GeV Gamma Ray Astronomy in the GLAST Era

Neil Gehrels

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## Recent Development in U.S.

### Astronomy and Astrophysics in the New Millennium

**NRC 10-year Report**

**Table 1.1** Prioritized Initiatives and Estimated Federal Costs for the Decade 2000-2010.

<table>
<thead>
<tr>
<th>Ground Based Initiative</th>
<th>Ground Based Cost ($M)</th>
<th>Space Based Initiative</th>
<th>Space Based Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Initiatives</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant Segmented-Mirror Telescope (GSMT)</td>
<td>350</td>
<td>Next Generation Space Telescope (NGST)</td>
<td>1000</td>
</tr>
<tr>
<td>Expanded Very Large Array (EVAL)</td>
<td>140</td>
<td>Constellation-X Observatory</td>
<td>800</td>
</tr>
<tr>
<td>Large-aperture Synoptic Survey Telescope (LSST)</td>
<td>170</td>
<td>Terrestrial Planet Finder (TPF)</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single-Aperture Far Infra Red (SAFIR) Observatory</td>
<td>100</td>
</tr>
<tr>
<td><strong>Moderate Initiatives</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telescope System Instrumentation Program (TSIP)</td>
<td>50</td>
<td><strong>Gamma-ray Large Area Space Telescope (GLAST)</strong></td>
<td>300</td>
</tr>
<tr>
<td>Advanced Solar Telescope (AST)</td>
<td>60</td>
<td>Laser Interferometer Space Antenna (LISA)</td>
<td>250</td>
</tr>
<tr>
<td>Square Kilometer Array (SKA) Technology Development</td>
<td>22</td>
<td>Solar Dynamics Observatory (SDO)</td>
<td>300</td>
</tr>
<tr>
<td>Combined Array for Research in Millimeter-wave Astronomy (CARMA)</td>
<td>11</td>
<td>Energetic X-ray Imaging Survey Telescope (EXIST)</td>
<td>150</td>
</tr>
<tr>
<td>Very Energetic Radiation Imaging Telescope Array System (VERITAS)</td>
<td>35</td>
<td>Advanced Radio Interferometry between Space and Earth (ARISE)</td>
<td>350</td>
</tr>
<tr>
<td>Frequency Agile Solar Radiotelescope (FASR)</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Pole Submillimeter-wave Telescope (SPST)</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Gamma Ray Large Area Space Telescope

- Launch in 2005
- 20 MeV to 300 GeV
- Wide-field imaging telescope
- NASA cost is $326 M
- http://glast.gsfc.nasa.gov/

Theme: Exploring Sites of Particle Acceleration in the Universe
## Mission Parameters

<table>
<thead>
<tr>
<th></th>
<th><strong>EGRET</strong></th>
<th><strong>AGILE</strong></th>
<th><strong>GLAST</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Range</strong></td>
<td>20 MeV - 30 GeV</td>
<td>30 MeV - 50 GeV</td>
<td>20 MeV - &gt; 300 GeV</td>
</tr>
<tr>
<td><strong>Energy Resolution (ΔE/E)</strong></td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Effective Area (peak)</strong></td>
<td>1500 cm²</td>
<td>700 cm²</td>
<td>12000 cm²</td>
</tr>
<tr>
<td><strong>Field of View</strong></td>
<td>0.5 sr</td>
<td>~ 3 sr</td>
<td>2.5 sr</td>
</tr>
<tr>
<td><strong>Angular Resolution</strong></td>
<td>5.8° @ 100 MeV</td>
<td>4.7° @ 100 MeV</td>
<td>~ 3.5° @ 100 MeV</td>
</tr>
<tr>
<td></td>
<td>0.5° @ 10 GeV</td>
<td>0.2° @ 10 GeV</td>
<td>~ 0.1° @ 10 GeV</td>
</tr>
<tr>
<td><strong>Sensitivity (&gt; 100 MeV)</strong></td>
<td>~ 10⁻⁷ cm⁻² s⁻¹</td>
<td>5 × 10⁻⁸ cm⁻² s⁻¹</td>
<td>~ 2 × 10⁻⁹ cm⁻² s⁻¹</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>1810 kg</td>
<td>60 kg</td>
<td>3000 kg</td>
</tr>
</tbody>
</table>

* 2 year survey at high latitudes
GLAST Capabilities

• Huge FOV (> 20% of sky)
• Broadband (4 decades in energy, including unexplored region > 10 GeV)
• Unprecedented PSF for gamma rays (factor > 3 better than EGRET)
• No expendables → long mission without degradation
• Large area (factor > 7 better than EGRET)
• Results in factor > 30 improvement in sensitivity
EGRET All Sky Map (>100 MeV)

Cygnus Region

3C279

Vela

Geminga

Crab

PSR B1706-44

PKS 0208-512

LMC

PKS 0528+134

Cosmic Ray Interactions With ISM
EGRET Discoveries

Gamma Ray Blazars

EGRET: 3C279/3C273

170 Unidentified Sources

Prolonged GeV Emission from GRBs

LMC Detection

Gamma ray image overlayed with 1400 MHz radio contours

Prolonged GeV Emission from GRBs

1.35 1.35 1.70

Photon Energies (MeV)

Time (Hours)
EGRET Discoveries cont.

5 New Pulsars

Crab
1706-44

Vela
1055-52

Geminga
1951+32

0656 +14

Geminga Radio-Quiet Pulsars

PKS 0528 +134

Prolonged GeV Emission from Solar Flares

Cosmic Diffuse Background

![chart]
GLAST versus EGRET: All-Sky Surveys

Virgo Region (E > 1 GeV)

Simulated GLAST One-Year All-Sky Map (E > 100 MeV)

5σ Sources from Simulated One-Year All-Sky Survey
- AGN
- 3EG Catalog
- Galactic Plane
- Galactic Halo
Cygnus Simulation

EGRET Observed

GLAST Simulated
Gamma-Ray Quasars

- EGRET sees most blazars only when they flare
- What is the population of high-energy blazars?
- What is the nature of the quiescent emission?
- What is the relation to radio luminosity and variability?
- What are the high-latitude unidentifieds?

○ = EGRET blazars seen sometimes
● = EGRET blazars seen always
★ = EGRET unidentified high-latitude variables
□ = Simulated GLAST 20σ AGN detections
Number and Localization of GLAST AGN
Blazar Spectra

- GLAST combined with TeV observatories will probe the complex spectra of blazars

Mrk 501

![Plot of blazar spectra with Energy and Frequency axes](image-url)
Unidentified Sources

- 172 unidentified sources in 3rd EGRET catalog
- Mystery of unidentifieds since 1970s
- Galactic unidentifieds may be SNRs, Gemingas, massive stars, molecular clouds, or new phenomenon!
- Mid-latitude sources are separate population from low-latitude sources (Nature, March 23rd issue)
Solving the Mystery of Unidentifieds With GLAST

- EGRET source positions are ~ 0.5° in size, too large for counterpart searches
- GLAST will provide much more accurate source positions, 30 arcsec to 5 arcmin

Image from NVSS 1.4 GHz survey, Condon et al. (1998)
Supernova shock acceleration models predict correct spectra and energetics.

Evidence of TeV electrons in non-thermal X-ray emission and ground-based gamma-ray observations.

Smoking gun would be an extended gamma-ray source, such as an interstellar cloud, located next to a SNR, which may be the case for Gamma Cygni.

This would provide proof that nuclei as well as electrons are accelerated as predicted.
Gamma Ray Bursts

EGRET:

GLAST:
GLAST Instrument and IDS Selection

- **GLAST instruments & InterDisciplinary Scientists (IDS's) selected.**
  - **Large Area Telescope (LAT), PI: P. Michelson, Stanford**
    - Si Tracker: Stanford, UCSC, Japan, Italy
    - CsI Calorimeter: NRL, France
    - Anticoincidence: GSFC
    - Data Acquisition System: Stanford, NRL
  - **GLAST Burst Monitor (GBM), PI: C. Meegan, MSFC**
    - Detectors: MPE
      - NaI 5 keV - 1 MeV
      - BGO 150 keV - 30 MeV
  - **IDS's**
    - C. Dermer (NRL) - non-thermal universe
    - B. Dingus (Wisconsin) - transients
    - M. Pohl (Ruhr U.) - diffuse galactic
    - S. Thorsett (UCSC) - pulsars
LAT Beam Test Verification

- Monte Carlo
- Data

3 cm Spacing
- 0% Converter Foils
- 95% Containment
- 68%

3 cm Spacing
- 4% Converter Foils
- 95%
- 68%

X-Projected Containment Radius (degree)

Energy (MeV)
LAT Hardware
GLAST GBM

GRB 940217

LAT and GBM simulation.
## GBM vs. BATSE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BATSE</th>
<th>GBM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Range</strong></td>
<td>25 keV - 1.9 MeV (LAD)</td>
<td>5 keV - 1 MeV (LED)</td>
</tr>
<tr>
<td></td>
<td>7 keV - 10 MeV (SD)</td>
<td>150 keV - 30 MeV (HED)</td>
</tr>
<tr>
<td><strong>Detectors</strong></td>
<td>NaI</td>
<td>NaI/BGO</td>
</tr>
<tr>
<td><strong>FOV</strong></td>
<td>Full Sky</td>
<td>8.6 sr</td>
</tr>
<tr>
<td><strong>Location Accuracy</strong></td>
<td>2° - 5°</td>
<td>1.5° - 3°</td>
</tr>
<tr>
<td><strong>Burst Sensitivity</strong></td>
<td>0.2 ph cm(^{-2}) s(^{-1})</td>
<td>0.6 ph cm(^{-2}) s(^{-1})</td>
</tr>
</tbody>
</table>
## AGILE

### Spacecraft and Satellite Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal orbital parameters</td>
<td>Equatorial orbit, 550 km</td>
</tr>
<tr>
<td>Possible ground station</td>
<td>Malindi (Kenya)</td>
</tr>
<tr>
<td>Spacecraft + payload mass</td>
<td>180-200 kg</td>
</tr>
<tr>
<td>Payload required power</td>
<td>~60 W</td>
</tr>
<tr>
<td>Downlink telemetry rate</td>
<td>~500 kbit/sec</td>
</tr>
<tr>
<td>Pointing configuration</td>
<td>3 - axes</td>
</tr>
<tr>
<td>Pointing accuracy</td>
<td>0.5 - 1 degree</td>
</tr>
<tr>
<td>Satellite expected life</td>
<td>&gt;~ 3 years</td>
</tr>
</tbody>
</table>
AGILE and GLAST Performance

EGRET–AGILE–GLAST Effective Area

On-axis Effective Area (cm²) vs. Energy (MeV)

- EGRET
- GLAST
- AGILE
Space Gamma Ray Astronomy

- **CGRO**
- **INTEGRAL**
- **HETE**
- **Swift**
- **AGILE**
- **GLAST**