FERMI: A NEW VIEW OF THE HIGH ENERGY UNIVERSE

LARGE AREA TELESCOPE: INTRODUCTION AND SCIENCE HIGHLIGHTS

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Stanford University
Principal Investigator, Large Area Telescope Collaboration

on behalf of the Fermi LAT Collaboration and the Fermi mission
• **Brief overview of Large Area Telescope (more in Bill Atwood’s talk), including some history**
• **Science Objectives**
• **Summary of early results**
Exploring the High-Energy Universe

- Gamma rays provide a direct view into Nature’s largest accelerators (neutron stars, black holes)

- Gamma rays probe cosmological distances (e.g., $\gamma + \gamma_{\text{EBL}} \rightarrow e^+ + e^-$)

- Huge leap in key capabilities, including a largely unexplored energy range; great potential for discovery: e.g. dark matter

Two instruments: Large Area Telescope (LAT), 20 MeV - >300 GeV
Gamma-ray Burst Monitor (GBM), 10 keV - 25 MeV
**Fermi LAT science objectives**

- **> 2000 AGNs**
  - blazars and radiogal = f(θ,z)
  - evolution z < 5
  - Sag A*

- **10-50 GRB/year**
  - GeV afterglow spectra to high energy

- **γ-ray binaries**
  - Pulsar winds
  - μ-quasar jets

- **Cosmic rays and clouds**
  - acceleration in Supernova remnants
  - OB associations
  - propagation (Milky Way, M31, LMC, SMC)
  - Interstellar mass tracers in galaxies

- **Possibilities**
  - starburst galaxies
  - galaxy clusters
  - measure EBL unIDs

- **Dark Matter**
  - neutralino lines
  - sub-halo clumps;
  - e⁺ + e⁻ spectrum

- **Pulsars**
  - emission from radio and X-ray pulsars
  - blind searches for new Gemingas
  - magnetospheric physics
  - pulsar wind nebulae
Compton Observatory / EGRET legacy

April 5, 1991 – June 4, 2000

3rd EGRET catalog

- AGN - blazars
- unidentified
- pulsars
- LMC
LAT images the sky one photon at a time: $\gamma$-ray converts in LAT to an electron and a positron; direction and energy of these particles tell us the direction and energy of the photon.
LAT Silicon Tracker

Silicon strip detectors from Hamamatsu Photonics and Japan GLAST Collaboration are a key part of LAT’s success

- 11,500 sensors
- 350 trays
- 18 towers
- $\sim 10^6$ channels
- 83 m$^2$ Si surface

LAT TKR performance

- Efficiency (%)
- Bad channels (%)

LAT TKR performance

- Efficiency
- Bad chans fraction

assembled Tkr tower
In addition to silicon-strip detectors for the tracker, Hamamatsu also supplied

Silicon photodiodes for the calorimeter,

Photomultiplier tubes for the anticoincidence detector readout
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

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

construction managed by Stanford Linear Accelerator Center (SLAC), Stanford University
### LAT as a Telescope

<table>
<thead>
<tr>
<th>Years</th>
<th>Ang. Res. (100 MeV)</th>
<th>Ang. Res. (10 GeV)</th>
<th>Eng. Rng. (GeV)</th>
<th>$A_{\text{eff}} \Omega$ (cm² 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>
</tr>
<tr>
<td>AGILE</td>
<td>2007–</td>
<td>4.7°</td>
<td>0.2°</td>
<td>0.03–50</td>
<td>1,500</td>
</tr>
<tr>
<td>Fermi LAT</td>
<td>2008–</td>
<td>3.5°</td>
<td>0.1°</td>
<td>0.02–300</td>
<td>25,000</td>
</tr>
</tbody>
</table>

- LAT has already surpassed EGRET and AGILE celestial gamma-ray totals
- Unlike EGRET and AGILE, LAT is an effective All-Sky Monitor whole sky every ~3 hours
• ~4-day First Light exposure, June 30 – July 3, 2008
• Orthographic projection
LAT 3 month sky map
LAT 3 month sky map

CTA1: first high-energy pulsar detected by a blind search
• exhibits all characteristics of a young high-energy pulsar (characteristic age \( \sim 1.4 \times 10^4 \) yr), which powers a synchrotron pulsar wind nebula embedded in a larger SNR.

• spin-down luminosity \( \sim 10^{36} \) erg s\(^{-1}\), sufficient to supply the PWN with magnetic fields and energetic electrons.

• \( \gamma \)-ray source at \( l,b = 119.652, 10.468; \) 95% error circle radius =0.038\(^\circ\) contains the X-ray source RX J00070+7302, central to the PWN superimposed on the radio map at 1420 MHz.

• pulsar off-set from center of radio SNR; rough estimate of the lateral speed of the pulsar is \( \sim 450 \) km/s
LAT High-Confidence Bright Source List

- based on first 3 months of sky-survey

205 sources

Unassociated • AGN ◇ Pulsar
+ X-ray binary ▽ Globular cluster

arXiv:0902.1340v1
[astro-ph.HE] 8 Feb 2009
### 205 Preliminary LAT Bright Sources

#### Census of Associations (not Identifications)

<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>14</td>
</tr>
<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>62</td>
</tr>
<tr>
<td>Bl Lac Objects</td>
<td>46</td>
</tr>
<tr>
<td>Blazar, uncertain type</td>
<td>11</td>
</tr>
<tr>
<td>Radio galaxies</td>
<td>2</td>
</tr>
<tr>
<td>Special cases (under study)</td>
<td>14</td>
</tr>
<tr>
<td>Unassociated</td>
<td>37</td>
</tr>
</tbody>
</table>
Three months of Fermi, the movie
Fermi detects the Sun

July 1 – Sept 24, 2008
Fermi detects the Moon

August 3 – August 7, 2008
3C454.3
Supermassive black hole
8 billion light-years from us

GLAST-LAT detection of extraordinary gamma-ray activity in 3C 454.3

ATel #1628: G. Tosti (Univ/INFN-Perugia), J. Chiang (SLAC), B. Lott (CENBG/Bordeaux), E. de Couto e Silva (SLAC), J. E. Grove (NRL/Washington), J. G. Thayer (SLAC) on behalf of the GLAST Large Area Telescope Collaboration on 24 Jul 2008; 14:25 UT
Password Certification: Gino Tosti (tosti@pg.infn.it)

Subjects: Gamma Ray, >GeV, AGN, Quasars

The Large Area Telescope (LAT), one of two instruments on the Gamma-ray Large Area Space Telescope (GLAST) (launched June 11, 2008), which is still in its post-launch commissioning and checkout phase has been monitoring extraordinarily high flux from the gamma-ray blazar 3C 454.3 since June 28, 2008. This confirms the bright state of the source reported by AGILE (see ATel #1592) and by the optical-to-radio observers of the GASP-WEBT Project (ATel #1625).

3C 454.3 has been detected on time scales of hours with high significance (> 5 sigma) by the LAT Automatic Science Processing (ASP) pipeline and the daily light curve (E>100 MeV) indicates that the source flux has increased from the initial measurements on June 28. Although in-flight calibration is still ongoing, preliminary analysis indicates that in the period July 10-21, 2008 the source has been in a very high state with a flux (E>100 MeV) that is well above all previously published values reported by both EGRET (Hartman et al. 1999, ApJS, 123,79) and AGILE (see e.g. ATel #1592 and Vercellone et al. 2008, ApJ, 676, L13).

Because GLAST will continue with calibration activities, regular monitoring of this source cannot be pursued. Monitoring by the LAT is expected to resume in early August. In consideration of the ongoing activity of this source we strongly encourage multiwavelength observations of 3C 454.3.

The GLAST LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.
Gamma-Ray Bursts observed by LAT

- LAT has reported 3 high-energy bursts since launch

First detection of short-duration burst at high energy

\[ Z = 4.35 \pm 0.15 \]
- **Fermi Gamma-ray Space Telescope** fully operational..
- In first few days of sky survey, the LAT corroborated many of the great discoveries of EGRET; now finding new sources as well;
- With 3 months of the 1\textsuperscript{st} year all-sky survey phase;
  - large number of pulsars detected, some only in $\gamma$-rays;
  - many flaring active galaxies observed; about half not seen by EGRET;
  - Flaring sources observed along the galactic plane;
  - High-energy emission seen from 3 GRBs; first time seen from short-duration burst;
  - Quiescent sun detected at high energies;
  - Major progress in understanding galactic diffuse emission
- With time, *Fermi* will probe deeper and deeper into the high-energy Universe
- diffuse EBL contains unique information about the epochs of formation and the evolution of galaxies and in what environments the stars of the universe formed

- direct EBL measurements require accurate model-based subtraction of bright foregrounds (e.g., zodiacal light)

- alternative approach: extract imprint of EBL absorption, as function of redshift, from high-energy spectra of extragalactic sources

\[ \gamma \gamma \rightarrow e^+ e^- , \text{ maximum when} \]

\[ \varepsilon_{\text{EBL}} \sim \frac{1}{2} \left( 1000 \text{ GeV} / E_\gamma \right) \text{ eV} \]
EGRET observations showed excess emission > 1 GeV when compared with conventional model tuned to reproduce local cosmic-ray nuclei and electron spectra.

- Variety of explanations
  - Variations in cosmic-ray spectra over Galaxy
  - Unresolved sources (pulsars, SNRs, …)
  - Dark matter
  - Instrumental

~100% discrepancy > 1 GeV
The Fermi LAT View

- Spectra shown for mid-latitude range → EGRET GeV excess in this region of the sky is **not** confirmed
- Sources are not subtracted but are a minor component
- LAT errors are systematics dominated and estimated ~10% → this is **preliminary**
- Work to analyse and understand diffuse emission over the entire sky is in progress
For the first time, can study time structure > tens of MeV.

Feature in the LC:
– pulse in interval “a” disappears at LAT energies.

For this burst, $\gamma\gamma$ absorption arguments provide a stringent lower limit of $\Gamma_{\text{min}} = 860$

Science Express, 19 Feb 2009, pg 1
Soft-to-hard spectral evolution followed by spectral softening