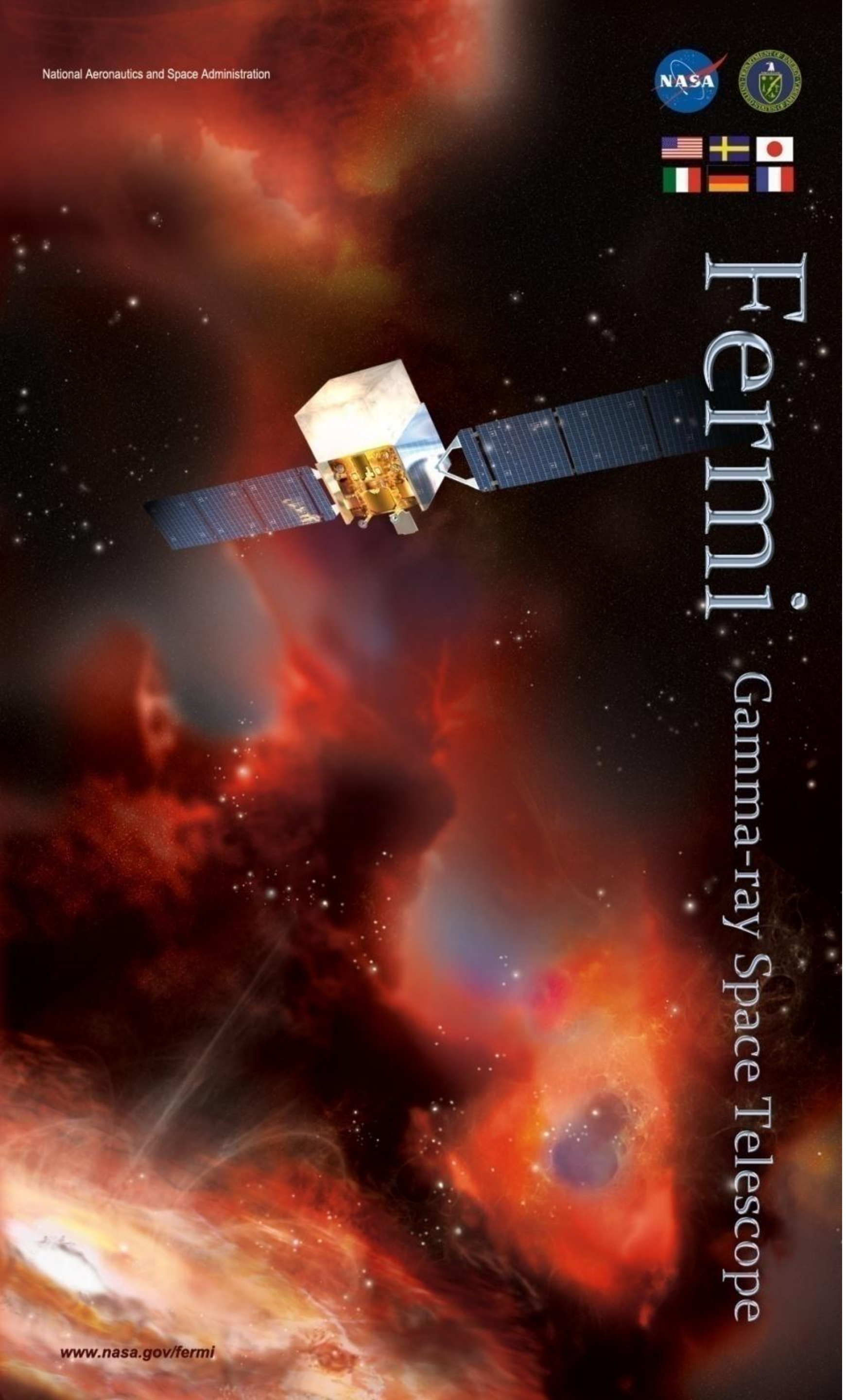


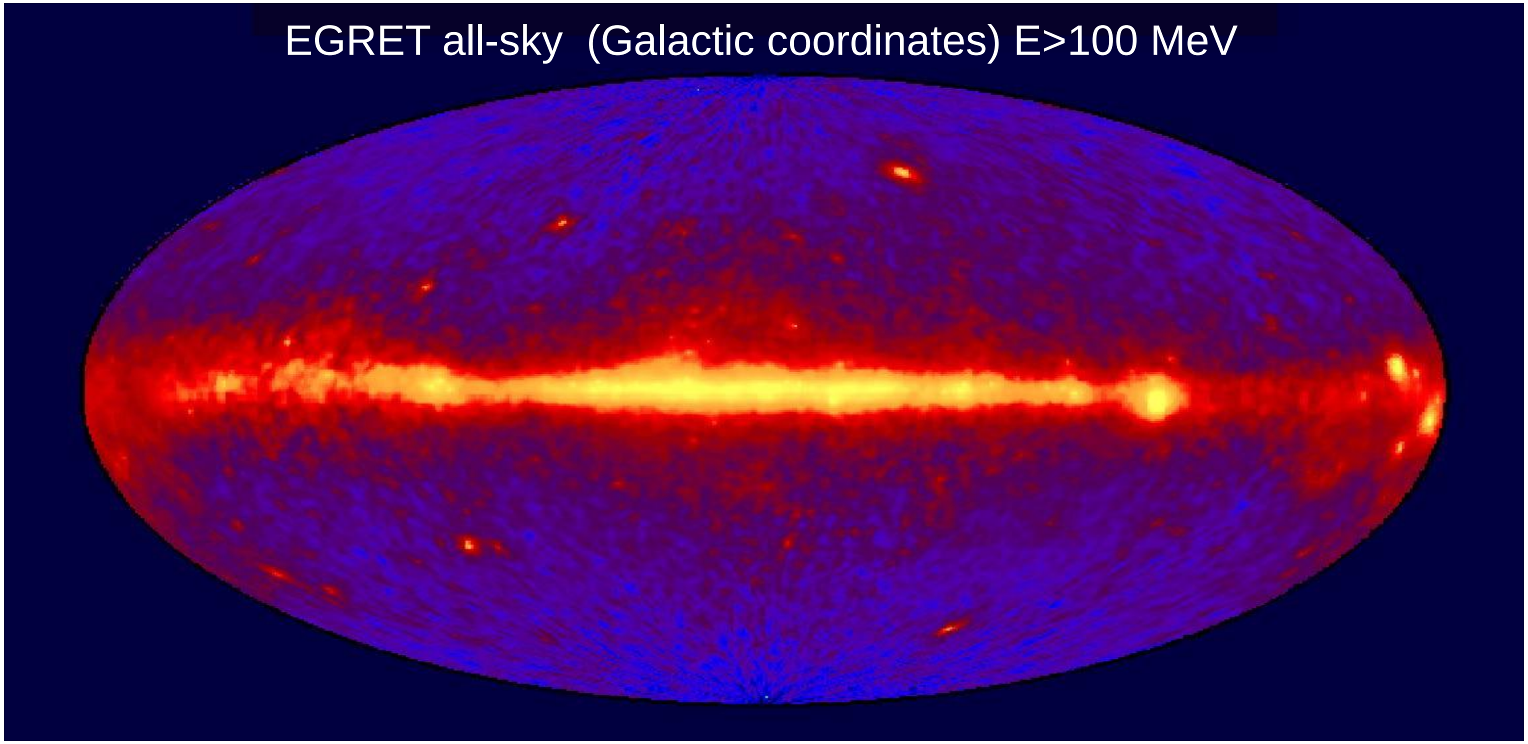

# The FERMI Large Area Telescope in orbit

**Jean Ballet** (CEA/DSM/IRFU/SAp)

*on behalf of the Fermi LAT Collaboration*

**LAPP June 26, 2009**

# Features of the EGRET gamma-ray sky




diffuse extra-galactic background (flux ~ $1.5 \times 10^{-5}$ $cm^{-2}s^{-1}sr^{-1}$)

Galactic diffuse (flux ~30 times larger)

high latitude (extra-galactic) point sources (typical flux from EGRET sources O($10^{-7}$ - $10^{-6}$) $cm^{-2}s^{-1}$)

Galactic sources (pulsars, un-ID'd)

**An essential characteristic**: VARIABILITY in time!

Field of view important for study of transients

Fermi
Gamma-ray Space Telescope

# *GLAST* LAT science objectives

**> 2000 AGNs**
blazars and radiogal = f(θ,z)
evolution z < 5
Sgr A*

**10-50 GRB/year**
GeV afterglow
spectra to high energy

**γ-ray binaries**
Pulsar winds
μ-quasar jets


**Possibilities**
starburst galaxies
galaxy clusters
measure EBL
unIDs

**Dark Matter**
neutralino lines
sub-halo clumps

**Cosmic rays and clouds**
acceleration in Supernova remnants
OB associations
propagation (Milky Way, M31, LMC, SMC)
Interstellar mass tracers in galaxies

**Pulsars**
emission from radio and X-ray pulsars
blind searches for new Gemingas
magnetospheric physics
pulsar wind nebulae

# The Observatory


Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 40 MeV

## KEY FEATURES

- Huge field of view
  - –LAT: 19% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.
- Huge energy range, including largely unexplored band 10 GeV - 100 GeV.

Total of >7 energy decades!

- Large leap in all key capabilities. Great discovery potential.

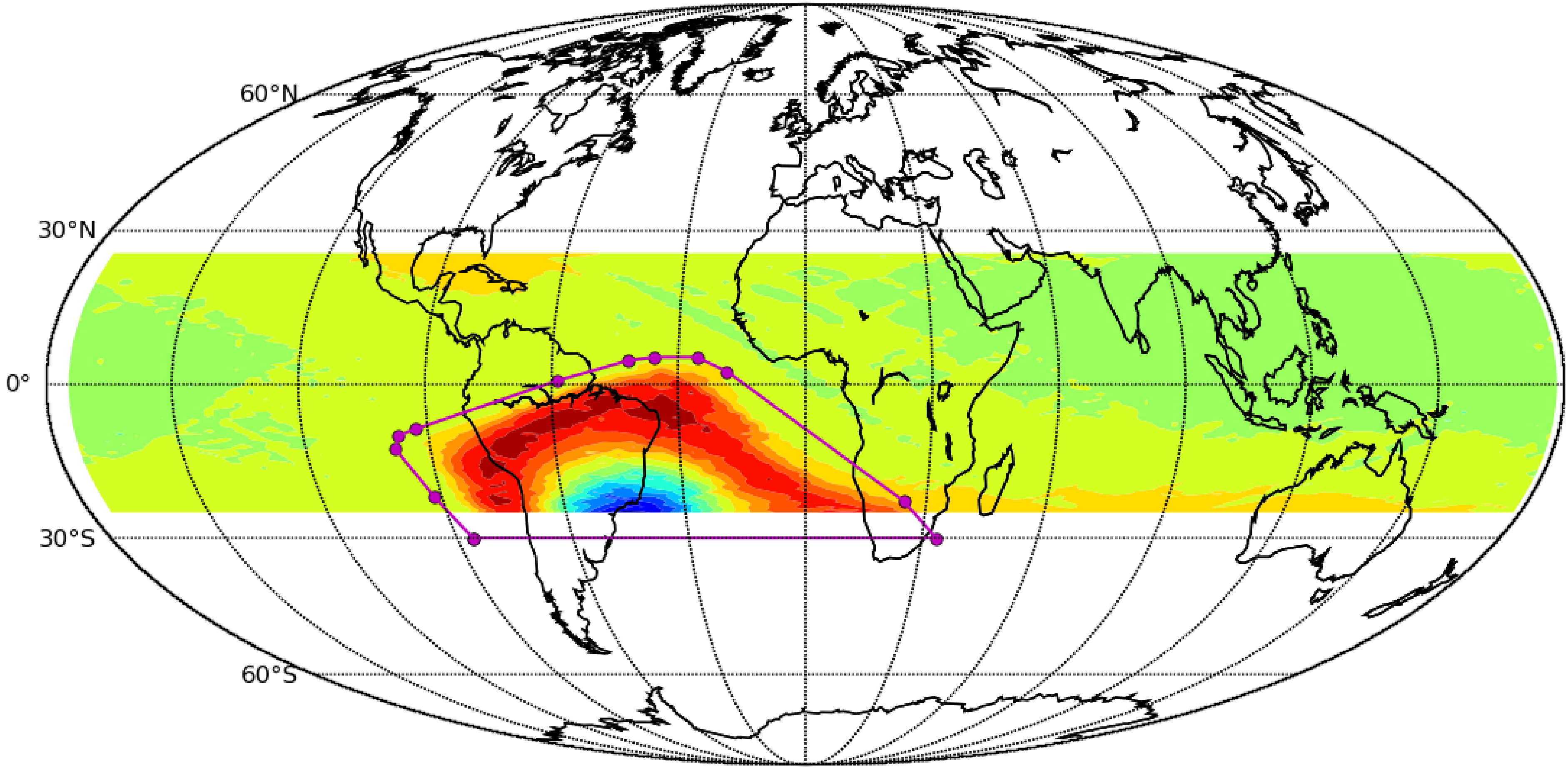
# Launch!

***Cape Canaveral***

***11 June 2008 at 12:05PM EDT***

***26 August 2008***
***NASA renames GLAST to Fermi***

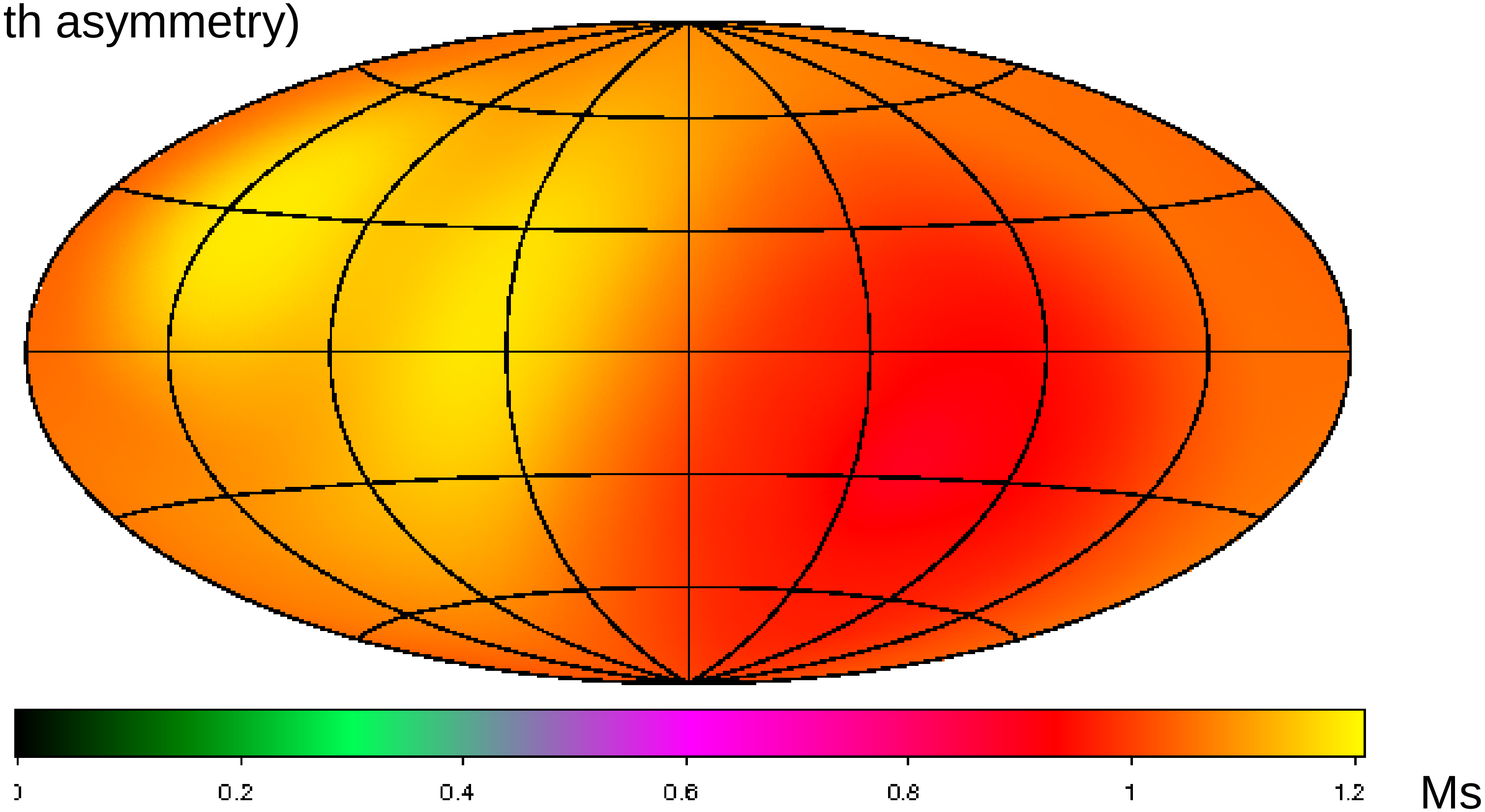
# Fermi in orbit




**Circular orbit, 565 km altitude (96 min period), 25.6 degrees inclination**
**Does not operate inside South Atlantic Anomaly**
**Inclined at 35° from zenith, on alternate sides at each orbit**

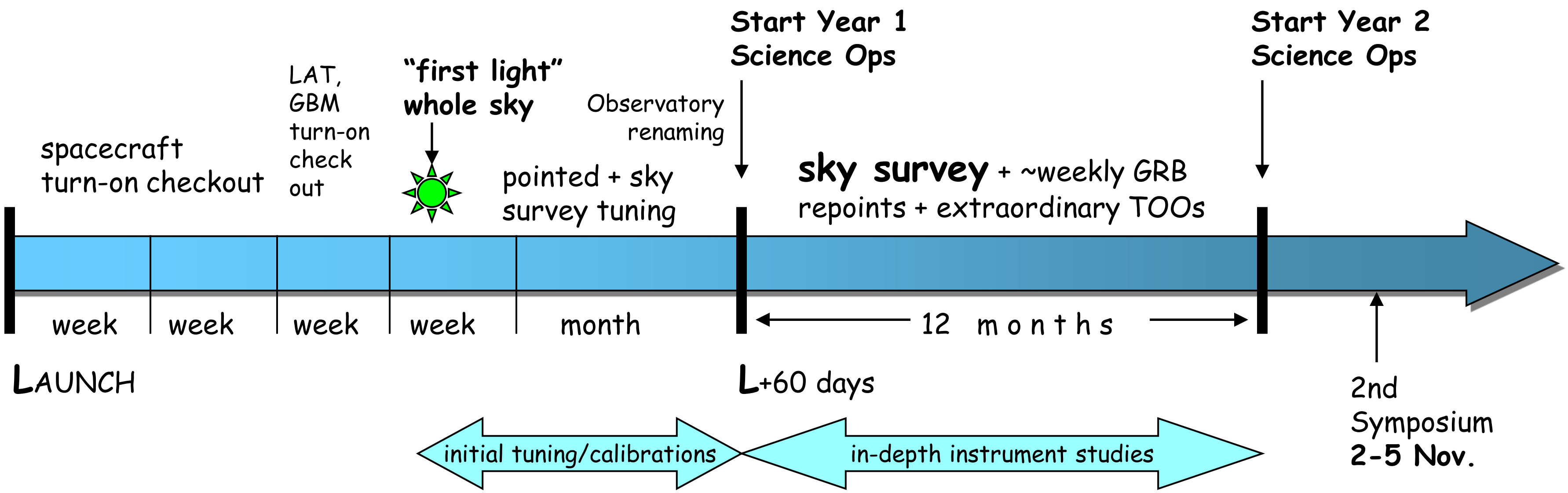
# Exposure map

- Data used are the first three months of all-sky scanning data, Aug. - Oct. 2008. Total live time is 7.53 Ms
- Scanning scheme makes exposure map very uniform (SAA creates 25% North-South asymmetry)

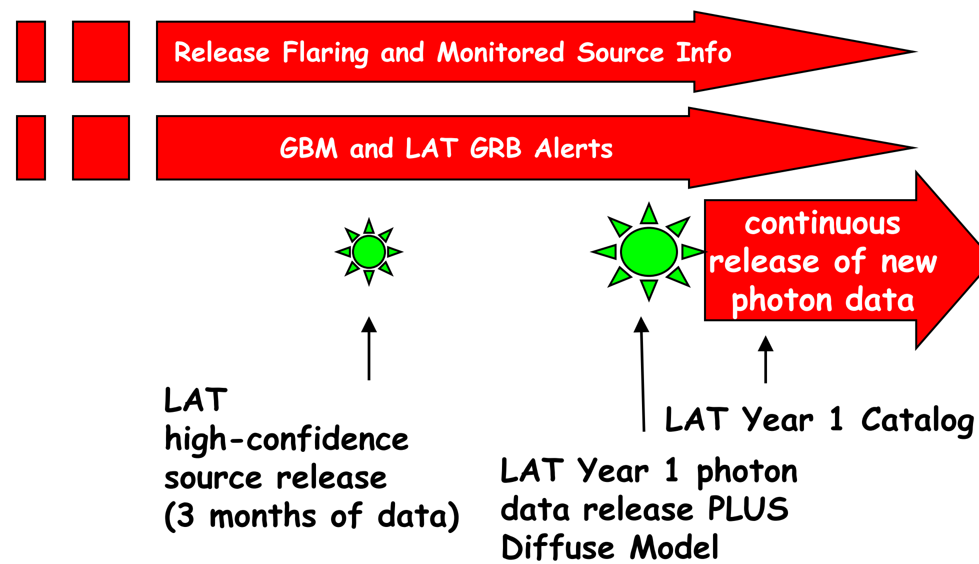



Equivalent on-axis observing time, Galactic coordinates, Aitoff projection

# Year 1 Science Operations Timeline




Distributed by Fermi Science Support Center at Goddard
http://fermi.gsfc.nasa.gov/ssc/data/access/




5 years operations (+ 5 years)

# LAT Collaboration – an AP-HEP partnership

- **France**
  - CNRS/IN2P3 (LLR, CENBG, LPTA)
  - CEA/Saclay, CNRS/INSU (CESR)
- **Italy**
  - INFN, ASI, INAF
- **Japan**
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- **Sweden**
  - Royal Institute of Technology (KTH)
  - Stockholm University
- **United States**
  - Stanford University (SLAC and HEPL/Physics)
  - University of California, Santa Cruz - Santa Cruz Inst. for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - The Ohio State University
  - University of Washington

**PI: Peter Michelson**
(Stanford)

~390 Scientific Members (including 96 Affiliated Scientists, plus 68 Postdocs and 105 Students)

**Cooperation between NASA and DOE, with key international contributions from France, Italy, Japan and Sweden.**

**Managed at SLAC.**

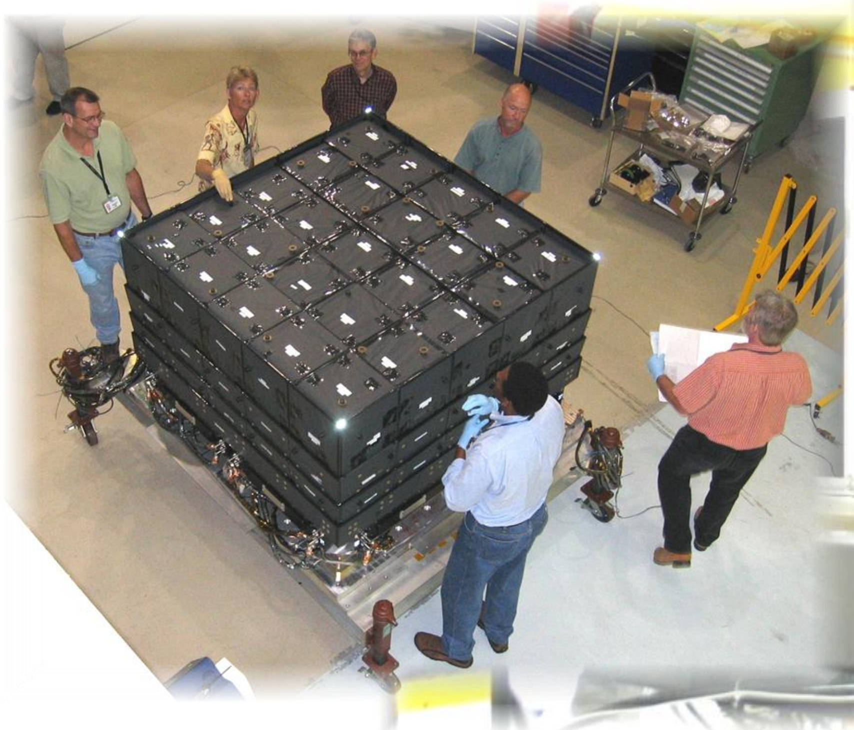
# Overview of the Large Area Telescope

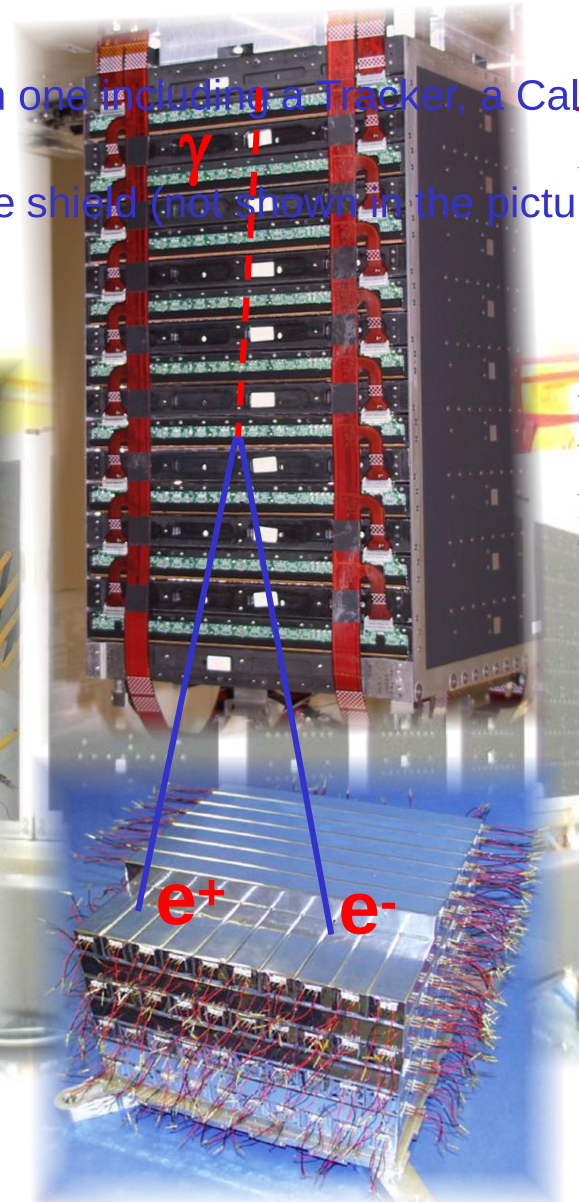
**Overall modular design:**

- ✓ 4x4 array of identical towers - each one including a Tracker, a Calorimeter and an Electronics Module
- ✓ Surrounded by an Anti-Coincidence shield (not shown in the picture)
- ✓ 3 ton – 650 W

**Anti-Coincidence (ACD):**

- ✓ Segmented (89 tiles).
- ✓ Self-veto @ high energy limited.
- ✓ 0.9997 detection efficiency (overall).






**Tracker/Converter (TKR):**

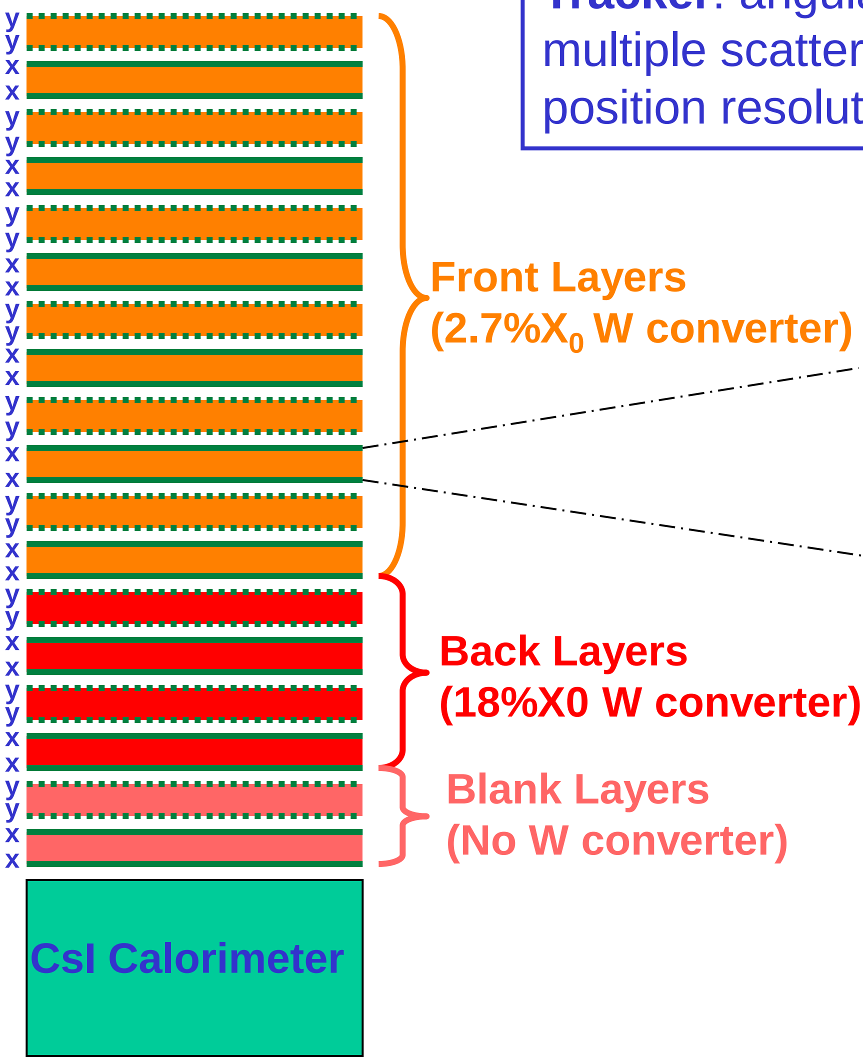
- ✓ Silicon strip detectors (single sided, each layer is rotated by 90 degrees with respect to the previous one).
- ✓ W conversion foils.
- ✓ ~80 $m^2$ of silicon (total).
- ✓ ~$10^6$ electronics chans.
- ✓ High precision tracking, small dead time.

**Calorimeter (CAL):**

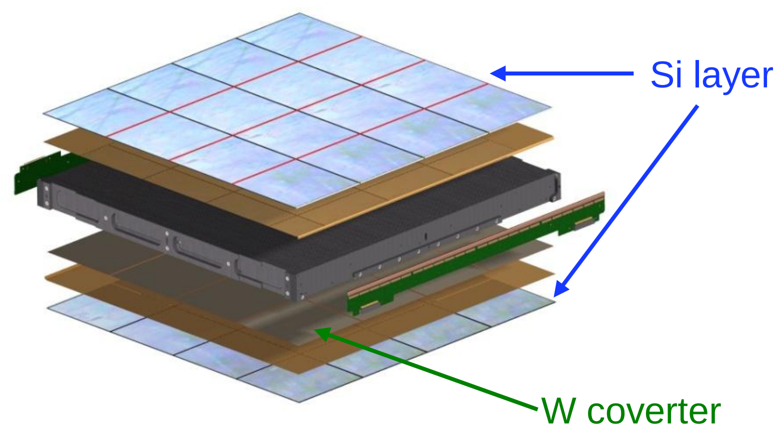
- ✓ 1536 CsI crystals.
- ✓ 8.5 radiation lengths.
- ✓ Hodoscopic.
- ✓ Shower profile reconstruction (leakage correction)

# Tracker Details

**Tracker Tower**




**Tracker**: angular resolution is determined by:
multiple scattering (at low energies) => Many thin layers
position resolution (at high energies) => fine pitch detectors

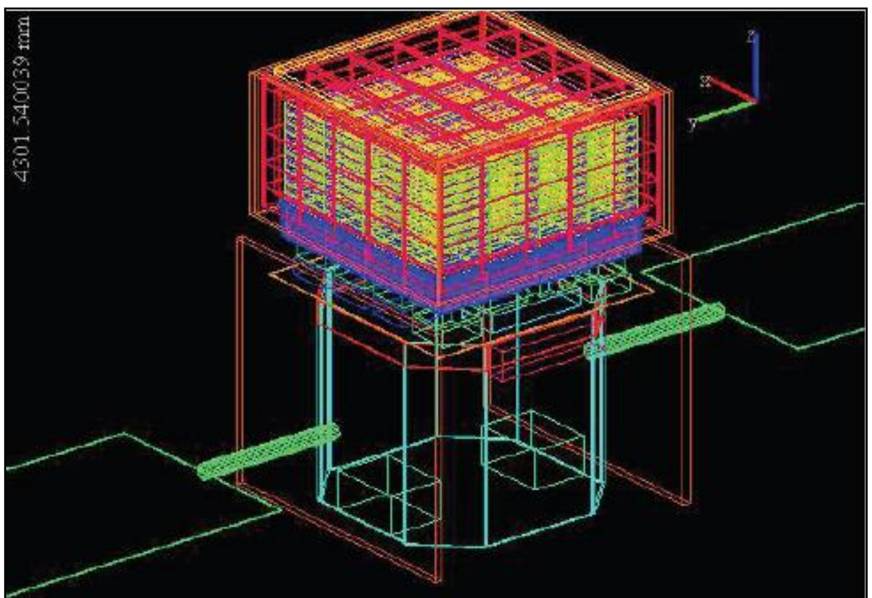


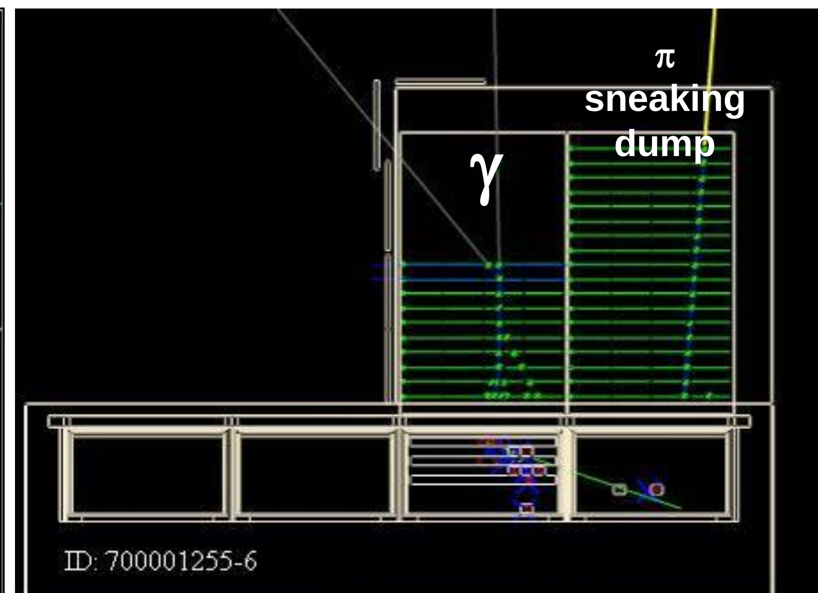

- **Front** (thin) conversion layers to have small multiple scattering errors at low energies
- **Back** (thick) layers to increase conversion probability

See Atwood *et al.* 2007, Astropart.Phys.28:422-434

# From simulation to reconstruction

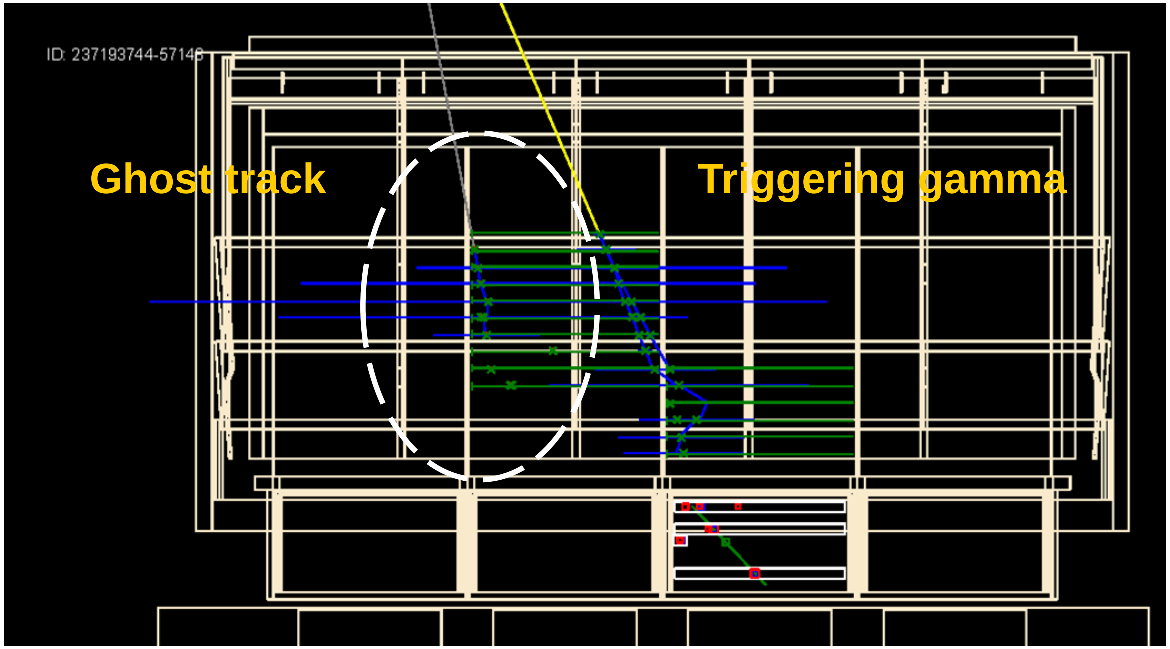
- ❑ **Accurate detector model**
  - – **>45k volumes**
- ❑ **Physical interactions modeled with Geant4**
- ❑ **MC validation**
  - – **ground test with CR muons on the full LAT**
  - – **beam test on a calibration unit**
    - – **100M evts of $\gamma$, e, p, e+, C, Xe between 50MeV and 300GeV collected at CERN and GSI in 2006**



# In flight response - pileup events

- CR rate is a steep function of earth magnetic field
- Fraction of off-time particles in the detector which leave ghost signal in coincidence with gammas
  - Between 2% and 15% depending on magnetic latitude
- Ghost effect
  - confuse/slow tracking and pattern recognition (→ CAL-seeded track recon)
  - Alter event topology and fake bkg rejection topological cuts



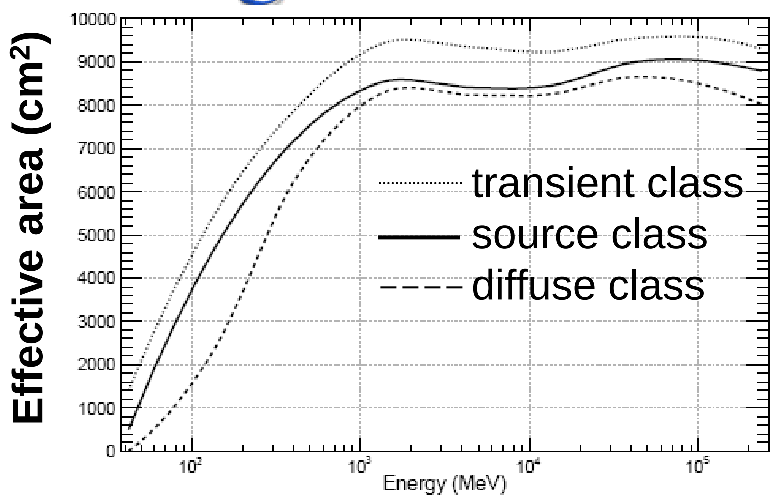
# Assessment of pile-up effects

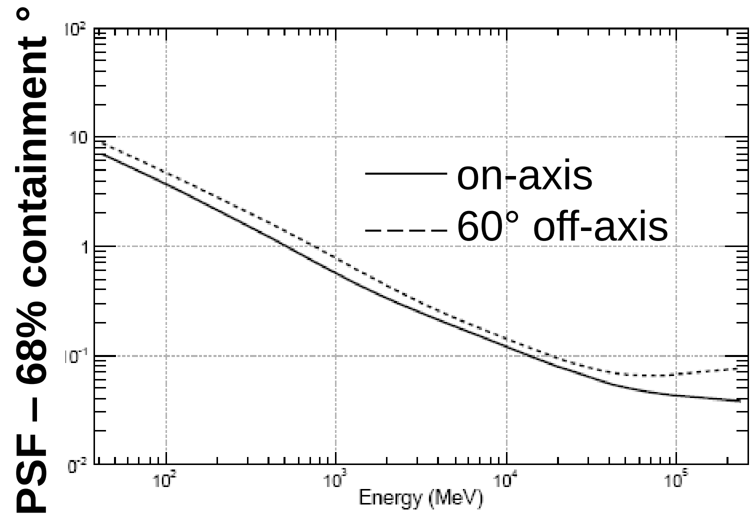
PRELIMINARY

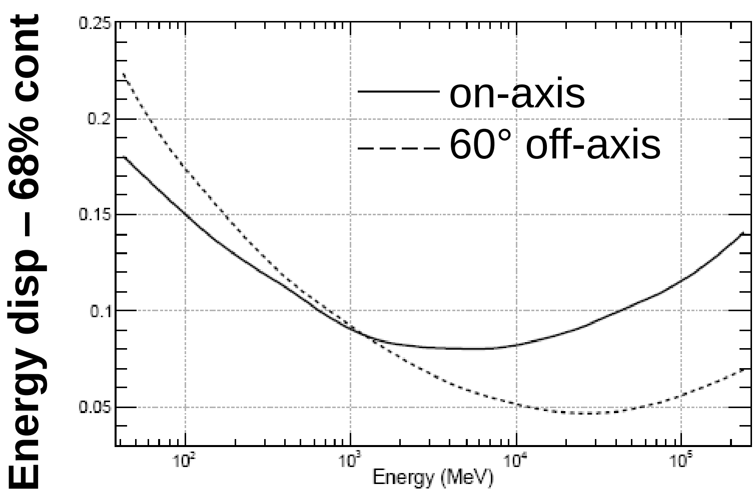
- Simulations enriched with ghosts from real periodic trigger events indicate
  - Larger effect at low energies
  - Maximum of 40% lower efficiency at 100MeV on-axis wrt pre-launch simulations
  - Rapidly decreasing with energy - negligible above 10GeV
  - Maximum effect on flux (over all spectrum) → 30% bias
  - Maximum effect on spectral parameters (for $E^{-2}$ power law) → 0.1 bias
- Very close to early papers assessment of systematics
  - Much reduced systematics when corrected for!
- On-going work for corrections
  - Correct IRFs for difference using simulations with ghosts
  - Filter ghost events before recon
  - Retrain event selection after addition of ghost in simulation + recon-filtering → release post-launch IRFs for public data

# Instrument Response Functions

Google: lat performance → http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm



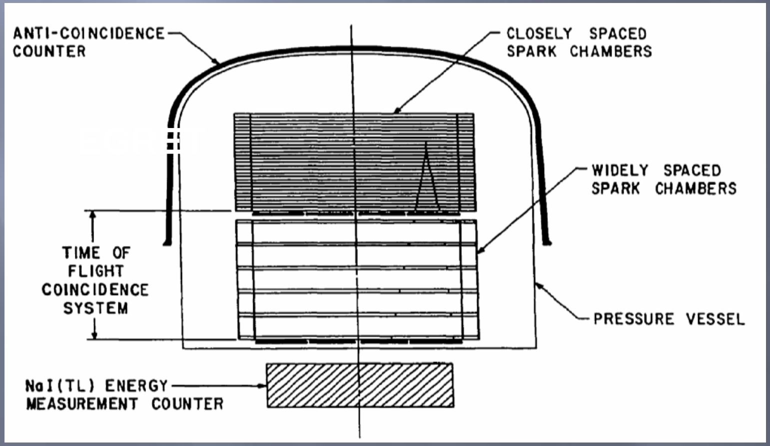




- Instrument response mapped into analytical functions or simple tables
- General simulation for all-purpose analysis vs specific analysis MC sim
- Serve large community of users
- Systematics from response representation choice and MC fidelity

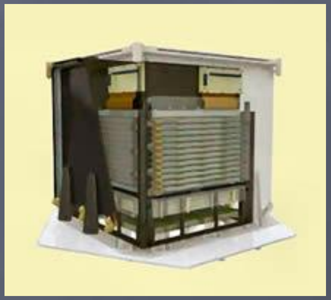
# LAT as a telescope

| | Years | Ang. Res. (100 MeV) | Ang. Res. (10 GeV) | Eng. Rng. (GeV) | $A_{eff}\,\Omega$ ($cm^2$ sr) | # γ-rays |
|---|---|---|---|---|---|---|
| **EGRET** | **1991–00** | **5.8°** | **0.5°** | **0.03–10** | **750** | **$1.4 \times 10^6$/yr** |
| **AGILE** | **2007–** | **4.7°** | **0.2°** | **0.03–50** | **1,500** | **$4 \times 10^6$/yr** |
| ***Fermi* LAT** | **2008–** | **3.5°** | **0.1°** | **0.02–300** | **20,000** | **$1 \times 10^8$/yr** |

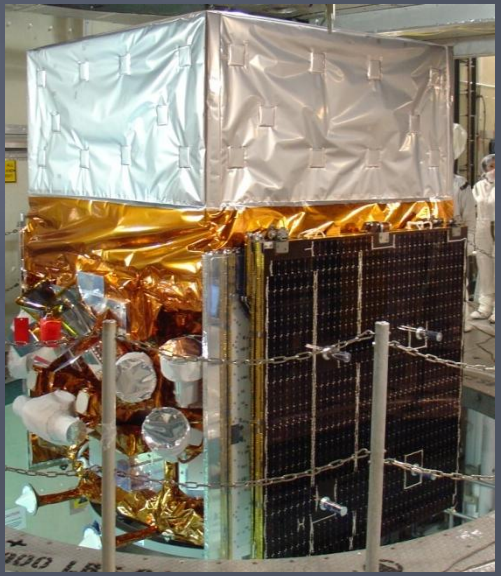
- After 3 months LAT has surpassed EGRET and AGILE celestial γ-ray totals
- Unlike EGRET and AGILE, LAT is an effective All-Sky Monitor
  whole sky every ~3 hours




CGRO EGRET



AGILE (ASI)

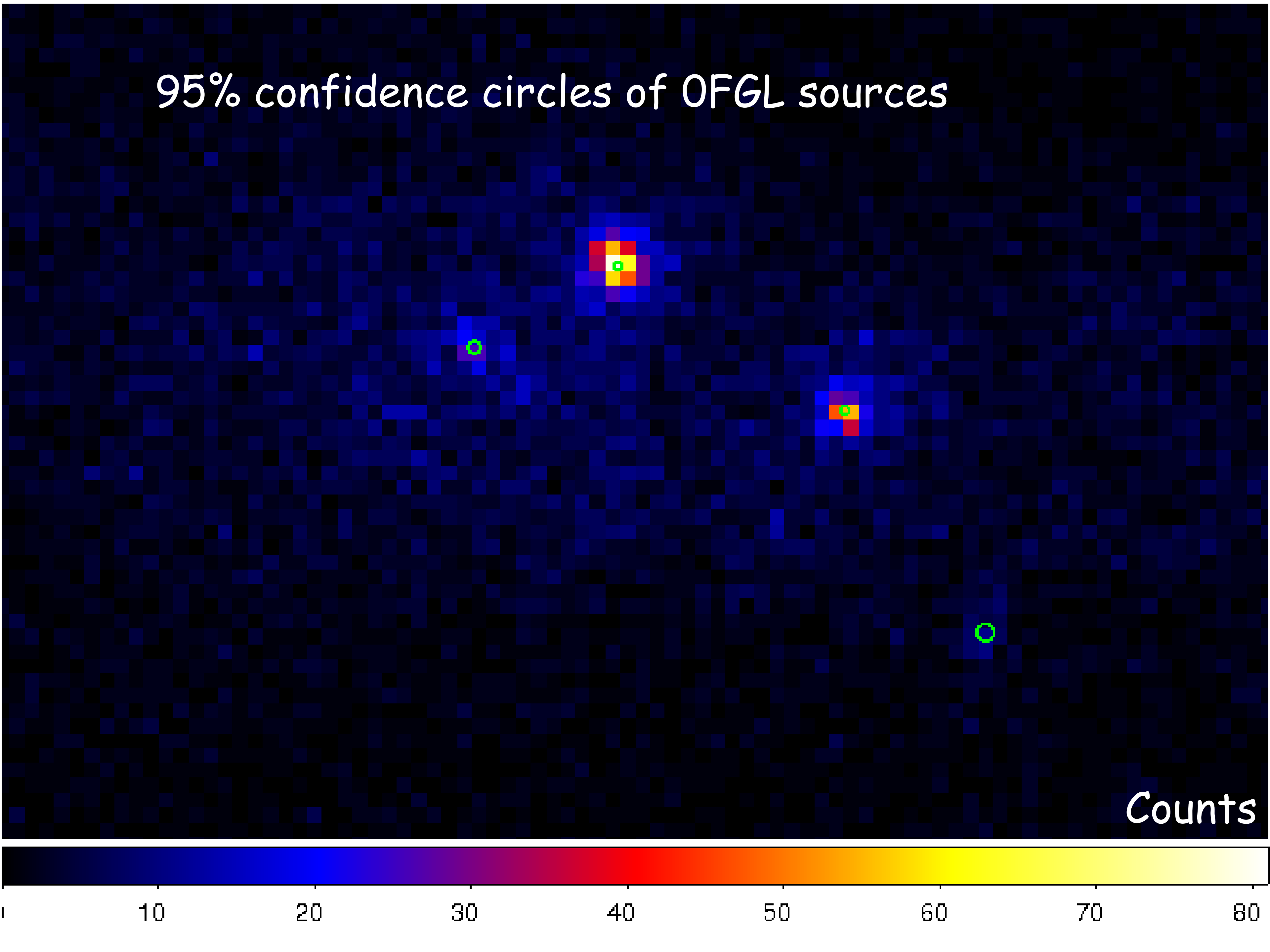


Fermi / LAT

# The LAT Bright Source List (0FGL)

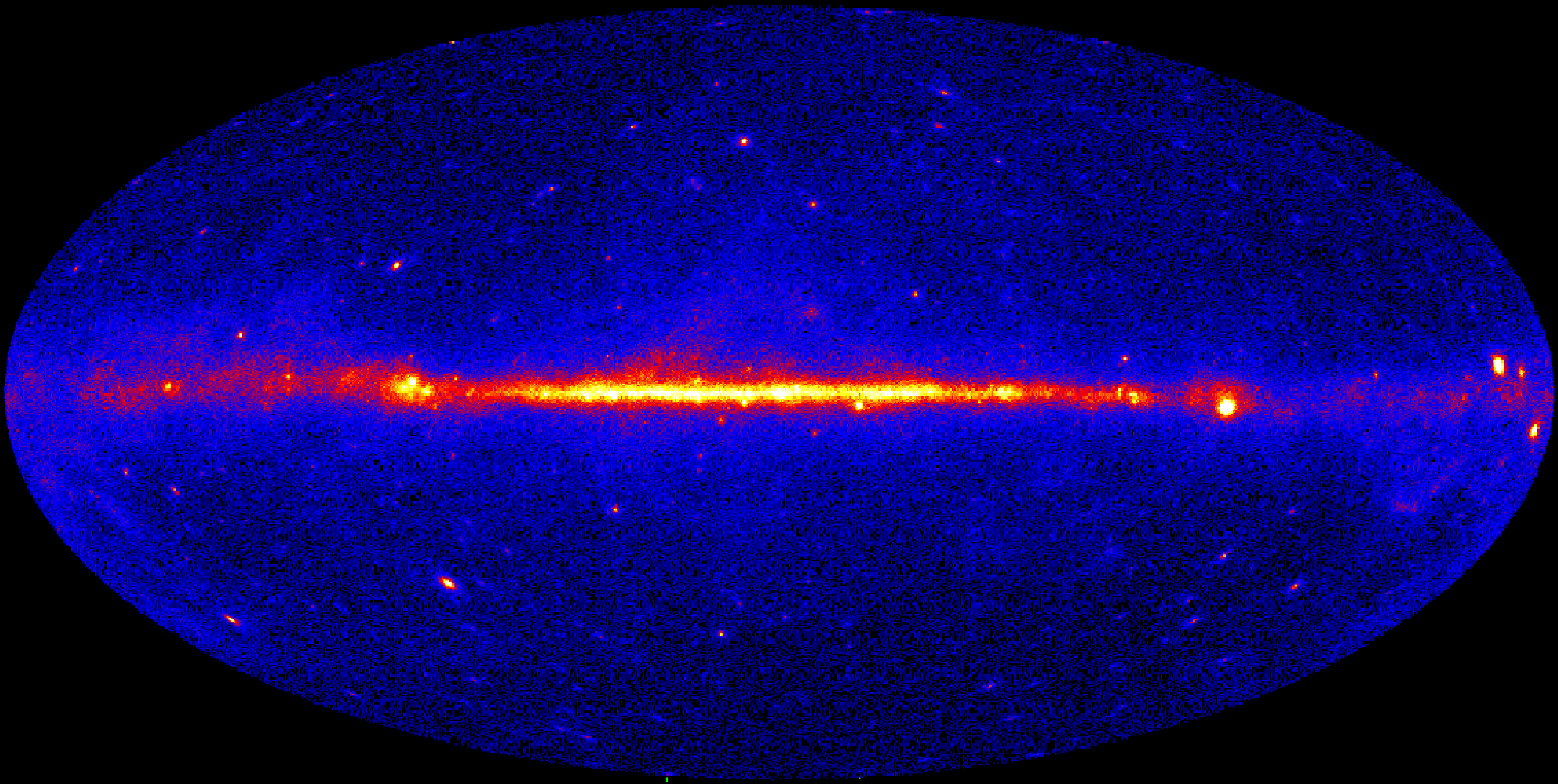
- 1.8 M events above 200 MeV with current cuts over 3 months
- Wavelet analysis (peak detection) for source detection
  1. Front events > 200 MeV + Back events > 400 MeV
  2. Front events > 1 GeV + Back events > 2 GeV
- Large overlap at low energy ➔ Maximum likelihood analysis for locations, source significance, fluxes below and above 1 GeV, and variability information.
- Confidence level greater than **10 σ** over 3 months. Not uniform - sources near the Galactic plane must be brighter because of the strong diffuse background
- Associations with known sources

The Point Spread Function is key to source detection and identification



95% confidence circles of 0FGL sources
Counts
10
20
30
40
50
60
70
80

# 205 LAT Bright Sources



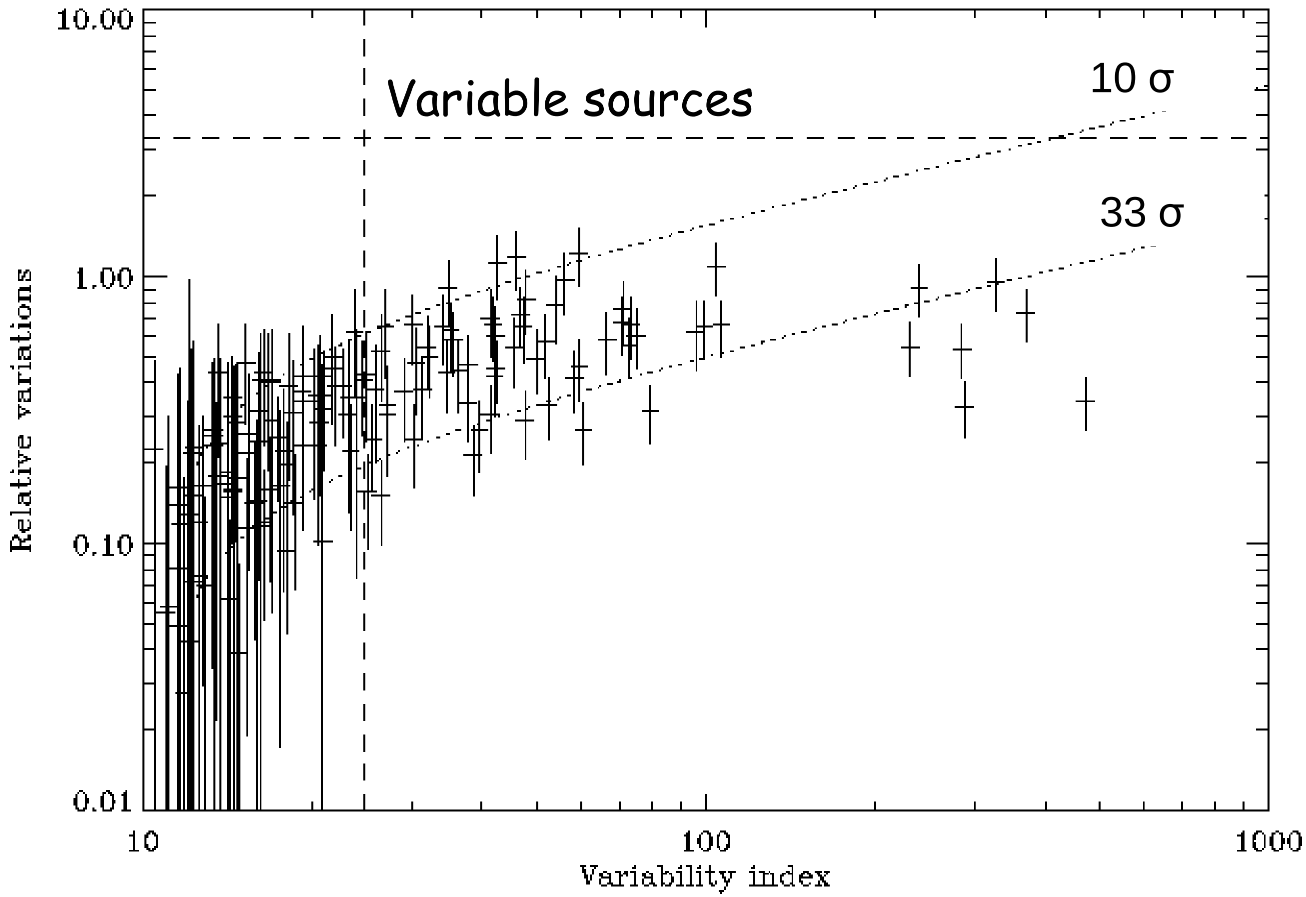
Front > 200 MeV, Back > 400 MeV

Crosses mark source locations, in Galactic coordinates. 1/3 at |b| < 10°.
Only 60 clearly associated with 3EG EGRET catalog. The sky changes!

# Source variability

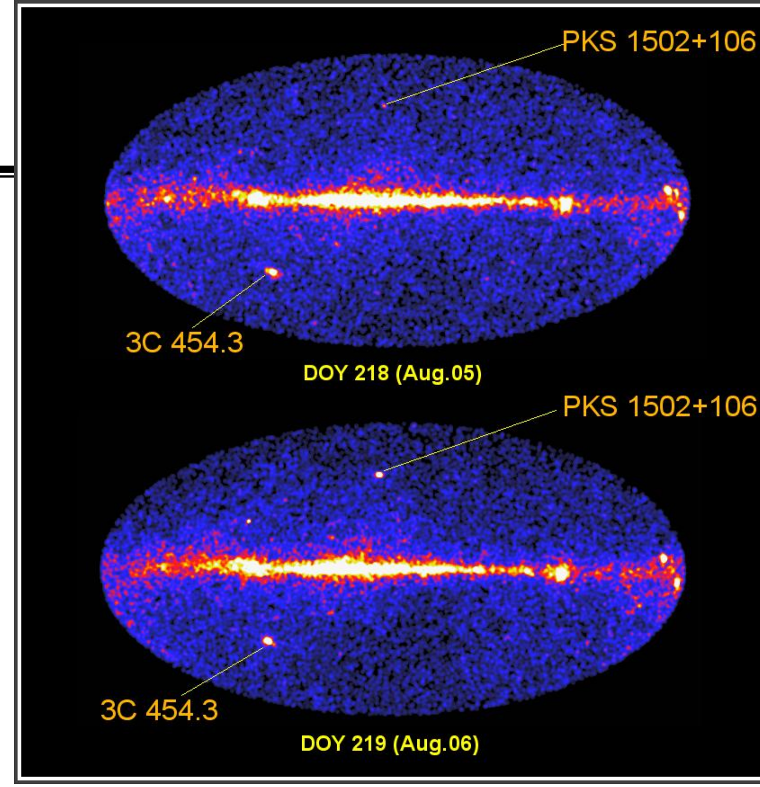
- Flag as variable for probability < 1%
- 1/3 sources flagged as variable
- Not very large fractional variability

**arXiv:0902.1340**
**ApJS accepted**

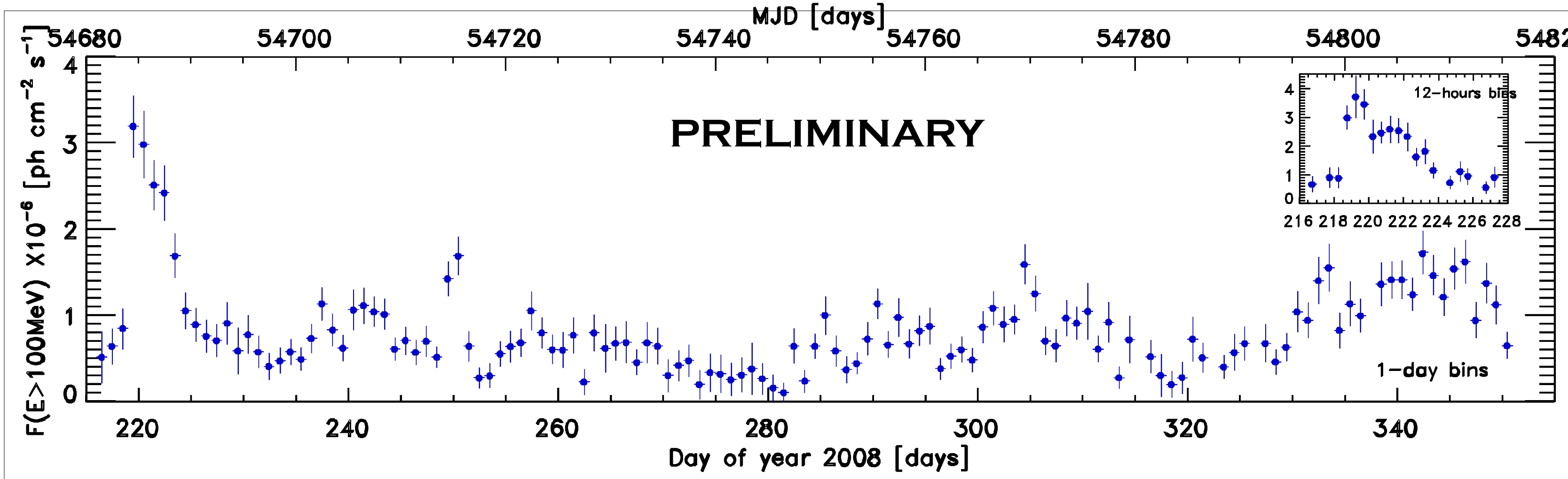


Fermi
Gamma-ray
Space Telescope

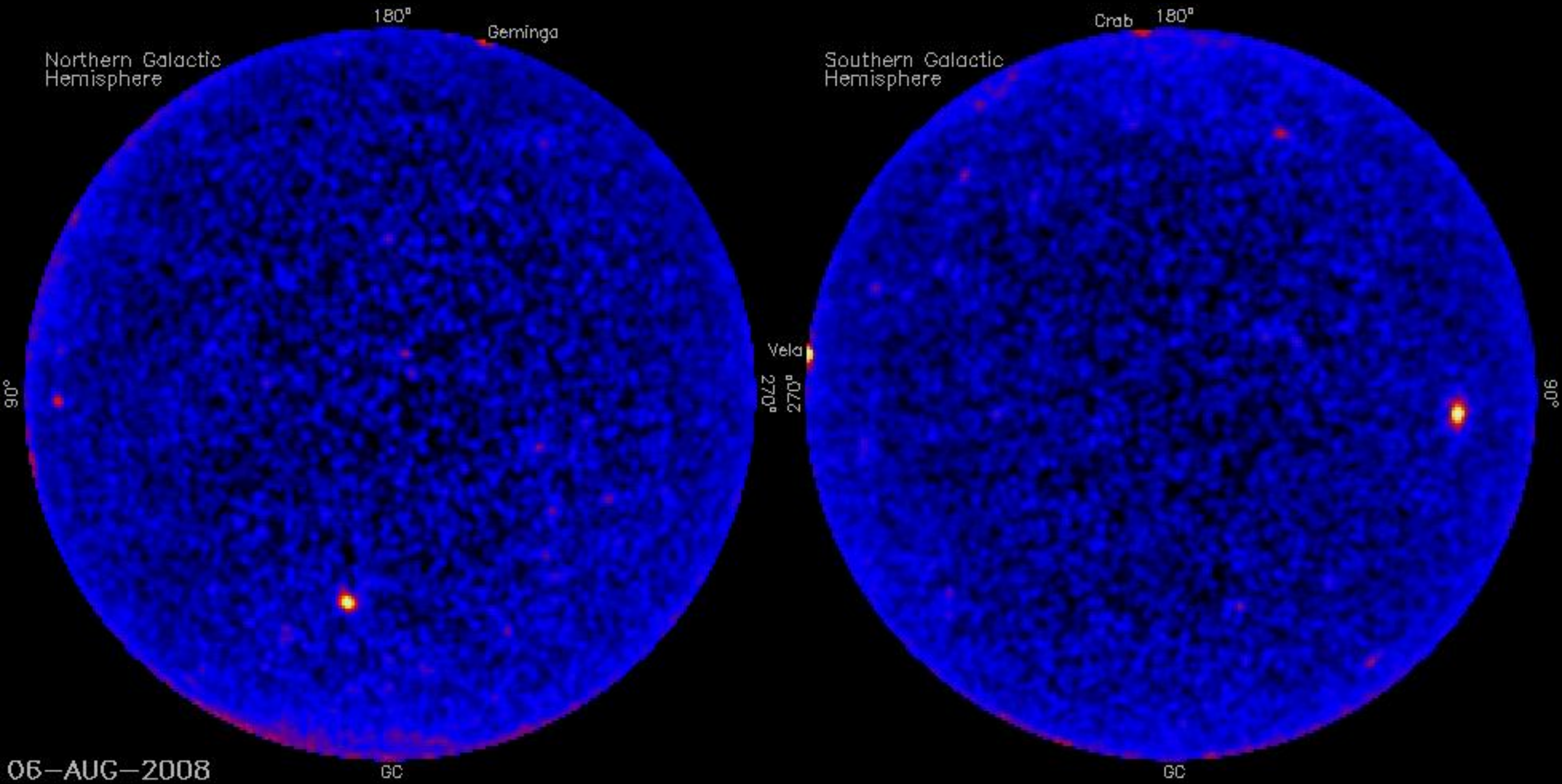
# Rapid variability




- PKS 1502+106 (aka OR 103), at z=1.84 (SDSS)
- **Extremely rapid flare, possibly the highest ΔL/Δt detected to date in the GeV band** (inset in the light curve)
- Flares reported via ATels (30) and light curves posted at FSSC



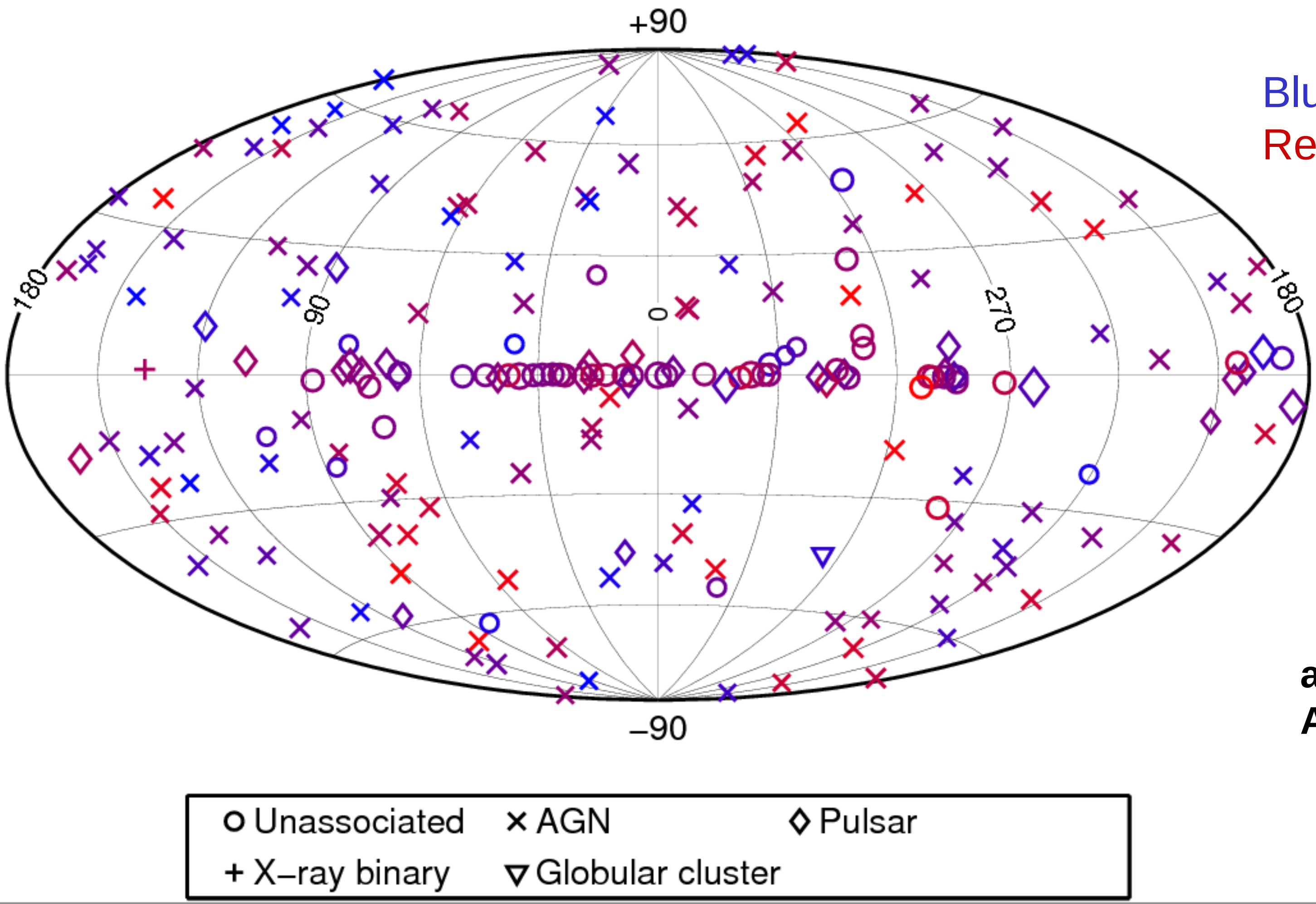
# The variable Fermi sky




1-day snapshots, > 100 MeV, viewed from the poles (orthographic proj).
Red is significant.
The Sun is clearly visible moving downwards right of the North pole

# Source association

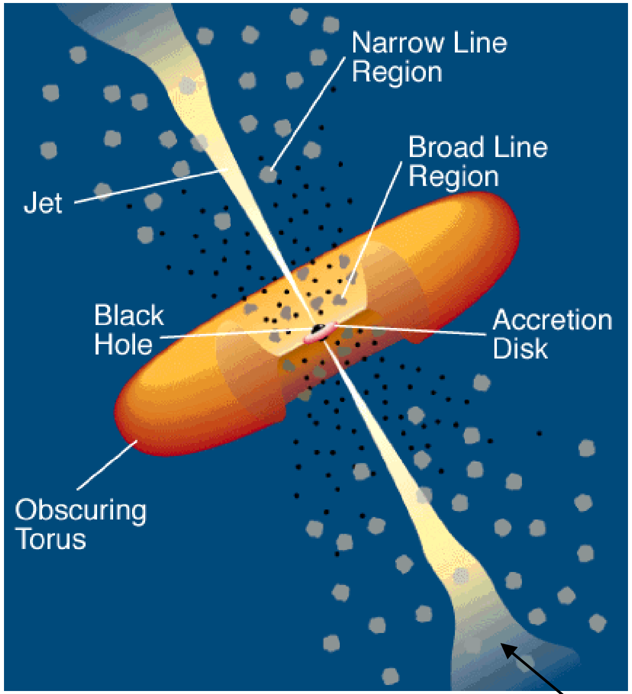
- 2/3 of the sources at |b|>10°, mostly AGN
- Not that many unassociated outside the plane
- Globular cluster 47 Tuc (plenty of ms pulsars), LMC / 30 Dor (diffuse)




Blue is hard
Red is soft

**arXiv:0902.1340**
**ApJS accepted**

# Blazars




Almost all galaxies contain a massive black hole
-99% of them are (almost) silent (e.g. our Galaxy)

-1% per cent is active (mostly radio-quiet AGNs): BH+disk: most of the emission in the UV-X-ray band

0.1% is radio loud: jets mostly visible in the radio

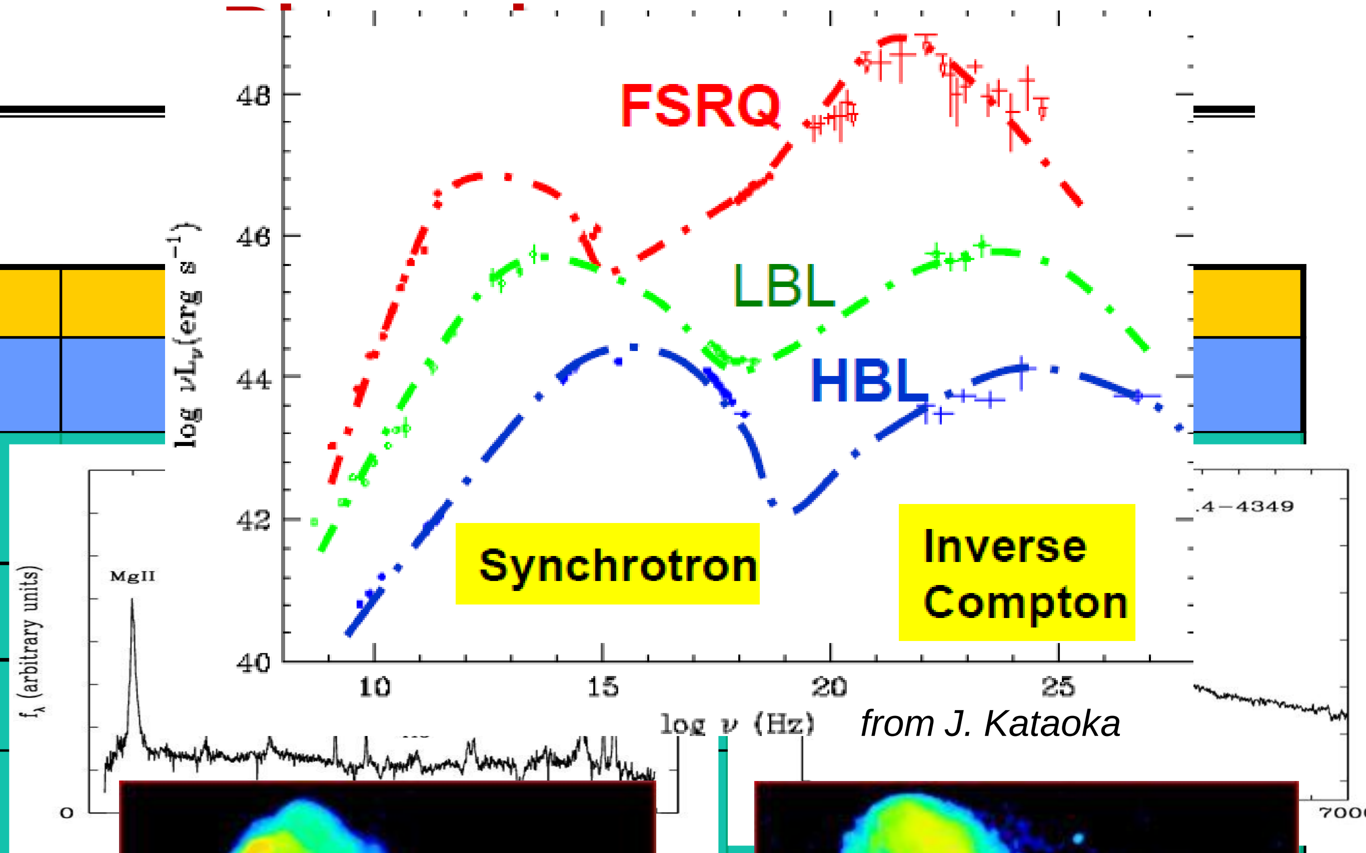
**Blazar characteristics**

- Compact radio core, flat or inverted spectrum
- Extreme variability (amplitude and t) at all frequencies
- High optical and radio polarization

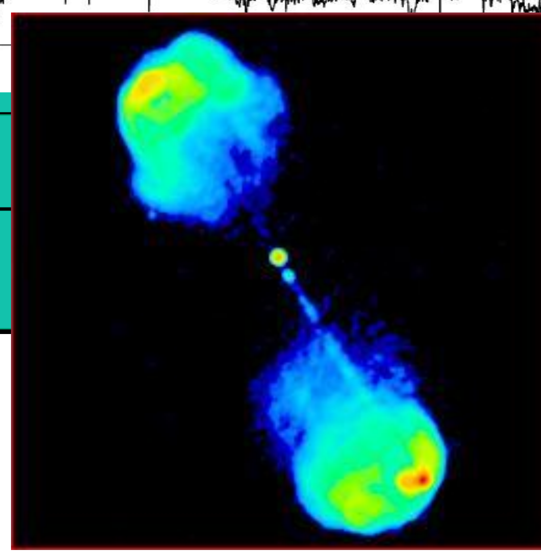
**FSRQs:** bright broad (1000-10000 km/s) emission lines often evidences for the “blue bump” (acc. disc)

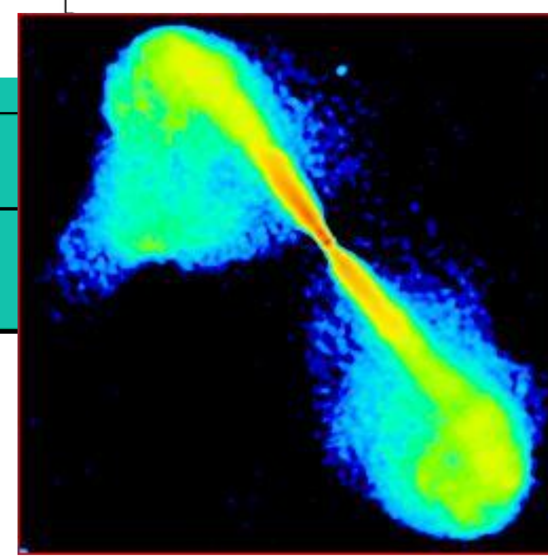
**BL Lac**: weak (EW<5 Å) emission lines no signatures of accretion

| class | |
|---|---|
| defining property | |
| environment | |
| Power | |
| Parent population | |
| Synchrotron hump in SED | |
| EGRET-detected | |
| Redshift of EGRET sources | |




from J. Kataoka



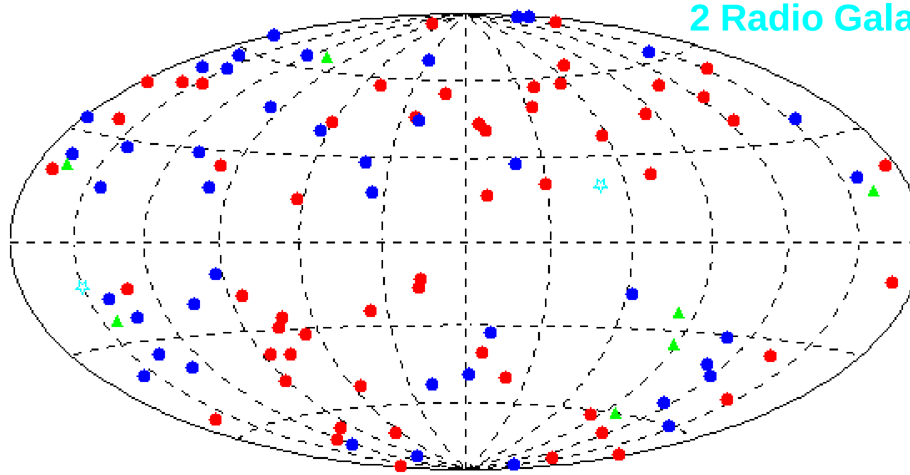


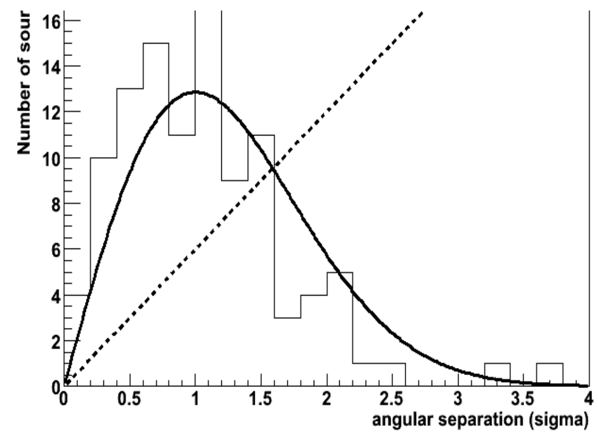
# LAT Bright AGN Sample (LBAS)

- 125 non-pulsar sources at |b|>10°
- 106 high-confidence (P>90%) associations with AGNs: (LBAS)
- 10 lower-confidence associations
- FSRQs: 57
- BLLacs: 42
- Uncertain class: 5
- Radiogalaxies: Cen A, NGC1275
- 40% BLLacs (23% for EGRET)
- 7 HBLs (3+1 for EGRET)
- 9 unidentified (3EG: 96/181 at |b|>10°)

**arXiv:0902.1559**
**ApJ accepted**

57 FSRQ
42 BLLac
5 of Uncertain class
2 Radio Galaxies





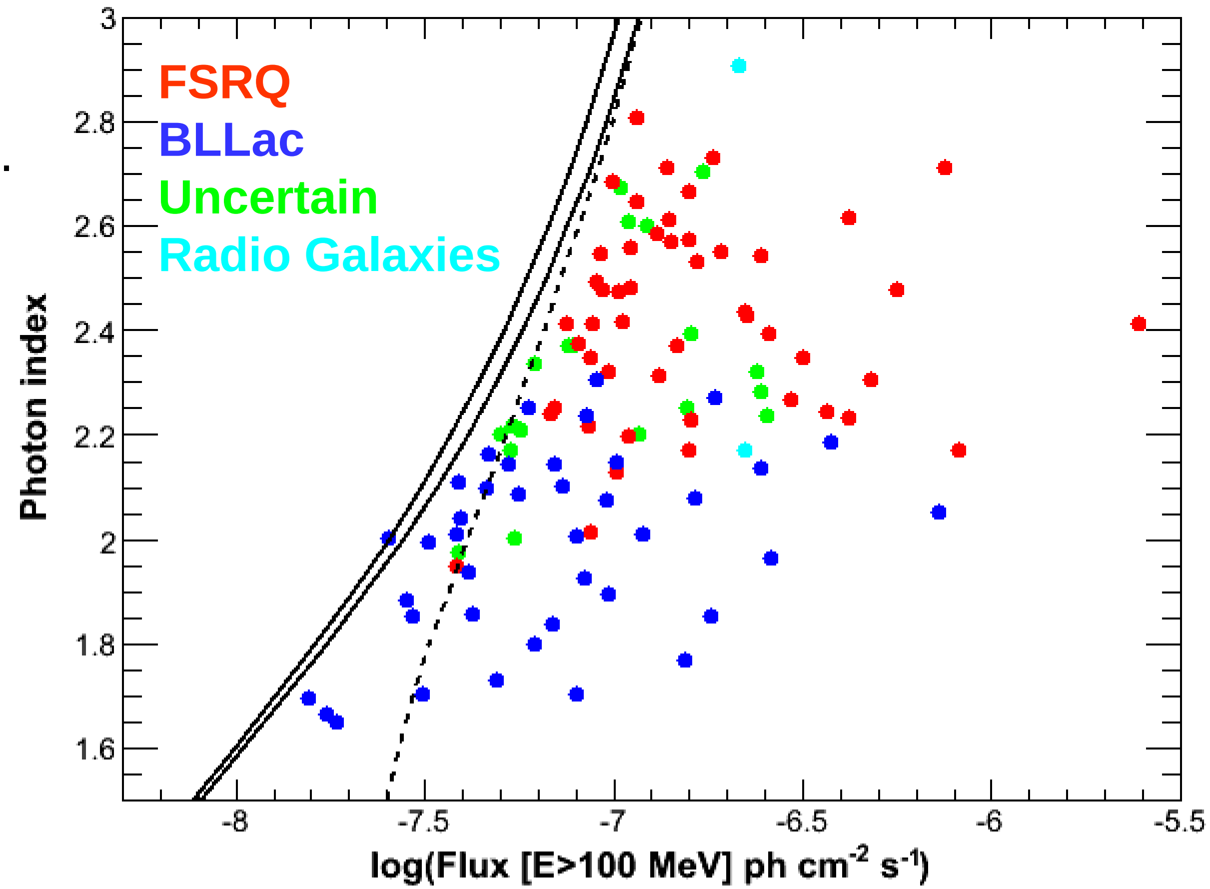

$\Theta_{95\%}$ ~0.14° (EGRET sample ~0.62°)

# Flux vs index

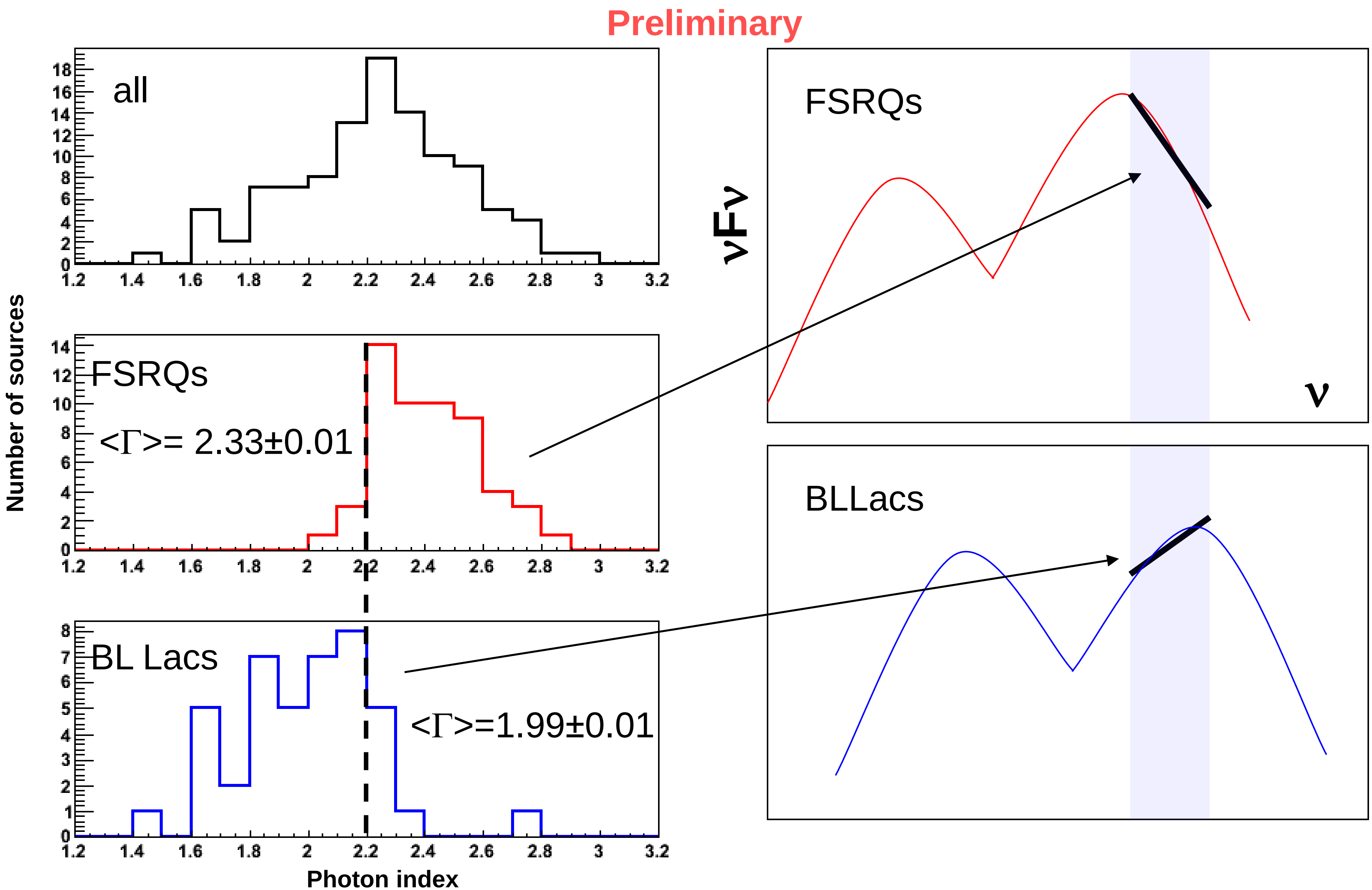
Preliminary

TS=100
b=20, 80 deg.

TS=100
b= 20 deg.
E< 3 GeV

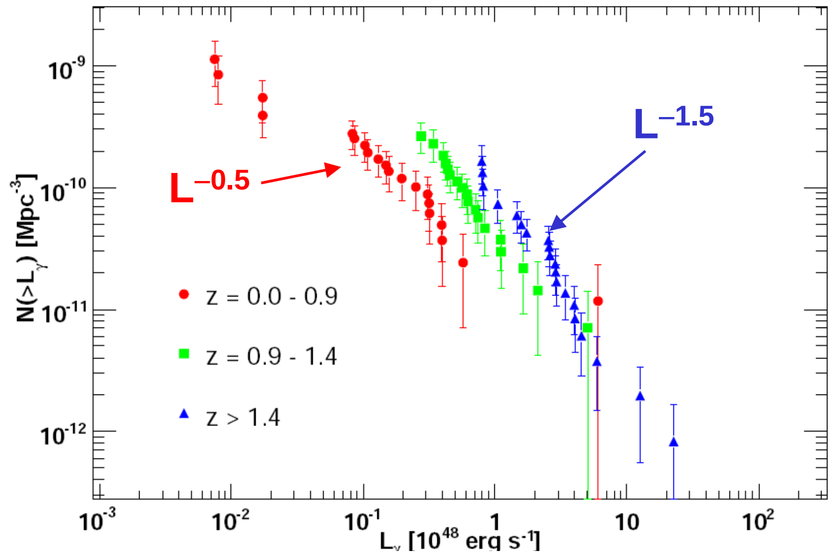


# Photon index distributions

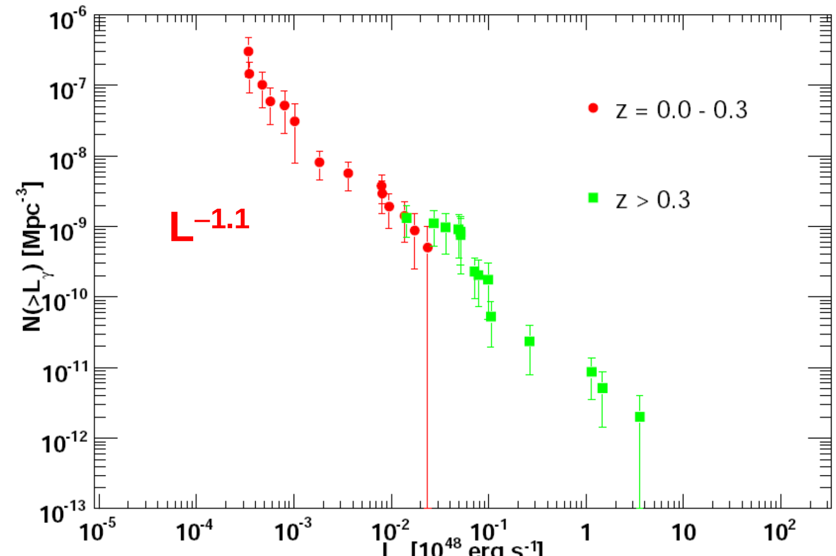


# Luminosity Functions

- **FSRQs**
  - **Strong evolution**
  - **More complicated than pure density or pure luminosity evolution**
  - **The 3 month LAT AGN sample measures the bright end of the luminosity distribution**




- **BL Lac objects**
  - **No evidence of evolution**



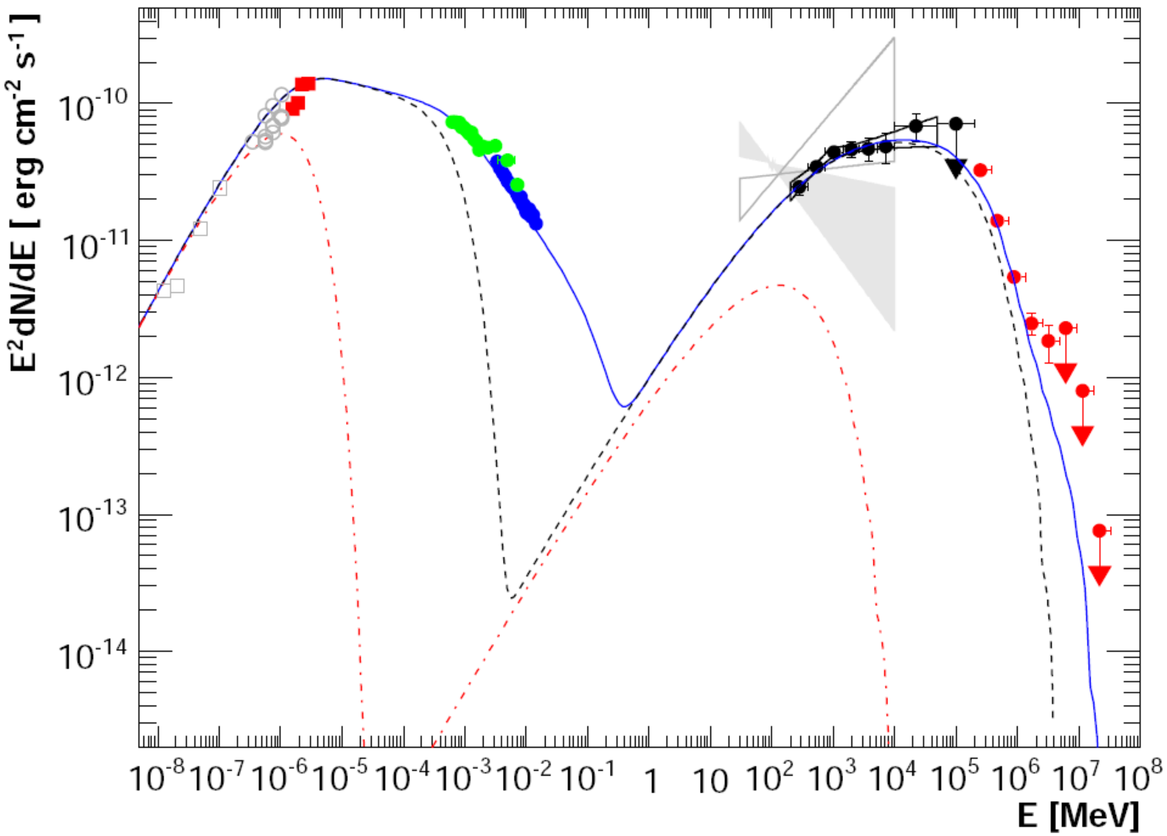

- **Combined emission from individual blazars in 3 month sample corresponds to 7% of EGRET extragalactic diffuse**

**(contact: M. Ajello)**

# Spectral coverage

LAT energy range is very broad (20 MeV - 300 GeV), includes the largely unexplored range between 10 and 100 GeV

Allows ground-based TeV data to be combined with the space-based GeV data. Multi-wavelength campaigns are regularly organized.




SED for PKS 2155-304

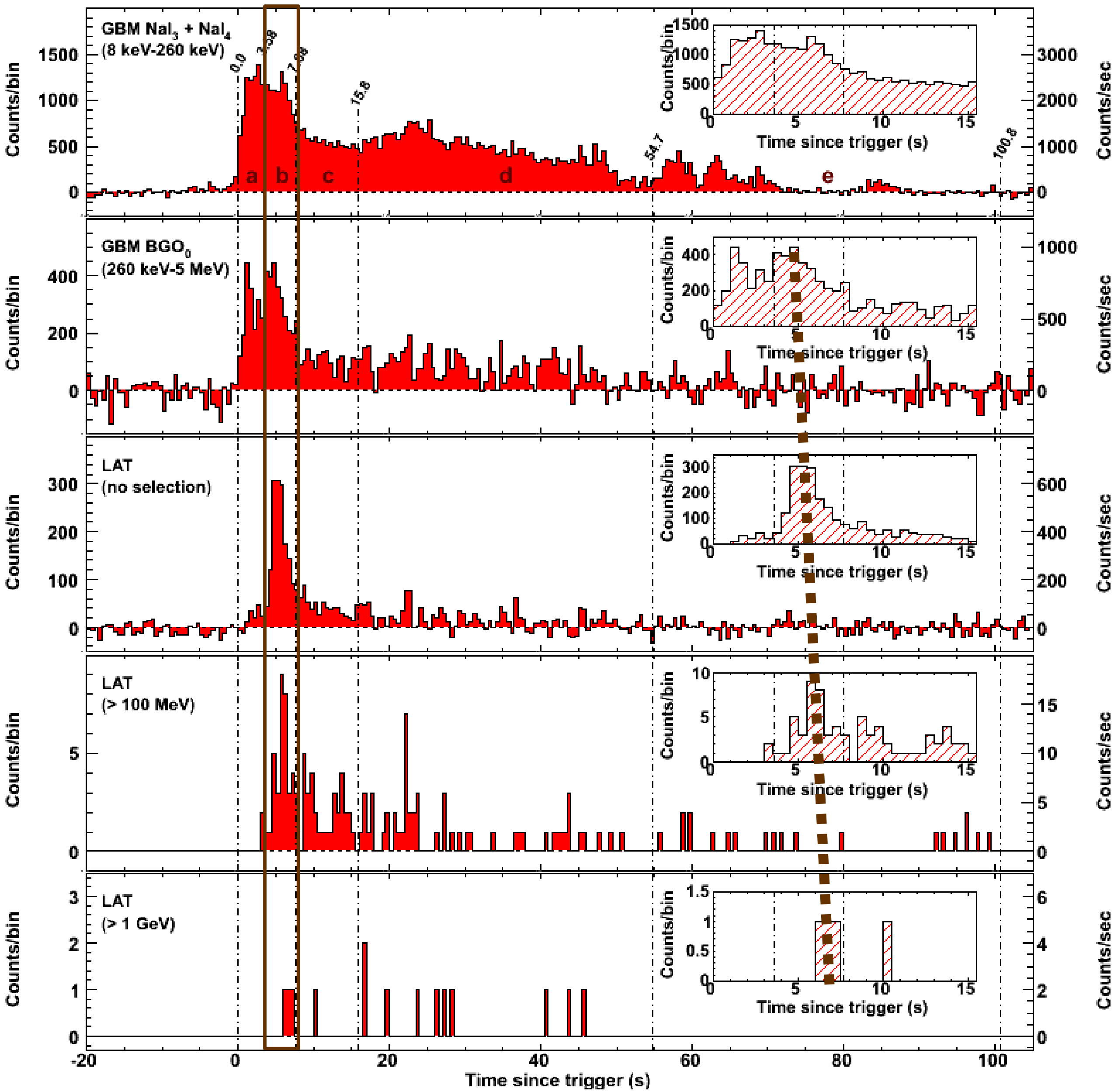
**Abdo et al. 2009**
**ApJ 696, L150**

# Fermi GRB detections

- **GBM**:
  - Detection rate: ~200-250 GRB/yr, 17% short
  - A fair fraction are in LAT FoV
  - Automated repoint enabled

- **8 LAT detections in first 10 months**
  - GRB080825C [GCN 8183 – Bouvier, A. et al.]
  - GRB080916C (z=4.35) [GCN 8246 – Tajima, H. et al.]. Bright!
  - GRB081024B [GCN 8407 – Omodei, N. et al.] First short GRB
  - GRB081215A [GCN 8684 – McEnery, J. et al.]
  - GRB090217 [GCN 8903 – Ohno. et al., GCN 8902, von Kienlin. et al.]
  - GRB090323 (z=3.6) [GCN 9021 – Ohno et al.]
  - GRB090328 (z=0.7) [GCN 9044 McEnery et al.]
  - GRB090510 (z=0.9), [GCN 9021 – Ohno et al; GCN 9350 Omodei et al.] Short, extremely intense

# GRB080916C: multi-detector light curve

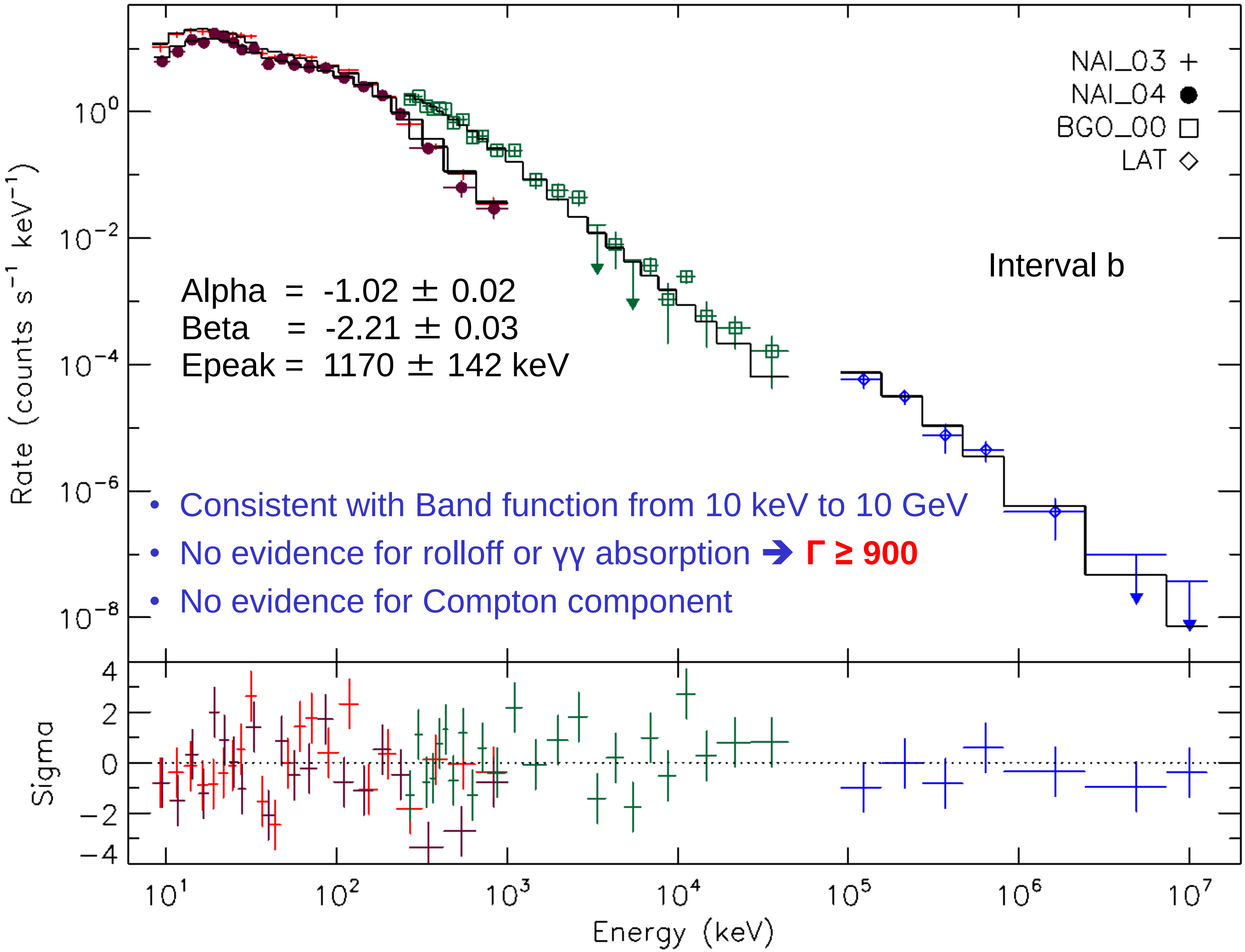



**$z = 4.35$ (optical)**

- Most of the emission in the 2nd peak occurs later at higher energies
- This is clear evidence of spectral evolution
- The delay of the HE emission seems to be a common feature of the GRBs observed by the LAT so far
- Highest energy photon (13 GeV) 16.5 s after $t_0$
  Quantum gravity limit
  $M_{QG,1} > 1.5\ 10^{18}$ GeV/c$^2$

**Abdo et al. 2009**
**Science 323, 1688**

# GRB080916C: spectrum



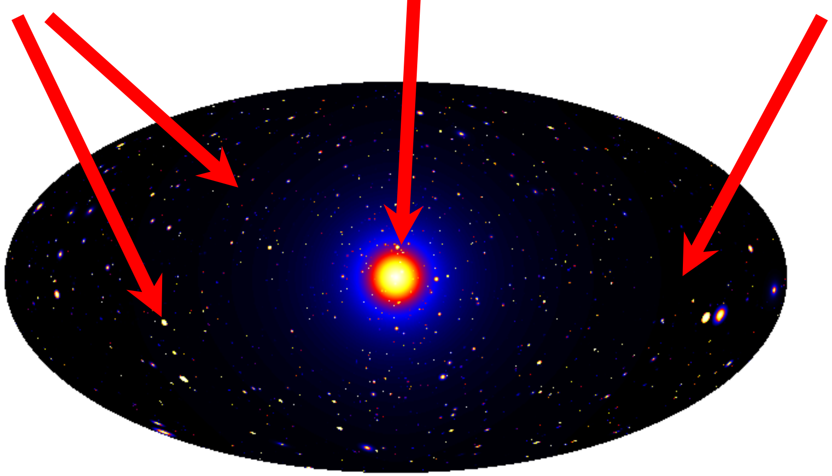

- Consistent with Band function from 10 keV to 10 GeV
- No evidence for rolloff or γγ absorption ➔ **Γ ≥ 900**
- No evidence for Compton component

# Dark matter: search strategies

**Satellites**:
Low background and good source id, but low statistics, astrophysical background

**Galactic center:**
Good Statistics but source confusion/diffuse background

**Milky Way halo:**
Large statistics but diffuse background



SIMULATION

All-sky map of DM gamma ray emission (Baltz 2006)

**Spectral lines:**
No astrophysical uncertainties, good source id, but low statistics

**Extra-galactic:**
Large statistics, but astrophysics, galactic diffuse background

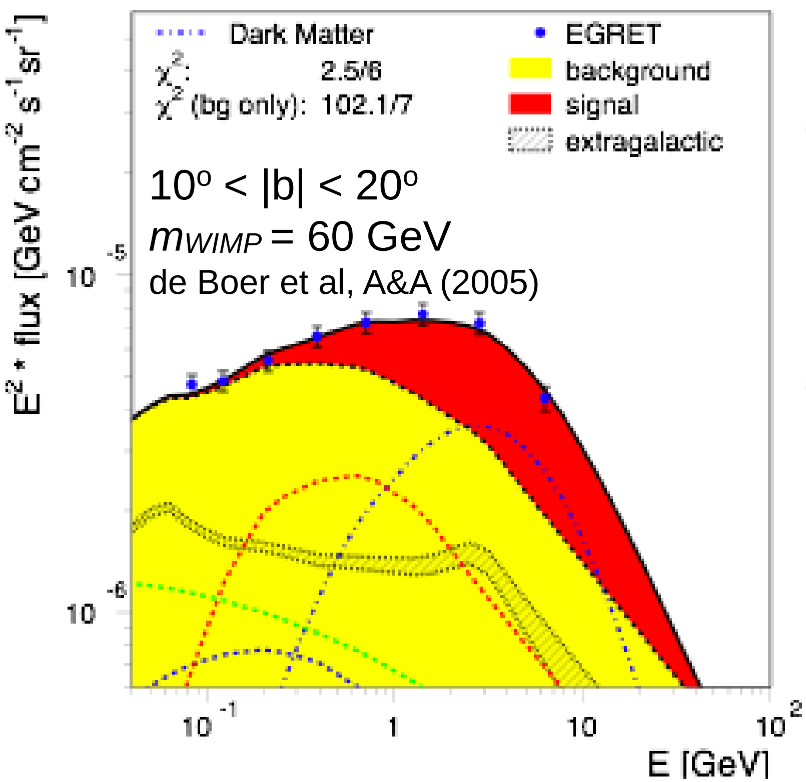
Uncertainties in the underlying particle physics model and DM distribution affect all analyses

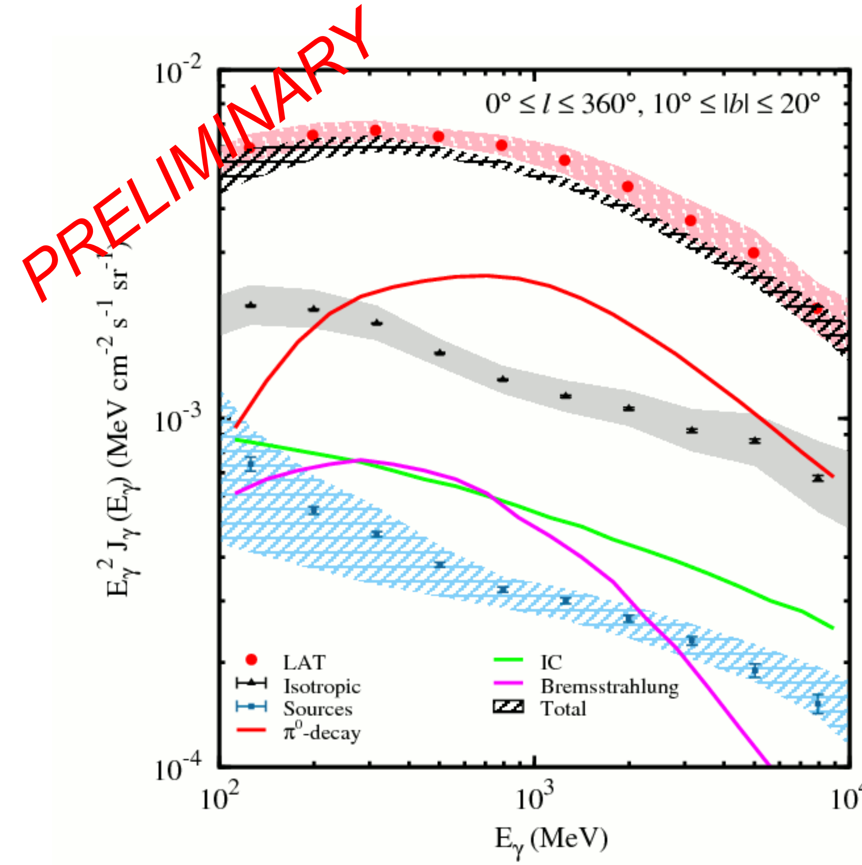
Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

# EGRET GeV Excess

EGRET observed an all sky excess in the GeV range compared to predictions from cosmic-ray propagation and γ-ray production models which could be attributed to dark matter annihilation

**The data collected by the Fermi LAT during the first 5 months of operation does not confirm the excess at intermediate latitudes and strongly constrains dark matter interpretations**

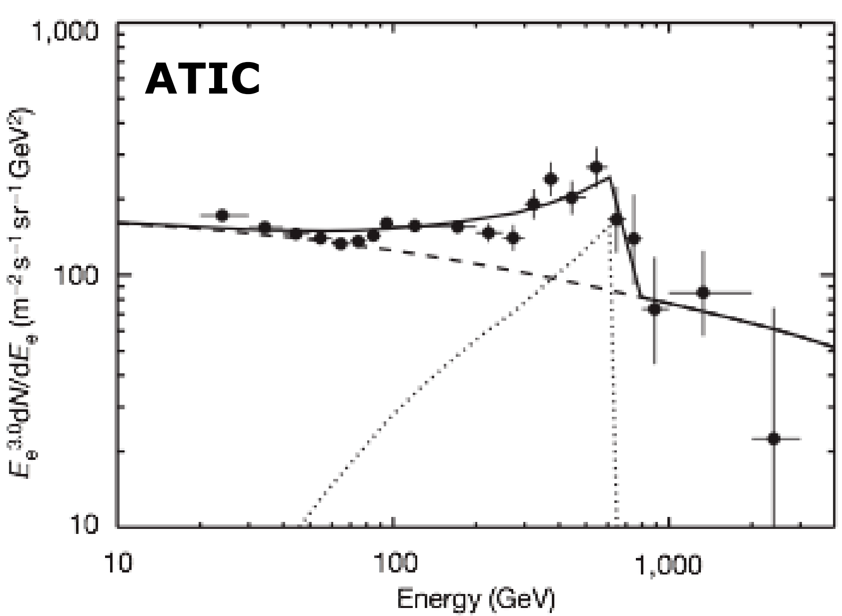


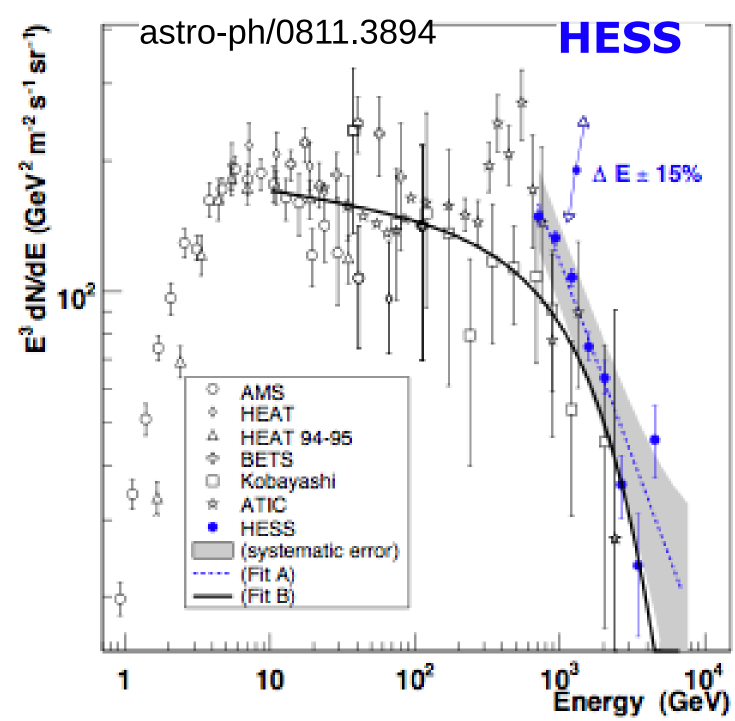
# CR $e^+e^-$ measurements

- ✓ATIC has observed an excess of electrons in the 300-800 GeV range with a steepening at the high energy end also observed by HESS
- ✓In addition to astrophysical explanations for these measurements (nearby source of high energy electrons), heavy dark matter primarily annihilating into leptons, such as suggested by UED theories, could explain the excess and the high energy downturn

The Fermi LAT is an excellent electron+positron detector (but it can't discriminate charge)
Measures combined CR e+p spectrum (up to energies of ~1 TeV) with very large statistics

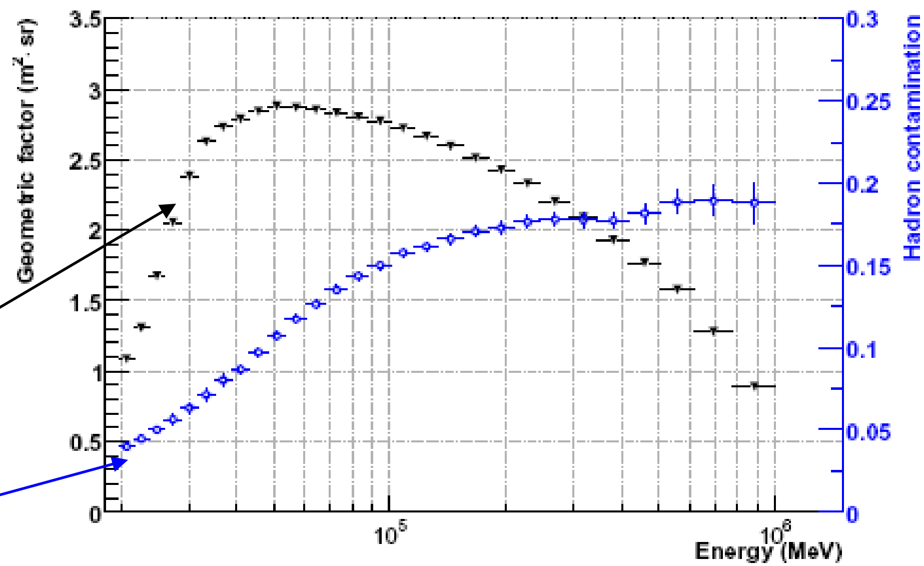



Chang et al., Nature **456**, 362-365 (2008)



# Electron-hadron separation

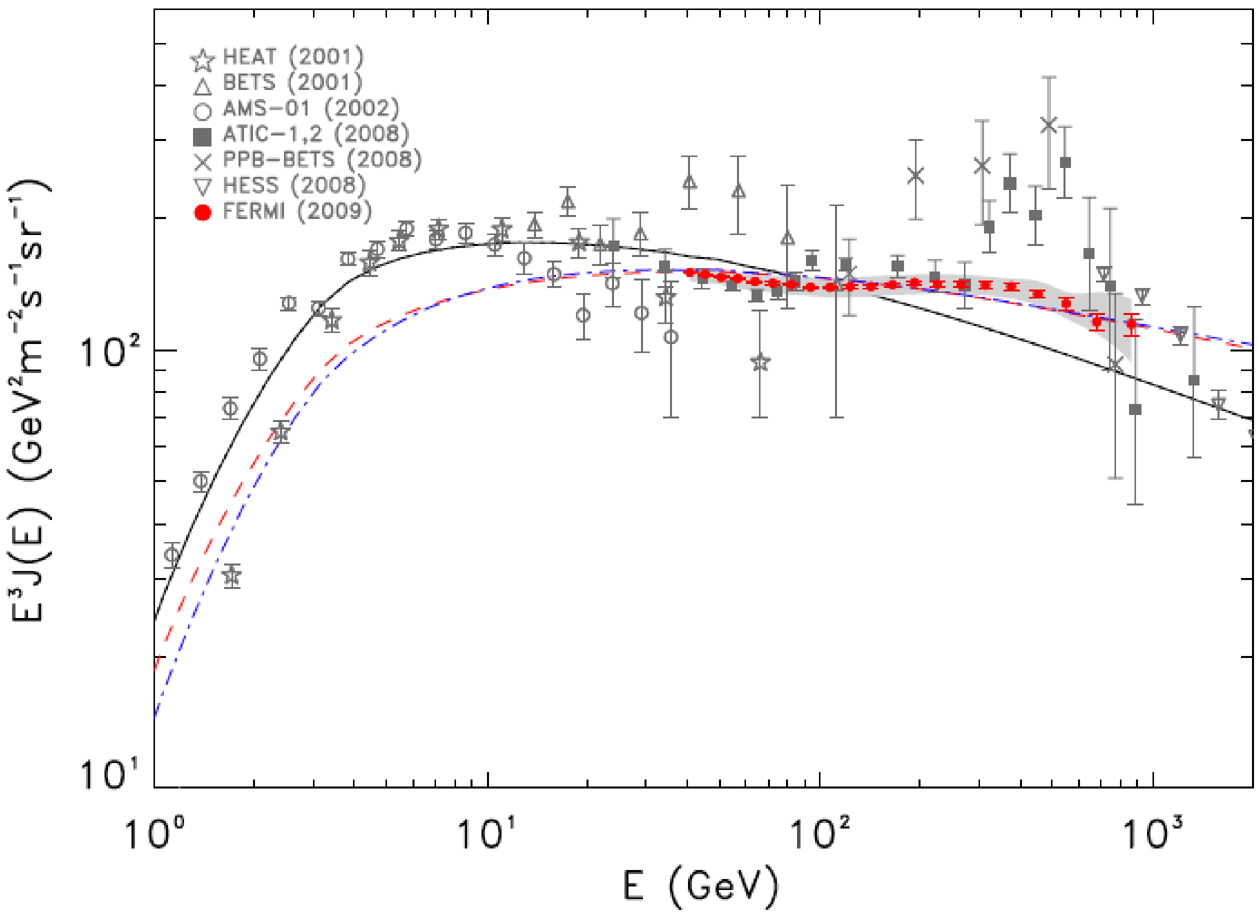
- Candidate electrons pass on average **12.5 $X_0$** ( Tracker and Calorimeter added together)
- Simulated residual hadron contamination (5-17% increasing with the energy) will be deducted from resulting flux of electron candidates
- Effective geometric factor exceeds 2.5 $m^2 sr$ for 30 GeV to 200 GeV, and decreases to ~1 $m^2 sr$ at 1 TeV
- Full power of all LAT subsystems is in use: tracker, calorimeter and ACD act together




*Geometric Factor*

*Residual hadron contamination*

# Fermi-LAT electron-positron spectrum




**Harder spectrum than conventional cosmic-ray model (GALPROP) but no very large peak below 1 TeV**

**Abdo et al. 2009**
**PRL 102, 181101**

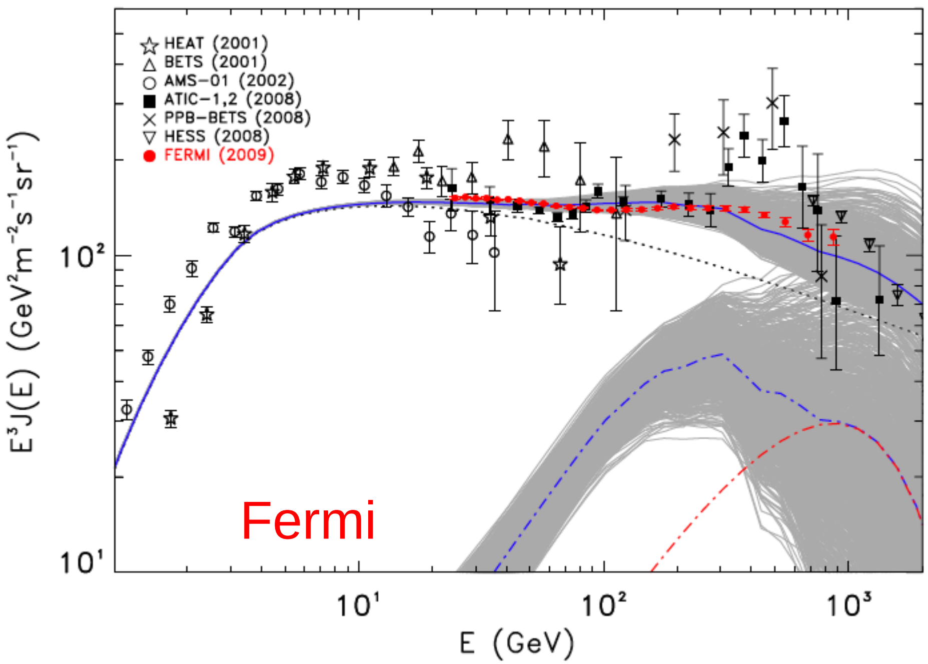
**<u>Total statistics</u> collected for 6 months of Fermi LAT observations**

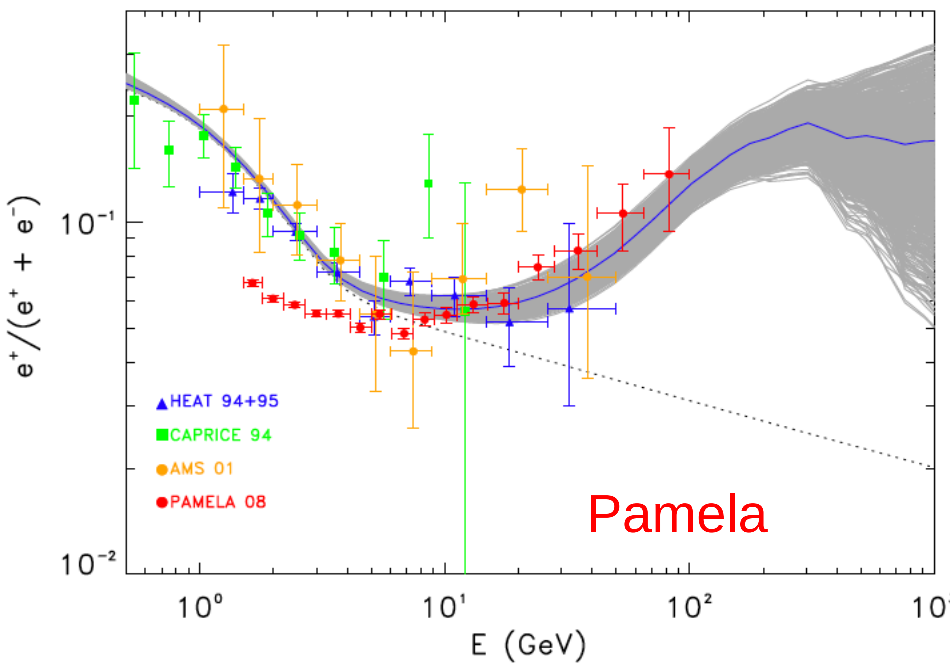
- **~4.5 million candidate electrons above 20 GeV**
- **544 candidate electrons in last energy bin (770-1000 GeV)**

# Pulsar origin of the bump?

Random variations of the **pulsar parameters** relevant for **e+e- production**

[*injection spectrum, e+e- production efficiency, PWN "trapping" time*]




Electron/positron **emission** from **pulsars** offers a **viable interpretation** of **Fermi** CRE data also **consistent** with the **HESS** and **Pamela** results

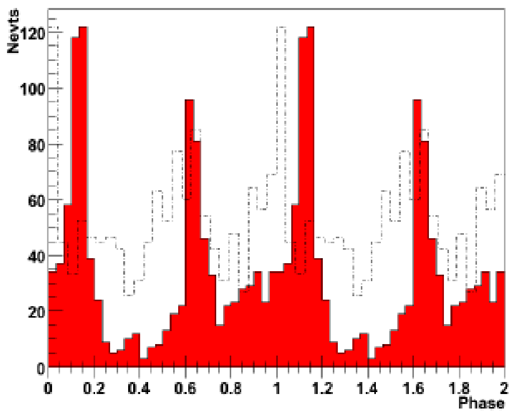
**But** not the only one

# Search for new γ-ray pulsars

6 known γ-ray pulsars from EGRET

One radio quiet (Geminga)

Look for others

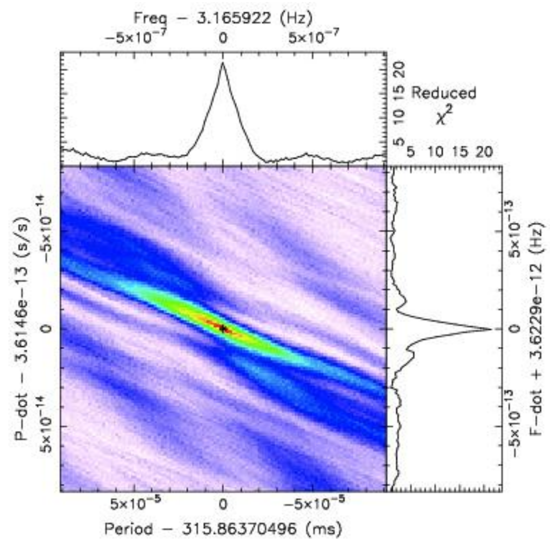



1. Radio-quiet gamma-ray sources list generated pre-Launch, with very accurate source locations from other wavelengths.
   a. 3EG J1835+5918 (possibly the "next Geminga")
   b. Compact objects of Pulsar Wind Nebulae (PWNe)
   c. Milagro sources (e.g. MGRO J2019+37)

2. Fermi-LAT sources – a list of gamma-ray sources generated post-Launch with a Fermi localization

# The Blind Period Search

The spin parameters (frequency, spin-down) are unknown, so to resolve the phase plot, a search over f, df/dt parameter space has to be implemented to find the timing solution.




Limitations:

1. Gamma-ray photon data is exceptionally sparse ( < 0.5 photons/s).
2. Such long datasets make fully coherent methods like FFTs require large numbers of fdot trials to prevent smearing of the signal. This large number of trials would also greatly reduce the significance of the signal.
3. FFTs of this magnitude require large amounts of memory: 1 month @ 64 Hz = 331 million bins = 5.3 GB of memory!
4. If the pulsar were to glitch (suddenly change its frequency), then the signal power would diminish greatly.

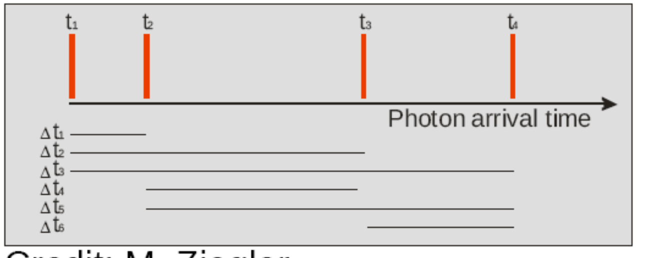
# The "Time-Differencing" Technique

Periodicity in photon arrival times will also show up in differences of photon arrival times.

Time differences cancel out long term phase slips and glitches because differencing starts the "clock" over (and over, and over...)

Despite the reduced frequency resolution (and therefore number of bins), the sensitivity is not much reduced because of a compensating reduction in the number of fdot trials

Atwood et. al., **ApJ Lett., 652, 49 (2006)**
Ziegler et. al., **ApJ 680, 620 (2008)**




Credit: M. Ziegler

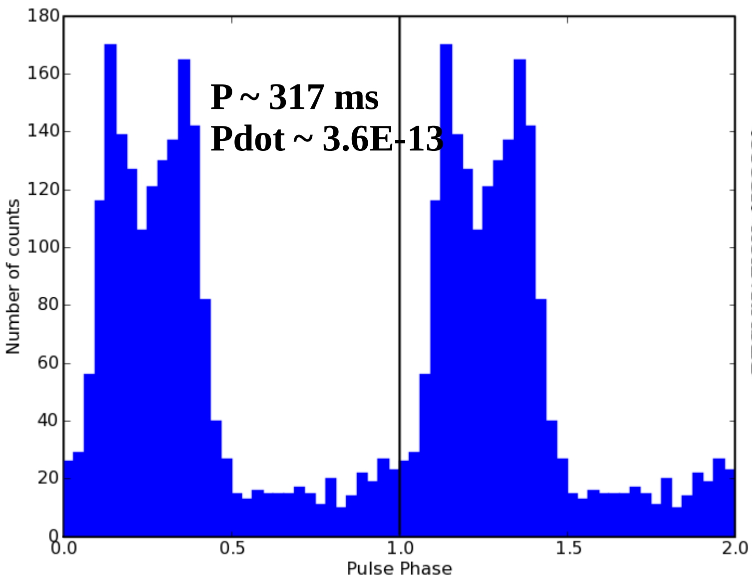
# of FFT bins = f * $t_{max\_diff}$ * 2

PC with 2GB can handle 33 x $10^6$ bin FFT

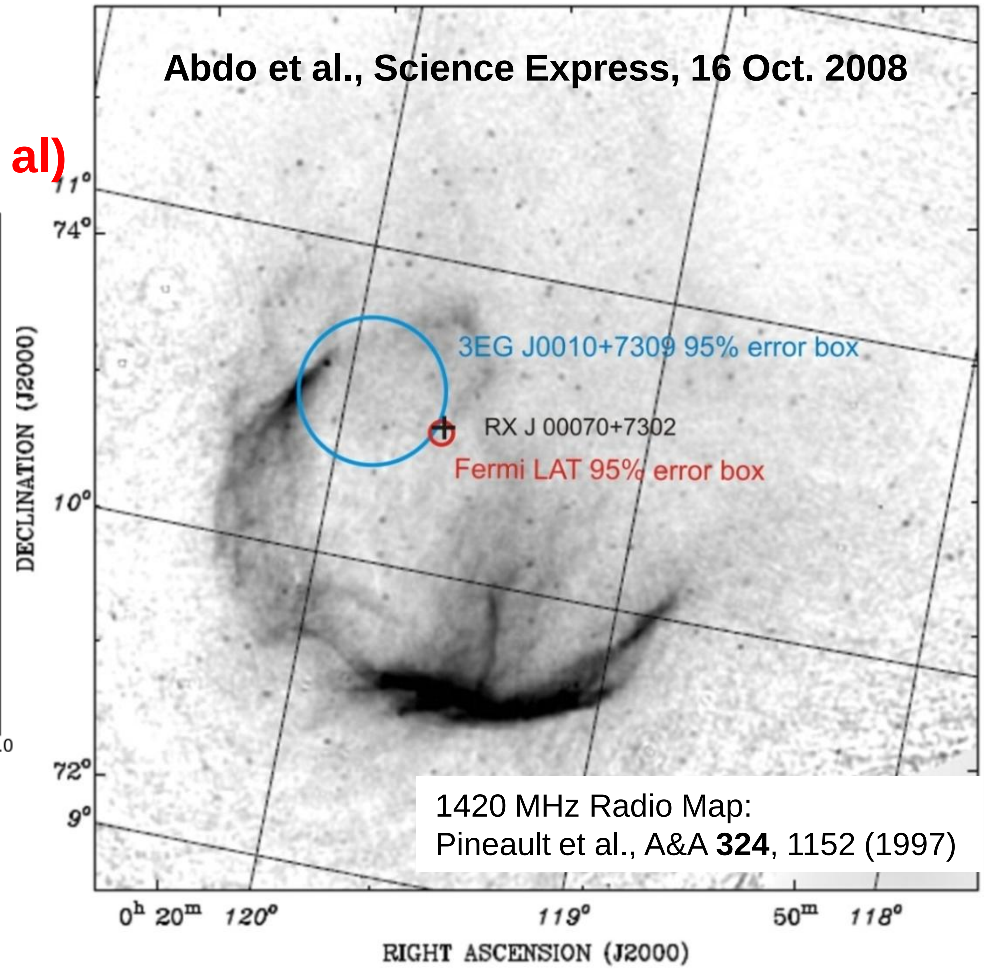
# Discovery of First Gamma-ray-only Pulsar

## A radio-quiet, gamma-ray only pulsar, in Supernova Remnant CTA1

**Quick discovery enabled by**
- **large leap in key capabilities**
- **new analysis technique (Atwood et al)**




- Spin-down luminosity ~$10^{36}$ erg $s^{-1}$, sufficient to supply the PWN with magnetic fields and energetic electrons.
- The γ-ray flux from the CTA 1 pulsar corresponds to about 1-10% of $E_{rot}$ (depending on beam geometry)




Age ~(0.5 – 1)x$10^4$ years
Distance ~ 1.4 kpc
Diameter ~ 1.5°

# Pulsar emission model

In the simplest model, the emission should depend on 4 parameters: spin period, magnetic field, magnetic dipole inclination, and viewing angle

- luminosity derived from rotational energy

  $E_{rot} = \frac{1}{2} I \Omega^2$

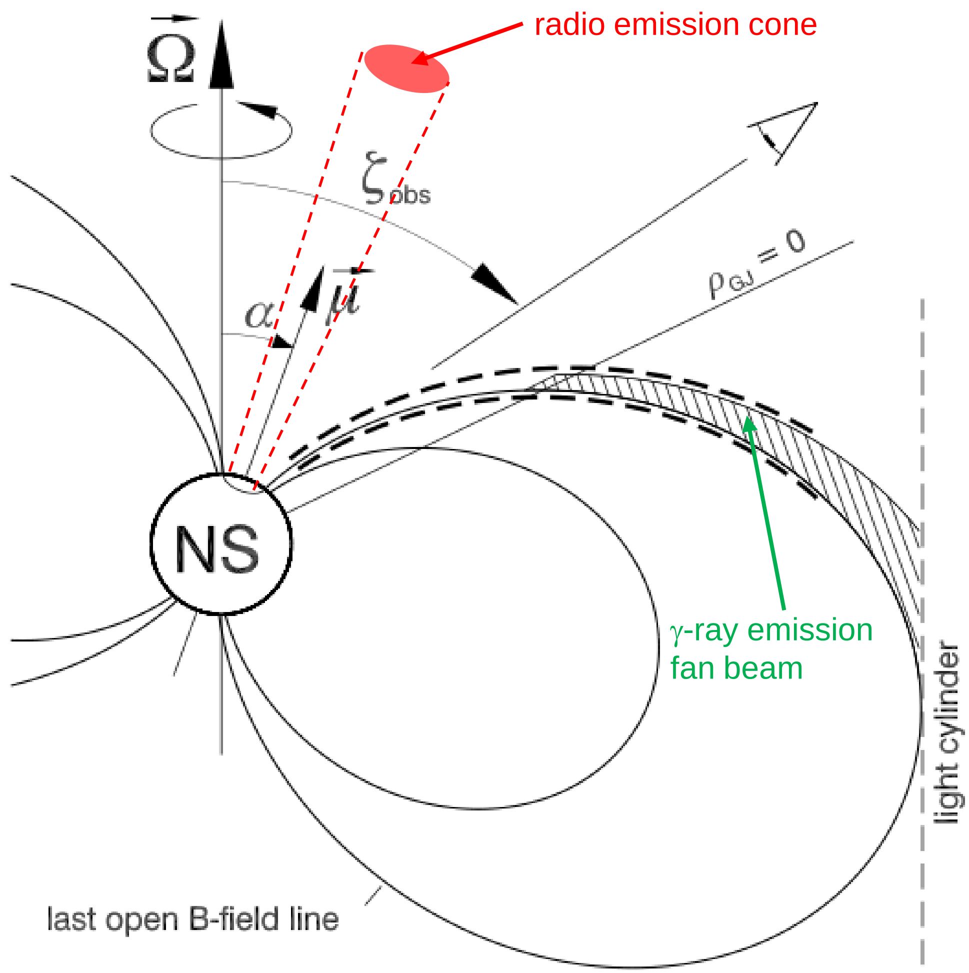
  $\dot{E} = - B^2 R^6 \Omega^4 / c^3$

- derived parameters:

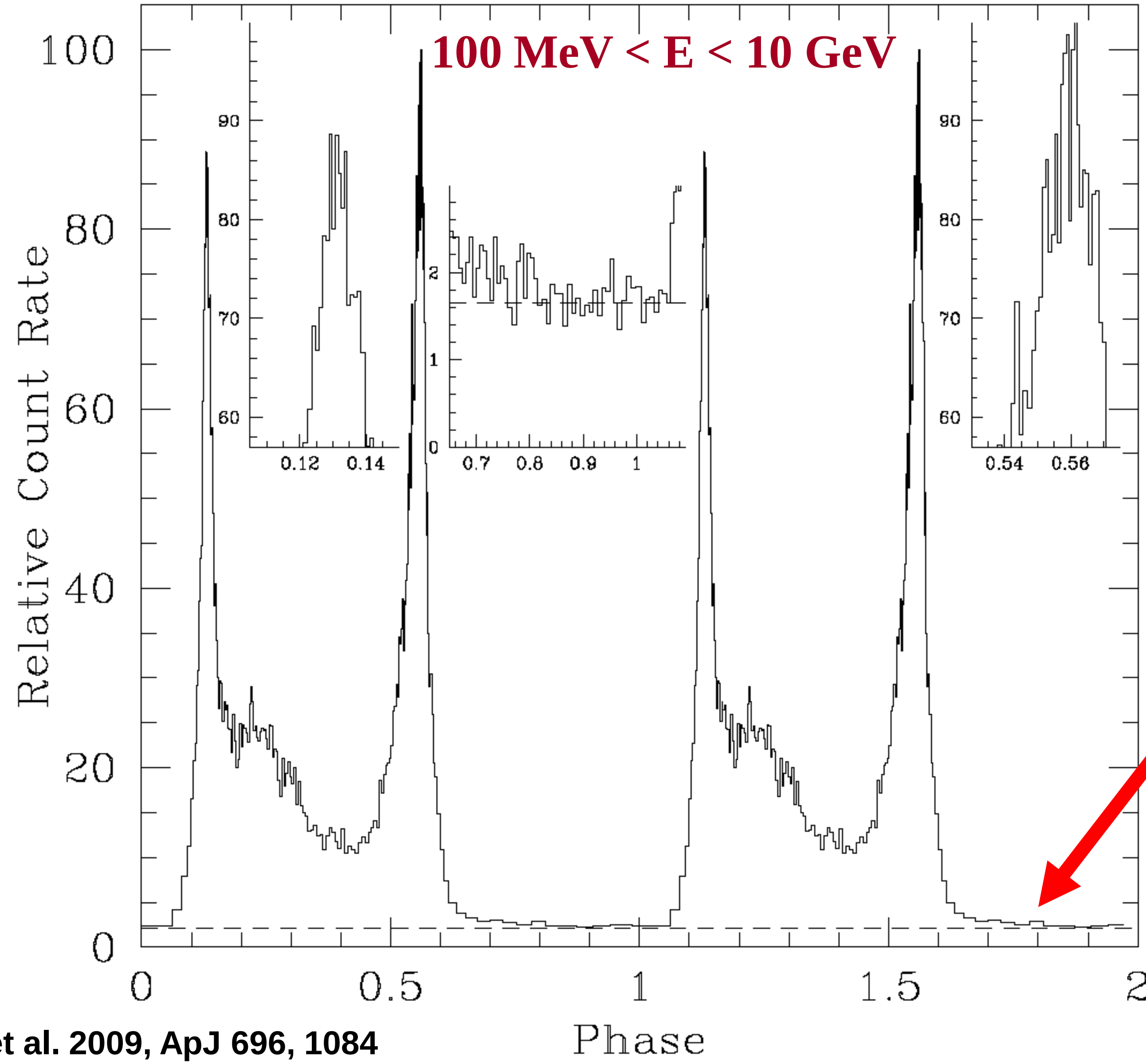
  rotational age : $\tau = \Omega / 2\dot{\Omega}$

  B field: $B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ G

  spin-down power: $L = I\Omega\dot{\Omega}$



# First *Fermi* view of the Vela Pulsar




Remarkably sharp peaks; features to ~0.3ms.

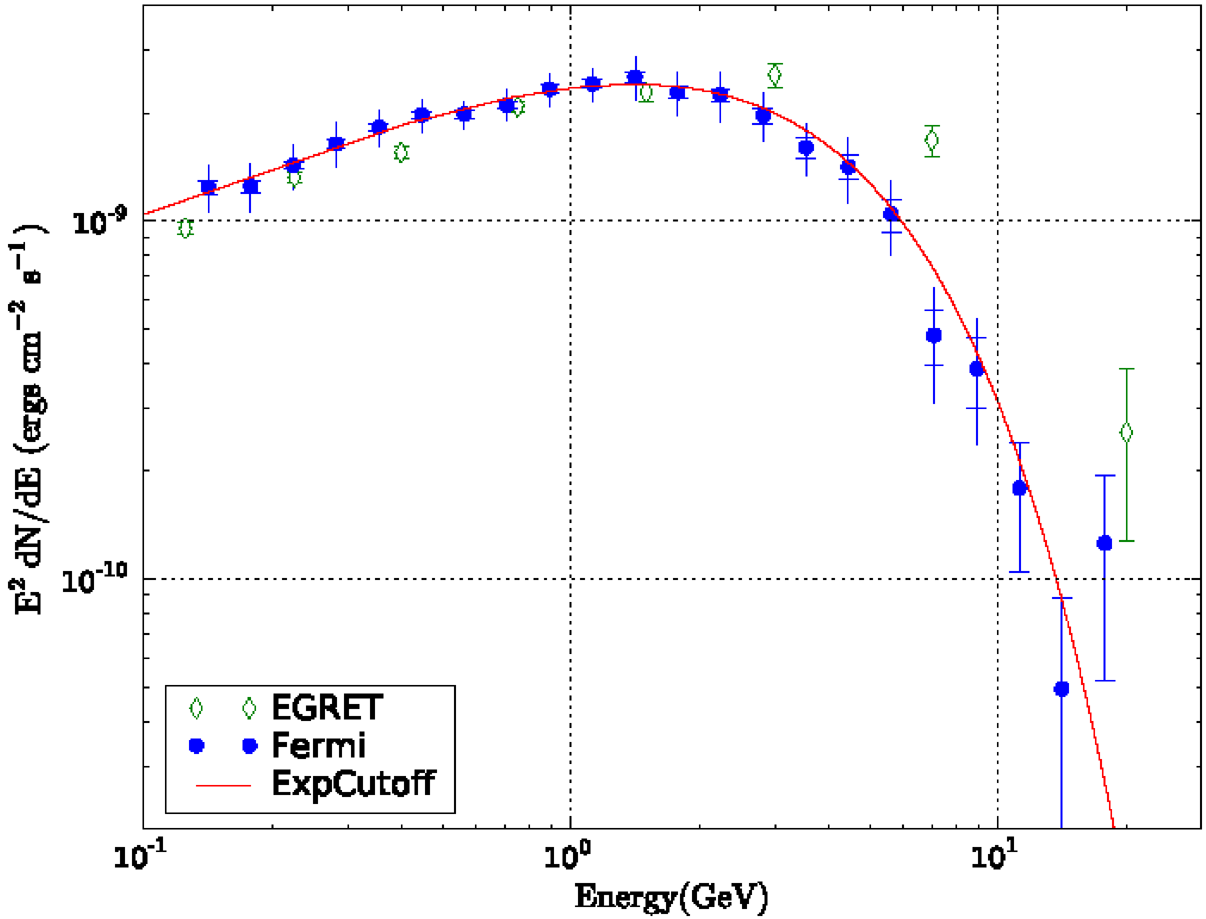
Turns nearly completely off between the double pulses.

- <2.8% of phase-averaged pulsed emission, 95% confidence
- Stringent limits or measurement will be available with more livetime

Abdo et al. 2009, ApJ 696, 1084

# Vela Pulsar – Phase-averaged SED

$$N(E) = N_0 E^{\Gamma} e^{-(E/E_c)^b}$$




Consistent with b = 1 (simple exponential)

$$\Gamma = -1.51^{+0.05}_{-0.04}$$

$$E_c = 2.9 \pm 0.1 \text{ GeV}$$

b = 2 (super-exponential) rejected at 16.5 σ

No evidence for magnetic pair attenuation – Near-surface emission ruled out

Abdo et al. 2009, ApJ 696, 1084

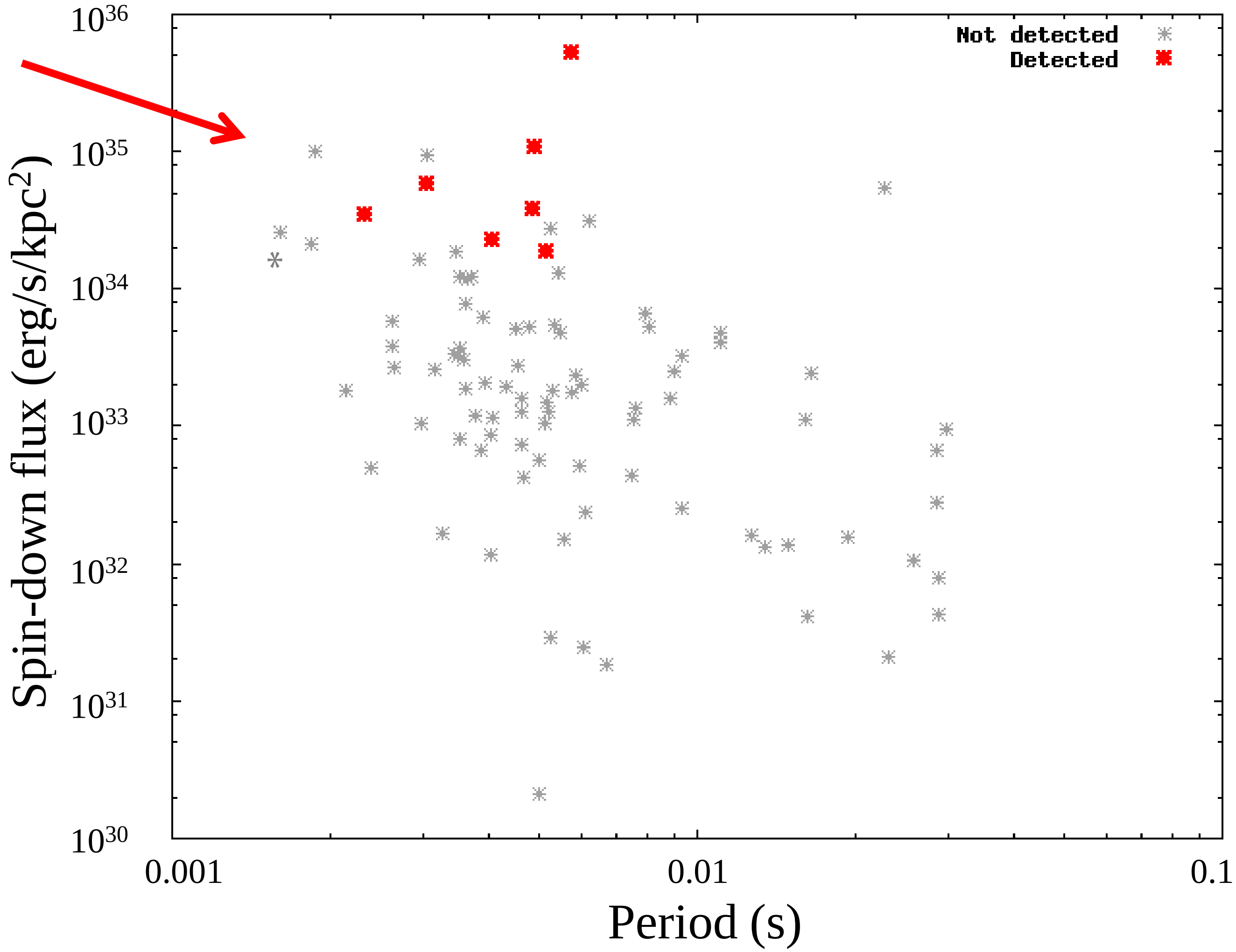
# Millisecond pulsars

Old pulsars in a binary accelerated by accretion from the companion
Very fast rotators but low magnetic field

Fermi sees those with high 'spin-down flux'

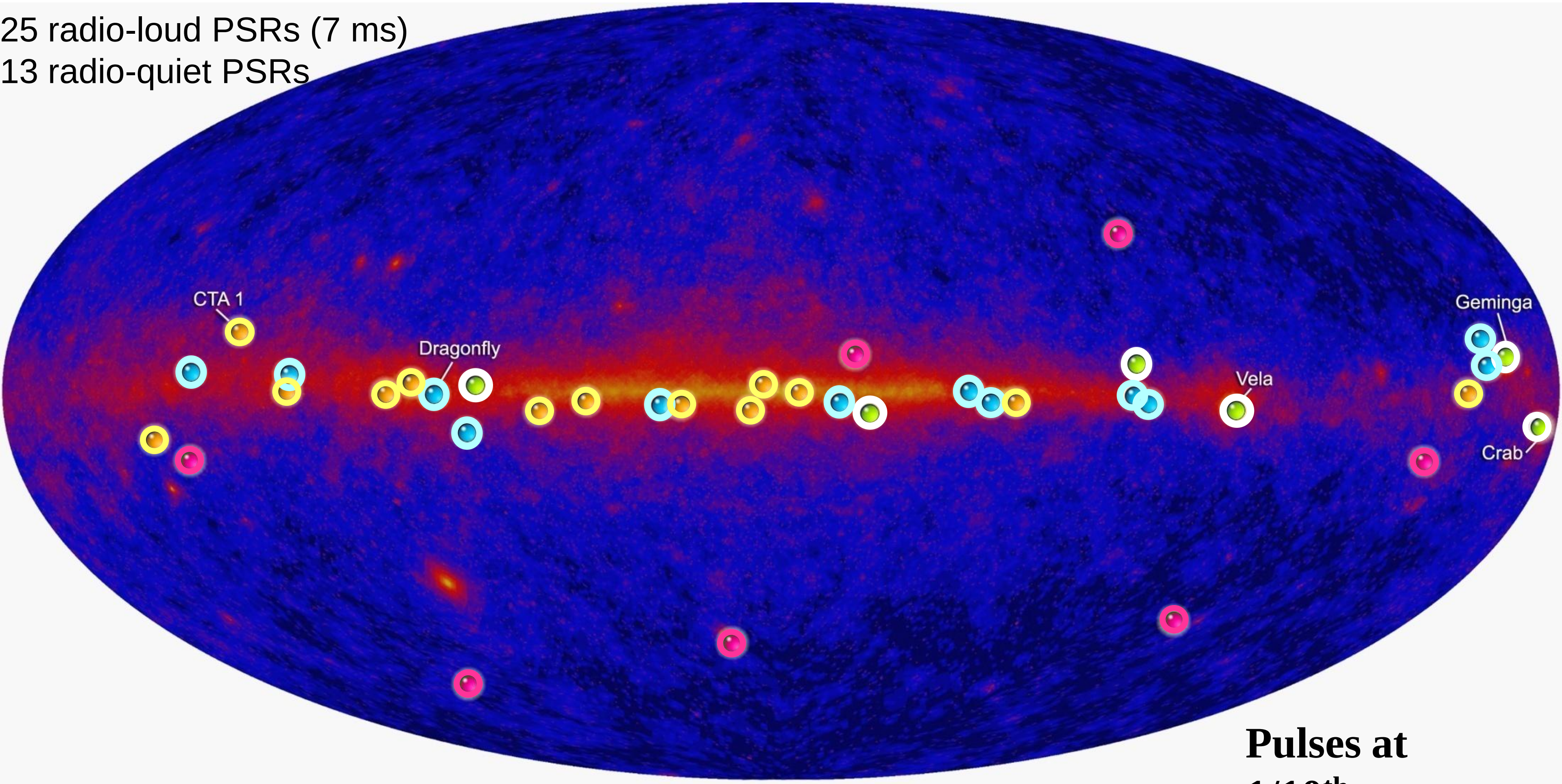
$$\dot{E}_{sd} / d^2$$

The nearby population



# The Pulsing Sky

25 radio-loud PSRs (7 ms)
13 radio-quiet PSRs




**Pulses at 1/10$^{th}$ true rate**

Fermi Pulsar Detections

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

# Publications

Published (11):

| | |
|---|---|
| **The Large Area Telescope on Fermi** | Atwood, W. B. et al. 2009, ApJ, 697, 1071 |
| **NGC1275** | Abdo, A. A. et al. 2009, ApJ, 699, 31 |
| **PKS 1454-354** | Abdo, A. A. et al. 2009, ApJ, 697, 934 |
| **PKS 2155-304 with HESS & Fermi** | Aharonian, F. et al. 2009, ApJL, 696, L150 |
| **PMN J0948+0022** | Abdo, A. A. et al. 2009, ApJ, 699, 976 |
| **Pulsar in CTA 1** | Abdo, A. A. et al. 2008, Science, 322, 1218 |
| **Vela Pulsar** | Abdo, A. A. et al. 2009, ApJ, 696, 1084 |
| **PSR J1028-5819** | Abdo et al. 2009, ApJL, 695, L72 |
| **PSR J0030+0451** | Abdo, A. A. et al. 2009, ApJ, 699, 1171 |
| **Cosmic ray e+ + e- spectrum** | Abdo, A. A. et al. 2009, PRL, 102, 181101 |
| **GRB 080916C** | Abdo, A. A. et al. 2009, Science, 323, 1688 |

Accepted (8):

**3-month bright AGN list** (AGN)
**3C 454.3** (AGN)
**3-month bright source list** (Catalog)
**On-orbit calibrations** (Calibration)

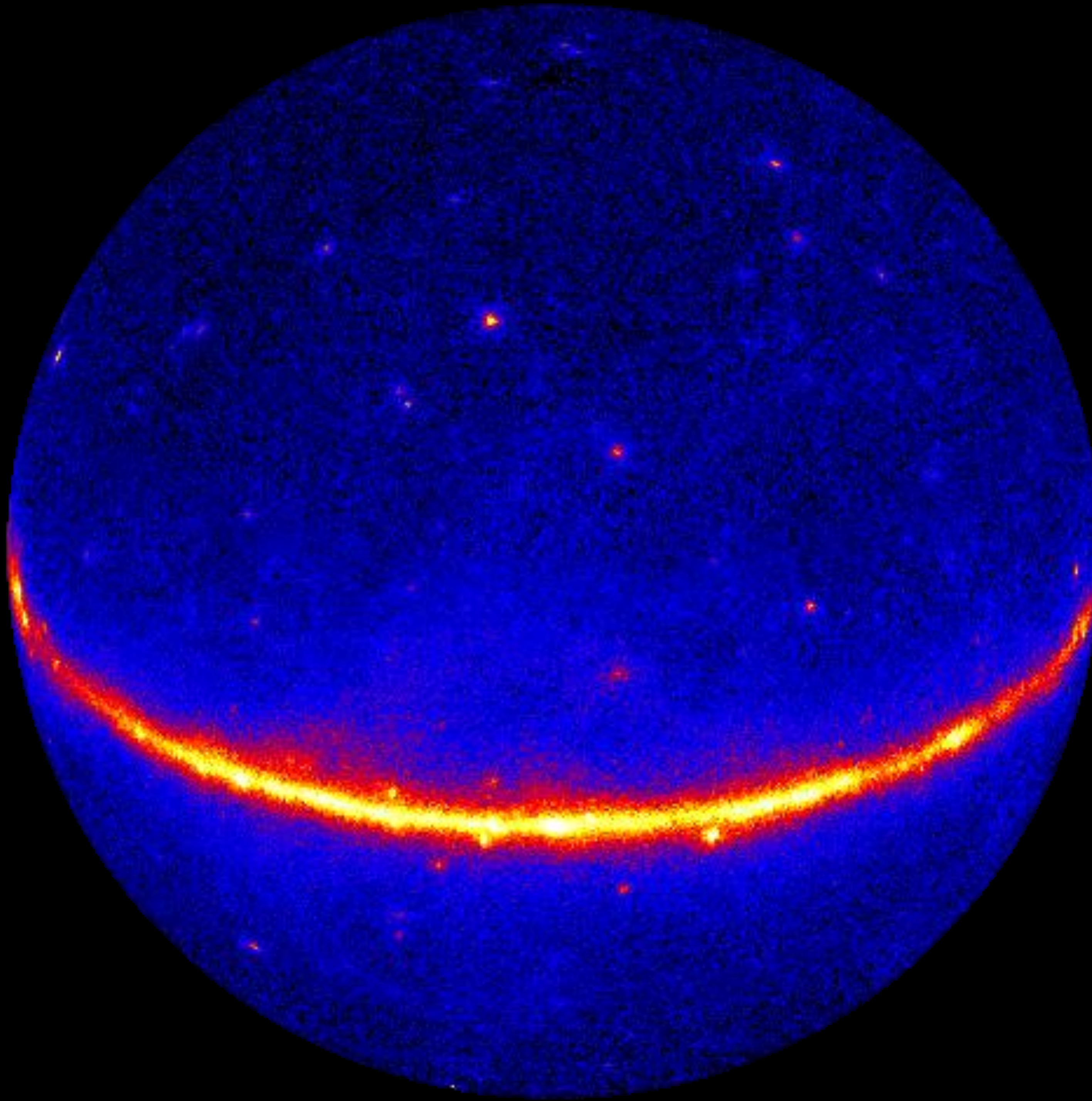
**Millisecond pulsars** (Pulsars)
**Blind search pulsars** (Pulsars)
**PSR J0205+6449** (Pulsars)
**PSR J2021+3651** (Pulsars

# Conclusions

- CGRO/EGRET found only 31 sources above 10 $\sigma$ in its lifetime, Fermi/LAT found 205 in the first 3 months
- Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.
- About 1/3 of the sources show definite evidence of **variability**.
- 38 **pulsars** are identified by gamma-ray pulsations (up from 6).
- Over half the sources are associated positionally with **blazars** (85% associations outside the plane, up from 60%).
- 37 sources have no obvious associations with known gamma-ray emitting types of astrophysical objects.
- 2 very bright **γ-ray bursts**, several fainter ones.
- 2 high-mass **X-ray binaries** (LSI +61 303 and LS 5039)
- Several **TeV sources**, including PWNe and SNR associations (W28, W41, W51, IC443)

Fermi-LAT
3 months
Front > 200 MeV
Back > 400 MeV

Orthographic
projection



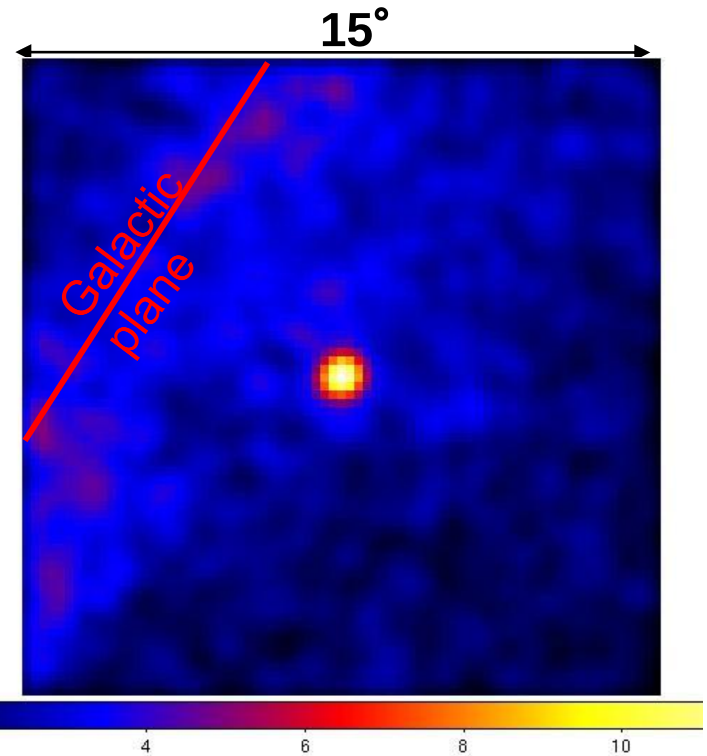
# PWN coincidences TeVCat / 0FGL

| TeV source | 0FGL | Note |
|---|---|---|
| Crab | J0531.0+1331 | Crab |
| IC443 | J0617.4+2234 | ‘PWN’ in TeVCat, but SNR? |
| HESS J1418-609 | J1418.8-6058 | LAT PSR J1418-60 |
| HESS J1616-508 | J1615.6-5049 | PSRJ1617-5055 ? |
| HESS J1804-216 | J1805.3-2138 | PSR J1803-2137? |
| HESS J1813-178 | J1814.3-1739 | G12.82-0.02 ? |
| MGRO J1908+06 | J1907.5+0602 | LAT PSR J1907+06 |

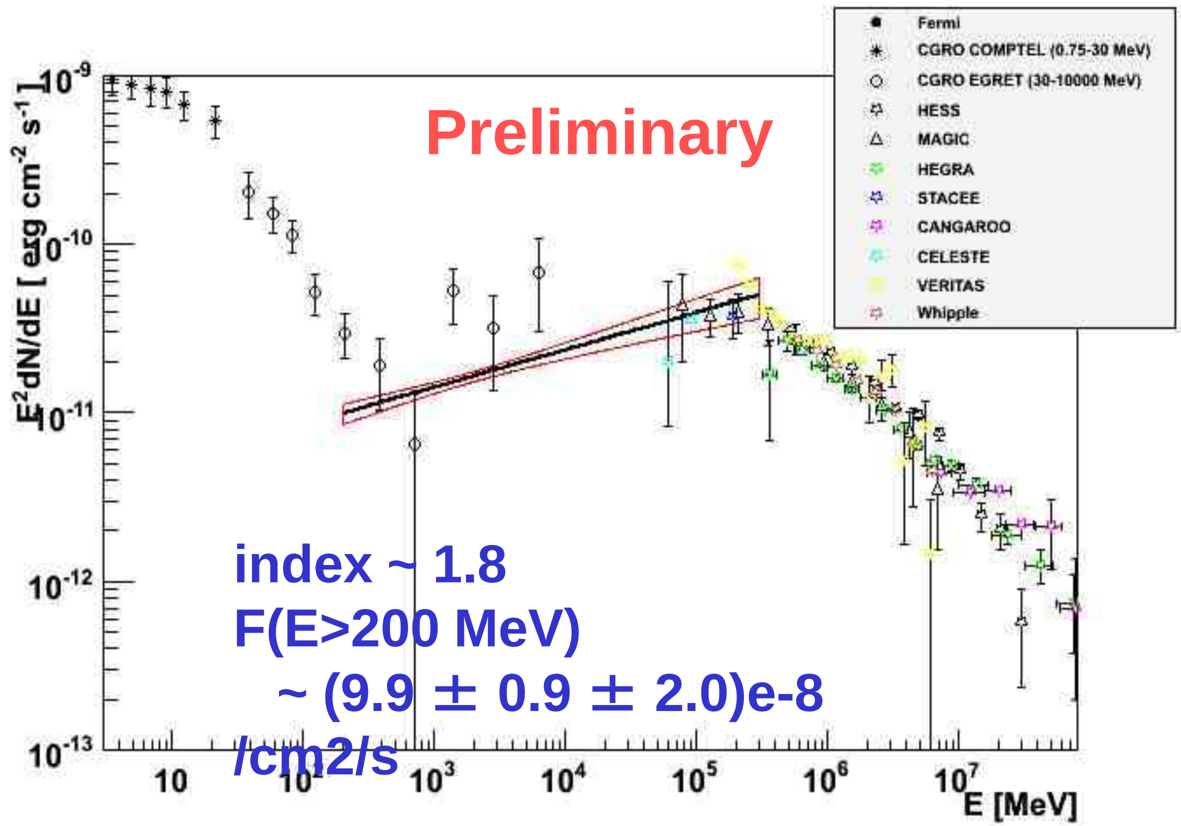
**Note : LAT sources may be pulsars, rather than SNRs/PWNe.**

# Prototype – Crab Nebula

- all phase : TS = 8054
- Off-pulse : TS = 905 → significant detection
- Off-pulse interval flux, normalizing to the full phases
- No significant cutoff



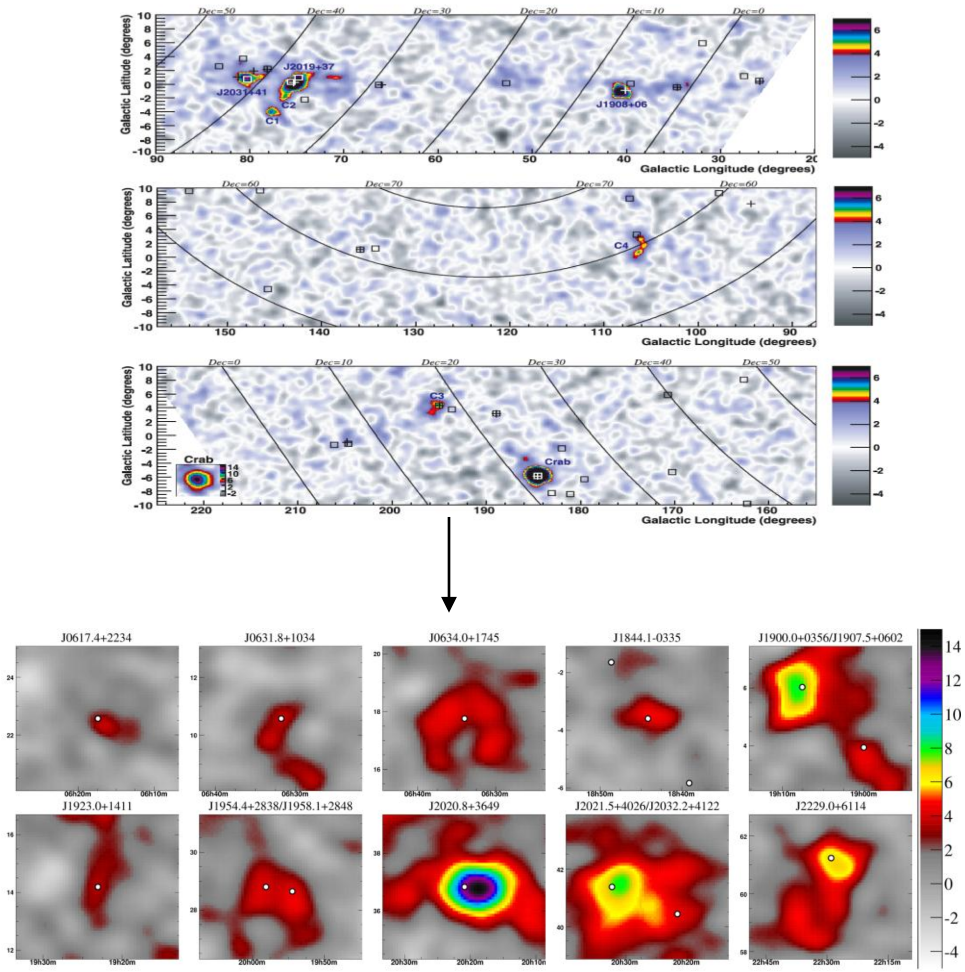

Off-pulse only
(40% of the total phase)



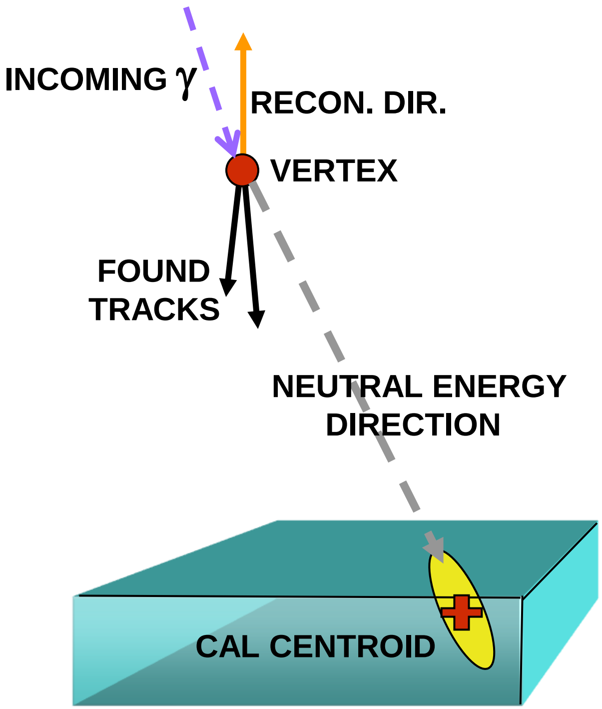

index ~ 1.8
F(E>200 MeV)
~ (9.9 ± 0.9 ± 2.0)e-8 /cm2/s

# More on TeV connections

- Milagro (TeV) observations (14/34 Galactic BSL sources with 3 sigma Milagro excess.
- 9/14 are gamma-ray pulsars
- All 6 previously know Milagro source associated with Fermi Pulsars.)



# Neutral Energy Concept




Sometimes at the start of the shower the charge pair does not well reflect the direction of the incoming photon.

Bremstrahlung can cause much (most) of the energy to windup in photons.

The Calorimeter Centroid is a measure of where these photons impact the calorimeter.

A "Neutral Energy" direction can be inferred by connecting the found **Vertex** with the **Cal. Centroid**.

One can determine the covariant error matrix for this inferred direction by using the errors on the centroid location.

**By having an imaging calorimeter, GLAST-LAT is the first Gamma Ray instrument able to do this!**

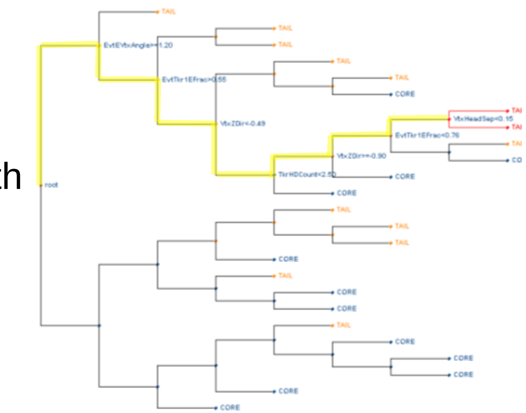
# Event Analysis

**The Monte Carlo allowed a detailed and modern statistical approach to refining the PSF**

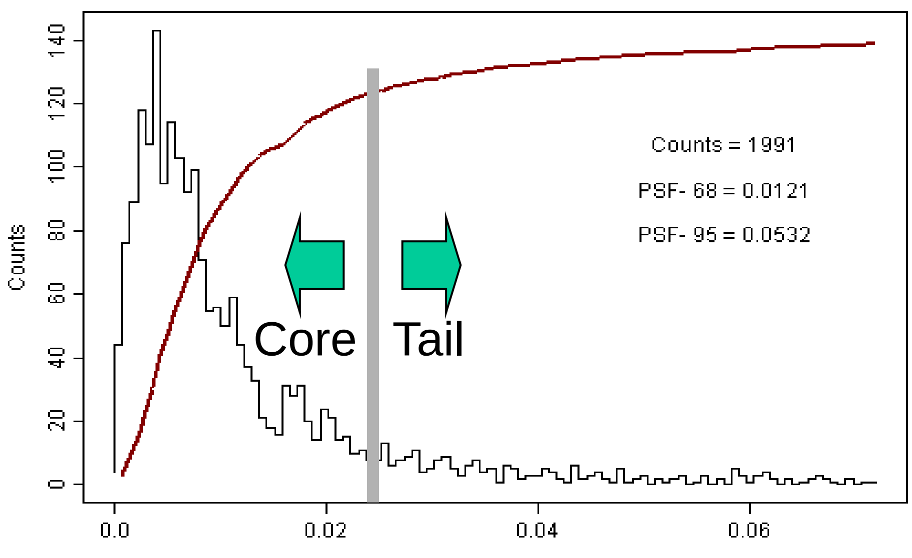
## Classification Trees

- An efficient use of **All** the Information
- Automatic generation procedure
- Statistically **robust** if averaged over several "Trees"
- Objective- independent of analyst biases

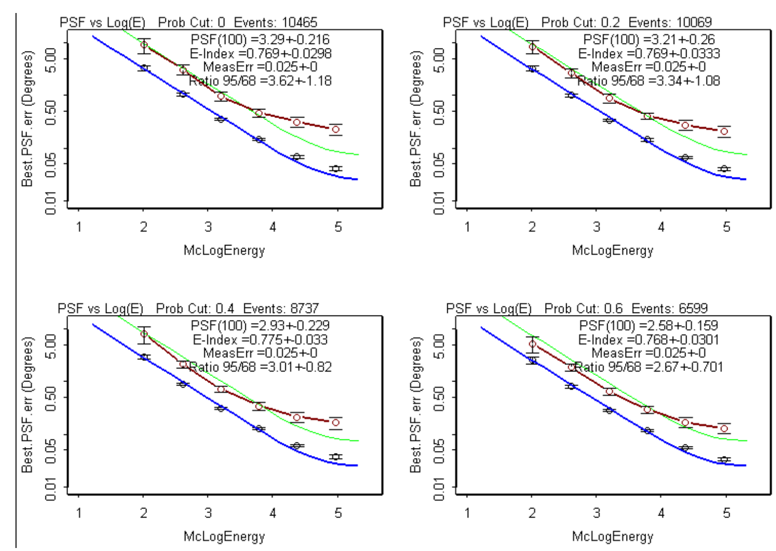
Tree
with one path illustrated



PSF Classes for CT training

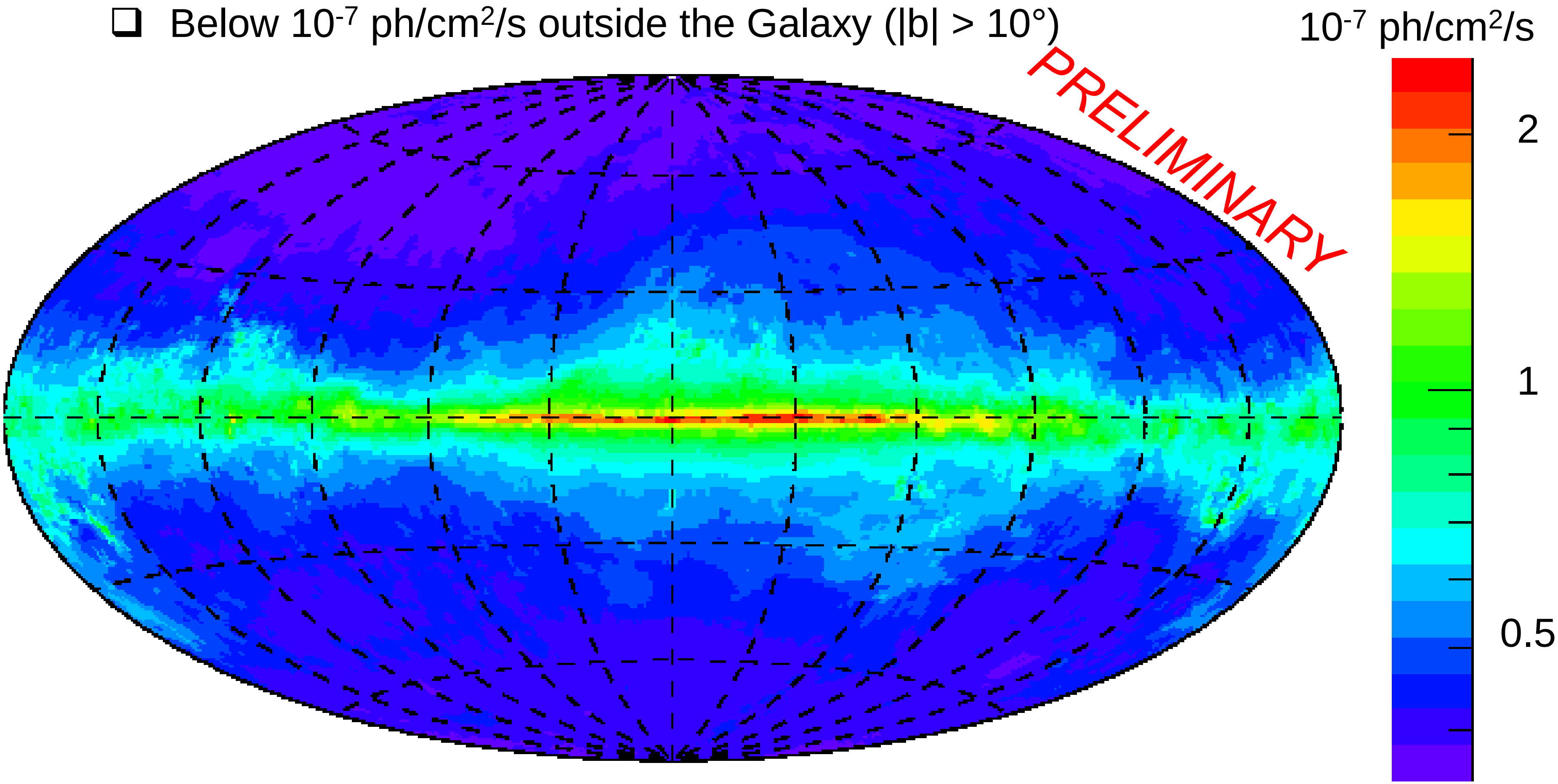



**Near On-Axis PSF** (cos(θ) < -.9)



# Sensitivity map

- Structure is mostly that of the interstellar medium
- Below $10^{-7}$ ph/cm$^2$/s outside the Galaxy (|b| > 10°)




Flux > 100 MeV required to reach 10 σ for average $E^{-2.2}$ spectrum

Galactic coordinates, Aitoff projection