First Year Results from the Fermi Gamma-ray Space Telescope

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The Fermi Observatory

Large Area Telescope (LAT)

- Large field of view >2.4 sr
- Entire sky every 3 hrs (every 2 orbits)
- Broad energy range (20 MeV - 300 GeV)

Gamma-ray Burst Monitor
(GBM)

- Views entire un occulted sky
- NaI: 8 keV - 1 MeV
- BGO: 150 keV - 40 MeV

Fermi LAT Collaboration

- France
  - IPNO, INFN, Saclay
- Italy
  - INFN, INAF, ROMA
- Japan
  - RIKEN, KEK
- Nationwide University
- NASA/GSFC
- Stanford
- Tsung-Dao Laboratories of High Energy Physics

Sweden
- Royal Institute of Technology (KTH)
- Stockholm University
- United States
  - Georgia State University (GSU) and INR, Phladelphia
  - University of California at Santa Cruz - Santa Cruz
  - University of Washington

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Large Area Telescope (LAT)

ACD
- Large Field of View >2.4 sr
- Broad Energy Range 20 MeV - >300 GeV
- 89 tiles
- Y

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

Calorimeter
- CsI crystals
- Hodoscopic array
- 8 layers

Candidate Gamma-ray Events

- Green tiles: - detected position of the charged particle
- Blue tiles: - reconstructed track extension
- Yellow tile: - estimated direction of candidate gamma-ray event

Tracker Performance and Calibration

- Hit Efficiency: >99% on average
- No significant change in alignment constants (inter-/inter-tower) after launch (1g acceleration)
- No evidence of increase in the overall noise level (>1 noise hit in Tracker per event)

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ACD and Calorimeter Stability

- Continuous Monitoring of ACD
- Minimum ionizing particle peak
- Pedestals
- Veto threshold
- Continuous Monitoring of CAL
- Zero suppression thresholds
- Trigger thresholds

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 in ~3 hrs
- Minor asymmetry due to passages through South Atlantic Anomaly
Fermi Gamma-ray Bursts

GRB 080916C keV to GeV Lightcurve

Implications of High Redshift

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

** 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
**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
- 13 of 16 radio-quiet LAT pulsars associated with unidentified EGRET sources

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**Early Highlights**

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

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**New Gamma-ray Pulsars**

- 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 not event times (Atwood et al. 2006, Ziegler et al. 2008)

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**Galactic Binary Systems - Orbital Signatures**

Look for modulation of gamma rays with orbital phase

Gamma-ray flux from region containing LS I +61 303 in 1-day bins

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**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

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**Vela Pulsar**

Accurate LAT timestamps plus accurate radio timing solutions

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Science Express July 2

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NABM/Fermi/Cruz deWilde

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E.HideInInspector
Supernova Remnants

Bright gamma-ray sources associated with several supernovae interacting with molecular clouds
Extension resolved in LAT data

LAT counts map (0.8 GeV)
X-ray (0.1-2.4 keV, black) and radio (1.4 GHz, green) contours
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LAT counts map (2-10 GeV)
Radio (1.4 GHz, green) contours

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
O 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
Counterpart Search - Fermi J0910-5041

Fermi J0910-5041 (ATEL #1176)
- October 15, 2008, gamma-ray increase over 2 days
- 10x above average gamma-ray flux
- Swift XRT TOO within 1 day

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

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Counterpart Search - 3EG J0903-3531

3EG J0903-3531 (ATEL #1177)
- October 5, 2008, gamma-ray increase over 3 days
- 5x above 3EG flux
- Swift XRT TOO within 2 days

Updated LAT 95% error circle (8 months) contains a flat-spectrum radio source and Swift/XRT source

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A New LAT Transient - J1057-6027

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

X-ray map: Swift XRT (0.3-10 keV)
Radio contours: MGPS

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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

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The Large Area Telescope

Tracker (TKR):
- 128-cell shower detector
- 90% detection efficiency
- 90% identification
- High-energy electrons
- High-rate, high-momentum tracking

Calorimeter (CAL):
- 1536 C lead crystals
- Low energy threshold
- High-resolution calorimeter
- Shower profile reconstruction

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Extras
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

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Galactic Highlights

Unidentifieds?

Pulsars (47+)

And nebulae

X-ray Binaries

Supernova Remnants

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New Gamma-ray Pulsar in CTA 1

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

1420 Hz radio map.

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

Rotational Phase

LAT 95% error radius = 0.038 deg

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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
110 GeV

0
2.5
1

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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

Hyper-exponential cutoff excluded at ~5 sigma
Consistent with emission well above the neutron star surface
Inverse Compton emission consistent with mean magnetic field in nebula 100 μG < B < 200 μG

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A Puzzle for Models

**LS I -61.303**
- TeV peaks near aphelion
- GeV peaks near perihelion
- LS I +61 303 phase-averaged spectrum shows clear cutoff

**VERITAS**

LAT `:,,.^ 
MAGIC

TeV and Multi-TeV Connections

**VERITAS excess map**

**LAT Detection of Perseus A**
- 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 (10 keV to 10 GeV)
- High-energy emission peaks at later times
- LAT photons up to 23 min after the trigger time

**LAT photons up to 23 min after the trigger time**

**GRB 080916C - the long bright one**

**BLAZAR GALAXIES**
- Looking down relativistic particle jets from galaxy cores
- Extremely variable
- Broadband emission from radio to gamma-ray wavelengths

**3C 454.3**
- Daily flux Aug-Oct 2008
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 Epeak from (b) to (d)

Abdo et al. 2009, Science, 323, 1688

Test of Quantum Gravity

+ Test for energy dispersion of photons (higher energy arrive later)
  + $\Delta T \propto \Delta E / M_{\text{QG}}$
+ Strong limit on Lorentz invariance violation
  + Highest E photon 13.2 GeV (1+z) $\sim$ 70.6 GeV
  + Arrived 16.5 sec after TO
  + $\Rightarrow M_{\text{QG}} > 1.30 \times 10^{18} \text{ GeV/c}^2$
  + $\Rightarrow M_{\text{QG}} > 0.1 \text{ M}_{\text{Planck}}$

$\text{E}_{\text{peak}}$

$\text{Energy (MeV)}$

$10^{-1}$ $10^{0}$ $10^{1}$ $10^{2}$ $10^{3}$

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