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
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

Alexander Moiseev RICAP May 13, 2009
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
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
  - Unprecedented 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 $8.8 \times 10^5$ 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**
CsI(Tl) crystals in 8 layers.

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

Sensitivity to point sources

<table>
<thead>
<tr>
<th></th>
<th>Years</th>
<th>Ang. Res. (100 MeV)</th>
<th>Ang. Res. (10 GeV)</th>
<th>Eng. Rng. (GeV)</th>
<th>$A_{\text{eff}} \Omega$ (cm$^2$ sr)</th>
<th># $\gamma$-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>

Alexander Moiseev    RICAP    May 13, 2009
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°. 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>
<td>1</td>
</tr>
<tr>
<td>HMXB</td>
<td>2</td>
</tr>
<tr>
<td>LMC</td>
<td>1</td>
</tr>
<tr>
<td>Flat Spectrum Radio Quasars</td>
<td>62</td>
</tr>
<tr>
<td>BI Lac Objects</td>
<td>46</td>
</tr>
<tr>
<td>Blazar, uncertain type</td>
<td>11</td>
</tr>
<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>
• exhibits all characteristics of a young high-energy pulsar (characteristic age \( \sim 1.4 \times 10^4 \) yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

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

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

• \( \gamma \)-ray source at \( \ell, b = 119.652, 10.468 \); 95% error circle radius \( \sim 0.038^\circ \) 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 \( \sim 450 \) 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

(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)
  - \(2 \times 10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}\) 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
• 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 (NR/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 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

- PKS 1502+106
- PMN J0948+002
- PKS 1454+106
- NGC 1275
- 3C 454.3
- PKS 2155–304

Alexander Moiseev
RICAP
May 13, 2009
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.

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

$\sim 100\%$ discrepancy $> 1$ GeV

Alexander Moiseev
RICAP
May 13, 2009
Fermi result

100 MeV – 10 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

### GRB 080916C: Fermi LAT observation

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>GCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>GCN CIRCULAR</td>
</tr>
<tr>
<td>NUMBER</td>
<td>8246</td>
</tr>
<tr>
<td>SUBJECT</td>
<td>GRB 080916C: Fermi LAT observation</td>
</tr>
<tr>
<td>DATE</td>
<td>08/09/16 18:25:23 GMT</td>
</tr>
<tr>
<td>FROM</td>
<td>Nicola Omodei at INFN(Pisa)/GLAST <a href="mailto:nicola.omodei@pi.infn.it">nicola.omodei@pi.infn.it</a></td>
</tr>
</tbody>
</table>

**Z = 4.35 ± 0.15**

### GRB 080825C: Fermi-LAT observations

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>GCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>GCN CIRCULAR</td>
</tr>
<tr>
<td>NUMBER</td>
<td>8183</td>
</tr>
<tr>
<td>SUBJECT</td>
<td>GRB 080825C: Fermi-LAT observations</td>
</tr>
<tr>
<td>DATE</td>
<td>08/09/05 17:45:46 GMT</td>
</tr>
<tr>
<td>FROM</td>
<td>Aurelien Bouvier at Stanford <a href="mailto:bouvier@stanford.edu">bouvier@stanford.edu</a></td>
</tr>
</tbody>
</table>

### First detection of short-duration burst at high energy

**Fermi-LAT observation of GRB 081024B**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>GCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>GCN CIRCULAR</td>
</tr>
<tr>
<td>NUMBER</td>
<td>8407</td>
</tr>
<tr>
<td>SUBJECT</td>
<td>Fermi-LAT observation of GRB 081024B</td>
</tr>
<tr>
<td>DATE</td>
<td>08/10/25 14:07:58 GMT</td>
</tr>
<tr>
<td>FROM</td>
<td>Nicola Omodei at INFN(Pisa)/GLAST <a href="mailto:nicola.omodei@pi.infn.it">nicola.omodei@pi.infn.it</a></td>
</tr>
</tbody>
</table>

Alexander Moiseev  
RICAP  
May 13, 2009
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)
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)

Submitted to PRL on March 19, 2009
Accepted April 21

Alexander Moiseev  RICAP  May 13, 2009
• 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 1\textsuperscript{st} 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