The Fermi Observatory

First Year Results from the Fermi Gamma-ray Space Telescope

Elizabeth Hays (NASA/GSFC)

Large Area Telescope (LAT)

ACD scintillator
89 tiles

Gamma-ray Burst Monitor

Tracker
Si strip detectors
Tungsten foil converters
pitch = 228 um
8.8x10^5 channels
18 planes

Calorimeter
CsI crystals
hodoscopic array
6.1x10^5 channels
8 layers

Candidate Gamma-ray Events

Tracker Performance and Calibration

Hit Efficiency

Tight Data

Ground Data

- Hit efficiency >99.9% on average
- No significant change in alignment constants (extra/inter-tower) after launch (4g acceleration)
- No evidence of increase in the overall noise level (-1 noise hit in Tracker per event)

October 15, 2009

https://ntrs.nasa.gov/search.jsp?R=20090038180 2019-06-30T21:58:31+00:00Z
ACD and Calorimeter Stability

- Continuous Monitoring of ACD
- Minimum ionizing particle peak
- Pedestals
- Veto threshold

Continuous Monitoring of CAL
- Zero suppression thresholds
- Trigger thresholds

CAL zero-suppression (single crystal)

On-orbit Energy Calibration

- Occasional charge injection runs
- Low energy - protons
- High energy - "heavy ions" triggers that overlap low and high range readout
- Energy scale monitored heavy cosmic-ray nuclei
  - 500 MeV Carbon
  - 8 GeV Iron

On-orbit Rates

- Overall trigger rate: ~few KHz
- Huge variations due to orbital effects
- Downlink rate: ~400-500 Hz
- ~90% from gamma filter
- ~20-30 Hz from diagnostic filter
- ~5 Hz from heavy ion filter
- Photon-selected event rate (passing standard background rejection cuts): ~1 Hz

Gamma ray... Cosmic ray... Both?

On-orbit effect - reduced effective area at low energy due to signals from out-of-time particles in the readout
Post-launch update - properly modeled in simulations
Planned update - improve reconstruction to regain area

A GeV, Wide-field Instrument

- Energy Dependence
- Incidence Angle Dependence

LAT Sensitivity with Time

Transient Science: Flares, bursts, multiwavelength campaigns, unidentified transients
Accumulated Science: New source types, populations, long-term monitoring, spatially extended and diffuse studies
Deepest and most uniform survey of the sky at these energies

All-sky coverage
- ~3 hrs
- (2 orbits)

Minor asymmetry due to passages through South Atlantic Anomaly
Fermi Gamma-ray Bursts

Fermi GRBs as of 090629

12 LAT GRBs (>2x pre-Fermi for E> 100 MeV)
2 short GRBs detected by LAT

GRB 080916C keV to GeV Lightcurve

GRB 080916C keV to GeV Lightcurve

Implications of High Redshift

+ Eiso ~ 8.3 x 10^54 ergs
  - Largest energy release ever observed
+ High redshift and high fluence imply strongly collimated jet
+ No cutoff => bulk Lorentz factor > 890 ± 21
  - Also constrain Lorentz invariance violation
    - 13.2 GeV at T < 16.5 s
    - M_{10^8} > 1.3 x 10^{18} GeV\cdot cm^2

Fermi LAT 3-month sky map

Fermi LAT 9-month sky map
Preliminary LAT and EGRET measurements dominated by systematics

- EGRET GeV excess not confirmed by LAT for intermediate latitudes

Model based on local cosmic-ray measurements (pre-Fermi) - in good agreement

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LAT Resolves a Nearby Galaxy

Large Magellanic Cloud

- D~50 kpc (~180 kly)
- Active star forming regions, massive stars and supernova remnants

Adaptively smoothed LAT count map with dust map contours from infrared observations

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LAT as a Nearby Galaxy

Large Magellanic Cloud

- D~50 kpc (~180 kly)
- Active star forming regions, massive stars and supernova remnants

LAT resolves galaxy plus a source consistent with 30 Doradus (Tarantula nebula, HII region)

- 50% from 30 Doradus
- 50% from LMC

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LAT as an Electron Detector

- ~100% efficient for E~20 GeV
- Good hadron rejection (up to 1.10^4 at 1 TeV)
- Detailed simulations and comparisons with data
- Systematics <20%
  - MC-data, acceptance, proton spectrum, energy calibrator

Residual hadronic contamination <20% over energy range

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Cosmic-ray e^+e^- spectrum from 20 GeV to 1 TeV

- LAT error band includes systematics
- Model assumes standard CR injection and propagation

Abdo et al. 2009, Physical Review Letters, 102, 181101
Early Highlights

- First 3 Months
- 206 bright sources (>10 α)
- ~1/3 variable
- 106 spatially associated with active galactic nuclei (AGN)
- 2 radio galaxies from 3-month survey

New Gamma-ray Pulsars

Gamma-ray Pulsar Discoveries

- Pre-LAT: 1 radio-quiet gamma-ray-loud pulsar
- LAT data used in a blind search for periodicity at known locations of interest
  - Pulsar candidates and unidentified LAT sources
  - Time-differencing technique applies FFT to time differences of event times (Atwood et al. 2006, Ziegler et al. 2008)
- 13 of 16 radio-quiet LAT pulsars associated with unidentified EGRET sources

Gamma-ray Pulsar

Vela Pulsar

Galactic Binary Systems - Orbital Signatures

Look for modulation of gamma rays with orbital phase

Galactic Binary Systems - LS I +61 303

A massive star with compact companion in ~26 day orbit

Competing effects in local environment
  - Inverse Compton scattering
  - Pair production absorption of TeV photons
Supernova Remnants
Bright gamma-ray sources associated with several supernovae interacting with molecular clouds
Extension resolved in LAT data

Unidentified Gamma-ray Sources
+ Previous MeV-GeV energy gamma-ray missions left many unidentified sources
+ LAT bright source list (3 months) includes ~40
+ No identification can mean
  + Multiple possible candidates
  + No plausible candidates
+ One way to make a very firm identification
  + Correlated variability with other observations

Unidentified Gamma-ray Transients
GRO J1838-04
EGRET observed 3.5 day flare near the Galactic Plane in June 1995
No blazar candidates found

LAT Automated Science Processing
Automatic transient monitoring
All-sky search runs every 6 hours, 1 day, 1 week
LAT flare advocates monitor results and trigger multiwavelength follow-up.
Reports at http://fermisky.blogspot.com/

LAT Unidentified Transient Detections
🌟 Unidentified transients
〇 Low latitude blazars from the bright source list

Two Early Unidentified Transients
High confidence >10 sigma
Counts per day (E>200 MeV)
- 2 deg radius exposure corrected
  - scaled to average background rate
Average background rate
LAT 95% error circle contains Swift XRT source (Landi et al. ATEL #1822) coincident with flat-spectrum radio source from SUMMS and AT20G (Sadler ATEL #1843)

Fermi J1057-6027 - June 11, 2009, gamma-ray increase over 1 day - Coincident with a known LAT source - 95% confidence radius 0.07 deg - 10x above average gamma-ray flux - Swift XRT TOO within 1 day (ATEL #2082, #2083) - AG Carinae, luminous blue variable (LBV) star with X-ray and radio emission, 7.7' away

A New LAT Transient - J1057-6027

Summary

+ LAT is an excellent gamma-ray (and electron) detector
+ Catching long, short, and some very distant gamma-ray bursts
+ Detecting new pulsars and probing their emission zones and mechanisms
+ Studying gamma-ray binary systems
+ Measuring extended emission from supernova remnants
+ Explaining previously unidentified gamma-ray emitters and exploring new territory - more science to come!

First Fermi Symposium
Nov 2-5, Washington, D.C.
http://fermi.gsfc.nasa.gov

Counterpart Search - 3EG J0903-3531

Updated LAT 95% error circle (6 months) contains a flat-spectrum radio source and Swift/XRT source

Counterpart Search - Fermi J0910-5041

LAT 95% error circle contains Swift XRT source (Landi et al. ATEL #1822) coincident with flat-spectrum radio source from SUMMS and AT20G (Sadler ATEL #1843)

Fermi J0910-5041 (ATEL #1788) - October 15, 2008, gamma-ray increase over 2 days - 10x above average gamma-ray flux - Swift XRT TOO within 1 day

The Large Area Telescope

-1- Counterpart Search - 3EG J0903-3531

-1- Counterpart Search - Fermi J0910-5041

-1- A New LAT Transient - J1057-6027

-1- Summary

-1- The Large Area Telescope
The Sun and the Moon

Detection of the quiet Sun in gamma rays!
Fluxes consistent with model expectations. Moon flux agrees with EGRET.

Size of Sun/Moon on the sky

RHESSI observes to ~20 MeV

PSF at 1 GeV
PSF at 10 GeV

October 19, 2009
E. Hays

Galactic Highlights

Unidentifieds (?) Pulsars (47+) X-ray Binaries Supernova Remnants

Vela Pulsar Energy Dependence

Peak 1 (P1) stronger at low energy.
Peak 2 (P2) stronger at higher energy.
(Confirms EGRET)
NEW: Peak 3 evolves with energy

Radio

P1
P2

Rotational Phase

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New Gamma-ray Pulsar in CTA 1

Science Express October 16
Ahab et al., 2008, Science

1420 Hz radio map.
P = 316 ms
PM = 3.6 x 10^-12
Characteristic age = 10 kyr
Flux (>100 MeV) = 3.8 x 0.2 x 10^-14 ph cm^-2 s^-1
Pulse undetected in radio/X-ray

LAT 95% error radius = 0.038 deg

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Pulsars and Wind Nebulae

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Crab Pulsar and Nebula

Pulsar 100 MeV to 20 GeV Nebula from MeV to TeV

Inverse Compton emission consistent with mean magnetic field in nebula 100 μG < B < 200 μG

Hyper-exponential cutoff excluded at ~5 sigma

Consistent with emission well above the neutron star surface

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A Puzzle for Models

Veblen counts E > 800 MeV

Data compared with a simulated point source at position of Vela Pulsar

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TeV and Multi-TeV Connections

VERITAS excess map


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BLAZAR GALAXIES

• Extremely variable
• Broadband emission from radio to gamma-ray wavelengths

3C 454.3 daily flux Aug-Oct 2008


LAT Detection of Perseus A

COS B

LAT

First new LAT radio galaxy

+ NGC 1275 = Perseus A = 3C84
+ In galaxy cluster at redshift z = 0.037
+ No previous detection with EGRET
+ Consistent with a point source
+ Long-term variability


GRB 080916C - the long bright one

+ 2nd GRB detected by LAT
+ 1st since EGRET with imaged photons and E > 1 GeV!
+ Brightest burst with a measured redshift
+ GROND measurement of redshift, z = 4.3
+ Prompt emission
+ >3000 LAT events in first 100 seconds
+ >140 LAT events for spectral analysis (>100 MeV)
+ Time-resolved spectroscopy over 6 decades in energy
+ High-energy emission peaks at later times
+ LAT photons up to 23 min after the trigger time
+ Abdo et al. 2009, Science, 323, 1688

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GRB 080916C Spectral Evolution

Spectrum for (b) 3.6 - 7.7 s compatible with a single component

- Rapid soft to hard evolution in (a) to (b)
- Gradual decrease of $E_{\text{peak}}$ from (b) to (d)

Test of Quantum Gravity

- Test for energy dispersion of photons (higher energy arrive later)
- $\Delta T \times \Delta E/M_{\text{QG}}$
- Strong limit on Lorentz invariance violation
  - Highest $E$ photon 13.2 GeV ($1+z$) = 70.6 GeV
  - Arrived 16.5 sec after TO
  - $\implies M_{\text{QG}} > 1.30 \times 10^{18}$ GeV/c²
    - $(-0.1 M_{\text{Planck}})$

Abdo et al. 2009, Science, 323, 1688