The Large Area Telescope of the Gamma-ray Large Area Space Telescope Mission

The GLAST LAT Collaboration

Abstract The Gamma-ray Large Area Space Telescope, GLAST, is a mission to measure the cosmic gamma-ray flux in the energy range 20 MeV to >300 GeV, with supporting measurements for gamma-ray bursts from 10 keV to 25 MeV. With its launch in late 2007, GLAST will open a new and important window on a wide variety of high- energy phenomena, including black holes and active galactic nuclei, gamma-ray bursts, the origin of cosmic rays and supernova remnants, and searches for hypothetical new phenomena such as supersymmetric dark-matter annihilation, Lorentz-invariance violation, and exotic relics from the Big Bang. The Large Area Telescope (LAT), which provides the measurements of high-energy photons, consists of a pair-conversion tracker, a hodoscopic crystal calorimeter, a segmented plastic-scintillator anticoincidence shield, and a flexible trigger and data-flow system. The LAT design is described, along with the expected science performance and detailed simulations of particle interactions, event reconstruction, and classification of events on which the performance analysis is based.

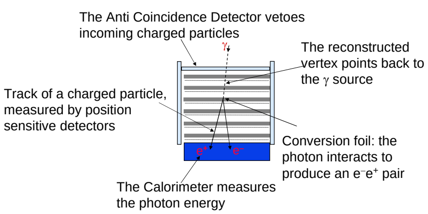
GeV Gamma-Ray Astrophysics

The high-energy γ-ray (30 MeV – 100 GeV) sky has been relatively poorly studied. Most of our current knowledge comes from observations made by the EGRET detector on CGRO, which revealed that the GeV γ-ray sky is rich and vibrant. It found that the luminosities of many blazars and some pulsars peak in this energy band, that the spectra of γ-ray bursts extend to at least GeV energies, and that intense γ-rays flares are a common feature of blazars.

There are several important motivations for studying non-thermal sources at GeV energies: The high-energy γ-rays are often produced by a different physical process than the better studied X-ray and optical emission, thus providing unique information for understanding these sources. Production of such high-energy photons requires that charged particles are accelerated to equally high energies, or much higher. Thus γ-ray astronomy is the study of extreme environments. The connections to cosmic-ray and neutrino astrophysics are natural and fundamental.

Pair-Conversion Technique

At these energies γ-rays are detected using the pair-conversion technique, outlined in the figure below. A tracker, calorimeter, and anticoincidence shield work together to measure the energies and directions of incoming γ-rays.

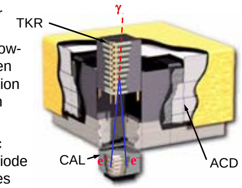


The angular resolution of a pair-conversion telescope is strongly affected by the design of the tracker. At the highest energies the resolution is limited by the position resolution of the detectors and the depth of the tracker. At moderate-to-low energies it is limited by multiple scattering (many thin layers are better than a few thick ones). The calorimeter should be thick to ensure good energy resolution up to high energies. The anticoincidence detector must have high efficiency for rejecting charged particles without introducing a large self veto from γ-ray showers in the Calorimeter.

The LAT utilizes modern technology and lessons learned from previous instruments to improve each of the major components, resulting in a pair-conversion telescope with much higher performance. The design is modular, with 16 towers arranged in a 4×4 pattern, each consisting of a Tracker, Calorimeter, and an electronics module. The 16 towers are covered by a segmented anticoincidence detector (ACD) to minimize self veto. The segmentation is such that the ACD tiles overlap the tower gaps.

Design of the LAT Subsystems

- Tracker (TKR): Si-strip detector stacks with superb position resolution and efficiency, with low-power readout. Multiple tungsten foils allow good angular resolution while providing high conversion efficiency. 1.5 X_0 total.
- Calorimeter (CAL): Hodoscopic array of CsI crystals with PIN-diode readout. Segmentation provides shower imaging for improved energy reconstruction and background rejection. 8.4 X_0 total at normal incidence.



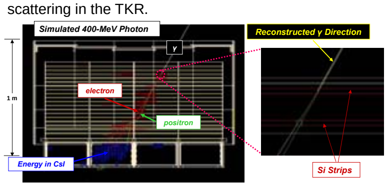
This cutaway diagram of the LAT shows the ACD, Tracker, and Calorimeter. The dimensions of the LAT are approx. 1.8×1.8×0.75 m.

- Anti-Coincidence Detector (ACD): Plastic scintillator array for high charged-particle efficiency and minimal self-veto of γ-ray showers (which limited EGRET at high energy).
- Electronics, DAQ, Trigger: Process and filter events from the LAT. Perform on-board searches for gamma-ray bursts.

Simulation and Reconstruction

A C++ framework (Gaudi) integrates into one configurable application all processing steps for event simulation and analysis:

- Generating the incident particle (cosmic ray or γ-ray). This is driven by an XML description of a source. Multiple sources can be used simultaneously.
- Following interactions of the particle and its daughters is accomplished using the GEANT4 particle interaction code, a standard in high-energy physics experiments. A detailed geometry and material description of the LAT was implemented.
- Converting energy depositions into simulated digitized detector signals to produce 'flight-like' data.
- Applying reconstruction algorithms (track finding and fitting) to determine the incident direction and energy, including pattern recognition to identify tracks and a Kalman-filter fitting algorithm. The fitting is iterative because it requires estimates of the event energy, which are derived from corrected CAL data plus the scattering in the TKR.



- Applying classification algorithms to determine the particle type and event 'quality'. The classification must be robust; only ~10^{-3} of the triggers on orbit will be celestial γ-rays.

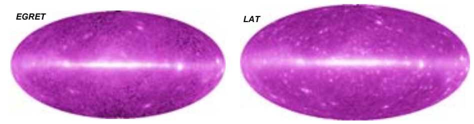
Simulations of the LAT have been verified with accelerator beam tests and a balloon flight of prototype hardware.

Instrument Performance

	LAT	EGRET
Energy Range	20 MeV – >300 GeV	20 MeV – 30 GeV
Peak Effective Area	9000 cm^2	1500 cm^2
Angular Resolution @ 10 GeV	0.1°	0.5°
Energy Resolution (on-axis, 100 MeV– 10 GeV)	<10%	10%
Field of View	2.4 sr	0.5 sr
Deadtime per Event	27 µs	100 ms

Sensitivity

The improved angular resolution, effective area and field of view of the LAT result in greatly improved source sensitivity, <6×10^{-9} cm^{-2}s^{-1} (c.f. 1×10^{-7} for EGRET), resulting in a remarkably deep and sharp view of the GeV γ-ray sky. This is illustrated below, where are shown for E>100 MeV the EGRET sky map compiled over several years (left) and a comparable one year LAT simulation (right).

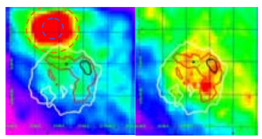


Observations with the LAT will expand the GeV γ-ray source catalog by at least an order of magnitude. This will transform our understanding of GeV astrophysics by allowing us to distinguish generic features of sources and underlying acceleration mechanisms from specific features of individual objects.

Spatial Resolution

The superior angular resolution and statistics provided by the LAT will permit many advances for studies of diffuse sources. Image deconvolution plays an important role in resolving the structure of diffuse sources.

Simulation of RX J1713-3946 before (left) and after de-convolution and source removal (right) illustrating the ability of the LAT to resolve the SNR from a nearby EGRET source for E > 700 MeV. The EGRET and LAT 68% PSF are shown by dashed contours. The solid contours indicate the original simulated image.



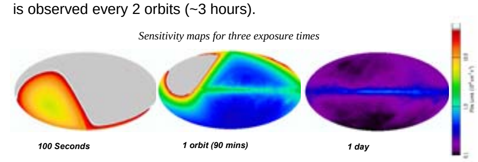
Energy Range and Discovery potential

The LAT sensitivity extends to higher energies than that of any previous space-based gamma-ray mission, opening the unexplored energy range above 30 GeV. The energy range of the LAT will overlap those of the next generation ground-based TeV gamma-ray instruments now coming on line, and inter-calibration should be possible.

Field of View and Transient Monitoring

The field of view of the LAT covers ~20% of the sky at any instant, and up to 75% of the sky every orbit. In scanning mode the entire sky is observed every 2 orbits (~3 hours).

Sensitivity maps for three exposure times



LAT Hardware Status and Schedule

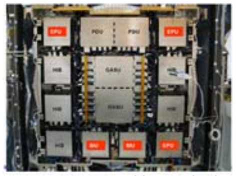
Integration and testing of the LAT is complete, and the LAT has been delivered and integrated to the GLAST spacecraft. The satellite will soon be starting the final environmental testing. In early Fall the satellite will be shipped to Cape Canaveral for integration with a "Delta II Heavy" rocket, for an expected launch near the end of the year.

The 4x4 Grid provides mechanical support and thermal control for the detector array. CAL Modules are inserted into each bay, while TKR Modules mount to the upper edge of each bay.

A single TKR Module being lowered onto the Grid, next to two TKRs that have already been installed. Empty Grid bays are filled with mass dummies.

A CAL Module being prepared for insertion into the Grid. The CAL and Grid are inverted for this operation.

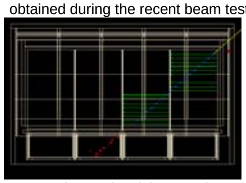
The LAT fully populated with TKRs (visible) and CALs, prior to installation of the ACD.



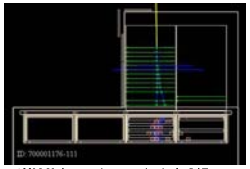
Data acquisition system modules mounted on the back of the LAT. The SIUs & EPU are RAD 750s, used to interface with the spacecraft and to filter events. Other boxes provide triggering, event formatting, etc.

The LAT undergoing environmental testing at the Naval Research Laboratory.

Functional tests and instrument calibration have been carried out in various stages, starting after integration of the first CAL and TKR and continuing to the fully integrated LAT. Two sample events are shown below: a muon in the full LAT at SLAC and a photon pair-conversion obtained during the recent beam test at CERN.



A muon track passing through the integrated LAT (in a YZ projection). Green crosses are hits in TKR. Red squares are hits in CAL. The yellow line denotes the incident muon direction as reconstructed from TKR hits.



100MeV photon pair conversion in the LAT Calibration Unit (CU). The CU was made of 2 complete flight-spare towers and a third calorimeter and was tested at CERN. These beam-test data are being used to fine-tune the full LAT MC simulation.

Collaborating Institutions

The LAT is managed at Stanford Linear Accelerator Center (SLAC); the PI is Peter Michelson (Stanford)

NASA Goddard Space Flight Center
Naval Research Laboratory
Ohio State University
Sonoma State University
University of California at Santa Cruz
Stanford University
Hansen Experimental Physics Lab
Stanford Linear Accelerator Center
Texas A&M University - Kingsville
University of Washington

Istituto di Fisica Cosmica, CNR (Milan)
Italian Space Agency (ASI)
Istituto Nazionale di Fisica Nucleare (INFN)
Bari, Padova, Perugia, Pisa, Rome, Trieste, Udine

Hiroshima University
Institute for Space and Astronautical Science
RIKEN
University of Tokyo
Tokyo Institute of Technology

Institut National de Physique Nucleaire et de Physique des Particules (IN2P3)
LLR, Bordeaux, Montpellier
Commissariat a l'Energie Atomique (CEA), Saclay

Royal Institute of Technology (KTH)
Stockholm University