High Energy Astrophysics with the Fermi Large Area Telescope

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On behalf of the Fermi LAT Collaboration

The Fermi Observatory

Large Area Telescope (LAT)
- Large Field of View (>2.4 sr)
- Views entire sky every 3 hrs (every 2 orbits)
- Broad Energy Range (20 MeV - >300 GeV)

Gamma-ray Burst Monitor (GBM)
- Views entire unocculted sky
- NaI: 8 keV - 1 MeV
- BGO: 150 keV - 30 MeV

LAT Performance from Ground Simulations

The LAT is a GeV, wide-field instrument

Candidate Gamma-ray Events - Flight Data

Green crosses = detected gamma-ray events
Blue lines = reconstructed track trajectories
Yellow line = reconstructed direction of candidate gamma-ray
Red crosses = reconstructed energy deposition in the calorimeter

March 23, 2009

E. Hays
**The 9 Month Skymap**

From simulations: 5n integral flux assuming a power law with index -2.0.

Orbit poles are exposed every other orbit

Long term scale asymmetry due to SAA passages

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**The Sun and the Moon**

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

RHESSI observes to -20 MeV

PSF at 1 GeV

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**LAT Sensitivity with Time**

- From simulations: 5n integral flux assuming a power law with index -2.0.

Orbit poles are exposed every other orbit

Long term scale asymmetry due to SAA passages

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**Fermi LAT Collaboration**

- France
  - IN2P3, CEA/Saclay
- Italy
  - INFN, ASI, INAF
- Japan
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- Sweden
  - Royal Institute of Technology (KTH)
- Stockholm University
- United States
  - Stanford University (SLAC and HEPL/Physics)
  - University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - Ohio State University
  - University of Washington

Principal Investigator:
Peter Michelson (Stanford University)

construction managed by
Stanford Linear Accelerator Center (SLAC), Stanford University

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EGRET Legacy: GeV Excess

- Extra gammas at ~1 GeV disagree with models based on local cosmic rays
- Spatial variation in cosmic ray spectra?
- Unresolved sources?
- Dark matter?
- Instrument calibration issue?

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Diffuse Emission from the Galaxy

- EGRET GeV excess not confirmed by LAT for this part of the sky
- Conventional model (local CR) in good agreement
- All-sky measurements ongoing - stay tuned!

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The Pulsing Sky

Pulsar Detections

Fermi Pulsar Detections

Pulses shown at 1/10th true rate

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Rotation Powered Pulsars

- Electrons (positrons) accelerated to relativistic speeds, emit synchrotron radiation
- Radio emission along magnetic axis
- >1500 radio pulsars catalogued
- Rotational periods from msec to secs, increasing over time

Neutron star ~1.4 x Mass Sun

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New Gamma-ray Pulsar in CTA 1

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

1420 Hz radio map

P = 315 ms
Pdot = 3.9 x 10^{-13}
Characteristic age = 10 kyr
Flux (100 MeV) = 3.6 x 2 x 10^{-7}
ph cm^{-2} s^{-1}
Pulse undetected in radio/X-ray

LAT 95% error radius = 0.038 deg

March 31, 2006
K. Hays

Vela Pulsar Lightcurve

100 MeV -> 10 GeV
Timesteps accurate to 300 ns
Phase analysis accurate to ~1 us
Abdo et al. 2009

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

Rotational Phase

March 23, 1994
K. Hays

Vela Pulsar Spectrum

Consistent with simple exponential cutoff
Super-exponential rejected at 16.5 sr
Excludes emission near neutron star surface

March 23, 1994
K. Hays
47 Tucanae (4.5 kpc) contains at least 23 ms pulsars.

New class of gamma-ray emitter! Combined emission from ms pulsars in the cluster? Consistent with average efficiency, $E_{\text{Flux}}_{\gamma\text{ray}}/E_{\text{dot}}_{\gamma\text{ray}} \approx 10\%$

Active Galactic Nucleus

3C 273 X-ray image

Relativistic Jet
Clouds of gas
Supermassive Black Hole
Accretion Disk
Dusty Torus

Fermi Gamma-Ray Bursts

3 Month Daily Movie

+ GBM
  + >115 bursts
  + 20 are short GRBs
  + 5 GBM bursts detected by LAT

+ LAT
  + GRB 080825C - the first one
  + >10 events above 100 MeV
  + GRB 080916C - the long, bright ('') one
  + GRB 081024E - the short one
  + detected >1 GeV photons
  + GRB 081215A - <6 deg. from on-axis - rate only, not imaged
  + GRB0909217 - another delayed LAT burst
How Relativistic is the Jet?

- High redshift and high fluence implies strongly collimated jet
- No spectral cut off (z=4.35)

- Constrains minimum Lorentz factor of material in particle jet

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 (10 keV to 10 GeV)
  + High-energy emission peaks at later times
  + LAT photons up to 23 min after the trigger time
+ Abdo et al. 2009, Science, 323, 1688
Test of Quantum Gravity

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

LAT Transients in the Galactic Plane

+ 2-day flares detected in the plane without obvious blazar counterpart
  + ATel #1771
    + Spatially coincident with 3EG J0003-3531
    + Variable EGRET source appearing in several viewing periods
    + 68% error radius 0.11 deg
    + No firm identification
    + ATel #1788
    + New GeV source, Fermi J0010-5041
    + 68% error radius 0.07 deg

Summary

+ The LAT is a powerful pulsar detector
  + Already influencing pulsar emission models
  + And a great flare monitor
  + Ideal for multiwavelength campaigns (always on!)
  + Excellent performance for GRBs bright above 100 MeV
  + The Bright Source List is similar in size to entire EGRET catalog (at only 3 months)
  + The Gamma-Ray sky is dynamic
  + Lots more Fermi science to come!

www.fermi.gsfc.nasa.gov