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

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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

Alexander Moiseev
RICAP
May 13, 2009
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

**Membership Counts**
- 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 cm² 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!

The LAT Instrument Overview

Pair-conversion gamma-ray telescope: 16 identical “towers” providing conversion of $\gamma$ 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 $\mu$m; 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.

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LAT Performance

Effective area (cm²)

Energy (MeV)

Angular resolution (68% cont. radius, degrees)

Sensitivity to point sources

<table>
<thead>
<tr>
<th></th>
<th>Year(s)</th>
<th>Ang. Res. (100 MeV)</th>
<th>Ang. Res. (10 GeV)</th>
<th>Eng. Rng. (GeV)</th>
<th>$A_{\text{eff}} \Omega$ (cm² sr)</th>
<th># γ-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGRET</td>
<td>1991-00</td>
<td>5.8°</td>
<td>0.5°</td>
<td>0.03–10</td>
<td>750</td>
<td>$1.4 \times 10^6$/yr</td>
</tr>
<tr>
<td>AGILE</td>
<td>2007</td>
<td>4.7°</td>
<td>0.2°</td>
<td>0.03–50</td>
<td>1,500</td>
<td>$4 \times 10^6$/yr</td>
</tr>
<tr>
<td>Fermi LAT</td>
<td>2008</td>
<td>3.5°</td>
<td>0.1°</td>
<td>0.02–300</td>
<td>25,000</td>
<td>$1 \times 10^8$/yr</td>
</tr>
</tbody>
</table>

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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


Crosses mark source locations, in Galactic coordinates. 1/3 at \(|b| < 10^\circ\). Only 60 clearly associated with 3EG EGRET catalog. The sky changes!
**LAT bright sources**

- based on first 3 months of sky-survey

<table>
<thead>
<tr>
<th>Class</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio/X-ray pulsar</td>
<td>15</td>
</tr>
<tr>
<td>LAT pulsar</td>
<td>14</td>
</tr>
<tr>
<td>Globular cluster (pulsars?)</td>
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<tr>
<td>HMXB</td>
<td>2</td>
</tr>
<tr>
<td>LMC</td>
<td>1</td>
</tr>
<tr>
<td>Flat Spectrum</td>
<td>62</td>
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<tr>
<td>Radio Quasars</td>
<td>46</td>
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<tr>
<td>BL Lac Objects</td>
<td>46</td>
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<tr>
<td>Blazar, uncertain type</td>
<td>11</td>
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<tr>
<td>Radio galaxies</td>
<td>2</td>
</tr>
<tr>
<td>Special cases (under study)</td>
<td>14</td>
</tr>
<tr>
<td>Unassociated</td>
<td>37</td>
</tr>
</tbody>
</table>

Legend:
- ○ Unassociated
- × AGN
- Pulsar
- + X-ray binary
- ▽ Globular cluster
• exhibits all characteristics of a young high-energy pulsar (characteristic age \( \approx 1.4 \times 10^4 \) yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

• spin-down luminosity \( \approx 10^{36} \) erg s\(^{-1} \), sufficient to supply the PWN with magnetic fields and energetic electrons.

\[ \text{Science, November 21, 2008, v.322, 1218} \]

• \( \gamma \)-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 \( \approx 450 \) km/s
Fermi pulsars

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

Pulses at 1/10th real rate

Δ 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
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

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**3C 454.3, flux 100-300 keV (six-hours)**

- Entries: 374
- Y Mean: $1.6408E-6$
- Y Rms: $7.5574E-7$

**3C 454.3, flux 100-300 keV (daily)**

- Entries: 188
- Y Mean: $2.3086E-6$
- Y Rms: $2.0099E-6$

**3C 454.3, flux 100-300 keV (weekly)**

- Entries: 26
- Y Mean: $2.3404E-6$
- Y Rms: $1.9482E-6$

Alexander Moiseev  RICAP  May 10, 2009
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 (CERN/High), 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-WEST 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 flux 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

NGC 1275
3C 454.3
PKS 1502+106
PMN J0948+002
PKS 1454+106
PKS 2155–304
EGRET observations showed excess emission > 1 GeV when compared with conventional model tuned to reproduce local cosmic-ray nuclei and electron spectra

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

~100% discrepancy > 1 GeV
Spectra shown for mid-latitude range → EGRET GeV excess in this region of the sky is not 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 080916C: Fermi LAT observation

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

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>

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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 $\Gamma_{\text{min}} = 860$
Why study the Large Magellanic Cloud?

**LMC is**
- seen ~ face-on ($i \approx 27^\circ$)
- nearby (~ 50 kpc)
- active (many massive star forming regions)

ATCA+Parkes H I (Kim et al. 2003)
EGRET vs. Fermi View of LMC

PRELIMINARY

adaptively smoothed counts map (s.n.r. = 5)
Fermi-LAT electron spectrum from 20 GeV to 1 TeV

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)

Alexander Moiseev RICAP May 13, 2009

Submitted to PRL on March 19, 2009
Accepted April 21
• 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 γ-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