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The Large Area Gamma-Ray Telescope for GLAST Observatory

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The Large Area Telescope (LAT) is currently being integrated for launch in 2007 as the main instrument on the Gamma-ray Large-Area Space Telescope (GLAST) observatory. It will continue and develop further the study of high-energy cosmic gamma radiation started by EGRET in 1991-2000, in the extended energy range from 20 MeV to 500 GeV. LAT will have high angular and energy resolution, large effective area and field of view, and effective charged particle background rejection. It consists of three detector subsystems: a silicon-strip Tracker interleaved with tungsten pair conversion layers, a CsI hodoscopic Calorimeter, and a plastic scintillator Anticoincidence array, all served by a powerful data acquisition system. The main LAT scientific objectives are the study of active galactic nuclei (AGNs), pulsars, diffuse gamma radiation, EGRET unidentified gamma-ray sources, gamma-ray bursts, and probing of the cosmic dark matter. Here we describe the main components of the LAT, its scientific objectives, and the current status of its development.

1. Introduction

The Large Area Telescope [1] of the GLAST Observatory will study the cosmic gamma-radiation in the energy range 20 MeV – 500 GeV. LAT is being developed by an international collaboration (USA-France-Italy-Japan-Sweden), and is scheduled for launch in 2007. Its predecessor, the Energetic Gamma Ray Experiment Telescope (EGRET), operated in orbit from 1991 to 2000. EGRET made the first complete survey of the sky in the energy range 30 MeV – >10 GeV [2], did extensive observations on active galactic nuclei (AGNs), pulsars, and diffuse gamma radiation, and discovered many sources of gamma radiation that are unidentified so far. LAT has superior performance compared to EGRET - 5 times larger effective area, better angular and energy 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.
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 AGN, supernova remnants (SNR), and pulsars, and of course to resolve the puzzle of unidentified gamma-ray sources remaining from the EGRET era. LAT will increase the number of known AGNs from ~70 to several thousand and will study their variability; it will discover up to several hundred gamma-ray pulsars. Detailed study of SNR will provide unique information about cosmic ray origin and acceleration. Exciting results are expected from the study of gamma-ray bursts, the most energetic events in the Universe, especially with the help of the Gamma-Ray Burst Monitor [3], also installed in GLAST. EGRET detected GeV-range photons in a few bursts; LAT has much better capability for studying this phenomenon. It is expected that GLAST will detect 50 - 100 bursts per year. Excellent timing characteristics will allow 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 ray and interstellar matter distribution. Special subjects of LAT observations will be the Sun (following up on EGRET's discovery of high energy gamma-rays in solar flares), and searching for signatures of dark matter that can be revealed in the annihilation of WIMPs. The wide energy range of the LAT provides unique opportunity to overlap with measurements made by ground-based TeV telescopes (CANGAROO, HESS, VERITAS, MILAGRO, MAGIC), which will contribute to multiwavelength measurements of gamma-ray objects (AGN, pulsars, bursts).

2. The basic LAT design

LAT incorporates the heritage of EGRET in its conceptual design as 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 (figure 1). LAT's tracking detector contains 18 layers, each containing silicon strip detectors to read out both x- and y-coordinates. The 18 layers are interleaved with tungsten converters where gamma-ray conversion can occur. The trajectories of the resulting electron and positron are precisely measured and reconstructed. Energies of detected gamma rays are measured by a CsI hodoscope Calorimeter, 8.4 radiation lengths (X_0) deep. The Tracker is covered on the top and sides by the Anticoincidence Detector (ACD). The LAT instrument will have to identify cosmic gamma rays against a background of charged cosmic rays 3-5 orders of magnitude more intense (mainly protons and electrons). The majority of the rejection power against cosmic rays will be provided by ACD. A schematic of LAT is shown in Figure 2.

LAT has a modular structure consisting of a 4×4 array of identical "towers", each comprised of a Tracker and a Calorimeter section, with all towers covered by the ACD. The dimensions of the entire LAT are 1733×1733×970 mm, with a sensitive area of 1492×1492 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 Tracker 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 a Calorimeter. This method of triggering provides the lowest possible energy threshold for gamma-ray detection (~20 MeV) 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 [4], and in a balloon flight [5]. The current understanding of LAT parameters is given in Table 1.

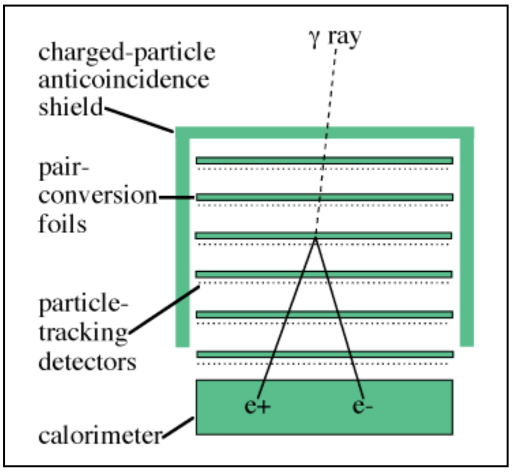

Figure1 Pair-conversion gamma-ray telescope technique

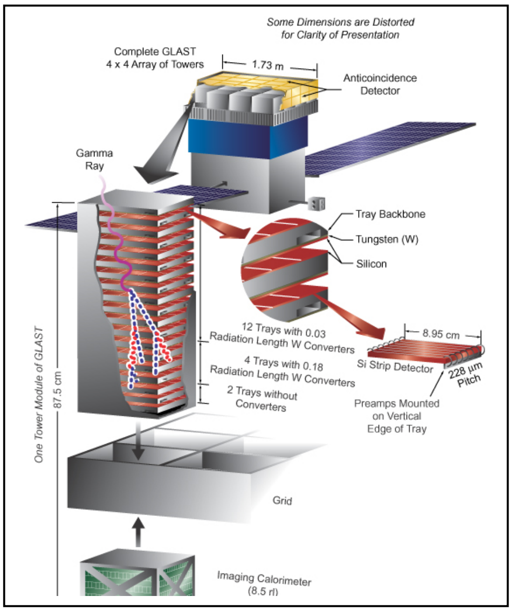

Figure2 Schematic of LAT

Table 1. Principal LAT Performance Parameters

Parameter	**Present Design Value**
Peak Effective Area (in range 1-10 GeV)	10,000 cm^2 at 10 GeV
Energy Resolution at 100 MeV on-axis	9%
Energy Resolution 10-300 GeV on-axis	<15%
Energy Resolution 10-300 GeV off-axis (>60^o)	<4.5%
Point Spread Function 68% at 100 MeV on-axis	3.37° (front), 4.64° (total)
Point Spread Function 68% at 10 GeV on-axis	0.086° (front), 0.115° (total)
Field of View	2.4 sr
Point Source Sensitivity (> 100 MeV)	3×10^{-9} cm^{-2} s^{-1}

3. LAT Subsystems

Tracking Detector: The LAT tracking detector (each of 16 identical towers) consists of 18 double-plane (x and y) single-side silicon strip detectors with carbon fiber structure. Each of the 12 upper layers has a 0.035X_0 tungsten converter, and the next 4 layers have 0.18X_0 converters. Two bottom layers do not have converters. There is ~1.5X_0 of total material in a Tracker, including the converters, silicon-strip detectors, and supporting material. The pitch of silicon strips is 228 µm, with 8.8×10^5 readout channels. 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 (requiring 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.

Calorimeter: The Calorimeter section in 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 at each end. Every photodiode has 2 different gains, so there are 4 overlapping gain ranges in each photodiode to provide wide dynamic range, from 2 MeV to 70 GeV deposited in a single crystal. Mechanical packaging is carbon composite cell structure. The Calorimeter is 8.4X_0 deep. Segmented calorimeter structure provides shower profile reconstruction and thus event pattern recognition, useful for background rejection, and 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), which has to be calibrated. 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 mission.

Anti-Coincidence Detector (ACD): This is the outermost LAT detector, which signals the arrival of charged particle background. ACD creates a veto signal, with overall efficiency of 0.9997, in response to the passage of a charged particle. ACD is an array of 89 independent plastic scintillator tiles. The light from each tile is collected by wavelength-shifting fibers and read out by 2 photomultiplier tubes (for redundancy). 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), to detect any particles which sneak 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, ACD must have low sensitivity to backsplash particles (mostly low energy photons), which escape upward from the Calorimeter when electromagnetic shower are created by gamma–rays above several GeV. Backsplash can create signals in the ACD and, in the absence of mitigation, veto a valid gamma-ray event, dramatically reducing sensitivity above ~10 GeV (self-veto effect). The segmented ACD solves this problem by considering the hit only in the tile crossed by the reconstructed particle trajectory. The requirements of high detection efficiency for charged particles and low sensitivity to backsplash are in conflict, and required careful ACD design optimization. More detailed information about LAT ACD is given in separate paper in these Proceedings [6].

Data Acquisition System and Triggering: This system provides data collection and processing from all detectors. The Level 1 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) by the energy deposition in a Calorimeter above some programmable threshold (>100 MeV in one crystal). The LAT average L1T trigger rate over an orbit is expected to be ~4 kHz, with the maximum up to 12 kHz. Using the ACD veto in the L1T reduces the orbit average rate to ~ 1kHz. The single event dead time is about 26 μs. During onboard processing this rate is reduced to fit the downlink rate, 300-400 Hz.

4. Current Status of LAT

As of June 2005, LAT is in Integration and Testing at SLAC. All LAT components are basically ready for integration into LAT. Figure 3 shows LAT in the process of integration, with 6 towers installed and tested. The aluminum cylinders are mass simulators, to be replaced by the remaining towers . Completion of LAT integration and testing is expected in early 2006, followed by environmental testing.

Figure3 LAT Integration in process (as of June 2005)

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