Fermi Gamma-ray Space Telescope


# FERMI GAMMA-RAY OBSERVATORY - SCIENCE HIGHLIGHTS FOR THE FIRST ± 8 MONTHS

**Alexander Moiseev**

*CRESST/NASA GSFC and University of Maryland*

**for the Fermi LAT Collaboration**

# Fermi Observatory

***Launched on June 11, 2008, from Cape Canaveral on 565 circular orbit with 25.6 inclination. Mission duration: 5 years, with the goal to extend it to 10 years***

## Two instruments onboard:

- **Large Area Telescope LAT (PI – Peter Michelson, Stanford University; managing organization - SLAC)**
  - **main instrument, gamma-ray telescope, 20 MeV - >300 GeV**
  - **scanning (main) mode - 20% of the sky all the time; all parts of sky for ~30 min. every 3 hours**
- **GLAST Burst Monitor GBM (PI – Charles Meegan, NASA/MSFC)**
  - **8 KeV – 40 MeV**
  - **observes whole unocculted sky all the time, searching for gamma-ray bursts**

# Fermi LAT Collaboration

## United States (NASA and DOE)

- *California State University at Sonoma*
- *Goddard Space Flight Center*
- *Naval Research Laboratory*
- *Ohio State University*
- *Stanford University (HEPL, KIPAC and SLAC)*
- *University of California at Santa Cruz – SCIPP*
- *University of Denver*
- *University of Washington*

## France

- *CEA/Saclay*
- *IN2P3*

## Italy

- *ASI*
- *INFN (Bari, Padova, Perugia, Pisa, Roma2, Trieste, Udine)*
- *INAF*

## Japan

- *Hiroshima University*
- *Institute for Space and Astronautical Science / JAXA*
- *RIKEN*
- *Tokyo Institute of Technology*

## Sweden

- *Royal Institute of Technology (KTH)*
- *Stockholm University*

**122 full members**

**95 affiliated scientists**

**38 management, engineering and technical members**

**68 post-doctoral members**

**105 graduate students**

# Fermi Science Objectives

**Fermi science objectives cover probably everything in high energy astrophysics:**

- **Active Galactic Nuclei (AGN), including Extragalactic background light (EBL)**
- **Gamma-ray bursts (GRB)**
- **Pulsars**
- **Diffuse gamma-radiation**
- **EGRET unidentified sources**
- **Solar physics**
- **Origin of Cosmic Rays**
- **Dark Matter and New Physics**

***Multiwavelength observations in cooperation with gamma-ray, X-ray, radio, and optical telescopes***

# Large Area Telescope LAT

**Heritage from OSO-III, SAS-II, COS-B, and EGRET, but:**

- large field of view (2.4 sr at 1 GeV, 4 times greater than EGRET) and large effective area (~8000 $cm^2$ on axis at 1 GeV)
- large energy range, overlapping with EGRET under 10 GeV and with HESS, MAGIC and VERITAS above 100 GeV, including poorly-explored 10 GeV – 100 GeV range.
- Good energy (<15% at E>100 MeV) and spatial resolution
  - Unprecendent PSF for gamma-rays, >3 times better than EGRET for E>1GeV
- Small dead time (<30 μs, factor of ~4,000 better than EGRET) – GRB time structure!
- Excellent timing (~ 1 μs) to study transient sources
- No consumables – chance for longer mission!

see for details Atwood, W. B. et al. 2009, ApJ arXiv:0902.1089v1

# The LAT Instrument Overview

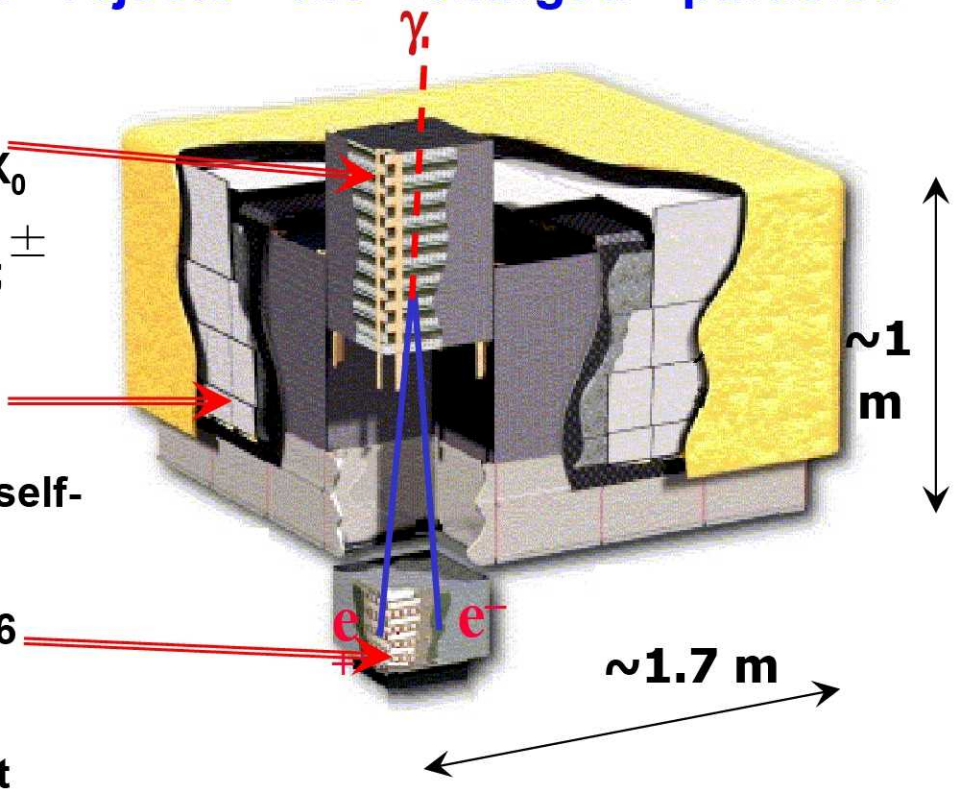
**Pair-conversion gamma-ray telescope:** 16 identical "towers" providing conversion of γ into $e^+e^-$ pair and determination of its arrival direction (Tracker) and energy (Calorimeter). Covered by segmented AntiCoincidence Detector which rejects the charged particles background

**Silicon-stripped tracker:** 18 double-plane single-side (x and y) interleaved with 3.5% $X_0$ thick (first 12) and 18% $X_0$ thick (next 4) tungsten converters. Strips pitch is 228 μm; total $8.8\times10^5$ readout channels

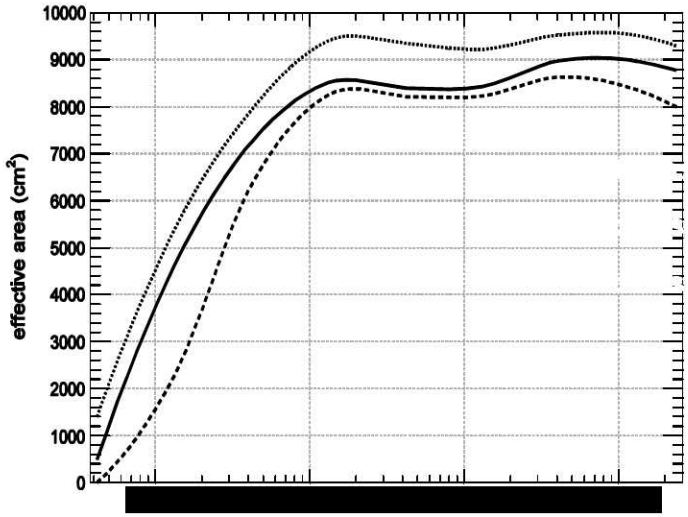
**Segmented Anticoincidence Detector:** 89 plastic scintillator tiles and 8 flexible scintillator ribbons. Segmentation reduces self-veto effect at high energy.

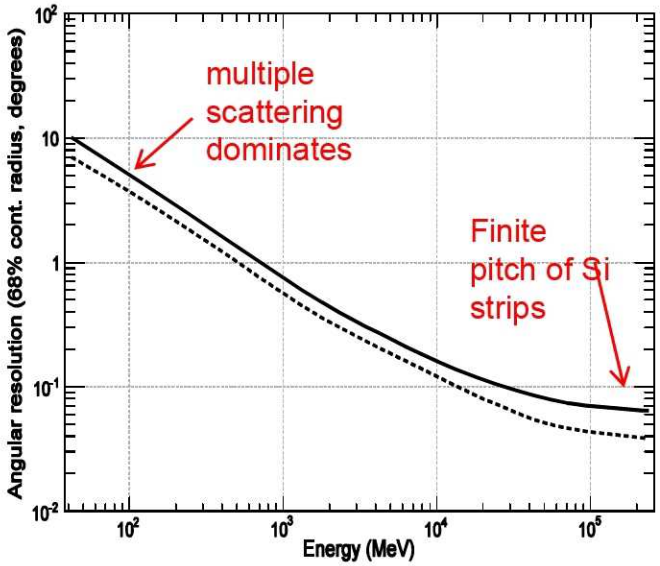
**Hodoscopic CsI Calorimeter** Array of 1536 CsI(Tl) crystals in 8 layers.

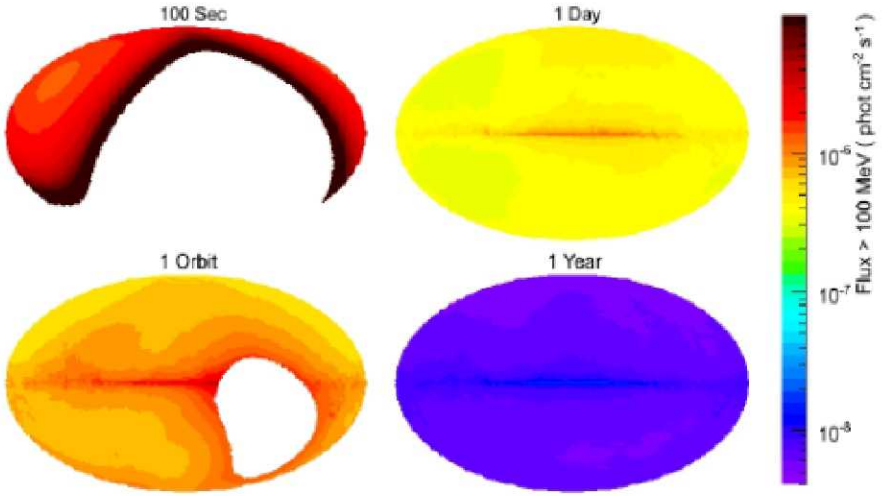
**Electronics System** Includes flexible, robust hardware trigger and software filters.



# LAT Performance




Sensitivity to point sources

| | Years | Ang. Res. (100 MeV) | Ang. Res. (10 GeV) | Eng. Rng. (GeV) | $A_{eff}\,\Omega$ (cm² 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 | 25,000 | $1 \times 10^8$/yr |

# Main results for the first 8 months

- pulsars
- flaring AGN
- GRB
- diffuse radiation
- LMC
- electron spectrum

Papers:

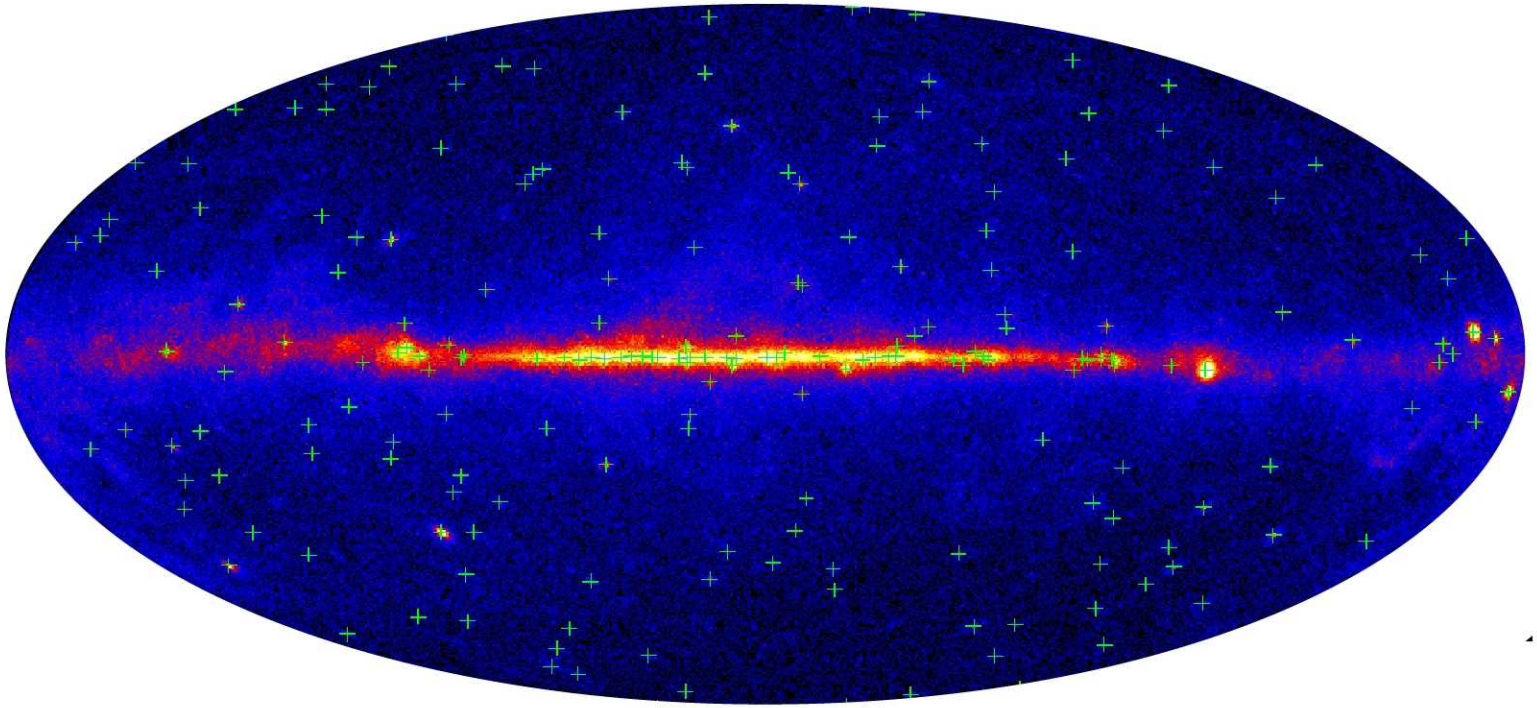
Submitted -

Accepted -

Published -

# LAT 3 month sky map

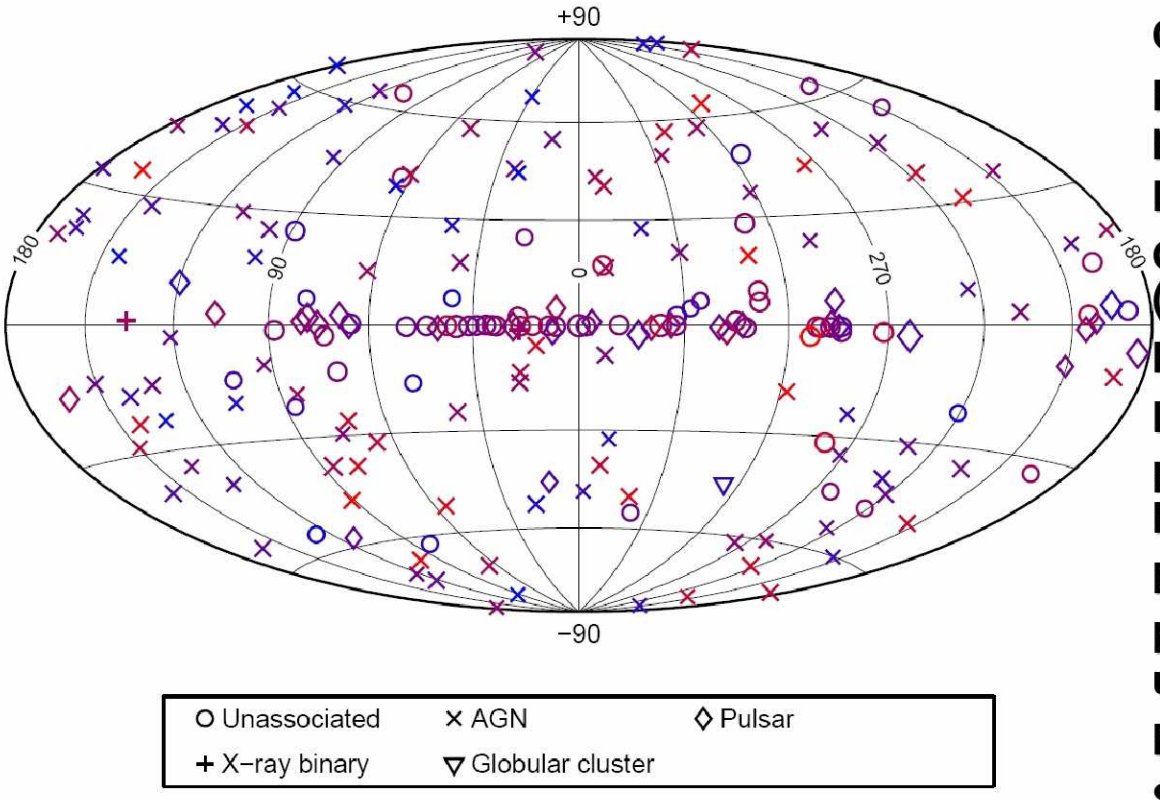
**205 bright sources ( sig. > 10σ). Paper submitted to ApJ Suppl.**



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

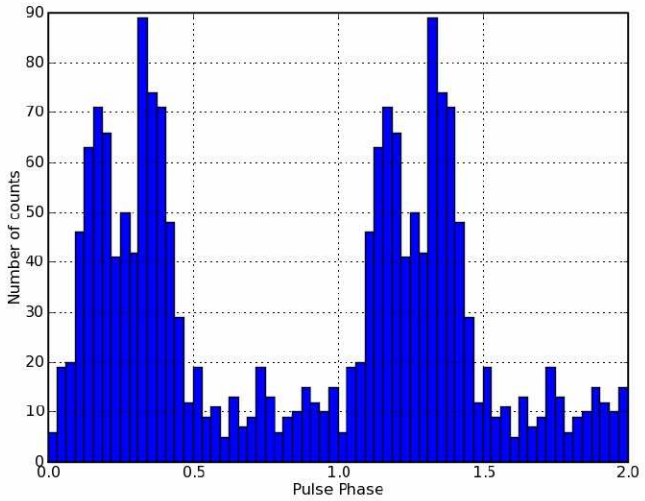
# LAT bright sources

**- based on first 3 months of sky-survey**




| Class | Number |
|---|---|
| Radio/X-ray pulsar | 15 |
| LAT pulsar | 14 |
| Globular cluster (pulsars?) | 1 |
| HMXB | 2 |
| LMC | 1 |
| Flat Spectrum Radio Quasars | 62 |
| Bl Lac Objects | 46 |
| Blazar, uncertain type | 11 |
| Radio galaxies | 2 |
| Special cases (under study) | 14 |
| Unassociated | 37 |

# CTA1 - First gamma-pulsar detected by Fermi in blind search

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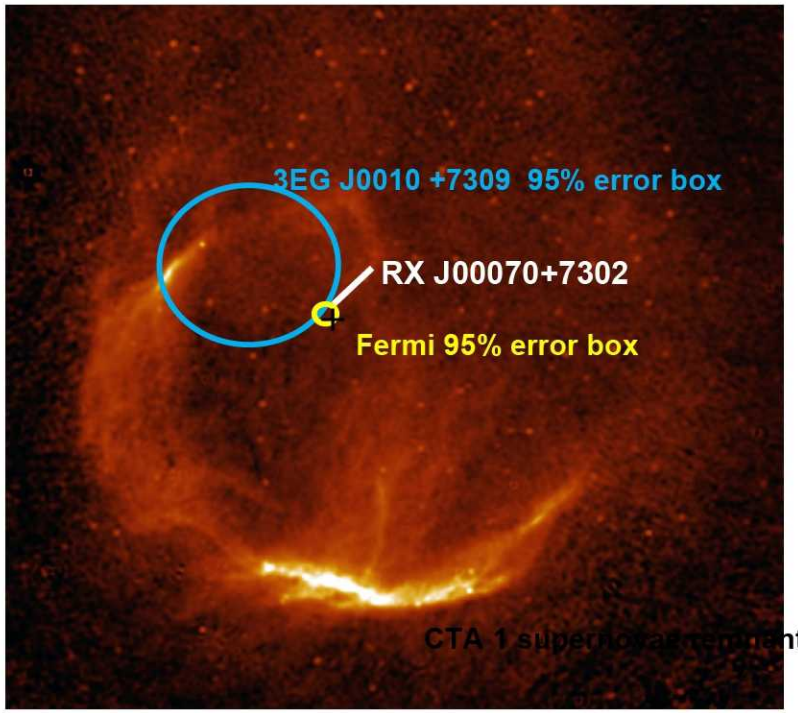



- exhibits all characteristics of a young high-energy pulsar (characteristic age ~1.4 x $10^4$ yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

- spin-down luminosity ~$10^{36}$ erg $s^{-1}$, sufficient to supply the PWN with magnetic fields and energetic electrons.

- $\gamma$-ray source at *l,b* = 119.652, 10.468; 95% error circle radius =0.038° contains the 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

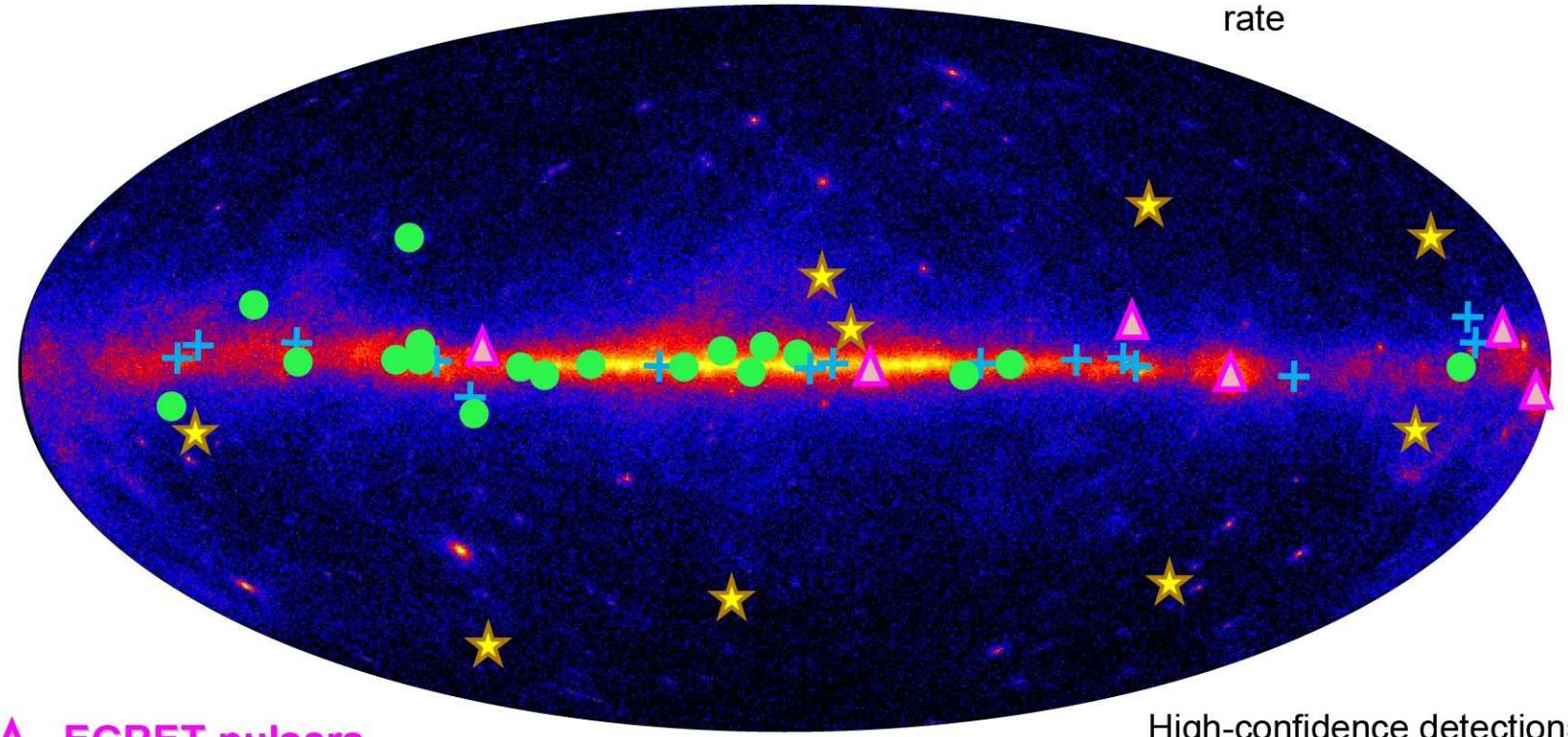
***Science, November 21, 2008, v.322, 1218***

# Fermi pulsars

**33 gamma-ray and radio pulsars (including nine ms psrs)**

**16 gamma-ray only pulsars**

Pulses at 1/10th real rate



△ EGRET pulsars

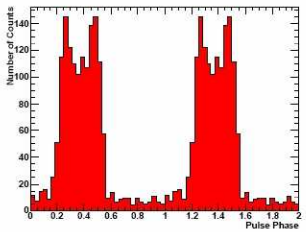
\+ young pulsars discovered using radio ephemeris

● pulsars discovered in blind search

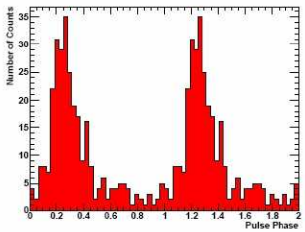
☆ millisecond pulsars discovered using radio ephemeris

High-confidence detections through 2/28/2009

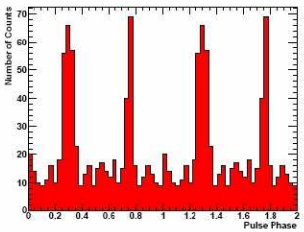
# Blind search γ-ray pulsar light curves



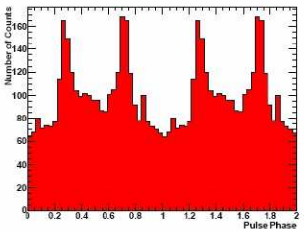

(a) LAT PSR J0007+7303



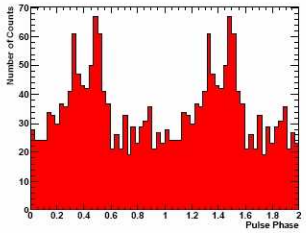

(b) LAT PSR J0357+32



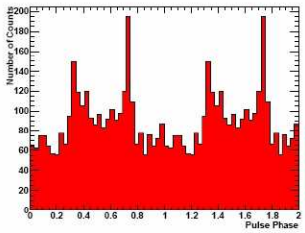

(c) LAT PSR J0633+0632



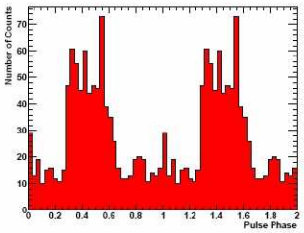

(d) LAT PSR J1418-6058



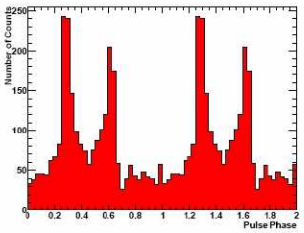

(e) LAT PSR J1459-60



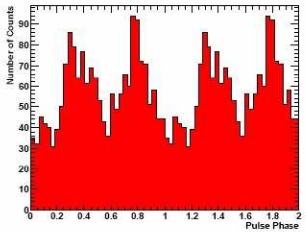

(f) LAT PSR J1732-31



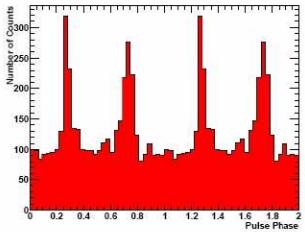

(g) LAT PSR J1741-2054



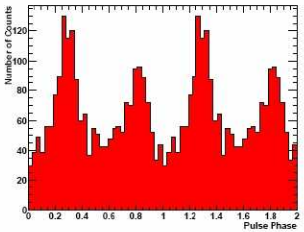

(h) LAT PSR J1809-2332



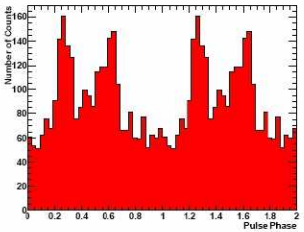

(i) LAT PSR J1813-1246



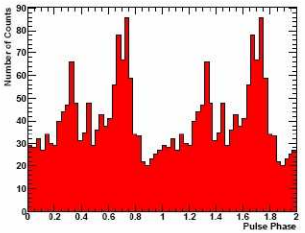

(j) LAT PSR J1826-1256



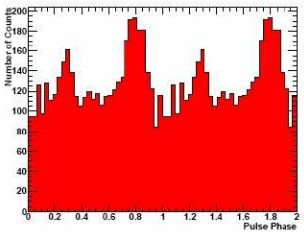

(k) LAT PSR J1836+5925



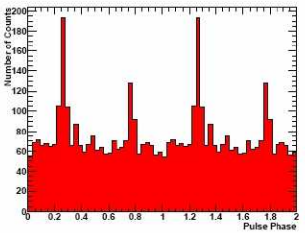

(l) LAT PSR J1907+06



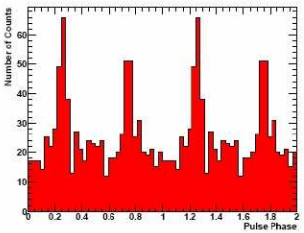

(m) LAT PSR J1958+2846




(n) LAT PSR J2021+4044



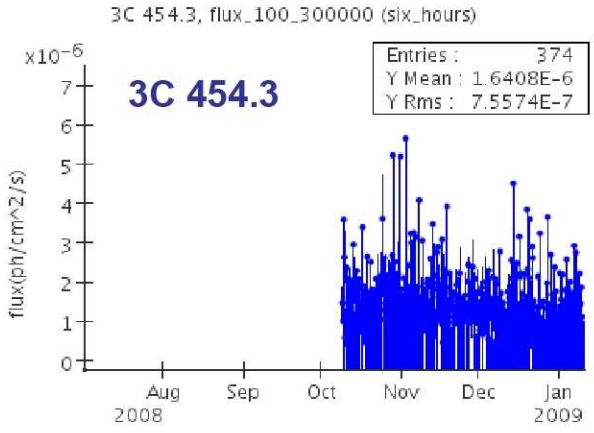

(o) LAT PSR J2032+4127

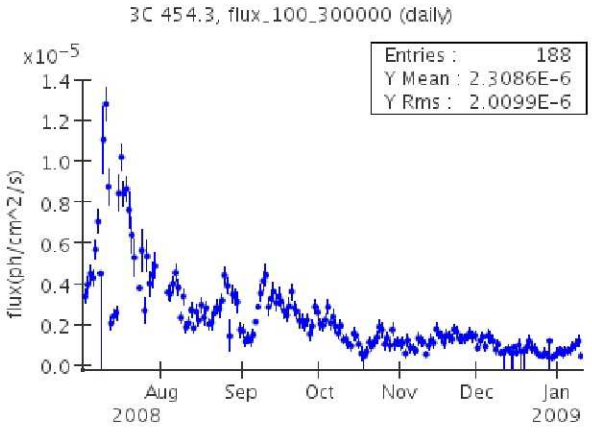


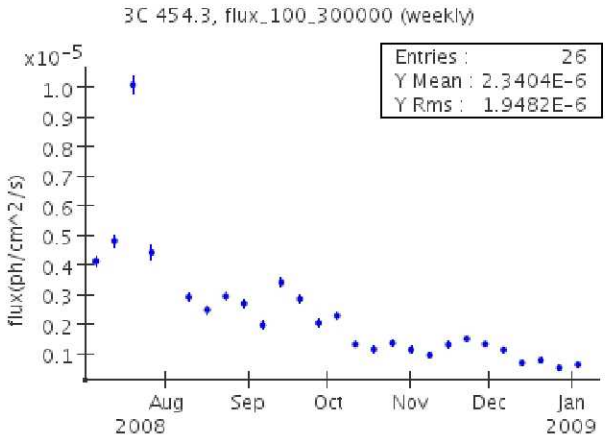

(p) LAT PSR J2238+59

# Source Monitoring Activities

- **Automated Science Processing (ASP)**
  - *Follow-up monitoring: Runs full likelihood analysis on list from source detection step + "Data Release Plan" (DRP) sources*
  - *Transient detection: Uses source detection (pgwave) to find all point sources in data from each epoch (6hr, day, week)*
  - *$2 \times 10^{-6}$ ph $cm^{-2}$ $s^{-1}$ threshold (daily) for public release of non-DRP*
- *Flare Advocates:*
  - *LAT scientists from Galactic and Extragalactic groups examine output from ASP pipeline and perform follow-up analyses, produce ATels, and propose ToOs*



Fermi Gamma-ray Space Telescope

The Astronomer's Telegram

for reporting and commenting on new astronomical observations

- *Announcements of flaring sources ⇒ multiwavelength follow-up*
- *25 blazar-related LAT ATELs have been issued since launch on 22 different sources*

## GLAST-LAT detection of extraordinary gamma-ray activity in 3C 454.3

ATel #1628; *G. Tosti (Univ/INFN-Perugia) , J. Chiang (SLAC), B. Lott (CENBG/Bordeaux), E. do Couto e Silva (SLAC), J. E. Grove (NRL/Washington), J. G. Thayer (SLAC) on behalf of the GLAST Large Area Telescope Collaboration*

*on* ***24 Jul 2008; 14:25 UT***

*Password Certification: Gino Tosti (tosti@pg.infn.it)*

**Subjects: Gamma Ray, >GeV, AGN, Quasars**
**Referred to by ATel #: 1634, 1849**

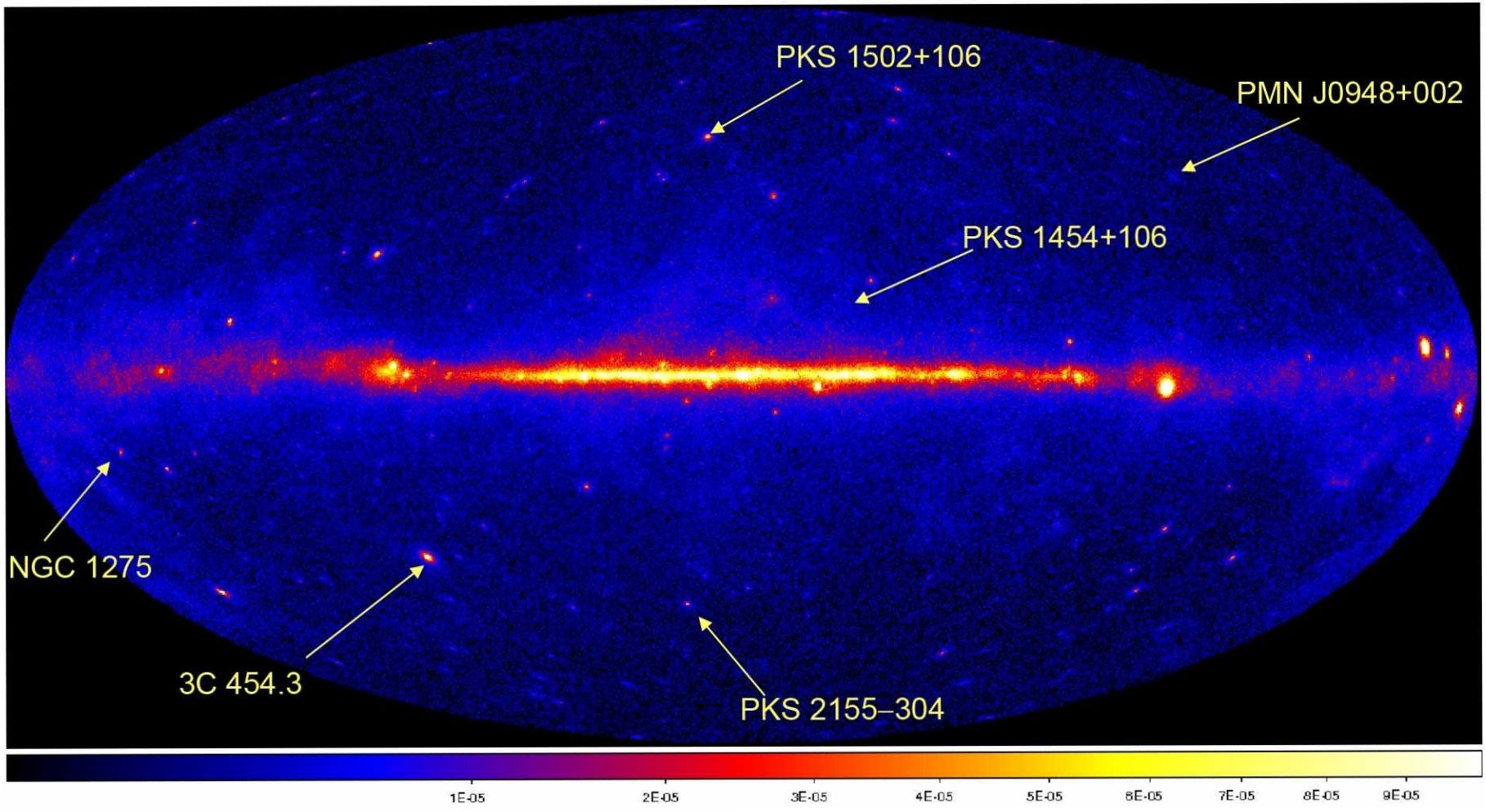
The Large Area Telescope (LAT), one of two instruments on the Gamma-ray Large Area Space Telescope (GLAST) (launched June 11, 2008), which is still in its post-launch commissioning and checkout phase has been monitoring extraordinarily high flux from the gamma-ray blazar 3C 454.3 since June 28, 2008. This confirms the bright state of the source reported by AGILE (see ATel #1592) and by the optical-to-radio observers of the GASP-WEBT Project (ATel #1625).

3C 454.3 has been detected on time scales of hours with high significance (> 5 sigma) by the LAT Automatic Science Processing (ASP) pipeline and the daily light curve (E>100 MeV) indicates that the source flux has increased from the initial measurements on June 28. Although in-flight calibration is still ongoing, preliminary analysis indicates that in the period July 10-21, 2008 the source has been in a very high state with a flux (E>100MeV) that is well above all previously published values reported by both EGRET (Hartman et al. 1999, ApJS, 123,79) and AGILE (see e.g. ATel #1592 and Vercellone et al. 2008, ApJ,676,L13).

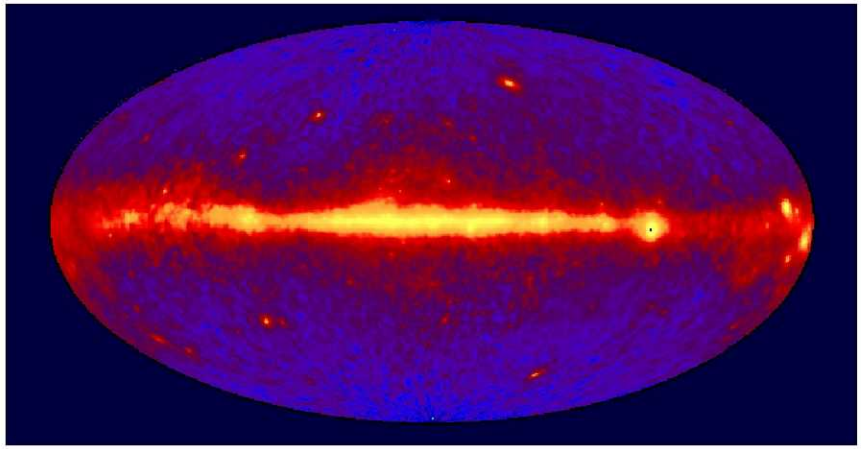
# Multiwavelength Campaigns

- *3C 454.3: Jul-Oct; radio, opt, UV, Swift*
- *BL Lac: 15 Aug-5 Sep; opt, UV, X-ray*
- *PKS 2155-304: 25 Aug-6 Sep; radio, opt, UV, X-ray, TeV (HESS)*
- *1ES 1959+650: Sep-Nov*
- *PKS 0528+134: 27 Sep-Oct; radio, IR, opt, UV, X-ray*
- *3C 273: 31 Oct-7 Feb; radio, opt, X-ray*
- *3C 279: Aug—Mar; radio, opt, X-ray, TeV*
- *Mrk 421: Jan-May; radio, opt, X-ray, TeV (VERITAS, MAGIC)*

# Fermi Results for Individual AGNs



# Diffuse radiation: EGRET "GeV excess"



EGRET observations showed excess emission > 1 GeV when compared with conventional model tuned to reproduce local cosmic-ray nuclei and electron spectra

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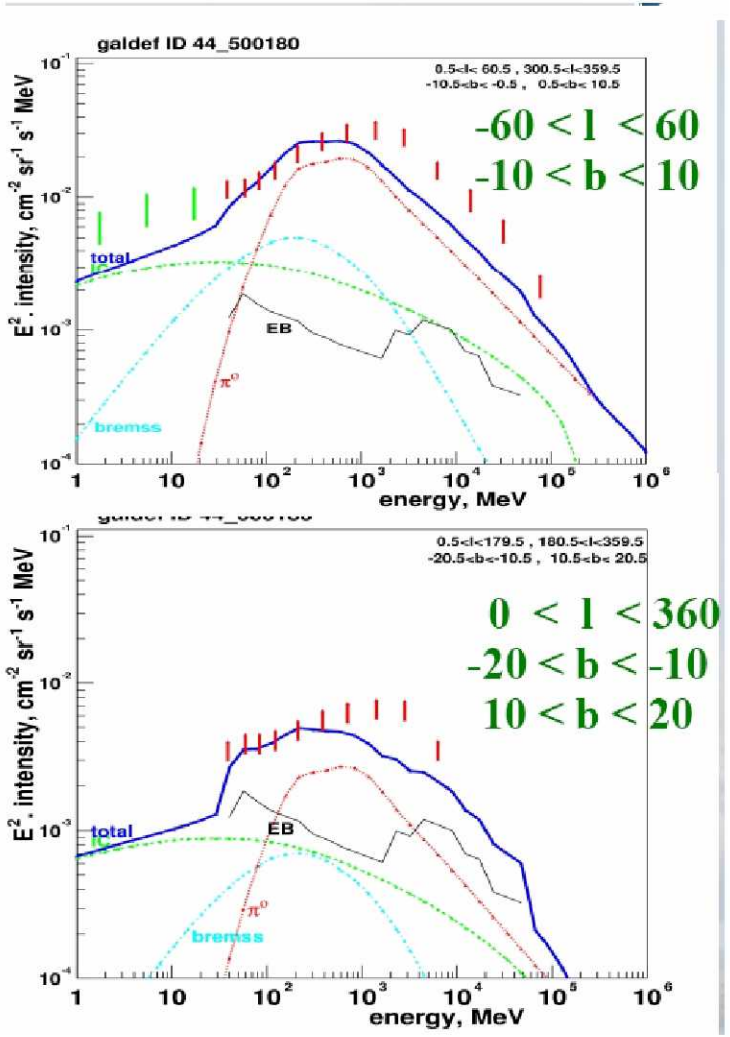
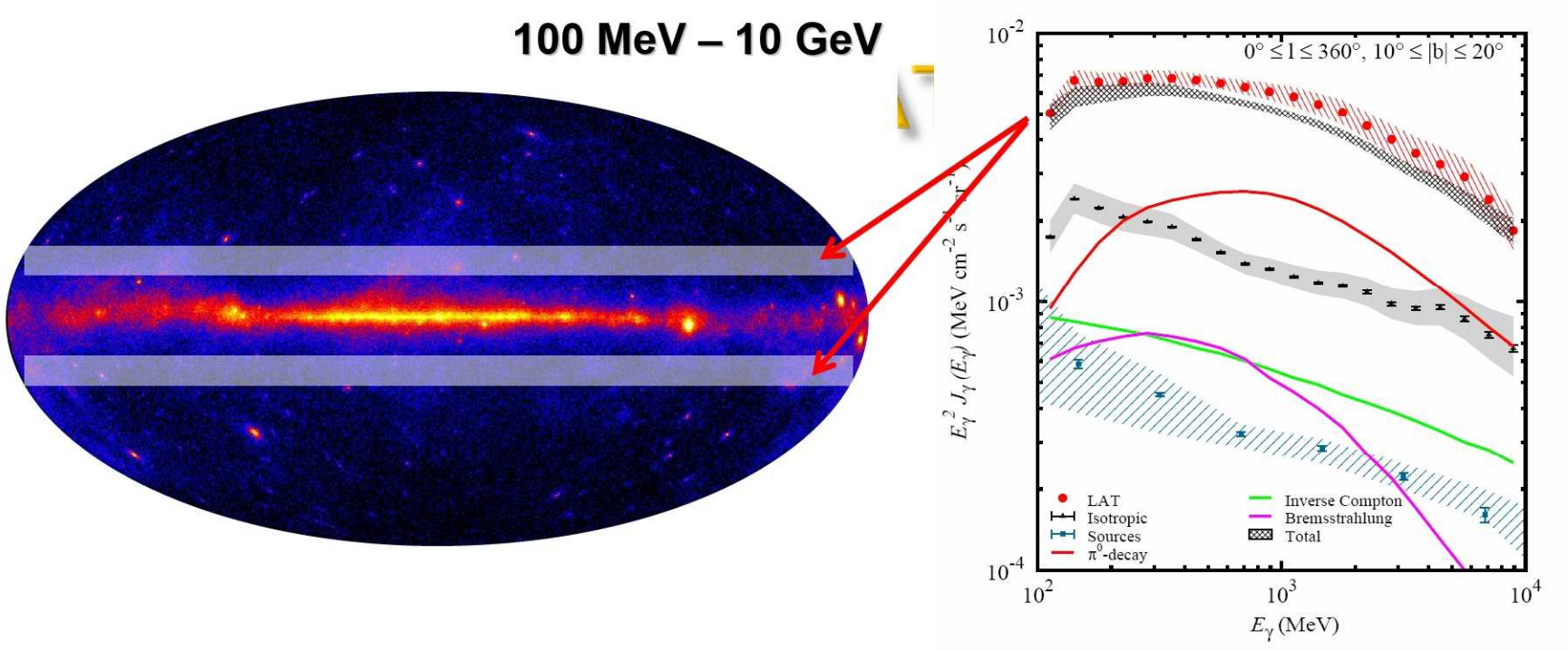



- Variety of explanations
  - Variations in cosmic-ray spectra over Galaxy
  - Unresolved sources (pulsars, SNRs, …)
  - Dark matter
  - Instrumental

**~100% discrepancy > 1 GeV**

# Fermi result




- Spectra shown for mid-latitude range → EGRET GeV excess in this region of the sky is <u>not</u> confirmed
- Sources are a minor component
- LAT errors are systematics dominated and estimated ~10%
- Work to analyse and understand diffuse emission over the entire sky and broader energy range is in progress

# Gamma-ray bursts observed by Fermi

- **LAT has reported 6 high-energy bursts since launch**

long-duration bursts

**GRB 080825C: Fermi-LAT observations**

**SOURCE:** GCN
**TITLE:** GCN CIRCULAR
**NUMBER:** 8183
**SUBJECT:** GRB 080825C: Fermi-LAT observations
**DATE:** 08/09/05 17:45:46 GMT
**FROM:** Aurelien Bouvier at Stanford <bouvier@stanford.edu>

**GRB 080916C: Fermi LAT observation** — Tajima et al. GCN 8246

**SOURCE:** GCN
**TITLE:** GCN CIRCULAR
**NUMBER:** 8246
**SUBJECT:** GRB 080916C: Fermi LAT observation
**DATE:** 08/09/16 18:25:23 GMT
**FROM:** Nicola Omodei at INFN(Pisa)/GLAST <nicola.omodei@pi.infn.it>

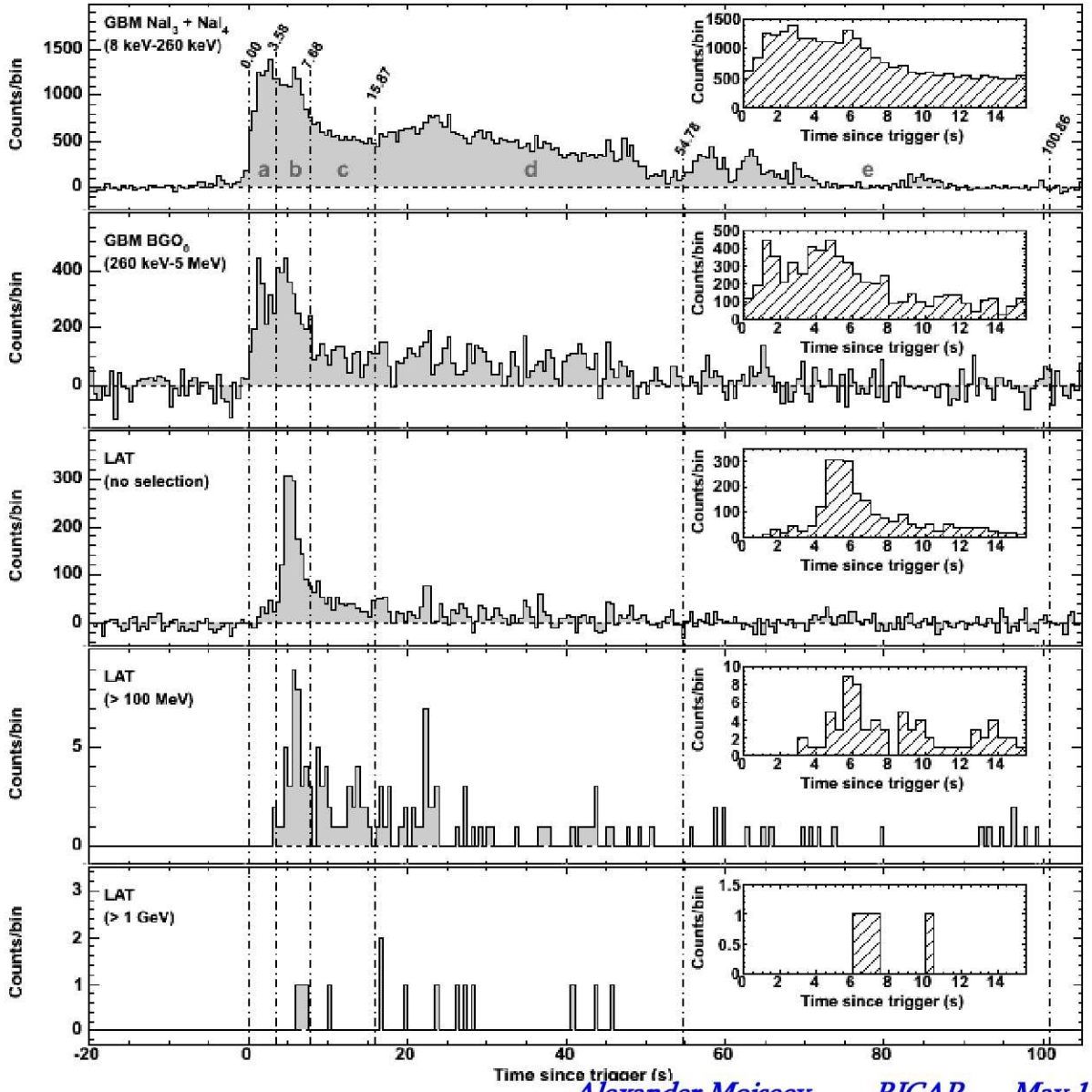
**Z = 4.35 ± 0.15**

First detection of short-duration burst at high energy

**Fermi-LAT observation of GRB 081024B** — Omodei GCN 8407

**SOURCE:** GCN
**TITLE:** GCN CIRCULAR
**NUMBER:** 8407
**SUBJECT:** Fermi-LAT observation of GRB 081024B
**DATE:** 08/10/25 14:07:58 GMT
**FROM:** Nicola Omodei at INFN(Pisa)/GLAST <nicola.omodei@pi.infn.it>

# Light curves: high energy!




- For the first time, can study time structure > tens of MeV.
- Feature in the LC:
  - —pulse in interval "a" disappears at LAT energies.

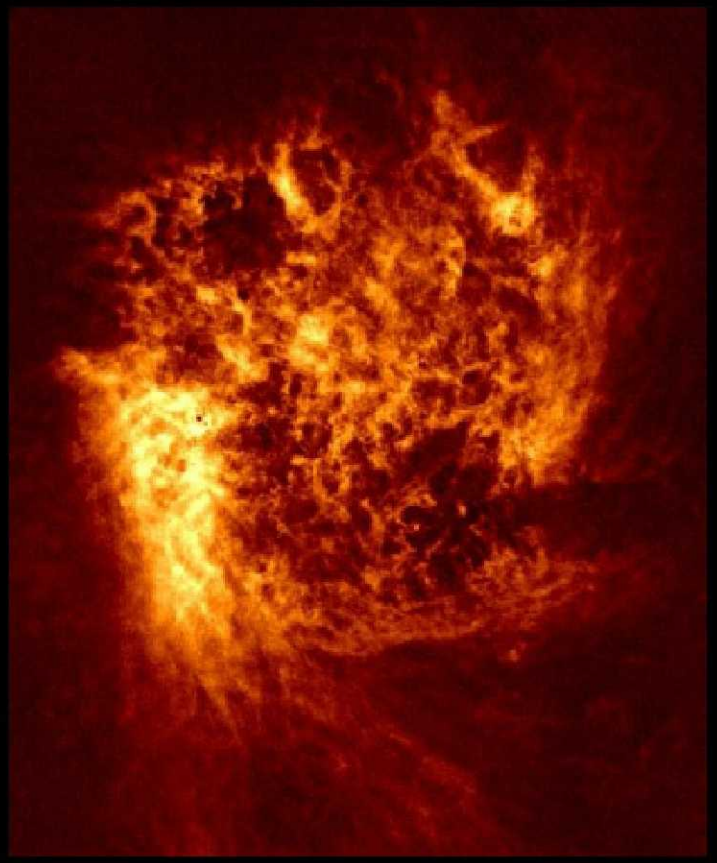
**For this burst, $\gamma\gamma$ absorption arguments provide a stringent lower limit of $\Gamma_{min} = 860$**

Science Express, 19 Feb 2009, pg 1

# Why study the Large Magellanic Cloud?

NASA/JPL-Caltech/M. Meixner (STScI) & the SAGE Legacy Team

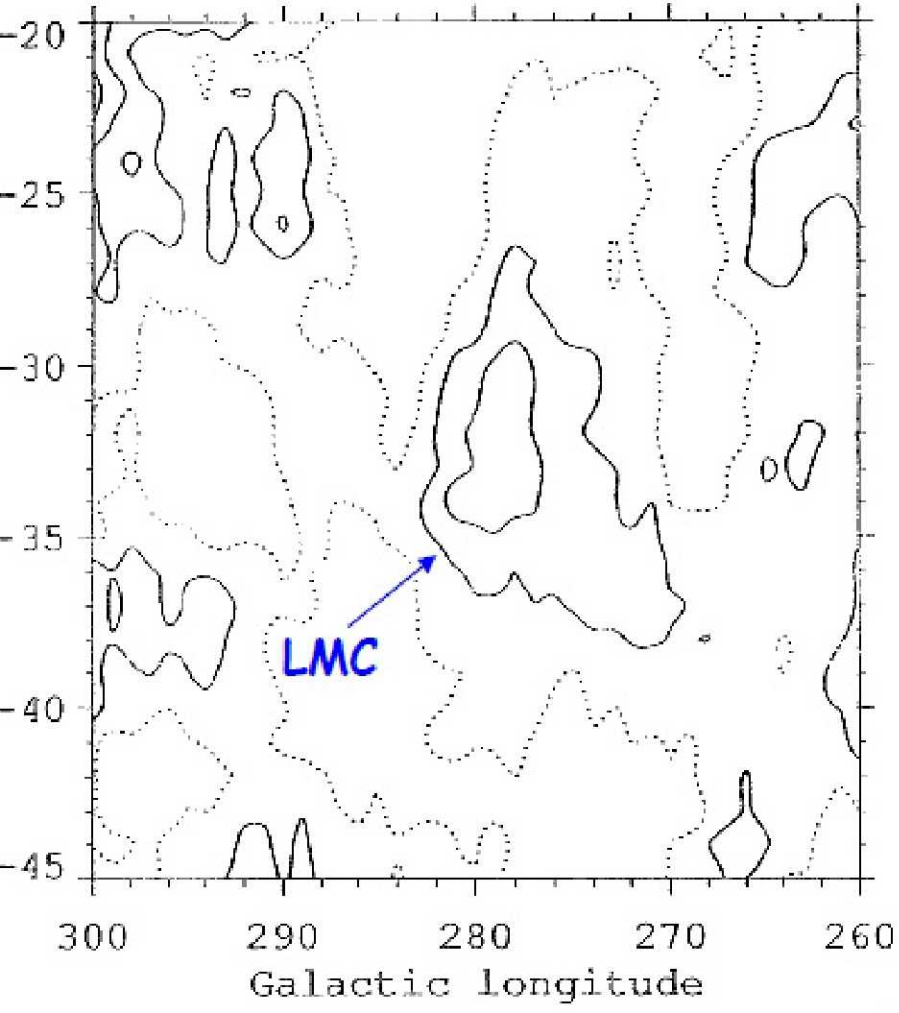
LMC is
- seen ~ face-on (i ≈ 27°)
- nearby (~ 50 kpc)
- active (many massive star forming regions)

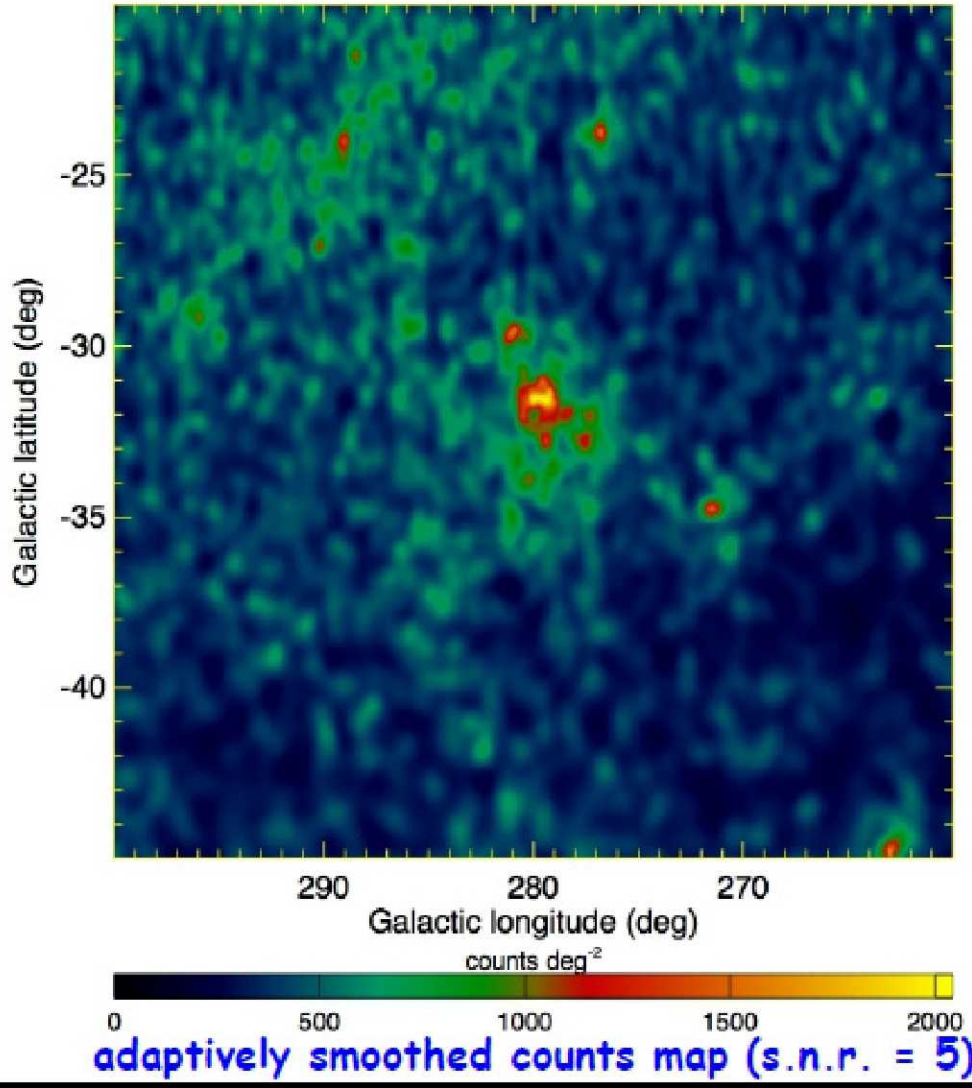


ATCA+Parkes H I (Kim et al. 2003)

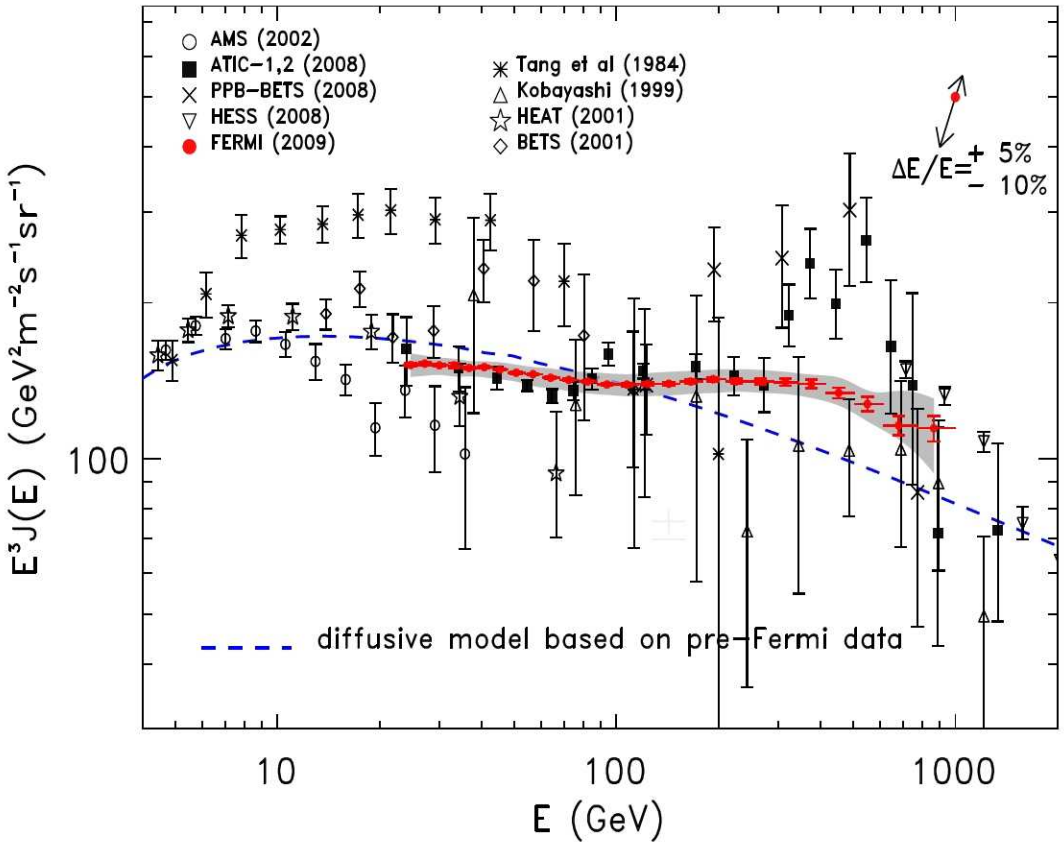
# EGRET vs. Fermi View of LMC

**PRELIMINARY**



# Fermi-LAT electron spectrum from 20 GeV to 1 TeV

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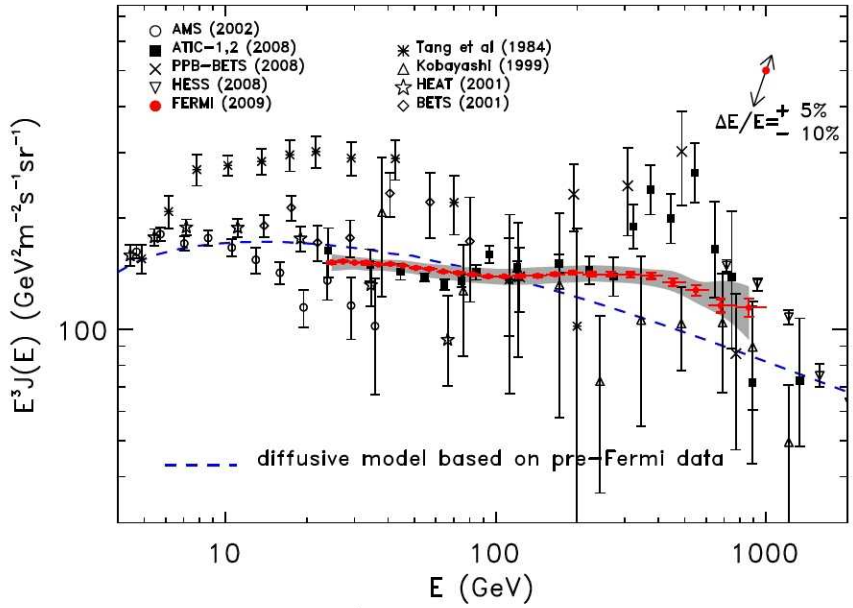
***Total statistics*** *collected for 6 months of Fermi LAT observations*

- *> 4 million electrons above 20 GeV*
- *> 400 electrons in last energy bin (770-1000 GeV)*




- *The measured spectrum is compatible with a power law within our current systematic errors. The spectral index (-3.04) is harder than expected from previous experiments and simple theoretical considerations*
- *"Pre-Fermi" diffusive model requires a harder electron injection spectrum (by 0.12) to fit the Fermi data, but inconsistent with positron excess reported by Pamela if it extends to higher energy*
- *Additional component of electron flux from local source(s) may solve the problem; its origin, astrophysical or exotic, is still unclear*
- *Valuable contribution to the calculation of IC component of diffuse gamma radiation*

- *Fermi Gamma-ray Space Telescope fully operational..*
- *In first few days of sky survey, the LAT corroborated many of the great discoveries of EGRET; now finding new sources as well;*
- *With 6 months of the 1st year all-sky survey phase;*
  - *large number of pulsars detected, many only in g-rays;*
  - *many flaring active galaxies observed; about half not seen by EGRET;*
  - *Flaring sources observed along the galactic plane;*
  - *High-energy emission seen from 6 GRBs; first time seen from short-duration burst;*
  - *Quiescent sun detected at high energies;*
  - *Major progress in understanding galactic diffuse emission*
- *With time, Fermi will probe deeper and deeper into the high-energy* **Universe**