GLAST Large Area Telescope:
Pre-Environmental Test Review

Science Overview

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Outline

• GLAST Science
• Science Requirements Overview
• The Look Ahead (how the pieces fit together prior to delivery)
  – verification strategy
  – how the pieces fit together
• Instrument Test Data Analysis (IA)
• Summary
What's a gamma ray?

- Photons at the highest-energy end of the electromagnetic spectrum:
Why study $\gamma$'s?

- $\gamma$ rays do not interact much at their source: they offer a direct view into Nature’s largest accelerators.
- Similarly, the Universe is mainly transparent to $\gamma$ rays: can probe cosmological volumes. Any opacity is energy-dependent.
- Messengers of the highest-energy phenomena in the Universe; may also signal new physics.

Two GLAST instruments:
LAT: 20 MeV – $>300$ GeV
GBM: 10 keV – 25 MeV
Features of the gamma-ray sky

- **Diffuse extra-galactic background**
  
  \( \text{flux} \sim 1.5 \times 10^{-5} \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1} \)

- **Galactic diffuse background**
  
  \( \text{flux} \sim O(100) \times \) larger

- **High latitude (extra-galactic) point sources**
  
  Typical flux from EGRET sources \( O(10^{-7} - 10^{-6}) \text{ cm}^{-2}\text{s}^{-1} \)

- **Galactic sources**
  
  (pulsars, un-ID’d)

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**An essential characteristic**: **VARIABILITY** in time!

Field of view, mission lifetime, and the ability to repoint, important for study of transients (e.g., flaring AGN, gamma-ray bursts).

Science community needs timely information about transients.
GLAST will have a very broad menu that includes:

- Systems with supermassive black holes (Active Galactic Nuclei)
- Gamma-ray bursts (GRBs)
- Pulsars
- Solar physics
- Origin of Cosmic Rays
- Probing the era of galaxy formation, optical-UV background light
- Solving the mystery of the high-energy unidentified sources
- Discovery! Particle Dark Matter? Other relics from the Big Bang?

Huge increment in capabilities.

GLAST draws the interest of both the High Energy Particle Physics and High Energy Astrophysics communities.

GLAST is the highest-ranked initiative in its category in the National Academy of Sciences 2000 Decadal Survey Report.
EGRET on CGRO firmly established the field of high-energy gamma-ray astrophysics and demonstrated the importance and potential of this energy band.

GLAST is the next great step beyond EGRET, providing a huge leap in capabilities:

- Very large FOV (~20% of sky), factor 4 greater than EGRET
- Broadband (4 decades in energy, including unexplored region $E > 10$ GeV)
- Unprecedented PSF for gamma rays (factor > 3 better than EGRET for $E>1$ GeV)
- Large effective area (factor > 5 better than EGRET)
- **Huge leap in sensitivity**
- Much smaller deadtime per event (25 microsec, factor >4,000 better than EGRET)
- No expendables ➔ long mission without degradation
Sources

Third EGRET Catalog

E > 100 MeV

-90

+90

+180

-180

Active Galactic Nuclei
Unidentified EGRET Sources
Pulsars
LMC
Solar FLare

EGRET 3rd
Catalog: 271 sources
Sources

5σ Sources from Simulated One Year All-sky Survey

Results of one-year all-sky survey. (Total: 9900 sources)

- Red: AGN
- Blue: 3EG Catalog
- Green: Galactic Halo
- Yellow: Galactic Plane

GLAST will either resolve a large fraction of the diffuse background, providing a wealth of sources, or it will discover a truly diffuse extragalactic flux!
Overview of LAT

- **Precision Si-strip Tracker (TKR)**
  18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch)
  Measure the photon direction; gamma ID.

- **Hodoscopic CsI Calorimeter (CAL)**
  Array of 1536 CsI(Tl) crystals in 8 layers.
  Measure the photon energy; image the shower.

- **Segmented Anticoincidence Detector (ACD)**
  89 plastic scintillator tiles.
  Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.

- **Electronics System**
  Includes flexible, robust hardware trigger and software filters.

**Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.**
Real LAT Events (from ACD CPT)
# LAT Science Requirements Summary (I)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>EGRET</th>
<th>LAT Requirement</th>
<th>LAT Goal</th>
<th>LAT Minimum</th>
<th>Science Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range Low Limit</td>
<td>20 MeV</td>
<td>&lt; 20 MeV</td>
<td>&lt; 10 MeV</td>
<td>&lt; 30 MeV</td>
<td>ALL</td>
</tr>
<tr>
<td>Energy Range High Limit</td>
<td>30 GeV</td>
<td>&gt; 300 GeV</td>
<td>&gt; 500 GeV</td>
<td>&gt; 100 GeV</td>
<td>ALL</td>
</tr>
<tr>
<td>Effective Area</td>
<td>1500 cm²</td>
<td>&gt; 8000 cm²</td>
<td>&gt; 12,000 cm²</td>
<td>&gt; 8000 cm²</td>
<td>ALL</td>
</tr>
<tr>
<td>Energy Resolution (on-axis, 100 MeV - 10 GeV)</td>
<td>10%</td>
<td>&lt; 10%</td>
<td>&lt; 8%</td>
<td>&lt; 20%</td>
<td>ALL</td>
</tr>
<tr>
<td>Energy Resolution (on-axis, 10-300 GeV)</td>
<td>&lt;20%</td>
<td>&lt;15%</td>
<td>&lt;30%</td>
<td></td>
<td>ALL</td>
</tr>
<tr>
<td>Energy Resolution (&gt;60° incidence, &gt;10 GeV)</td>
<td>&lt; 6%</td>
<td>&lt; 3%</td>
<td>NA 5</td>
<td></td>
<td>Dark Matter</td>
</tr>
<tr>
<td>Single Photon Angular Resolution - 68% (on-axis, E&gt;10 GeV)</td>
<td>0.5°</td>
<td>&lt; 0.15°</td>
<td>&lt; 0.1°</td>
<td>&lt; 0.3°</td>
<td>ALL</td>
</tr>
</tbody>
</table>
## LAT Science Requirements Summary (II)

<table>
<thead>
<tr>
<th></th>
<th>Requirement Description</th>
<th>Requirement Details</th>
<th>Target</th>
<th>UGOs, GRBs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Photon Angular Resolution - 68% 6 (on-axis, E=100 MeV)</td>
<td>5.8°</td>
<td>&lt; 3.5°</td>
<td>&lt; 3°</td>
</tr>
<tr>
<td></td>
<td>Single Photon Angular Resolution - 95% 6 (on-axis)</td>
<td>&lt; 3 x θ68%</td>
<td>&lt; 2 x θ68%</td>
<td>&lt; 4 x θ68%</td>
</tr>
<tr>
<td></td>
<td>Single Photon Angular Resolution (off-axis at 55°)</td>
<td>&lt; 1.7 times on-axis</td>
<td>&lt; 1.5 times on-axis</td>
<td>&lt; 2 times on-axis</td>
</tr>
<tr>
<td></td>
<td>Field of View 7</td>
<td>0.5 sr</td>
<td>&gt; 2 sr</td>
<td>&gt; 3 sr</td>
</tr>
<tr>
<td></td>
<td>Source Location 8,9 Determination</td>
<td>5 arcmin</td>
<td>&lt; 0.5 arcmin</td>
<td>&lt; 0.3 arcmin</td>
</tr>
<tr>
<td></td>
<td>Point Source Sensitivity 9,10 (&gt; 100 MeV)</td>
<td>~1 x 10^-7 cm^-2 s^-1</td>
<td>&lt; 6 x 10^-9 cm^-2 s^-1</td>
<td>&lt; 3 x 10^-9 cm^-2 s^-1</td>
</tr>
<tr>
<td></td>
<td>Instrument Time Accuracy 11</td>
<td>0.1 ms</td>
<td>&lt; 10 μsec</td>
<td>&lt; 2 μsec</td>
</tr>
<tr>
<td></td>
<td>Background Rejection 12 (Contamination of high latitude diffuse sample in any decade of energy for &gt;100 MeV.)</td>
<td>&lt;1%</td>
<td>&lt;10%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td></td>
<td>Dead Time</td>
<td>100 ms /event</td>
<td>&lt; 100 μs /event</td>
<td>&lt; 20 μs /event</td>
</tr>
</tbody>
</table>
### LAT Science Requirements Summary (III)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Goal</th>
<th>Minimum</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 GRB Location Accuracy On-Board</td>
<td>&lt; 10 arcmin</td>
<td>&lt; 3 arcmin</td>
<td>NA</td>
<td>GRBs</td>
</tr>
<tr>
<td>18 GRB Notification Time To Spacecraft</td>
<td>&lt; 5 sec</td>
<td>&lt; 2 sec</td>
<td>NA</td>
<td>GRBs</td>
</tr>
</tbody>
</table>

1. Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.

2. Maximum (as function of energy) effective area at normal incidence. Includes inefficiencies necessary to achieve required background rejection. Effective area peak is typically in the 1 to 10 GeV range.

3. Equivalent Gaussian 1 sigma, on-axis.

4. Effective area for side incidence is 0.1 to 0.2 that of normal incidence for high resolution measurements.

5. NA = Not Applicable. Minimum values are not applicable for parameters that were not Requirements in the AO 99-OSS-03 Announcement of Opportunity.


7. Integral of effective area over solid angle divided by peak effective area. Geometric factor is Field of View times Effective Area.

8. High latitude source of $10^{-7}$ cm$^{-2}$ s$^{-1}$ flux at >100 MeV with a photon spectral index of -2.0 above a flat background and assuming no spectral cut-off. 1 sigma radius. 1-year survey.

9. Derived quantities delimited by double-lined box.

10. Sensitivity at high latitudes after a 1-year survey for a 5 sigma detection.

11. Relative to spacecraft time.

12. Assuming a high-latitude diffuse flux of $1.5 \times 10^{-5}$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ (>100 MeV) assuming a photon spectral index of -2.1 with no spectral cut-off.

13. For burst (< 20 sec duration) with > 100 photons above 1 GeV. This corresponds to a burst of ~5 cm$^{-2}$ s$^{-1}$ peak rate in the 50 - 300 keV band assuming a spectrum of broken power law at 200 keV from photon index of -0.9 to -2.0. Such bursts are expected to occur in the LAT FOV ~10 times per year.

14. Time relative to detection of GRB.
Looking Forward: Science Requirements

Verification Strategy

- LAT energy range and FOV are vast. Verification consists of a combination of simulations, beam tests, and cosmic ray induced ground-level muon tests.
  - primary verification is done by analysis, using the simulation (see following slides)
  - ground-level muon data provide additional inputs to the simulation related to instrument characteristics (dead channels, noise, uncovered idiosyncrasies, geometry checks, etc.)
  - beam tests provide inputs for tuning the simulation and reconstruction algorithms, and they also sample performance space over the full energy range
- For science performance, beam tests can be done with just a few towers together (2 TKR, 3 CAL, 5 ACD tiles).
- Full-LAT tests are mainly functional tests.
How the Analysis Pieces Fit Together

Instrument Response
- geometry
- sensor response (dead channels, noise, etc.)
- trigger

Event Reconstruction
- onboard filter
- onboard science

Event Classification
- High-level Science Analysis
- Performance

Huge effort across LAT collaboration

Detailed flux review J. Ormes et al.

Gamma events
- Sky model and benchmark fluxes

Muon test data, SVAC runs

Beam test check

- Beam test tune; self-consistency checks, basic physics checks
- FSW algorithms wrapped into SAS; FES+Testbed
Example (simplified) recipe: Aeff

- Throw benchmark flux of photons at 6m$^2$ target in which LAT is embedded
  - “all_gamma” flux, covering all relevant angles and energies
  - target area optimized for efficiency while maintaining correct distribution

- Pass all events through full simulation, trigger, filter, reconstruction, background rejection, good event selections, etc. (previous slide)

- In bins of energy and incident angle (instrument coordinates), calculate Aeff:
  \[
  \text{(\# events passing/\#events thrown)} \times 6\text{m}^2
  \]

- Field of view is given by Aeff as a function of incident angle
  - defined in requirements as integral of Aeff over solid angle normalized to Aeff at $\theta=0$. 
GLAST/LAT performance

Energy Resolution: ~10% (~5% off-axis)

F.o.V.: 2.4 sr
Experience

From Lowell Klaisner’s talk:

LAT Team has done these analyses before:

**Project History**

<table>
<thead>
<tr>
<th>GLAST - The History</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>First International GLAST Meeting</td>
<td>August-94</td>
</tr>
<tr>
<td>GLAST Mission Concept Study</td>
<td>March-95</td>
</tr>
<tr>
<td>GLAST NASA SR&amp;T Program</td>
<td>February-96</td>
</tr>
<tr>
<td>1st GLAST Beam Test - ESA, prototype CsI Calorimeter</td>
<td>July-96</td>
</tr>
<tr>
<td>2nd GLAST Beam Test - ESA, hodoscopic CsI, proto TKR trays</td>
<td>October-97</td>
</tr>
<tr>
<td>GLAST Advanced Technology Development Program</td>
<td>August-97</td>
</tr>
<tr>
<td>ATD Beam Test Prototype - ESA Beams</td>
<td>December-99</td>
</tr>
<tr>
<td>GLAST Mission Proposal to NASA</td>
<td>November-99</td>
</tr>
<tr>
<td>GLAST Mission Selection</td>
<td>February-00</td>
</tr>
<tr>
<td>ATD Balloon Flight</td>
<td>August-01</td>
</tr>
<tr>
<td>Preliminary Design Review</td>
<td>January-02</td>
</tr>
<tr>
<td>Critical Design Review</td>
<td>May-03</td>
</tr>
<tr>
<td>First Flight Tracker and CAL Modules Installed in GRID</td>
<td>April-05</td>
</tr>
<tr>
<td>All 16 towers and Anticoincidence Detector installed on LAT</td>
<td>November-05</td>
</tr>
<tr>
<td>All flight DAQ modules installed on LAT</td>
<td>February-06</td>
</tr>
</tbody>
</table>

Simulation Performance Studies

Beam tests

Cosmic ray test data

plus data challenges
Instrument Test Data Analysis Activities

- Some Results (Friday’s IA meetings)
  - **Multiple Trigger Engines**
    - confirmed are configured properly and rates/per engine agree with expectations for ground cosmic rays
  - **ROI for ACD tiles shadowing TKR towers**
    - confirmed are configured properly and performance agrees with expectations
  - **Study LAT performance when the PDU voltages were changed and added external rate to the data flow system**

- Work in progress
  - **Quantities that depend on calibrations/thresholds agree with expectations for surface cosmic rays**
    - position/width of muon peaks/CAL module
    - CAL pedestals
    - ACD pedestals
  - **Extrapolate muon tracks to the CAL**
    - verify position resolution and “PSF with muons”

- Ongoing
  - **Quantities that depend on calibrations/thresholds agree with expectations for surface cosmic rays**
    - peak position/width of ToT distributions for MIPs
    - noise occupancies for ACD, TKR and CAL
  - **Study characteristics when LAT is positioned horizontally**
  - **Study characteristics when the PDU voltages were changed and added external rate to the data flow system**
    - Search for increase in noise occupancy, extra sources of noise in CAL/ACD
  - **Extrapolate muon tracks to the ACD**
    - verify geometry and efficiencies
  - **Deadtime for different readout modes agree with expectations**
    - zero suppression enabled/disabled
    - CAL range (one or four)
  - **Study characteristics when we add external rate to the data flow system**
    - Does the deadtime change in an expected way?

Many detailed looks at the data. No show stoppers found!
Summary

- Elements are in place to complete the science requirements verification prior to the pre-ship review in August.
- The instrument test data are extremely useful for other detailed studies
  - not part of the pass/fail verification
  - excellent way to learn more about the instrument characteristics prior to launch