High Energy Astrophysics with the Fermi Large Area Telescope

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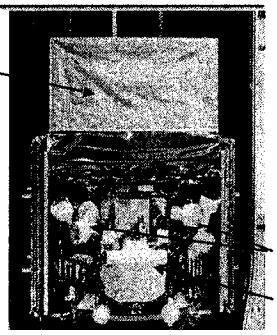
(NASA/GSFC)
On behalf of the Fermi LAT Collaboration

The Fermi Observatory

Large Area Telescope (LAT)

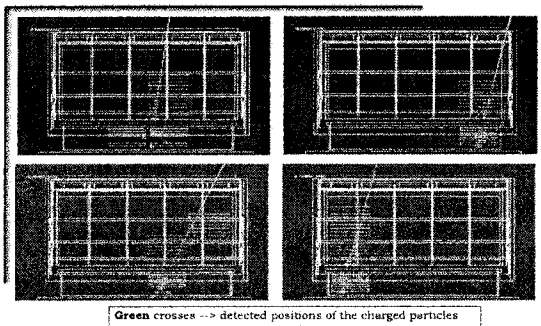
- Large Field of View (>2.4 sr)
- Views entire sky every 3 hrs (every 2 orbits)
- Broad Energy Range (20 MeV - >300 GeV)



Gamma-ray Burst Monitor (GBM)

- Views entire unocculted sky
- **NaI:** 8 keV - 1 MeV
- **BGO:** 150 keV - 30 MeV

Candidate Gamma-ray Events – Flight Data

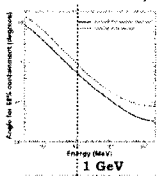


Green crosses --> detected positions of the charged particles
Blue lines --> reconstructed track trajectories
Yellow line --> estimated direction of candidate gamma ray
Red crosses --> detected energy depositions in the calorimeter

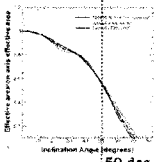
LAT Performance from Ground Simulations

The LAT is a GeV, wide-field instrument

Energy dependence of PSF. 68% containment <0.5 deg above 1 GeV

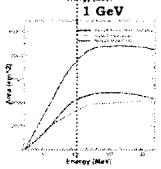


Dependence of effective area on inclination angle (10 GeV). ~50% efficiency at 50 deg.

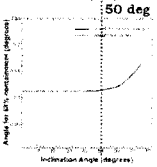


1 GeV **50 deg**

Energy dependence of effective area. Peaks above 1 GeV

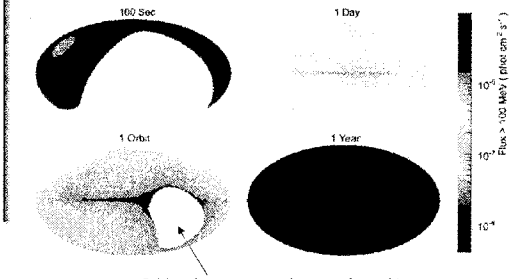


PSF dependence on inclination angle (10 GeV) Resolution maintained to >50 deg.



LAT Sensitivity with Time

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



Orbit poles are exposed every other orbit
Long time scale asymmetry due to SAA passages

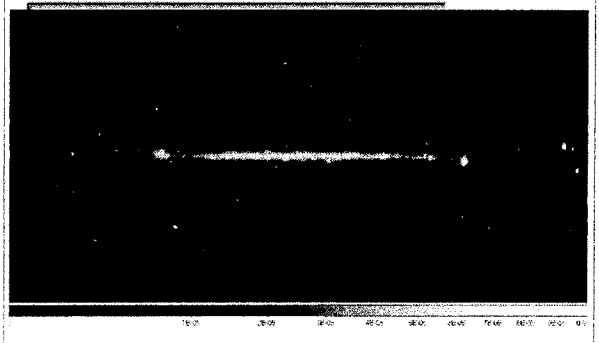
Fermi LAT Collaboration

- 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)

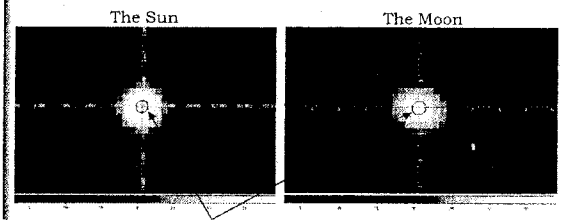
construction managed by
Stanford Linear Accelerator Center (SLAC), Stanford University

The 9 Month Skymap



The Sun and the Moon

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



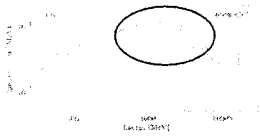
RHESSI observes to ~20 MeV

Size of Sun/Moon on the sky

PSF at 1 GeV

PSF at 10 GeV

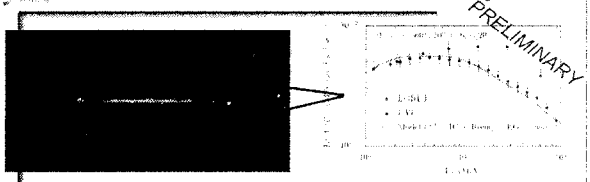
EGRET Legacy: GeV Excess



Hunter et al. 1997

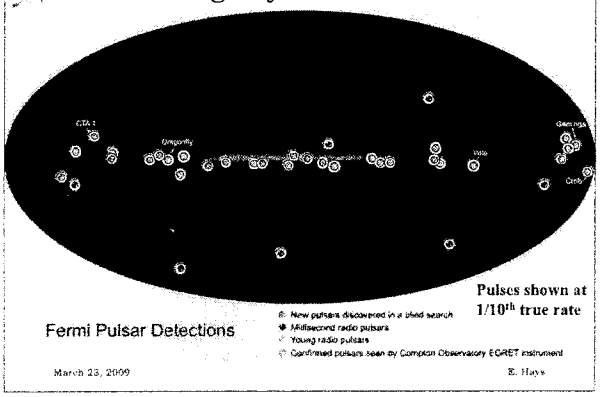
- Extra gammas at ~1 GeV disagree with models based on local cosmic rays
  - Spatial variation in cosmic ray spectra?
  - Unresolved sources?
  - Dark matter?
  - Instrument calibration issue?

Diffuse Emission from the Galaxy



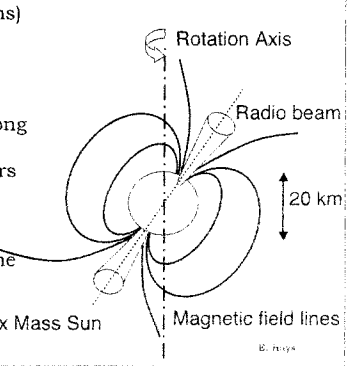
- EGRET GeV excess not confirmed by LAT for this part of the sky
- Conventional model (local CR) in good agreement
- All-sky measurements ongoing - stay tuned!

The Pulsing Sky



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

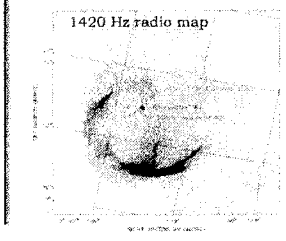


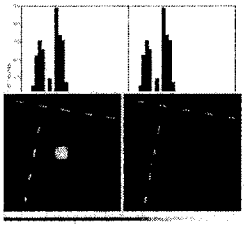
New Gamma-ray Pulsar in CTA 1

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

P ~ 316 ms
Pdot ~ 3.6 x 10^{-13}
Characteristic age ~ 10 kyr
Flux (>100MeV) = 3.8 ± 0.2 x 10^{-7} ph cm-2 s-1

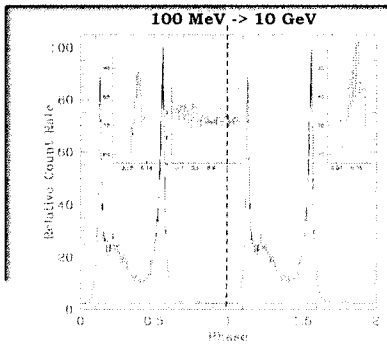
Pulse undetected in radio/X-ray





LAT 95% error radius = 0.038 deg

Vela Pulsar Lightcurve



Timestamps accurate to 300 ns

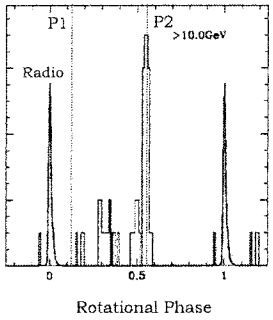
Phase analysis accurate to ~1 us

Abdo et al. 2009 ApJ in press, arXiv:0812.2960

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

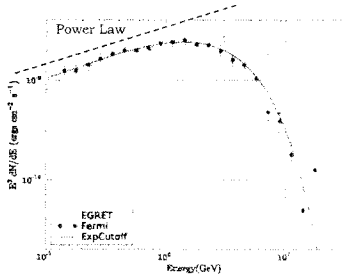


Vela Pulsar Spectrum

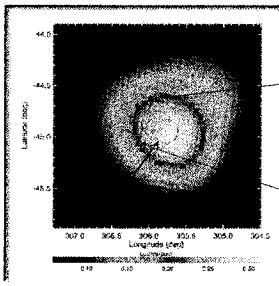
Consistent with simple exponential cutoff

Super-exponential rejected at 16.5σ

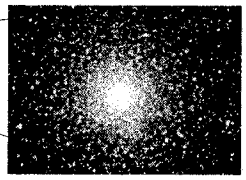
Excludes emission near neutron star surface



Globular Star Clusters



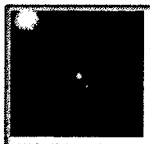
47 Tucanae (4.5 kpc) contains at least 23 ms pulsars



Not detected as extended in gamma rays

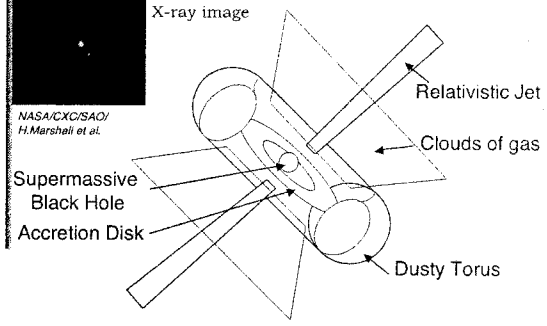
New class of gamma-ray emitter!
Combined emission from ms pulsars in the cluster?
Consistent with average efficiency, $EFlux_{gamma}/Edot_{Rot}$ ~10 %

Active Galactic Nucleus

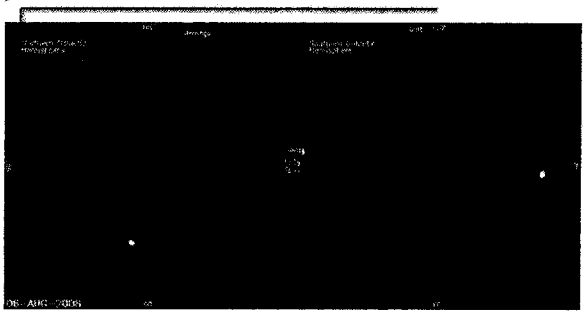


3C 273
X-ray image

NASA/CXC/SAO/
H.Marshall et al.

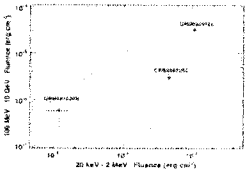


3 Month Daily Movie



Fermi Gamma-Ray Bursts

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

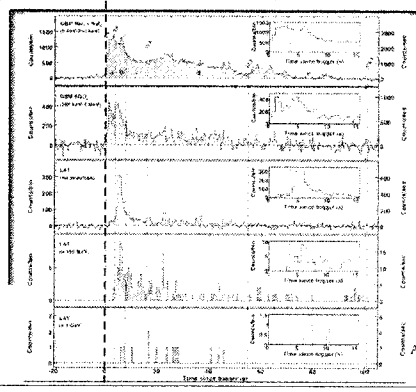


- LAT
  - GRB 080825C - the first one
    - >10 events above 100 MeV
  - GRB 080916C - the long, bright (!) one
  - GRB 081024B - the short one
    - detected >1 GeV photons
  - GRB 081215A - 86 deg. from on-axis - rate only, not imaged
  - GRB090217 - another delayed LAT burst

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

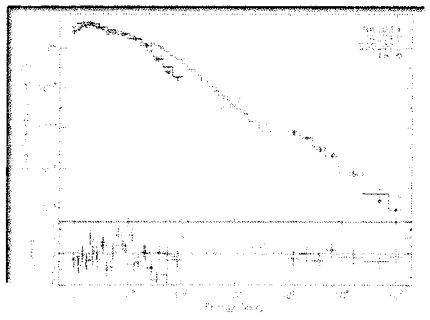
- 2nd GRB detected by LAT
  - 1st since EGRET with imaged photons and E > 1 GeV !
- Brightest burst with a measured redshift
  - GROND measurement of redshift, z = 4.3
- Prompt emission
  - >3000 LAT events in first 100 seconds
  - >140 LAT events for spectral analysis (>100 MeV)
  - Time-resolved spectroscopy 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

GRB 080916C lightcurve



Abdo et al. 2009, Science

GRB 080916C Spectrum



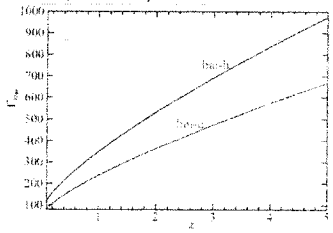
Spectrum for main peak in LAT (3.6 - 7.7 s)

Compatible with a single component from 10 keV to 10 GeV

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

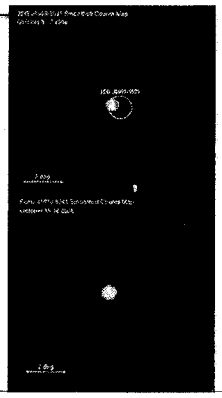


Test of Quantum Gravity

- Test for energy dispersion of photons (higher energy arrive later)
  - $\Delta T \propto \Delta E / M_{QG}$
- Strong limit on Lorentz invariance violation
  - Highest E photon 13.2 GeV (1+z) = 70.6 GeV
  - Arrived 16.5 sec after T0
  - ==> $M_{QG} > 1.30 \times 10^{18}$ GeV/c^2
  - (~0.1 M_{planck})

LAT Transients in the Galactic Plane

- 2 ~day flares detected in the plane without obvious blazar counterpart
  - ATel #1771
    - Spatially coincident with 3EG J0903-3531
      - Variable EGRET source appearing in several viewing periods
    - 68% error radius 0.11 deg
    - No firm identification
  - ATel #1788
    - New GeV source, Fermi J0910-5041
    - 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