

Supporting the GLAST User Community

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The Gamma-ray Large Area Space Telescope (GLAST) Science Support Center (GSSC) is the scientific community's interface with GLAST. The GSSC will provide data, analysis software and documentation. In addition, the GSSC will administer the guest investigator program for NASA HQ. Consequently, the GSSC will provide proposal preparation tools to assist proposers in assessing the feasibility of observing sources of interest.

1. Introduction

The GLAST Science Support Center (GSSC) will support the scientific community's analysis of the GLAST data. Here we describe the data analysis opportunities that will be available to the community through the GSSC's services. However, first we describe the mission and its capabilities.

2. GLAST Mission Overview

GLAST is an international and multi-agency space mission that will study the cosmos in the 10 keV–300 GeV energy range. The launch is currently scheduled for the end of May, 2007, on a Delta II into low earth orbit (565 km).

The main instrument, the Large Area Telescope (LAT), will have an effective area ($>8000 \text{ cm}^2$), angular resolution ($<3.5^\circ$ at 100 MeV, $<0.15^\circ$ at $>10 \text{ GeV}$), field-of-view ($>2 \text{ sr}$), and deadtime ($<100 \mu\text{s}$) that will provide a factor of 30 or more advance in sensitivity compared to previous missions, as well the capability for studying transient phenomena. The field-of-view (FOV) of $>2 \text{ sr}$ is the effective area integrated over the sky divided by the peak effective area; usable observations can be performed up to $\sim 70^\circ$ from the LAT's axis. The GLAST Burst Monitor (GBM) will have a FOV larger than that of the LAT and will provide spectral coverage of gamma-ray bursts extending from the LAT's lower limit down to 10 keV. Although pointed observations will be possible, the observatory will most likely scan the sky continuously because of the LAT's large FOV; this survey mode is planned for at least GLAST's first year. In survey mode the spacecraft's axis is rocked perpendicular to the orbital plane once per orbit, achieving near-uniform exposure every two orbits. Thus in survey mode the spacecraft's pointing changes continuously.

2.1. The LAT

A product of a NASA/Department of Energy/international collaboration, the LAT builds on the success of the Energetic Gamma Ray Experiment Telescope (EGRET) on the *Compton Gamma Ray*

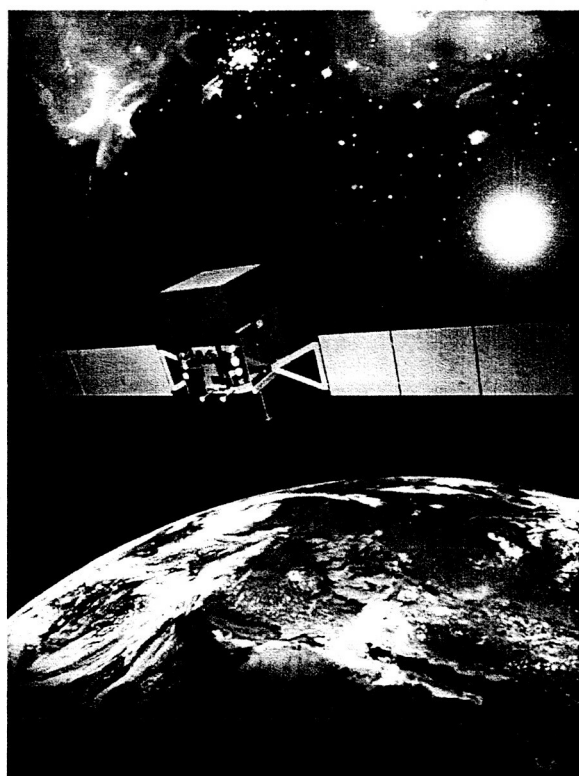


Figure 1: GLAST in Orbit. Figure courtesy of SASS, the spacecraft contractor.

Observatory (CGRO). The PI is P. Michelson (Stanford) and the instrument is managed at the Stanford Linear Accelerator Center (SLAC). The LAT will be a pair conversion telescope (see Figure 2): gamma rays will pair-produce in tungsten foils; silicon strip detectors will track the resulting pairs; the resulting particle shower will deposit energy in a CsI calorimeter; and an anticoincidence detector will veto the large flux of charged particles that will also be incident on the LAT. The anticoincidence detector will be segmented to eliminate the self-vetoing at high energy that plagued EGRET. The LAT's outside dimension will be $1.8\text{m} \times 1.8\text{m} \times 1\text{m}$, and it will weigh $\sim 3000 \text{ kg}$.

Astrophysical photons will be only a small fraction of all the events the LAT will detect, most of which

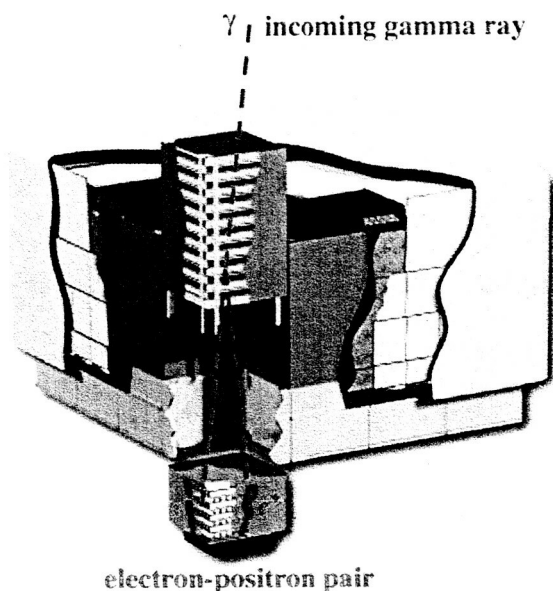


Figure 2: Structure of the LAT—the gamma ray interacts in a tungsten foil which is housed in the assembly that is shifted up in this cutaway illustration. The resulting electron-positron pair passes through the silicon strip detectors interspersed with the tungsten foils, and the CsI calorimeter (shifted down in this figure) below the tungsten foils and silicon strip detectors. Charged particles are vetoed by the anticoincidence detector, the light grey tiles under the yellow thermal blanket.

will be charged particles. Therefore, event filtering on board will reduce the ~ 4 kHz detected event rate to ~ 300 Hz that will be telemetered to the ground; ground processing will identify the true ~ 2 – 3 Hz photon rate.

The tracks of the particle shower produced by a photon or cosmic ray interacting in the LAT will be analyzed by the LAT Instrument and Science Operations Center (LISOC) located at SLAC, resulting in a determination of whether the event was a photon, and a characterization of the event's arrival time, direction and energy. The list of detected photons is the primary dataset that will be used for astrophysical analysis.

2.2. The GBM

A descendant of *CGRO*'s Burst And Transient Source Experiment (BATSE), the GBM will detect gamma-ray bursts and extend GLAST's burst spectral sensitivity to the <10 keV to >25 MeV band. The PI is C. Meegan (MSFC) and the co-PI is G. Lichti (MPE). Consisting of 12 NaI(Tl) (10–1000 keV) and 2 BGO (1–25 MeV) detectors, the GBM will monitor >8 sr of the sky, including the LAT's FOV. Bursts will

be localized to 9° (1σ , brightest 40% of the bursts) by comparing the rates in different detectors. The GBM will trigger if the rates in ≥ 2 detectors increase simultaneously by $\geq 5.5\sigma$. The trigger will use a variety of energy bands and time windows.

From the GBM's telemetry the GBM Instrument Operations Center (GIOCC) will produce 'continuous' and burst data products. The primary continuous data are two sets of rates from all the GBM's detectors with differing temporal and spectral resolution, regardless of whether a burst was detected. The primary burst data are lists of the counts in each detector from the period of the burst. Both the continuous and burst data products include calibration data, catalogs, and other ancillary data.

2.3. GLAST Science

GLAST will study a wide range of energetic astrophysical phenomena. In many cases GLAST will extend EGRET's pioneering observations, but we anticipate new phenomena will be revealed. The references provide an entree into the relevant literature.

Active Galactic Nuclei (AGN)[1, 2] are extremely energetic sources observed at the center of some galaxies; AGN are believed to be powered by accretion onto super-massive black holes (10^6 – 10^{10} solar masses). EGRET detected ~ 70 AGN whose gamma-ray emission is believed to be radiated by relativistic jets pointed in our direction. We expect GLAST will detect several thousand AGN.

Gamma-ray bursts (GRBs)[3] are short, very bright flashes of gamma-rays followed by fading afterglows at lower energies (radio, optical and X-ray). EGRET saw 45 high energy gamma-ray photons (in total) from several GRBs, including an 18 GeV photon 75 minutes after a burst.[4] GLAST will determine whether there are additional spectral and temporal high energy components. The synergy between the GBM and the LAT is crucial for providing spectra over 7 energy decades and for detecting bursts over a large FOV. GLAST will repoint autonomously toward strong bursts, keeping them within the LAT FOV for ~ 5 hours (except when the burst location is occulted by the earth). In addition, GLAST will inform the ground within less than 10 seconds that a burst has occurred.

The shocks in supernova remnants[5, 6] accelerate particles that may then radiate gamma-rays. Since supernova remnants are thought to be the origin of the primary cosmic ray population below 10^{15} eV, gamma-ray observations may increase our understanding of the cosmic ray phenomenon and propagation.

Pulsars[7] are spinning magnetized neutron stars that emit gamma rays when young. EGRET identified five pulsars, but may have detected a number of others as point sources without discovering their pulsations.

GLAST observations should distinguish between two competing explanations of pulsar high energy emission: the outer gap[8] and polar cap models.[9]

Gamma rays interact with lower energy photons, producing electron-positron pairs. Consequently gamma rays originating at cosmological distances are attenuated while propagating through the optical-UV radiation field produced by stars between the source and us. The energy-dependent attenuation depends on the density and evolution of the radiation field. GLAST will observe cutoffs in the spectra of AGN and GRBs from which the infrared radiation density can be measured.[10]

The particles that constitute the cosmological dark matter may annihilate in a cuspy halo around the Galactic Center, producing a spectral feature that GLAST might detect.[11]

The interaction of cosmic rays with the interstellar medium and inverse Compton emission by the cosmic rays' electron component result in a diffuse Galactic emission[12] on top of isotropic diffuse extragalactic emission thought to be the sum of unresolved AGN and other components.[13] While this diffuse emission is a background complicating the detection of point sources, it is scientifically interesting.

As a result of GLAST's great increase in sensitivity over previous missions such as EGRET, we expect to discover new source classes, and to find that previous classes consist of subclasses. GLAST should allow the identification of the 172 unidentified strong sources in the 3rd EGRET catalog (out of the 271 detected sources).[7, 14, 15]

3. GLAST Data Policy

During the first year of the mission, LAT data are proprietary to the instrument team, although information on detected transients and ~ 20 selected sources will be made public as soon as possible. During this first year the LAT team will calibrate their instrument and undertake an all-sky survey that will result in a point source catalog. The catalog will be updated in subsequent years.

A month after the end of the first year, these LAT data will become publicly available. Starting the second year, all subsequent science data acquired by the mission will be in the public domain within 24 hours without a proprietary data period.

GBM data, particularly from bursts, will become publicly available from the beginning of the mission.

Full details on the GLAST Data Policy will be included in a public document and will be posted at http://glast.gsfc.nasa.gov/ssc/data/Data_Policy.html.

4. User Support by the GSSC

The GSSC was established at Goddard Space Flight Center (GSFC) to take advantage of the synergy with the Office of General Investigator Programs (OGIP) that runs similar organizations supporting the *RXTE*, *Swift*, *XMM-Newton*, *Integral*, and *Astro-E2* missions. The GSSC therefore draws upon the user support expertise and infrastructure within OGIP. In particular, OGIP also houses the High Energy Astrophysics Science Archive Research Center (HEASARC), NASA's archive for high energy astrophysics missions. The HEASARC maintains a common data storage and analysis environment for high energy missions, and will be the ultimate archive of GLAST data after the mission ends and the GSSC is disbanded. By developing its database and software systems within the HEASARC environment, the GSSC insures that the GLAST data will be easily accessible to the scientific community during and after the GLAST mission. In particular, the GLAST Standard Analysis Environment (SAE) is not yet another analysis system but adds GLAST-specific tools to the HEASARC's HEADas software system. The HEASARC will be the GLAST data's final archive.

The GSSC has different roles before and after the observatory's launch:

Before Launch—The GSSC will educate the user community about the mission's capabilities through posters and talks at scientific conferences, special workshops and tutorial sessions providing hands-on experience with simulated GLAST data and by maintaining an up-to-date website with the current status and information about the GLAST mission.

During the Mission—The GSSC's website will provide updates about the mission's status, serve as a gateway to the data, tools, instrument response functions (IRFs) and documentation, and include a help desk and Frequently Asked Questions (FAQ) section of the GSSC website. The GSSC will also host conferences and workshops to provide education and experience with the GLAST Science Software and a forum for users to report on GLAST's scientific results.

5. Guest Investigator Program

The GLAST mission will support a Guest Investigator (GI) program that the GSSC will administer for NASA Headquarters. The GI program will include a GLAST Fellows program. The program will be part of NASA's Research Opportunities in Space and Earth Science (ROSES), and will consist of yearly cycles. The GI program will provide the opportunity for scientists anywhere in the world to propose GLAST observations and for investigators at US institutions to receive funding for their GLAST-related research.

For the mission's first year (the first GI cycle), GIs may not propose GLAST pointed observations. During this first year the LAT team will post information on bright transients and ~20 selected sources. GIs may request funding for multiwavelength observations, support projects (e.g., developing new analysis methods) and GLAST-related theoretical research during the first cycle.

During the subsequent yearly cycles, GIs may also request pointed observations or special instrument modes as part of their proposal, if scientifically justifiable. However, continued surveying of the sky will probably be the most efficient method of accumulating exposure for the largest number of sources, and we anticipate that most observing programs will be satisfied by survey mode. During this phase of the mission, all data will be available to the public from the GSSC's website.

To assist scientists prepare GI proposals, the GSSC will provide a set of tools for planning observations and submitting proposals. The proposal planning tools will include an exposure and sensitivity calculator as well as observation simulation tools to assist potential GIs assess the feasibility of observing their desired targets (see <http://glast.gsfc.nasa.gov/ssc/proposals/ProposalTools.html>). These tools will simulate the spacecraft's orbit and the instruments' observations with varying levels of fidelity. For example, an online detectability calculator will use orbit-averaged exposure accumulation rates and tables for sources with power law spectra, while the user will be referred to the simulation tools within the SAE, the analysis system that will be used to analyze actual data, for more sophisticated calculations.

Target of Opportunity (TOO) requests will be submitted through an interface similar to the one used for submitting GI proposals.

6. The GSSC Within the GLAST Ground System

Although the specifics are not directly relevant to the user community, the GSSC has an important role within the ground system as the advocate for the community's scientific goals. The observations proposed successfully through the GI program are converted into first an annual, and then a weekly, science timeline by the GSSC. To ensure that instrument operations do not disturb the science timeline, the two instrument operation centers—the LISOC and GIOC (see §2 above)—route instrument commands and software uploads through the GSSC, which schedules their implementation. The GSSC provides the weekly science timeline as well as the timelines for the two instruments to the Mission Operations Center (MOC),

which integrates these timelines with the spacecraft timeline, resulting in a weekly timeline for the observatory. The science timelines are posted on the GSSC website at the different stages of their development to inform the community of the observatory's observing plan.

The GSSC also plays a central role in processing TOOs. Requests will be submitted to the mission through the GSSC website, and the GSSC will evaluate the feasibility of the proposed TOO and its impact on the science timeline. If the TOO is approved, the GSSC asks the MOC to implement the TOO.

7. Providing Data to the Community

All public data from the GLAST mission will be available through the GSSC's website (see <http://glast.gsfc.nasa.gov/ssc>); Table 1 lists the data products that will be available. Much of the data will be served through the HEASARC's Browse interface (an interface to all of NASA's high energy astrophysics data from both current and previous missions—see <http://heasarc.gsfc.nasa.gov/db-perl/W3Browse/w3browse.pl>); the GSSC website will link to this interface. Those data not available through Browse will be served directly from the GSSC's website. The data necessary for the response functions will be stored in the HEASARC's CALDB directory structure. Table 1 indicates whether the access is through Browse, the GSSC website (labelled simply 'GSSC') or CALDB.

8. GLAST Standard Analysis Environment (SAE)

The GSSC will provide a suite of data analysis tools and libraries for the analysis of GLAST data. This software is being developed by the instrument teams with assistance from the GSSC. The instrument teams and the scientific community will all use the SAE suite, which will run on Windows and different flavors of UNIX platforms, and will not require the purchase of additional software. Most of the SAE will be implemented as FTOOLS, and all will be part of the HEADas system maintained by the HEASARC. Consequently the data files input and output from the tools will be in FITS format. Therefore, the SAE will be an extension of the data analysis environment familiar to the high energy astrophysics community. In addition, we are developing a GUI interface to run these tools.

The SAE can be divided into a number of analysis areas:

Table I GLAST DATA PRODUCTS

Data Product	Description	Access
SCIENCE DATA		
LAT Events	Full detailed description of events (particle and gamma-rays) reconstructed by the LAT	Browse
LAT Photons	LAT events considered to be photons. Includes all the data necessary to calculate the instrument response functions (IRFs).	Browse
LAT IRFs	Data necessary to calculate LAT IRFs	CALDB
LAT Burst Catalog	Catalog of burst information derived from the LAT	Browse
LAT Point Source Catalog	Detected gamma-ray sources with derived information	Browse
Interstellar Emission Model	Model for diffuse Galactic and extragalactic gamma-ray emission	GSSC
LAT Transient Data	Summary information for transient sources GRBs, (solar flares, AGN flares)	GSSC
GBM CTIME	For each detector, the counts accumulated every 0.256 s in 8 energy channels	Browse
GBM CSPEC	For each detector, the counts accumulated every 8.192 s in 128 energy channels	Browse
GBM Calibration	Tables of fiducial detector response parameters from which the burst-specific DRMs are calculated	GSSC
GBM Time Tagged Events	Time tagged events from the GBM centered on the time of triggered GRBs	Browse
GBM Burst DRMs	DRMs for the burst, one for each significantly different pointing	Browse
GBM TRIGDAT	The GBM burst alert data in a single FITS file	Browse
GBM Background Files	GBM Background Files	Browse
GBM Burst Catalog	List and characterization of all bursts	Browse
GBM Trigger Catalog	List and characterization of all GBM triggers	Browse
GBM Burst Spectra Catalog	Catalog of deconvolved spectra	Browse
Pulsar Ephemerides	Ephemerides of pulsars that might be detectable by GLAST	Browse
GCN Notices and Circulars	GCN notices and circulars generated by GLAST	Browse
Accepted GI Proposals	Database of Accepted GI Proposals	GSSC
MISSION DATA		
Science Timelines	Long (annual) and short (weekly) term science timelines describing where the spacecraft was or will be pointing	GSSC
• Long Term Science Schedule	Planned observing schedule for the current yearly cycle in 1 week periods. Updated as needed	GSSC
• Preliminary Science Timelines	Preliminary detailed one week observing schedule prepared 3 weeks in advance	GSSC
• Final Science Timelines	Final detailed one week observing schedule used to generate commands uploaded to the spacecraft. Generated ~3 days before upload and replaces the Preliminary Timeline once generated	GSSC
• As-flown timeline	Timeline describing the history of GLAST's pointing	GSSC
LAT pointing and livetime history	LAT orientation and mode at 30 s intervals. These data are used to calculate exposures	Browse
TOO Data	Lists of all accepted and executed Target of Opportunity requests and their status	GSSC

General Analysis—The SAE will consist of several general purpose tools including a data sub-selection tool, tools to generate source models and extract source parameters from existing catalogs, and the workhorse of the GLAST data analysis, the Likelihood tool to perform maximum likelihood fits of the data with the specified models (see below). The suite also provides an event binning tool to create time, energy and spatially binned data sets and tools to com-

pute exposure and response matrices.

GRBs—The SAE suite will provide several tools to assist in the study of gamma-ray bursts including tools for spectral and temporal data analysis and model fitting as well as tools for generating the necessary response functions and binning events for analyzing GLAST data with existing tools such as XSPEC. These tools will be used to analyze both LAT and GBM data, either individually or simultaneously. The

GBM team will also provide their IDL-based burst analysis tool RMFit, to which they will add the capability to analyze both LAT and GBM data.

Pulsars—The SAE suite will include a barycenter arrival time correction tool, period search and profiling tools, and a pulsar ephemeris extraction tool to retrieve pulsar ephemerides from a pulsar database.

Data Simulation—The SAE suite also provides an observation simulator that simulates LAT data based on an input source model and spacecraft orbit profile. An orbit simulation tool is also included.

9. Why a New Likelihood Tool?

One of the primary goals in the analysis of LAT data is to find the location and spectral parameters of high energy gamma-ray sources. This information is obtained by performing maximum likelihood fits of spatial-spectral models to the data. A major new likelihood tool is required for the LAT data because:

The large LAT point spread function at low energy and the great sensitivity means photons from many point sources merge. Analysis is therefore inherently three dimensional: two spatial and one spectral.

GLAST will usually survey the sky. Each photon will therefore have a different direction in instrument coordinates, and thus its own instrument response.

The LAT instrument response will be a function of many observables, such as energy, distance from the source, and angle between the photon direction and the LAT's axis. The data space of observables will therefore be large but sparsely populated.

Ideally, the analysis will be unbinned, i.e., using infinitesimally small bins in the data space, each containing 0 or 1 photons. However, the runtime for large datasets is prohibitively long, and therefore a binned version is under development.

10. GLAST Users' Committee

The GLAST Users' Committee (GUC) has been established; the chair is J. Grindlay (Harvard). The GUC reviews the mission's support for the scientific community in general, and the scientific role of the GSSC in specific. Conversely, the GSSC supports the GUC by facilitating meetings and gathering information. The GUC has been considering issues such as the data policy, the GI program and the SAE. Information on the GUC and its membership can be found on the GSSC's website.

11. Summary

The identification and characterization of photons detected by the LAT is a complex data analysis task

that will be undertaken by the LAT team. Most investigators will analyze a simple list of photons characterized by a few observables such as energy, arrival time, and direction in both celestial and instrument coordinates. Similarly, the GBM's primary burst data will be a list of counts detected in the different GBM detectors. Although the astrophysical data analysis problem is simply posed, the techniques necessary to extract the maximum information from these data are sophisticated and computer-intensive. The goal is to create an analysis system that uses advanced techniques but is easy to learn and use. The GSSC will provide the scientific community with these photon lists as well as ancillary data, with analysis software, and with the expertise to analyze the data. In addition, the GSSC will support the GI program that will provide investigators with the possibility of requesting pointed observations and with the funding necessary to carry out their research.

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