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

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Gamma-ray Astrophysics

- Gamma-rays cover a huge swath of the electromagnetic spectrum
- The gamma-ray sky is still very new
- High-Energy gamma-rays probe the non-thermal universe
  - Explore extreme environments hosting powerful particle accelerators
Why High Energy Gamma-Rays?

- High energy gamma-rays explore nature’s accelerators - “Where the energetic things are”
  - natural connections to UHE cosmic-ray and neutrino astrophysics

High energy photons often produced in a different physical process to the lower energy emission -> Independent handle on the physical conditions.

High energy gamma-rays can be attenuated by pair-production with lower energy photons

- Probe conditions in emission regions (gammas need to get out)
- Explore the optical/UV diffuse background
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 unoccluded sky

Launched on June 11, 2008
The >1 GeV Sky
The Variable Gamma-ray Sky

Northern Galactic Hemisphere

Southern Galactic Hemisphere

Fermi LAT
05-AUG-2008
Fermi Highlights and Discoveries

Terrestrial γ-ray Flashes

Fermi Highlights and Discoveries

Fermi Bubbles

Radio Galaxies

GrBs

Blazars

Nova

SNRs & PWN

Starburst Galaxies

LMC & SMC

Globular Clusters

Galactic γ-ray Binaries

Pulsars: isolated, binaries, & MSPs

Sun: flares & CR interactions

Terrestrial γ-ray Flashes

Unidentified Sources (577/1873)
Fermi MISSION ELEMENTS

- Mission Operations Center (GSFC)
- Fermi Science Support Center (FSSC)
- LAT Instrument Science Operations Center (SLAC)
- GBM Instrument Operations Center (MSFC)
- GRB Coordinates Network (GSFC)
- HEASARC GSFC

Critical components include:
- DELTA 7920H
- TDRSS SN S & Ku
- GPS

Key operations centers:
- White Sands
- LAT Instrument
- Science Operations Center
- Fermi Spacecraft
- Large Area Telescope & GBM

Telemetry 1 kbps

Alerts
- Data, Command Loads
- Schedules
- Telemetry

Science support:
- Fermi Science Support Center (FSSC)

Instrument operations centers:
- GBM Instrument Operations Center (MSFC)

Mission critical functions:
- S & Ku
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
  - 1.5 Mbps LAT data
  - 0.5 Mbps 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
    - Often arrives before science data due to smaller volume
Data Latency

GBM DATA PATH

T0  T1  T2  T3  T4  T5  T8  T9  T12
Fermi  White Sands Complex  Mission Operation Center  GSFC  GBM Instrument Operations Center  MSFC/NSSTC  Fermi Science Support Center

180m + 12m + 70m + 120m + 4m + 20m + 8m + 60m = 474m = 7h54m

LAT DATA PATH

T0  T1  T2  T3  T4  T7  T10  T11  T14
Fermi  White Sands Complex  Mission Operation Center  GSFC  LAT Instrument Science Operations Center  SLAC  Fermi Science Support Center

Data sit on SSR

180m + 12m + 70m + 120m + 26m + 60m + 26m + 60m = 554m = 9h14m

Data ingest, conservative estimate

Level 0 processing conservative estimate.

sometimes achieve higher bandwidth.

Nominal case, assuming no manual intervention or new calibrations.

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

• LAT - 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.
Survey mode

- Rock north for one orbit and south for the next
- Cover entire sky and always keep LAT FoV away from the Earth limb
- Rotate about Z-axis to keep sun off the LAT radiators (on +-Y faces)
• 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.
  • Requirement to be able to slew 75 deg in less than 10 mins (to catch GRB)
GRB090902B - Autonomous repoint

- LAT pointing in celestial coordinates from -120 s to 2000 s
  - Dark region = occulted by Earth ($\theta_z > 113^\circ$)
  - Blue line = LAT FoV ($\pm 66^\circ$), White points = LAT events
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.
  - Somewhat inefficient observing mode (some occultation)
Observations summary

- Almost exclusively in nominal data taking in survey mode
  - 50 deg rocking angle from May 27 2009 onwards
- ARRs (~2/month)
  - 2.5 hours duration (5 hour before Nov 2010)
- Target of Opportunity/pointed mode observations
  - Crab nebula, Sun, flaring blazars, galactic center
- Modified survey mode observation
  - PSR B1259 periastron, sun
- LAT Calibrations
  - ~<12 hours/year

- For past and planned future observations see:
  - http://fermi.gsfc.nasa.gov/ssc/observations/timeline/posting/
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
Where are we pointing

• 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
• This defines the spacecraft attitude, NOT the LAT
  – Before use, correct for offset between the spacecraft and the LAT
Spacecraft files (aka FT2 files)

- These combine the orbit position and attitude information from the spacecraft.
  - Entries spaced every 30 s
- LAT_MODE – describes spacecraft observation mode
  - 3: pointed mode
  - 4: Maneuver mode
  - 5: survey mode
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!
We moved out of the way
Flight Operations Team

- 7 people
  - Responsible for operating the observatory and monitoring the health and performance of Fermi
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 supermassive 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
Science Support Center Team

- 6 scientists and 4 programmers/support staff
  - Planning/scheduling observations (including target of opportunity)
  - Software development
  - Data/software repository
  - User support
    - Documentation
    - Help desk
    - ...

Queries to FSSC Helpdesk

4-week binning

# Helpdesk Responses

Weeks since Feb. 1, 2009
Published Refereed Papers

See: http://fermi.gsfc.nasa.gov/cgi-bin/bibliography_fermi for a full list of Fermi-related publications
Questions?