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STATUS OF GLAST, THE GAMMA-RAY LARGE-AREA SPACE TELESCOPE[*]

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GLAST is a satellite-based observatory consisting of the Large-Area Telescope (LAT), a modular 4x4-tower pair-conversion telescope with a field-of-view greater than 2 steradians, capable of measuring gamma-ray energies in the range 20 MeV to 300 GeV, and the GLAST Burst Monitor (GBM), a set of NaI and BGO detectors covering 8 steradians and sensitive to photons with energies between 10 keV and 25 MeV, allowing for correlative observations of transient events. The observatory is currently being constructed and is scheduled to be launched in August 2007.

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1. Introduction

GLAST[1] is a satellite-based observatory consisting of two instruments: the Large-Area Telescope (LAT) and the GLAST Burst Monitor (GBM). Together they will provide for correlative measurements of gamma-ray phenomena in the energy range between 10 keV and 300 GeV. The observatory is scheduled to be launched in August 2007 for an expected five- to ten-year mission.

2. The GBM

The GLAST Burst Monitor[2] is similar in design to the highly successful BATSE instrument onboard the CGRO mission and will provide similar capabilities. It is a set of sodium iodide (NaI) and bismuth germanate (BGO) detectors mounted

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around the outside of the satellite. It has a sky coverage of 8 steradians, which enables prompt alerts to the LAT detector and to the ground of a region of interest, as well as autonomous repointing requests for events outside the current field-of-view of the LAT. The localization precision is expected to be better than 15º in the first several seconds, with an ultimate resolution of better than 1.5º. Its spectral response just overlaps that of the LAT, which allows for simultaneous spectral fitting. The assembly of the GBM is on schedule for delivery for spacecraft integration in January 2006.

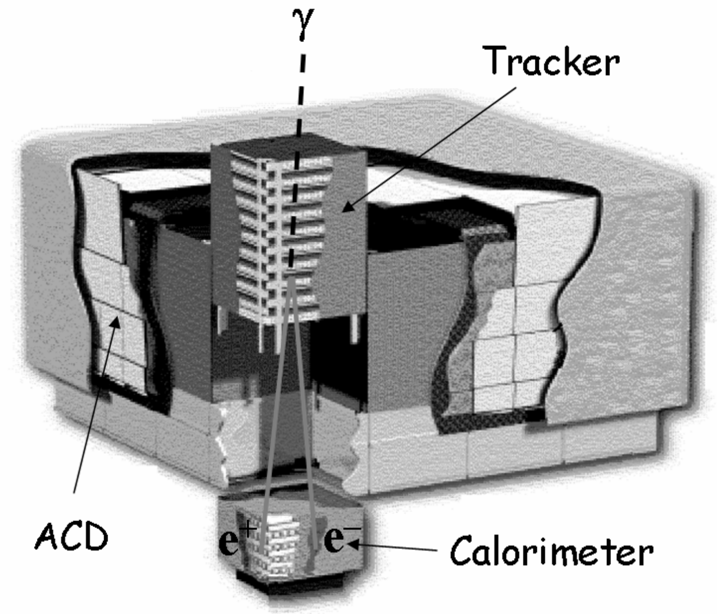

Figure 1. The Large Area Telescope is composed of sixteen modules, each containing a tracker and a calorimeter, all surrounded by a scintillator anticoincidence shield.

3. The LAT

The Large-Area Telescope[3] is a pair-conversion telescope, which takes much of its basic design concept from its predecessor EGRET[4,5]. Figure 1 shows a schematic representation of the LAT. It is built of 16 identical modules, called towers, enclosed in an anti-coincidence detector (ACD) made of overlapping scintillator tiles, which are read out by optical fibers. Each tower consists of a tracker and a calorimeter. The tracker (TKR) is based on silicon-strip technology, and features 18 pairs of planes, measuring orthogonal coordinates, and separated by thin tungsten-alloy conversion foils. A calorimeter (CAL) made of a hodoscopic stack of thallium-doped cesium iodide [CsI(Tl)] crystals is situated below the tracker in each tower.

When a photon traverses the detector, there is some probability that it will convert or materialize into an electron-positron pair in the tracker, where the paths of the two daughter particles can be measured in the silicon-strip detectors. The electron and positron typically exit through the bottom of the trackers and produce an electromagnetic shower in the calorimeter modules.

For every high-energy photon impinging on the detector, there are several thousand cosmic rays. The role of the ACD is to aid in distinguishing the cosmic rays from the photons; photons will in general pass through the ACD undetected, whereas charged particles will produce scintillation light.

4. Comparison with EGRET

GLAST is a follow-on to the very successful EGRET detector which flew on the Compton Gamma-Ray Observatory[6,7] and took data between 1991 and 2000. The LAT was designed to improve on the performance of EGRET, in terms of field-of-view and resolution (and hence sensitivity), dead-time, background rejection, and reliability. Since the detectors are entirely solid-state, there are no consumables. The LAT silicon-strip detectors provide better measurement accuracy than the EGRET spark chambers, and significantly lower dead-time. EGRET was taller than it was wide, whereas the LAT is much more squat, which translates into a considerably larger field of view. Table 1 compares the performance of EGRET with that expected of the LAT.

Table1. A comparison of the performance of EGRET and the LAT

EGRET		LAT	
			Factor
Energy	20 MeV – 30 GeV	20 MeV – 300 GeV	10
Energy Resolution	~10%	~10%	1
Peak Effective Area	1500 cm^2	10,000cm^2	6
Field of View	0.5 sr	2.4 sr	4
Sensitivity (1 year)	~$10^{-7}\gamma cm^{-2}s^{-1}$	3 $10^{-9}\gamma cm^{-2}s^{-1}$	30
Source Localization	15'	<0.5'	30
Dead-time	100 ms	<50 μs	2000

5. Gamma-Ray Science

No instrument currently deployed explores the energy range accessible by the LAT. Also, the LAT is a survey instrument, sampling the entire sky over the course of a single day. These features position it to explore a wide range of phenomena.

5.1. *Galactic Diffuse Emission*

The LAT sensitivity and resolution will help us to resolve many more point sources than were detected by EGRET and will lead to a better characterization of the diffuse background.

5.2. *Pulsars*

Detailed observation of known sources and detection of new ones, with excellent time resolution, should help distinguish among the proposed emission models.

5.3. *Supernova Remnants (SNRs)*

For SN candidates, the LAT sensitivity and resolution will allow mapping to separate extended emission from the SNR from possible pulsar components, and thus to measure the possibly differing energy spectra.

5.4. *Unidentified EGRET Sources*

About 170 sources detected by EGRET have not yet been identified with known sources. The increased resolution and sensitivity of GLAST will help us to complete the identification of some of these objects, and generate many new ones.

5.5. *Gamma-Ray Bursts (GRBs)*

EGRET fully detected 4 GRBs. GLAST is expected to see about 200 per year (above 100 MeV) with about a third of them localized to better than ten arcminutes. The LAT and GRB together will measure spectra over seven decades of energy. In addition, the small dead-time of the LAT will allow us to better characterize the short-time-scale GRBs.

5.6. *Active Galactic Nuclei (AGN) and Blazars*

EGRET detected 70-90 AGN. GLAST is expected to detect many more, perhaps 5,000-10,000. In addition, the GLAST energy range is broad, overlapping those of ground-based experiments for good multi-wavelength coverage. The wide field-of-view will allow GLAST to monitor AGN for time variability on many scales. GLAST, in combination with TeV observatories will probe the complex spectra and variability of blazars.

5.7. *Dark Matter Searches*

The possibility of the detection of decays of the neutralino, the lightest super-symmetric particle, depends strongly on its mass. The higher sensitivity and better source resolution will allow us to extend the energy range of the search.

6. Components of the LAT

6.1. *Tracker (TKR)*

The tracker is made of 75 m^2 of silicon wafers, which is the largest area by far ever deployed in a space-faring instrument. Aluminum strips, over 880,000 in all, are embedded in the wafers on a 228-μm pitch. Pairs of planes measuring orthogonal directions alternate with tungsten converter foils, with about 1.5 radiation lengths in the full detector (at normal incidence). The device is self-triggering and has a measured noise occupancy of less than 10^{-6} per strip at an efficiency of greater than 99%. The total power consumed by all 16 tracker modules is about 175 watts.

6.2. *Calorimeter (CAL)*

Each of the sixteen calorimeter modules is composed of eight hodoscopic layers of twelve CsI(Tl) crystals, with dimensions 2x2.7x33 cm^3, 1536 in all, with a total weight of about 1500 kg. Alternate layers are aligned in orthogonal directions. A showering gamma ray sees about 8.5 radiation lengths (for normal incidence). Each crystal is read out from both ends, using the light attenuation in the crystal to provide a measurement of the position along its length. Two PIN photodiodes at each end provide for four overlapping gain ranges. Like the tracker, the calorimeter is self-triggering. The power consumed by the calorimeter electronics is about 90 watts.

6.3. *Anticoincidence Detector (ACD)*

The ACD is a five-sided box which fits over the tracker. It is composed of 89 scintillator tiles, 1 cm thick. Segmentation of the detector minimizes self-vetoing due to backsplash from high energy electromagnetic showers in the calorimeter. Wave-shifting fibers are embedded in the scintillator, and the fibers carry the scintillator light to phototubes situated below the towers. The towers are overlapped where possible to reduce gaps, and the remaining gaps are covered with ribbons of scintillating fibers. The charged particle efficiency is greater than 99.97%. Total power consumed is less than 15 watts.

7. Status of the LAT Construction

As of this writing, all flight tracker and calorimeter modules have been completed. Eight TKR-CAL towers have been assembled into the flight grid and run on cosmic rays, and four more have been installed. The ACD is complete and has been delivered to SLAC for integration. Integration is on schedule for the LAT to be delivered for test and observatory integration in January 2006.

8. LAT Software

There are two faces of LAT software, one looking towards high-energy physics and the other towards astronomy. The first is concerned with reconstructing the parameters of each event, and with separating the gamma-ray signal from the charged-particle, albedo, and other backgrounds. The second is concerned with finding sources, measuring spectra, and producing catalogs. Some of the software components span the two aspects.

8.1. *Event Simulation and Reconstruction*

Much of the software used in the simulation and reconstruction of events in the LAT is home-grown, but we tried to avail ourselves as much as possible of standard freeware for object-oriented I/O, code management, file version management, code documentation, etc. GLEAM, our simulation, reconstruction and analysis program, is written in C++ using the Gaudi[8] framework.

For simulated data, particles are generated according to various source models and propagated in a model of the LAT, using GEANT4[9]. The response of the detector is modeled to produce digitized data, which are then reconstructed, both using realistic calibrations (electronic gains, detector misalignments, etc.). Real data is fed into exactly the same software, allowing meaningful comparisons to be easily made. Figure 2 is a display of an actual photon detected during testing of the eight-tower configuration with surface cosmic rays, and reconstructed by GLEAM. Figure 3 shows a large-angle cosmic-ray muon event.

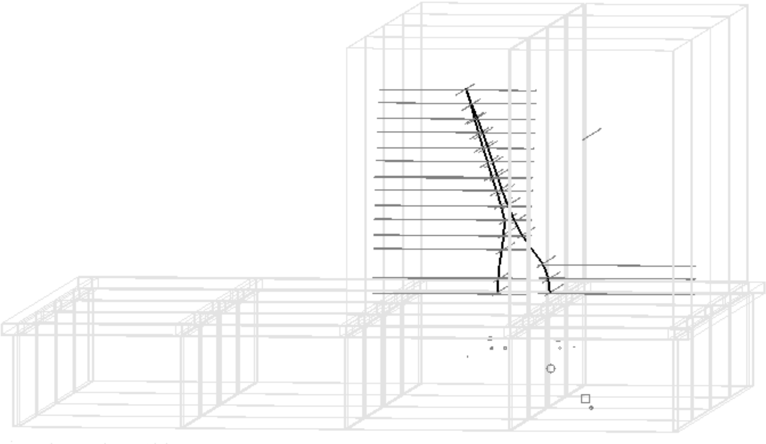

Figure 2. A low-energy gamma ray detected and reconstructed during the commissioning of the 8-tower assembly. The outline of the instrument is shown, as well as the hit strips in the tracker and the centroid of the energy deposits in the calorimeter crystals. The downward-pointing vee is the reconstructed electron-positron pair. The ACD has not yet been incorporated into the instrument.

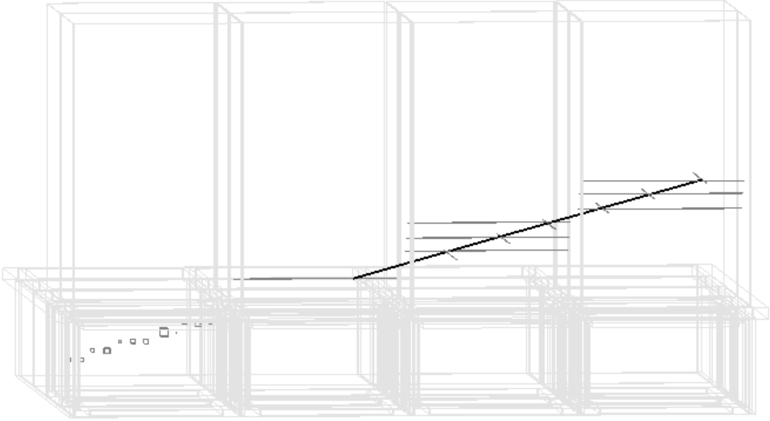

Figure 3. A cosmic-ray muon detected and reconstructed in the 8-tower assembly. This event demonstrates the large field-of-view of the LAT.

An automated pipeline has been developed which allows us to simulate and/or analyze large numbers of events with minimal manual intervention. All the data taken during cosmic-ray testing of the apparatus has been put through this pipeline, which ultimately will be connected to GLAST's publicly accessible data archive.

8.2. *Science Tools*

The science tools operate on the output of GLEAM processing, namely, lists of photons with origins, energies, and times. The data will be stored in HEASARC[10] in FITS[10] format, and will be examined and manipulated with a series of FTOOLs[10] specific to this mission, but using standard interfaces. In a typical analysis, data will be downloaded from the archive, count and exposure maps will be produced according to the criteria for that analysis, and, for example, sources will be identified and characterized, by using a succession of science tools. The results might be combined with information from other experiments using such high-level tools as Xspec[10], from the Xanadu[10] suite.

8.3. *Data Challenges*

An important strategy for preparing the software for flight is a series of data challenges. These consist of end-to-end trials of the software, from simulation to science results. They are designed to provide real deadlines for code projects, to help us learn what works and what needs improvement, to foster teamwork and communication among developers, and to involve new users across the collaboration. There are three progressively more elaborate data challenges in the series: one has already taken place, the second is in the planning stage.

The first, DC1, had modest goals: we produced one day of simulated all-sky survey data with no background, which contained some simple physics and a few surprises. The second, DC2, will take place in early 2006. It will include one month of simulated data (including the South-Atlantic Anomaly), a rich background, variable sources, and integration of data from the GBM. The instrument response will include effects such as dead channels and finite buffer sizes. DC3, in 2007, will be a simulation of full flight-science production.

Soon after DC3, we will embark on the *real* data challenge: the launch of GLAST is scheduled for August 2007, which will mark the beginning of a fruitful five- to ten-year mission.

Acknowledgments

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