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GLAST Large Area Telescope: Design and Science Prospects

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Abstract: The Gamma ray Large Area Space Telescope (GLAST) is the next-generation high energy γ-ray astronomy mission, scheduled for launch in early 2008, for a duration of at least 5 years. The observatory comprises two instruments. The Large Area Telescope (LAT) will survey the sky in the energy range from 20 MeV to $>$ 300 GeV, while the GLAST Burst Monitor (GBM) will monitor γ-ray bursts and other transients in the 10 keV to 25 MeV range. The unprecedentedly-large etendue ($>$ 2 m^2 sr) and an earth-avoiding observing mode will permit the LAT to survey the entire sky many times per day and within its first few weeks the LAT will collect more GeV photons than have been detected by all other γ-ray missions. This capability together with superior angular resolution and short dead time per event will permit the LAT to make great advances in high-energy astrophysics. The scope of LAT science will be extraordinarily broad, extending from lunar albedo to γ-ray bursts at large redshift.

The overall GLAST mission will be describe elsewhere [1]. This contribution focuses on the design, performance, operations and scientific prospects of the LAT.

Introduction

The EGRET instrument onboard CGRO, active from 1991 to 1999, revolutionized the field of high-energy γ-ray astrophysics[2]. Despite its rich harvest of results, EGRET was limited by its sensitivity, source localization capabilities, and deadtime. Following on EGRET's legacy, the main instrument on GLAST, the Large Area Telescope (LAT), has been designed to address these issues, and as a result promises to deepen and broaden our understanding of the γ-ray sky. After a description of the design of the LAT, this contribution will review its status, performance and operational plans, and give a brief summary of the main scientific questions that GLAST will address.

The Large Area Telescope

The LAT has been developed by an international collaboration of particle physicists and astrophysicists. It is a pair conversion telescope: high-energy γ-ray photons convert (preferentially) into an electron-positron pair in one of 16 tungsten foils, and the charged particles' trajectories

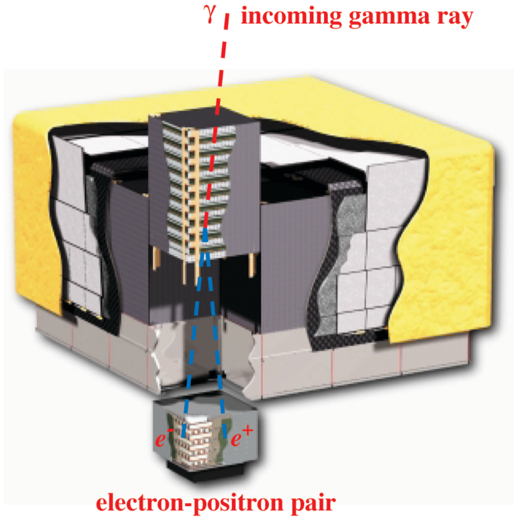

Figure 1: Schematic diagram of the LAT, showing and exploded view of one module of the tracker and of the calorimeter. The segmented anticoincidence detector can also be seen. The LAT is covered by a thermal blancket and micrometeoroid shield, shown here in yellow. The approximate dimensions are 1.8 × 1.8 × 0.75 m.

are subsequently detected in stacked layers of position-sensitive detectors interleaved with the tungsten. An electromagnetic calorimeter underneath the tracker furnishes the energy measurement of the initial γ-ray. Finally, an anticoincidence detector surrounding the tracker is used to veto charged cosmic-ray events A cutaway drawing of the LAT is shown in Fig. 1. In order to meet the challenges of a space mission, the LAT has been designed with detector technologies that were chosen based on an extensive history of application in space-science and high-energy physics, with demonstrated high reliability and no use of consumables, such as gas. In order to ensure scalability and to suppress single-point failures, the LAT is built as an array of 4×4 independent towers, each tower consisting of one tracker and one calorimeter module. Upon triggering, the data acquisition electronics initiates the read out of these three subsystems and utilizes on-board event processing to reduce the rate of events transmitted to the ground to a rate compatible with the downlink available to the LAT (1.2 Mbps, orbit-average). The on-board processing is optimized for rejecting events triggered by cosmic-ray background particles while maximizing the number of events triggered by γ-rays that are transmitted to the ground. Heat produced by the tracker, calorimeter, and DAQ electronics is conducted outward to radiators through constant-conductance heat pipes in the Grid.

The LAT converter-tracker (TKR)

The tracker is the heart of the LAT instrument, being responsible for converting γ-rays, providing the main trigger primitive of the instrument, and measuring the direction of each photon[3]. Each tracker module is an array of 18 trays (see Fig. 2), made of a stiff, lightweight carbon-composite panel with silicon-strip detectors (SSDs) bonded on both sides, the strips on top running parallell to those on the bottom and measuring only one direction, x or y. Also bonded to the bottom surface of all but the 3 lowest trays, between the panel and the detectors, is an array of tungsten foils, one to match the active area of each detector wafer. Each tray is rotated 90° with respect to the one above or below. The detectors on the bottom of a tray combine with those on the top of the tray below to form a 90° stereo pair with a 2 mm gap between them, and with the tungsten converter foils located just above, so that the trajectories of the primary charged tracks are recorded as close as possible to the conversion point, in order to minimize the impact of multiple scattering. The SSDs are AC-coupled, 400 μm thick, 228 μm pitch single-sided wafers, bonded with epoxy in series of four detectors to form ladders of 384 36 cm long microstrips. Four ladders are assembled into one layer, readout by a single multichip module, equipped with 24 FE ASICs for signal amplification and shaping, and 2 redundant controller chips for 0-suppression and data transmission. Such boards are located on the sides of each tray to minimize the dead area between adjacent towers (2mm clearance).

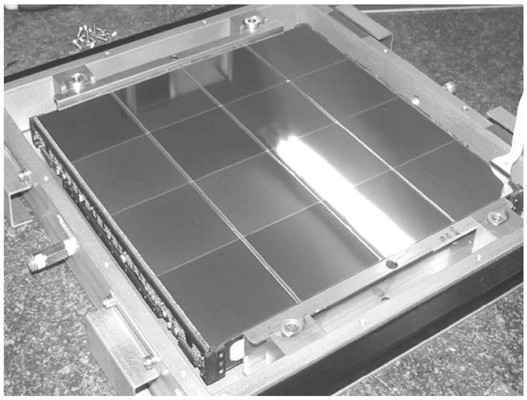

Figure 2: Picture of a tray, with the array of SSDs visible on top. One of the two acquisition boards can be seen on the left of the tray.

The high intrinsic efficiency and reliability of this technology enables straightforward event reconstruction and an excellent point spread function (PSF) with small tails.

The LAT hodoscopic calorimeter (CAL)

Each calorimeter module has 96 CsI(Tl) crystals, optically isolated from each other and arranged horizontally in 8 layers of 12 crystals each. The total depth of the calorimeter is 8.6 radiation lengths (for a total instrument depth of 10.1 radiation lengths). Each layer is rotated by 90° with respect to its neighbors, forming an x,y (hodoscopic) array (see Fig. 3). This segmentation allows accurate corrections at high energies for the part of the shower not contained in the CAL. In conjunction with a readout on both sides of each log, the hodoscopy also improves the reconstruction of the shower direction: the position resolution ranges from a few millimeters for low energy depositions ($\sim$10 MeV) to a fraction of a millimeter for large energy depositions ($>$ 1 GeV). The calorimeters shower imaging capability and depth enable the LAT's high-energy reach up to 1TeV and contribute significantly to background rejection.

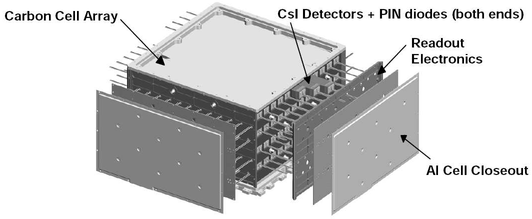

Figure 3: Schematics of a calorimeter module.

The LAT anti-coincidence detector (ACD)

In order to ensure high efficiency for charged particle detection, adequate tolerance to backsplash, and reliability, the ACD has been designed as follows [4]: plastic scintillators are segmented into tiles, each read out with two redundant wavelength shifting fibers. The tiles are overlapping in one direction and covered by flexible scintillating fiber ribbons in the other direction, in order to provide complete coverage of the tracker modules. The ACD comprises a total of 89 tiles of various sizes, covering the top of the TKR and arranged in rows on its sides. The overall ACD efficiency for detection of singly charged relativistic particles incident on the TKR exceeds the required 0.9997.

LAT operations

Operations support and science data processing for the LAT will be provided by the Instrument Science Operations Center (ISOC) at the Stanford Linear Accelerator Center (SLAC). The LAT ISOC will produce and deliver processed LAT data to the GLAST Science Support Center for distribution to the scientific community. The LAT data products which will be released in the first year of operations are described in http://glast.gsfc.nasa.gov/ssc/data/policy/LAT_Year_1_Data_Release.html. Within the LAT ISOC, Automated Science Processing (ASP) will be performed as soon as the data are available, for time critical science analyses: GRB detection and follow up, and flaring source monitoring and detection.

Figure 4: The ACD assembled and ready for integration to the LAT.

LAT performance and science

The science performance of the LAT is governed primarily by three factors: LAT hardware design, event reconstruction algorithms, and background and event quality selections. Thus, although the hardware integration and testing are now complete, as the event selection algorithms continue to be optimized the performance will be updated. A summary of the latest performance estimates are shown in Fig. 5[1].

Virtually all areas of current high-energy astrophysical research will be revisited with the new

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[1] Further information and future updates can be found in http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

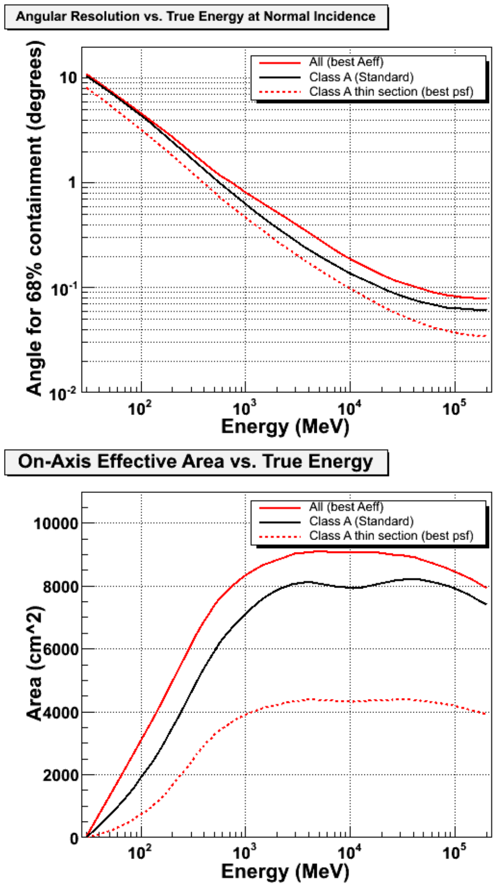

Figure 5: Angular resolution (top), and total effective area (bottom), as currently estimated by the LAT team. The 'Class A' results from an analysis aimed at the extragalactic diffuse γ-ray flux measurement, most challenging for background rejection.

data that the LAT will gather [5]. With its wide field of view ($\sim$ 2.4 sr) and its sensitivity improved by a factor of $\sim$ 30 compared to EGRET, the LAT will be able, in a matter of days, to reproduce the EGRET final catalog and, within a year, the number of detected sources should greatly excess a thousand. The most common sources will undoubtedly be blazars, for which the LAT will be able to provide time resolved spectra and detailed population studies. The LAT should also detect known Galactic sources and discover many new ones, especially pulsars, young supernova remnants, and micro-quasars. Refining our understanding of the Galactic and extragalactic diffuse γ-ray emission is also a key objective for the mission. Moreover, GLAST with its two instruments will completely renew our understanding of γ-ray bursts, characterizing especially their behavior at high-energy. Finally, the LAT will open a new window in astro-particle physics, with the indirect searches for WIMP annihilation signals, the study of the extra-galactic background light, and more speculatively the possibility to constrain unification models that predict violation of Lorentz invariance.

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