An Overview of Recent Fermi Results

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Competition
Energetic Gamma Ray Experiment Telescope
Aboard the Compton Gamma Ray Observatory
Launch 1991
3rd EGRET Catalog

- of 271 sources:
  - 5 pulsars
  - 1 solar flare
  - 66 high-confidence blazar identifications
  - 27 possible blazar identifications,
  - likely radio galaxy (Cen A)
  - 1 normal galaxy (LMC)
  - 170 unidentified sources
Large Area Telescope (LAT)

- Pair Conversion Telescope
- Image the sky one photon at a time
- Roughly 1m x 1m x 40cm
The Observatory

- Large Area Telescope
  - 20 MeV -> 300 GeV

- 2.5 steradian field of view!
- 20% of the sky at any instant
  - expose all parts of sky for ~30 minutes every 3 hours
- Huge energy range, including largely unexplored band
  - 10 GeV - 100 GeV
- Large leap in all key capabilities.
- Great discovery potential!
LAT Performance

- The effective area is ~ 1m x 1m

The Moon is ½ degree in diameter
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, KIPAC, 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

also members from Australia, Germany, Great Britain, Spain

Sponsoring Agencies

- **Department of Energy**
- **National Aeronautics and Space Administration**
- **CEA/Saclay** ASI
- **IN2P3/CNRS** INFN
- **MEXT** K. A. Wallenberg Foundation
- **KEK** Swedish Research Council
- **JAXA** Swedish National Space Board

~390 Members
(~95 Affiliated Scientists, 68 Postdocs, and 105 Graduate Students)

collection managed by
SLAC National Accelerator Laboratory,
Stanford University
Prospects for GLAST: Perspective

- The combination of area, FOV, angular resolution, readout time, and observing efficiency together represent a tremendous advance for astronomy at GeV energies

<table>
<thead>
<tr>
<th></th>
<th>Years</th>
<th>Ang. Res. (100 MeV)</th>
<th>Ang. Res. (10 GeV)</th>
<th>Eng Rng (GeV)</th>
<th>$A_{\text{eff}} \Omega$ (cm$^2$ sr)</th>
<th># $\gamma$-rays</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGRET</td>
<td>1991–00</td>
<td>5.8°</td>
<td>0.5°</td>
<td>0.03–10</td>
<td>750</td>
<td>$1.4 \times 10^6$</td>
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<tr>
<td>LAT</td>
<td>2008–</td>
<td>3.5°</td>
<td>0.1°</td>
<td>0.02–300</td>
<td>25,000</td>
<td>$1 \times 10^8$/yr</td>
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CGRO EGRET

Fermi / LAT
First Light

- ~4-day First Light exposure,
- June 30 – July 3, 2008
“The Large Area Telescope (LAT) on Fermi in 3 months produced a deeper and better-resolved map of the gamma-ray sky than any previous space mission.”
Fermi Large Area Telescope Bright Gamma-ray Source List

205 sources
205 Preliminary LAT Bright Sources with $>10\,\sigma$

<table>
<thead>
<tr>
<th>Class</th>
<th>Number</th>
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</thead>
<tbody>
<tr>
<td>Radio/X-ray pulsar</td>
<td>15</td>
</tr>
<tr>
<td>LAT pulsar</td>
<td>15</td>
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<tr>
<td>Globular cluster (pulsars?)</td>
<td>1</td>
</tr>
<tr>
<td>HMXB</td>
<td>2</td>
</tr>
<tr>
<td>LMC</td>
<td>1</td>
</tr>
<tr>
<td>Flat Spectrum Radio Quasars</td>
<td>64</td>
</tr>
<tr>
<td>BI Lac Objects</td>
<td>46</td>
</tr>
<tr>
<td>Blazar, uncertain type</td>
<td>9</td>
</tr>
<tr>
<td>Radio galaxies</td>
<td>2</td>
</tr>
<tr>
<td>Special cases (under study)</td>
<td>13</td>
</tr>
<tr>
<td>Unassociated</td>
<td>37</td>
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</table>

Majority are AGN or Pulsars
205 Preliminary LAT Brightest Sources

- EGRET on the Compton Observatory found fewer than 30 sources above 10 $\sigma$ in its lifetime.
- Typical 95% error radius is less than 10 arcmin. For the brightest sources, it is less than 3 arcmin. Improvements are expected.
- About 1/3 of the sources show definite evidence of variability.
- More than 30 pulsars are identified by gamma-ray pulsations.
- Over half the sources are associated positionally with blazars. Some of these are firmly identified as blazars by correlated multiwavelength variability.
- Over 40 sources have no obvious associations with known gamma-ray emitting types of astrophysical objects.
Supernova

• The end state of stars
• Violent explosions.
• The ejecta from a SNR is called a Supernova Remnant (SNR)
• Example, Tycho’s SNR – exploded in 1572
Pulsars

- Part of the remains of a supernova will collapse into the center and become a neutron star.
- Supported only by its degeneracy pressure
- ~10km
- Strong magnetic fields
- Rapidly Spinning
- Highly beamed radiation creates a pulsed signature
CTA1: first high-energy pulsar detected by a blind search
Pulsar in CTA 1

- Pulsars typically first seen in radio
- In the center of supernova remnant CTA 1
- Has a period of 0.3 seconds
- Age of $10^4$ years
- First radio quiet pulsar
Brightest persistent source in GeV Sky

- “Fermi LAT Observations Of The Vela Pulsar”
- In the constellation of Vela
- 32,400 pulsed photons collected
- Period of ~90 ms
The phase-averaged Vela spectral energy distribution \( E^2 dN/dE \) is shown. Both statistical (capped) and systematic (uncapped) errors are displayed. We believe that the latter are conservative; they dominate at all energies below 7 GeV. EGRET data points (diamonds, Kanbach et al. 1994) are shown for comparison. The curve is the best-fit power law with a simple exponential cut-off.
Fermi Sees Lots of Pulsars
Fermi electron spectrum Spectrum

• Although optimized for gamma rays, the LAT also can measures direction and energy of incident electrons.
• Fermi analysis code was separately tuned for selection of electrons.
• Unable to distinguish between electrons and positrons
Measurement of the Cosmic Ray $e^+ + e^-$ spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope

- 4 million + events.
- The result shows a harder spectrum (bump) compared to conventional model.
- Possible reasons:
  - harder electron population at source
  - Nearby sources of electrons (pulsars)
  - Dark matter
Explosions in the Sky!

- Gamma-ray Bursts are the most luminous explosions in the sky.
- Speculated to occur due to collapse of supernova star to a black hole.
- Some may be due to merge of neutron stars.
- The LAT can measure GRBs over 7 decades.
GRB 080916C

- Observed Sept 16, 2008
- Majority of events in first 15 seconds.
- Largest apparent energy release of any GRB
- Found at z=4.35
Spectra over many decades

• Arrival time as a function of energy allows the constraint of quantum gravity!
• (some) quantum gravity models predict frequency dependent speed of light
Detection of NGC 1275

- Fermi detected emission from NGC 1275, a galaxy in the Perseus cluster.
- Galaxy cluster is in the Perseus constellation.
Fig. 1.— A $\gamma$-ray sky map obtained with Fermi at $E > 200$ MeV, centered on NGC 1275 (image radius $r = 8^\circ$, which is the value used throughout this paper). Sky survey data between August 4 and December 5 are accumulated. Full details are given in the text.

Fig. 3.— LAT spectrum of NGC 1275 from 200 MeV to 25 GeV (open circles). A dashed line (parameters given in the upper right of the figure) shows the best-fit power-law function determined from the GTLIKE as given in the text.

The spectrum is described by the equation:

$$F(E) = k(E/E_0)^{-\Gamma}$$

where:
- $k = (2.45 \pm 0.26) \times 10^{-9}$
- $\Gamma = 2.17 \pm 0.05$
- $E_0 = 100$ MeV