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

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Launch from Cape Canaveral, June 11, 2008
3rd EGRET catalog

- AGN - blazars
- unidentified
- pulsars
- LMC

EGRET Legacy. April 5, 2991 - June 4, 2000
First Light - 4 days, 133K photons

- **GLAST launch** - June 11, 2008
- **13 days after launch**: LAT and GBM activation - June 24. Start of on-orbit calibration

- **20 days after launch**: LAT First light - July 1-4!
- **53 days after launch (!)**: Start of nominal science observations - August 4

- **Renamed to Fermi** - August 28

Alexander Moiseev  NASA/GSFC  RICAP  May 13, 2009
Fermi Science Questions

Fermi science objectives cover probably everything in high energy astrophysics:

• How do super massive black holes in Active Galactic Nuclei create powerful jets of material moving at nearly light speed? What are the jets made of?

• What are the mechanisms that produce Gamma-Ray Burst (GRB) explosions? What is the energy budget?

• How does the Sun generate high-energy γ-rays in flares?

• How do the pulsars operate? How many of them are around and how different are they?

• What are the unidentified γ-ray sources found by EGRET?

• What is the origin of the cosmic rays that pervade the Galaxy?

• What is the nature of dark matter?

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

Two instruments onboard:

✓ Large Area Telescope LAT
  - 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
  - 8 KeV – 40 MeV
  - observes whole unocculted sky all the time, searching for gamma-ray bursts
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 along axis at 1 GeV)

- Large energy range, overlapping with EGRET under 10 GeV and with HESS, MAGIC, CANGAROO 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 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-strip 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. Strip pitch is 228 $\mu$m; total 8.8×10⁵ 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

LAT is all-sky monitor, unlike EGRET and AGILE

L vs. Energy (MeV)
Main results for the first 8 months

- Pulsars
- Active Galactic Nuclei (AGN)
- Gamma-Ray Bursts (GRB)
- Diffuse radiation
- Electron + positron spectrum

- 13 papers in refereed journals (7 published, 6 accepted)
- 9 papers ready (5 submitted, 4 ready to submit)
- 38 rapid publications
  - 29 Astronomer’s telegrams (ATEL), 9 Gamma-ray burst coordination network (GCN) circulars
LAT 3 month sky map: 205 high confidence bright sources (> 10 $\sigma$)
Only 60 clearly associated with EGRET sources
CTA 1 - First gamma-ray pulsar discovered by Fermi in blind search

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.

This source was a very bright and well positioned unidentified EGRET source. This source was deliberately targeted during LAT checkout.

γ-ray source at l,b = 119.652, 10.468; 95% error circle radius =0.038° contains the X-ray source RX J00070+7302
Vela Pulsar

- Acceleration in Magnetosphere
  - Outer magnetosphere
  - Near the NS surface
- LAT data consistent with simple exponential cut-off
  - favors outer-gap model

\[
N(E) = N_0 E^{\Gamma} e^{-\left(\frac{E}{E_c}\right)^{\delta}}
\]

\[
\Gamma = -1.5^{+0.05}_{-0.04}
\]

\[
E_c = 2.9 \pm 0.1 \text{ GeV}
\]

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The Pulsing γ-ray Sky

More in talks by F. Loparco, F. Gargano, F. Giordano

Fermi Pulsar Detections

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

Pulses at 1/10th true rate
Unified Picture of AGNs

- **Powered by accretion onto a central, supermassive black hole**
- **Accretion disks produce optical/UV/X-ray emission via various thermal processes**
- **Jets**: highly collimated outflows with $\Gamma \sim 10$
  - Large brightness temps, superluminal motion, rapid variability in $\gamma$-rays
- **Unified Model**: observer line-of-sight determines source properties, e.g., radio galaxy vs blazar
- **Other factors**: accretion rate, BH mass and spin, host galaxy

Image Credit: C.M. Urry & P. Padovani
Fermi Results on AGNs

- 58 FRSQs, 42 BL Lacs, 4 Unc., 2 radio galaxies
- Automated Science Processing (ASP) with $2 \times 10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}$ threshold (daily)
- Flare Advocates

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Some 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 detects the Sun and the Moon

The Sun, July 1 - Sept 24, 2008

The Moon, August 3 - August 7, 2008
Gamma-ray Bursts Detected by GBM and LAT

- GRB 080825C
- GRB 080916C - strongest ever seen
- GRB 081024B - short
- GRB 081215A - LAT rate increase
- GRB 090217
- GRB 090323 - ARR
- GRB 090328 - ARR

10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}

"Typical" Prompt GRB Spectrum

168 GBM GRBs
7 LAT GRBs

Fermi GRBs

Photon Energy (MeV)
GRB 080916C - Strongest ever seen

- Redshift = 4.35 → $E_{\text{iso}} = \sim 10^{55}$ ergs
- Evolving Band function fits well
- Delay of High-E photons of $\sim 5$ s
- Max photon energy of 13 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 analyze and understand diffuse emission over the entire sky and broader energy range is in progress
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. ATIC bump is not confirmed

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

Measurement of the Cosmic Ray positron spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope
A. A. Abdo et al. (Fermi LAT Collaboration)

Published 4 May 2009

Details in electron session by C. Sgro, L. Baldini, M. Pesce-Rollins, and D. Grasso
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
  - First precise measurement of high energy electron spectrum
  - Extensive search for dark matter signatures

- With time, Fermi will probe deeper and deeper into the high-energy Universe
THANK YOU!