THE GLAST GAMMA RAY LARGE AREA TELESCOPE

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The Gamma-ray Large Area Space Telescope (GLAST) is an international space mission that will study the cosmos in the energy range 10 $KeV - 300\ GeV$, the upper end of which is one of the last poorly observed regions of the celestial electromagnetic spectrum to be explored. GLAST will have an imaging gamma-ray telescope vastly more capable than instruments flown previously. The main instrument, the Large Area Telescope (LAT), will have superior area, angular resolution, field of view, and dead time that together will provide a factor of 60 or more advance in sensitivity, and capability for the study of transient phenomena.

1 Introduction

One of the last bands of the electromagnetic spectrum to be explored for astronomy is the range above 20 MeV. The principal reason for the late start was technological: for energies up to tens of GeV, detectors must be placed in orbit, and even from orbit detection of the low fluxes of celestial gamma rays is difficult.

First came EGRET (Launched in 1991): it made the first complete survey of the sky in the 30 $MeV - 10\ GeV$ range. The main discoveries of this mission were the detection of gammas with energy $> 100\ MeV$ coming from Active Galactic Nuclei (observed more than 60) and the measurement of diffuse gamma ray background to over 10 GeV. But the majority of the sources that shine in the gamma sky don't have a counterpart in low energy: one hundred and seventy sources in the *3rd EGRET* catalog are unidentified. GLAST will enable identification of *EGRET* sources by providing much finer positional error bounds.

EGRET raised many interesting issues and questions which can be addressed by a NASA mid-class mission (Delta II rocket). The GLAST mission was conceived to address important outstanding questions in high-energy astrophysics, many of which were raised but not answered by results from *EGRET*. The main instrument on board the GLAST detector is the Large

Area Telescope (LAT) that is a pair conversion telescope, like *EGRET*, but the detectors will be based on solid-state technology, obviating the need for consumables and greatly decreasing instrument deadtime. In this paper we will describe the development of the LAT detector and we will focus our attention in some scientific topics of interest for GLAST.

2 The Large Area Telescope

The primary interaction of photons with matter in the GLAST energy range is pair conversion. This process forms the basis for the underlying measurement principle by providing an unique signature for gamma rays, which distinguish them from charged particles. The flux of Cosmic rays, in fact, is as much as 10^5 times larger. The pair conversion process permits the determination

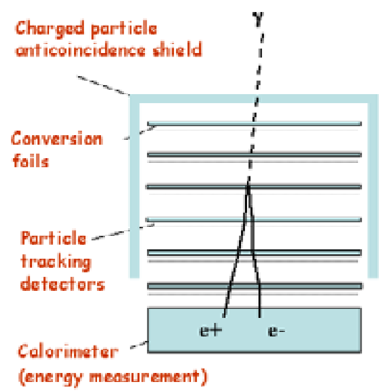

Figure 1. *Principle of photon detection in GLAST.*

of the incident photon directions via the reconstruction of the trajectories of the resulting e^+e^- pairs. This technique is illustrated in Figure 1 in which the incident radiation first passes through an anticoincidence shield, which is sensitive to charged particles, then through thin layers of high-Z (tungsten) material called *conversion foils*. The photon converts in these layers producing an electron-positron pair. The trajectories of these charged particles are measured by the tracking detectors, and their energies are then measured by a calorimeter. *GLAST* was designed to have a low profile to give wide field of view.

The Large Area Telescope (LAT) comprises an array of 16 identical "tower" modules (see Figure 2), each with a tracker (Si strips) and a calorimeter (CsI with PIN diode readout) and DAQ module. The towers are surrounded by a finely segmented ACD (plastic scintillator with PMT readout) while the support structure is an aluminum strong-back "Grid" with heat pipes for transport of heat to the instrument sides. The **Anticoincidence**

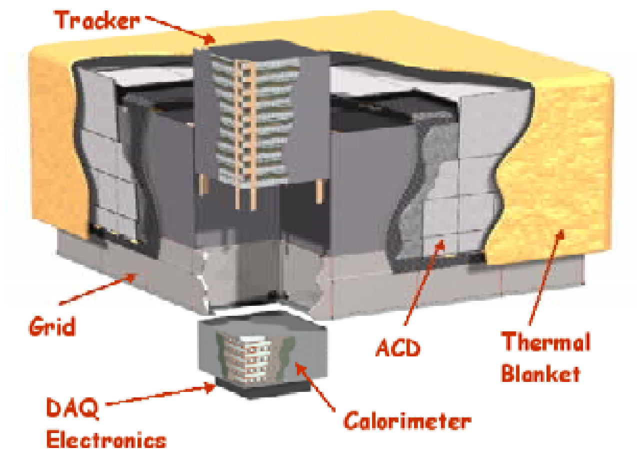

Figure 2. The LAT instrument components

Detector (ACD) has a segmented plastic scintillator to minimize self-veto at high Energy and to enhance the background rejection: the estimated efficiency is greater then 0.9997. The purpose of the ACD is to detect incident charged cosmic ray particles that outnumber cosmic gamma rays by more than 5 orders of magnitude. Signals from the ACD can be used as a trigger veto or can be used later in the data analysis[2].

Each of the 16 **Tracker** tower modules consists of a stack of 19 "tray" structures. Silicon detector wafers cover either side of a tray with the strips on each side running in the same direction. Every other tray is rotated by 90^o, so each W foil is followed immediately by an x, y plane of detectors with a $2mm$ gap between x and y layers. The detectors are located close to the conversion foils to minimize multiple-scattering errors. The bottom tray has a flange to mount on the support grid. The electronics hybrids are glued vertically to the tray sides to minimize the gap between towers. Each silicon plane on a tray has a $37cm \times 37cm$ active cross section, giving a total silicon area of $83m^2$ (comparable with the ATLAS detector planned for the CERN LHC project). In all there are 11500 Silicon Strip Detectors and a total of 1 million channels.

The **Calorimeter** is made of $96CsI$ crystals (thallium doped) per tower arranged into a hodoscopic, imaging configuration and with PIN diode readout on each end. The electronics chain for each PIN diode is composed of a preamplifier which feeds two shaping amplifiers. Discriminators divide the energy domain into four energy ranges, two peak-detecting track and holds. A third faster shaping amplifier, peaking at $0.5\mu s$ is used for fast trigger discrimination. The main features of the calorimeter detector are the large dynamic range ($5{\times}10^5$), low nonlinearity (less than 2%), low power consumption, and minimal dead time (less than $20\mu s$ per event).

The LAT trigger is a 3-level system. Primary requirements are high efficiency for all measurable gamma rays, and background reduction to fit with telemetry capacity. Two separate conditions may initiate a hardware trigger for a given tower (LT1). The first request is for the tracker to have three planes hit in a row. The second involves the calorimeter, considering the number of hits in the module. Tower triggers are ORd in the central ACD-TEM and fanned out to each tower. The ACD information is optionally used to reduce LT1 rate ("controlled mode"). The second level trigger (LT2) is a tower-based trigger, in parallel for all towers. It uses a fast track finding algorithm and extrapolates track candidates to the ACD tiles to search for vetoes. The veto is not applied to events with large energy deposits in CAL. LT3 is a full instrument event reconstruction trigger. The main features of the three level trigger are summarised in Table 1. Albedo photon events are removed by comparing the reconstructed photon direction with that of the Earth's horizon. The cosmic ray event rate is reduced to less than 15 Hz.

Level	Type	Location	Components	Function	Pk Rate	Avg. Rate
L1: initiate readout of the detectors.	Hard-ware	OR of independent triggers in each tower.	TKR: coinc. of x,y planes CAL-LOW: # of hits CAL-HIGH: energy ACD: high threshold	Two redundant triggers for gamma-rays. Avoid self-veto at high E. Select C,N,O for calibration.	9 kHz (3.4 kHz with ACD veto enabled)	5.5 kHz (2 kHz with ACD veto enabled)
L2: cosmic-ray rejection	Soft-ware	Individual towers + ACD	L1 information. Simple track reconstruction. Extrapolation to ACD.	Reject tracks that point to fired ACD tiles, unless CAL energy is high.	1.7 kHz	1 kHz
L3: final on-board back-ground rejec-tion	Soft-ware	SIU (Full Instrument)	Full event reconstruction (all subsystems). SC ancillary data (attitude information).	Loose cuts to reject background, including Earth albedo, suffi-ciently for downlink.		<30 Hz

a. Rates are calculated from detailed simulations of the backgrounds, the detector response, and the trigger logic.

Table 1. The 3 different trigger levels adopted in the GLAST Large Area Telescope.

3 Summary of GLAST Science Topics

The universe is largely transparent to gamma rays in the energy range of GLAST. Energetic sources near the edge of the visible universe can be detected by the light of their gamma rays. There are good reason to expect that GLAST will see known classes of sources up to redshift 5, or even greater if the sources existed at earlier times. The small interaction cross section for gamma rays can provide a direct view into nature's highest energy accelerators. In addition, gamma rays point back to their sources unlike cosmic rays which are deflected by magnetic fields.

The main advantages of the LAT detector will be the wide field of view ($2sr$) and the extremely short dead time per event ($< 100\mu s$). These performances, together with the excellent background rejection (better than $2.5\times10^5 : 1$) will allow GLAST to detect both faint sources and transient signals in the gamma-ray sky. The capabilities of the GLAST LAT detector compared to those of *EGRET* are summarized in table 2. Several performances of the LAT detector, such as the angular and energy resolution, the field of view and the effective area are plotted in figure 3, and compared to those of EGRET.

Quantity	EGRET	LAT (Minimum Spec.)
Energy Range	20 MeV−30 GeV	20 MeV−300 GeV
Peak Area	1500 cm^2	8000 cm^2
Field of View	0.5 sr	$> 2sr$
Angular Resolution	5.8^o	$< 3.5^o$ (100 MeV) $< 0.15^o$ ($>$ 10 GeV)
Energy resolution	10%	10%
Deadtime per event	100 ms	$< 100\mu s$
Source Location Det.	$15'$	$< 0.5'$
Point Source Sensitivity	$1\times10^{-7}cm^{-2}s^{-1}$	$< 6\times10^{-9}cm^{-2}s^{-1}$

Table 2. *GLAST LAT specification and performance compared with EGRET*

EGRET discovered that a class of **Active Galactic Nuclei** (AGN), known as blasars, is a bright and variable source of high energy gamma rays (for reference see the 3rd EGRET catalog reported in figure 4). The peak in energy from many blasars is emitted in the GLAST energy band. The emission is believed to be powered by accretion onto supermassive black holes in the centre of distant galaxies. GLAST will be able to extend the number of

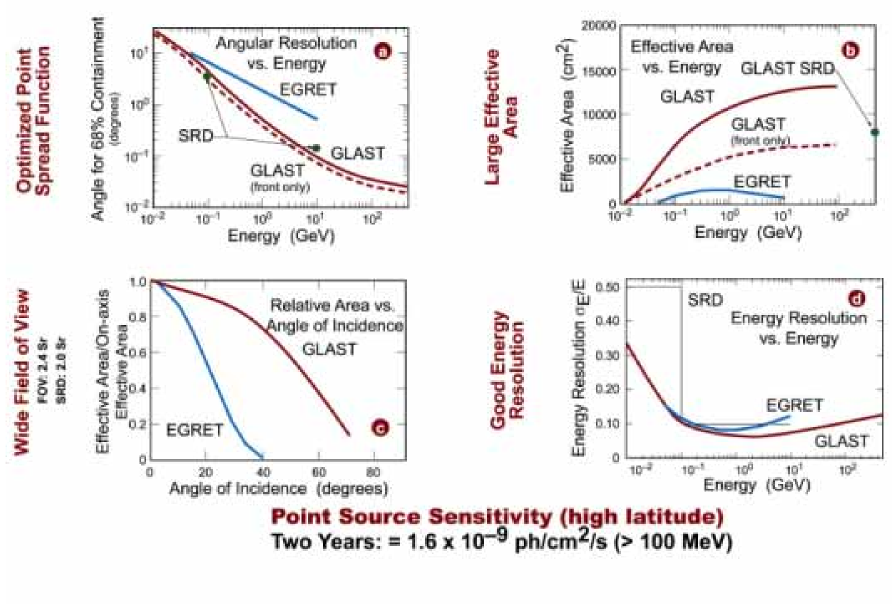

Figure 3. *LAT detector performance compared with EGRET for a point source observation.*

AGN gamma-ray sources from 70 to thousands: it will be an all-sky monitor for AGN flares scanning the whole sky every three hours. Moreover it will be able to study the variability of the flares decreasing the minimum time scale for detection of variability.

Due to its short dead time GLAST will continue the recent revolution of **Gamma Ray Bursts** (GRB), measuring the variability of signals at high energy and tracking the gamma ray afterglow[1]. There are good reasons to think that with the information collected by GLAST it will be possible to discriminate between several emission models, starting for example from the signatures that different theoretical scenarios leave in the signal; the presence of internal shocks or the emission of high energy photons due to the collision between a single shell and the surrounding medium are some examples.

Another breakthrough could be the direct discovery of **Dark Matter Halos**, and the understanding of the nature of the matter from which they are composed[3]. The large area and the low instrumental background of GLAST will also allow searches for the decay of exotic particles in the early universe

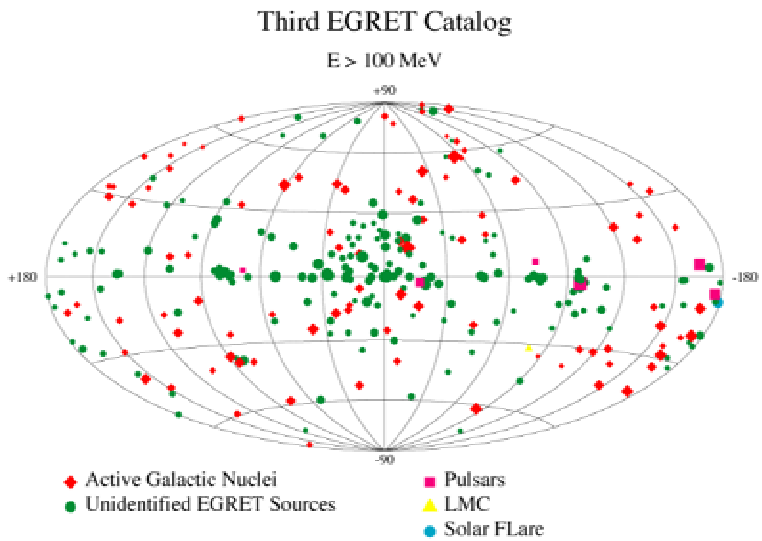

Figure 4. 3rd EGRET catalog for sources of energies greater than 100 MeV. The majority of the sources result still unidentified.

and for annihilations of postulated weakly-interacting massive particles (or $WIMPs$). Most of the isotropic background measured by EGRET will be resolved by GLAST as diffuse emissions from AGN. A diffuse cosmic residual would be a tremendous discovery and could be related to strange particle decay. Recent work suggests that annihilation of the lightest supersymmetric particles, a candidate Galactic Halo WIMP, could leave a signature in the diffuse background detectable by GLAST.

GLAST will also be able to discovery many pulsars that emit in the gamma-ray energy band. The number of pulsars detected during the GLAST lifetime will be potentially 250 or more, providing good statistics to distinguish between the two primary models proposed to describe the particle acceleration and gamma ray production: the outer gap and the polar cap models.

Equally important, GLAST will spatially resolve the remnants of supernovae explosions (SNR), precisely measuring their spectra. In principle these observations could be address the problem of whether SNRs are the source of cosmic rays. Cosmic rays are the main sources of production of the gamma diffuse background in the Milky Way via their interaction with the interstellar medium. GLAST will detect the diffuse emission from a number of local group galaxies and map their emission within the largest of these for the first time. Spatial and spectral studies will test cosmic-ray production and diffusion models[4,5].

4 Conclusion

GLAST will provide an important step forward in gamma astronomy and in the comprehension of the nature of the high energy universe. GLAST is planned as a facility-class mission involving an international collaboration from the particles physics and astrophysics communities. Currently scientists from the United States, Japan, France, Germany and Italy are involved in detector construction, testing, assembling and in software development. GLAST is planned to be launched early in 2006 from the Kennedy Space Center on board a Delta 2920 vehicle. It will have a 550 km altitude circular orbit, with an inclination of 28.5^o.

For more information see the GLAST web site at:
`http://www-glast.stanford.edu/`
For information about the local Pisa activity see:
`http://www.pi.infn.it/glast/`

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