The GLAST Large Area Telescope Instrument

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The LAT instrument on the Gamma-ray Large Area Space Telescope (GLAST) project is a gamma-ray pair-conversion telescope designed to improve upon the sensitivity of the Compton Gamma-Ray Observatory EGRET instrument by at least a factor of 30. The LAT design is based upon a silicon-strip tracker/converter, a CsI calorimeter, and a plastic-scintillator anticoincidence shield. The project is approaching its critical design review and is scheduled for launch in 2006. This talk gives an overview of the LAT science objectives, the LAT design, and the status of the engineering effort and instrument production plans.

1. INTRODUCTION

NASA's EGRET experiment on the Compton Gamma-Ray Observatory revolutionized the field of gamma-ray astronomy [1]. It was the first instrument with the effective area and background rejection necessary to detect and observe a large number of galactic and extragalactic gamma-ray sources. Such sources have an inherent interest to astrophysicists and particle physicists studying high-energy, nonthermal processes. Telescopes capable of studying emission of the highest energy gamma rays play an important role in completing the broad, multi-wavelength-band coverage that is crucial to progress in modern astrophysics.

The success of EGRET and the questions raised by its discoveries demand a follow-on mission with greatly expanded capabilities. The NASA/DOE GLAST mission includes two instruments: the Large Area Telescope (LAT) and a Gamma-ray Burst Monitor (GBM). The LAT is designed to improve upon the sensitivity of EGRET by a factor of 30 at 100 MeV and by even more at higher energies, including the largely unexplored 30–300 GeV band. It is being designed and built by a multinational collaboration, including scientists and engineers from France, Italy, Japan, Sweden, and the United States. The launch is scheduled for 2006, followed by an operational period of at least five years.

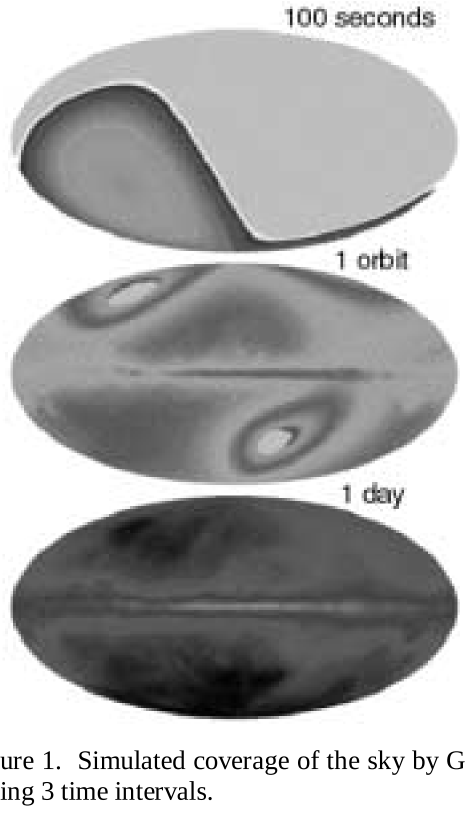

Figure 1. Simulated coverage of the sky by GLAST during 3 time intervals.

2. GLAST SCIENCE CAPABILITIES

The scientific program of GLAST will follow closely along the lines of those subjects studied by EGRET. The large increase in sensitivity of GLAST with respect to EGRET raises the distinct possibility of discoveries of new phenomena and new types of gamma-ray sources. In fact, this is characteristic of all previous high-energy gamma-ray missions and is one of the most exciting aspects of the GLAST mission.

The third EGRET catalog of point sources contains 271 point-like sources, of which 172 are as yet unidentified [2]. Those that are identified with known objects fall into only a few classes, most notably active galactic nuclei (AGN) at high galactic latitudes and pulsars within the plane of the galaxy. During its first years of operation, the LAT is expected to produce a catalog of around 10,000 sources, including several thousand AGN, while operating primarily in a zenith-pointed, scanning mode. In addition, rapid alerts will be produced for transients such as gamma-ray bursts and AGN flares with latencies as small as 12 seconds.

The large LAT effective area of about 1 m^2 coupled with its large field of view of about 2.4 sr are key to its capability for observing transient behavior. Figure 1 shows that within 100 s the LAT can observe bright pulsars and AGN flares. In one orbit it sees the entire sky, except for the orbit poles. In just a day or two, with some rocking motion toward the orbit poles, the LAT can detect all of the EGRET catalog sources with at least 5σ significance.

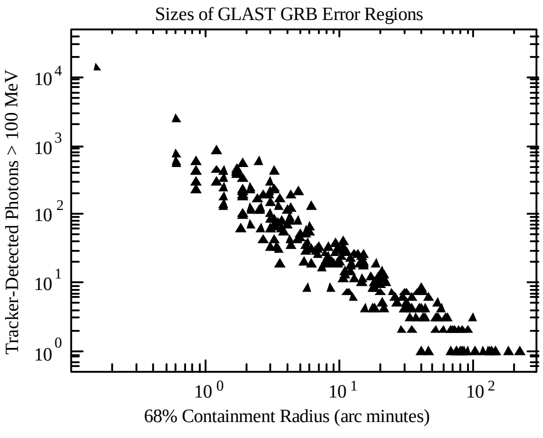

Figure 2. Results of a simulation of LAT source-location accuracy for gamma-ray burst detections, assuming a spectral index of 2.

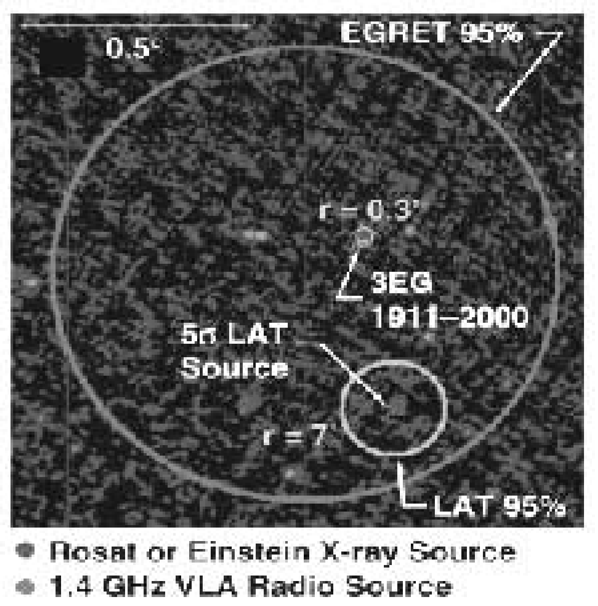

Figure 3. A comparison of EGRET and GLAST point-source localization.

The wide field of view will allow the LAT to observe far more high-energy gamma-ray bursts than the handful seen so far by EGRET. We expect to detect one to two hundred bursts per year with photon energies above 100 MeV, and about one third of those will be localized better than 10 arc minutes in real time (see Figure 2). The brightest bursts will be localized to as good as 1 arc minute, allowing the possibility of couterpart detection from the ground. By using the GBM as a trigger, even bursts with just a single 100 MeV photon in the LAT can be recorded. In addition, with its dead time of only tens of microseconds, GLAST will be able to measure nearly all high-energy photons within the most intense part of a burst, which often has a pulse width that is comparable to the EGRET 100 ms dead time.

With a sample of upwards of 5000 AGN distributed across the sky, the typical angle between adjacent sources will be only about 3°. Hence source confusion will be an important issue for GLAST, even out of the crowded galactic plane. This is especially true for photons below 100 MeV, where the achievable resolution of about 3° is inherently limited by multiple scattering in the converter material. For that reason, the LAT design is optimized for detection and measurement of GeV photons, with a single-photon angular resolution of better than 0.1° at 10 GeV. In fact, for a typical source with a $1/E^2$ flux energy dependence, most of the power for source detection and localization comes from GeV photons. Figure 3 demonstrates the LAT source localization capability. Even a source at the 5σ detection threshold will be localized by GLAST to within 7 arc minutes at 95% confidence.

In addition to their intrinsic interest as regions of high-energy particle acceleration, AGN are also interesting as distant sources of gamma rays that can be used as cosmological probes. Observations of cutoffs in the spectra of gamma rays from many distant sources can be used to infer the amount of extragalactic background light (EBL). This work will require collaboration between GLAST and ground-based atmospheric Cherenkov telescopes, as sensitivity to EBL infrared photons requires observations of cutoffs in the TeV range. Cutoffs seen in GLAST data will be sensitive to the flux of EBL ultraviolet photons. GLAST will also contribute the large statistical power needed to look for a systematic redshift dependence out to large distance, in order to validate models and to differentiate between intrinsic source effects versus interaction with EBL. Source localization and other means of source identification, such as observation of transient behavior, will be essential for obtaining the necessary redshift measurements.

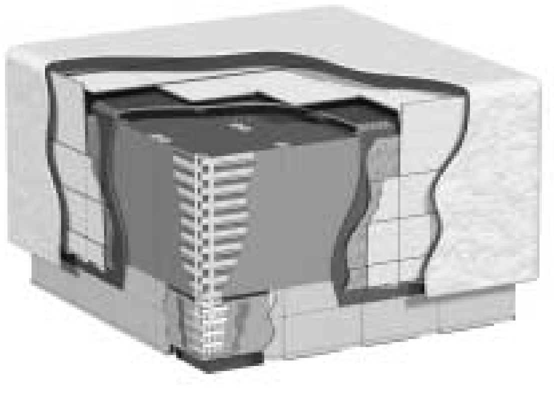

Figure 4. Cutaway view of the GLAST instrument, composed of a 4×4 array of tower modules surrounded by a veto shield and thermal blanket.

3. LAT DESIGN

Figure 4 shows a cutaway view of the LAT instrument design. There are three detector subsystems:

1. The Anti-Coincidence Detector (ACD) system consists of 89 plastic scintillator tiles read out by waveshifting fibers and photomultiplier tubes. It is required to be hermetic, with 99.97% efficiency for minimum-ionizing particles, but it must also be highly segmented, to avoid the self-veto problem that greatly reduced the high-energy effective area of EGRET. The tiles overlap in one dimension, and a scintillating fiber ribbon covers the gap in the other dimension. During operation, cosmic rays are vetoed only if there is a measured track that extrapolates back to a hit tile. One main technical challenge for the ACD design has been to obtain the necessary segmentation within budgets while preserving the high detection efficiency required. Another is to support the large structure against launch loads with minimal extraneous material and mass.
2. The Tracker/Converter system consists of 16 modules, each with 18 x,y planes of silicon-strip detectors. A tungsten foil of 3% radiation length is supported in front of each of the first 12 x,y planes, and a foil of 18% radiation length is in front of each of the following 4 x,y planes. The layout minimizes the lever arm for multiple scattering degradation of the resolution by localizing the position measurements close to the tungsten foils and by ensuring high efficiency for measurement of the first two points following the conversion. The 228-micron strip pitch ensures good two-track separation for event reconstruction and excellent angular resolution of high-energy conversions. The main technological challenge has been to read out the 36-cm long strips with less than 210 microwatts of power per channel while maintaining a noise occupancy low enough to allow self triggering. Other challenges are to build a low-mass, stiff carbon-composite support structure, to obtain large (8.95 cm square) SSDs with high reliability and affordable price, and to package the readout electronics while leaving minimal gaps between modules.
3. The Calorimeter also consists of 16 modules, each with 8 layers of CsI crystals read out by PIN

diodes, for a total thickness of 8.4 radiation lengths (the tracker brings the total to 10 radiation lengths). The crystals are horizontal bars, each with diodes at both ends to provide a longitudinal position measurement. The alternating layers are crossed to ensure a three-dimensional reconstruction of each shower. This fine segmentation is important for background rejection, and the longitudinal shower profile provides a means of correcting for shower leakage. The main challenges in the Calorimeter design have been to produce a readout that can handle the very large dynamic range needed while delivering good energy resolution (<10%) and to design a structure that can support the large mass during launch while also allowing for the large thermal expansion coefficient of the crystals.

In addition to the detector subsystems, there is an aluminum "grid" onto which everything mounts, a cooling and thermal control system, a thermal blanket, a trigger system, and an electronic data-acquisition and control system. Each of the 16 tracker/calorimeter "towers" has a tower electronics module (TEM), including data acquisition and trigger electronics plus power supplies, mounted just below the calorimeter. In addition, there is a global trigger module, including the ACD veto electronics, 5 event-processing modules, a spacecraft interface module, and a power distribution unit.

The LAT detector system has large in-flight data processing demands compared with previous space-based experiments. The level-one trigger rate of several kHz must be reduced to a rate of a few tens of Hz to downlink. This is done in two steps. The level-two trigger software crudely finds tracks in the tracker data and extrapolates them to look for an ACD match, in order to veto cosmic-rays. The level-three trigger software running in 4 event processors (the 5th is a spare) does a nearly complete reconstruction of each event and applies a variety of cuts to filter out earth-albedo gamma rays as well as most of the remaining cosmic-ray background.

4. LAT PROTOTYPE TESTS

The LAT design began 10 years ago with a detailed Monte Carlo simulation model used to prove and optimize the design. Over the intervening years, several beam tests and a balloon flight have been carried out with hardware developed both to validate the simulation model and to test the instrumentation concepts and prototype detector assemblies.

In 1997 a small 12-layer silicon-strip tracker and a CsI calorimeter, surrounded by an ACD, operated in the SLAC tagged-photon test beam and demonstrated that our simulation model reproduced very well the observed point-spread function at all photon energies and for a variety of converter thicknesses and detector-layer spacings [3]. At the end of 1999, the LAT team operated in the same beam the Beam-Test Engineering Model (BTEM), which was essentially a complete LAT tower (tracker and calorimeter modules) and an ACD prototype [4]. The BTEM demonstrated the readout-electronics concept of the tracker, achieving the required low noise and low power performance (210 μW per channel and less than 1 channel in 10,000 noise occupancy), as well as the necessary compact packaging of the electronics and detectors. It also tested the hodoscopic calorimeter concept and measured splashback into the ACD, providing data for sizing the ACD tiles in the final design.

The same BTEM hardware was adapted into a balloon payload for a flight that took place in the summer of 2001 from Palestine, Texas. The instrument performed well throughout the flight, with 4.5 million triggers recorded, at a rate in agreement with Monte Carlo predictions based on known cosmic-ray fluxes. The tracker temperature was stable, even in the low pressure at altitude (2 psi in the chamber holding the instrument), and there was no problem from the large shocks suffered during parachute opening and landing (up to 50 g acceleration measured by onboard accelerometers). The tracker and calorimeter continued to function normally after disassembly of the payload. In particular, there was no damage to the silicon detectors, which were inspected after removing the tracker sidewalls. Publications of cosmic-ray measurements made during the flight are in preparation.

5. LAT STATUS AND PRODUCTION PLANS

The preliminary design review of the LAT instrument was carried out in January of 2002. At present the subsystems are completing their detailed engineering design and preparing "engineering models." For example, the calorimeter engineering model is a complete, functional calorimeter module

(1/16 of the LAT), built to the flight-instrument design, with the intended materials. Similarly, the tracker engineering model is a complete module. However, for reasons of cost, it is being built with dummy detectors and ASICs, made of aluminized silicon. This module is intended only for mechanical and thermal testing, and its electronics will simply produce the correct amount of heat via resistors. Four additional fully instrumented, functional trays are also being built, for system and environmental testing of the electronics.

The engineering models will undergo testing during the autumn of 2002, to produce results in time for critical design reviews (CDR) during the period from January through April of 2003. Procurement of some long-lead-time items is already in progress: CsI crystals for the calorimeter, and silicon-strip detectors and carbon-carbon material for the tracker. Fabrication will immediately follow CDR, and integration of the subsystem modules into the LAT will begin in mid 2004. About a year later the LAT will be integrated into the observatory, which will launch in the third quarter of 2006.

6. CONCLUSIONS

The LAT, with at least a 30-fold improvement in sensitivity over the previous generation high-energy gamma-ray telescope, promises to make large strides in advancing our knowledge and understanding of the astrophysics of high-energy, nonthermal processes occurring around some of the most exotic objects in the universe. This large improvement in sensitivity is achieved by application of modern detector technology, much of it developed in the field of elementary particle physics. However, to implement such a large million-channel detector in a space mission requires not only advanced technology but also a robust design that can be manufactured with good quality control, can survive intact the launch and orbital environment, and can operate reliably for at least 5 years. The LAT design emphasizes modularity and repetition, redundancy, well-developed and proven technologies, and assemblies that are amenable to rapid fabrication by industrial vendors. The design concepts have already been well proven by a series of prototypes, and good progress is being made on the final design and a series of engineering models. We are looking forward to a launch in 2006, followed by many bountiful years of data.

ACKNOWLEDGEMENTS

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