

Orbital Observatory GLAST – new step in the study of cosmic gamma-radiation

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Abstract

The new Gamma-ray Large Area Space Telescope (GLAST) is scheduled for launch in the middle of 2008. It contains the high energy gamma-ray telescope LAT (Large Area Telescope) which covers the energy range from 20 MeV to >300 GeV and the GMB (GLAST Burst Monitor), covering 8 keV – 30 MeV energy range. The GLAST science objectives include understanding the mechanism of charged particle acceleration in active galactic nuclei, pulsars and supernova remnants, determining the nature of the still-unidentified EGRET sources, detailed study of gamma-ray diffuse emission, high-energy emission from gamma-ray bursts and transient sources, and probing dark matter. A brief overview of the mission is given. © 2001 Elsevier Science. All rights reserved

1. Introduction

The Gamma-ray Large Area Space Telescope (GLAST) observatory, scheduled for launch by NASA in the middle of 2008, will study cosmic gamma-radiation in the energy band from 10 keV to above 300 GeV. The observatory is being built by an international collaboration consisting of research organizations and universities from Germany, France, Italy, Japan, Sweden, and the United States, with more than 300 team members. An important feature of the collaboration is that it comprises scientists from high energy particle physics and high energy astrophysics. A brief overview of the mission is given in this paper; for a detailed description see papers [1-3]. The GLAST observatory consists of 2 instruments (Fig.1) – Large Area Telescope (LAT) [1,2] and GLAST Burst Monitor (GBM)[3]. The main instrument, the LAT, is a wide field-of-view, imaging high-energy telescope for detecting celestial gamma rays in the energy range from ~20 MeV to >300 GeV. The GBM covers the energy range from 8 keV to 30 MeV and observes the whole unocultured sky all the time, searching for gamma-ray bursts. The GLAST predecessor, EGRET (Energetic Gamma Ray Experiment Telescope) on the Compton Gamma Ray Observatory, which operated in orbit from 1991 to 2000, made the first complete survey of the sky in the energy range 30 MeV - >10 GeV, did extensive observations on active galactic nuclei (AGN), pulsars, and diffuse gamma-radiation, and discovered many sources of gamma-radiation that are unidentified so far [4]. The LAT has superior performance compared to EGRET: 5 times larger effective area, much broader energy range and better angular resolution, wider field of view, and much smaller dead time. This will provide more than a factor of

30 in sensitivity as well as better capability to study transient phenomena. The science tasks for LAT originate from the results obtained by EGRET and a number of other astrophysical space missions as well as from TeV ground-based gamma-ray instruments. Since gamma-rays, unlike charged cosmic rays, are not deflected by interstellar magnetic fields, they are an excellent tool to study point sources such as Active Galactic Nuclei (AGN), supernova remnants (SNR), and pulsars, and of course to resolve the puzzle of unidentified gamma-ray sources remaining from the EGRET era. The LAT should increase the number of known AGNs from ~70 to several thousand and will study their variability; it will



Figure 1 GLAST on orbit – artistic view

discover up to several hundred gamma-ray pulsars. Detailed study of SNR will provide unique information about cosmic ray origin and acceleration. With the help from GBM, exciting results are expected from the study of gamma-ray bursts, the most energetic events in the Universe. Excellent timing characteristics will allow the study of time profiles of the bursts, crucial to understanding their mechanism. The study of diffuse gamma-ray radiation will be a very significant contribution to the measurement of cosmic rays and interstellar matter distribution. Special subjects of LAT observations will be the Sun, following up on the EGRET's discovery of high energy gamma-rays in solar flares. Probing the nature of dark matter will certainly be one of the most exciting objectives for LAT. The wide energy range of the LAT provides unique opportunity to overlap with measurements made by ground-based TeV telescopes such as CANGAROO, HESS, VERITAS, MILAGRO, and MAGIC, which will contribute to multiwavelength measurements of gamma-ray objects.

The main operating mode for the LAT is scanning mode when it will be observing ~20% of the sky at any instant. The LAT will observe all parts of the sky for ~30 min. every 3 hours. The planned GLAST mission duration is 5 years, with the goal to extend it to 10 years. GLAST will have a 565km circular orbit, with 25.4° inclination

2. GLAST Mission Operation

In order to provide a successful and effective mission operation GLAST mission offices have been established. A key element is the GLAST Mission Operations Center (MOC) which executes the main operation functions such as communication with the GLAST and service satellites (GPS, TDRSS), receiving and transmission of the information with ground stations, analysis of situations and making decisions in GLAST operation. The LAT Instrument Science Operation Center (ISOC) and GBM Instrument Operation Center (GBM IOC) provide data processing, data monitoring and quality analysis, instrument calibration and configuration, operations optimization. They work in close connection with the science teams in order to quickly resolve all operation issues. After first processing, the data are transferred from ISOC to GLAST Science Support Center which converts primary data into science data, and after that to the High Energy Astrophysics Data Archive (HEASARC GSFC). The MOC also forwards alerts to GRB Coordinate Network which connects all instruments involved in gamma-ray burst detection. This network provides prompt information about gamma-ray burst occurrence in order to point instruments in the burst direction. Currently all mission operation offices are busy with careful development of operation plans and detailed simulation of all phases, steps and possible situations in observatory operation. Special attention is given to the critical phase in GLAST operation - Launch and Early Operations (L&EO), during which the instruments first after-launch tests and calibrations will be performed.

3. The Large Area Telescope (LAT)

3.1. The LAT Instrument Overview

In its conceptual design the LAT inherits from gamma-ray telescopes OSO-III, SAS-II, COS-B, and EGRET as well as from high energy particle physics instruments. It is a pair conversion telescope – detection of a gamma-ray occurs in the position-sensitive detector, the Tracker, through conversion of a gamma ray into an electron-positron pair (Fig.2). The trajectories of the resulting electron and positron are precisely measured and reconstructed. Energies of detected gamma-rays are measured by a CsI hodoscopic Calorimeter, 8.4 radiation lengths (X_0) deep. The Tracker is covered on the top and sides by the Anticoincidence Detector (ACD). The LAT will have to identify cosmic gamma-rays against a background

of charged cosmic rays 3-5 orders of magnitude more abundant (mainly protons, alpha-particles and electrons). The majority of the rejection power against cosmic rays will be provided by the ACD.

LAT has a modular structure consisting of a 4×4 array of identical “towers”, each comprised of a Tracker and a Calorimeter sections, with all towers covered by the ACD. The dimensions of the entire LAT are 1733×1733×970 mm. The information from all LAT detectors is collected by the Data Acquisition System (DAQ), which does the data initial processing and data transmission. The LAT is self-triggered, unlike that of EGRET, where a time-of-flight coincidence system provided triggering. LAT is triggered by either the presence of signals from 3 consecutive layers of the Tracker or by energy deposition above 100 MeV in a single crystal of the Calorimeter. This method of triggering provides the low energy threshold for gamma-ray detection (~20MeV) but is much more challenging with regard to background removal. The DAQ operation is also very challenging, with a first-level trigger rate up to 10 KHz, which must be reduced to 300-400 Hz before transmission to the ground. Instrument design is based on numerous detailed computer simulations, validated by the tests of prototypes at accelerators and in a balloon flight.

3.1.1. The Tracker

The Tracker [5] contains 18 double-plane single-side silicon-strip detectors to read out both x- and y-coordinates. They are interleaved with 3.5% X_0 thick (first 12) and 18% X_0 thick (next 4) tungsten converters where gamma-ray conversion can occur. The last two layers do not have converters. The thickness of converters was carefully optimized to provide precise tracking (requiring thinner radiators to reduce multiple scattering) and high pair conversion efficiency to increase gamma-ray detection efficiency and consequently to increase the LAT effective area (requires thicker converters). The upper layers with thin converters provide high track position resolution, and the thick converters increase the total conversion efficiency. Layers without converters are used for triggering and track reconstruction. There is ~1.5 X_0 of

total material in the Tracker, including the converters, silicon-strip detectors, and supporting material. The strip pitch is 228 μm , totaling 8.8×10^5 readout channels.

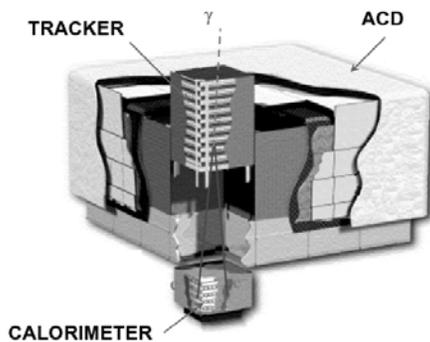


Figure 2 The schematic of LAT

3.1.2. The Calorimeter

The Calorimeter [6] section of each tower contains 96 CsI(Tl) crystals, arranged in 8 alternating orthogonal layers, with 1536 crystals in the whole Calorimeter. Each crystal is 326 mm long and 27 mm by 20 mm in cross-section, wrapped in light-reflecting material and viewed by dual PIN photodiodes to provide wide dynamic range, from ~2 MeV to ~70 GeV deposited in a single crystal. Mechanical packaging is a carbon composite cell structure.

Segmented structure provides shower profile reconstruction and thus event pattern recognition, useful for background rejection; it also improves energy resolution by correcting every trajectory for the amount of material passed. Calibration of the crystal is an important issue. Readout from both ends provides precision of ~1mm in position (energy dependent) of the center of gravity of the energy deposition, which is used in the shower image recognition and track direction determination. Every crystal has its own position response, calculated as a ratio between signals at the ends; it has to be calibrated. The energy response of every crystal also has to be calibrated over a wide range of energy deposition by using a beam of heavy nuclei on the ground and cosmic ray nuclei during the space mission.

3.1.3. The ACD

The Anticoincidence Detector [7] is the outermost LAT detector, which signals the arrival of charged particle background. It creates a veto signal, with overall efficiency of >0.9997, in response to the passage of a charged particle. The ACD is an array of 89 plastic scintillator tiles. The light from each tile is

collected by wave-length shifting fibers and read out by two photomultiplier tubes (for redundancy). In order to provide maximum hermeticity to charged particles, the tiles are overlapped in one direction, but have gaps in the other direction for thermal expansion. These gaps are covered by scintillating fiber ribbons (8 in total), which detect particles coming through the gaps between tiles. The ribbons are pre-shaped to follow the profile of overlapped tiles. The required charged particle detection efficiency is achieved by careful design of the tiles to maximize the light yield, with highly uniform light collection over the tile area, and by careful selection of the signal detection threshold. In addition to the requirement of high efficiency for charged particle detection, the ACD must have low sensitivity to backslash particles (mostly low energy photons), which escape backward from the Calorimeter when an electromagnetic shower is created by a gamma-ray with energy above several GeV. Backslash can create signals in the ACD and, in the absence of mitigation, veto a valid gamma-ray event, dramatically reducing the LAT sensitivity above a few GeV (self-veto effect). The segmented ACD solves this problem by considering the hit only in the tile crossed by the reconstructed particle trajectory.

3.1.4. The DAQ and Triggering

This system provides data collection and processing from all the detectors. The LAT first level trigger (L1T) can be created in two ways: 1) tracker hits in 6 sequential x and y layers (3-in-a-row trigger); or 2) energy deposition in a calorimeter above some programmable threshold. The LAT average L1T rate over an orbit is expected to be ~ 4 KHz, with the maximum up to 12 KHz. Using the ACD veto in L1T reduces the orbit average to ~ 1 KHz, with the single event dead time of 25 μ s. During very challenging onboard processing this rate is further reduced to fit the downlink rate, 300-400 Hz.

3.2. The LAT performance

LAT has a large field of view (≈ 4 times greater than EGRET), and large effective area. This combination of performance parameters makes a scanning mode of observation very efficient in finding new gamma-ray sources and detailed study of particular sources at the same time. The large energy range overlaps with GBM under 30 MeV and with ground-based telescopes above 50-100 GeV. This broad span provides a unique opportunity for making simultaneous measurements. LAT will also make the first detailed observations in the poorly-explored 10 GeV – 100 GeV energy range. Angular resolution is unprecedented for space-based gamma-ray astronomy; it is >3 times better than EGRET for > 1 GeV. This feature will make a decisive contribution in source identification. We expect to find thousands point sources of gamma-radiation for one year of LAT observations, compared to 271 found by EGRET for 9 years of operation. Energy resolution is in the range 5% to 20%, depending on the photon energy and angle of incidence. We also explored the capability of LAT to detect high-energy cosmic ray electrons and distinguish them from cosmic ray hadrons that are 3-4 orders of magnitude more abundant. Currently available data on cosmic ray electrons are obtained only in balloon-borne experiments and suffer from insufficient statistics and inconsistency. It was determined that LAT will collect $\sim 10^7$ electrons above 20 GeV per year, with 5-20% energy resolution and $<3\%$ residual hadron contamination, providing statistically significant and unbiased electron spectrum measurement in the energy range from 20 GeV to ~ 1 TeV[8].

3.3. LAT calibration and science data analysis

The LAT is a complicated instrument, requiring very good calibration in order to provide energy, direction and timing reconstruction. The analysis assumes a very good knowledge of instrument response to the incident gamma-ray flux: Instrument Response Function (IRF). We also need to know with high confidence the background rejection capability, which includes the ability to recognize event pattern. In addition to these factors, temperature variation, incident charged particle rate, and instrument aging affect the calibration parameters. Calibration therefore represents a major challenge. Another factor is that the compressed instrument development schedule did not allow the time to perform calibration on the whole instrument. The decision was to perform a series of beam tests on the separate LAT detectors and subsystems starting in 1997, to perform a balloon flight of a single-tower prototype [9], and finally to run a comprehensive beam test on a LAT prototype [10]. The results of all these tests were compared with

comprehensive LAT Monte Carlo (MC) simulations, based on the Geant4 package, and needed corrections and adjustments in simulations were made. This combination of tests resulted in obtaining the IRF, and all LAT data analysis is based on Monte Carlo simulations, now experimentally validated.

3.4. LAT prototype balloon flight

As a part of the LAT development effort, the functional prototype, the Balloon Flight Engineering Model (BFEM), of approximately the size of one LAT tower, containing all the components of the full instrument – Tracker, Calorimeter, ACD, and DAQ, was built and launched on high altitude balloon on August 4, 2001, from Palestine, TX. All the detectors and the trigger, the challenging part of the LAT design, worked well, validating the basic concept of the LAT design. The BFEM handled very well the trigger rate (~1.5 KHz). A wide variety of event types was seen; the majority of them were cosmic rays as expected but some showers and gamma-ray pair production events were observed. The event pattern recognition approach was improved according to the real events obtained in this flight.

3.5. LAT prototype beam tests at CERN and GSI

In order to validate the LAT simulations, a campaign of beam tests was performed from July to November 2006, in parallel with the LAT integration and ground tests. The LAT prototype (Calibration Unit: CU) for these tests was built with spare flight modules (2 tracker modules, 4 calorimeter modules, and 5 ACD tiles) and flight-like electronics. The CU was exposed to beams of photons (0 – 2.5 GeV), electrons (1 – 300 GeV), protons and pions (a few GeV – 100 GeV) at CERN and to Carbon and Xenon beams (1.5 GeV/n) at GSI. Some impressive numbers from these tests: ~1,700 runs, ~100M processed events, 330 configurations (particle, energy, angle, impact position), 60 people directly involved. Results confirm that the current MC simulation is fairly accurate in reproducing the behavior of the LAT subsystems. The angular resolution of the tracker, the electromagnetic shower shape in the calorimeter and signals in the ACD, as well as the instrument response to heavy ions are well reproduced.

3.6. Preparation for science data analysis

The LAT team wants to be ready to absorb and process quickly the huge amount of raw data to be collected, expected to be ~25M events a day transmitted to the ground. In order to create the science data from the raw data, we need to apply all the LAT detector calibration parameters and instrument response function in order to reconstruct the events, learn how to recognize and efficiently remove the background charged particles and albedo photon events (very challenging task!), and apply the LAT-Spacecraft-Sky coordinate conversion. This part of data processing has been under development and testing for several years, and currently is practically completed.

The next step was to work with the science data studying different subjects from the LAT science objectives. In order to be well prepared for this crucial step, and to minimize the time needed to achieve scientific results, the LAT team ran several Data Challenges with simulated LAT data. In one of these, the astrophysical objects were put in “55-day Gamma-ray All-Sky Survey Simulations” using realistic orbit and altitude profile, as well as real LAT detector responses. This simulation was done by a group of people and was kept a secret to let the users (LAT members) test their science tools and their skills to find the objects and determine their properties. The “truth” was revealed at the end. This activity proved to be very efficient in the development of the science tools.

In order to improve the communication between LAT scientists, nine Science Working Groups were established, corresponding to the GLAST science objectives; team members joined according to their personal interests. These groups are running weekly teleconferences; each group has a webpage. All publications and external presentations are subject to group review.

4. GLAST Burst Monitor (GBM) Overview

The GBM is designed to enhance the GLAST capability in the study of gamma-ray bursts (GRB). With energy range from ~ 8 KeV to 30 MeV, the GBM determines burst location on-board and creates a signal that allows GLAST to be re-pointed to place the burst within the LAT field-of-view under certain conditions. The GBM comprises 12 NaI and 2 BGO scintillating detectors, as well as a Data Processing Unit and a Power Supply. The NaI detectors are 12mm thick by 125mm in diameter, covered by a thin Be window. They cover the energy range from ~ 8 KeV to 1 MeV and are used to determine GRB location. The BGO detectors are 125mm thick by 125mm diameter, and cover the 150 KeV – 30 MeV energy range, providing energy overlap between the NaI detectors and the LAT. The detectors are oriented and positioned on GLAST so as to provide approximately uniform coverage of the unocculted sky. The GBM trigger occurs if the count rates in two or more of the NaI detectors exceed the adjustable significance above the background rate, with the nominal value of 4.5σ . The predicted rate of GRB events detected by GBM is ~ 200 per year.

5. GLAST tests and current status

Both the GLAST instruments – the LAT and the GBM – passed all functional and environmental tests required by a Delta-II launch before being integrated on the spacecraft. After integration, the Observatory has been undergoing functional, electromagnetic interference, electromagnetic compatibility, vibration, acoustic, and shock tests interleaved by the end-to-end and comprehensive performance tests. GLAST has successfully passed all tests thus far. Following these tests, GLAST will undergo thermal vacuum testing, which will be the final tests before shipping to the launch site.

6. Data Release plan and operations

During the first year the release of GLAST data will be restricted to allow the instrument teams to calibrate their instruments (initial on-orbit checkout, 60 days) and carry out their proposed sky survey. There will be the possibility to re-point the observatory for bright sources and extraordinary targets of opportunities. During the first year the GLAST team will release data on gamma-ray bursts and will release the spectra and lightcurves for ~ 20 selected sources. For the second and consecutive years the observing plan will be driven by peer-reviewed guest investigator proposals. The default mode of observation will still be sky survey. After the first year data are not proprietary.

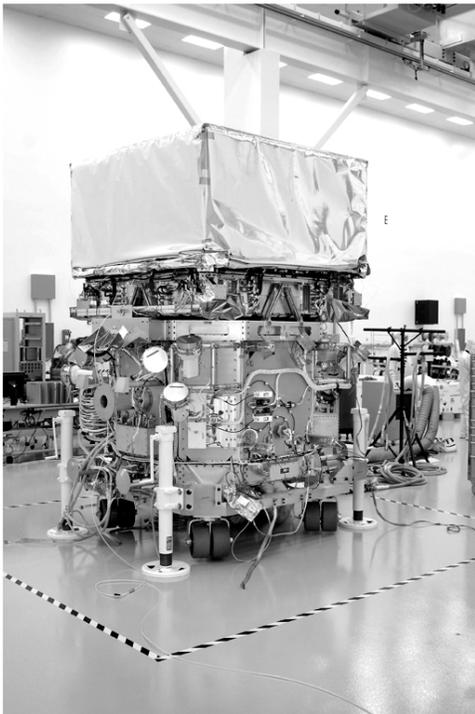


Figure 6 GLAST Observatory

7. Summary

At the present time the GLAST is on its final steps toward orbit. Most of the required tests have been passed, and we are all looking forward to the flight data.

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