The Fermi Gamma-ray Space Telescope: Spacecraft, operations and mission

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The Fermi Observatory

Large Area Telescope (LAT)
Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - 300 GeV - includes unexplored region between 10 - 100 GeV

Gamma-ray Burst Monitor (GBM)
Observes entire unocculted sky
Detects transients from 8 keV - 40 MeV

• Huge improvement over previous missions in this waveband
  – Increased effective area
  – Improved angular resolution
  – Broader energy range
  – Wide field of view
Fermi Observatory

Large Area Telescope (LAT):
• 20 MeV - >300 GeV
• 2.4 sr FoV (scans entire sky every ~3hrs)

Gamma-ray Burst Monitor (GBM)
• 8 keV - 40 MeV
• views entire unocculted sky

Launched on June 11, 2008
Launch!

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.
- Communications:
  - Science data link via TDRSS Ku-band (40 Mbps, 8-10, 10 min contacts per day)
  - S-band via TDRSS (8kbps) or ground stations (1.26 Mbps)
Raw Data

- Data consists of
  - 1.2 Mbps LAT data
  - 26 kbps GBM data
  - 51 kbps housekeeping data (from SC, LAT and GBM)

- The onboard solid state recorder (SSR) has two partitions, read out in parallel
  - Science (LAT+GBM data)
  - Housekeeping
Data Latency

GBM DATA PATH

<table>
<thead>
<tr>
<th>T0</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T8</th>
<th>T9</th>
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<tbody>
<tr>
<td>Fermi</td>
<td>White Sands Complex</td>
<td>Mission Operation Center</td>
<td>GSFC</td>
<td>GBM Instrument Operations Center</td>
<td>MSFC/NSSTC</td>
<td>Fermi Science Support Center</td>
<td>GSFC</td>
<td>= 474m = 7h54m</td>
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</table>

LAT DATA PATH

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<th>T1</th>
<th>T2</th>
<th>T3</th>
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<td>GSFC</td>
<td>= 554m = 9h14m</td>
</tr>
</tbody>
</table>

4.3Mbps, unlikely (at the moment) to do much better than this.

Level 0 processing conservative estimate. Sometimes achieve higher bandwidth.

Nominal case, assuming no manual intervention or new calibrations.

Data ingest, conservative estimate.

Data sit on SSR
• LAT - level 2 requirement: <72 hours from detection of gamma-ray photon to availability in public archive
  – Typical latency is ~8 hours
  – Everyone gets access to the data at the same time.
• GBM Data is delivered to FSSC within 24 hours for routine data taking.
  – GRB, Solar flares, TGFs - times, fluxes, location delivered in near real time.
Rock north for one orbit and south for the next
Cover entire sky and always keep LAT FoV away from the Earth limb
In survey mode, the LAT observes the entire sky every two orbits (~3 hours).

Multiwavelength observations in coordination with the LAT are limited only by the ability to coordinate to other observations in other wavebands.

Can also perform pointed observations of particularly interesting regions of the sky.
Observation modes

• Normal Survey mode (default)
  – 1 orbit rock north, 1 orbit rock south, repeat
  – Covers entire sky every two orbits (~3 hours)
  – Efficient observing, LAT boresight stays away from the Earth.

• Modified survey (improve exposure up to 2x)
  – N orbits rock north, M orbits rock south, repeat
  – Covers entire sky every N+M orbits
  – Efficient observing mode

• Target of Opportunity (improve exposure up to 4x)
  – Allows rapid initiation of pointed mode observations
  – Boresight traces earth limb while target is occulted.
  – Least efficient observing mode (Significant occultation of LAT FoV by Earth)

• Pointed mode (improve exposure up to 4x)
  – Planned pointed mode observation
  – Perform small segment of sky survey while target is occulted.
  – Inefficient observing mode (some occultation)
The flaring and variable sky

- Automated search for flaring sources on 6 hour, 1 day and 1 week timescales.
  - LAT scientists perform follow-up analyses, produce ATels, and propose ToOs
- >100 Astronomers telegrams
  - Discovery of new gamma-ray blazars
  - Flares from known gamma-ray blazars
  - Galactic plane transients
Observations summary

• Almost exclusively in nominal data taking in survey mode
  – 50 deg rocking angle from May 27 2009 onwards
• ARRs (~2/month)
  – Duration reduced to 2.5 hours (from 5 hours)
• 3 Target of Opportunity Observations
  – 3C 454.3
  – Cygnus X-3
  – Crab Nebula (April 2011)
• 1 modified survey mode observation
  – Two orbits south, 1 orbit north to enhance coverage during PSR B1259 periastron.
• LAT Calibrations
  – ~<12 hours/year
2.5 day TOO on 3C454.3 (the red points are from the TOO interval)

- Unfortunately, the rapid flux increase flattened just as we started the TOO.

Allows production of lightcurves on <3 hour timescales (for very bright sources)
• Unfortunately the second flare was much shorter (4 day vs 16 days) than the first one. The TOO observations commenced after the end of the flare.
- Gamma-ray flare was short, and stopped just before the TOO commenced.
Shockingly bright flares in Sept 2010 and April 2011.

Rapid identification of flares by LAT team enabled Chandra and HST TOO observations in Sept, and sequence of Chandra observations in April (target visibility issues for HST)

Rapid (hourscale) variability of PeV electrons poses severe challenges for acceleration mechanisms

A Successful TOO!
Impact on rest of sky

- Factor of ~4 exposure at 3C454.3, however large region with no exposure (including M87 which was flaring at the time)
Target location offset 10 deg. towards the orbit equator
Planned exposure did not favor direction of Crab
ToO provided estimated 3.9x exposure for regional zenith exclusion (2.2x if rocking angle cut of 52 deg is also applied)
A substantial fraction of the sky received no exposure during the ToO
Ended early
  – Operational complications
  – Crab nebula stopped flaring in gamma-rays
Where are we pointing (1)

- 3 star trackers (2 active, 1 spare)
  - Acquires, tracks and identifies up to 6 bright stars in its FoV
- Also have set of 4 gyroscopes that measure angular rates of the spacecraft
  - Used to propagate attitude solution during star tracker outages (and between updates)
- Propagated solution from the gyros is corrected by attitude measurements from the star trackers (similar to orbit location)
  - Solution is robust to outliers and outages in star tracker measurements
  - Track the residuals between star tracker measurements and propagated solution (always tiny compared with LAT psf)
- Attitude solution reported at 5 Hz
How do we know where we are?

• **GPS**
  – Propagate orbit model, refine orbit solution using GPS location data, data lying close to predicted location given higher weight (Kalman filter)
    • Filtered solution robust against outliers or GPS outages
    • Filtered solution more accurate than any individual GPS meas.
  – Orbit location (from filter) reported at 1 Hz
Spacecraft files (aka FT2 files)

- These combine the orbit position and attitude information from the spacecraft.
  - Entries spaced every 30 s
Absolute timing and orbit location

• GPS also provides an absolute timestamp
  – Used to calibrate an onboard oscillator.

• Absolute timestamps are accurate to <300 ns (verified in ground test, and on orbit).
• Orbit position determination good to ~<20 m

• Both of these are important when considering very short timescales
  – Millisecond pulsars!
New Pulsar in CTA 1

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

$P \sim 316$ ms
$P_{\text{dot}} \sim 3.6 \times 10^{-13}$
$\text{Flux (}>100\text{MeV}) = 3.8 \pm 0.2 \times 10^{-7}$ ph cm$^{-2}$ s$^{-1}$

Pulse undetected in radio/X-ray

LAT 95% error radius = 0.038 deg (in 1 month!)
EGRET 95% error radius = 0.24 deg

**Unidentified EGRET sources - many are pulsars!**
LAT is resolving the MeV-GeV gamma-ray emission from extended sources.

Uchiyama et al, 2011

(a) W51C  
(b) W44  
(c) IC 443  
(d) W28

Perkins et al, 2011

Cen A

Preliminary
Nov 9, 2009 - add new TGF trigger
  - TGF trigger rate increased by factor of ~10 to 1 per 3.7 days
  - Feb/March 2011, solar activity
GRB090902B - Autonomous repoint

- LAT pointing in celestial coordinates from -120 s to 2000 s
  - Dark region = occulted by Earth (θz>113°)
  - Blue line = LAT FoV (±66°), White points = LAT events
Fermi detections as of 2011-01-20

530 GBM GRB (since Aug 2008)
27 LAT GRB
20 (>100 MeV, TS > 16)
7 LAT LLE-only GRB

Circles:
In Field-of-view of LAT (<70°): 275
Out of the FOV

Squares:
LAT detections

PRELIMINARY
Rapid flashes of gamma-rays produced by highly energetic particles produced in thunderstorms.
Terrestrial Gamma-ray flashes

Briggs et al, GRL, 2011

TGFs are concentrated in the tropics near thunderstorms

Antimatter from Thunderstorms!
GBM positron event

Mirror point
Fermi above Egypt
Magnetic field line

TGF 091214

Counts per microsecond

Main peak
"Mirrored" peak

Time (milliseconds)
GBM team have made non-GRB high level data/results available.
GBM team noticed that the Crab flux appeared to be decreasing, and compared with other instruments.

Light curves for each instrument are normalized to its average rate from MJD 54690-54790.

Instruments on four separate spacecraft show decline in Crab flux since August 2008.
The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission timeline, provides analysis tools for the scientific community, and archives and serves the Fermi data. This website is the portal to Fermi for all guest investigators.

This all-sky view from Fermi reveals bright emission in the plane of the Milky Way (center), bright pulsars and super-massive black holes.

Credit: NASA/DOE/International LAT Team

Public data and extensive support for science Analysis Tools

http://fermi.gsfc.nasa.gov/ssc/

FSSC Supports Guest Investigator Analysis
Data Downloads from Science Support Center

Cumulative Data Volume Served

- Total
- Photons
- Spacecraft
- Events

Reprocessed data Release

Fermi Symposium
Queries to FSSC Helpdesk

4-week binning

# Helpdesk Responses

Weeks since Feb. 1, 2009
Published Refereed Papers
Questions?
• Finally closed the unexplored energy range between 10 and 100 GeV
• Allow joint fits between LAT (MeV-GeV) and IACTs (GeV-TeV)