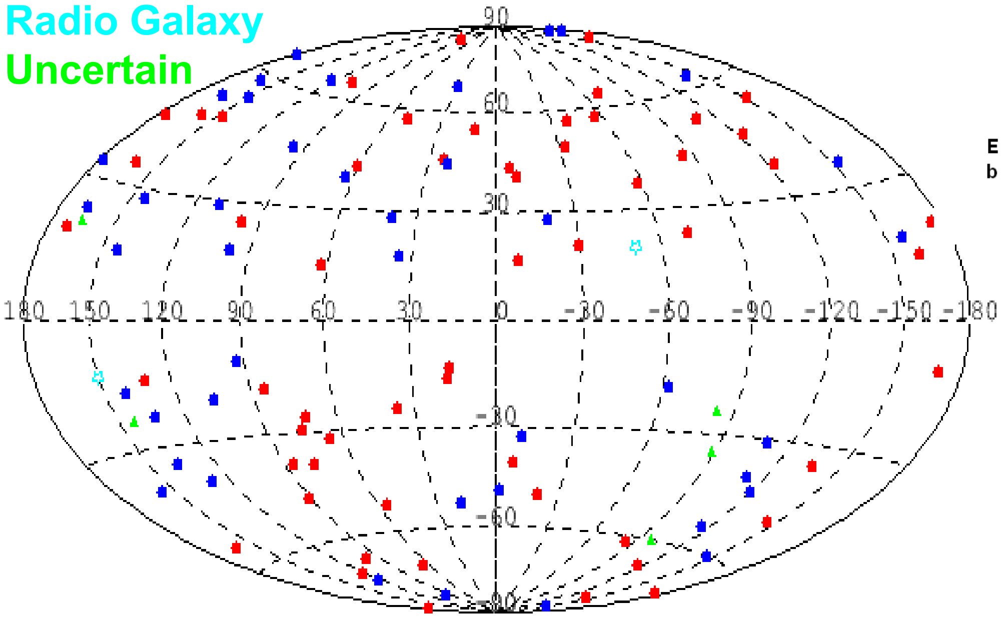
159 ATels in 3 years

- 159 ATels posted on behalf of the LAT collaboration from July 24th, 2008 to Aug.29th, 2011 (MJD 54671- 55802, i.e. 1131 days). From ATel #1628 to ATel #3580.
- Most of them followed FA activities (new gamma-ray blazar pop-up or bright flares of known gamma-ray blazars), other followed science activities by the galactic, pulsar, solar, LLE working group independently by the FA service.
- Most of the ATel have blazar targets.
- 18 ATels are Swift quicklook results only (from ToO observations triggered by a LAT flare and issued on behalf of the Fermi collaboration).
- 3 ATels are about joined Fermi-Swift results.
- 1 ATel is about joined Fermi-Integral results.
- 1 ATel is about joined Fermi-optical results.
- 1 ATel is about joined Fermi-HESS results.
- 18 ATels are about likely galactic sources.
  (objects/regions: 3EG J0903-3531, Cygnus Region, Cygnus X-3, J1057-6027, J0109+6134, V407 Cyg, J1512-3221, Cygnus X-3, binary system PSR B1259-63, Crab Nebula, PSR B1259-63, Galactic center region, binary 1FGL J1018.6-5856).
- 3 ATels are about the Sun.

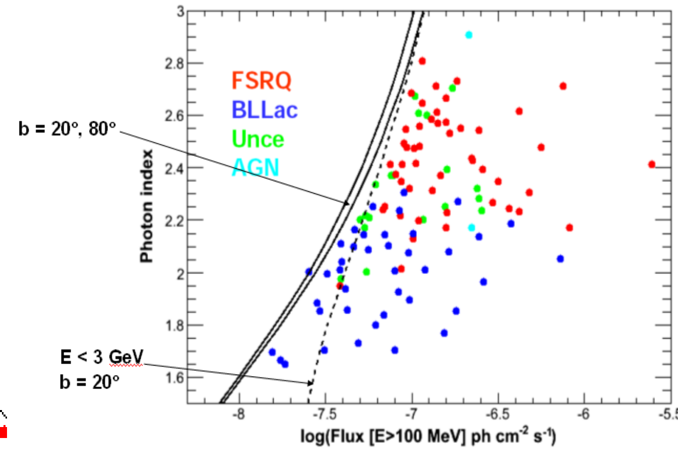
High confidence list: blazar population properties

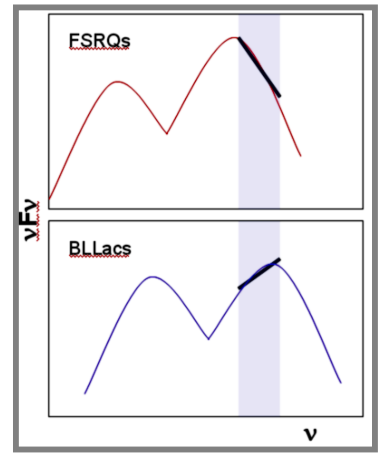
- Aug/Sep/Oct 2008 high confidence list: 205 sources with >10σ detection
- 132 with |b| > 10° (7 pulsars, 14 unid)
  - 111/125 are bright, flat spectrum radio sources
  - 98/111 have optical classifications, 89/111 have redshifts
  - CRATES (all-sky radio catalog), CGRaBS (all-sky optical spectra)

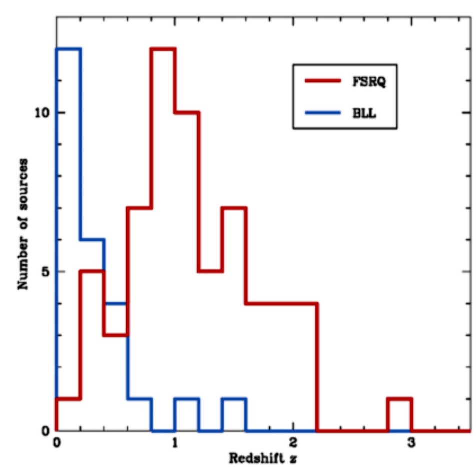
FSRQ
BL Lac
Radio Galaxy
Uncertain

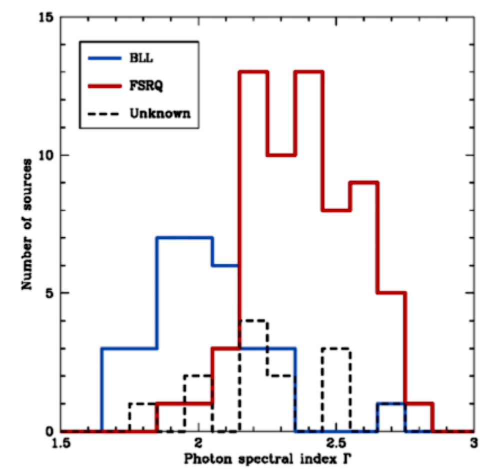


Photon index vs flux









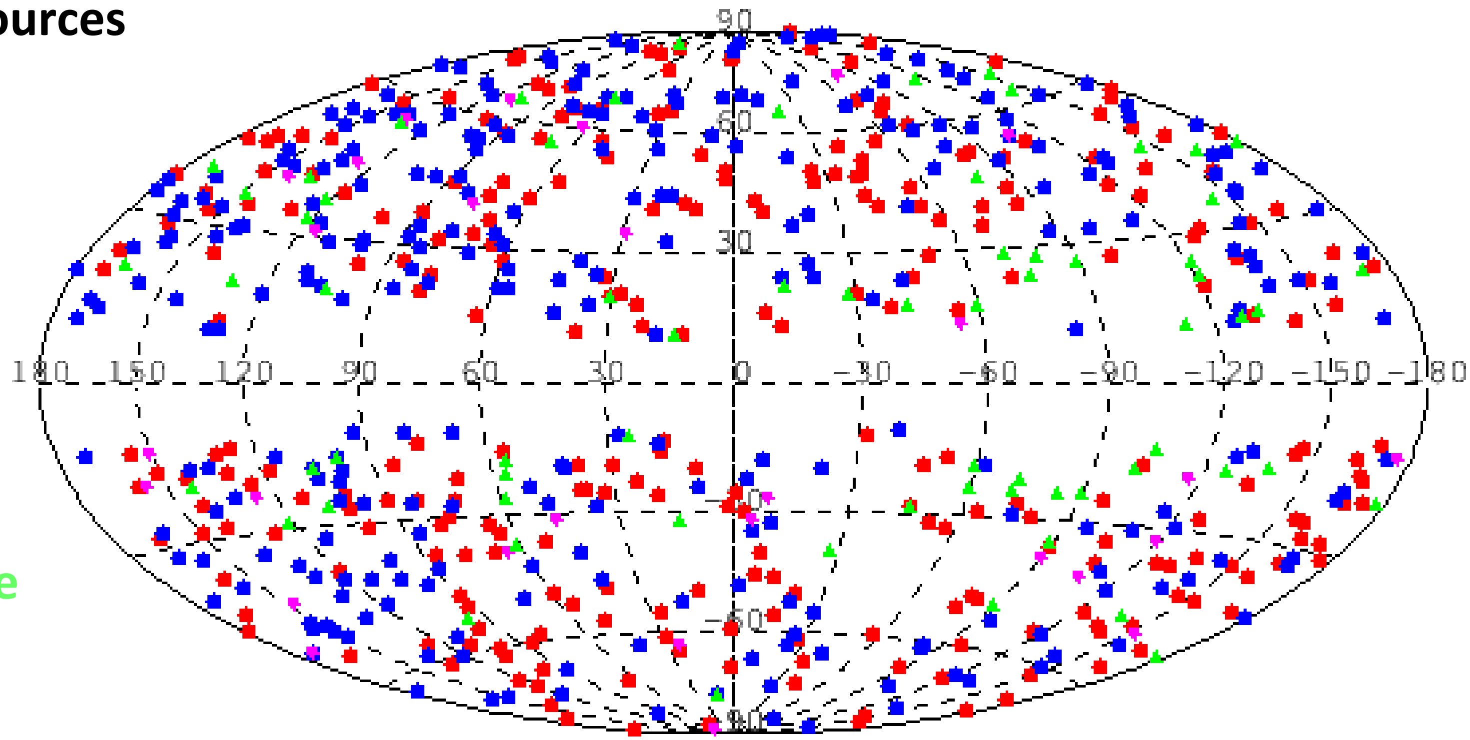
The First LAT AGN catalog (1LAC -1 year release)

• 11 month data set

• 1079 TS>25, |b|>10° sources

• 668 AGNs (P_{assoc}>80%)
+186 candidates

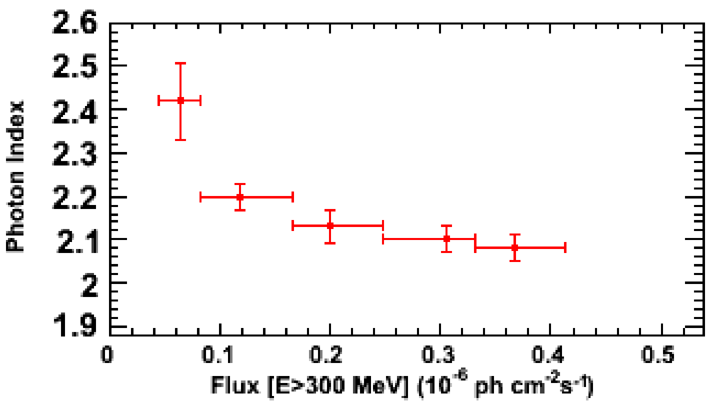
• Census:
  • 286 FSRQs
  • 284 BLLacs
  (141 with measured z)
  • 69 of unknown type
  • ~10 Radio galaxies

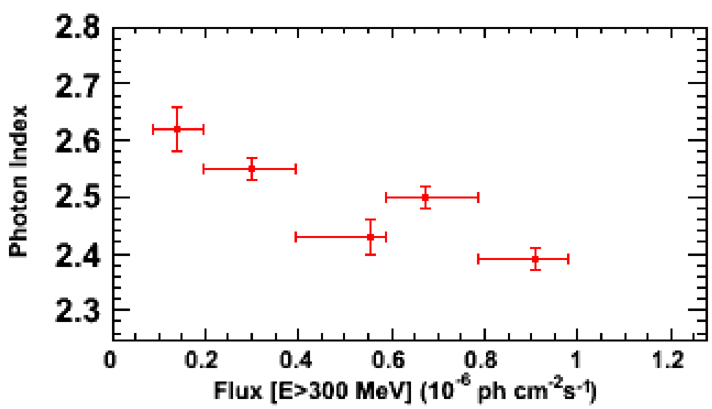


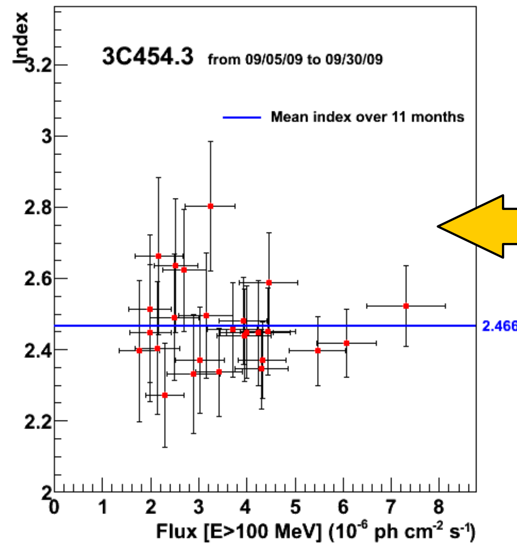
Differences between Northern Hemisphere and Southern one (FSRQs: 7%, BLLACs: 25 %)

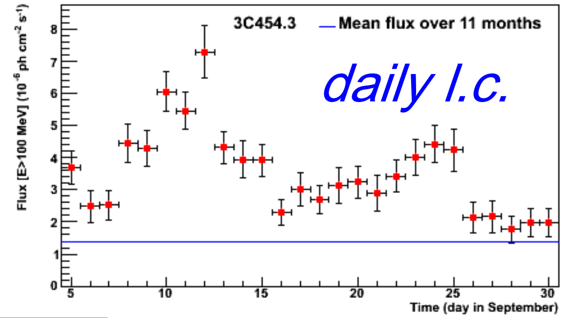
Relative constancy of photon index

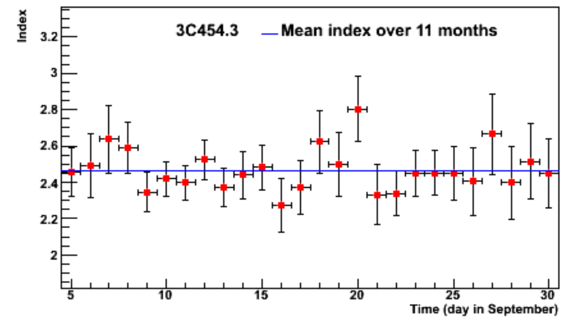
weekly l.c.

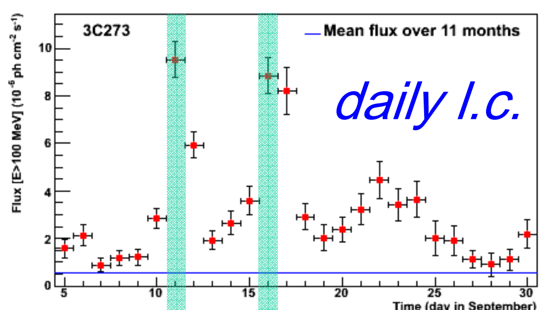


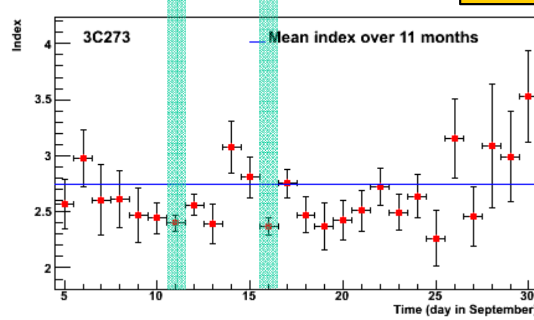


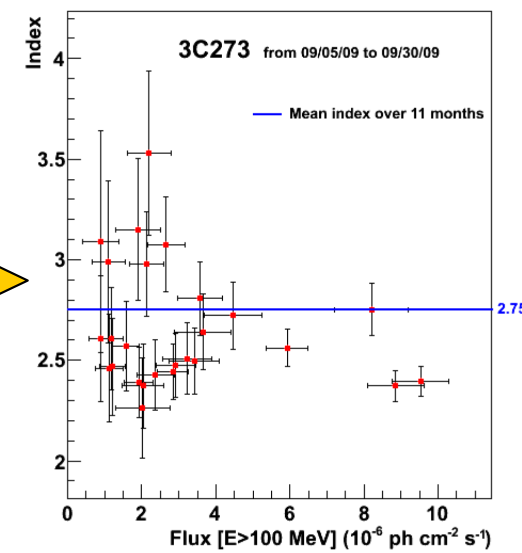








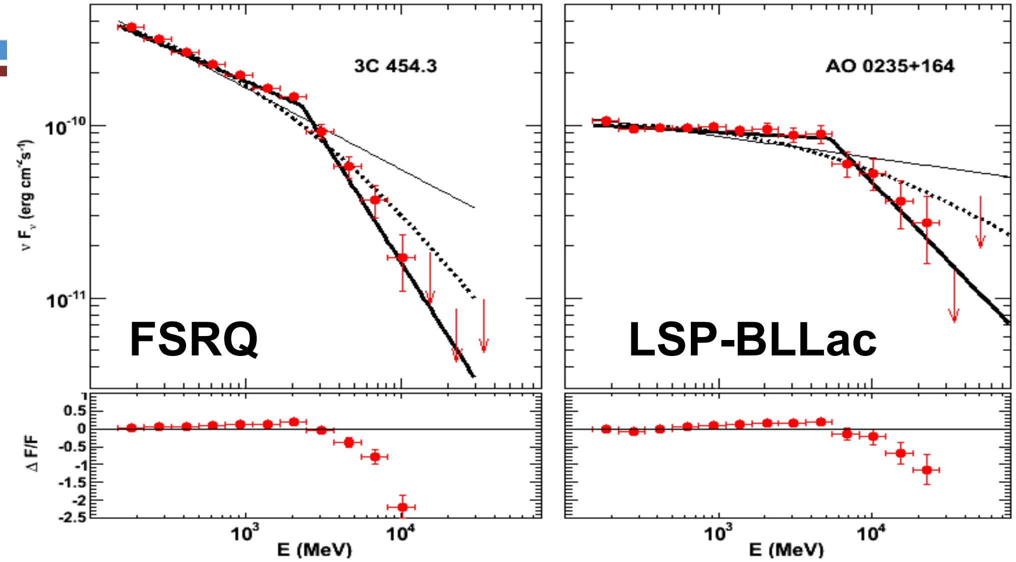


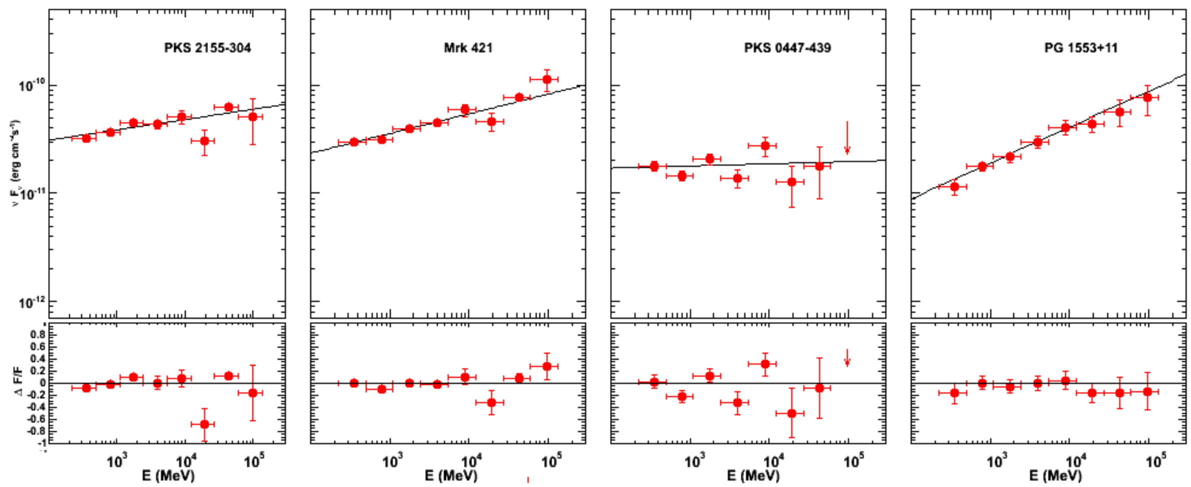


« Harder when brighter » effects observed but moderate variations ($\Delta\Gamma$ <0.3) seem to be the rule
Process stabilizing the spectral shape?

Non-power law spectra

- General feature in FSRQs and many LSP-BLLacs
- Absent in HSP-BLLacs
- Broken power law model seems to be favored
- $\Delta\Gamma$~1.0 > 0.5 → not from radiative cooling
- Possible explanations:
  - feature in the underlying particle distribution
  - Klein-Nishina effect
  - γ–γ absorption effect
- Implications for EBL studies and blazar contribution to extragalactic diffuse emission

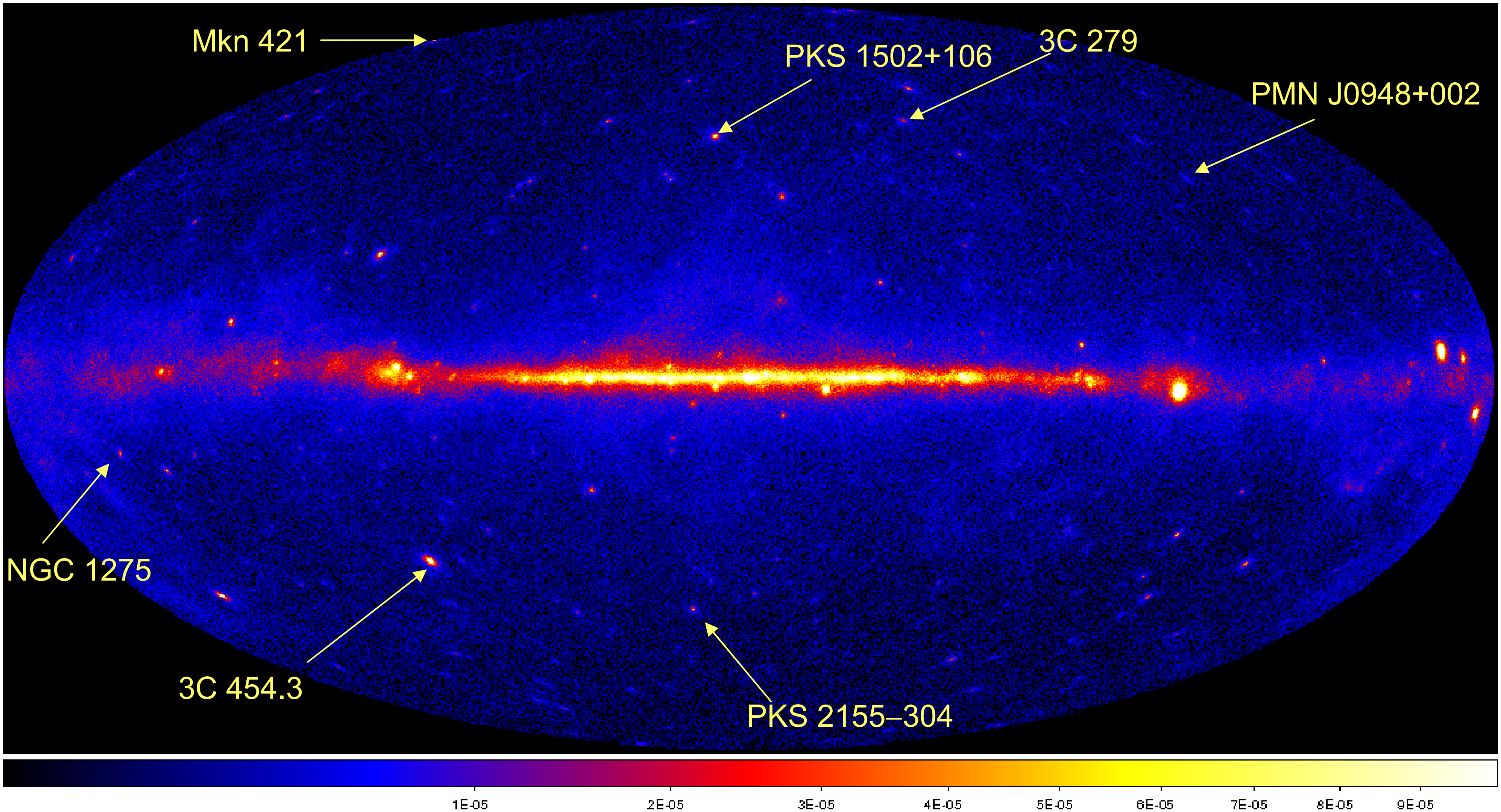




HSB-BLLacs

Challenge for modelers to account for the break and the relative constancy of spectral index with time

Some Fermi LAT results for individual AGNs



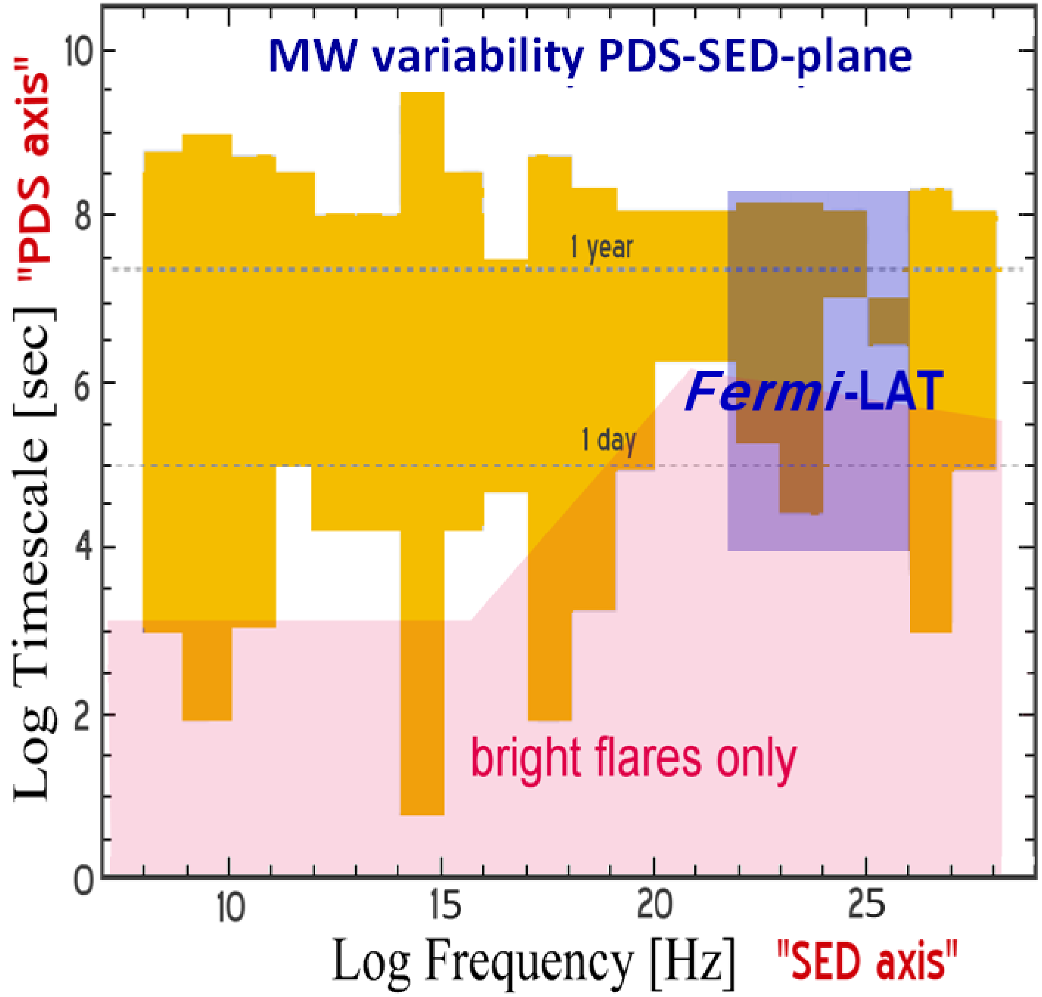
Multi-waveband variability of gamma-ray blazars

- ❑ Variability found everywhere in blazars: on all time-scales in all photon frequencies.
- ❑ Multi-wavelength (MW) variability: measures in the PDS-SED-plane (i.e. timescale-energy plane).
- ❑ Physical parameter space of multi-wavelegth (MW) variability for blazars: (L, v/c, D, m_{BH}, B, …)
- ❑ Mono-band (mono-mission) studies: variability behaviors, broad Power Density Spectra/Structure Functions, PDS slopes/breaks, local analysis (wavelets, flare pulse fitting,…).

→ Standalone Fermi LAT data.

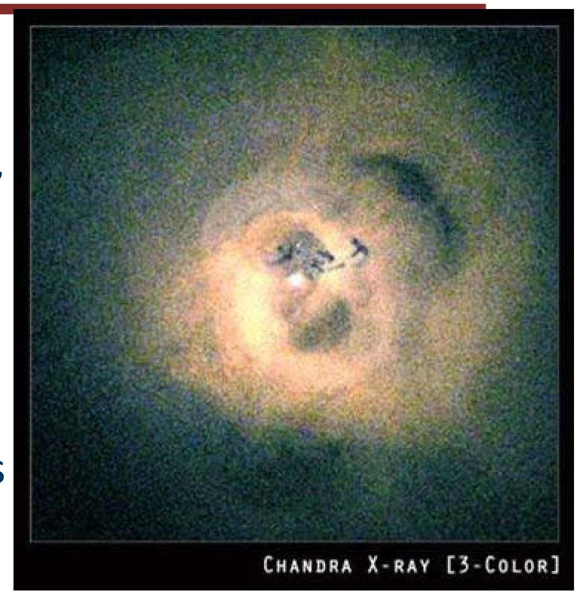
- ❑ Broad-band MW studies: cross-correlation and time lags. MW Spectral Energy Distribution (SED) modeling. Gamma-ray-synchrotron amplitude ratio studies, orphan flares, Physics of the gamma-ray emission in AGN, identification of newly discovered gamma-ray sources, spectral index hysteresis, etc.

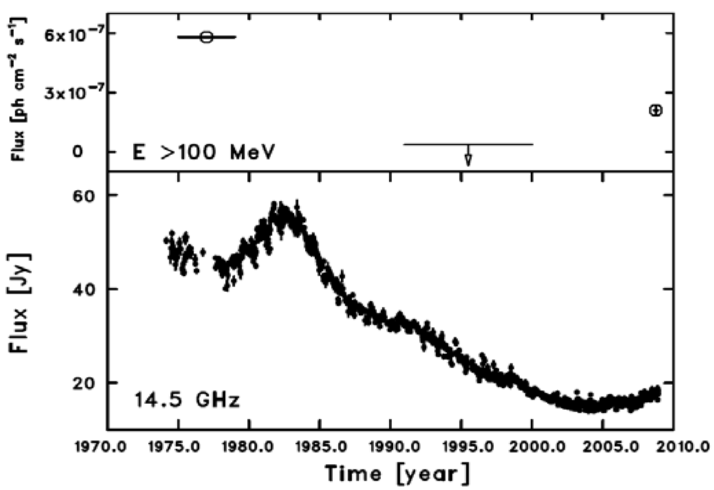
→ Fermi LAT and MW coordinated observing campaigns (ground-based and space-borne instruments/telescopes, from radio-band to X-rays and TeV Cherenkov showers).

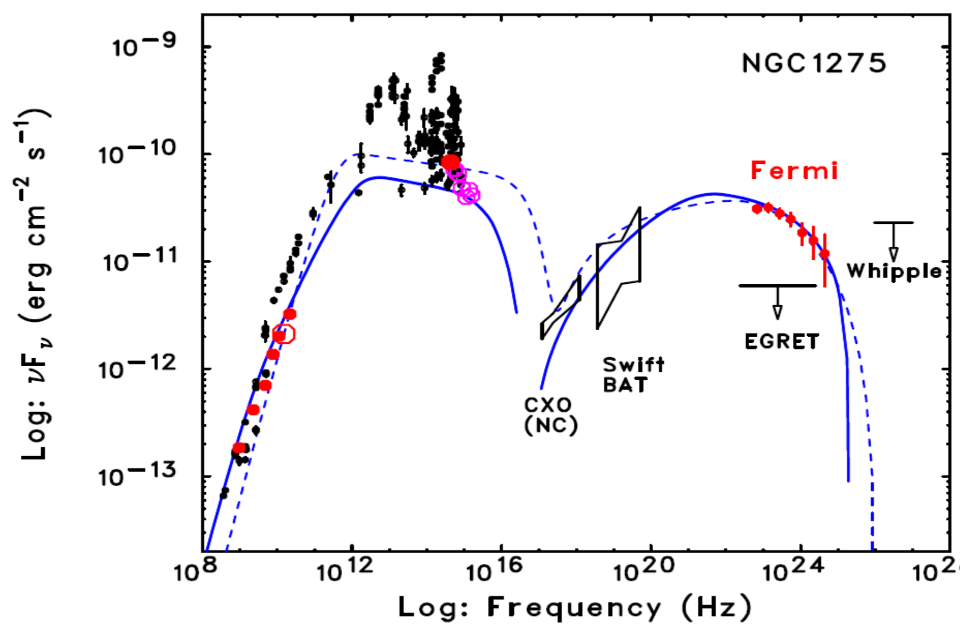


Fermi-LAT detection of NGC 1275 (Per A, 3C 84)

- NGC 1275: Classic example of a “cooling core” cluster. Voids or “bubble” seen in the X-ray must be inflated by some central source of power, i.e., an AGN.
- Variable emission on month to year time scales $\Rightarrow$ AGN. Cannot be dark matter or diffuse cluster emission.
- Inferred blazar luminosity, $L_\gamma \sim 10^{44}$-10^{45} erg s^{-1}, is consistent with power needed to inflate the voids.
- SED fitted with single zone SSC model (solid curve) and spine-sheath model (dashed)



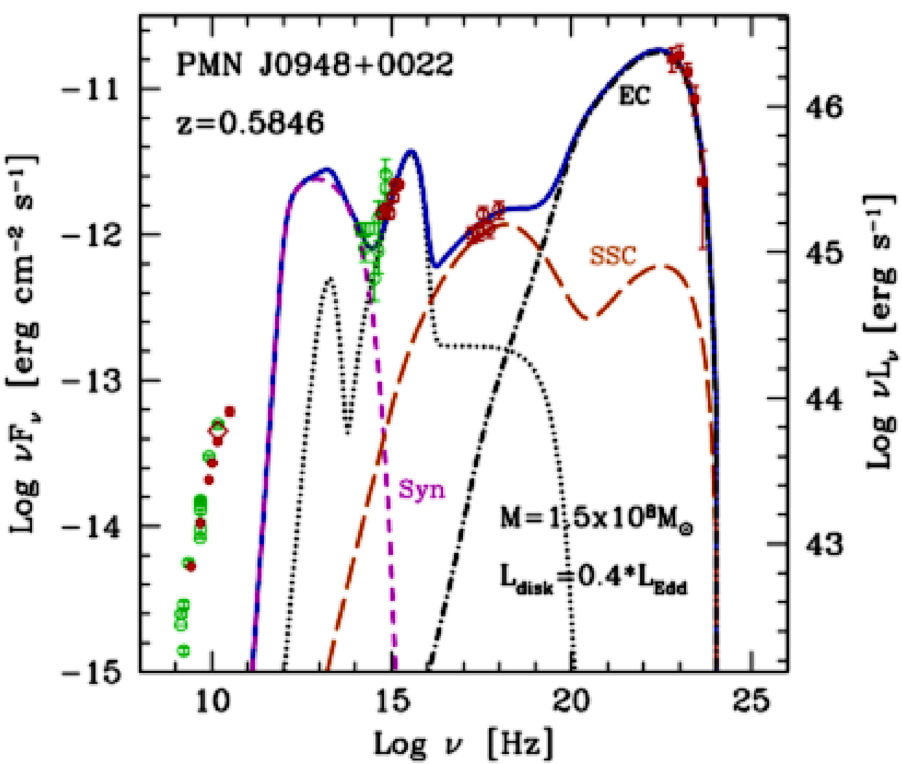




LAT detection of PMN J0948+0022 (a narrow Line Seyfert 1) and very large outburst from 3C 454.3

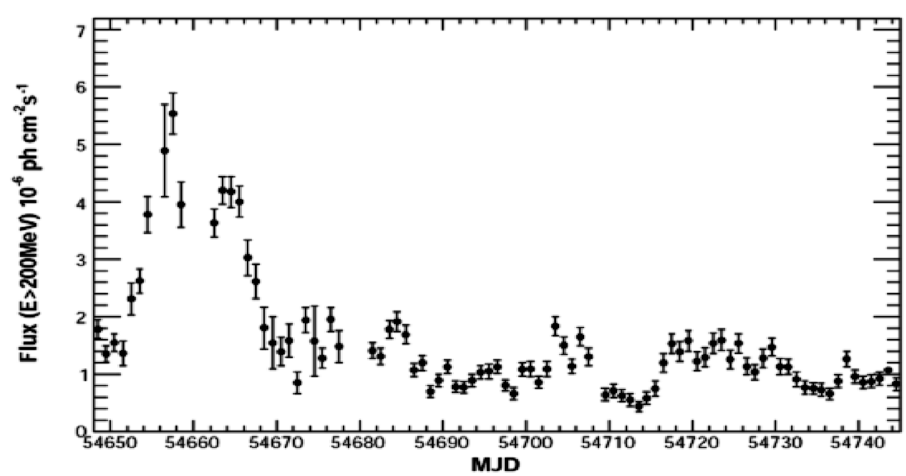
PMN J0948+0022

- Seyfert galaxies are not normally associated with blazar emission
- PMN J0948+0022 SED is similar to an FSRQ's, but at much lower luminosity.
- Seyfert galaxies have lower mass BHs (~$10^7 M_{sun}$) & NS1s have high accretion rates ⇒ Eddington ratio is a key determinant of SED characteristics.



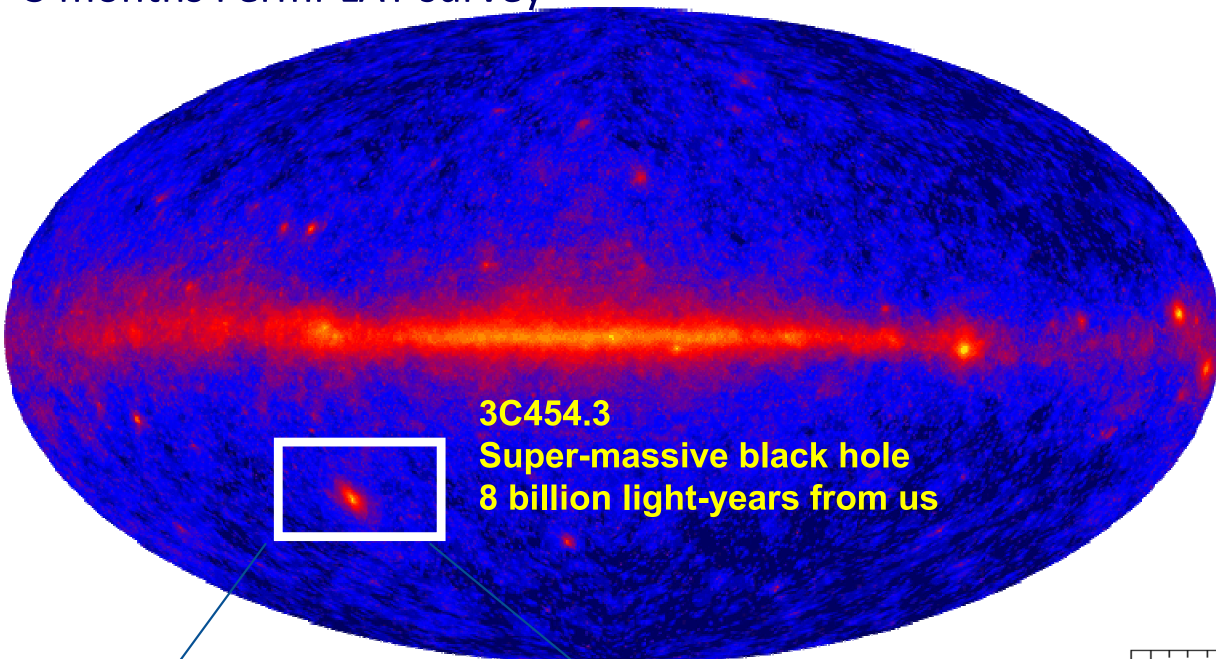
3C 454.3

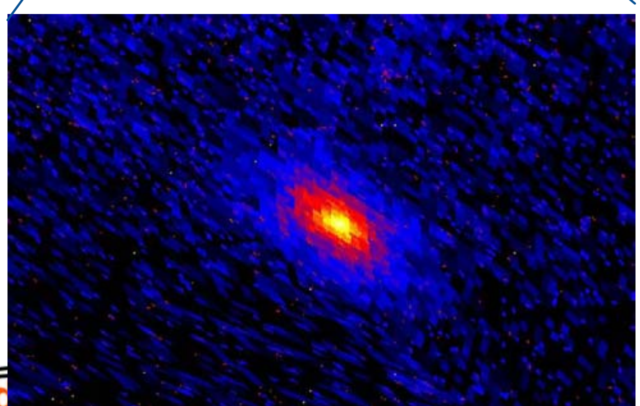
- OVV quasar, very active since 2000; z = 0.859; VLBI, superluminal motion, $\delta \sim 25$
- Brightest blazar during first few months of operations and variability time scales of < 3 days ⇒ $\delta > 6$
- First definitive evidence of a spectral break in the GeV range: E_{br} = 2 GeV, Γ_1=2.3, Γ_2=3.5
- $\Delta\Gamma$=1.2 > 0.5 ⇒ not from radiative cooling.
- This feature could either arise from "intrinsic" absorption, e.g., via $\gamma\gamma$ opacity from accretion disk photons or it may represent a characteristic energy in the underlying particle distribution.

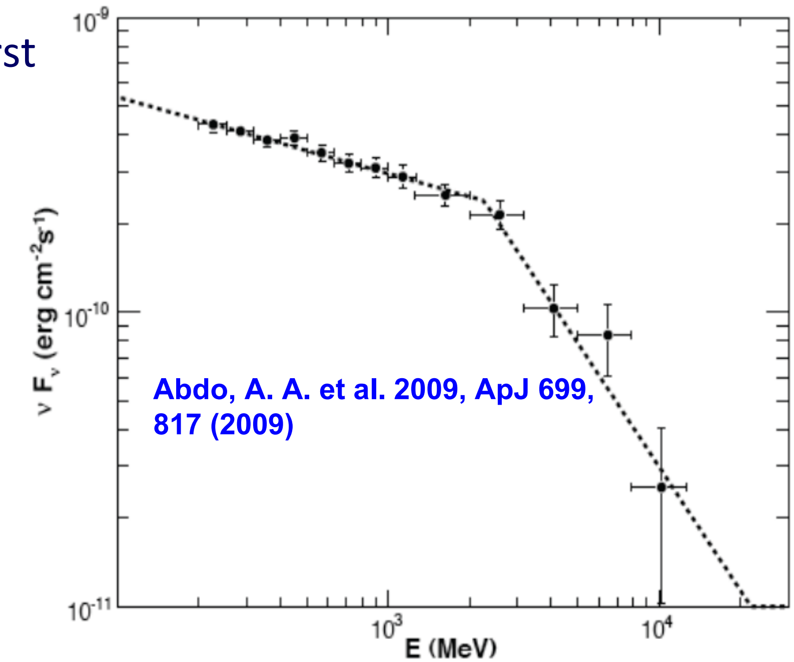


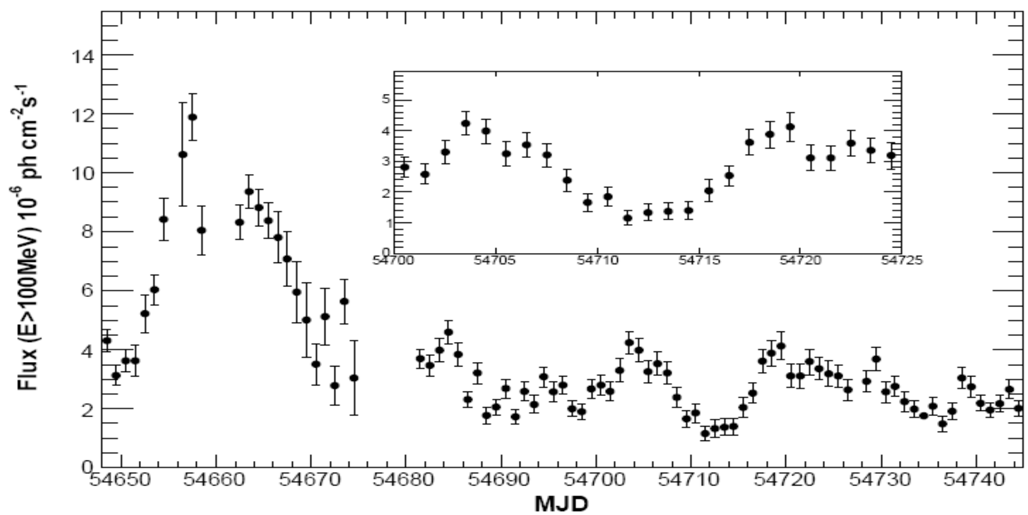
3C 454.3 the blazar of the record

The brightest gamma-ray extra-galactic source observed in the first 3 months Fermi-LAT survey



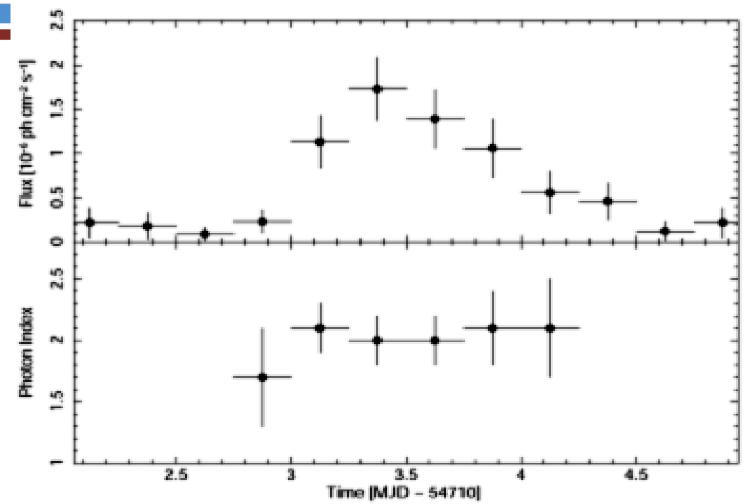




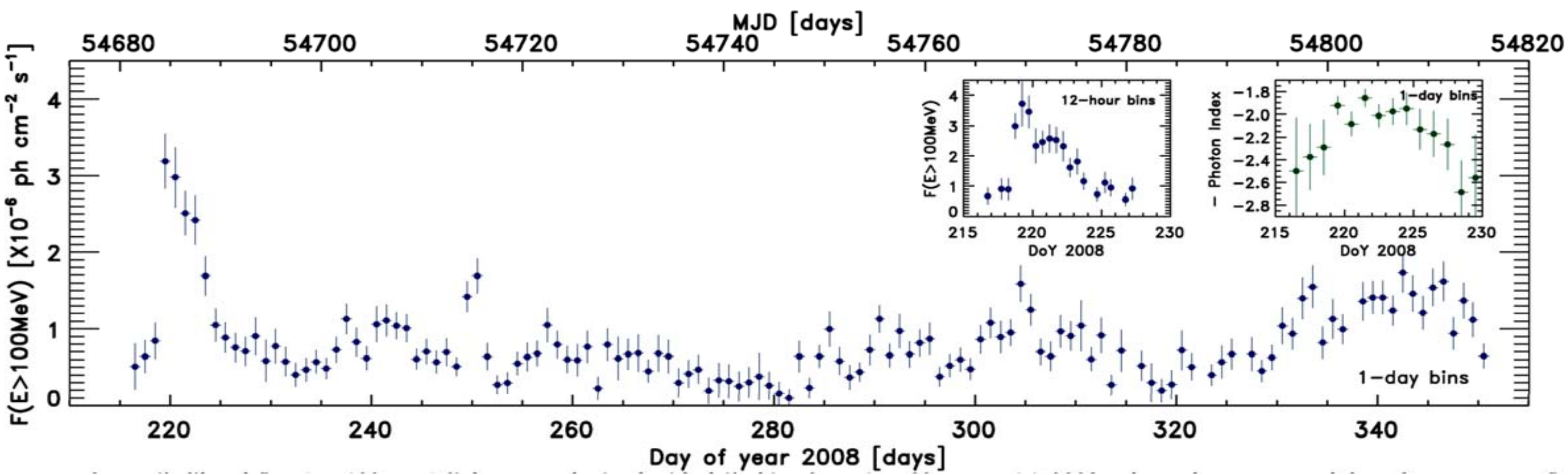


Fast flaring blazars: PKS 1454-354 and PKS 1502+106

- **PKS 1454-354**: factor ~5 increase of >100 MeV flux in 12 hours; achromatic flux variations
- ⇒ weak radiative cooling regime, GeV variability driven by seed photon changes (cf. PKS 2155–304)

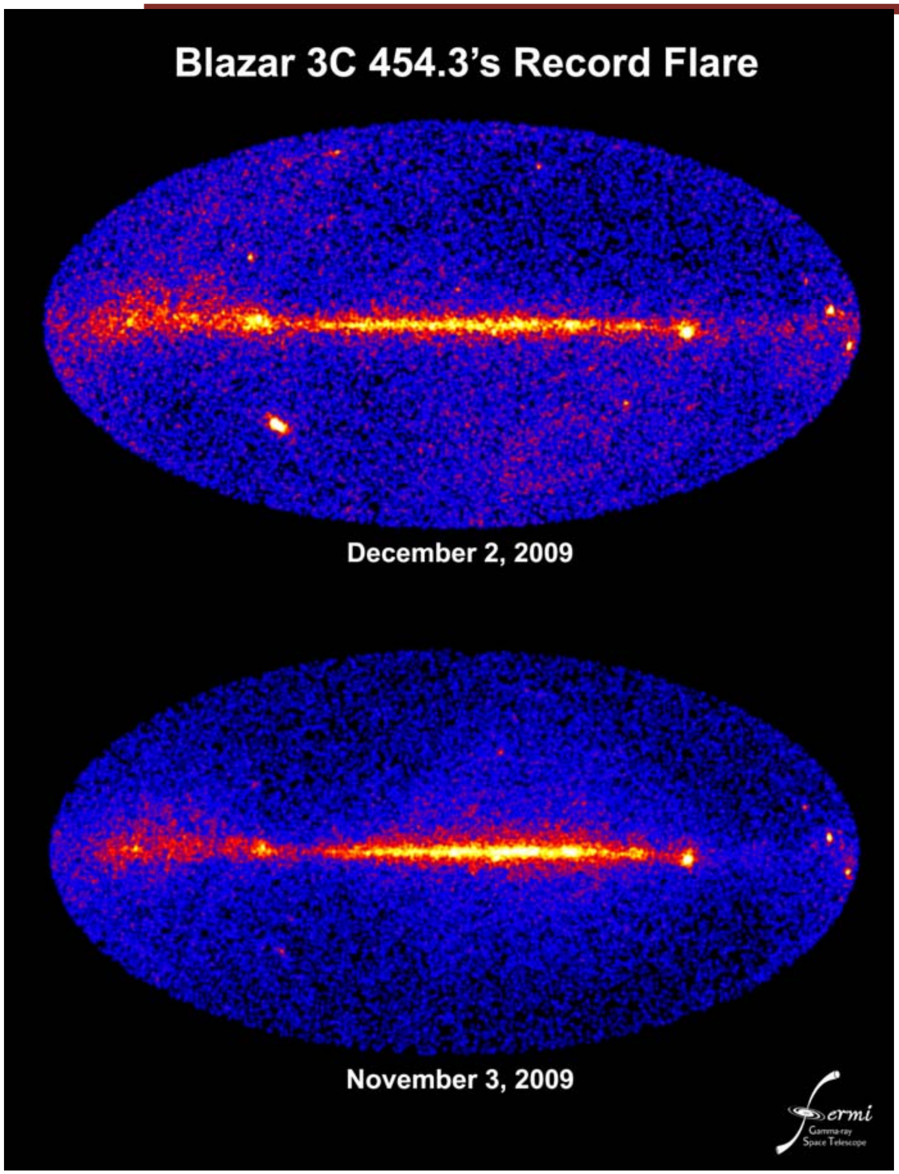


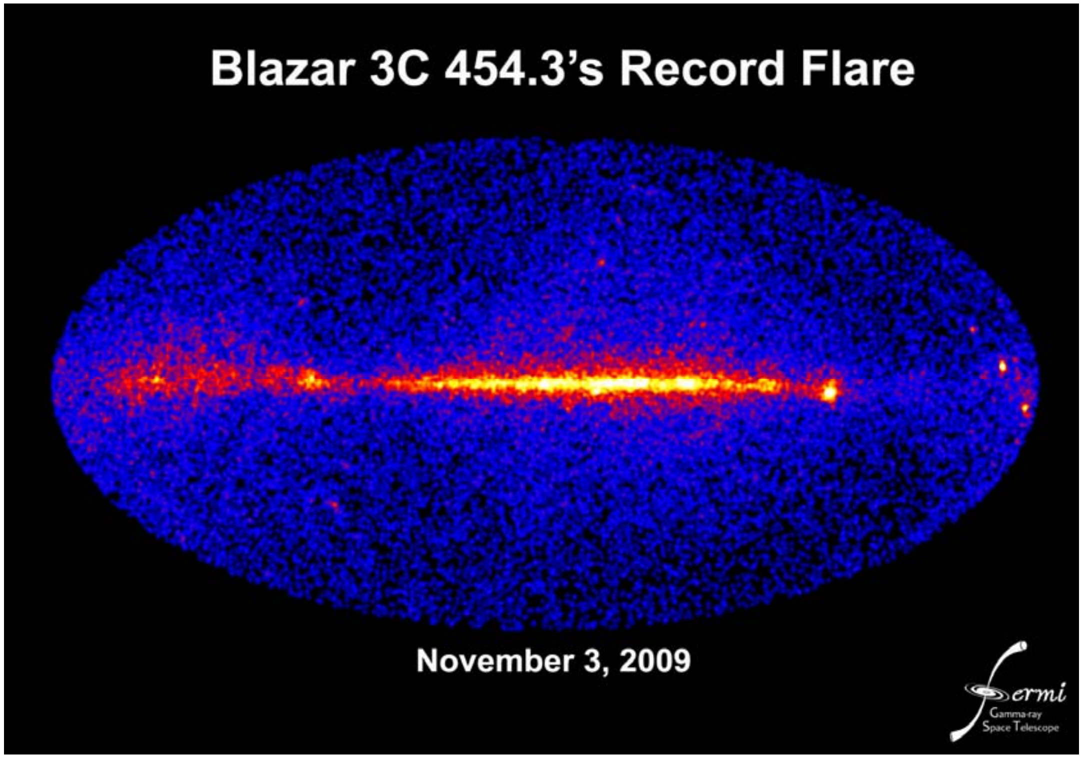
- **PKS 1502+106**: z=1.839, factor 3 increase in <12 hrs, highest ΔL/Δt in GeV band. Enduring gamma-ray brightness and substantial variability shown. Multifrequency campaign developed (see the dedicated poster).



stefano.ciprini@asdc.asi.it – ASDC Roma

3C 454.3 the blazar of the record

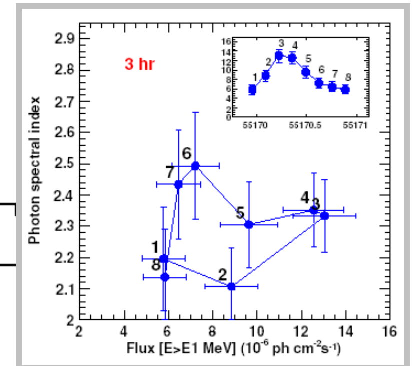


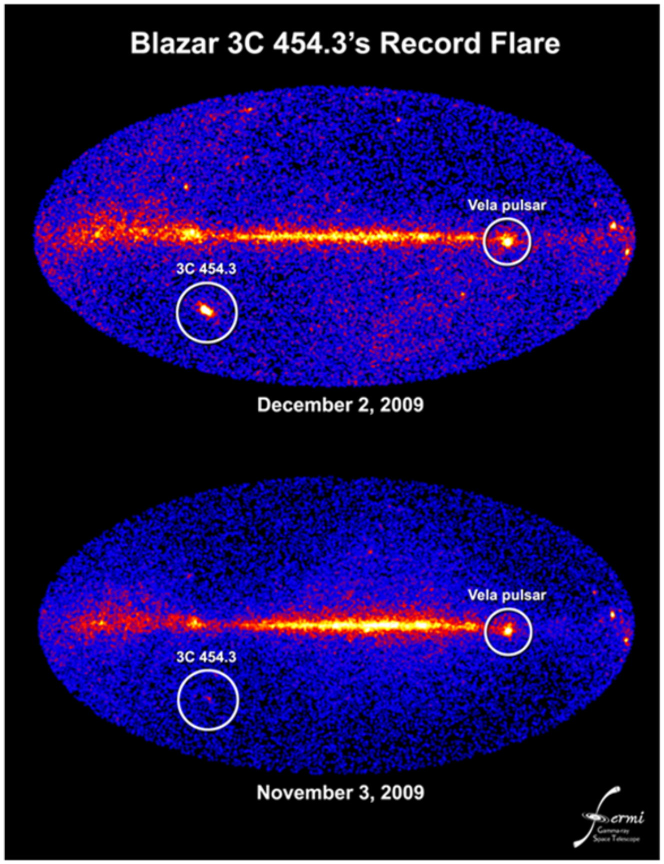


Daily photon count maps

The big outbursts of 3C 454.3 (Dec. 2009 and Apr. 2010)

- Correlated spectral-temporal properties of 3C 454.3 during two very strong flaring episodes (it was the brightest object in the gamma-ray sky during the peak) studied.





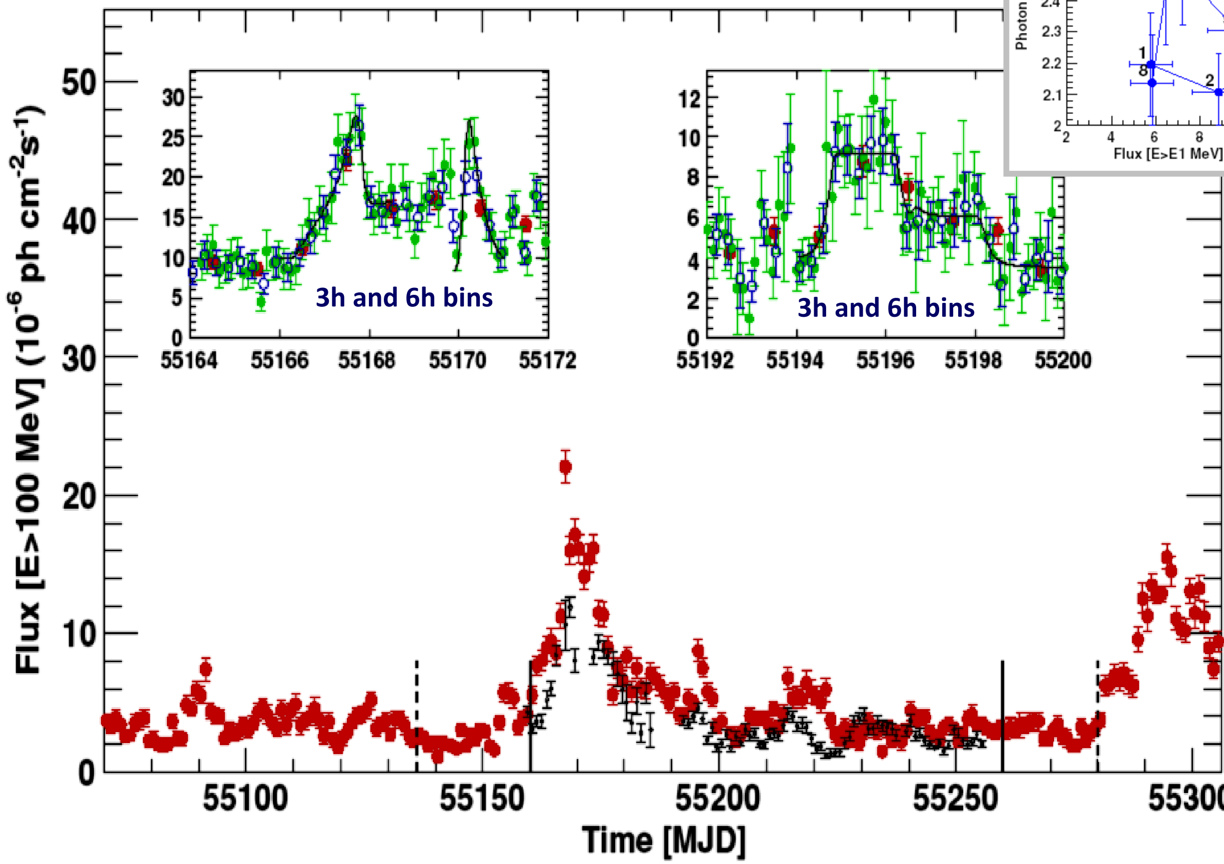


Figure 1. Light curve of the flux of 3C 454.3 in the 100 MeV–200 GeV band (red) between MJD 55,070–55,307 (2009 August 27–2010 April 21). The solid (dashed) lines mark the period over which the PSD (CWT) analysis has been conducted. The light curve of the 2008 July–August flare, shifted by 511 d, is shown for comparison (black). The insets show blow-ups of the two periods when the largest relative flux increases took place. The red, blue, and green data points in the insets correspond to daily, 6 hr, and 3 hr averaged fluxes, respectively. The fit results discussed in the text are displayed as solid curves.

The big outbursts of 3C 454.3 (Dec. 2009 and Apr. 2010)

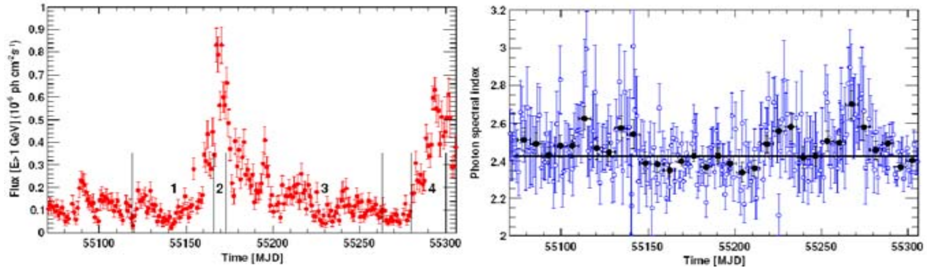


Figure 3. Top: light curve of the flux in the 1 –200 GeV band. Bottom: variation of the daily (blue points) and weekly (black points) photon spectral index derived from a PL fit. The black line depicts the mean weekly spectral index.

- ❑ First-order structure function (SF), power density spectrum (PDS), global methods, and Morlet continuous wavelet transform (CWT), local method, are applied to the unprecedented-resolution gamma-ray light curve of 3C 454.3 (interval MJD 55140-55260).
- ❑ Break around 6.5 days is hinted (power-index slopes α = 1.29±0.10 between 3 hr and 6.5 days and α = 1.64±0.10 between 6.5 and about 26 days. PDS confirms values (α = 1.40 ± 0.19 and a = 1.56 ± 0.18).
- ❑ Steepening toward longer lags (flattening toward higher frequencies).
- ❑ Morlet-CWT (best tradeoff between localization and period/frequency resolution), showed only marginal features below timescales of 1 day. The
- ❑ big outburst of Dec.2009 well localized and decomposed in a chain of mino CWT power peaks. 6.5 day timescale confirmed by the major power peak still out of the finite-series cone of influence (at about MJD 55166)
- ❑ Another energetic peak in this period is found with scale of about 2.5 days

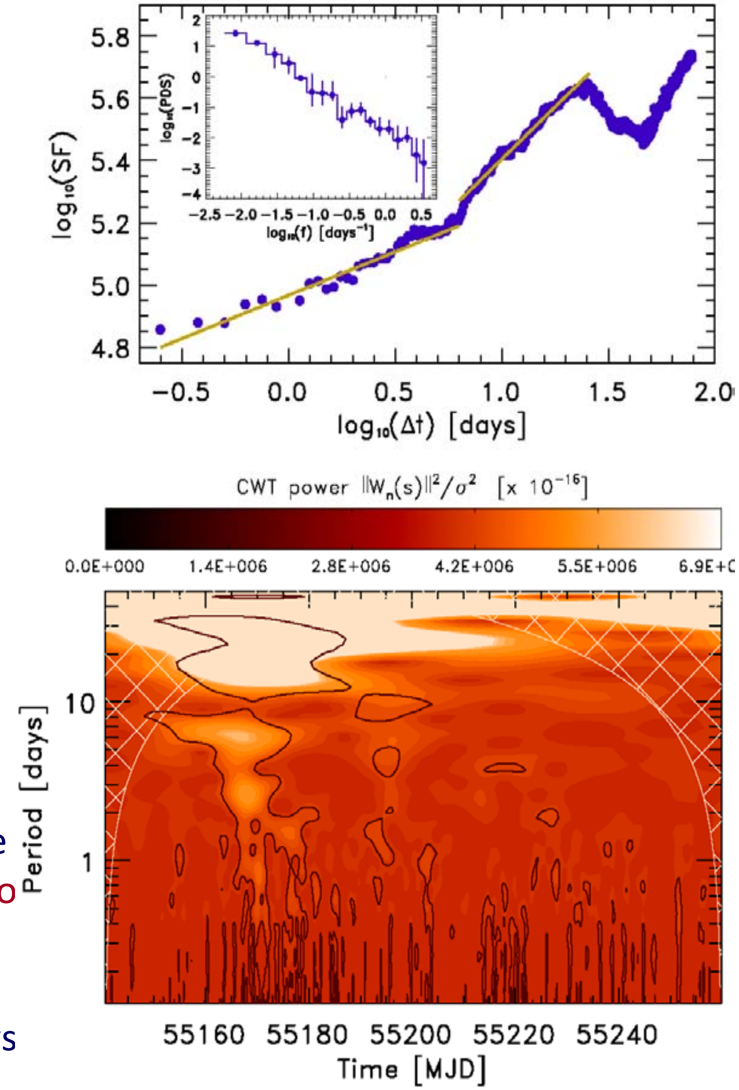


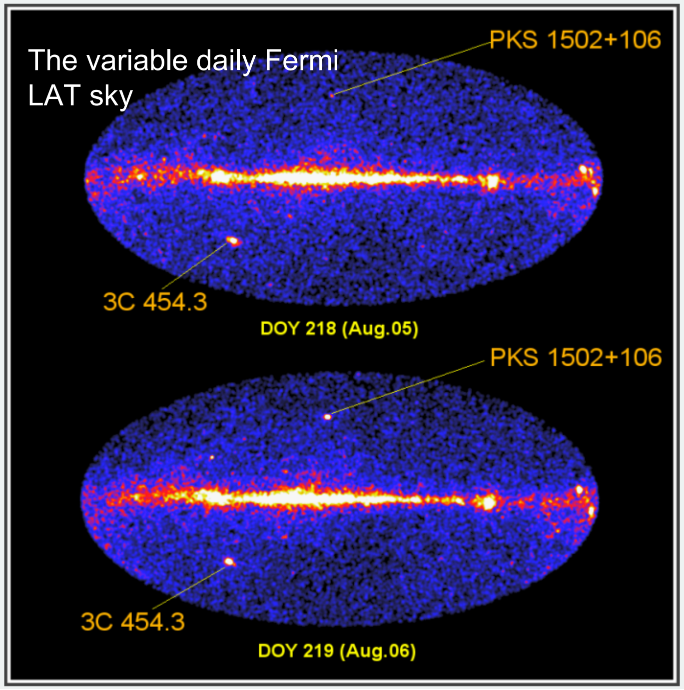
Figure 2. Top panel: SF of the 3 hr bin flux light curve for the period MJD 55,140–55,260 and corresponding PDS (inset). Bottom panel: plane contour plot of the continuous Morlet wavelet transform power density for the same light curve. Thick black contours are the 90% confidence levels of true signal features against white/red noise background, and cross-hatched regions represent the "cone of influence," where spurious edge effects become important.

PKS 1502+106: the Fermi-Swift ToO multifrequency campaign

❑ A non-PIC (not planned in advance) but ToO Campaign based on a LAT flare and the Flare Advocate activity. ATel sent, ToO to Swift performed (PI discretionary time), and a MW campaign started. **The fisrt ToO Fermi campaign**

❑ Observatories involved: Swift (a 16-day monitoring), VLBA (through the MOJAVE program, USA), Owens Valley Radio Observatory 40m (USA), Effelsberg-100m (Germany), Metsähovi-14m (Finland), RATAN-600 (Russia), Kanata Higashi-Hiroshima (Japan).

❑ Archival unpublished observation analyzed too (INTEGRAL, Spitzer, XMM-Newton).

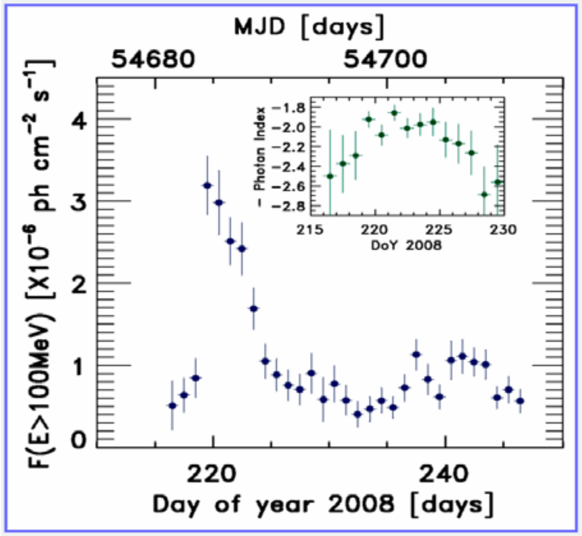


MW analysis:

❑ **simultaneous** (MW coordinated campaigns),

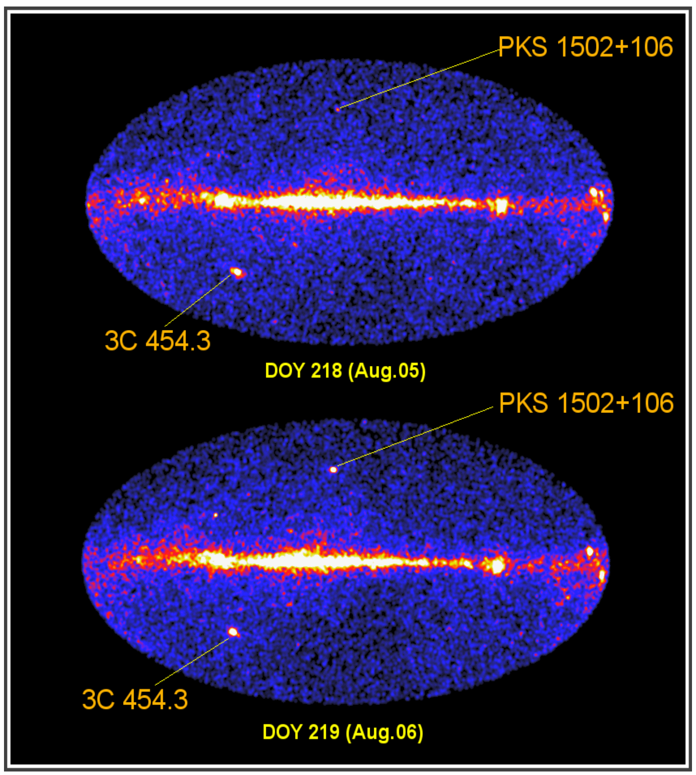
❑ **forward in time** (= post outburst MW monitoring),

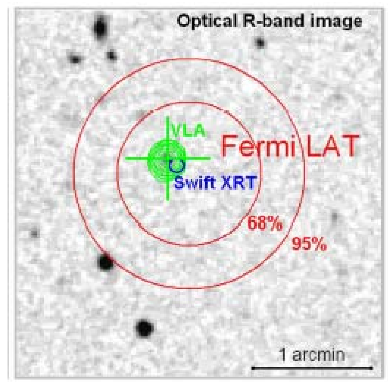
❑ **back in time** (= archival mission databases) too.



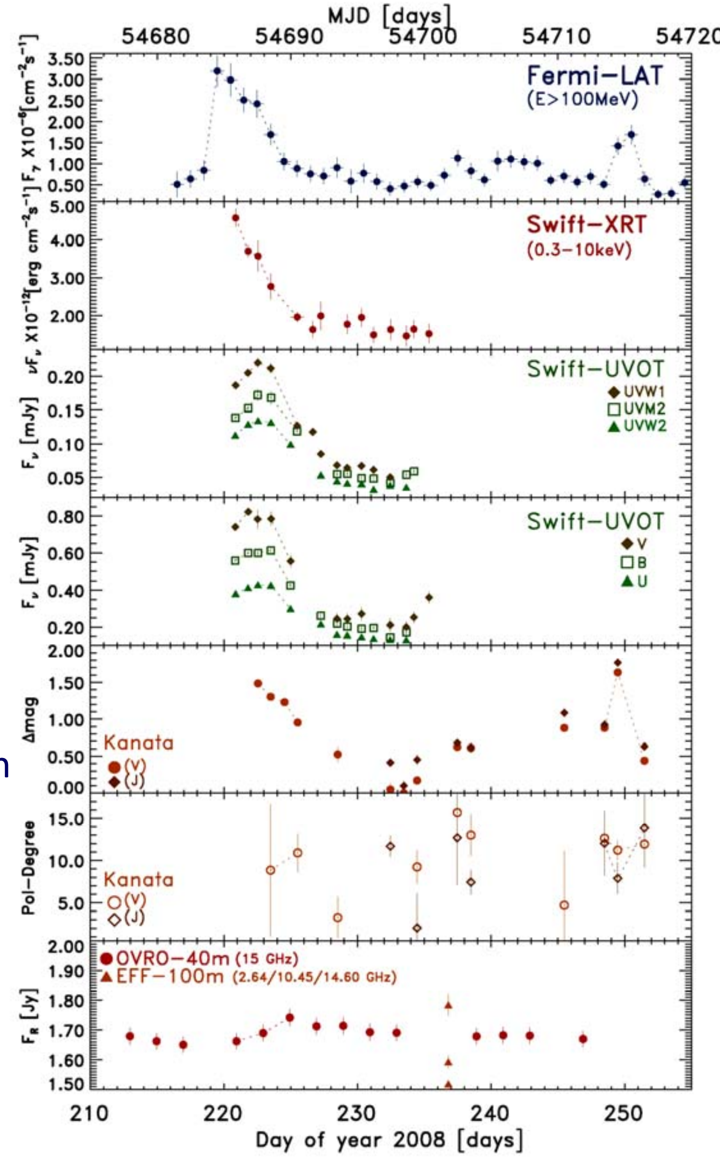
PKS 1502+106, a new and distant gamma-ray blazar in outburst discovered by Fermi LAT

- A new and luminous gamma-ray blazar (not seen by EGRET).
- 1. new gamma-ray source to be identified, + 2. variability shown, + 3. peculiar properties (high gamma-ray dominance, z= 1.839) → needs for a multifrequency synergy.
  - Simultaneous Fermi-Swift monitoring. The first Fermi-Swift campaign made. (started on Aug.7, 2008). Swift follow up for 16 days.
  - Ground based radio-optical snapshots (VLBI structure and radio-mm spectra) and monitoring (radio-optical flux).

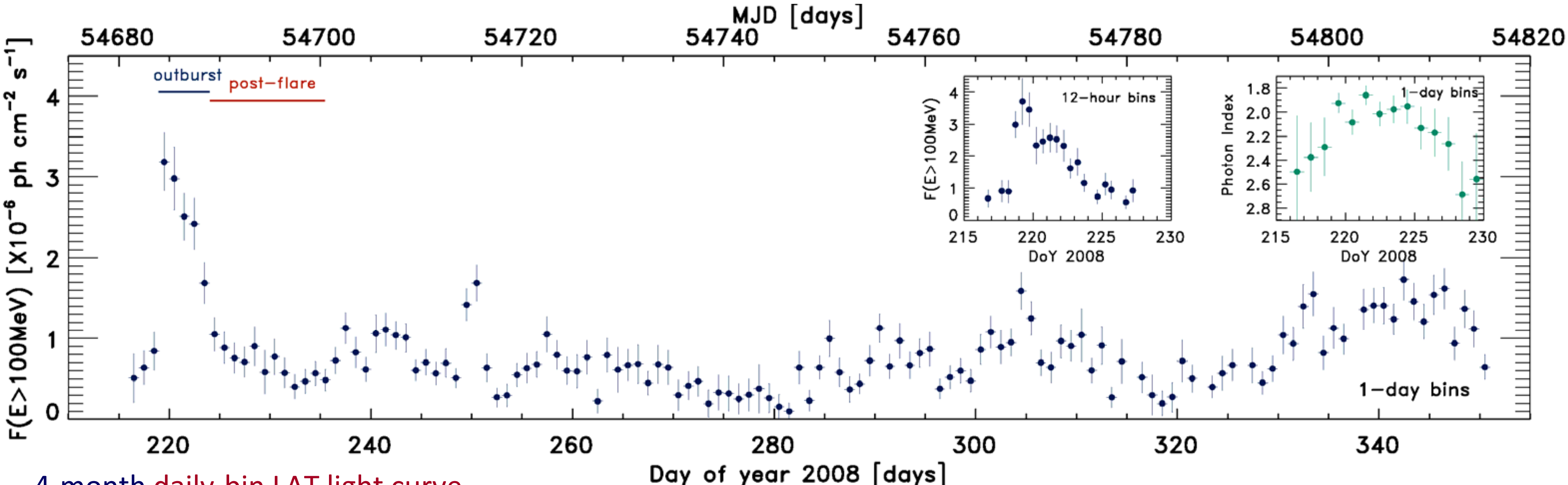




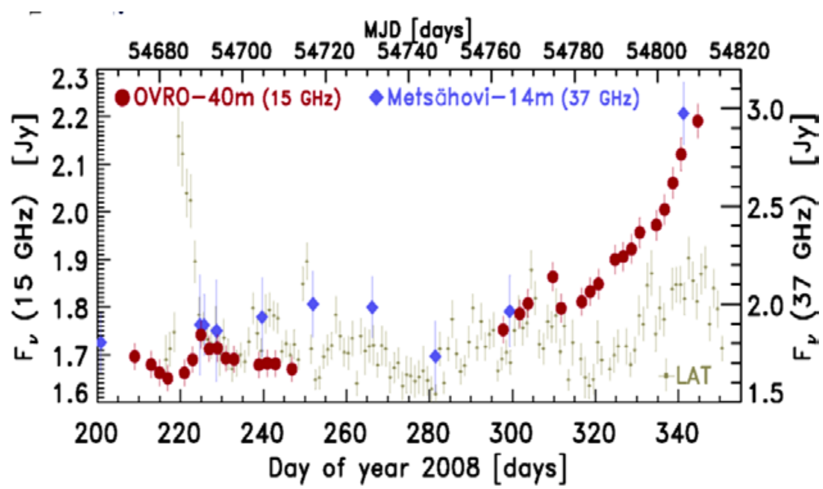
- Rather asymmetric outburst seen by the LAT
- Multifrequency localization + multifrequency correlated variability (flare) was seen.
- → Firm identification!
- → 4-days time lag between GeV and UV-optical flare peak.

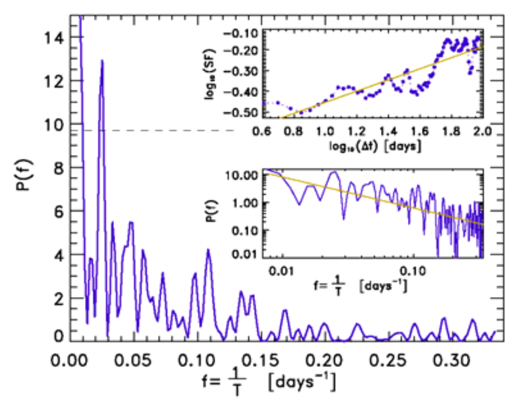


PKS 1502+106, a new and distant gamma-ray blazar in outburst discovered by Fermi LAT



- 4-month daily-bin LAT light curve obtained with no gaps after the outburst (1/f^(1.3) variability).
- Gamma-ray-radio connection well investigated: 3 MOJAVE VLBA mapping with Fermi on flight. OVRO-40m daily simultaneous monitoring at 15 GHz. Metsahovi-14m weekly monitoring at 37 GHz. Effelsberg 100m single dish and RATAN 600-ring tel., radio-mm simultaneous multi-band snapshots.

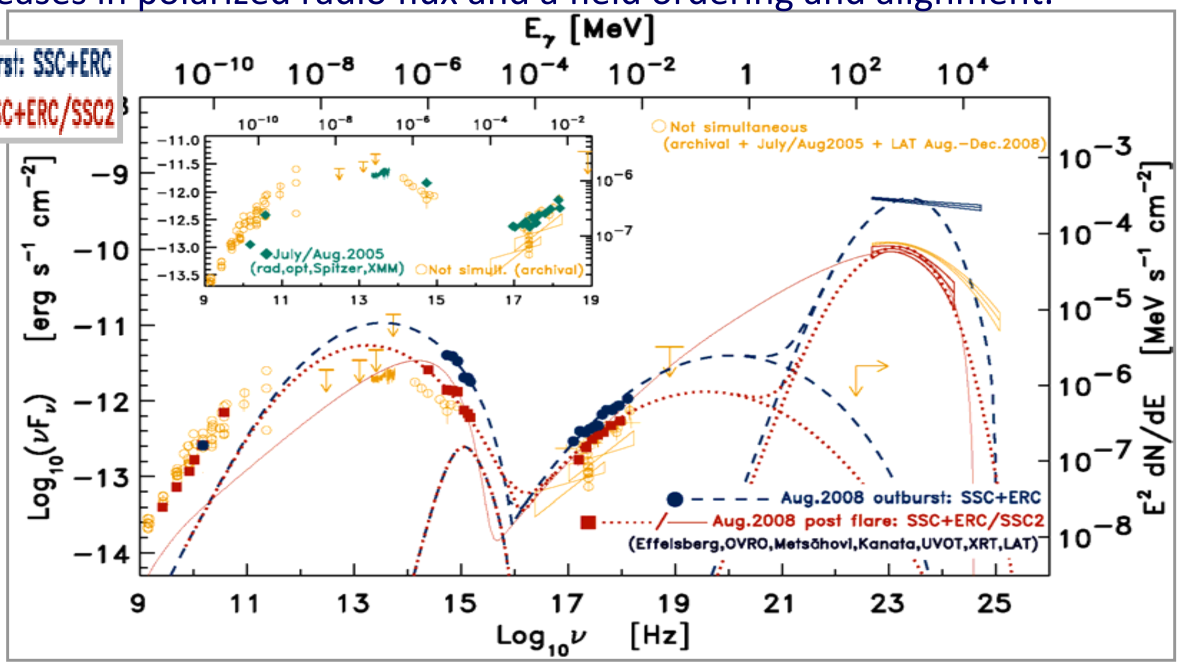


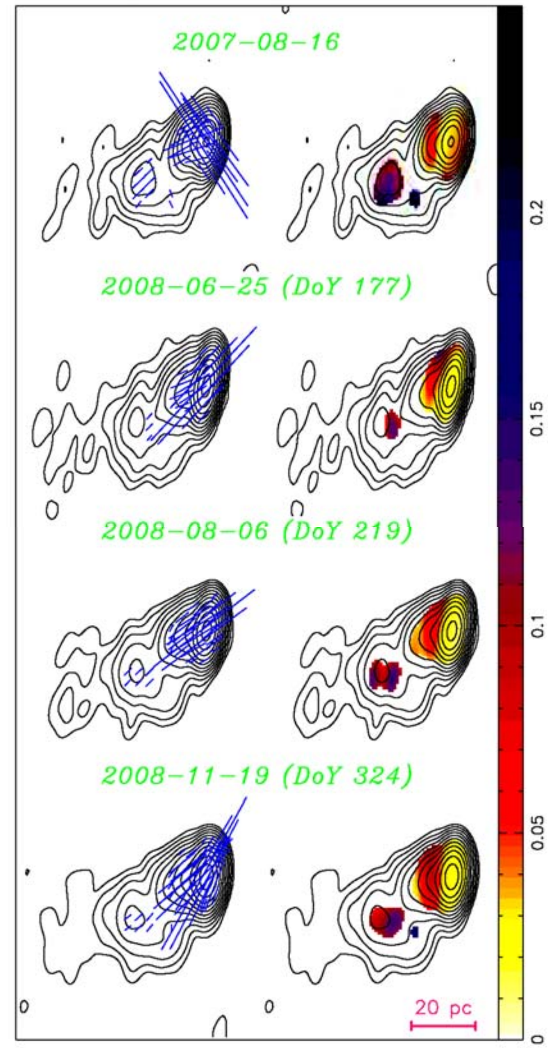


PKS 1502+106, a new and distant gamma-ray blazar in outburst discovered by Fermi LAT

- ❑ PKS 1502+106 (OR 103): a luminous gamma-ray blazar, distant (z=1.839), powerful HE-emitter (photons till 50 GeV). Huge gamma-ray dominance in the SED: → External Compton model in addiction to SSC (external-jet photon seeds).
- ❑ Bright BLR (huge intrinsic absorption) → powerful central engine (and/or jet) emission!
- ❑ Curved gamma-ray spectrum (accumulating and averaging on 4-months) and outburst characterized by a fast-rise with a slower decay, with a plateau of 2.5 days.
- ❑ Variability, modulation 1-months cycles + faster fluctuations. 1/f^(1.3) variability.
- ❑ Cross- correlation among gamma-ray, X-ray, UV, optical, near-IR observed. Hinted 4-days time lag between the gamma-ray and UV-optical emission.
- ❑ VLBI: rotation of the electric vector position angle. Flares tend to occur after the ejections of superluminal radio knots and outburst in the VLBI core, with accompanying increases in polarized radio flux and a field ordering and alignment.

Time resolved SED (outburst epoch + post outrburst epoch)

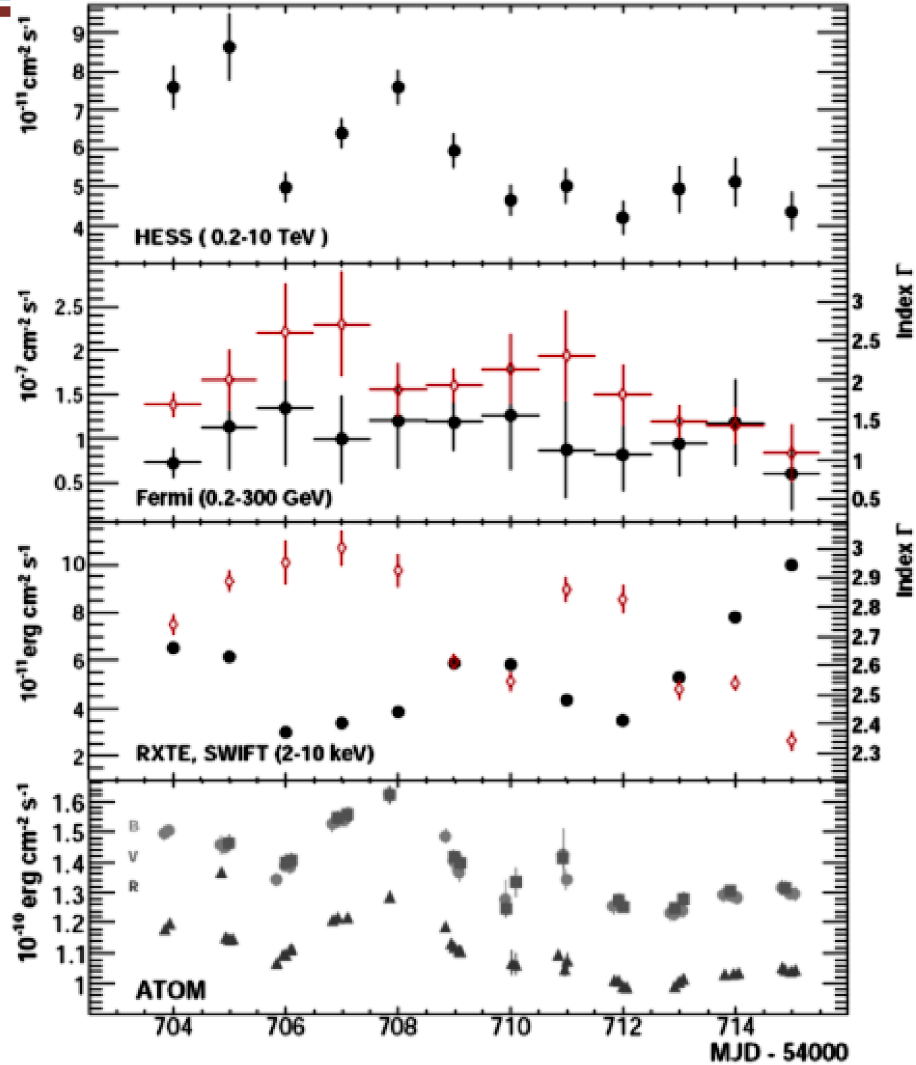


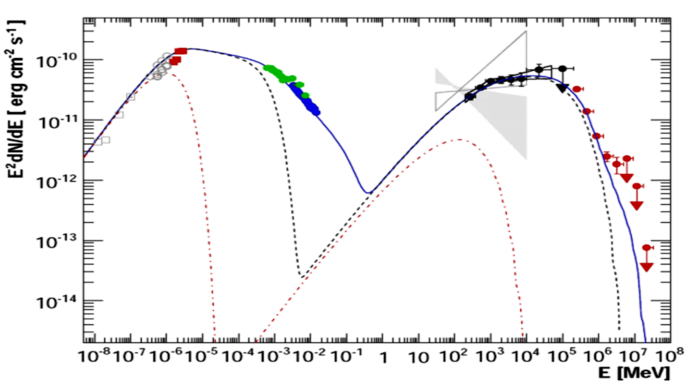


stefano.ciprini@asdc.asi.it – ASDC Roma

PKS 2155-304: Fermi-HESS MW campaign (Fermi, HESS, ATOM, RXTE Swift)

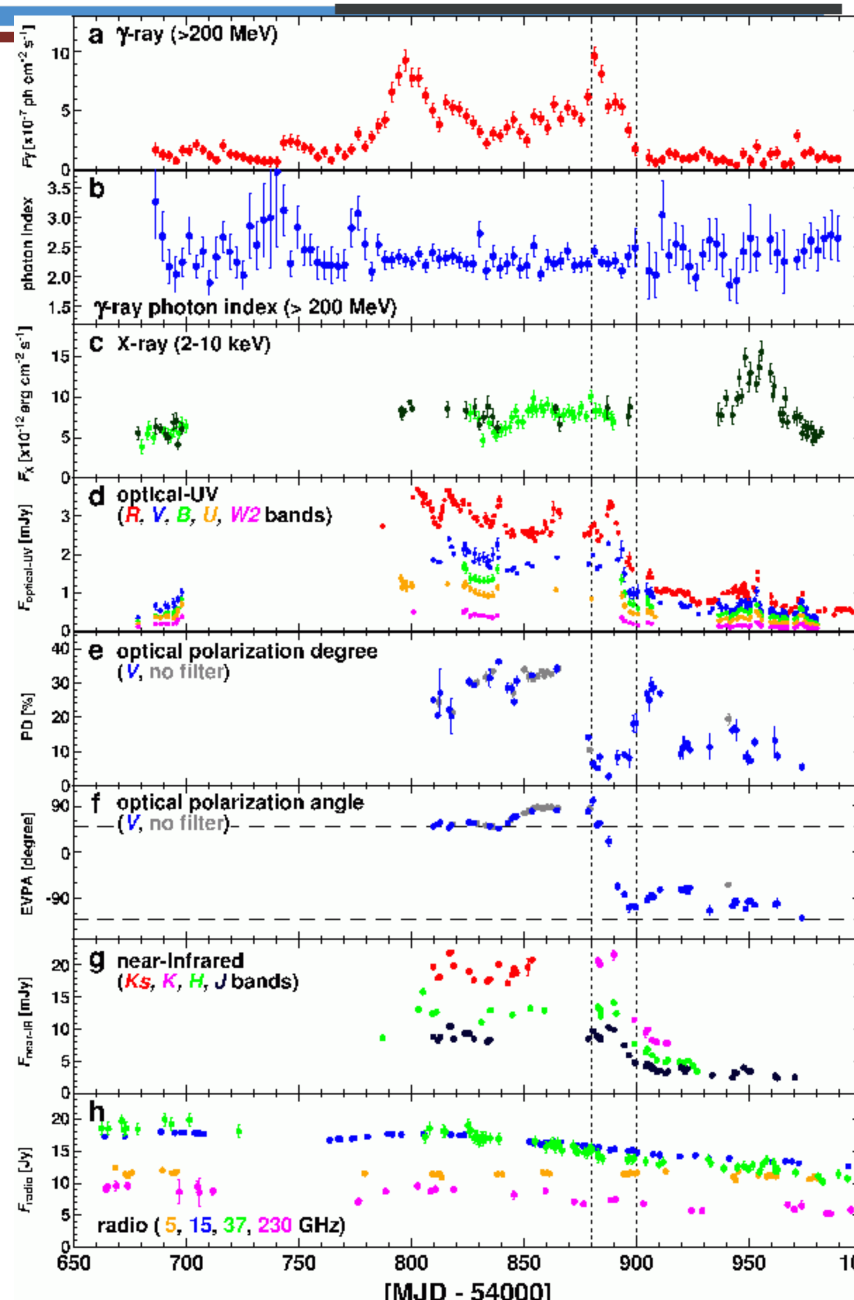
- X-ray and VHE fluxes are not correlated, in contrast to July 2006 flare
- Lack of spectral variability in HESS band ($\Delta\Gamma_{VHE} < 0.2$) $\rightarrow$ weak radiative cooling regime
- Signifcant spectral variability in X-rays ($\Delta\Gamma_X \sim 0.5$) $\rightarrow$ strong cooling regime
  - $\Rightarrow$ Electrons producing the X-rays have higher energies than those producing the TeV.
- Optical and VHE fluxes are correlated
  - Optical is driving the TeV variability
- Lack of opt-GeV correlation
- X-ray flux and HE photon index are correlated
- Multizone SSC models are required.





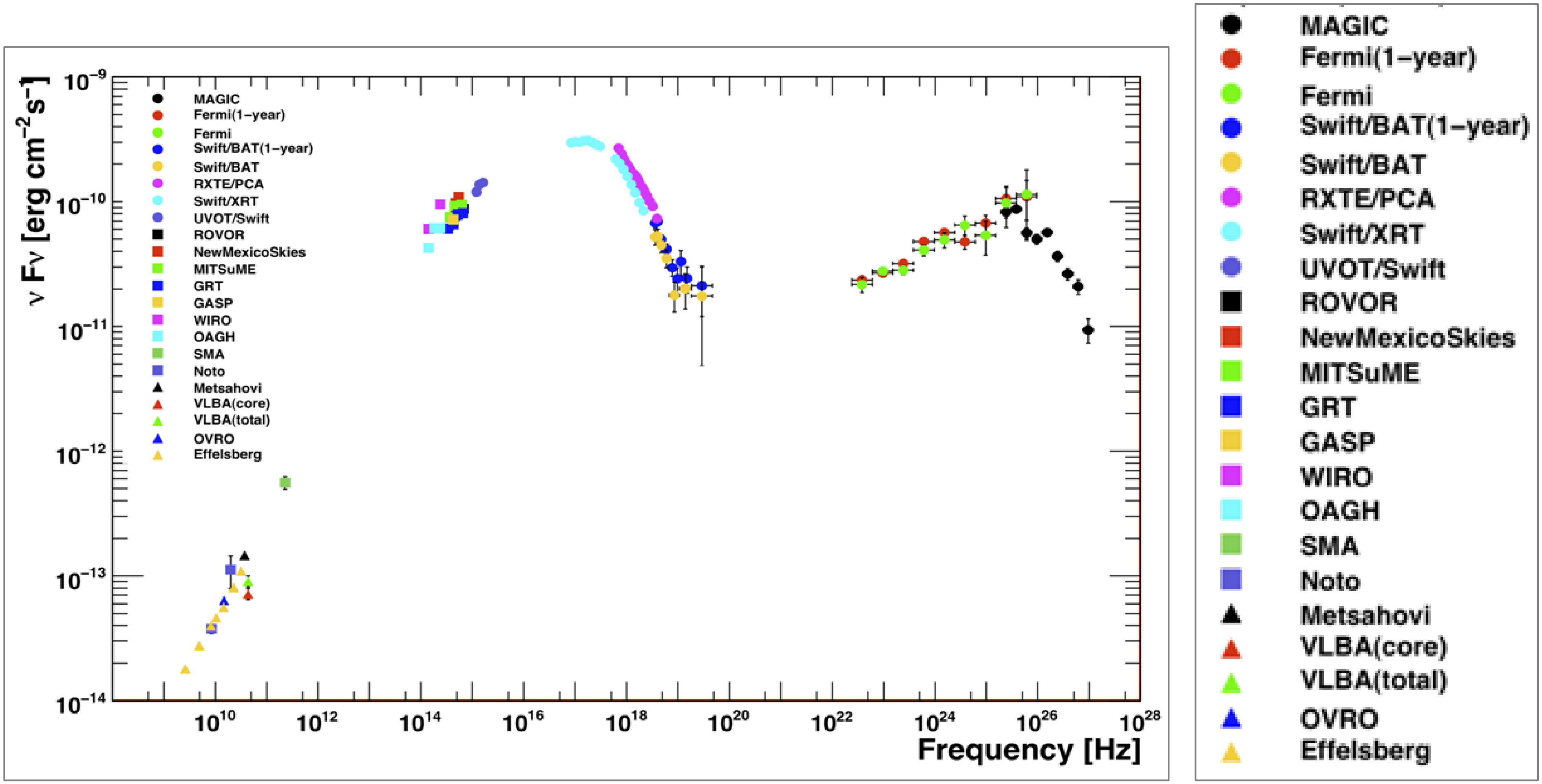
Multi-wavelength campaign on 3C 279

- Bright FSRQ, z=0.536
- Intensive Multiwavelength Campaign~300 d
- Coincidence of γ-ray flare and change in optical polarization (KANATA)
- Drop from 30% to 5%
- EVPA changes by 208°
- Orphan X-ray flare detected
- Polarization event lasts 20 days
- Co-spatiality of γ-ray and optical emissions
- Non-axisymmetric structure of the emission zone
- Curved trajectory along the jet
- $r_{event} > 10^5$ Schwarzschild radii



MW campaign on Mrk421

- 4.5 months long (Jan 20th – June 1st , 2009)
- ~20 instruments participated covering frequencies from radio to TeV
- 2-day sampling at at optical/X-ray and TeV (when possible: breaks due to moon, weather…)

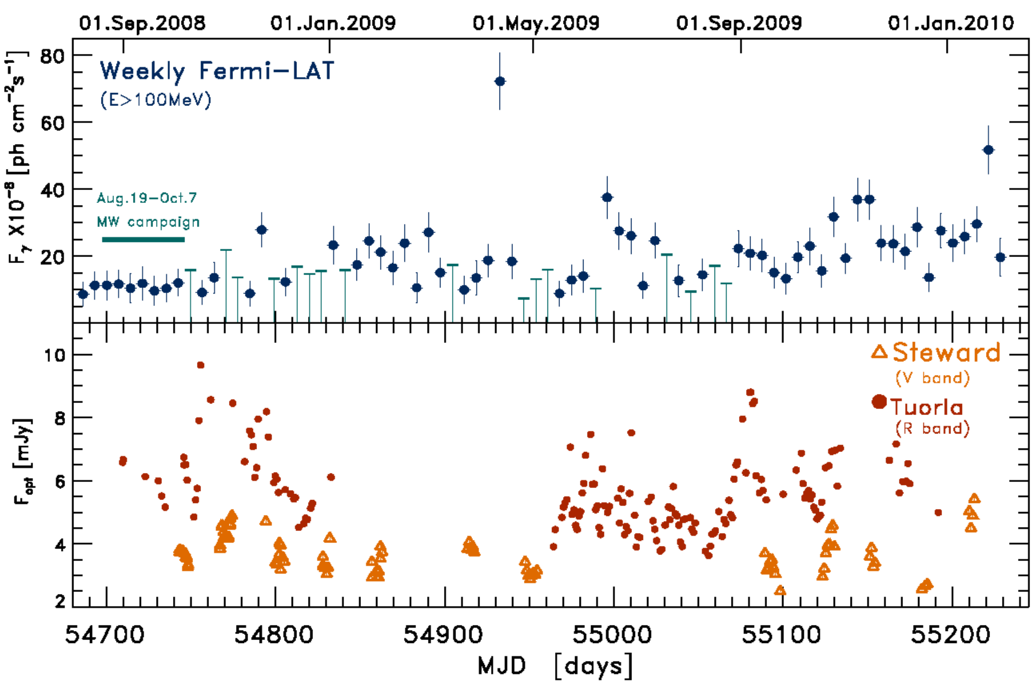


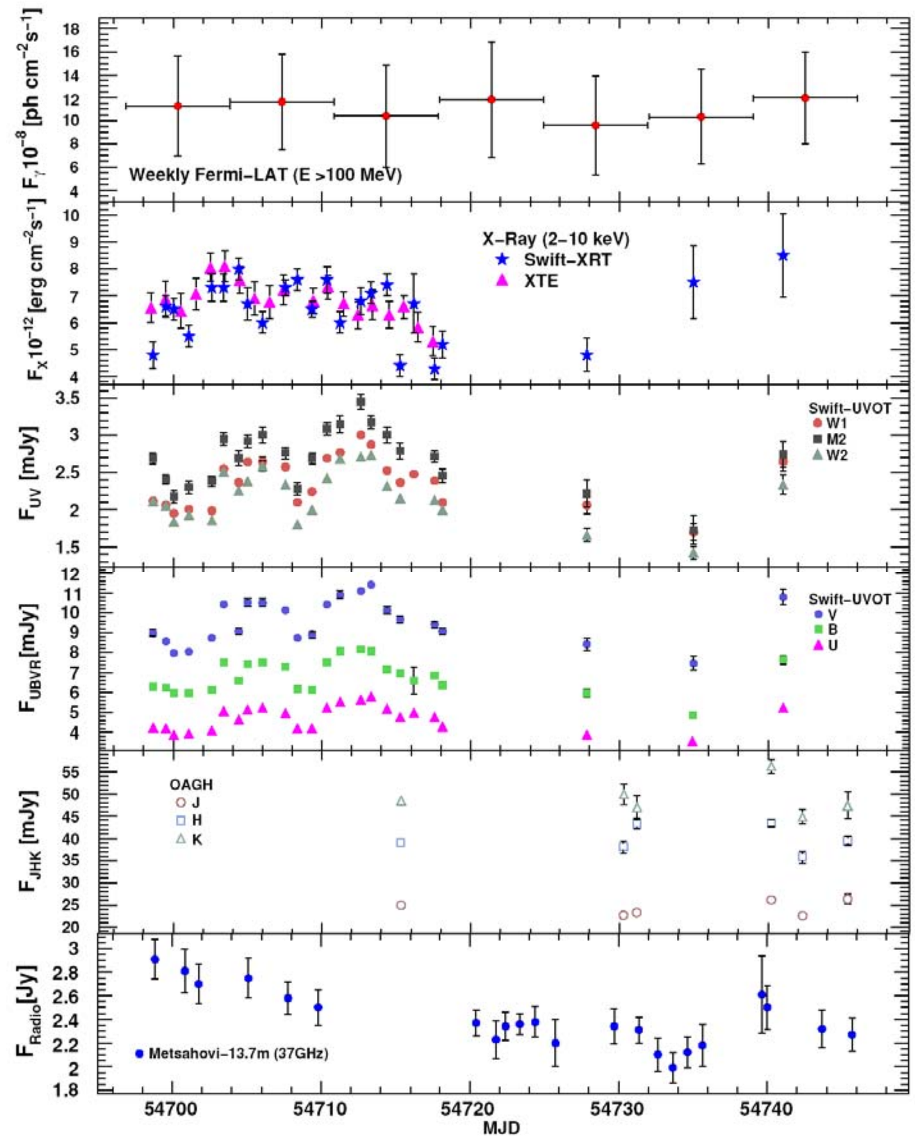
Most complete SED collected for Mrk421 until now
First time that the high energy bump is resolved without gaps from 0.1 GeV to almost 10 TeV

BL Lacertae, characterizing the low-activity state of the eponymous blazar

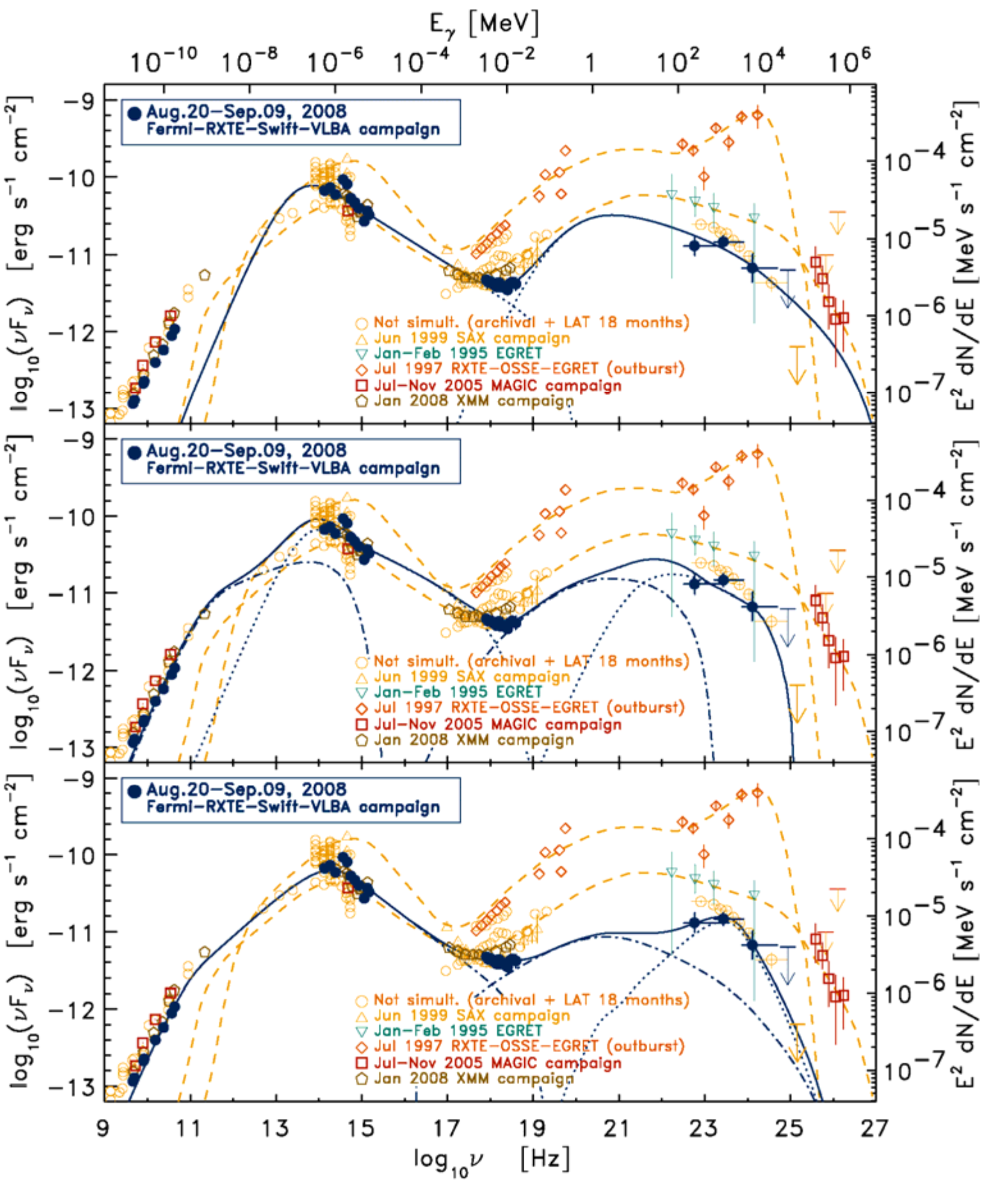
BL Lac Coordinated Multifrequency Campaign (PIC) and Long-term Monitoring Observations

PIC (48 days) Instrument	Energy Range	2008 Epoch Range	No. of Observations
VLBA	4.6–43.2 GHz	Sep 2	7
Metsähovi	37 GHz	Aug 20–Oct 6	22
OAGH	*JHK*	Sep 6–Oct 6	18
MDM	*UBVRI*	Oct 6–10	15
Swift-UVOT	*W2 M2 W1 UBV*	Aug 20–Oct 2	141
Swift-XRT	0.4–8 KeV	Aug 20–Sep 18	24
RXTE-PCA	3–18 KeV	Aug 20–Sep 8	19
Fermi-LAT	100 MeV–100 GeV	Aug 19–Oct 7	48 days
18 months Instrument	**Energy Range**	**EpochRange (MJD)**	**No. of Observations**
Tuorla	*R*	54709.8–55191.8	162
Steward	*V*	54743.2–55213.1	89
Fermi-LAT	100 MeV–100 GeV	54682.7–55070	78 weeks



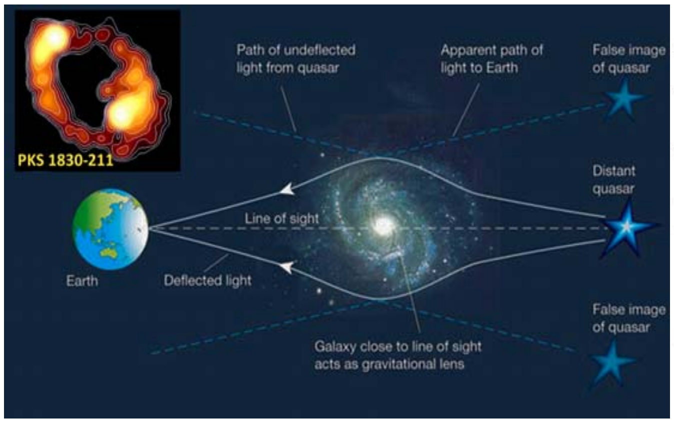


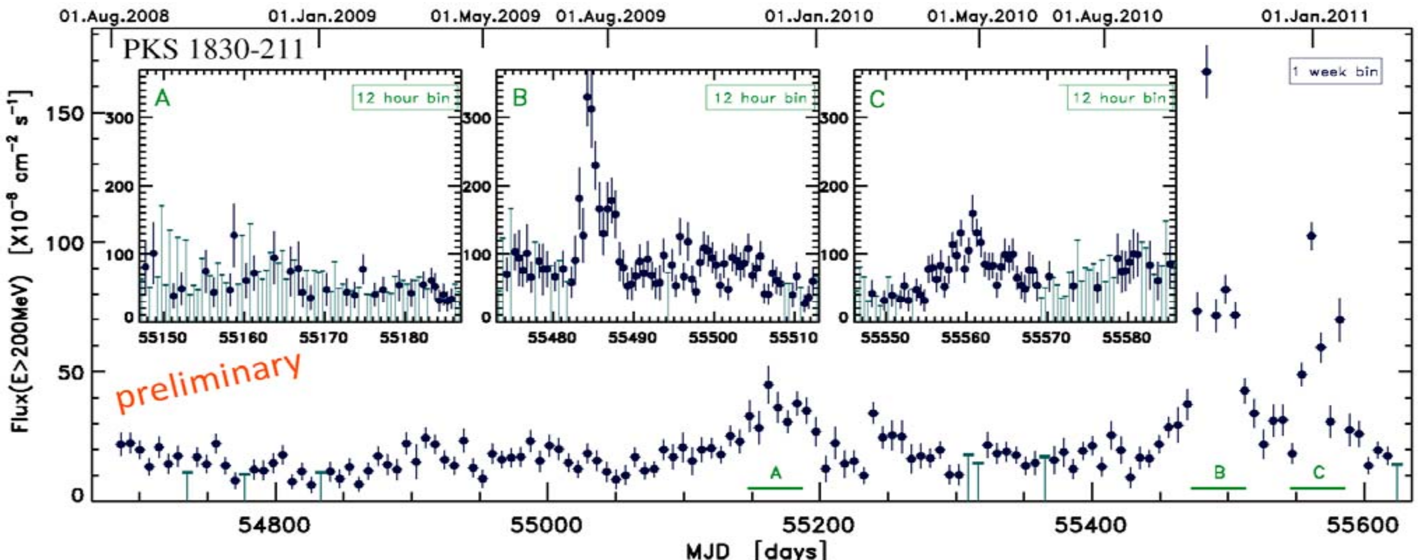
BL Lacertae, characterizing the low-activity state of the eponymous blazar



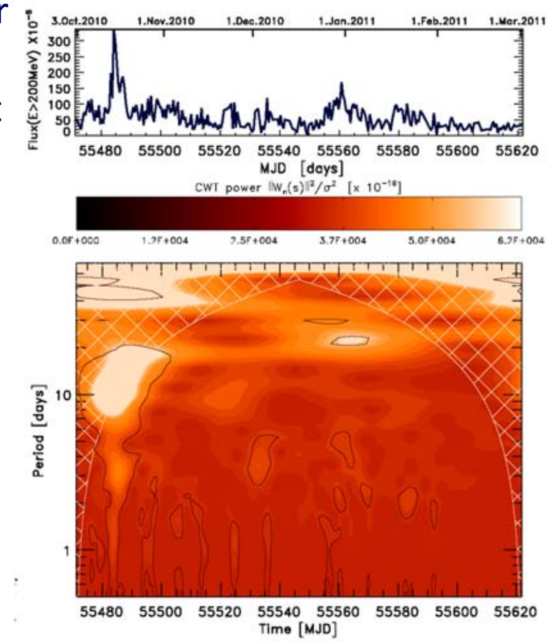
- Gamma-ray flux factor 20 lower than the 1997 EGRET outburst. A significant shift toward lower energies (maximum photon energy detected in 18-months is about 20 GeV) preventing detection by ground-based TeV telescopes. This was a TeV (MAGIC) detected source.
- 48-day MW campaign. Lowest observed gamma-ray luminosity state not corresponding to the the lowest luminosity state in near-IR-optical emission.
- No gamma-ray variability seen and uncorrelated variable UV and X-ray fluxes.
- Relatively flat (possible concave) X-ray spectrum as observed by both RXTE and Swift-XRT. (ISP-class signature).
- Both single zone two proscess (SSC plus ERC) model and single process SSC over two zones can represent the averaged radio-to-gamma-ray SED during the campaign. Parameters in with values calculated by the VLBA simultaneous snapshot.
- 2 innermost components resolved by the VLBA to the radio emission at 43 GHz.
- Our analysis does not ruled out a possible UV excess also during this low-activity, non-variable, gamma-ray state.

PKS 1830-211, a gamma-ray loud, distant, absorbed, and gravitationally lensed blazar



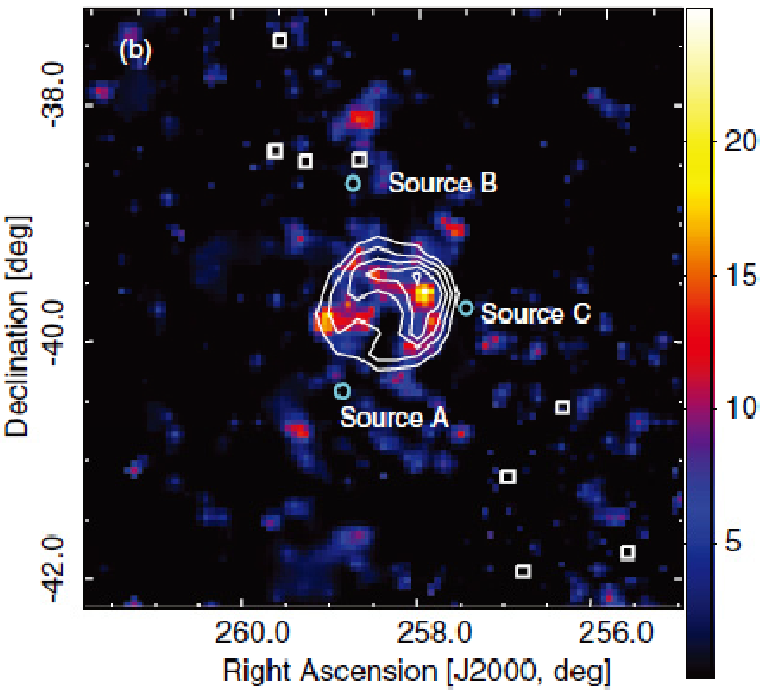


- ❑ Intense gamma-ray outburst from the blazar PKS 1830-211 (z =2.507) in October 2010, followed by high activity and other flares. Variability analysis still ongoing.
- ❑ A gravitationally lensed, highly dust-absorbed and reddened (by our Galaxy) flat spectrum radio quasar, peaked at MeV energy band.
- ❑ Analysis of 3-year Fermi LAT observations and simultaneous Swift observations (ToO during the LAT outburst) between Oct. 15 and 24, 2010.
- ❑ Swift-UVOT: only upper limits. Swift-XRT: no sign of a simultaneous X-ray flare. 0.3-10 KeV flux rather stable → Uncorrelated daily flux (but low count rate).
- ❑ No evident sign of echo gamma-ray flares caused by the lens.
- ❑ External-Compton (where seeds photons are from dusty torus) can fit the collected SED data. X-rays data are very similar to what was seen by Chandra in 2005 while gamma-rays are flaring → X-rays can origin from a different region or radiation mechanism.

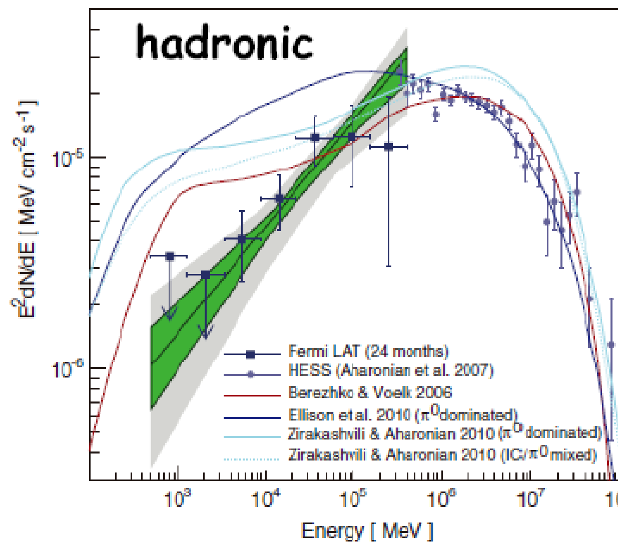


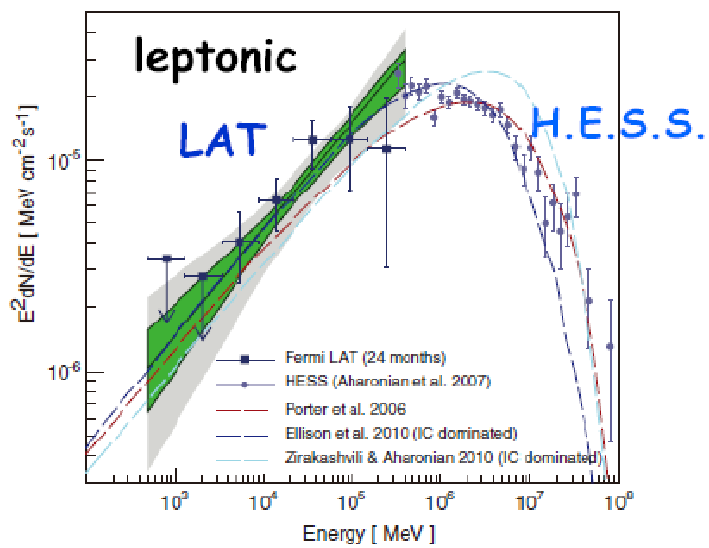
RXJ1713.7-3946

- GeV γ-ray excess above diffuse emission correlates with TeV γs
- Broadband spectrum favors leptonic origin as the emission mechanism



Abdo+11, ApJ 734:28





Fermi LAT achievements during the 1st year

- ❑Detected the moon and the quiet Sun (solar disk and extended emission)
- ❑Detected 46 high confident pulsars: 16 Gamma ray selected; 24 discovery through radio timing solutions (8 are milliseconds PSRs); 6 EGRET Pulsars confirmed
- ❑Detected orbital variations in gamma-ray emission from the binary systems LSI +61 303 and LS 5039
- ❑Detected emission from the globular cluster 47 Tucanae
- ❑Detected pulsar wind nebulae (PWNs)
- ❑Observed extended emission from supernova renmants (SNRs)
- ❑Detected a glitch in PSR 1706-44 (first detection of a glitch in gamma-rays)
- ❑Resolved the gamma-ray emission from the LMC
- ❑Detected the radio galaxies NCG 1275 and Cen A
- ❑Detected 9 GRB >100 MeV, including detection of high energy gamma-ray detection of a short burst.
- ❑Put constrain on the speed of light excluding linear LIV models
- ❑Detected large population of gamma-ray bright AGN (mostly blazars)
- ❑determine luminosity function and contribution to the unresolved extragalactic diffuse emission.
- ❑Detected spectral differences between FSRQ and BL Lac populations
- ❑Many flares and new gamma-ray blazar discovered (never seen in the GeV range). A few radiogalaxies detected. Several wide multifrequency campaigns planned and completed. Flare advocate activity is performing well.
- ❑HE synergy between Fermi and Swift and among Fermi and TeV telescopes demonstrated. Radio-gamma-ray connection promising.
- ❑Measured the high energy spectrum of the diffuse Galactic emission
- ❑does NOT confirm the GeV excess seen by EGRET (nailing down the diffuse galactic GeV emission)
- ❑Measured the e-e+ spectrum from 20 GeV to 1 TeV
- ❑does NOT confirm the excess seen by ATIC.

Gamma-ray light curves of Fermi-detected blazars

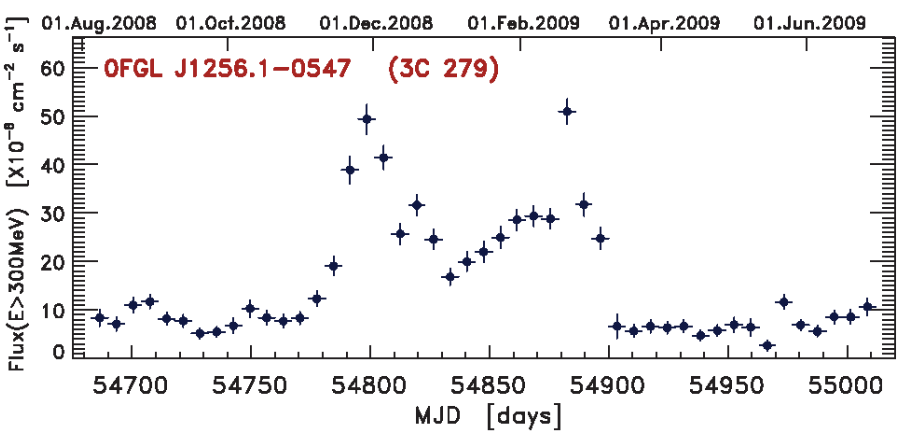
❑ The first dataset of Fermi AGN/blazar light curves: → sample: Fermi LAT 3-month high confidence list of blazars (LBAS, 106 AGN/blazars); → 11 months of all-sky survey observations; → integral photon fluxes (E>300 MeV); → weekly timebins for all (and 3-/4-day bins for the 15 brightest one).

❑ For the first time a consistent and homogeneous sample of MeV-GeV gamma-ray light curves of AGN/blazars is presented.

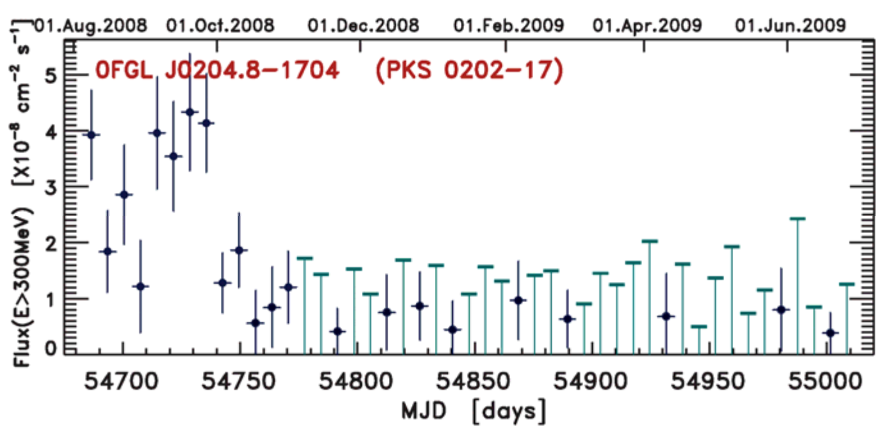
❑ A first systematic outlook and characterization of gamma-ray blazar variability. This was preparatory for deeper analyses through improved sampling (fixed/adaptive time binning) and longer baseline (3-year of all-sky survey now) on single bright sources and specific sub-samples.

❑ On the basis of the chi^2 test and excess variance, variability was detected in 68 over 106 high-confidence Fermi-detected blazars of the LBAS sample.

❑ Variability amplitude of low synchrotron frequency peaked (LSP) blazars tends to be generally larger than for the intermediate/high synchrotron frequency peaked (ISP/HSP) blazars.

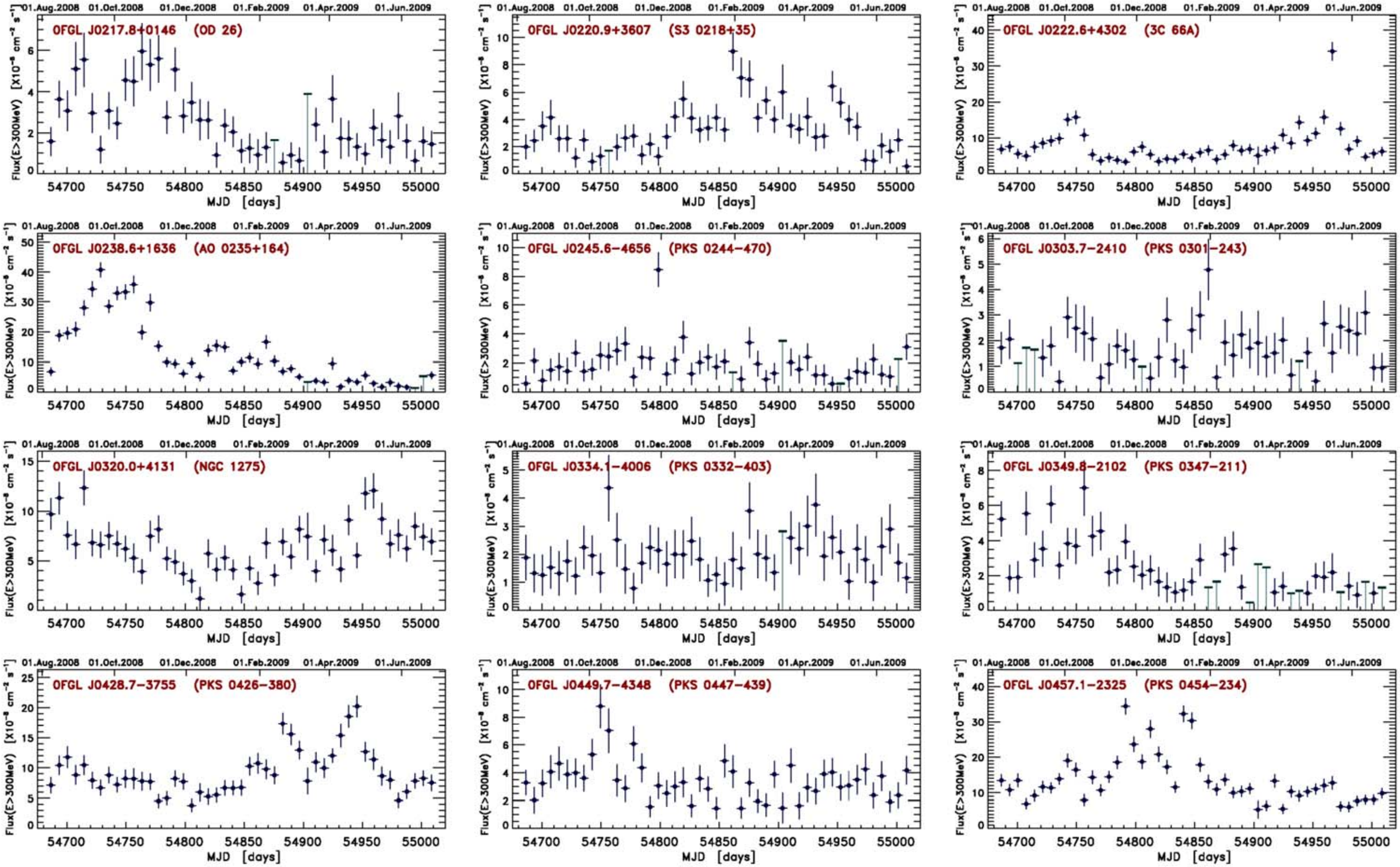


One of the best light curves obtained.



One of worst light curves obtained.

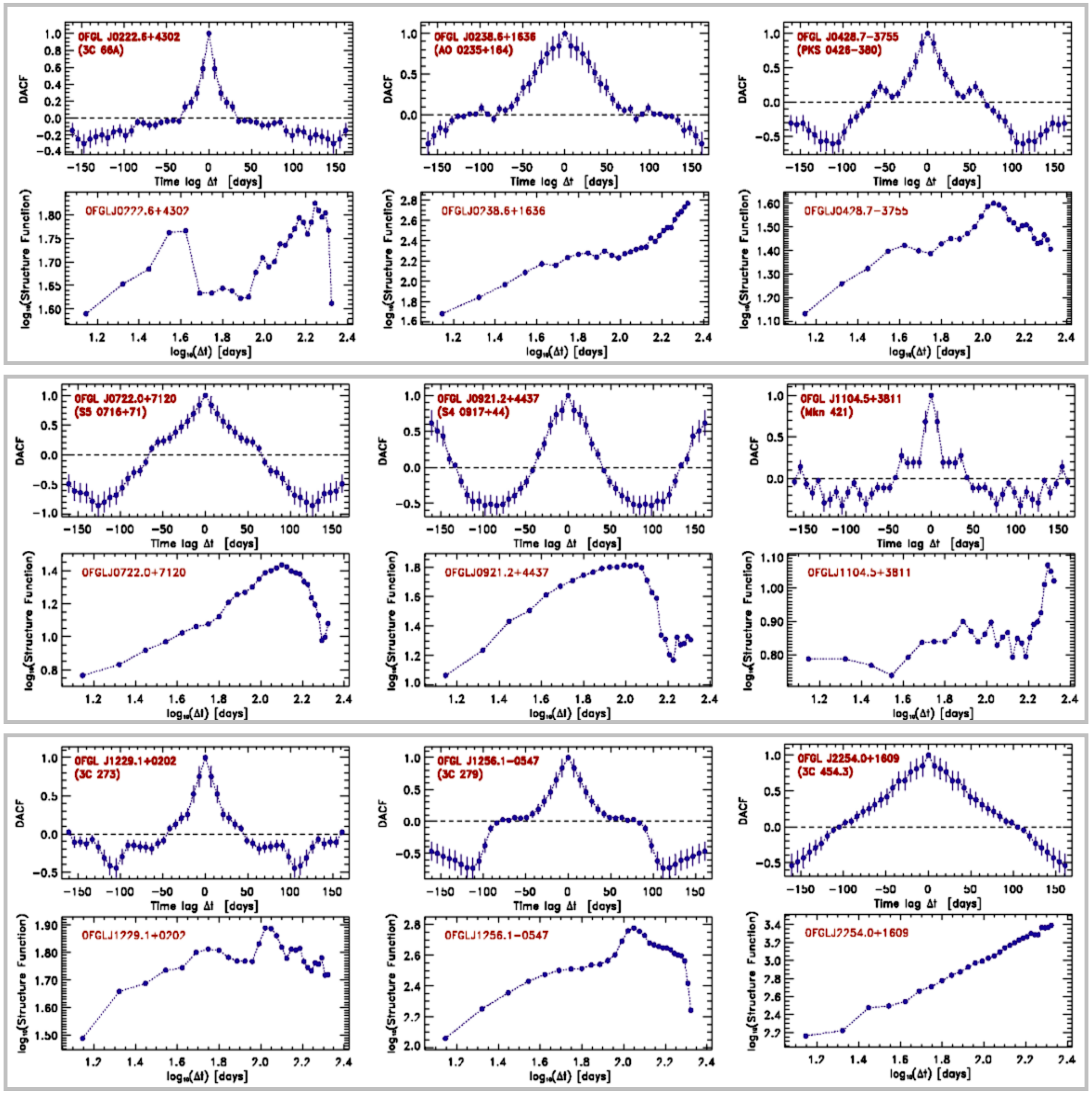
Other examples (1-week bin, first 11 months of survey)



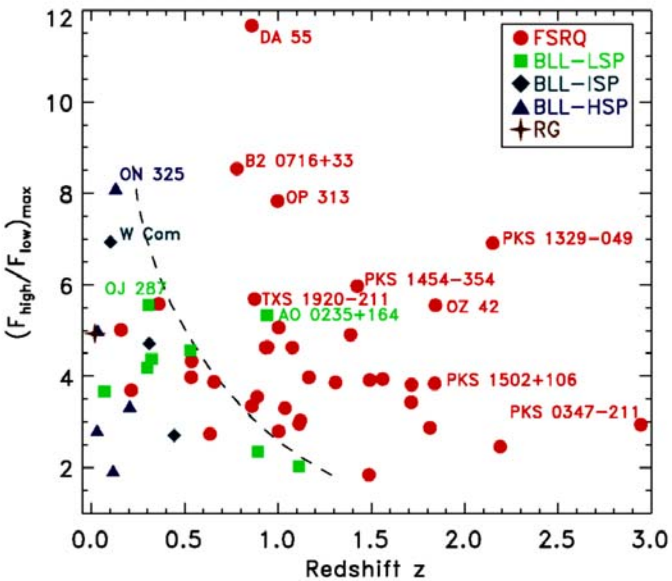
SF and DACF of weekly LAT blazar light curves

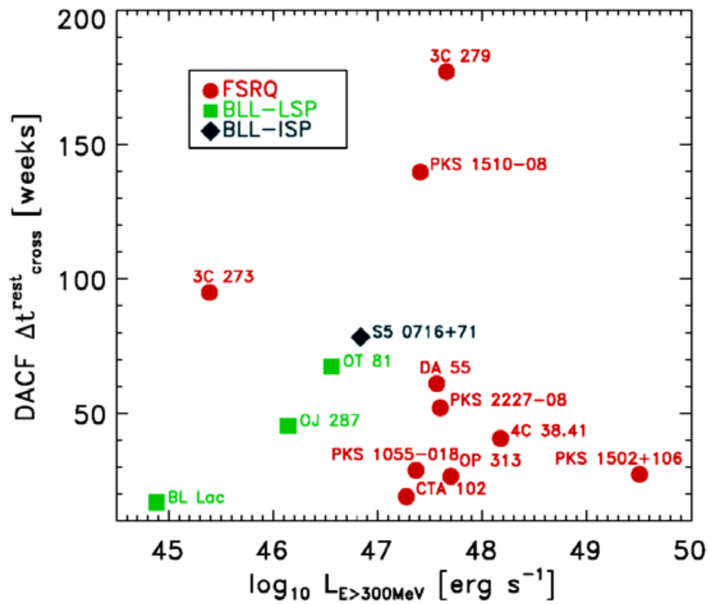
- ❑ 84 best light curves analyzed. Evenly sampled LCs (true UL taken into account as value below the sensitivity, and TS>4 fluxes).
- ❑ Discrete Auto Correlation Function (DACF) and first-order Structure Function (SF) (global methods like the PDS), show different autocorrelation patterns, zero lag peak amplitudes, temporal trends/slopes
- ❑ Different variability modes/flavours (more flicker-dominated or more shot-noise dominated).
- ❑ Distributions peaks around alpha 1.1-1.6 range, in agreement with some studies and PDS evaluated from optical light curves samples.
- ❑ Synchrotron Self Compton model dominated variability at these timescales (> 1week) and MeV-GeV energies?

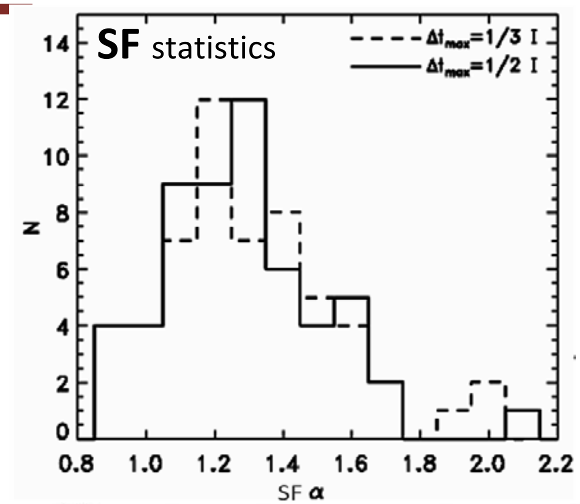
Long-term optical monitoring of blazars is very useful for cross-correlation studies during the current Fermi era.

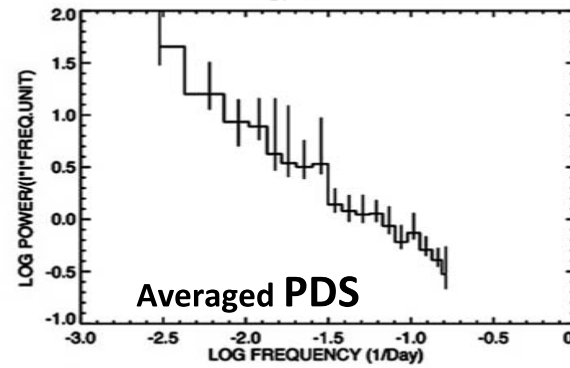


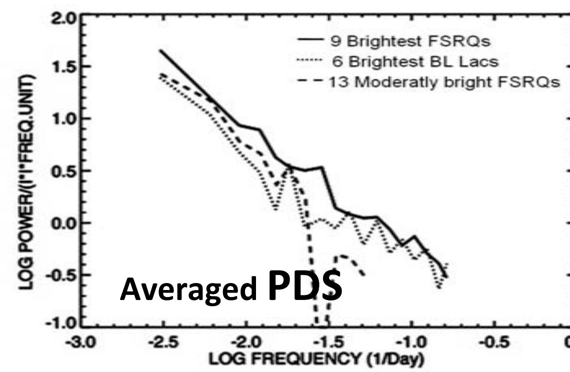
SF, DACF, PDS of LAT blazar light curves











- ❑ Very Brownian variability (more power is observed on long term time scales / lower frequencies) for blazars like 3C 434.3, and AO 0235+164, for example.
- ❑ No hint for periodicity found in any source.
- ❑ Distribution of the PDS indexes evaluated with the SF is peaked for values between about 1.1 and 1.6.
- ❑ DACF zero crossing (autocorrelation) times in rest (comoving) frame versus the total apparent gamma-ray isotropic luminosity in the rest frame, points out that some BL Lac objects can have intrinsic correlation timescales similar to Flat Spectrum Radio Quasars, even being not so powerful.
- ❑ Direct PDS calculation (averaging many sources and correcting for variability > Nyquist freq. through simulations) point out similar average index for BL Lacs and FSRQs populagtions: 1.5+/-0.2 (again halfway between flickering and Brownian noise).

Flare pulse fitting of Lat blazar light curves

- ❑ Blazars light curves (3-day/4-day bin), fitted with a phenomenological function defined as the sum of two exponential terms

$$F(t) = F_b + F_0\left(e^{\frac{t_0 - t}{T_r}} + e^{\frac{t - t_0}{T_d}}\right)^{-1}$$

where T_r and T_d is rise and decay time

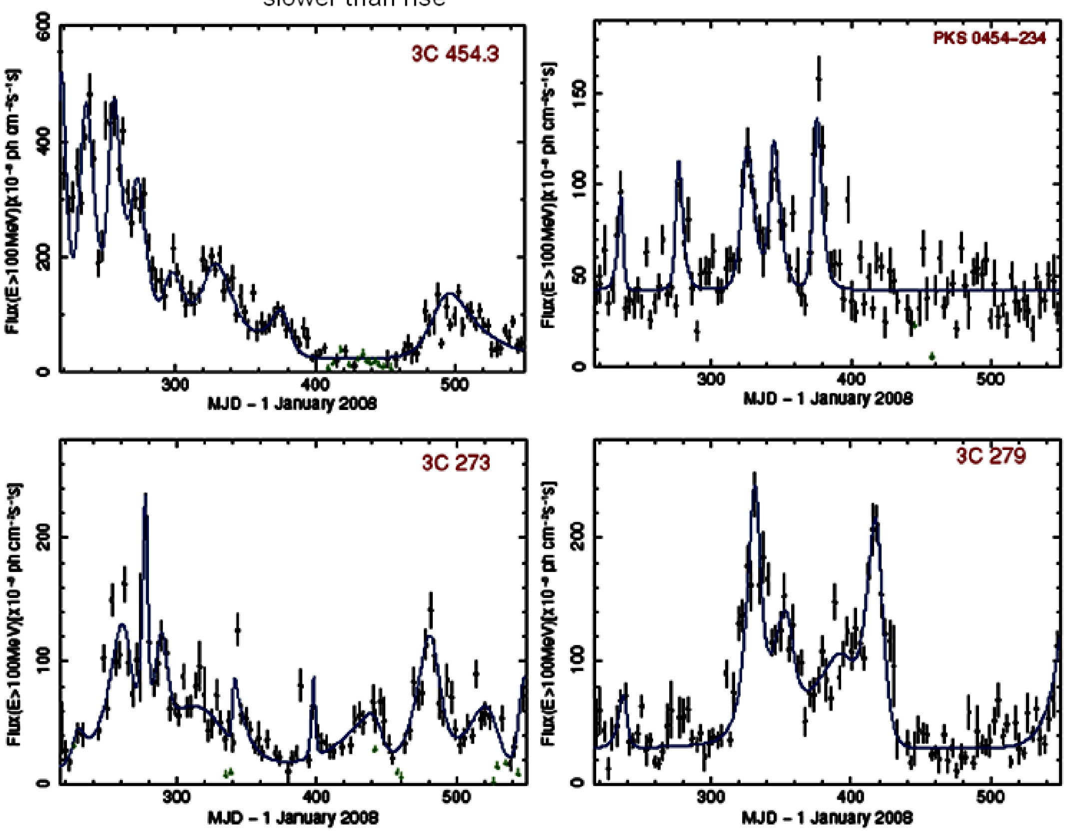
- ❑ Two parameters which describe the flares characteristics

$$\xi = \frac{T_d + T_r}{T_d - T_r}$$

Flare symmetry
-1 < ξ < +1
So > 0 if decay slower than rise

$$T_{fl} = 2(T_r + T_d)$$

flare length *i.e.* width at ~20% of peak flux)



- ❑ High states exceeding one fourth of the duration of entire observations window are absent.
- ❑ Most of the sources were bright over a time interval shorter than the 5% of the total range.
- ❑ Flares shapes are principally symmetric.
- ❑ Only very few flares are markedly asymmetric

- ❑ LAT blazars shows two different temporal profiles:

1) sources with a stable baseline and sporadic flaring activity (→ rare events or intermittence ?)
2) sources with a strong activity and complex and structured patterns (→ more Brownian behavior, longer timescales, flare vent superposition, different underlying physics ?)

Gamma-ray variability of Fermi-detected blazars: some conclusions

- Low gamma-ray brightness states observed too. High flux states are less than 1/4 of the light curve duration (most sources active in periods shorter than 5%).
- FSRQs and LSP/ISP BL Lac objects: the largest variations. HSP: lower variability but persistent emission (all bins detected)
- PKS 1510-08, PKS 1502+106, 3C 454.3, 3C 279, and PKS 0454-234 (all FSRQs): the brightest and most violently variable. In a few cases this was true also for BL Lac objects (3C 66A and AO 0235+164). PKS 1502+106 (OR 103), 4C 38.41 (S4 1633+38), and 3C 454.3 were also the most intrinsically gamma-ray powerful during the first 11-month of survey.
- Different DACF patterns, zero crossing times (4-13 weeks with peak at 7 weeks), SF power-law indices imply different variability modes (flicker-dominated or Brownian-dominated). 1/(f^α) trend with α mostly distributed between 1.1-1.6.
- AO 0235+164 and 3C 454.3 fully Brownian. Other powerful gamma-ray sources half-way behaviour.
- For the brightest sources (3- or 4-day bin analysis) the average PDS is described by a power law without evidence of a break. Average slopes α =1.5.
- Generally, gamma-ray PDSs have slopes similar to those obtained from long-term optical or radio light curves.
- Fermi-detected blazars: essentially steady sources with perturbations or with a series of discrete, though possibly overlapping, flares produced, for example, by traveling shock fronts. Emission might be produced in multiple regions (inhomogeneous blazar emission zone) or in an essentially homogenous region (all particles are accelerated).
- Random walk processes, such as instabilities and turbulence in the accretion flow through the disk or in the jet, can origin intermittent behavior. Stochastic processes characterized by a large number of weakly correlated elements.
- Flare temporal shapes confirm different temporal profiles: stable baseline with sporadic flaring activity or strong activity with complex and structured temporal features.
- Symmetric shapes: also explained by the superposition of a series of peaks. Marked asymmetric profile can mean fast injection of accelerated particles and a slower radiative cooling and/or escape from the active region.

III Fermi Symposium in Roma (May 2011)

Enrico Fermi and the other "ragazzi di Via Panisperna"

October 1934: discovery of artificial radioactivity induced by slow neutrons

Discovery:	**Saturday**	**20.10.34 (*)**
First paper:	**Monday**	**22.10.34**
Patent:	**Friday**	**26.10.34**

(*) A. De Gregorio : not on October 22!

O. D'Agostino E. Segrè E. Amaldi F. Rasetti E. Fermi

+ B. Pontecorvo = The boys of Via Panisperna

Il Messaggero

Data 04-05-2011
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SCIENZA Verranno presentati alla Sapienza i risultati dell'Osservatorio intitolato al premio Nobel. Una sfida anche italiana

Da Roma all'universo sotto il segno di Fermi

I risultati dell'Osservatorio Fermi (lanciato nel giugno 2008) saranno presentati a Roma nell'aula Magna dell'Università La Sapienza dove, dal 9 al 12, si terrà il Terzo Simposio Fermi. L'Osservatorio spaziale, che studia il cielo in raggi gamma, nell'ultimo anno ha già dato dei risultati che sono delle primizie mondiali e ha vinto il Premio Bruno Rossi 2010 della American Astronomical Society. Ha un'impronta molto italiana: Asi, Inaf e Infn hanno infatti dato un contributo fondamentale di strumenti e scienza. Centinaia di astrofisici provenienti da tutto il mondo discuteranno il nuovo fantastico Universo svelato da Fermi. Giovedì 12, alle 18.30, sempre nell'Aula Magna della Sapienza, l'astrofisico Giovanni F. Bignami terrà una conferenza pubblica sul tema «Da Roma all'Universo: Fermi in orbita». Fermi inteso come eroe dei due mondi, dalla fisica alla astrofisica, da Roma a Chicago. La sua eredità rivive in orbita in una nuova collaborazione Italia-USA.

di GIOVANNI F. BIGNAMI

ENRICO Fermi arrivò a New York da Stoccolma

buito alla sua realizzazione. Penso che Enrico, anzi il professor Fermi, una persona notoriamente difficile da accontentare, ne sarebbe molto feli-

sieme al suo più giovane collega, Bruno Rossi. Rossi, anche lui ebreo, fuggì dal fascismo come Fermi (ed Enrico lo aspettava all'attracco della na-

di ed altri, alla nascita della scienza spaziale in Italia e in Europa.

Beppo aveva già, comunque, inviato in America il suo

Amaldi talk

III Fermi Symposium in Roma (May 2011)

“Ragazzi di Fermi”

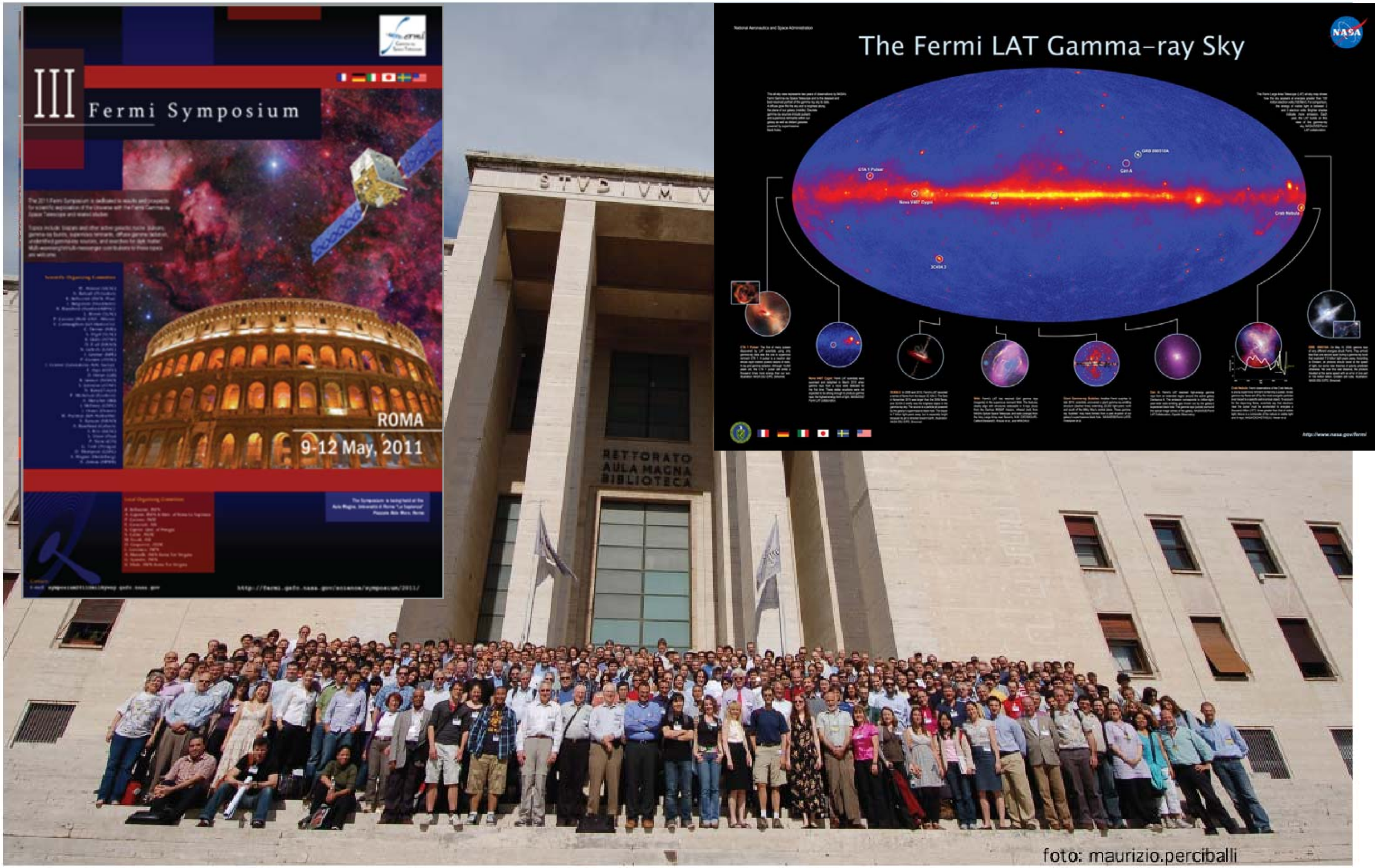


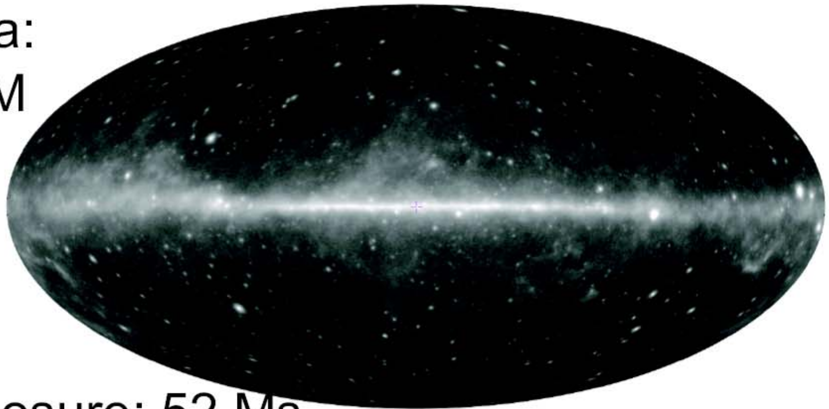
foto: maurizio.perciballi

Basic science data facts (May 2011)

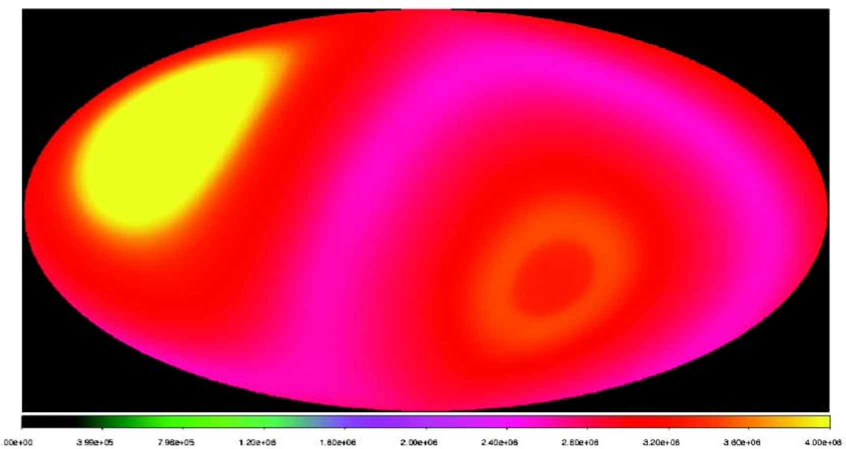
- ~170 billion LAT event triggers
- GBM Triggers: 1194 (654 GRB, 141 TGF, 174 SGR, 56 solar flare)
- # Autonomous Repoint Requests (ARR): 58
- Highest-z LAT GRB: 4.35
- Highest-energy photon from a GRB: 33 GeV (at 82s, z=1.82)
- Highest-z LAT AGN: 3.1
- # Gamma-ray pulsars: 88
  - # MSPs: 27
  - # Gamma-ray-only (blind) pulsars: 26
  - # new radio MSPs due to LAT data: 31
- Public data access: >8TB

2nd Fermi Catalog (2FGL)

Data:
28 M

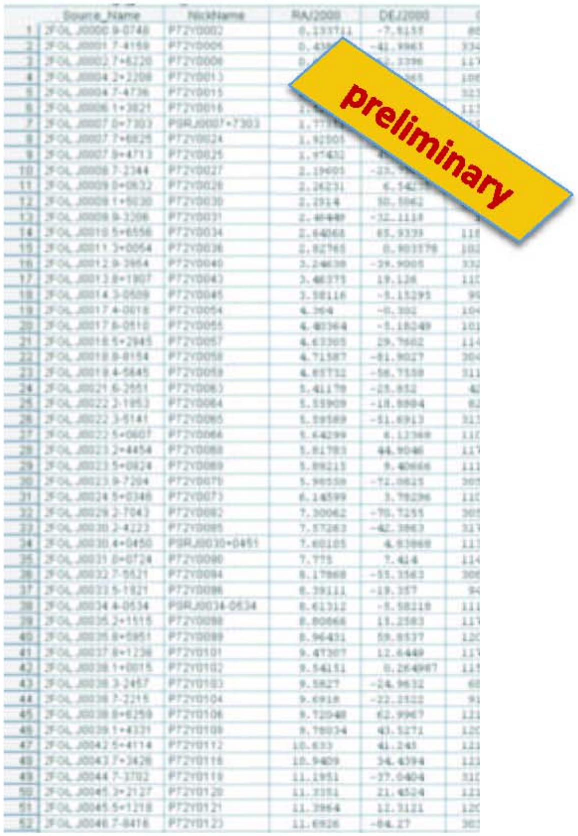


Exposure: 52 Ms



2FGL Table

1888 entries
[1FGL: 1451]



Two years (excluding 3 GRBs) NEW
“Pass7 processing” NEW

[1FGL: 11 months]

+ Light curves, SED plots, associations

2nd Fermi Catalog (2FGL)

2FGL Classifications

Type	Number	Percentage of total
Active Galactic Nuclei	832	44%
Candidate Active Galactic Nuclei	268	14%
Unassociated	594	32%
Pulsars (pulsed emission)	86	5%
Pulsars (no pulsations yet)	26	1%
Supernova Remnants/ Pulsar Wind Nebulae	60	3%
Globular Clusters	11	< 1%
Other Galaxies	7	< 1%
Binary systems	4	< 1%
TOTAL	1888	100%

Very Preliminary - Work Still In Progress

Gamma-ray bubble in our Galaxy

Fermi Bubble

So far: there appear to be a pair of giant (50 degree high) gamma-ray bubbles at 1-5 GeV, and probably up to at least 50 GeV.

What are they?

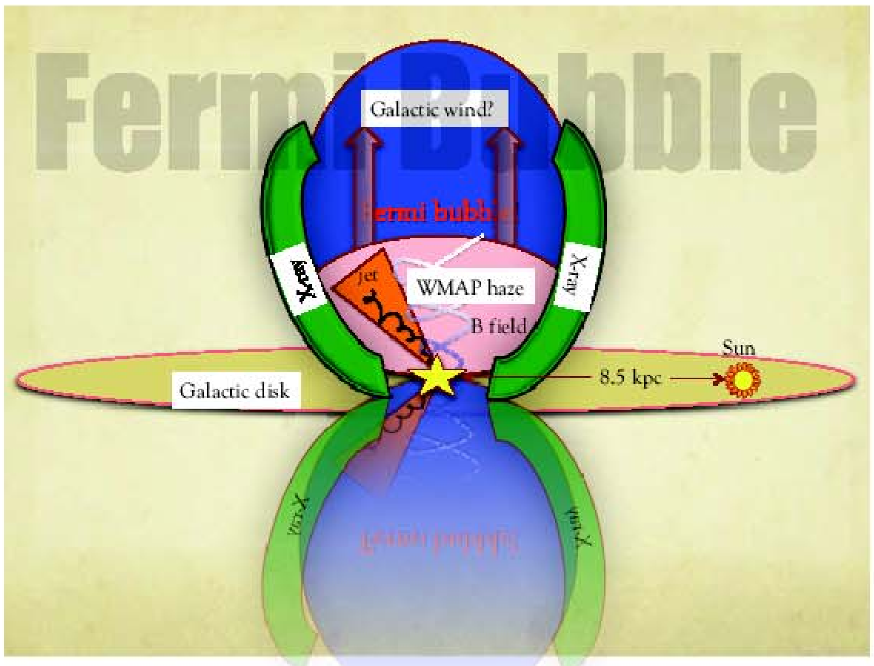
Black hole "burp"

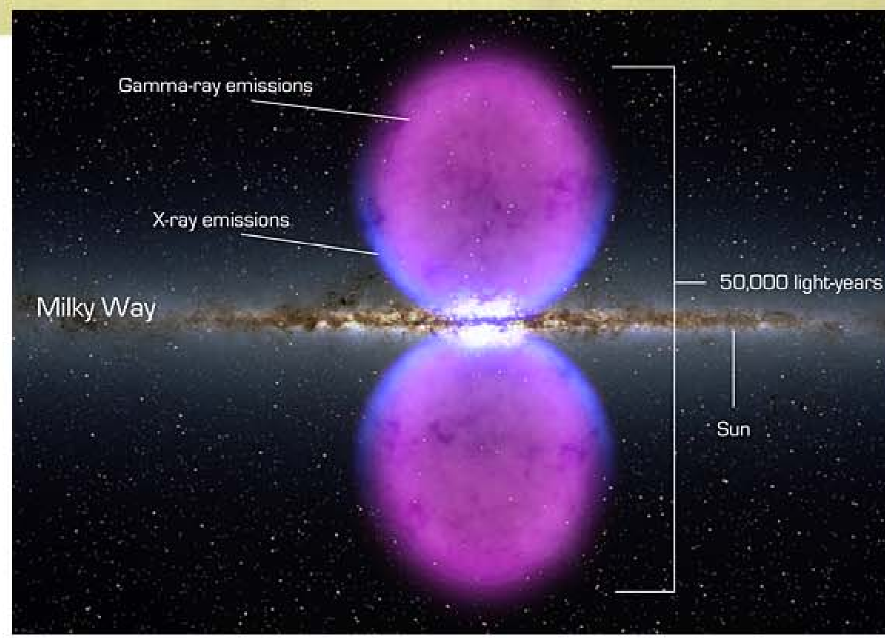
Superwind bubble?

Dark matter? (Dobler et al arXiv:1102.5095)

Fermi Bubble

- *Continue observation of Fermi*
- *XMM-Newton data coming soon*
- *The eROSITA and Planck experiments will provide improved measurements of the X-rays and microwaves, respectively, associated with the Fermi bubbles*
- *Magnetic field structure of the bubbles*
- *Study of the origin and evolution of the bubbles also has the potential to improve our understanding of recent energetic events in the inner Galaxy and the high-latitude cosmic ray population.*





The Sun in gamma-rays

The Sun is Waking Up!

SUMMARY

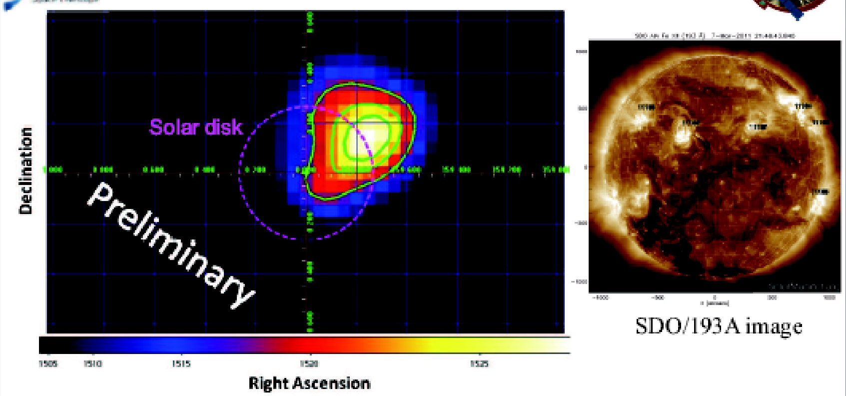
The M2-class solar flare, SOL2010-06-12T00:57, was modest in many respects yet exhibited remarkable acceleration of energetic particles.

The flare produced an ~50 s impulsive burst of hard X-and gamma-ray emission up to at least 400 MeV.

The gamma-ray line fluence from this flare was about ten times higher than that typically observed from this modest class of X-ray flare.

Analysis of the combined nuclear line and high-energy gamma-ray emissions suggests that the accelerated proton spectrum at the Sun softened from a power-law index of ~-3.2 between ~5-50 MeV, to ~-4.5 between ~50-300 MeV, to one softer than ~-4.5 >300 MeV (Preliminary).

Gamma-ray emission region



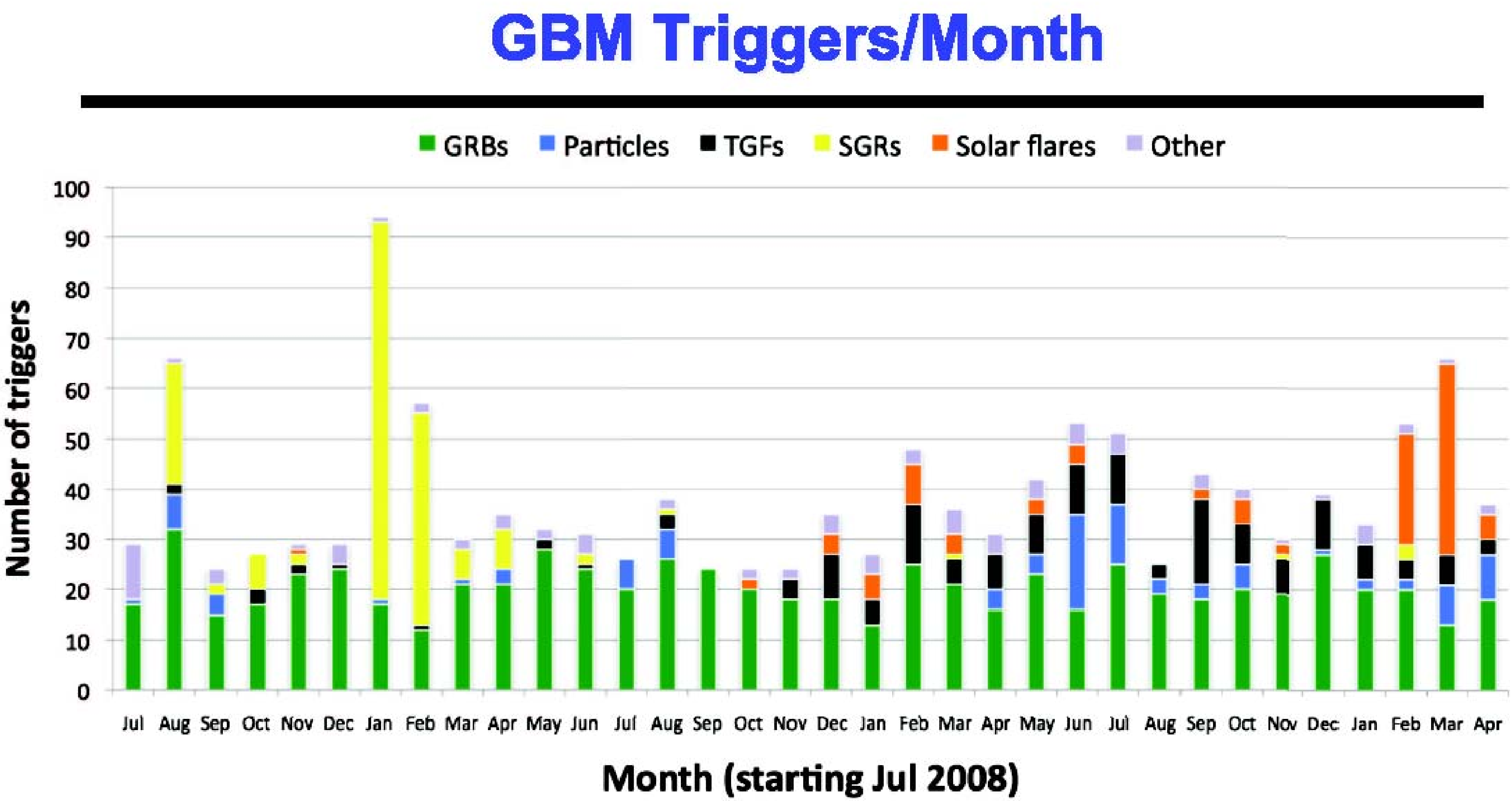
- Sigificance map (so-called TS map) was produced for the LAT data accumulated during the whole duration
- Green lines show the 1sigma, 2sigma, 3sigma contours
- The LAT HE photons came from the North-western part of the Sun, from where M3.7 flare was emitted (active region 11164)

10

Summary

- Fermi-LAT detected the longest HE emission from the Sun following the 2011 March 7 flare. The duration was ~12 hours.
- The LAT emission came from the North-West part of the Sun, from where the M3.7 flare is emitted
- The LAT spectrum showed clear turnover around 200 MeV, suggesting that pion decay is promising
- The March 7 flare is associated with a fast CME of 2200 km/s
- We considered three possible scenarios which might explain the long-lived LAT emission
- Further quantitative discussion is ongoing, and paper is now being prepared

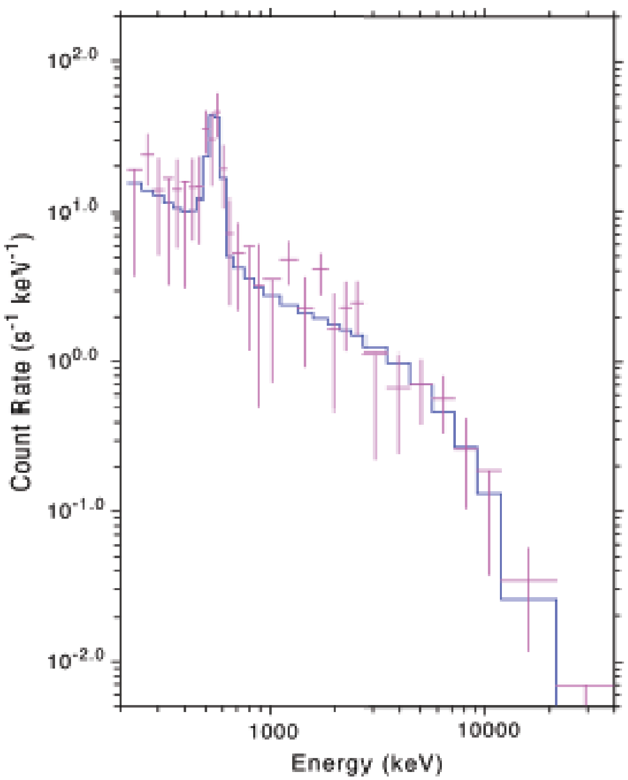
Fermi GBM triggers



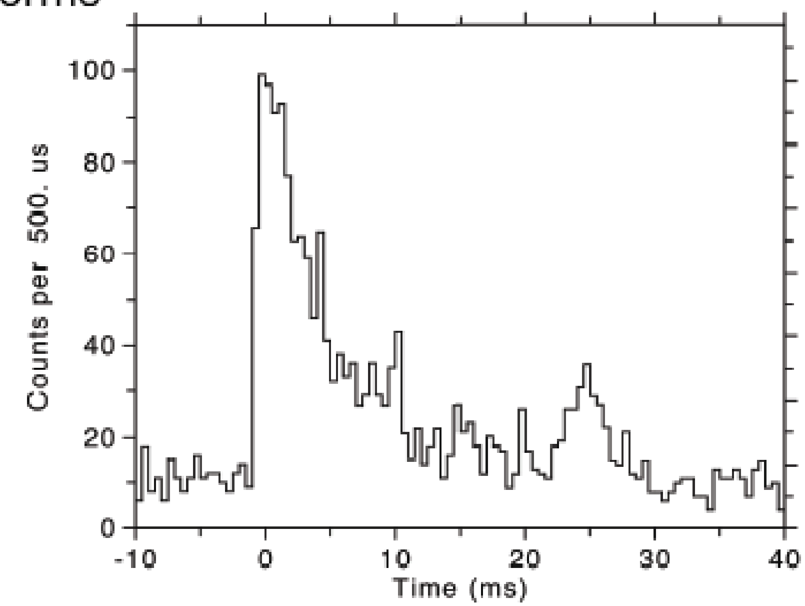
- Nov 9, 2009 - add new TGF trigger
  - TGF trigger rate increased by factor of ~10 to 1 per 3.7 days
- Feb/Mar 2011 - solar activity

Terrestrial gamma-ray flashes

Terrestrial Gamma-ray flashes

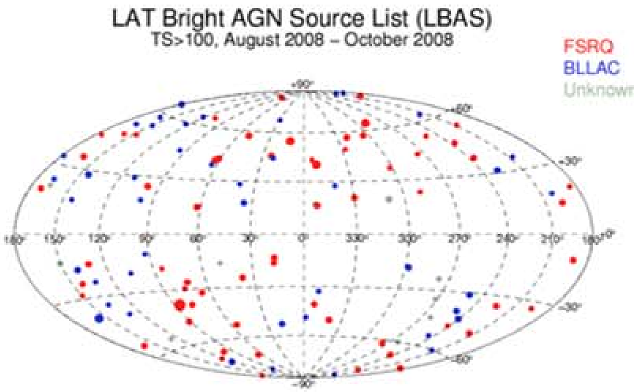


TGFs are concentrated in the tropics near thunderstorms

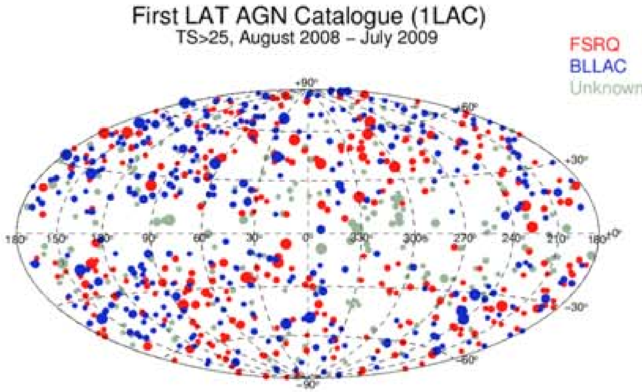


Antimatter from Thunderstorms!

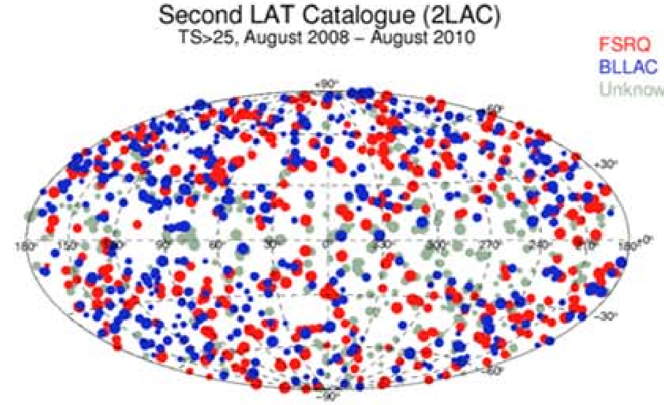
2-year LAT AGN catalogs (2LAC)



LBAS Abdo, et al. 2009, ApJ, 700, 597



1LAC Abdo, et al. 2010, ApJ, 715, 429



2LAC Abdo, et al. In preparation

	# |b|>10˚	FSRQ	BL Lac	LSP (FSRQ + BL Lac)	ISP (only BL Lac)	HSP (only BL Lac)
LBAS	106/116	58%	34%			
1LAC	523/599 (592/670)	47.4% (44.4%)	52.6% (55.6%)	59%	12%	29%
2LAC preliminary						

Caveats:

- LAT preference for hard sources -> HSP are favoured wrt LSP
- LAT selects radio sources fainter than those in radio catalogs of flat radio sources (eg. CRATES) -> many optically unclassified source (but blazar candidates) which will be targets for optical follow up.

In the 1LAC sample we had 60.8% of BL Lac without redshift.
In the 2LAC sample we are having the same proportionality.

- More correlated observations to answer "where"
- Move from "where" and characterization of sources to connect to primary goals
- 2LAC correlations
- All those gorgeous LAT light curves begging analysis!
- Breaks
- Compact region emission

Gamma-ray flaring Crab nebula

High Energy Activity from the 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)
Password Certification: Marco Tavani (tavani@iasf-roma.inaf.it)

Subjects: Pulsars
Referred to by ATel #: 2856, 2858, 2861, 2866, 2867, 2868, 2872

AGILE is detecting an increased gamma-ray flux from a source positionally consistent with the Crab Nebula.

Integrating during the period 2010-09-19 00:10 UT to 2010-09-21 00:10 UT the AGILE-GRID detected enhanced gamma-ray emission above 100 MeV from a source at Galactic coordinates (l,b) = (184.6, -6.0) +/- 0.4 (stat.) +/- 0.1 (syst.) deg, and flux F > 500 e-8 ph/cm2/sec above 100 MeV, corresponding to an excess with significance above 4.4 sigma with respect to the average flux from the Crab nebula (F = (220 +/- 15)e-8 ph/cm^2/sec, Pittori et al., 2009, A&A, 506, 1563).

We strongly encourage multifrequency observations of the Crab Nebula region.

Fermi LAT confirmation of enhanced gamma-ray emission from the Crab Nebula region

ATel #2861; R. Buehler (SLAC/KIPAC), F. D'Ammando (INAF-IASF Palermo), E. Hays (NASA/GSFC) on behalf of the Fermi Large Area Telescope Collaboration
on ***23 Sep 2010; 17:34 UT***
Distributed as an Instant Email Notice (Transients)
Password Certification: Rolf Buehler (buehler@slac.stanford.edu)

Subjects: >GeV, Pulsars
Referred to by ATel #: 2866, 2867, 2868, 2872

Following the detection by AGILE of increasing gamma-ray activity from a source positionally consistent with the Crab Nebula occurred from September 19 to 21 (ATel #2855), we report on the analysis of the >100 MeV emission from this region with the Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope.

Preliminary LAT analysis indicates that the gamma-ray emission (E >100 MeV) observed during this time period at the location of the Crab Nebula is (606 +/- 43) x10^-8 ph/cm2/sec, corresponding to an excess with significance >9 sigma with respect to the average flux from the Crab nebula of (286 +/- 2) x10^-8 ph/cm2/sec, estimated over all the Fermi operation period (only statistical errors are given). Ongoing Fermi observations indicate that the flare is continuing.

The flaring component has a spectral index of 2.49 +/- 0.14. Its position, Ra: 83.59 Dec: 22.05 with a 68% error radius of 0.06 deg, is coincident with the Crab Nebula.

Fermi will interrupt its all-sky scanning mode between 2010-09-23 15:49:00 UT and 2010-09-30 15:49:00 UT to observe the Crab Nebula. Afterwards regular gamma-ray monitoring of this source will continue. We strongly encourage further multifrequency observations of that region.

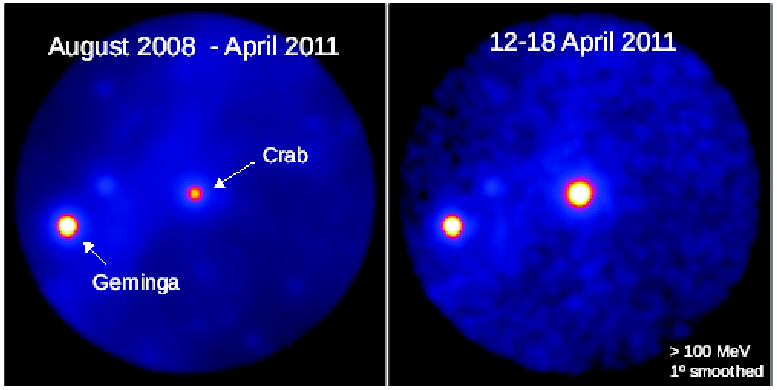
For this source the Fermi LAT contact person is Rolf Buehler (buehler@stanford.edu).

The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

No corresponding flare in X-rays with INTEGRAL (Atel # 2856), Swift (Atel # 2858, 2866), or RXTE (Atel # 2872) or NIR (Atel #2867). No evidence for active AGN near Crab (Swift, Atel # 2868).

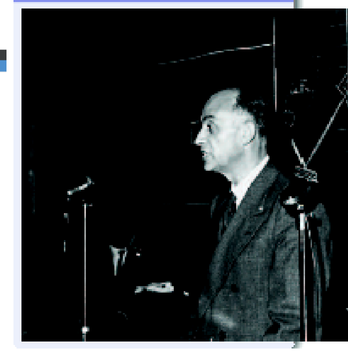
Gamma-ray flaring Crab nebula

The 2011 outburst



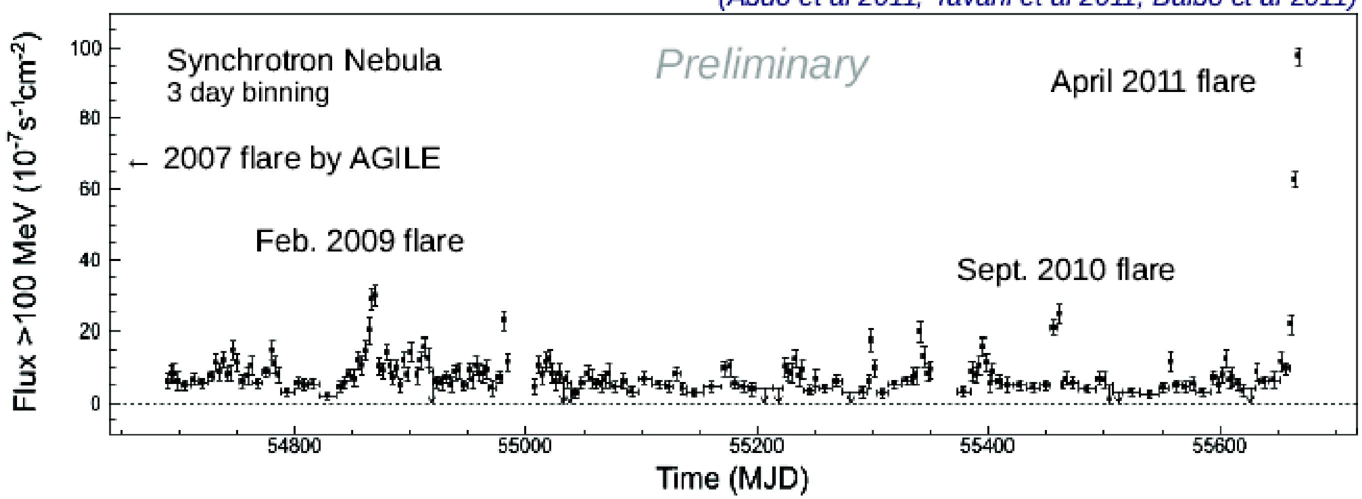
During the flare, the Crab was the brightest source in the gamma-ray sky

Enrico Fermi, 1949



Three day Crab synchcrotron curve

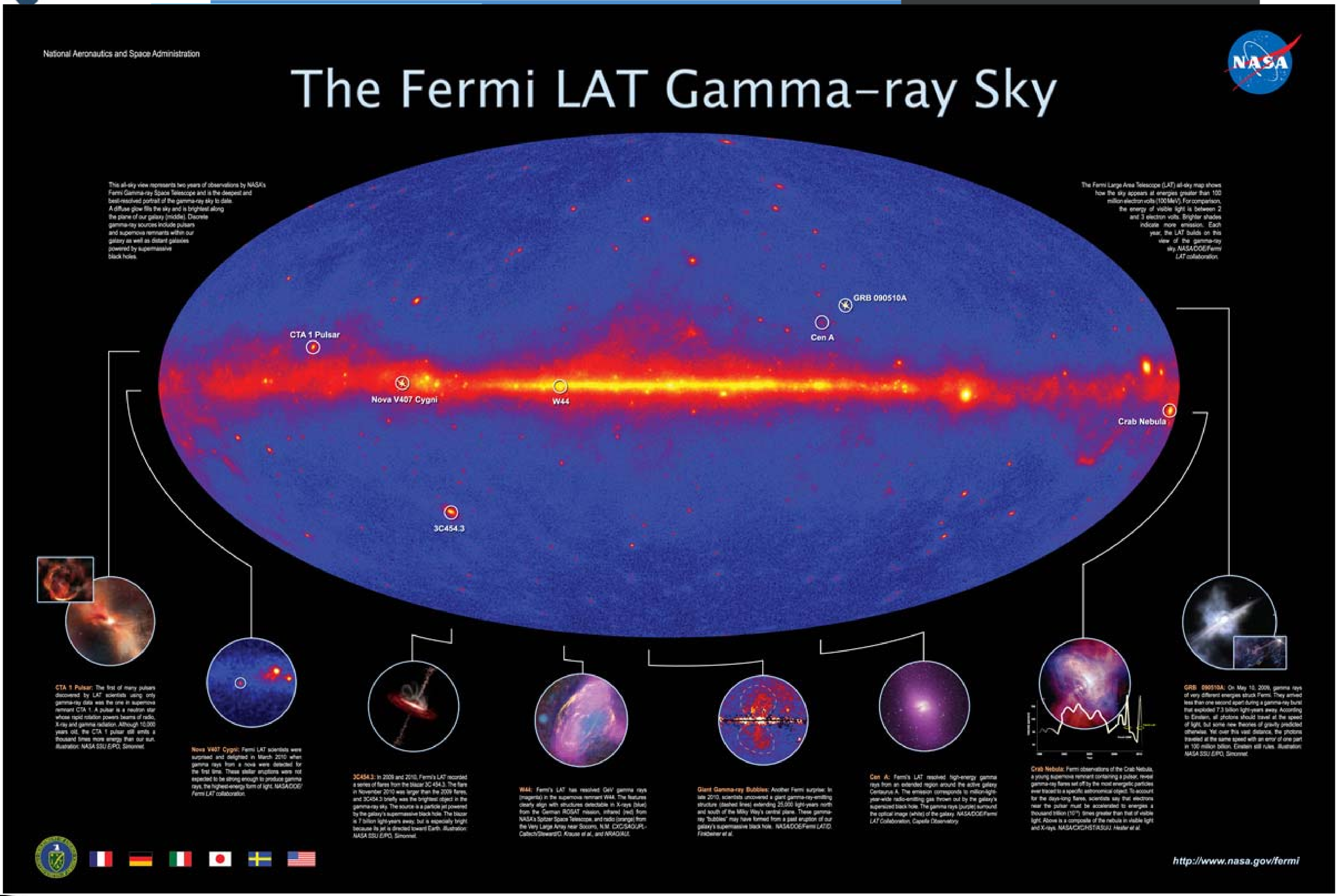
(Abdo et al 2011, Tavani et al 2011, Balbo et al 2011)



- We're just beginning...
  - Exposure continues to increase
    - Fainter sources become detectable
    - Increasingly detailed studies of bright sources
    - Catalogs become deeper and more detailed
  - Time domain studies enter longer regimes
  - Solar cycle beginning to warm up
  - Plus, efforts continue to further improve performance and enhance analysis, particularly at low and high energies
- The longer we look, the more surprises we will see

Average flux ~6 10^{-7} ph/cm²/s above 100 MeV, whith three flares as extreme persistent variability. Flux increase by ~5 during 2009 and 2010 flares.

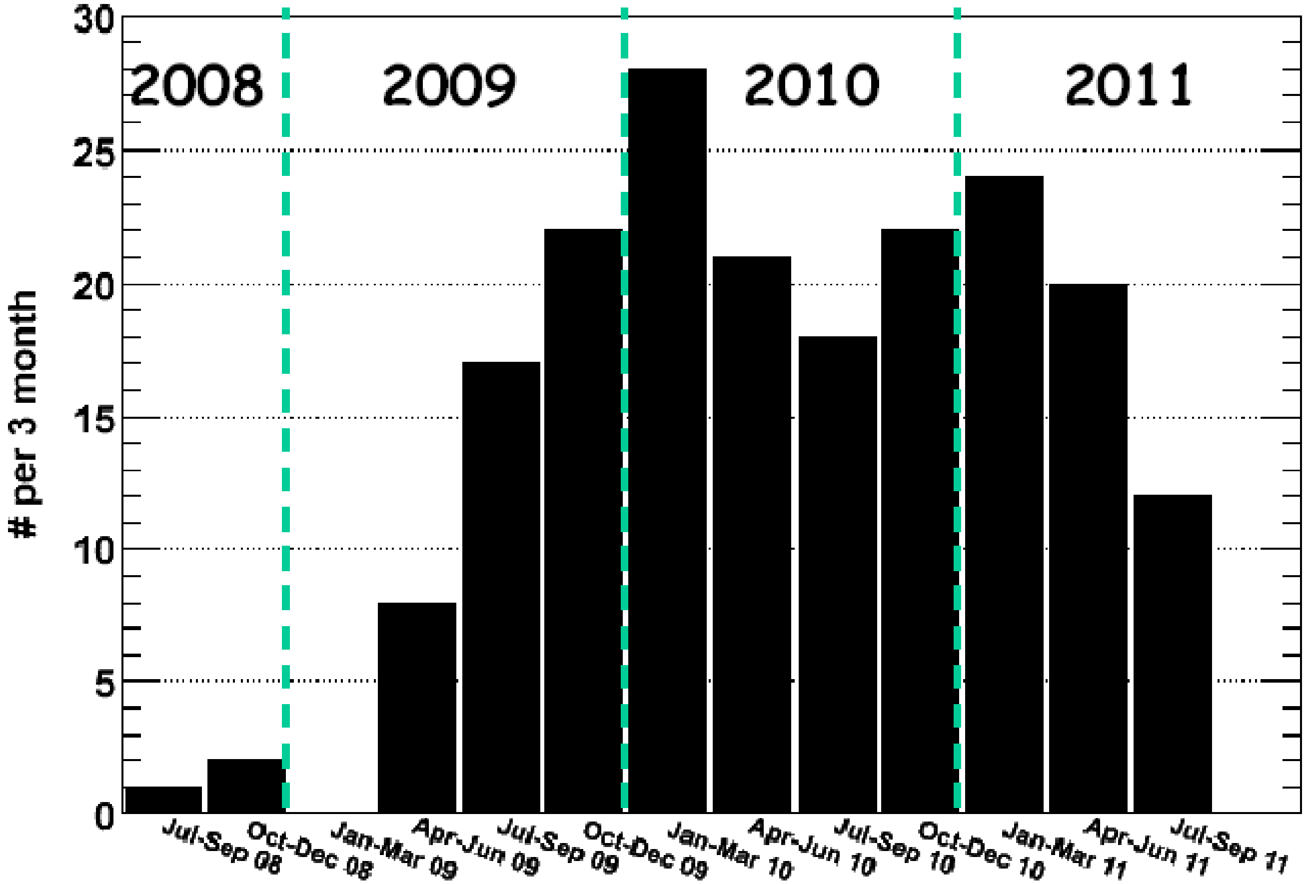
Last cumulated all-sky gamma-ray map (E>100MeV)



Fermi LAT Publications

- Publications by Fermi-LAT members

(Cat I+II+III, as of mid-Sep. 2011)



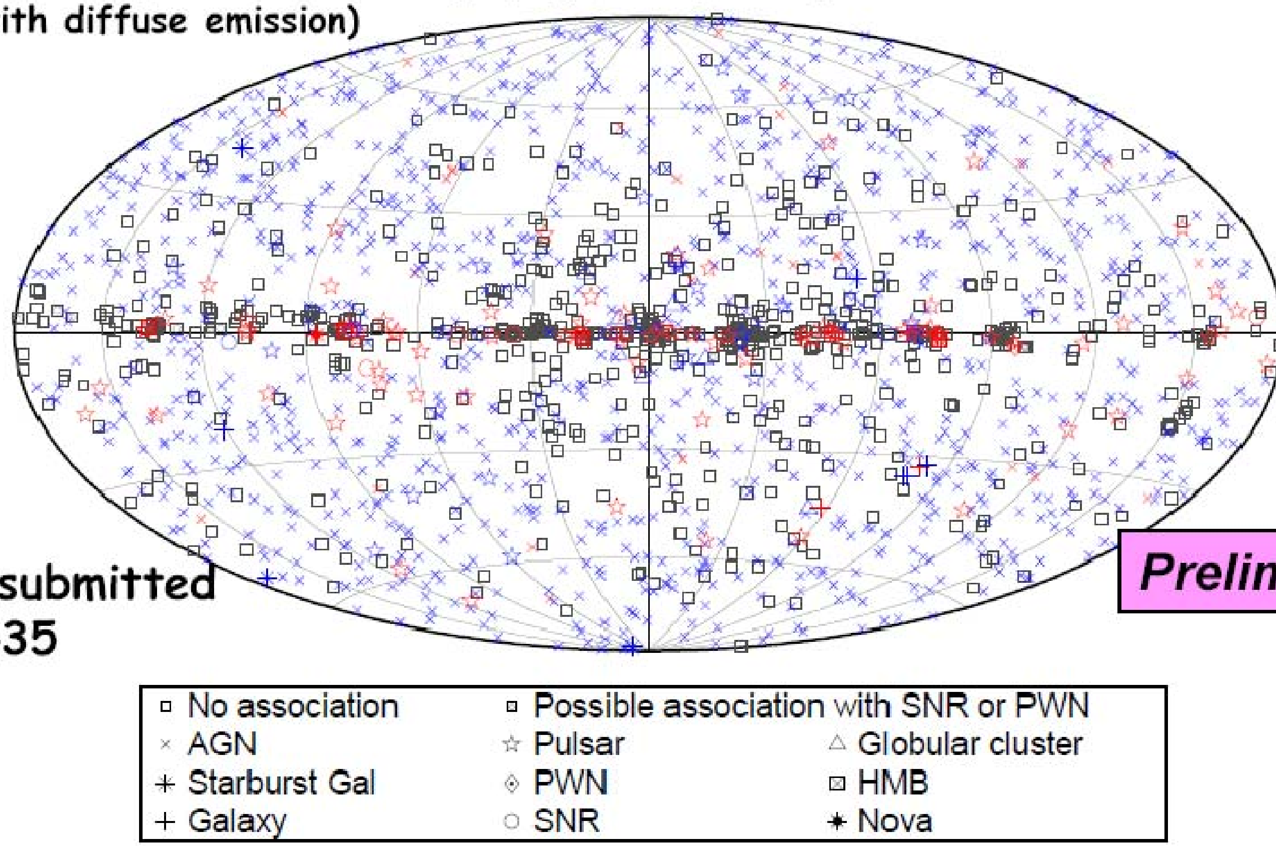
~200 papers already publised

6-7 papers/month

2FGL: Second Source Catalog

- 1873 sources (~4σ significance)
  - 127 firm identifications and 1170 reliable associations
  - 576 unassociated with known γ-ray source class

please pay attention to flags (e.g., 126 possibly confused with diffuse emission)



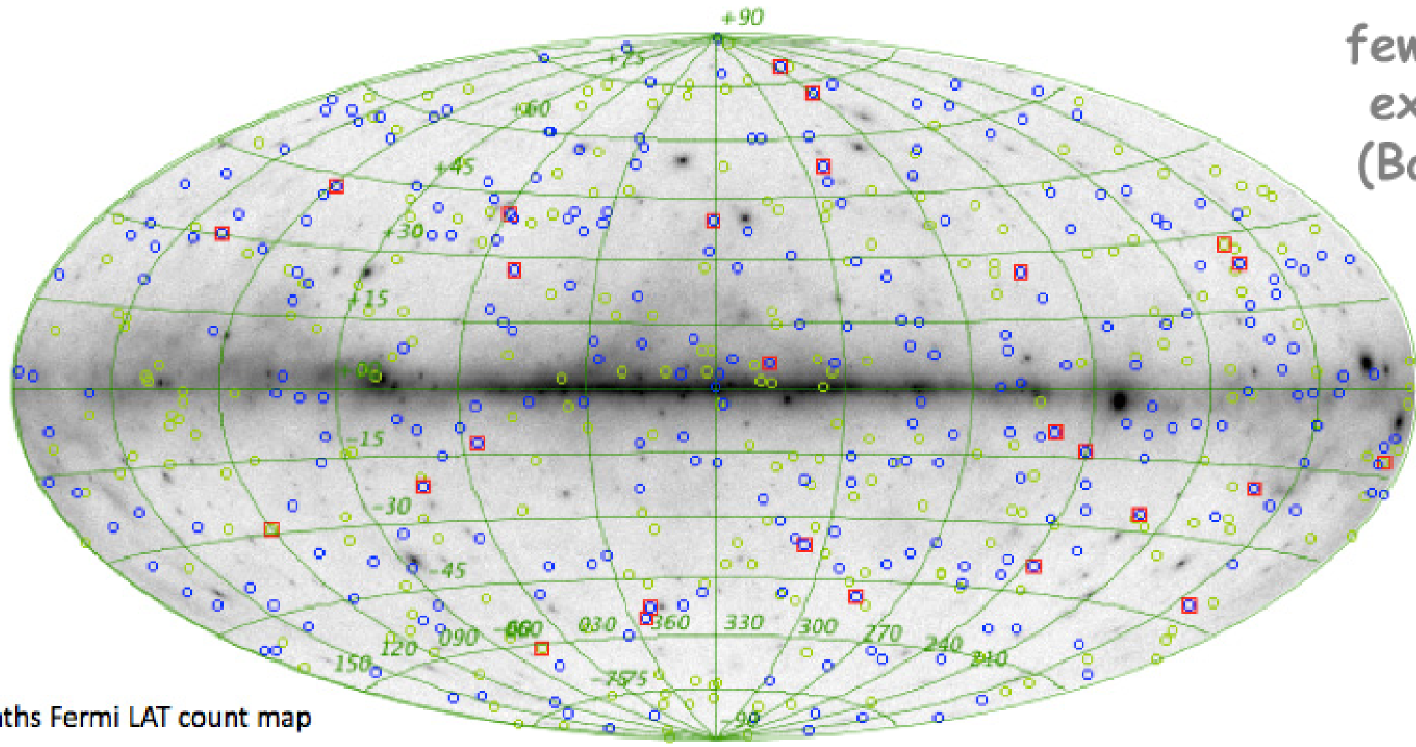
Abdo+, ApJS submitted
arXiv:1108.1435

Fermi GRBs after 3 years

Fermi GRBs as of 2011-08-01

- In 3 years
  - 682 GBM GRBs (345 in LAT FOV) ~0.6/day
  - 32 LAT GRBs (19 with >10 photons >100 MeV) ~0.6/month

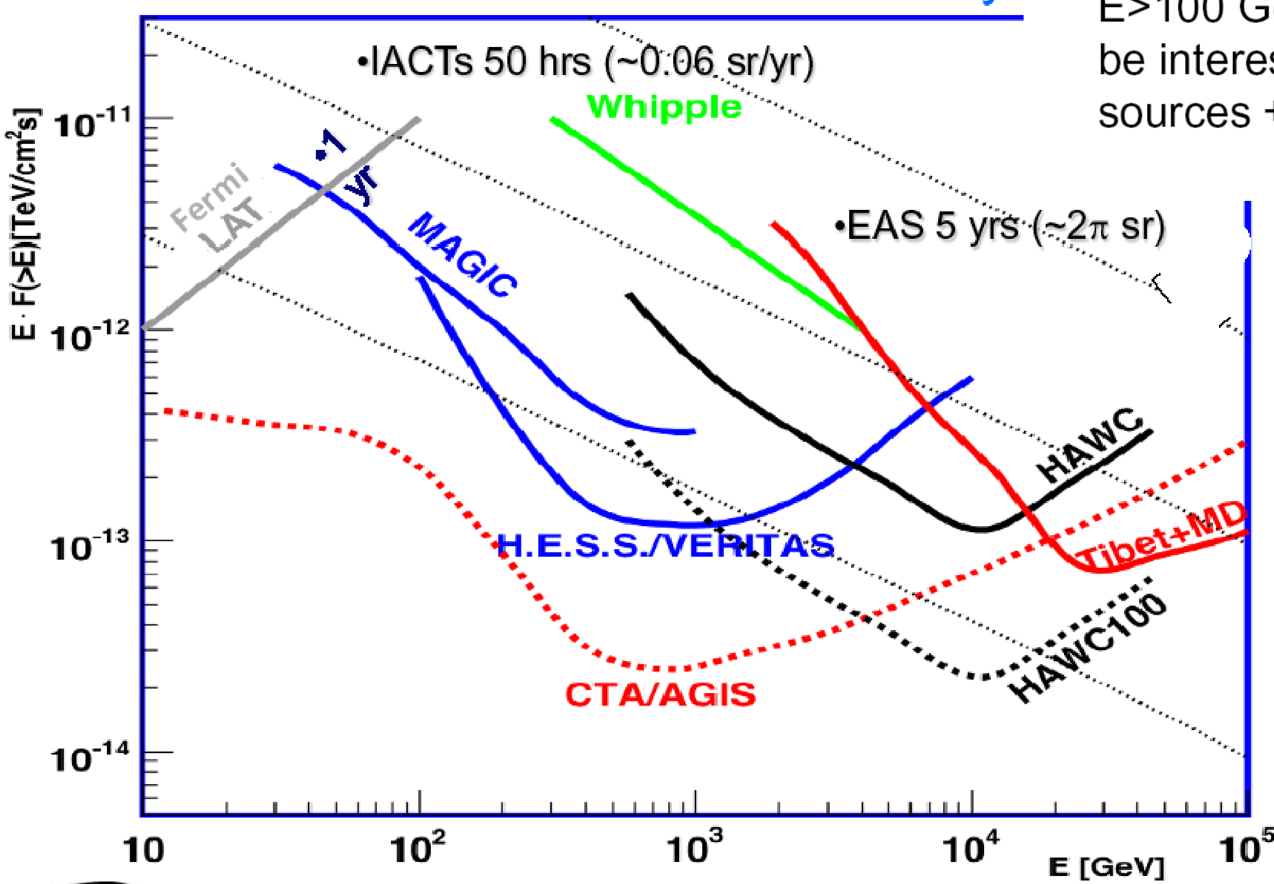
fewer than expected (Band+09)



11 months Fermi LAT count map

Preliminary

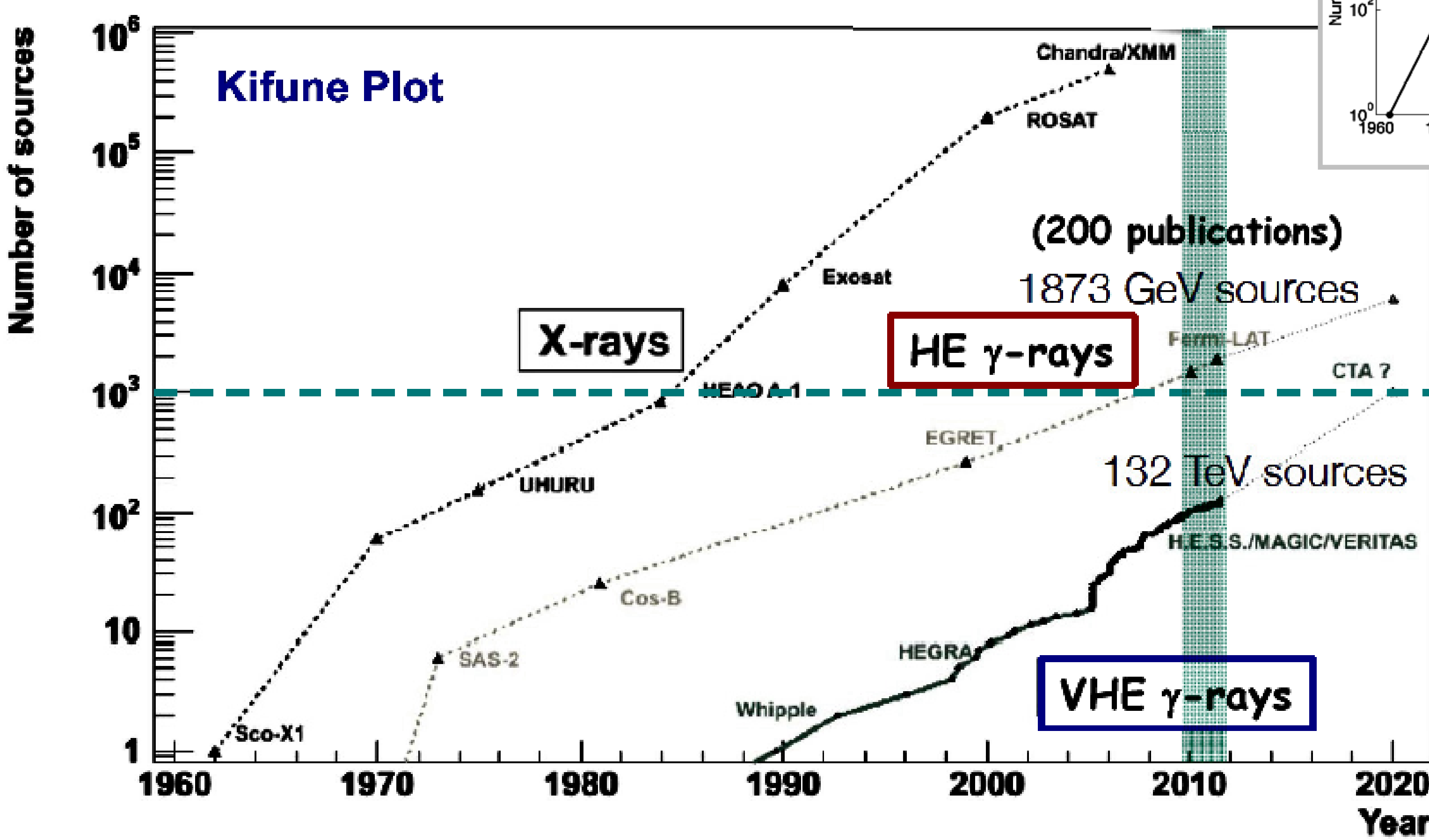
Fermi and ATCs' sensitivity

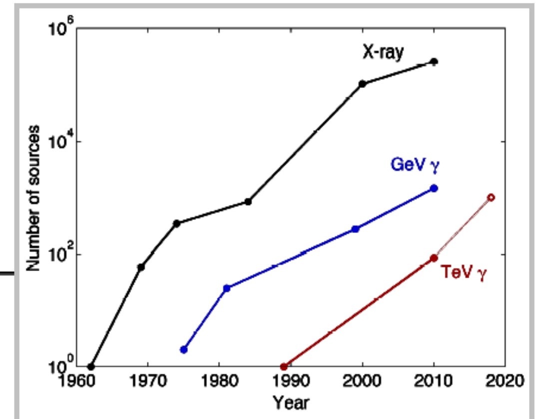


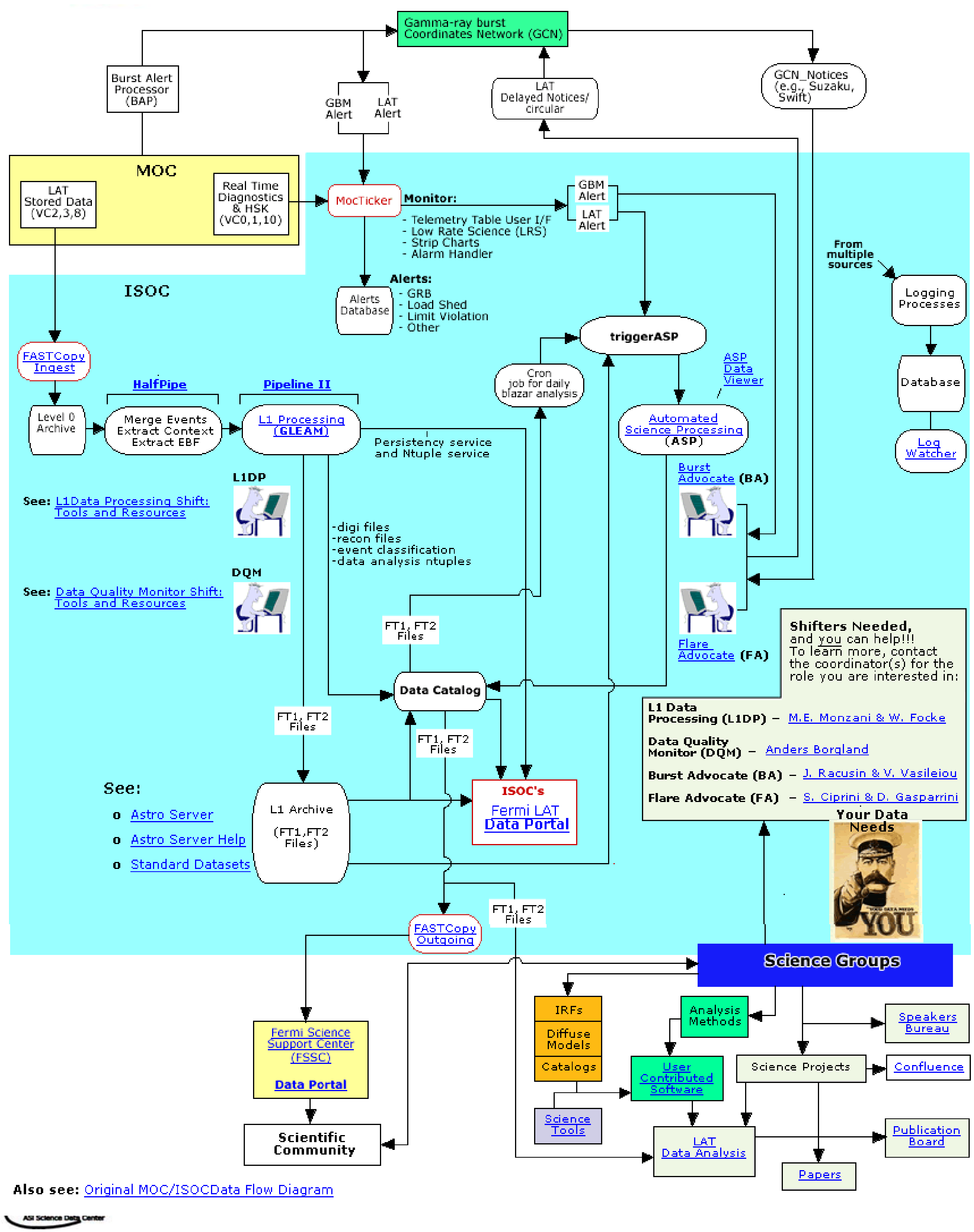
- New extragalactic sources need Cherenkov telescopes follow up for spectrum and light curve.
- Fermi able to pick sources with E>10 GeV which can be followed by Cherenkov telescopes. Trigger warning up TOO has to be defined.
- Fermi made first survey of ALL Galactic plane at E>100 GeV. Very complicated background. Can be interesting study of morphology of known sources + new candidates.

Prospects for CTA from Fermi

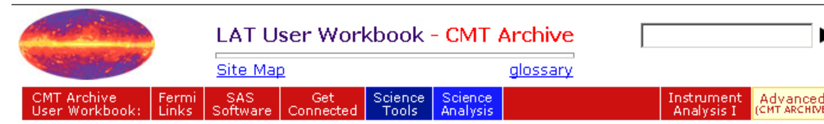
- # of sources increases in GeV
- Future: 1000 sources in TeV by CTA!?







Fermi LAT data flow and analysis steps (in the Fermi collaboration)



Fermi @ ASDC

ASI Science Data Center

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The Fermi Gamma-ray Space Telescope

Fermi ASI Scientific Page (italian)

Fermi,formerly GLAST, is a powerful space observatory that will open a wide window on the universe. Gamma rays are the highest-energy form of light, and the gamma-ray sky is spectacularly different from the one we perceive with our own eyes. With a huge leap in all key capabilities, Fermi data will enable scientists to answer persistent questions across a broad range of topics, including supermassive black-hole systems, pulsars, the origin of cosmic rays, and searches for signals of new physics.

Mission Objectives:

- **Explore the most extreme environments in the Universe, where nature harnesses energies far beyond anything possible on Earth**
- **Search for signs of new laws of physics and what composes the mysterious Dark Matter.**
- **Explain how black holes accelerate immense jets of material to nearly light speed.**
- **Help crack the mysteries of the stupendously powerful explosions known as gamma-ray bursts.**
- **Answer long-standing questions across a broad range of topics, including solar flares, pulsars and the origin of cosmic rays.**

Latest Fermi News

Fermi LAT Photon and Spacecraft Data Query

The Photon database currently holds 558405336 photons collected between 04/08/2008 15:43:37 and 24/05/2011 04:32:18 (239557418 and 327904340 seconds **Mission Elapsed Time (MET)**).

NOTE: For queries encompassing the whole sky (or close to it), please use the pre-generated by Heasarc **Weekly Allsky Files**.

Email:
Enter your e-mail address to receive notification when done

Search by Name
Object Name: MKN421

Coordinates Equinox: J2000

RA-Dec
RA: 166.113542
Dec: 38.2085588

Galactic Coordinates
L: 179.832439
B: 65.031366

Ecliptic Coordinates
Lon: 151.217076
Lat: 29.503225

Radius: degree 20

... and/or search by date?

Observations Dates: Gregorian

If you do not enter anything, it will return results from the past 6 months.
For Gregorian dates, please enter in the format YYYY-MM-DD HH:MM:SS, with the start and (optional) end time separated by commas.
For MET (Mission Elapsed Time), enter any integer values >= 0, separated by commas.
If you would like to search from the beginning of the mission, put in START instead of a start value.
If you would like to search up until the most recent point, put in END instead of an end value.

... and/or search by energy?

Energy Range: MeV
Enter the minimum and (optional) maximum energy, separated by a comma.
(By default, only data between 100 MeV and 300 GeV is returned.)

FERMI Data
Photon Data
Spacecraft Data
Clear Submit

- ❑ Fermi LAT public data download (FT1, FT2 fits event-filles) @ ASDC
- ❑ Fermi LAT data selection and preview (count maps, point sources) @ ASDC

ASDC Fermi LAT data preview

LAT Data Query Results

The submitted query parameters for query ID=L1105250657434 were:

Search Center (RA,Dec)	= (166.113542,38.2085588)
Radius	= 20.0 degrees
Start Time (MET)	= 3.12400652E8 seconds (2010/11/25 17:57:30)
Stop Time (MET)	= 3.28035452E8 seconds (2011/05/25 16:57:30)
Minimum Energy	= 100 MeV
Maximum Energy	= 300000 MeV

The filenames of the result files consist of the Query ID string with an identifier appended to indicate which database the file came from. The identifiers are of the form: _DDNN where DD indicates the database and NN is the file number. The file number will generally be '00' unless the query resulted in a very large data return. In that case the data is broken up into multiple files.
The values of the database field are:

- PH - Photon Database
- SC - Spacecraft Pointing, Livetime, and History Database

File Name	Number of entries	Size (MB)	Status
L1105250657434_PH00.fits	1641965	144.12	Available
L1105250657434_PH01.fits	877135	76.99	Available
L1105250657434_SC00.fits	436011	58.65	Available

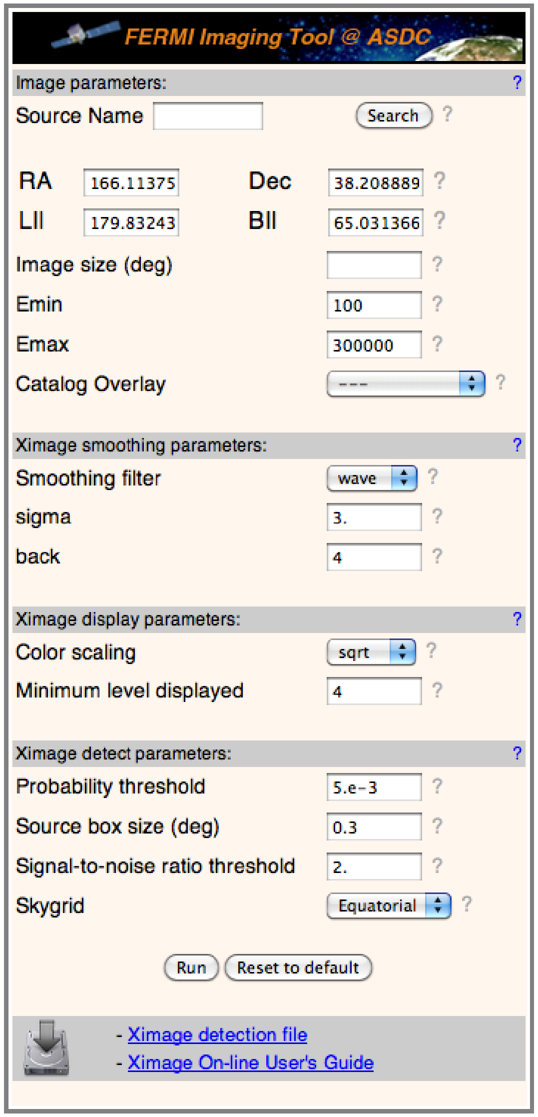
Data Preview WORKING

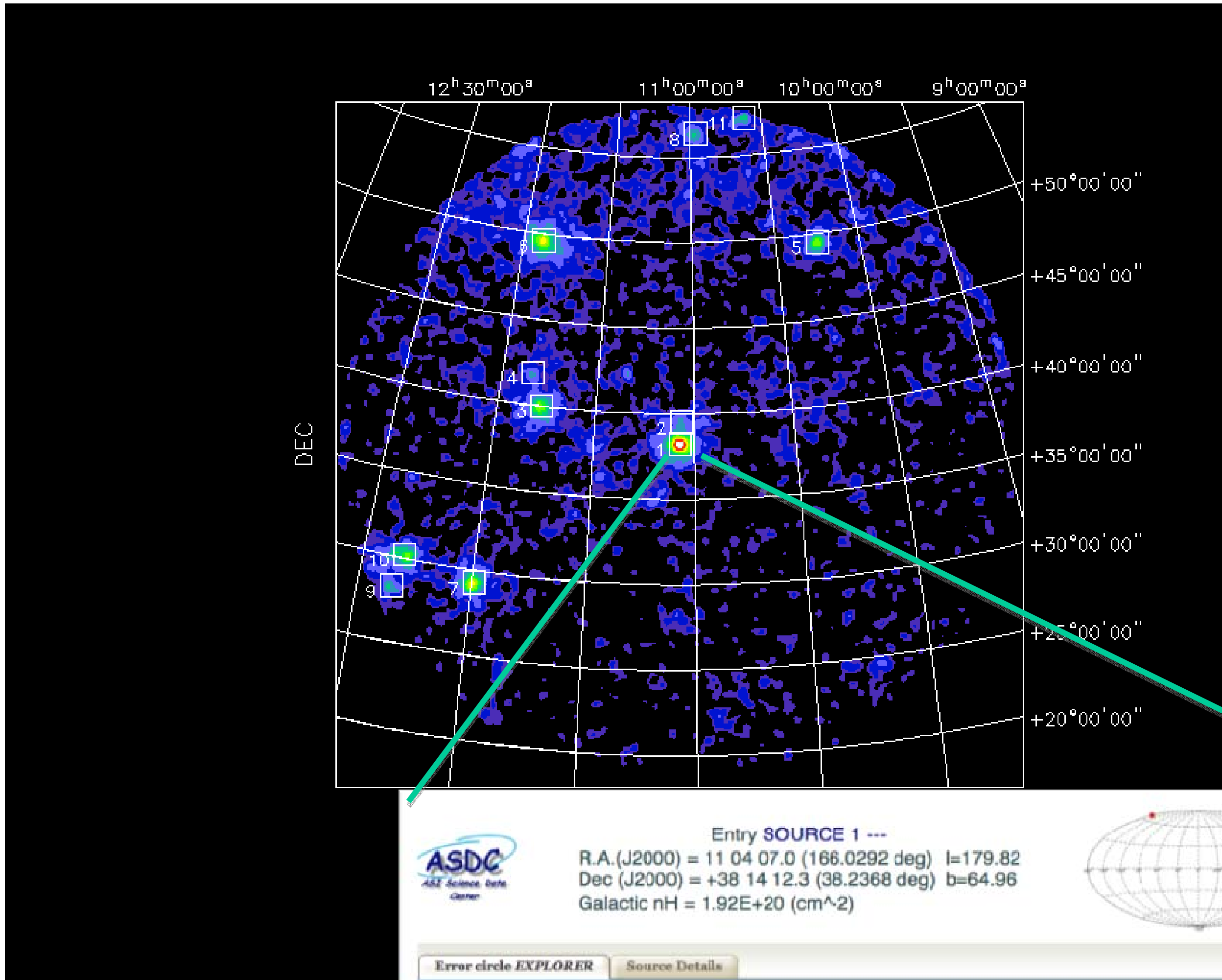
To get the results from another query, enter the query ID string below:

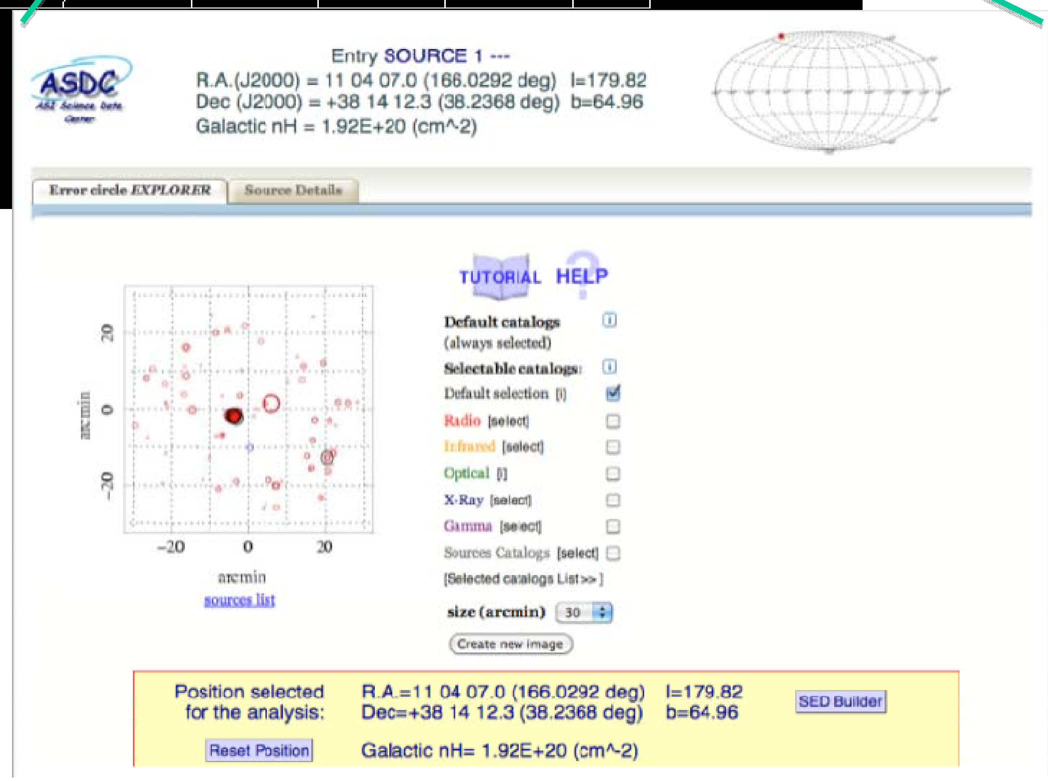
Submit Reinizializza

Clicking on "data preview" an image will be generated running XIMAGE detect task on the Fermi count map, produced with standard ST in the queried time interval. It aims to provides a preview of the source field to help the user in any possibile improvement of the data query before to run the likelihood analysis. The map is interactive: move the cursor on image to explore it. WARNING The XIMAGE detect task runs with pre-fixed values, you can change them using the dedicated menu. We remind the user that the data analysis should be run with the proper Fermi ST.

Data preview


FERMI Imaging Tool @ ASDC
Image parameters:
Source Name
Search
RA 166.11375
Dec 38.208889
LII 179.83243
BII 65.031366
Image size (deg)
Emin 100
Emax 300000
Catalog Overlay ---
Ximage smoothing parameters:
Smoothing filter wave
sigma 3.
back 4
Ximage display parameters:
Color scaling sqrt
Minimum level displayed 4
Ximage detect parameters:
Probability threshold 5.e-3
Source box size (deg) 0.3
Signal-to-noise ratio threshold 2.
Skygrid Equatorial
Run
Reset to default
- Ximage detection file
- Ximage On-line User's Guide


12h30m00s
11h00m00s
10h00m00s
9h00m00s
+50°00'00"
+45°00'00"
+40°00'00"
+35°00'00"
+30°00'00"
+25°00'00"
+20°00'00"
DEC


Entry SOURCE 1 ---
R.A.(J2000) = 11 04 07.0 (166.0292 deg) l=179.82
Dec (J2000) = +38 14 12.3 (38.2368 deg) b=64.96
Galactic nH = 1.92E+20 (cm^-2)
Error circle EXPLORER
Source Details
TUTORIAL HELP
Default catalogs (always selected)
Selectable catalogs:
Default selection
Radio [select]
Infrared [select]
Optical
X-Ray [select]
Gamma [select]
Sources Catalogs [select]
[Selected catalogs List>>]
size (arcmin) 30
Create new image
arcmin
sources list
Position selected for the analysis:
R.A.=11 04 07.0 (166.0292 deg) l=179.82
Dec=+38 14 12.3 (38.2368 deg) b=64.96
Galactic nH= 1.92E+20 (cm^-2)
Reset Position
SED Builder

ASDC Fermi source catalogs

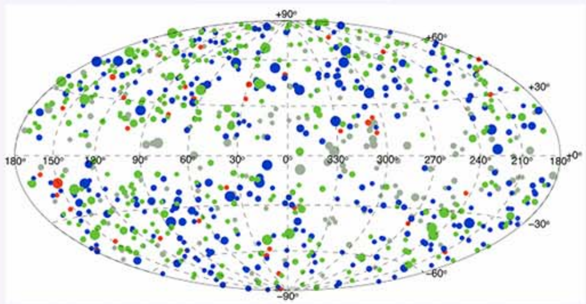
Fermi Catalog @ASDC

- Bright Source List
- LBAS
- 1st Fermi LAT catalog
- 1st LAT AGN catalog
- GBM GRB list
- LAT GRB list
- Fermi Pulsar Catalog

The 1 Year Fermi-LAT AGN Catalog

@ ASDC v1.0

Show/hide columns
Advanced filtering
Print current view of table
Print complete table
Reset all filters



All Blazars | BL Lacs | FSRQs | AGNs | AGUs

Clean | Low Lat | Affiliated | LSP | ISP | HSP

VO mode: off (turn on) Help

Cone Search
Source Name
Resolve name
RA, Dec L,B Clean
(e.g. 00 02 34.6,-53 01 10.2 or 0.64417,-53.0195)
radius 5 arcmin Search
Reset filter

This is an interactive version of the Fermi-LAT 1-year AGN Catalog extracted from Abdo et al 2010

This catalog contains the AGN counterpart of 1st Fermi LAT Source Catalog

Export Current view of Table in: Latex format | FITS format | Raw text format | CSV text format

Previous Page Next Page Page Size (# of lines) 50 Refresh page | Reset all filters | Show all entries

Entry number (Selection mode: Include, All)		Source name	Other name	RA Counterpart (J2000.0) hh mm ss.d	Dec Counterpart (J2000.0) dd mm ss.d	Association Probability	Flux 1Gev-100 Gev flux1_100 + err	Spectral index sp_index	Redshift	SED classification	Optical classification
1	Select ASDC data Explorer	1FGL J0004.7-4737	PKS0002-478	00 04 35.5	-47 36 18.6	0.99	(8+/-3) e-10	2.56	0.88	LSP	BZQ (FSRQ)
2	Select ASDC data Explorer	1FGL J0005.7+3815	B20003+38A	00 05 57.1	+38 20 15.1	0.99	(6+/-3) e-10	2.86	0.229	LSP	BZQ (FSRQ)
3	Select ASDC data Explorer	1FGL J0008.3+1452	RXJ0008.0+1450	00 08 05.5	+14 50 23.3	0.7	(8+/-2) e-10	2	0.045	--	AGN
4	Select ASDC data Explorer	1FGL J0008.9+0635	CRATESJ0009+0628	00 09 03.8	+06 28 21.2	0.93	< 8e-10	2.28	0	LSP	BZB (BL Lac)
5	Select ASDC data Explorer	1FGL J0011.1+0050	CGRaBSJ0011+0057	00 11 30.4	+00 57 51.8	0.96	(6+/-2) e-10	2.51	1.492	LSP	BZQ (FSRQ)
6	Select ASDC data Explorer	1FGL J0013.1-3952	PKS0010-401	00 12 59.8	-39 54 25.8	1	(5+/-3) e-10	2.09	0	--	BZB (BL Lac)
7	Select ASDC data Explorer	1FGL J0013.7-5022	BZBJ0014-5022	00 14 11.2	-50 22 32.6	1	(6+/-2) e-10	2.23	0	HSP	BZB (BL Lac)

Fermi LAT data analysis resources

ASDC Fermi page, data retrieval and preview

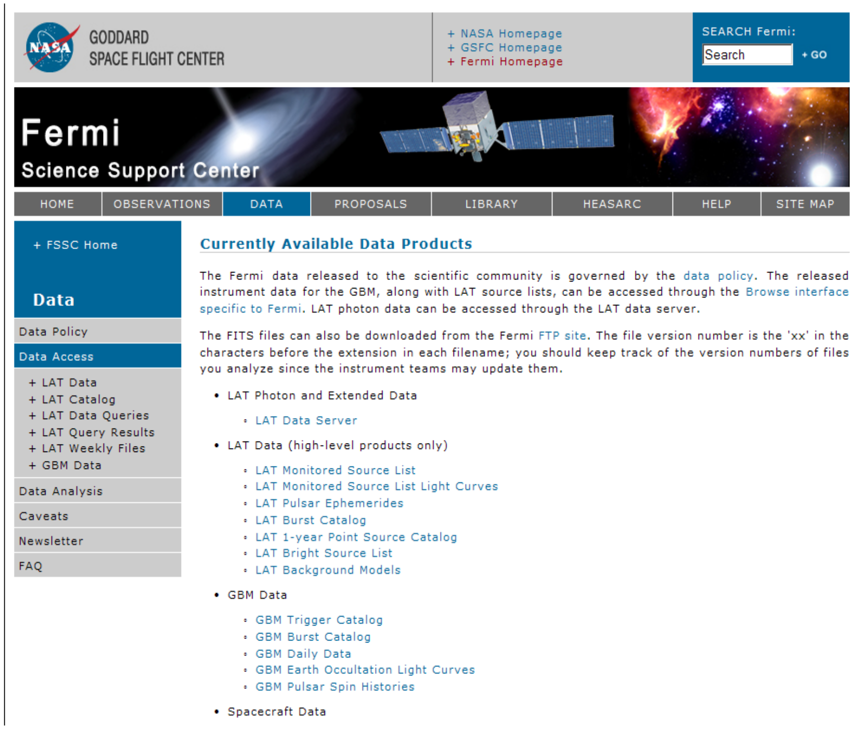
- http://fermi.asdc.asi.it

Fermi Science Support Center

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

Data analysis portal

- http://fermi.gsfc.nasa.gov/ssc/data/analysis/



Overview: LAT Data Analysis "Science Tools"

- http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/overview.html

LAT user workbook (extensive and detailed) - Science Analysis section

- http://glast-ground.slac.stanford.edu/workbook/scienceAnalysis_Home.htm

Fermi LAT data analysis resources

Analysis Threads

- http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/

Likelihood Analysis with Python

- http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/python_tutorial.html

LAT user workbook (extensive and detailed) - "ScienceTools" section

- http://glast-ground.slac.stanford.edu/workbook/sciTools_Home.htm

LAT user workbook (extensive and detailed) - Science Analysis section

- http://glast-ground.slac.stanford.edu/workbook/scienceAnalysis_Home.htm

Fermi Data Analysis: LAT Science Tools