GAMMA-RAY LARGE AREA SPACE TELESCOPE (GLAST)

PROJECT DATA MANAGEMENT PLAN

December 20, 2007

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

GAMMA-RAY LARGE AREA SPACE TELESCOPE
(GLAST) OBSERVATORY

PROJECT DATA MANAGEMENT PLAN

December 20, 2007

NASA Goddard Space Flight Center

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GLAST OBSERVATORY PROJECT DATA MANAGEMENT PLAN

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ACRONYMS AND ABBREVIATIONS

ACD	Anti-Coincidence Detector
ACS	Attitude Control System
AGN	Active Galactic Nuclei
ASD	Astrophysics Science Division
ASP	Automated Science Processing
ATC	Absolute Time Command
ATS	Absolute Time Sequence
BAP	Burst Alert Processor
BATSE	Burst and Transient Source Experiment
BGO	Bismuth Germanate
C&DH	Command And Data Handling
CAL	Calorimeter
CALDB	Calibration DataBase
CCSDS	Consultative Committee for Space Data Systems
CGRO	Compton Gamma-Ray Observatory
DAQ	Data Acquisition System
DAS	Demand Access System
DPU	Data Processing Unit
EGRET	Energetic Gamma Ray Experiment Telescope
EPDS	Electrical Power and Distribution System
ETR	Eastern Test Range
FITS	Flexible Image Transport System
FOT	Flight Operations Team
FOV	Field-of-View

GBM	GLAST Burst Monitor
GCN	Gamma-ray burst Coordinates Network
GI	Guest Investigator
GIOC	GBM Instrument Operations Center
GLAST	Gamma-ray Large Area Space Telescope
GN	Ground Network
GRB	Gamma-Ray Burst
GSFC	Goddard Space Flight Center
GSSC	GLAST Science Support Center
GUG	GLAST Users' Group
HEASARC	High Energy Astrophysics Science Archive Research Center
HQ	Headquarters
IAU	International Astronomical Union
ICD	Interface Control Document
IDS	Interdisciplinary Scientist
IOC	Instrument Operations Center
IRF	Instrument Response Function
IRSA	Infrared Science Archive
LAT	Large Area Telescope
LISOC	LAT Instrument Science Operations Center
MAS	Multiple Access System
MAST	Multimission Archive at Space Telescope Science Institute
MOC	Mission Operations Center
MPE	Max Planck Institute for Extraterrestrial Physics
NaI	Sodium Iodide

NASA	National Aeronautics and Space Administration
NRA	NASA Research Announcement
NSSDC	National Space Science Data Center
NSSTC	National Space Science and Technology Center
OGIP	Office for Guest Investigator Programs
PDB	Project Database
PDMP	Project Data Management Plan
PI	Principal Investigator
PIL	Parameter Interface Layer
PMT	Photomultiplier Tube
SAA	South Atlantic Anomaly
SN	Space Network
SOOG	Science Operations Oversight Group
SSD	Silicon Strip Detector
SSR	Solid State Recorder
SU	Stanford University
SU-SLAC	Stanford University-Stanford Linear Accelerator Center
SWG	Science Working Group
ROSES	Research Opportunities in Space and Earth Sciences
RTS	Relative Time Sequence
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TKR	Tracker
TOO	Target of Opportunity
WSC	White Sands Complex

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This Gamma-ray Large Area Space Telescope (GLAST) Project Data Management Plan (PDMP) describes the activities of the GLAST Project for processing, analyzing, and archiving the data acquired by the Observatory for all phases of the mission. This document includes plans for the integration of the GLAST data environment with other elements of the NASA astrophysics data infrastructure. The PDMP also specifies the mechanisms for disseminating data, software and supporting documentation, in a timely and orderly manner, to the wider scientific community, and for providing expertise to support the scientific community's use of the GLAST data.

The PDMP articulates the plans of the GLAST Project for processing, formatting, storing, accessing, archiving, and distributing all GLAST data. It presents milestones for reducing and interpreting the data, and specifies the conditions for discarding the mission data. The document describes the GLAST Guest Investigator (GI) Program and the roles of the organizations that support the GI Program. It discusses facilities, analysis software development, documentation, support services and data delivery, and archiving requirements and schedule. The PDMP also indicates the interfaces between the GLAST-wide data analysis system and the particle and astrophysics communities, and the requirements that must be met by the integrated system to realize these interfaces successfully.

As opposed to the PDMPs for some other missions, this PDMP leaves the formats of data products exchanged by the ground elements to the appropriate Interface Control Documents (ICDs), File Format Documents (FFDs), and Memoranda of Understanding (MOUs), and operational details to a separate Ground System Operations Agreement. In addition, a separate Science Policy Document is the controlling statement of the mission's data access policies. Where appropriate, the text refers to the relevant document. Conversely, for clarity and context this PDMP includes details about the instruments and spacecraft that are covered in greater detail in other documents; specifically, this PDMP is *not* the controlling document for the requirements for instrument capabilities.

The GLAST Science Support Center (GSSC) at NASA's Goddard Space Flight Center (GSFC) facilitates participation in the GLAST observation program by the general astronomical community for all phases of the mission in a form consistent with other high energy astrophysics missions. A fundamental role of the GSSC is to oversee the creation of the GLAST archive and its delivery to the High Energy Astrophysics Science Archive Research Center (HEASARC).

The instrument teams have established Instrument Operation Centers (IOCs) for both the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The LAT IOC is called the LAT Instrument Science Operations Center (LISOC) while the GBM's is called the GBM Instrument Operation Ccenter (GIOC). The Mission Operations Center (MOC) at GSFC will be the interface to the spacecraft. The MOC is staffed by the Flight Operations Team (FOT). There may be mirror data sites outside the United States associated with the instrument teams. This PDMP describes the relationship between the MOC, the IOCs, the GSSC, the HEASARC, and the scientific community. In addition, this document establishes the roles, functions and responsibilities with regard to data operations of the MOC, the IOCs, the GSSC and the HEASARC to each other, other elements of the NASA Astrophysics Data infrastructure, the GIs, and the general scientific community. An overview of the GI Program is included, as it affects many of the data flow requirements. Details will be provided in the NASA Research Announcements (NRAs) issued for each phase of the program (approximately annually).

1.2 DEVELOPMENT, MAINTENANCE, AND MANAGEMENT RESPONSIBILITY

Developing, maintaining and managing this PDMP is a GLAST Project responsibility. The Project Scientist and the Science Working Group (SWG) are responsible for the development of this plan and the Project Scientist is responsible for assuring that its requirements are met.

1.3 CHANGE CONTROL

This PDMP is a GLAST Project-controlled document. Each year all plans stated in the PDMP will be reviewed and updated as necessary. An operational PDMP will be in place a year before launch; minor post-launch revisions are anticipated resulting from operational experience. The associated Science Policy Document will most likely be updated more frequently and extensively after GLAST's launch before each NRA release. Proposed changes will be submitted to the GLAST Project Scientist, who will coordinate the conduct of such reviews.

1.4 RELEVANT DOCUMENTS

Relevant documents, including NASA and GLAST Project documents, that provide detailed information in support of top-level information given in this PDMP, are listed below. Project documents can be found at https://glast.gsfc.nasa.gov/project/cm/mcdl/, ground system documents at https://glast.gsfc.nasa.gov/project/gsmo/cm/mcdl/, and GSSC documents at http://glast.gsfc.nasa.gov/ssc/dev/current_documents/; some of these sites are password protected.

- GLAST Science Requirements Document, 433-SRD-001
- GLAST Mission Operations Concept Document, 433-OPS-0001
- GLAST Mission System Specification, 433-SPEC-0001
- GLAST Project Plan, 433-PLAN-0001 (Appendix—The Level I requirements)
- The GLAST Announcement of Opportunity for Flight Investigations (AO 99-OSS-03)
- The Ground System Requirements Document, 433-RQMT-0006
- "GLAST Large Area Telescope Flight Investigation: An Astro-Particle Physics Partnership Exploring the High-Energy Universe," P. Michelson, PI.
- "Gamma Ray Burst Monitor," C. Meegan, PI.
- GLAST SWG (Science Working Group) presentations, 05/25/00, 'GLAST Data Rights,' revised at the 2/03 SWG meeting.
- NASA/DOE Implementing Arrangement
- LAT IOC (Instrument Operations Center) Performance Specification, 433-RQMT-0003
- LAT Science Analysis Software Requirements Document, LAT-SS-20.0
- LAT IOC Performance Specification - Level II(B) Specification, LAT-SS-15.1
- LAT Science Analysis Software Management Plan, LAT-MD-360.1
- GBM IOC Requirements, GBM-REQ-1021.
- GBM Mission Operations and Data Analysis Software Requirements, GBM-REQ-xxxx.
- MOC (Mission Operations Center) System Specification

- Ground System MOC Functional and Performance Requirements Document, GLAST-GS-RQMT-0001
- GLAST Science Support Center Functional Requirements Document, 433-RQMT-0002
- Science Data Products Interface Control Document, GLAST-GS-ICD-0006
- Science Data Products File Format Document, GLAST-GS-DOC-0001
- Operations Data Products Interface Control Document, GLAST-GS-ICD-0002
- Mission Operations Agreement, GLAST-GS-MOA-0001
- GSSC-HEASARC Memorandum of Understanding
- Guidelines for Development of a Project Data Management Plan (PDMP), NASA Office of Space Science and Applications, March 1993
- Science Policy Document

2 MISSION OVERVIEW

In this section we provide basic information, concepts and terminology necessary for understanding the mission's data management.

2.1 MISSION OBJECTIVES

The principal objective of the GLAST mission is to perform gamma-ray measurements over the entire celestial sphere, with sensitivity a factor of 30 or more greater than that obtained by earlier space missions. GLAST will accomplish the next major step in high-energy gamma-ray astrophysics by providing major improvements in angular resolution, effective area, field-of-view (FOV), energy resolution and range, and time resolution.

GLAST's scientific objectives will be satisfied by two instruments. Covering the <20 MeV – >300 GeV energy range, the Large Area Telescope (LAT) will have a large collecting area, an imaging capability over a large FOV, and the time resolution sufficient to study transient phenomena. The LAT will also achieve sufficient background discrimination against the large fluxes of cosmic rays, earth albedo gamma rays, and trapped radiation that are encountered in orbit. The GLAST Burst Monitor (GBM) will: provide the spectral and temporal context in the 10 keV to 30 MeV energy band for gamma-ray bursts (GRBs) observed by the LAT; detect and localize bursts; and alert the LAT that a burst is in progress. GLAST may alter its observing plan to observe strong GRBs during and after the low-energy gamma-ray emission.

2.2 SCIENTIFIC OBJECTIVES

The high-energy gamma-ray universe is diverse and dynamic. Measuring the various characteristics of the many types of gamma-ray sources on timescales from milliseconds to years places severe demands on the GLAST mission. GLAST has the following specific scientific objectives:

1) Identify and study nature's high-energy particle accelerators through observations of active galactic nuclei, GRBs, pulsars, stellar-mass black holes, supernova remnants, Solar and stellar flares, and the diffuse galactic and extragalactic high-energy background.
2) Use these sources to probe important physical parameters of the Galaxy and the Universe that are not readily measured with other observations, such as the intensity and distribution of intergalactic infrared radiation fields, magnetic field strengths in cosmic particle accelerators, diffuse gamma-ray fluxes from the Milky Way and nearby galaxies, and the diffuse extragalactic gamma-ray background radiation.
3) Use high-energy gamma rays to search for a variety of as yet undetected and/or new phenomena, such as particle dark matter and evaporating black holes.

2.3 OBSERVATORY DESCRIPTION

The Observatory will consist of two instruments, the LAT and the GBM, and the spacecraft. The instruments are described in depth in the following section, and therefore here we provide a brief description of the spacecraft and its capabilities.

The spacecraft is being constructed by General Dynamics. Figure 2-1 shows the observatory, particularly the location of the LAT and GBM. The +Z axis is normal to the LAT. The spacecraft consists of a number of subsystems described below.

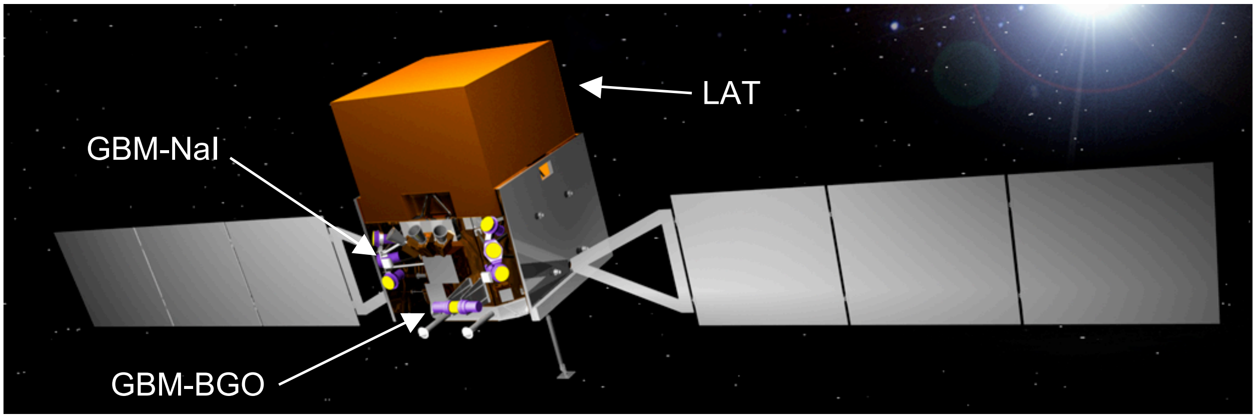

Figure 2-1: Schematic Diagram of GLAST Spacecraft and Science Instrument Locations

Structure—the primary structure is aluminum with titanium flexures supporting the LAT.

Electrical Power—two single axis GaAs solar arrays provide >1700 Watts end-of-life power to a single 125 Amp-Hour NiH_2 battery.

Thermal—passive radiators with heaters and heat pipes will maintain the spacecraft's temperature within the safe operating range. The instruments have their own thermal systems.

Guidance Navigation & Control (GNC)—the orientation of the spacecraft is determined from two star trackers (with a third as backup). The spacecraft's position is determined primarily through the Global Position System (GPS); the backup will be 'two-line' orbital elements uplinked from the ground. The GPS signal will also provide the primary time determination.

The spacecraft slews using four reaction wheels. With all four reaction wheels operating a 75º slew is required to take less than 10 minutes (with a goal of less than 5 minutes). At least 5 slews should be possible per orbit (the number is limited by the heating of the reaction wheels during a slew).

Propulsion—a hydrazine blow-down module with 12 22N thrusters will 'deorbit' the spacecraft safely at the end of the mission.

Command and Data Handling (C&DH)—this system is built around a RAD750 CPU and a 160 Gbit solid-state recorder (SSR) that stores up to 30 hours of science and 36 hours of housekeeping data accumulated at the average rate before these data are transmitted to the ground. The subsystem can accommodate peak science data rates of 40 Mbps from the LAT and 12 Mbps from the GBM, and 51 kbps of housekeeping data from the spacecraft and the two instruments. The data flow is described in greater detail in §6.1.

Communications—the primary communication will be through the Tracking and Data Relay Satellite System (TDRSS): a downlink of science and housekeeping data at Ku-band frequencies at 40 Mbps; a direct 4 kbps uplink of commands and software at S-band frequencies; and an S-band downlink (variable data rates) for burst alerts and alarms. Typically, there will be ~6-7 eight to ten minute real time telemetry contacts per day. S-band uplink and downlink (no science data) directly to ground stations will be possible as a backup to TDRSS.

Consequently, the spacecraft will have a large gimballed Ku-band antenna on the –z side (the usually Earth-facing side opposite to the LAT), two omni-directional S-band antennae and a GPS antenna.

Flight Software (FSW)—the software will support the mission in its different operating modes, and will manage the communications among the instruments, the ground and the spacecraft. Among its many functions, the FSW will generate and distribute a signal once a second to the instruments based on the GPS time received by the GNC subsystem. Also, the FSW will notify the instruments of the entry into, and exit from, the SAA as defined for that instrument. The FSW controls the autonomous repoint of the observatory in response to a burst.

2.4 MISSION TIMELINE

GLAST will be launched in Spring, 2008, from the Eastern Test Range (ETR) by a Delta 2920H-10 (also known as a Delta II 'Heavy') into an initial orbit of ~565 km altitude at an 25.3° inclination and an eccentricity <0.01. The Delta's extra lift capacity will used to lower the orbital inclination by a few degrees from the ETR's latitude. There are no mission constraints on the launch window, although noon is nominal. The mission design lifetime is a minimum of 5 years, with a goal of 10 years.

After launch the mission will go through three phases: on-orbit initial checkout (Phase 0), a one year science verification period during which a full sky survey will be performed (Phase 1), and then at least four years of operations determined by the scientific goals and requirements of guest investigations (Phase 2). There will be one cycle of guest investigations during the verification and sky survey phase, and annual guest investigation cycles during Phase 2. Note that in this document "phases" refers to the periods of time with different operations, and "cycle" to the period of time (nominally one year) during which the guest investigations solicited by an NRA are carried out.

2.4.1 PHASE 0: ON-ORBIT CHECKOUT

On-orbit checkout is expected to take 60 days. The spacecraft subsystems will be evaluated and checked first. Subsequently, the instruments will be turned on, tested, and calibrated. The main observation modes will be checked out. A few pointed observations of bright sources will be used to calibrate the LAT's alignment.

The spacecraft and instrument operations teams will be augmented for extended operations as necessary during this phase. The Flight Operations Team (FOT) will staff the MOC around the clock for the initial checkout and then reduce staffing to only a prime shift on weekdays by the end of this phase. The MOC and the IOCs will control the mission timeline at the beginning of Phase 0, with scheduling transitioning to the GSSC by the end of the checkout period.

2.4.2 PHASE 1: VALIDATION AND SKY SURVEY

As soon as it is declared operational, GLAST will carry out a one year validation and sky survey phase. During this phase the performance of the science instruments will be fully characterized and validated, and the data processing pipelines will be refined based on operational experience. The spacecraft will operate primarily in a sky survey mode designed for relatively uniform sky coverage. The survey may be interrupted by a Target-of-Opportunity (TOO) observation to follow a bright transient. The first GI cycle will coincide with Phase 1. The selected Phase 1 guest investigations must not interfere with the validation of the instruments or the all-sky survey.

2.4.3 PHASE 2: GUEST INVESTIGATOR (GI) OBSERVATIONS

During Phase 2 the mission timeline may implement the selected GI observations proposed in response to NRAs for the GLAST GI Program. Because of the LAT's wide FOV, survey mode is anticipated to be the baseline operational mode during this phase of the GLAST mission. The expected frequency, criteria and figures-of-merit for the different observation modes will be captured in the Science Policy Document. However, since the observatory is designed to "point anywhere at any time," several observational modes will be available to GIs to support their scientific investigations.

2.5 OBSERVING MODES

The GLAST instruments will have very wide FOVs, and the observatory will be very flexible in the direction in which it can point. An observational constraint will be to avoid pointing at or near the Earth to maximize the detection of astrophysical photons; however, the LAT may occasionally observe the Earth's limb to detect albedo gamma rays for instrument calibration. Orientation requirements for the LAT's cooling radiators and the observatory solar panels may impose engineering constraints, particularly during slewing maneuvers. No science data will be taken when the observatory is in the South Atlantic Anomaly (SAA) since the instruments will lower the voltage on their photomultiplier tubes (PMTs). GLAST will operate in a number of observing modes.

Transitions between modes may be commanded from the ground or autonomously by the spacecraft. Commanded mode changes may be requested by the instrument teams, GIs or the Project Scientist, and implemented following appropriate review by the IOCs, the GSSC and the MOC; the Science Policy Document will outline the approval process. Based on data from the LAT or the GBM, the LAT can request autonomous repointing of the spacecraft and change the observing mode to monitor the location of a GRB (or other short timescale transient) in or near the LAT's FOV. After a pre-determined time the spacecraft will return to the scheduled mode.

2.5.1 SURVEY MODE

In survey mode, which will probably predominate during most of the mission, the LAT's pointing will be relative to the zenith (the point directly opposite the Earth), and therefore will change constantly relative to the sky. Uniformity will be achieved by "rocking" the pointing perpendicular to the orbital motion. For example, every orbit the pointing may be slewed from 35° on one side of the orbit to 35° on the other, resulting in a two orbit periodicity. The maximum rocking angle is 60°. In this mode the pointing accuracy will be <2° (1σ, goal of <0.5°), with a pointing knowledge of <10 arcsec (goal <5 arcsec). The figure-of-merit to be optimized by a particular rocking profile is nominally uniformity of sky coverage, but may change as the mission progresses, and will be stated in the Science Policy Document.

2.5.2 INERTIAL POINTING MODE

When justified by the demands of a particular investigation, the LAT z-axis will be pointed at a fixed point near a target in this inertially-stabilized mode. A pointing observation may be optimum for pulsar timing studies (to reduce the effect of variations in a pulsar's period) or for other studies where building up exposure over a short time will be useful. In this mode the pointing accuracy will also be <2° (1σ, goal of <0.5°), with a pointing knowledge of <10 arcsec (goal <5 arcsec). This mode keeps the earth out of the FOV; the default Earth Avoidance Angle (the angle between the +z axis and the Earth's limb) is 30°. When the target is unocculted but within the Earth Avoidance Angle of the Earth's limb, the spacecraft will keep the target in the LAT's FOV while keeping the Earth out of the LAT's FOV. The observatory may observe a secondary target when the Earth occults the primary target. The Earth Avoidance Angle will be defined in the Science Policy Document.

2.5.3 ENGINEERING MODES

Special engineering modes will be implemented to generate diagnostic data on the instruments' performance. For example, for short periods of time the LAT can acquire and transmit unfiltered data (i.e., without the on-board cuts that eliminate most of the events that are not astrophysical gamma rays); the on-board cuts can be tested on the ground with unfiltered data. These engineering modes may occur during any of the observing modes. In many of these modes the acquired data are scientifically usable.

2.5.4 SAFE MODE

Finally, the spacecraft can be placed into safe mode either autonomously or via ground command if anomalous behavior is detected that threatens the mission's safety.

2.6 DATA OVERVIEW

The data are described in greater detail in §6, but a brief overview introducing basic concepts and terminology is useful for understanding the intervening sections. The data at different points in the processing are referred to as 'Level X data,' and the processing that creates Level X data is called 'Level X processing.'

Level 0 data will consist of 'cleaned-up' telemetry: the telemetry packets are time ordered; repeated packets are removed; and corrupted packets are flagged. Both housekeeping and scientific data are included in the Level 0 data.

Level 1 data will result from the processing of Level 0 data by the instrument teams and are ready for astrophysical analysis. In particular, the LAT Level 1 processing will calculate the direction and energy of an incoming photon from the particles detected in various parts of the LAT. Note that in the GLAST mission the instrument teams will perform the Level 1 processing.

Level 2 data will result from astrophysical analysis of the Level 1 data. Thus Level 2 data might consist of source detections and spectra. While the GSSC and the IOCs will perform routine Level 2 processing, Level 2 processing will be the focus of the general scientific community's analysis of GLAST data.

Level 3 data will be compendia of Level 2 data, such as source catalogs.

2.7 MISSION SUMMARY

Table 2-1: Mission Overview	
Mission Summary	
Project Name	Gamma-ray Large Area Space Telescope (GLAST)
Orbit Description	≤28.5° inclination, initial ~565 km circular orbit, 94 minute period
Launch Date	Spring 2008
Launch Vehicle	Delta II 7920H-10C
Nominal Mission Duration	5 years
Mission Life Goal	10 years
Data Acquisition	
On-Board Data Storage Capacity	160 Gbits
Average LAT Science Data Rate	1.2 Mbps
Average GBM Science Data Rate	16 kbps
Housekeeping Data Rate	51 kbps
SSR Science Data Capacity	30 hours
SSR Housekeeping Data Capacity	36 hours
Attitude control accuracy	$<2^{\circ}$ (1σ)
Attitude determination accuracy	<10 arcsec (1σ)
Space to Ground Communications Data Rates	
Space Forward Average	250 bps S-band SA TDRSS
Purpose	TOO
Average	4 kbps S-band MA TDRSS
Purpose	Large software loads
Space Return Average	40 Mbps Ku-band
Purpose	Science data downlink ~6-7 per day
Average	1, 2, 4, 8 kbps S-band SA TDRSS
Purpose	Real time data during Ku-band contacts
Average	1 kbps S-band MA TDRSS (DAS)
Purpose	Burst alerts, safe mode
Ground Forward Average	2 kbps S-band
Purpose	Commands
Ground Return Average	51 kbps S-band
Purpose	Real-time housekeeping
Average	2.4 Mbps S-band
Purpose	Store housekeeping
Data Loss	<2%
Data Corruption	$<10^{-10}$

3 INSTRUMENT OVERVIEWS

3.1 THE LARGE AREA TELESCOPE (LAT)

3.1.1 EXPERIMENTAL OBJECTIVES

The LAT's principal objective will be high sensitivity gamma-ray observations of celestial sources in the energy range from ~20 MeV to >300 GeV. The LAT will have a wide FOV (>2 sr), large effective area (>8,000 cm^2 maximum effective area at normal incidence at a few GeV), and excellent angular resolution (on-axis single photon 68% space containment angle: <0.15° for E>10 GeV and <3.5° for E=100 MeV). The LAT will provide good energy resolution ($\Delta E/E$<10% in the central part of the energy range) to enable spectral studies of high-energy sources. The actual values may be better than the required values given here.

The LAT will detect point sources that are more than 200 times fainter than the Crab nebula. For strong point sources, the position will be determined to about 0.5 arcminute. Spectra will be measurable over the entire energy range for the stronger sources.

The diffuse radiation away from the Galactic plane will be separable into Galactic and extragalactic components. The energy spectra of the Galactic plane diffuse emission will be measured with high accuracy and spatial variations will be resolved on a scale of about 0.5º. Features that subtend more than 0.25º will be identified as extended and not as point sources. The improved point source sensitivity of the LAT relative to previous missions will allow the study of the spectral and spatial variation of the extragalactic component, leading to the determination of the unresolved point source contribution to the diffuse radiation measured by the *Compton Gamma-Ray Observatory's (CGRO's)* Energetic Gamma-Ray Experiment Telescope (EGRET).

The large FOV and low dead time (<100 μs/event required, actual will most likely be much smaller) will allow the LAT to monitor the sky for high-energy transients, particularly GRBs. On-board data processing will allow near real-time notification to the ground of transients.

The GLAST LAT Collaboration includes scientists from Stanford University, including SLAC (PI: Prof. P. Michelson); GSFC; University of California at Santa Cruz; Naval Research Laboratory; University of Washington; Sonoma State University; Texas A&M University-Kingsville; Stockholm University and Royal Institute of Technology, Stockholm; Commissariat a l'Energie Atomique, Departement d'Astrophysique, Saclay, France; Institut National de Physique Nuclearie et de Physique des Particules, France; Instituto Nazionale di Fisica Nucleare, Italy; Agenzia Spaziale Italiana, Italy; Instituto di Fisica Cosmica, CNR; Hiroshima University; Institute of Space and Astronautical Science, Tokyo; Riken; and the Tokyo Institute of Technology. In addition, Affiliated Scientists are drawn from 29 institutions world-wide.

3.1.2 LAT INSTRUMENTATION

Shown schematically in Figure 3-1, the LAT consists of an array of 16 tracker (TKR) modules, 16 calorimeter (CAL) modules, and a segmented anticoincidence detector (ACD). The TKR and CAL modules are mounted to the instrument grid structure. Abstracted from the Science Requirements Document (433-SRD-001), Table 3-1 summarizes the required capabilities of the LAT instrument.

Each TKR module consists of 18 XY tracker planes. Each XY plane has an array of silicon-strip tracking detectors (SSDs) for charged particle detection. The first 12 planes have 0.035 radiation length[1] thick tungsten plates in front of the SSDs, the next 4 planes have 0.18 radiation length thick tungsten plates, and the last 2 planes, immediately in front of the CAL, do not have tungsten plates. The SSDs in each plane actually consist of two planes of strips, one running in the x and the other in the y direction, thereby localizing the passage of a charged particle. Gamma rays incident from within the LAT's FOV preferentially convert into an electron-positron pair in one of the TKR's tungsten plates. The initial directions of the electron and positron are determined from their tracks recorded by the SSD planes following the conversion point. Cosmic rays also interact within the TKR modules. Reconstruction of the interactions from the tracks identify the type of particle as well as its energy and incident direction.

Each CAL module consists of 8 planes of 12 CsI(Tl) crystal logs each. The logs are read out at each end by a PIN diode (a type of light sensitive diode). The CAL's segmentation and read-out provide precise three-dimensional localization of the particle shower in the CAL. At normal incidence the CAL's depth is 8.5 radiation lengths.

The ACD is composed of plastic scintillator segmented into tiles, supplemented with fiber ribbons, and read out by waveshifting fibers connected to PMTs.

The LAT's Data Acquisition System (DAQ) performs preliminary cuts on events within the LAT, to reduce the rate of background events that will be telemetered to the ground. The DAQ processes the captured event data into a data stream with an average bit rate of 1.2 Mbps for the LAT. The DAQ will also perform: command, control, and instrument monitoring; housekeeping; and power switching.

3.1.3 DATA ACQUISITION

The astrophysical photons of primary interest will be a tiny fraction of the particles that will penetrate into the LAT's TKR. The LAT will perform on-board analysis cuts that will reduce the ~2.5 kHz of events that trigger the TKR to ~400 Hz of events that will be sent to the ground for further analysis; of these ~400 Hz only ~2-5 Hz are astrophysical photons. The data for an event that passes the on-board analysis cuts is stored in a packet with a time stamp and details of the signals from the various LAT components. Because the number of signals for a given event varies, the data packets have variable length. These data packets describing each event are the LAT's primary data product. The LAT will transfer these packets to the spacecraft's SSR for subsequent transmission to the ground.

The LAT flight software includes a burst trigger that searches for spatial and temporal clustering of events that have passed further cuts. When statistically significant clustering is detected, the LAT sends burst alert records with the time and calculated location of the event cluster (see §7.4).

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[1] A radiation length is defined as the length in a specific material in which an energetic electron will lose $1\text{-}e^{-1}$ of its energy by bremsstrahlung.

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Table 3-1: LAT Description and Required Capabilities	
1. LAT Detectors	
Tracker (TKR)	16 tungsten plates intermixed with 18 XY tracking planes of silicon-strip detectors, in 16 'towers'
Calorimeter (CAL)	Hodoscopic configuration of CsI(Tl) crystals, in 16 'towers', each with 8 layers of 12 CsI logs
Anticoincidence Detector (ACD)	Array of plastic scintillator tiles, read out with waveshifting fibers coupled to photomultiplier tubes
2. LAT Capabilities	
Energy Range	<20 MeV to >300 GeV
Energy Resolution	<10% on axis, 100 MeV—10 GeV
Effective Area	>8,000 cm^2 maximum effective area at normal incidence; includes inefficiencies to achieve required background rejection
Single Photon Angular Resolution	<0.15º, on-axis, 68% space angle containment radius for E > 10 GeV <3.5º, on-axis, 68% space angle containment radius for E = 100 MeV
Field of View	> 2 sr
Source Location Determination	< 0.5 arcmin for high-latitude source
Point Source Sensitivity	< 6 x 10^{-9} ph cm^{-2} s^{-1} for E > 100 MeV, 5σ detection after 1 year sky survey
Time Accuracy	< 10 microseconds, relative to spacecraft time
Background Rejection (after analysis)	< 10% residual contamination of high latitude diffuse sample in any decade of energy for E > 100 MeV.
Dead Time	< 100 microseconds per event
3. GLAST-LAT Interface	
Mass	3000 kg (allocation)
Size	1.5 m x 1.75 m x 1.0 m
Power	650 W (allocation)
Average Science Data Rate	1.2 Mbps

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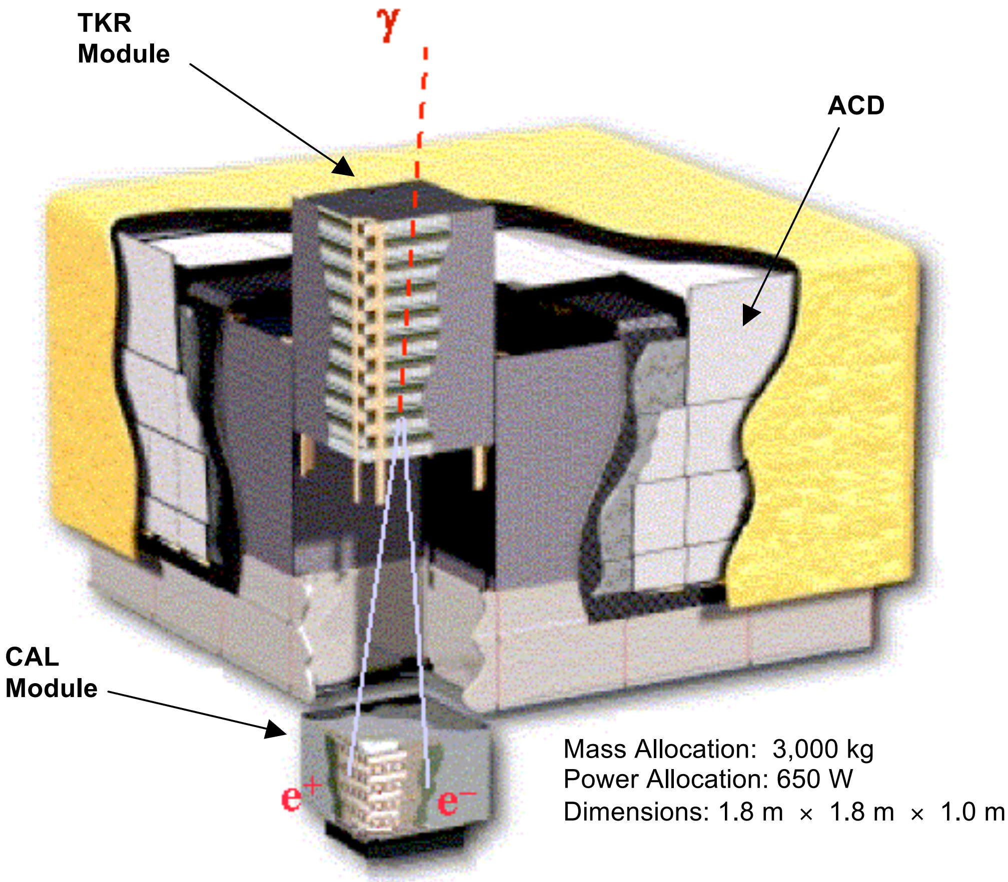

Figure 3-1: LAT Instrument Schematic

3.2 THE GLAST BURST MONITOR (GBM)

3.2.1 EXPERIMENTAL OBJECTIVES

The GBM will provide simultaneous low-energy spectral and temporal measurements for all GRBs within the LAT FOV. The combined GBM and LAT effective energy range will span more than 7 energy decades from 10 keV to >300 GeV. The GBM extends the energy coverage from below the typical GRB spectral break at ~100 keV to above the LAT's low-energy cutoff for inter-instrument calibration. Furthermore, the GBM's sensitivity and FOV will be commensurate with the LAT's to ensure that many bursts will have simultaneous low-energy and high-energy measurements with similar statistical significance. The GBM will also assist the LAT to detect and localize GRBs rapidly by providing prompt notification of a burst trigger and its location within 15º. Finally, the GBM's coarse GRB localizations over a wide FOV will be used to repoint the LAT at particularly interesting bursts outside the LAT FOV for gamma-ray afterglow observations, or to notify external follow-up observers.

Table 3-2 lists the GBM's estimated performance (from the performance review of 2/2/07), as well as the driving scientific measurement.

Table 3-2: GBM Scientific Performance

Parameter	Estimated	Main Driver
Low Energy Limit	~8 keV	Characterize spectra below break
High Energy Limit	~30 MeV	Overlap LAT energy range
Energy Resolution[a]	~7%	Continuum spectroscopy
Field of View[b]	9 sr	Match or exceed LAT FOV
Time Accuracy[c]	4 μs	Measure rapid variability
Average Dead Time	2.6 μs/count	Measure intense pulses
Burst Sensitivity, ground[d]	0.44 cm^{-2} s^{-1}	Consistent with LAT GRB sensitivity
Burst Sensitivity, onboard[e]	0.71 cm^{-2} s^{-1}	Consistent with LAT GRB sensitivity
Burst Alert Locations[f]	~8°	Sufficient to repoint LAT
Burst Alert Time Delay[g]	1.8 s	Less than typical GRB duration

[a] FWHM, 0.1–1 MeV
[b] Co-aligned with LAT FOV
[c] Relative to spacecraft time, with corrections
[d] Peak flux for 5σ detection in ph cm^{-2} s^{-1} (50–300 keV), ground processing
[e] Peak flux for 5σ detection in ph cm^{-2} s^{-1} (50–300 keV), onboard processing
[f] 1σ error radius for 1 s burst with flux of 10 $cm^{-2}s^{-1}$ (50 to 300) keV
[g] Time from burst trigger to spacecraft notification (used to notify ground or LAT)

Using detection criteria similar to those of *CGRO*'s Burst And Transient Source Experiment (BATSE), the predicted GBM burst detection rate is in the range of 150–225 per year, depending on GLAST's observing plan (i.e., the fraction of the GBM FOV blocked by the Earth). In practice, the GBM will detect GRBs at a higher rate through a more flexible trigger algorithm that will improve background estimates, and that will use several different energy ranges and timescales.

For bright GRBs, the combination of GBM and LAT measurements will constrain the time-averaged burst spectrum over more than seven energy decades with typical statistical uncertainties for the spectral parameters of less than 1% (~2-10% for GRBs dimmer by a factor of ten). In addition to measuring low-energy spectra below the LAT threshold, the GBM will significantly improve the constraints on high-energy spectral behavior compared to those of the LAT alone. The combination of GBM and LAT data will therefore provide a powerful tool to study GRB spectra and their underlying physics.

The GBM collaboration includes scientists from the Marshall Space Flight Center (PI: Dr. C. A. Meegan), the Max Planck Institute for Extraterrestrial Physics (MPE; Co-PI: Dr. J. Greiner), the University of Alabama in Huntsville, and Los Alamos National Laboratory. The Marshall and University of Alabama scientists are housed at the NSSTC.

3.2.2 GBM INSTRUMENTATION

To achieve the required GBM performance, the design and technology borrow heavily from previous GRB instruments, particularly from BATSE. Like BATSE, the GBM uses two types of cylindrical crystal scintillation detectors, whose light is read out by PMTs.

An array of 12 sodium iodide (NaI) detectors (0.5 in. thick, 5 in. diameter) will cover the lower end of the energy range up to 1 MeV. The GBM will trigger off of the rates in the NaI detectors. Each NaI detector consists of the crystal, an aluminum housing, a thin beryllium entrance window on one face, and a 5 in. diameter PMT assembly (including a pre-amplifier) on the other. These detectors will be distributed around the GLAST spacecraft (see Figure 3-2) with different orientations to provide the required sensitivity and FOV. The cosine-like angular response of the thin NaI detectors will be used to localize burst sources by comparing rates from detectors with different viewing angles. To cover higher energies, the GBM also includes two 5 in. thick, 5 in. diameter bismuth germanate (BGO) detectors. The combination of the BGO detectors' high-density (7.1 g cm^{-3}) and large effective *Z* (~63) will result in good stopping power beyond the low end of the LAT energy range at ~20 MeV. The BGO detectors will be placed on opposite sides of the GLAST spacecraft to provide high-energy spectral capability over approximately the same FOV as the NaI detectors. For redundancy, each BGO detector has two PMTs located at opposite ends of the crystal.

The signals from all 14 GBM detectors are collected by a central Data Processing Unit (DPU). This unit digitizes and time-tags the detectors' pulse height signals, packages the resulting data into several different types for transmission to the ground (via the GLAST spacecraft), and performs various data processing tasks such as autonomous burst triggering. In addition, the DPU is the sole means of controlling and monitoring the instrument. For example, the DPU controls the PMTs' power supply to maintain their gain.

3.2.3 DATA ACQUISITION

There are three basic types of GBM science data: (1) continuous data consisting of the count rates from each detector with various (selectable) energy and time integration bins; (2) trigger data containing lists of individually time-tagged pulse heights from selected detectors for periods before and after each on-board trigger; and (3) Alert Telemetry containing computed data from a burst trigger, such as intensity, location, and classification. The Burst Alert, the first packet of the Alert Telemetry, is expected to arrive at the Gamma-ray burst Coordinates Network (GCN) within 15 s of the burst trigger. Alerts originating in the GBM will also be sent to the LAT to aid in LAT GRB detection and repointing decisions. The remaining data types will be transmitted via the scheduled Ku-band contacts. The GBM is expected to produce an average of 1.4 Gbits/day, with a minimum of 1.2 Gbits/day and a maximum allocated rate of 3.0 Gbits/day.

The main GBM operating modes, continuous and burst trigger, correspond to the type of data being collected and transmitted. Additional modes will be used in response to anomalies.

1. **Continuous mode** will be the normal operating mode of the instrument. All instrument voltages will be on, and the continuous data types will be acquired and transmitted. Pre-trigger event data will be acquired but not transmitted to the ground.
2. **Burst trigger mode** will be enabled upon command from the autonomous burst trigger software, or by direct command from the spacecraft. In addition to the continuous data types, the trigger data types will also be acquired and transmitted. Instrument voltages will be unaffected. The instrument will return autonomously to continuous mode under software control.
3. **Diagnostic mode** will be enabled and disabled upon direct command from the spacecraft. Some instrument voltages may be turned off or adjusted, and mode-specific data types may be acquired and transmitted in addition to some combination of continuous and trigger data types. This mode will be used infrequently in response to anomalies, and possibly during the initial on-orbit checkout.

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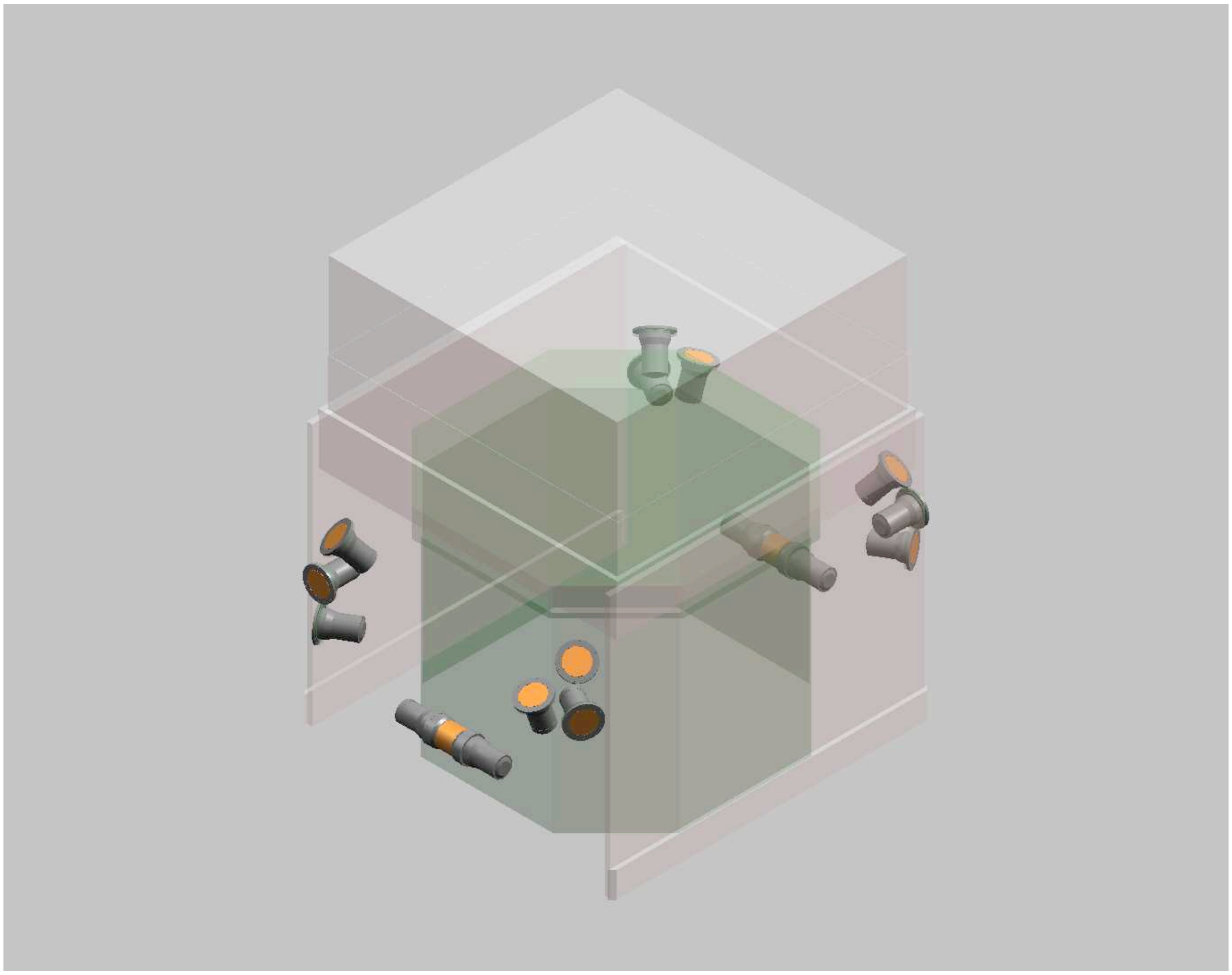

Figure 3-2: Placement of GBM Detectors on GLAST

4. **Safe mode** will be enabled and disabled upon direct command from the spacecraft, or may be enabled autonomously by the GBM.
5. **SAA** mode will be enabled and disabled upon direct (stored) command from the spacecraft. Detector high voltages will be turned off while the spacecraft is in the SAA. If the mode is entered from continuous mode, only engineering data will be acquired and transmitted. If the mode is entered from burst trigger mode, pre-trigger event data may also be transmitted.

4 GLAST'S GROUND ELEMENTS

Several elements (organizations) are involved in GLAST's ground operations; this section describes their roles and responsibilities for managing GLAST's data. Figure 4-1 shows schematically the relation between and among these elements.

4.1 THE MISSION OPERATIONS CENTER (MOC)

The MOC is the interface to the spacecraft. The MOC is located at GSFC, and will be staffed after launch by the Flight Operations Team (FOT). The MOC will maintain communications with the spacecraft. It will: receive all the data from the spacecraft; monitor the performance of the spacecraft; format and uplink commands and revised flight software to the spacecraft; detect and resolve anomalies; perform Level 0 processing of all the data from the spacecraft; and distribute the resulting data to the other ground elements. The MOC will be staffed by the FOT 8 hours a day, 5 days a week; in the event of a Target of Opportunity (TOO) or an anomaly, a member of the FOT will be paged to come to the MOC when the MOC is not staffed.

4.2 GLAST SCIENCE SUPPORT CENTER (GSSC)

The GSSC is the interface between the GLAST mission and the scientific community. It has the responsibility of organizing and administering the GI program and of providing GIs and other scientists with data, analysis software and related information. The GSSC will maintain various databases for use during the mission; these databases will become the mission archives in the HEASARC at the end of the mission. The GSSC will also support the planning of the science observations and support science operations decisions such as TOO observations. Finally, the GSSC will support the Project in running the mission.

The GSSC combines the functions often performed by a Science Operations Center—which carries out high level data processing, archiving and mission planning—and a Guest Observer Facility—which supports GIs. The GSSC will not support a dedicated facility to which investigators come to obtain and analyze data.

The GSSC assists the project scientists in organizing the meetings of GLAST-related committees such as the GLAST Users' Group (GUG), as well as scientific workshops and conferences the project will convene.

The GSSC is located in the Astrophysics Science Division (ASD) at GSFC, where it is a mission-specific constituent of the Office for General Investigator Programs (OGIP). OGIP coordinates all guest observer programs within ASD, and consists of the HEASARC and support centers for other missions that will operate concurrently with GLAST such as *INTEGRAL*, *Swift*, *XMM-Newton*, *Suzaku* and *RXTE*. By co-locating the GLAST GSSC with other support centers and the HEASARC, the GSSC will use common resources such as web services, archival services, data backup, database servers and data/software standards.

4.3 THE LAT INSTRUMENT SCIENCE OPERATIONS CENTER (LISOC)

The LISOC, the LAT's IOC, is located at SLAC, the LAT's PI institution. The LISOC consists of a number of internal elements, but this internal structure is not discussed here. The LISOC will be responsible for communications with the MOC, monitoring the performance of the

LAT, the Level 1 processing and transmitting the results to the GSSC. Before launch the LISOC is responsible for: developing the LAT Instrument Response Functions (IRFs) as part of the effort to calibrate the LAT; constructing the Level 1 processing pipeline; and developing the science analysis tools. During Phases 0 and 1 the LISOC will refine the processing pipeline based on the LAT's on-orbit performance. During the mission the LISOC will: perform the Level 1 processing for both the scientific community and the LAT team's scientific investigations; monitor the LAT's performance; and support the project in operating the LAT. The LISOC may support mirror data centers outside the United States associated with the instrument team's international members.

4.4 THE GBM INSTRUMENT OPERATIONS CENTER (GIOC)

The GIOC is located at the National Space Science and Technology Center (NSSTC) in Huntsville, AL. Before launch the GIOC is responsible for: developing the GBM IRFs as part of the effort to calibrate the GBM; constructing the Level 1 processing pipeline; and developing the science analysis tools. Immediately after launch the GIOC will refine the processing pipeline based on the GBM's on-orbit performance. During the mission the GIOC will: perform the Level 1 processing for both the scientific community and the GBM team's scientific investigations; monitor the GBM's performance; and support the project in operating the GBM. The GIOC may support a mirror data center in Germany.

The GIOC is also responsible for the Burst Alert Processor (BAP), a computer with GIOC-written software to capture autonomously the Burst Alert Telemetry and submit Notices to the Gamma-ray burst Coordinates Network (GCN) for dissemination to the burst community. The BAP will also calculate better burst positions from the Burst Alert Telemetry, and submit these improved positions to the GCN. The primary BAP resides in, and is maintained by, the GSSC. The GIOC will maintain a secondary BAP at the NSSTC as a backup for the primary BAP; this secondary BAP may be used to calculate even more accurate positions with human guidance.

4.5 THE GAMMA-RAY BURST COORDINATES NETWORK (GCN)

The GCN is a system housed in the ASD that distributes the locations of GRBs detected by spacecraft and the reports of follow-up observations made by ground-based optical, infrared and radio observers. The first function initiates follow-up observations as rapidly as possible while the second informs the astrophysical community about the burst.

When a spacecraft such as *INTEGRAL* or *Swift* detects and localizes a burst, the burst location is transmitted to the GCN which then disseminates the location and other pertinent information as a fixed format GCN Notice. As desired by the subscriber, the Notice can be sent as an e-mail, a message through an internet socket or a page. In general, there are no humans involved from the detection of the burst until the Notice arrives at the subscriber, and in many cases a robotic telescope responds autonomously to the Notice.

Observers can report their results as GCN Circulars, which are similar to IAU Circulars (circulars put out by the International Astronomical Union). These are free format messages that are e-mailed to the GCN by registered observers, and then disseminated to subscribers by e-mail. The GCN Circulars are also posted on the GCN website.

Additional information can be found at http://gcn.gsfc.nasa.gov.

4.6 THE HIGH ENERGY ASTROPHYSICS SCIENCE ARCHIVE RESEARCH CENTER (HEASARC)

The HEASARC is one of three NASA wavelength-specific research archives; the others are the Infrared Science Archive (IRSA) for infrared data and the Multimission Archive at Space Telescope science institute (MAST) for UV/optical data. These centers support active missions and sustain in usable form archival data from missions that have ended. The archives are co-located with scientists actively undertaking research, connecting the data with the necessary science expertise. The multi-mission approach to the archives leads to cost savings and a uniform analysis environment for future missions by reusing software and archive resources. These centers coordinate data management, software and media standards for space astrophysics.

The GSSC will maintain its databases and its website on HEASARC servers, and will avail itself of the HEASARC archives and software infrastructure. The GSSC will ingest nearly all the science data products into the HEASARC's data system and serve these data to the scientific community through the HEASARC's Browse interface. Thus, when the GSSC is disbanded at the end of the mission, the GSSC's databases will remain in the HEASARC as the GLAST mission's permanent archives.

The HEASARC will provide and maintain the archive and software infrastructure necessary for the analysis of GLAST data and the integration of this data into the HEASARC's multi-mission system. The HEASARC standards are found online at http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_recomm.html. Where necessary, the HEASARC's system will expand to accommodate the GLAST data and its analysis software.

The calibration data necessary to generate the IRFs will reside in the CALDB system. Consequently the HEASARC will provide and maintain the CALDB infrastructure and will augment this structure to accommodate GLAST's needs.

The HEASARC will provide and maintain the servers used by the GSSC to serve the investigator community, at no cost to the GLAST project, except for a multi-processor cluster the GSSC will use for searching the LAT photon database. The HEASARC servers will run the GSSC's databases, host the GSSC's website and communicate with the investigator community.

The GSSC will purchase and maintain the disks necessary to maintain the GSSC databases and website. These disks will be mounted on the servers that the HEASARC will provide for the GSSC, and therefore must be compatible with other HEASARC software and hardware. Procurement of these disks will begin at least nine months before launch. When the GSSC is disbanded, ownership of these disks and the data they contain will be transferred to the HEASARC.

The relationship between the HEASARC and the GSSC is defined by the GSSC-HEASARC Memorandum of Understanding (MOU).

4.7 OTHER GROUND ELEMENTS

Telemetry from the observatory will reach the MOC through two pathways. The primary pathway is the Space Network (SN), which consists of the TDRSS satellites, the White Sands Complex (WSC) through which TDRSS downlinks and uplinks data and commands, and the associated networks that deliver the data to the MOC. The secondary pathway, the Ground Network (GN), consists of the ground stations of the United Space Network (USN) through which the observatory downlinks housekeeping data and uplinks commands directly, and the associated networks. The GN is a backup for mission operations and not for downlinking science data.

4.8 ASSOCIATED ORGANIZATIONS

The NASA HQ's Astrophysics Division within the Science Mission Directorate is responsible for all post-launch GLAST Mission science operations and provides funds for the GI Program and NASA-funded portions of mission operations and data analysis.

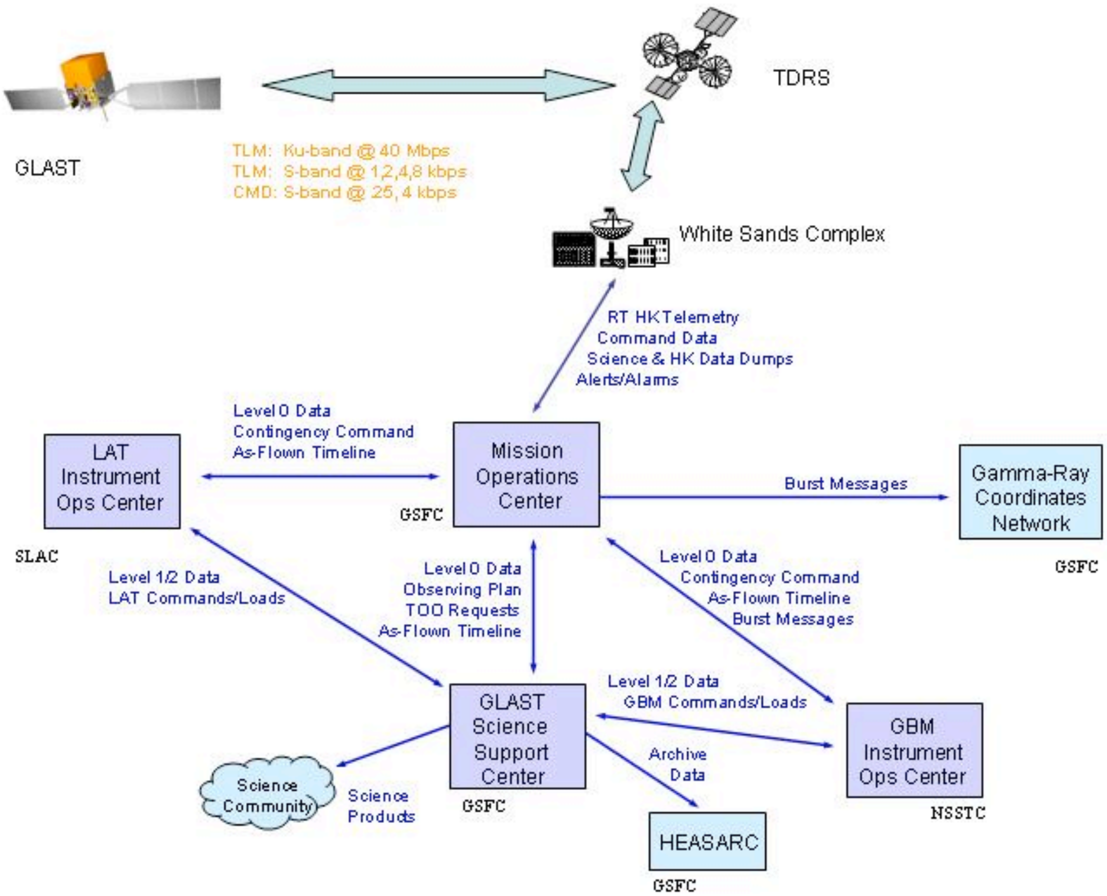

Figure 4-1: GLAST Ground Operations Overview. Only the elements involved in the data management during normal operations are shown.

The Office of Science of the U.S. Department of Energy (DOE) provides funds to SU-SLAC in support of data reduction at the LISOC.

In addition to the organizations that are established and staffed on a full-time basis, there are working groups, committees and teams that meet periodically to assist in the development and support of the GLAST GI Program. These groups include representatives of NASA HQ, the Project, the instrument teams and potential GIs from the scientific community.

The GLAST Science Working Group (SWG) is responsible for maintaining a broad and critical scientific overview of GLAST's development. The SWG advises the GLAST project of new developments in related scientific fields, and reviews documents that could affect the scientific productivity of the mission (e.g., the Science Requirements Document, this PDMP, the Mission Science Plan). After launch the SWG may be folded into the GLAST Users' Group (GUG).

The GLAST Users' Group (GUG) advises the GLAST Program Scientist at NASA Headquarters on policies that will affect the user community. The GLAST Project Scientist is responsible for implementing the policies developed by NASA HQs based on the recommendations of the Users' Group. The GSSC supports the GUG by hosting the GUG website, drafting the minutes of GUG meetings, and providing other services as needed.

The Science Operations Oversight Group (SOOG) will meet frequently (initially weekly) during operations to review and coordinate any changes in the observatory's parameters that affect Science. The SOOG consists of the Project Scientist, the instrument PIs, the GUG chair, and the leads of the GSSC, LISOC and GIOC; these members may delegate an alternate representative. Further details can be found in the Science Policy Document.

The National Space Science Data Center (NSSDC) at GSFC is the "deep archive." The GSSC will archive the Level 0 data in tapes stored by the NSSDC off the GSFC campus. The NSSDC will not distribute these data to the public without prior agreement with the GLAST project.

The Pulsar Committee will coordinate the campaign to observe pulsars GLAST might detect and to extract their ephemerides.

5 DATA DESCRIPTION

5.1 RAW DATA

Raw data are provided by the spacecraft telemetry to the ground. They may contain duplicate data packets, data packets out of time order, damaged packets, etc. All raw data will be retained at WSC (the SN's ground station) for seven days in case it becomes necessary to retransmit it for any reason. Raw data will be archived at the MOC for the duration of the mission.

5.2 LEVEL 0 DATA

Level 0 data will have undergone minimal processing. No information will be lost, but duplicate data packets will be removed, quality checks will be made, and the data packets will be time-ordered. The raw data will be decompressed (if necessary) and separated into spacecraft and instrument packets. Performed at the MOC, Level 0 processing converts the raw data into the Level 0 data. The GSSC will filter the LAT Level 0 data to remove ITAR-restricted datatypes before the data are provided to the LISOC since Stanford, and therefore LISOC, policy restricts the handling of such data. Instrument-specific Level 0 data will be archived at the IOCs. The GSSC will keep the Level 0 data for 3-4 months, and then archive them at the National Space Science Data Center (NSSDC).

5.3 LEVEL 1 DATA

Level 1 data result from "automatic" pipeline processing of Level 0 data. The resulting Level 1 data are generally the starting point for scientific analyses. Level 1 processing of LAT and GBM data will be performed at the LISOC and the GIOC, respectively. The instrument teams will access the resulting Level 1 data at their respective IOCs while the general scientific community will extract the Level 1 data from databases at the GSSC (see §5.7 below).

In LAT Level 1 processing, the Level 0 data describing the interactions within the LAT will be analyzed to identify and characterize the interacting particle (e.g., photons, electrons, protons, etc.). Thus tracks will be fitted to the hits in the TKR and CAL, the particle trajectories and energies will be calculated, and the event will be classified. The Level 1 data for an event will include at least the event arrival time, apparent energy and apparent origin on the sky. Other LAT Level 1 data will include histories of the instrument live time and pointing. The data products transferred from the LISOC to the GSSC are itemized in §6.4.1 below.

GBM Level 1 processing will primarily re-format and reorganize the data. The gains of each detector will be calibrated by monitoring the pulse-height channels of one or more background spectral lines. These gains will then be used to convert the raw detector pulse-height channels to an apparent energy. The Level 1 data will consist of continuous and burst data. Continuous data are the rates in all GBM detectors in different energy bands, regardless of whether a burst has been detected. Burst data are the counts, rates, catalog information (e.g., fluence, duration, peak flux), and ancillary data necessary for analyzing the burst. The data products transferred from the GIOC to the GSSC are itemized in §6.5.1 below.

5.4 LEVEL 2 DATA

Level 2 data will result from routine scientific analysis, usually using the science analysis software developed for more focused studies by the general scientific community (including GIs) and the instrument teams. For LAT observations these data may result from: exploratory science analyses; quick-look analyses to detect transient sources and to support operations planning; standard analysis of transient sources; refined analyses of on-board GRB and AGN (Active Galactic Nuclei) transient alerts; and accumulations of LAT sky maps for a variety of time intervals. For GBM observations Level 2 data might result from the uniform fitting of GRB spectra with standard spectral models.

5.5 LEVEL 3 DATA

Level 3 data will consist of catalogs and compendia of Level 2 data. The LAT team will produce a catalog of gamma-ray sources, including (but not limited to) flux histories and tentative source identifications. The first LAT catalog will be based on the first-year sky-survey data; updates are to be released following the 2^{nd} and 5^{th} years of operation, and the end of the mission. The GBM team will release catalogs of GBM burst energy spectra. Both instrument teams will maintain catalogs of transient events.

5.6 ANCILLARY DATA

The LAT team will produce, update and make public the diffuse Galactic interstellar and extragalactic emission models used for the analysis resulting in the LAT source catalogs; the latest models will be included in the science analysis tool releases. As a spatially varying background underlying point sources, the diffuse emission must be included in the detection and analysis of point sources. The diffuse Galactic emission is intrinsically interesting because it results from the interaction of cosmic rays with gas and photons in our galaxy.

Ephemerides of pulsars likely to be gamma-ray sources will also be provided in a standardize format.

5.7 DATABASES

The GSSC will create databases of Level 0, 1, 2 and 3 data, as well as other data, to support scientific analysis. Most of the data products will be in FITS format (aside from the Level 0 data) and will be ingested into the HEASARC's archive and served to the scientific community through the HEASARC's Browse interface from the beginning of Phase 2. Therefore, almost all the science data will be in HEASARC databases from early in the mission, where they will be maintained by the HEASARC after the GSSC is disbanded following the end of the mission. All remaining GLAST data products will be provided to the HEASARC by the end of the mission. In addition, the instrument teams will maintain databases for their own use.

As appropriate, the GSSC databases will be searchable by event energy, time, or other appropriate parameters. The databases will include calibration data, instrument response functions, event data, timeline data, exposure history, and source catalogs. For the LAT, the Level 1 processed event database will consist of the parameters determined from the analysis of all triggered events identified as gamma rays or cosmic rays, including reconstructed track and energy information, identification of events by particle type (cosmic rays, photons), event time, etc.

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Table 5-1 lists all the databases that the GSSC will maintain with the ground element that originated the data. The table also includes the identifiers for the databases or their data may have in different systems. The scientific data originate in the IOCs and therefore are described in the Science Data Products ICD and FFD (see §6.4.1 and §6.5.1). The GSSC has an identifier for all databases that it maintains. The Standard Analysis Environment (SAE), the software system that will be provided to analyze GLAST data (see §10), has its own system of identifiers for the databases upon which it relies. Finally, Table 5-1 lists the access that will be provided to the database. 'Browse' indicates that the database will be publicly accessible through the HEASARC's Browse system, 'Modified Browse' that a GLAST-specific variant of Browse will be used, 'Website' that the data (or a subset) will be presented through the GSSC website and 'Internal' that the data are not accessible by the public. The response functions will be maintained in the GLAST CALDB.

Table 5-1: Data Product and GSSC Databases

Data Product	Science Data Products ICD ID	Origin	GSSC Database ID	SAE ID	Access
1000 Planning and Scheduling Operations databases					
Level 0 Data		MOC	1510		Internal
As-flown Timeline		MOC	1710		Website
Short Term Science Timelines		GSSC	1720		Website
Long Term Science Timelines		GSSC	1721		Website
GLAST Ephemerides		MOC	1730		Internal
TDRSS Ephemerides		MOC	1731		Internal
TDRSS Forecast Schedule		MOC	1740		Internal
Requested TDRSS Contact Schedule		MOC	1741		Internal
Accepted GI Observations		GSSC	1760		Internal
Notifications and Acknowledge-ments		MOC	1770		Internal
Anomaly Reports		MOC	1780		Website
LAT Instrument Commands		ISOC	1810		Internal
LAT Instrument Memory Loads		ISOC	1811		Internal
LAT Flight Software Loads		ISOC	1812		Internal

LAT SAA Definition Updates		ISOC	1820		Internal
GBM Instrument Commands		GIOC	1850		Internal
GBM Instrument Memory Loads		GIOC	1851		Internal
GBM Flight Software Loads		GIOC	1852		Internal
GBM SAA Definition Updates		GIOC	1860		Internal
Integrated Observatory Timelines		MOC	1890		Internal
2000 User and GI Support databases					
GCN Notices		GCN	2710		GCN
GCN Circulars		GCN	2711		Website
Accepted GI Proposal Abstracts		NASA OGIP database	2730		Browse Website
Help Desk Questions and Answers		GSSC	2740		Website
3000 Science Data GBM databases					
GBM CTIME (Daily Version)	GS-001	GIOC	3110		Browse
GBM CTIME (Burst Version)	GS-101	GIOC	3111		Browse
GBM TTE	GS-103	GIOC	3120		Browse
GBM TRIGDAT	GS-107	GIOC	3130		Browse
GBM Background Files	GS-108	GIOC	3140		Browse
GBM CSPEC (Daily Version)	GS-002	GIOC	3210		Browse
GBM CSPEC (Burst Version)	GS-102	GIOC	3211		Browse
GBM Calibration Data	GS-008	GIOC	3410		CALDB
GBM DRMs	GS-104	GIOC	3411		Browse
GBM Gain and Energy Resolution History	GS-005	GIOC	3420		Internal
GBM PHA Lookup Tables	GS-007	GIOC	3421		Internal

GLAST Position and Attitude History	GS-006	GIOC	3510		Internal
GBM Housekeeping	GS-004	GIOC	3511		Internal
GBM Burst Catalog	GS-206, GS-106	GIOC	3610		Browse
GBM Trigger Catalog	GS-207	GIOC	3620		Browse
GBM Burst Spectra Catalog	GS-306	GIOC	3630		Browse
4000 Science Data LAT databases					
LAT Event Data	LS-002	ISOC	4110	D1ev	Modified Browse
Pointing/ Livetime History Data	LS-005	ISOC	4120	D2	Modified Browse
LAT Interstellar Emission Model	LS-010	ISOC	4140	D7	Website
LAT CALDB	LS-004	ISOC	4410	D3	CALDB
LAT Low-Level Calibration	LS-003	ISOC	4420		Internal
LAT Configuration History	LS-006	ISOC	4430		Website
LAT Burst Catalog	LS-009	ISOC	4610	D6	Browse
LAT Transient Catalog	LS-007	ISOC	4611	D9	Browse
LAT Point Source Catalog	LS-008	ISOC	4620	D5	Browse
5000 Science Data GSSC derived databases					
Photon Summary Data	SS-002	GSSC	5110	D1ph	Modified Browse
Pulsar Ephemerides	SS-001	GSSC	5630	D4	Website
6000 GSSC internal operations databases					
Ingest Data Product Tracking		GSSC	6710		Internal
Data Processing		GSSC	6720		Internal
Data Processing Anomalies		GSSC	6721		Internal
Issue Tracking		GSSC	6730		Internal
Re-Transmission Requests		GSSC	6740		Internal

6 NORMAL DATA FLOW

In this section we describe the normal flow of science and housekeeping data from the instruments through the different elements of the GLAST mission to the final archive. In the next section we describe the flow of burst alert data. Since our goal is to narrate the end-to-end data flow, we of necessity must touch upon the content of other sections.

6.1 DATA FLOW ON THE GLAST OBSERVATORY

The two instruments and the spacecraft will generate science and housekeeping telemetry packets continuously and store them on the Solid State Recorder (SSR), from which the packets will be downlinked periodically during a Ku band contact. The SSR will have two partitions: science and housekeeping. The fundamental concept is that science data from both LAT and GBM will be stored in the science partition, while housekeeping data from the spacecraft and the instruments will be stored in the housekeeping partition. However, the LAT will include all its housekeeping data in the science partition, and store only salient data in the housekeeping partition. Although the data in the SSR could be read out in any order, the readout will normally be first in, first out. Data will be stored in the SSR in the order received, regardless of the source (i.e., the data are not stored by source).

Each of the instruments will send data to the SSR though two interfaces. The science data will be transmitted through a dedicated Low Voltage Differential Signal (LVDS) interface to the SSR science partition. The average data rate on the LAT LVDS will be 1.2 Mbps, with a peak rate of 40 Mbps. The GBM calls its LVDS interface the High Speed Science Data Bus (HSSDB); the HSSDB will carry an average data rate of 15 kbps, with a peak rate of 12 Mbps. The housekeeping data will be sent to the SSR housekeeping partition at a rate of 51 kbps over the '1553 bus,' so called because this serial Command, Telemetry and Data Bus (CTDB) will be compliant with MIL-STD-1553B. The spacecraft will also use the 1553 bus to send its housekeeping data to the SSR. The LAT housekeeping data rate on the 1553 bus will be 4 kbps, the GBM ~3.2 kbps, and the spacecraft ~43.8 kbps.

During a Ku band contact the housekeeping data on the 1553 bus will also be downlinked to the ground on an S band link, providing the MOC and the rest of the ground system with real time housekeeping data.

The 1553 bus will also be used for communication among the spacecraft and the two instruments. Over the 1553 bus the spacecraft will send commands to the instruments at appropriate times, the instruments will send each other burst telecommands, and the instruments will send the spacecraft burst alert telemetry to be transmitted to the ground.

The LAT will create and downlink housekeeping data at a higher rate than its 1553 bus data rate and SSR housekeeping partition memory allocations. Therefore, the LAT will send all its housekeeping data along with the science data to the SSR science partition over the LVDS bus, and the most significant 4 kbps of housekeeping data to the SSR housekeeping partition over the 1553 bus. It is the housekeeping data sent over the 1553 bus that will be downlinked in real time over the S band downlink during a Ku band contact.

Science data from each instrument and required ancillary data from the spacecraft will be loaded into telemetry packets on-board the observatory. All data packets will have unique identifiers for the source of the data (e.g., LAT, GBM, spacecraft). Time tags will be inserted on-board at the time of data acquisition. The telemetry will be formatted following the recommendations of the Consultative Committee for Space Data System (CCSDS).

6.2 DATA FLOW TO THE MOC

The observatory will communicate with the MOC primarily through the Space Network (SN). The MOC will schedule ~6-7 contacts per day during which science and housekeeping data will be downlinked on the Ku-band at 40 Mbps, and commands will be uplinked on the S-band at 4 kbps (other data rates may be possible). The 30 hour capacity of the SSR onboard the spacecraft permits the loss of a number of contacts without the loss of science data. In some spacecraft orientations the observatory cannot communicate with the TDRSS satellites via Ku band; however, given the SSR's large storage capacity and the flexibility of the SN system, a scheduled telemetry contact need not disrupt an observatory pointing. The MOC will monitor the downlink data quality in realtime using frame status and accounting information from White Sands Complex (WSC). If the data quality is unacceptable, the MOC may initiate the retransmission from WSC or the spacecraft of some or all of the data. If time allows, retransmission from the spacecraft will occur during the contact; if not, the MOC will request a data retransmission during a later contact. The TDRSS contact schedule will include sufficient margin to accommodate retransmissions, but if needed, additional contacts can be scheduled. Similarly, after a contact the MOC will verify that the data have been received, distributed and stored correctly. If data are lost or below the quality threshold, a retransmission will be requested within 7 days from WSC, or from the spacecraft, if necessary. Therefore, WSC will store the received data for at least 7 days after its downlink.

On-demand S-band uplinks and downlinks will also supported. Burst Telemetry and spacecraft alarms will be downlinked through TDRSS's Demand Access Service (DAS) at 1 kbps (see §7). Burst Telemetry consists of a Burst Alert, informing the ground that either the GBM or the LAT has triggered on a burst, and additional spectral and temporal information about the burst. If a scheduled Ku-band contact is in progress, the Burst Telemetry or spacecraft alarms will be downlinked over the Ku-band. Similarly, high priority commands (e.g., implementing TOOs or responding to an observatory crisis) may be uplinked at 250 bps (a higher rate may be feasible).

Scheduled S-band contacts with the GN may be used during observatory checkout and for contingencies. The spacecraft will be capable of downlinking real-time housekeeping at 2.5 Mbps, and uplinking commands at 2 kbps. During normal operations the GN link will be exercised occasionally to ensure its operational proficiency.

6.3 PROCESSING BY THE MOC

The MOC will perform Level 0 processing on the raw data immediately upon receipt of the last bit it receives from a Ku-band contact. Level 0 processing will correct transmission artifacts such as duplicate data packets and packets out of time order, and will annotate the data quality. The MOC is not responsible for removing repeated data between the end of one scheduled Ku-band contact and the beginning of the subsequent scheduled contact. The MOC then will send all the Level 0 data to the GSSC for archiving; see Table 6-1. The MOC will transmit the GBM science and housekeeping data to the GIOC; the GBM's collaborators at MPE will obtain non-ITAR-controlled GBM data directly from the MOC. Due to policy restrictions in force at Stanford University, and thus at SLAC, the LISOC cannot receive any data that may contain ITAR-controlled information. The MOC will transfer Level 0 files that only contain LAT information directly to the LISOC. The GSSC will transfer the Level 0 files that that might contain spacecraft information to the LISOC after suitable redaction (see §6.6). The MOC will use LISOC-provided software to ensure that only non-ITAR data are sent to the LISOC. The MOC will retain the raw telemetry for the duration of the mission. The IOCs are ultimately responsible for the quality of their Level 0 science data, and will request retransmission of mission or corrupted data.

The MOC will monitor the health of the spacecraft using the real time spacecraft housekeeping data during each Ku-band contact. The MOC will also analyze select engineering and instrument data after each contact. The GLAST Project Scientist, the GSSC and the IOCs will be notified if any anomalies are detected. The MOC will maintain a database of all telemetry and command mnemonics; this database will be archived at the GSSC.

Table 6-1: MOC Data Product

Product	Description	Delivered	Latency	Size
Level 0 Data	Level 0 data from the instruments and the spacecraft. The GSSC receives everything. The GIOC receive the data relevant to their instrument. The LISOC receives non-ITAR controlled data.	Per downlink		

6.4 PROCESSING BY THE LISOC

The LISOC will receive LAT Level 0 data from the MOC. During Phase 2 the LISOC will complete the Level 1 processing within 24 hours of receipt of the data. The resulting Level 1 data will be provided to the GSSC for dissemination to the astronomical community, and will be used by the LAT team for its investigations. The LISOC will provide data to mirror sites maintained by LAT instrument team collaborators.

The LAT team will be responsible for maintaining a model of the Galactic interstellar and extragalactic diffuse emission, which is the background against which point sources are detected and analyzed (this emission is of course intrinsically interesting). Periodically the LISOC will send the GSSC an updated diffuse emission model.

The LISOC will monitor the LAT's performance using the housekeeping data that are included with the science data. They will produce time histories of relevant instrument parameters (e.g., PMT gains, detector noise occupancy). Within the LISOC, a separate database of highly energetic cosmic rays will be accumulated to assist in the determination of the relative positions of the SSDs in the TKR. Similarly, other parameters of diagnostic or calibration use may be accumulated. Examples might include histograms of TKR strip hits to identify bad strips, histograms of ACD PMT output to identify malfunctioning PMTs, statistics on ACD tile response, and histograms of CAL readout response to identify noisy or dead CAL channels. A standard report of instrument health will be generated weekly and posted to websites maintained (or linked to) by the LISOC and the GSSC. Separate status reports may be considered for these sites that are open to the general public as well as ones useful to the scientific community, and an archive of the reports will be maintained at the GSSC.

Periodically the LAT team will run the LAT in an engineering mode to test its health and status and to re-calibrate the instrument. Ideally the schedule for these tests should be developed at the beginning of the yearly GI cycles to minimize disrupting the mission timeline, but on occasion an unanticipated test may be required. The LISOC will request that the GSSC schedule the test.

The LAT team will update the instrument's flight software based on in-orbit operational experience. In particular, the LAT team will turn off malfunctioning components (e.g., ACD tiles or TKR modules), or will mask out components that have failed. The LISOC will prepare a command set implementing the flight software update. The command set will be sent to the MOC through the GSSC, and then uplinked to the spacecraft through the TDRSS Multiple Access System (MAS).

6.4.1 LAT SCIENCE DATA PRODUCTS

The data products in Tables 6-2 and 6-3 will be produced by the LISOC and delivered to the GSSC as FITS files, except where noted. The formats are all described in the Science Data Products FFD, which is the controlling document. The identifier in the first column is from this FFD; the 'LS' prefix indicates that the data product is transferred from the LISOC to the GSSC. Most of these products will be ingested into the HEASARC data system and accessed through Browse; the remaining products will be transferred to the HEASARC by the end of the mission.

Latency is defined as the time between the arrival of the last data required to produce the data product and delivery of the resulting product.

The LISOC will process the Level 0 data for each orbit, and send the resulting event and spacecraft position files to the GSSC; see Table 6-2.

The primary LAT Level 1 data products are the LAT Events (LS-001) and LAT Photons (LS-002). LAT Events consists of events that were reconstructed from the Level 0 data that were downlinked to the ground. The event datafiles that the LISOC will provide to the GSSC will include a large set of parameters resulting from the event reconstruction describing the event, but will not describe the "hits" in the LAT's TKR or CAL. These events will be stored at the GSSC in the event database. The LAT Photons data product contains events with a high probability of resulting from photons and a subset of specific parameters relevant to calculating the IRF for those photons; this data product will be stored in the photon database (D1ph) that will be used by most scientists. Utilities will be provided to access the event database, but the GSSC will not supply software to use the events and parameters not included in the photon database.

Table 6-2: LISOC Data Products Delivered After Each Processing Run

ICD ID	Product	Description	Delivered	Latency	Size (bytes)
LS-001	LAT Events	Subset of merit n-tuple for subset of the events telemetered to the ground	Per processin g run (~18 per day)	1 day	250 MB

Table 6-2: LISOC Data Products Delivered After Each Processing Run					
LS-002	LAT Photons	Selected parameters from the subset of events identified as gamma-ray photons	Per processing run (~18 per day)	1 day	25 MB
LS-003	LAT Livetime Cubes	LAT livetime as a function of sky position and off axis angle	Per processing run (~18 per day)	1 day	
LS-005	LAT Pointing and Livetime History	LAT orientation and mode at 30 s intervals; used to calculate exposures	Per processing run (~18 per day)	1 day	100 kB

Finally, the LISOC will provide other data products from time to time, as needed (see Table 6-3). These additional products include new response functions, an updated model of the diffuse emission model and catalogs.

Table 6-3: LISOC Data Products Delivered As Updates

ICD ID	Product	Description	Delivered	Freq.	Size (bytes)
LS-008	LAT Point Source Catalog	Table of detected gamma-ray sources with derived information	On update	N/A	10 MB
LS-009	LAT Burst Catalog	List and characterization of gamma-ray bursts: location, duration, intensity	On update	N/A	TBD
LS-010	Interstellar Emission Model	Model for diffuse gamma-ray emission from the Milky Way, input for high-level data analysis; will be refined using GLAST data	On update	N/A	40 MB
LS-011	LAT Energy Redistribution	Constants for parameterization of the LAT's energy redistribution	On update	N/A	12 kB (12 kB/ file)
LS-012	LAT Effective Area	Constants for parameterization of the LAT's effective area	On update	N/A	120 kB (~30 kB/ file)
LS-013	LAT PSF	Constants for parameterization of the LAT's point spread function	On update	N/A	64 kB (17 kB/ file)

6.5 PROCESSING BY THE GIOC

The GIOC will process one day's worth of continuous data within 24 hours after receiving the last Level 0 data from that day from the MOC. Similarly, the GIOC will process data from instrument triggers (not all of which will result from bursts) within 24 hours of receiving the relevant Level 0 data. The resulting Level 1 data will be provided to the GSSC for dissemination to the astronomical community, and will be used by the GBM team for its own investigations. Requests for engineering mode operations and revisions to the flight software will be submitted through the GSSC (see §8). The GIOC will also supply data to mirror data centers maintained by the GBM instrument team collaborators.

The GIOC will monitor the GBM's performance using the housekeeping data that are included with the science data. The GIOC will produce time histories of relevant instrument parameters (e.g., PMT gains). A standard report of instrument health will be generated weekly and posted to websites maintained (or linked to) by the GIOC and the GSSC. Separate status reports may be considered for these sites that are open to the general public as well as ones useful to the scientific community.

The GBM team will update the instrument's flight software based on in-orbit operational experience. The GIOC will prepare a command set implementing the flight software update. The command set will be sent to the MOC through the GSSC and then uplinked to the spacecraft.

High-level GBM Level 2 processing will result in catalogs of burst locations, spectra and lightcurves.

6.5.1 GBM SCIENCE DATA PRODUCTS

The data products in Tables 6-4, 6-5 and 6-6 will be produced by the GIOC and delivered to the GSSC as FITS files. They are all described in the Science Data Products ICD and FFD, which are the controlling documents. The identifier in the first column is from this ICD; the 'GS' prefix indicates that the data product is transferred from the GIOC to the GSSC. Most of these products will be ingested into the HEASARC data system and accessed through Browse; the remaining products will be transferred to the HEASARC by the end of the mission.

Latency is defined as the time between the arrival of the last data required to produce the data product and delivery of the resulting product.

The GIOC will transfer three categories of data products: daily, burst and updates.

The daily data products consist of data that are produced continuously regardless of whether a burst occurred; see Table 6-4. Thus these products are the count rates from all detectors, the monitoring of the detector calibrations (e.g., the position of the 511 keV line), and the spacecraft position and orientation. The underlying Level 0 data arrive continuously with each Ku band downlink. However, the GIOC will form FITS files of the resulting Level 1 data covering an entire calendar day (UT); these daily files are then sent to the GSSC. Consequently, the data latency is about one day: the first bit from the beginning of a calendar day may arrive a few hours after the day began while the last bit will be processed and added to the data product file a few hours after the day ended. These data products may be sent to the GSSC as they are produced, not necessarily in one package for a given day.

Table 6-4: GIOC Daily Data Products

ICD ID	Product	Description	Number of Files per Day	Latency	Size (bytes)
GS-001	CTIME (daily version)	The counts accumulated every 0.256 s in 8 energy channels for each of the 14 detectors.	14	24 hours after receipt of last input data	230 MB (16 MB/file)
GS-002	CSPEC (daily version)	The counts accumulated every 8.192 s in 128 energy channels for each of the 14 detectors.	14	24 hours after receipt of last input data	290 MB (20.6 MB /file)
GS-005	GBM gain and energy resolution history	History of the detector gains and energy resolutions; required for calculating DRMs.	14	24 hours after receipt of last input data	42 kB (3 kB/ file)
GS-006	GLAST position and attitude history	History of GLAST's position and attitude, required for calculating DRMs	1	24 hours after receipt of last input data	3 MB

The burst data products are the files pertaining to a given burst that are produced and sent to the GSSC within a day after the burst; see Table 6-5. These include lists of counts, binned counts, and the response and background spectra necessary to analyze the burst data. The burst products also include catalog files with summary data resulting from pipeline processing and a file with the TRIGDAT messages sent down over TDRSS immediately after a burst.

Table 6-5: GIOC Burst Data Products

ICD ID	Product	Description	Number of Files per Burst	Latency	Size (bytes)
GS-101	CTIME (burst version)	For each detector, the counts accumulated every 0.256 s in 8 energy channels	14	1 day	16 MB (1.15 MB /file)
GS-102	CSPEC (burst version)	For each detector, the counts accumulated every 8.192 s in 128 energy channels	14	1 day	16 MB (1.15 MB /file)

GS-103	GBM TTE	Event data for the burst	14	1 day	40-60 MB (3-4.5 MB /file
GS-104	GBM DRMs	8 and 128 energy channel DRMs for all 14 detectors	28	1 day	6 MB (0.4 MB /file)
GS-105	GBM Trigger Catalog Entry	Classification of GBM trigger with some characteristics	1	1 day, updated periodical ly	20 kB
GS-107	GBM TRIGDAT	All the GBM's messages downlinked through TDRSS	1	1 day	50-100 kB
GS-108	GBM Background Files	Backgrounds for spectral fitting	14	1 day	14 kB (1 kB /file)

The final category of GIOC data products are those that are updated and sent to the GSSC periodically as required by new analysis; see Table 6-6. These include calibrations that either do not change with time or change slowly. The catalogs—trigger, burst and spectral—are in this category. A preliminary version of the burst catalog file is distributed with the other burst data, while a number of updates will be provided subsequently as the data are reanalyzed, often with human intervention.

Table 6-6: GIOC Data Products Delivered as Updates

ICD ID	Product	Description	Number of Files	Frequency	Size (bytes)
GS-003	Ground-initiated TTE	Event data accumulation initiated by a ground command	14	Periodically	40-60 MB (3-4.5 MB /file
GS-004	GBM Calibration	Tables of fiducial detector response parameters from which the burst-specific DRMs are calculated	TBD	Every ~6 months	100 GB
GS-007	GBM PHA Look-Up Tables	Tables of the correspondence between CTIME and CSPEC energy channels and the photopeak energy for each detector	4	Every ~6 months	4 kB (1 kB/ file)
GS-008	GBM DRM Database Compressed Leaf Files	DRMs on a grid of zenith and azimuth angles	TBD	Every ~6 months	100 GB
GS-105	GBM Trigger Catalog Entry	Classification of GBM trigger with some characteristics	1	Updated periodically after initial file	20 kB

GS-106	GBM Burst or Spectral Catalog Entry	Values of the quantities describing the burst (e.g., durations, fluences)	1	Updated periodically	100-200 kB

6.6 PROCESSING BY THE GSSC

The GSSC will receive all the Level 0 data from the MOC. The GSSC will maintain the Level 0 data for 3-4 months, after which the data will be transferred to the NSSDC for long-term archiving. These data will be written on tapes that will be physically provided to the NSSDC for storage off the GSFC campus.

Due to Stanford University's data policies, which apply to SLAC and the LISOC, the LISOC cannot receive any data that may contain ITAR-controlled information. The MOC will transfer Level 0 files that only contain LAT information (and no ITAR-restricted spacecraft information) directly to the LISOC. The GSSC will transfer the LAT Level 0 files that that might contain spacecraft information to the LISOC only after suitable redaction to remove ITAR-controlled information. The LISOC will provide the GSSC with the redaction software. The GSSC and the NSSDC will archive only the non-redacted Level 0 files.

The GSSC will receive Level 1 processed data from the IOCs. The Level 1 science data will be ingested into the HEASARC's databases and served to the scientific community through the HEASARC's Browse interface. Thus the HEASARC will possess the Level 1 data from early in the mission, and will maintain these data after GLAST is deorbited as the mission's final archive. Under normal circumstances the GSSC will not perform Level 1 processing for either instrument. However, in case of an emergency, the GSSC will have current Level 1 processing software installed on the GSSC servers as backups for the IOCs. The software will not be run without the concurrence and supervision of the relevant IOC. GSSC staff will be familiar with operating the software.

The GSSC will also perform certain Level 2 processing of LAT data to keep the astronomical community informed of the progress and results of the mission, and to assist GIs in planning GLAST-related research. Such processing may include maps of counts and exposure for the entire sky and for selected regions (e.g., the Galactic center or the region about 3C273); these maps will be posted on the GSSC website.

During Phase 2 of the mission the GSSC will be the primary source of data for the GIs and the general astronomical community. During Phase 2 the Level 1 data will be accessible from the GSSC's databases within 24 hours after their arrival at the GSSC. After the observations necessary for a guest investigation have been performed, the investigator will extract the data from the science databases (see the discussion below). The investigator will then transfer the files back to his/her computer; the analysis software will be available through the GSSC's website.

Finally, the GSSC will be responsible for producing and maintaining databases of the data products it will receive from the IOCs or those it will produce itself (see §5). These GSSC databases will be used during the mission, and will become the final archives maintained by the HEASARC afterwards. They will be constructed to conform to the standards of the HEASARC, and will be maintained within the HEASARC. For operational purposes the GSSC may distribute some of its databases over a multi-processor system during the mission, but will provide the HEASARC with a mutually agreed-upon archival form by the end of the mission.

Table 6-8: GSSC Data Products

ICD ID	Product	Description	Created	Production Latency	Size
Level 0 Data	Level 0 data from the instruments and the spacecraft. The LISOC will receive redacted files.	Per downlink			
SS-002	Pulsar Ephemerides	Ephemerides of pulsars that may be detectable by the LAT	Periodically	N/A	TBD

7 BURST ALERT DATA FLOW

When either the GBM or the LAT detects a burst, the detecting instrument will inform the other instrument through a series of telecommands (see §7.1 and §7.2 below) and will transmit Burst Alert Telemetry (see §7.3 and §7.4 below) to the ground through the TDRSS DAS (or the Ku-band downlink if the burst occurs during a scheduled contact). The first packet transmitted to the ground is called the Burst Alert. In addition, the GBM will send the LAT a one bit signal over a dedicated wire when the GBM triggers. Note that the GBM flight software will include algorithms that will determine whether the trigger is likely to be a burst (as opposed to a solar flare or a particle event).

If the GBM triggers on the burst and determines that the burst meets the criteria for an autonomous repoint then the GBM will send a telecommand to the LAT recommending such a repointing of the observatory. Similarly, the LAT may detect a burst and determine that an autonomous repoint is warranted. Whether the repoint request originates in the GBM or the LAT, the spacecraft receives the repoint request from the LAT. The spacecraft may reject the request if autonomous repoints are not enabled, such as during a TOO observation. The criteria for, and duration of, autonomous repoints will be specified in the Science Policy Document, but nominally they will occur approximately once a week and last for 5 hours; a higher threshold will most likely be applied to bursts outside the LAT's FOV.

The Burst Alert Telemetry is routed by WSC to the MOC, which immediately passes it to the primary Burst Alert Processor (BAP). The BAP is a processor supplied by the GIOC but housed in, and maintained by, the GSSC. The BAP will format the burst telemetry, particularly the burst position calculated by either the GBM or the LAT, and pass the resulting Notices to the GCN for dissemination to all interested observatories by internet socket, e-mail or pager. The expected time between the burst trigger and the submission of the first Notice to the GCN is less than 15 s. Taking advantage of greater CPU speed and memory than available onboard, the BAP will also calculate an improved burst location using the GBM Burst Alert Telemetry, and send out the improved position as a GCN Notice. The LISOC may provide software for the BAP to analyze LAT data sent down in the Burst Alert Telemetry. The MOC will also send the secondary BAP at the GIOC the Burst Alert Telemetry for further analysis with human intervention; if a better location results, the GIOC will send out another GCN Notice. The secondary BAP is also a backup for the primary BAP. Finally, each IOC may further refine the burst position using the full data downlinked through a scheduled Ku-band contact and report the resulting positions through GCN Circulars. The IOCs may also issue GCN Circulars describing additional burst characteristics such as the fluence, duration, and spectral hardness.

The data products listed below are described in the LAT-GBM Burst Telecommand and Alert Telemetry ICD (433-ICD-0001), which is the controlling document.

7.1 GBM TELECOMMANDS TO THE LAT

The following telecommands are sent by the GBM to the LAT over the 1553 bus. Note that there is also an "Immediate Trigger Signal," a one-bit signal that is sent over a dedicated wire between the GBM and the LAT when the GBM triggers.

Table 7-1: GBM Telecommands to the LAT

Name	Contents	Frequency per trigger	Size
G2LCALCINFO	Trigger location and characterization	Up to 5 times	46 Bytes

(TRIGDAT11)			
G2LCREPREC (TRIGDAT12)	Repoint recommendation	1 (suppresses further TRIGDAT11 messages)	28 Bytes
G2LCLOSEOUT	End of GBM telecommands	1	18 Bytes

7.2 LAT TELECOMMANDS TO THE GBM

The following telecommands are sent by the LAT to the GBM over the 1553 bus.

Table 7-2: LAT Telecommands to the GBM

Name	Contents	Frequency per trigger	Size
L2GLATTRIGGER	Time the LAT triggered	1	22 Bytes
L2GLATCLOSEOUT	End of LAT telecommands	1	22 Bytes

7.3 GBM BURST ALERT TELEMETRY

The following Burst Alert Telemetry records are sent by the GBM to the ground through TDRSS, unless a previously scheduled Ku band contact is in progress. The GIOC will package these records into the TRIGDAT data product (GS-107) that it will provide the GSSC (see §6.5).

Table 7-3: GBM Burst Alert Telemetry

Name	Contents	Frequency per trigger	Size
Immediate Summary Information (TRIGDAT01)	Notice that the GBM has triggered	1	38 Bytes
Trigger Rates (TRIGDAT02)	Rates in each detector in each energy channel over trigger timescale	1	266 Bytes
Background Rates (TRIGDAT03)	Background rates in each detector in each energy channel at trigger time	1	246 Bytes
Calculated Information (TRIGDAT04)	Trigger location and characterization (i.e., whether a burst, spectral parameters)	Up to 5	62 Bytes
Max Rates (TRIGDAT05)	Maximum rates in each detector in each energy channel from time bin with highest S/N ratio	Up to 3	274 Bytes
Time History (TRIGDAT09)	Rates in each detector in each energy channel for time bins with different resolution spanning the trigger	Up to 124	266 Bytes

The time history records (TRIGDAT09) are accumulated as shown in Table 7-4.

Table 7-4: TRIGDAT09 Time Coverage

Time Range Relative to Trigger (s)	Time Resolution (s)	Number of Records
Continuous Coverage		
-133.120 to -2.048	8.192	17
-2.048 to 22.528	1.024	25

+22.528 to 481.280	8.192	56
Greater Time Resolution for Trigger		
-1.024 to 2.048	0.256	13
-0.256 to 0.512	0.064	13

7.4 LAT BURST ALERT TELEMETRY

The following burst alert telemetry records are sent by the LAT to the ground through TDRSS (unless a previously scheduled Ku band contact is in progress).

Table 7-5: LAT Burst Alert Telemetry

Name	Contents	Frequency per trigger	Size
LATTRIGGER	Notice that the LAT has triggered, and includes trigger classification, localization, time of earliest photon, and number of photons in different energy channels.	1	88 Bytes
LATUPDATE	Updates to LATTRIGGER with the same information content as LATTRIGGER	Up to 10	88 Bytes
LATCLOSEOUT	Last record from the LAT, with the same information content as LATTRIGGER	1	88 Bytes

8 COMMANDING AND OBSERVATORY TIMELINE

Most commanding of the GLAST observatory will occur through weekly loads that will be uplinked on the S-band during a scheduled contact. The science timeline created by the GSSC is implemented through the weekly load. When necessary, additional command loads can be uplinked, either during a scheduled downlink or in a specially scheduled uplink.

8.1 COMMAND TYPES

There will be three classes of commands: real-time commands that are executed immediately upon arrival at the spacecraft; Absolute Time Commands (ATCs) that are uplinked, stored in two spacecraft buffers and executed at specific absolute times; and Relative Time Sequence (RTS) tables that are stored in the spacecraft's memory and are invoked by the flight software, a real-time command or an ATC. For example, an ATC may invoke an RTS at a specific time, and the RTS may then change all the gain settings of the GBM. A load of ATCs is called an Absolute Time Sequence (ATS) table. Real-time commanding will be used primarily during the observatory checkout, while ATS commanding will predominate during normal operations. A weekly ATS load is planned; this load will implement the science timeline for one week.

Each command sent to the observatory includes a tag identifying the intended recipient: the spacecraft or one of the instruments. The instruments execute commands when they arrive; the instruments do not have a command buffer.

The MOC will maintain the Project Database (PDB) that will translate the human-intelligible command names or mnemonics into the bit patterns the CPUs on board the spacecraft will understand. In addition to commands, the ground system will use PROCs, procedures with parameters that are sent from an IOC through the GSSC to the MOC where the PROCs are expanded into a series of commands. PROCs may incorporate logic and telemetry verifications along with the commands to be issued.

8.2 THE LONG-TERM SCIENCE TIMELINE

The GSSC is responsible for generating and monitoring GLAST's observing plan. During Phase 1 (the first year of scientific operations) the timeline will be relatively simple: GLAST will conduct an all-sky survey in survey mode that will be interrupted only by Project Scientist-approved TOO observations, autonomous repointings following transients and GRBs, calibration observations, or by spacecraft anomalies.

During Phase 2 the observing timeline may be affected by the GI program. Each proposal cycle the peer review panels will recommend which proposed GI observations should be accepted. The GSSC will then construct a science timeline for the period of that cycle (nominally a year), attempting to schedule the tentatively-accepted GI observations into a long-term schedule. Only those GI proposals requesting observations whose observations can be fitted into the long-term schedule will be accepted, regardless of a positive peer review panel recommendation. However, the frequency of pointed observations will probably be low enough that the most likely reason a GI-proposed observation cannot be scheduled is a conflict between two time-constrained observations.

The definitive scheduling of an observation within a given week will occur only when that week's timeline is constructed. If an observation scheduled for a given week is not performed or is truncated significantly because of a TOO, autonomous repoint or some other disruption of the schedule, the observation will generally be re-scheduled to a later week. Therefore, periodically the long-term schedule will be revised.

Both the long-term and the weekly science timelines will be accessible from the GSSC website.

The IOCs will periodically request that one of the GLAST instruments be operated in an engineering mode to collect diagnostics on the instrument's performance. The Project Scientist (or his/her designee) will approve such requests, and the GSSC will schedule the engineering mode operation. Optimally, the schedule for engineering mode operation will be developed at the beginning of each yearly cycle.

The GSSC will develop software to simulate GLAST observations to support timeline planning and to evaluate sky survey techniques for uniformity of coverage over various timescales, for frequency of full sky coverage, and for spacecraft feasibility.

8.3 THE WEEKLY COMMAND LOAD

The GSSC will create weekly science timelines implementing the observations planned for that week in the yearly timeline. Because of the long lead time necessary to schedule TDRSS Ku band contacts, a preliminary science timeline must be created and sent to the MOC nearly a month before its implementation. The MOC will request Ku band contacts from TDRSS based on this preliminary science timeline, and TDRSS will provide the MOC with the scheduled contacts approximately a week before implementation. The GSSC can refine the science timeline, particularly by adding instrument commands, and resubmit the final science timeline to the MOC a few days before implementation. In general the final science timeline can alter the observations included in the preliminary science timeline as long as the scheduled TDRSS contacts are not disrupted; because of the margin on the scheduled TDRSS contacts (i.e., more contact time will be scheduled than required) the GSSC may revise the schedule and miss a TDRSS contact if necessary, after consulting with the MOC. GLAST's Ku band antenna is on the earth side of the spacecraft while the TDRSS satellites are in geosynchronous orbit (i.e., much higher than GLAST's orbit), and therefore Ku contacts are possible only at specific orientations of GLAST and the TDRSS satellites.

After the preliminary science timeline has been circulated, the IOCs will send the GSSC instrument commands to be included into the final science timeline. While the instrument commands will include a requested execution time, the GSSC will check whether the commands conflict with the observing plan (e.g., by changing a mode in the middle of an observation). The GSSC will check that each IOC sends commands only for their instrument. The GSSC will archive internally all commands received from the instrument teams.

The MOC will integrate spacecraft commands (e.g., implementing the Ku band contacts) with the GSSC's science timeline, resulting in an integrated observatory timeline. The MOC will check whether commands satisfy engineering constraints. Before implementation the GSSC will receive and evaluate the integrated observatory timeline to insure that the spacecraft commands do not disrupt any GI observations. The integrated observatory timeline is then translated into the Absolute Time Sequence (ATS) command load that is uplinked to the spacecraft on the S-band link during a scheduled contact. At the end of week covered by the ATS the MOC will create the as-flown timeline, which the GSSC will compare to the science timeline, noting observations that were pre-empted or shortened by TOOs or autonomous repointings. If needed, the GSSC will compensate GIs whose observations were disrupted by scheduling additional observations in following weeks. All the above-mentioned timelines will be archived by the GSSC, and the science and as-flown timelines will be posted on the GSSC website.

8.4 ADDITIONAL COMMAND LOADS

If needed, commands and flight software upgrades can be uplinked in between the uplink of the weekly ATS load implementing the integrated observatory timeline. The GSSC will insure that such real time commands do not disrupt an observation; however, the GSSC will pass a command immediately to the MOC if an IOC marks it as very high priority (e.g., if the safety of the instrument is an issue). Large flight software upgrades and time critical commands (e.g., to save an instrument or the observatory) will be uplinked through TDRSS Multiple Access Facility (MAF). While non-critical commands can be uplinked at any time, implementing commands through the weekly observatory timeline will be preferred.

8.5 TOO

The GLAST Project Scientist (or his/her designee) may declare a TOO observation based on criteria stated in the Science Policy Document. A TOO may be considered because: an approved GI's TOO criteria have been satisfied; a source is undergoing an extreme variation (e.g., a giant radio flare); or a scientific discovery or development justifies an immediate observation. TOO requests will be submitted to the Project Scientist through the GSSC website using the Remote Proposal System (RPS). If the request is to carry out a TOO proposed in an accepted GI proposal, the requester will explain how the proposal's criteria have been met. If the requested TOO is not associated with a GI proposal, the requester will justify the TOO. The Project Scientist (or his/her designee) will ask the GSSC duty officer whether a TOO is feasible. The GSSC will consider observational constraints (if any) and the impact on the timeline.

Within 2 hours after the Project Scientist or his/her designee authorizes a TOO, the GSSC duty officer will send to the MOC a TOO order defining the TOO, and will notify the IOCs, the scientist requesting the TOO, and the scientific community (via the GSSC website) of the TOO. The MOC will construct the commands, schedule a forward telemetry service, transmit the commands to the spacecraft, verify that the commands have been executed, and notify the GSSC of whether the TOO was implemented. The MOC has 4 hours from the receipt of the TOO order from GSSC until the commands are sent to TDRSS. If the MOC is not staffed when the TOO order is issued, a member of the FOT will come in to the MOC to implement the TOO order.

Some TOOs do not need to be implemented immediately. For example, those requested during non-business hours can usually wait until the GSSC and FOT are both staffed during normal working hours. Then the GSSC will send to the MOC a new science timeline with the TOO observation, and the MOC will create a new ATS to be uplinked to the spacecraft. Similarly, if a TOO observation initiated by a TOO order (i.e., within a few hours after the TOO is approved) will extend for a number of days, the GSSC will send to the MOC a new science timeline implementing the TOO observation, and ask the MOC to cancel the TOO order. The

MOC will then create a new ATS, cancel the TOO order, and uplink the ATS implementing the remainder of the TOO observation.

8.6 OPERATIONS DATA PRODUCT SUMMARY

These data products are all described in the Operations Data Products ICD.

8.6.1 MOC

The following data products will be produced by the MOC and delivered to the other ground system elements.

Table 8-1: Spacecraft Operations Data Products

Product	Description	Delivered	Latency	Size	Provided to
Level 0 Data	Level 0 data from the instruments and the spacecraft. The GSSC receives everything, the IOCs receive the data relevant to their instrument	Per downlink			GSSC GIOC ISOC
As-flown timeline	Timeline describing the history of GLAST's pointing	Once per week			GSSC
Integrated Observatory Timeline	Timeline of the commands and observing plan for the weekly ATS upload	Once per week			GSSC
Anomaly Reports	Alerts from the spacecraft or instruments.	Per incident			GSSC
TDRSS Ephemerides	TDRS ephemerides from Flight Dynamics	Once per week			GSSC
GLAST Ephemeris	GLAST's STK-generated ephemeris for the coming month; used for scheduling observations	Once per week			GSSC
Notifications, Acknowledgements and Dispositions	TBD	As needed			GSSC
Requested TDRSS Contact Schedule	The request for TDRSS contacts (time, TDRS to be used) made by the MOC a ~month beforehand.	Once per week			GSSC
TDRSS Forecast	The granted TDRSS	Once per			GSSC

Schedule	contacts (time, TDRS to be used). Required by the GSSC for creating the final science activity schedule.	week			
Observatory Telemetry and Command Database Updates	Updates to the database that defines the telecommands, telemetry, discretes, analogs, limits, flight parameter mnemonics, and ground system parameters. Note that this database will be ITAR-controlled.	When updated			GSSC

8.6.2 LAT

The following data products will be produced by the LISOC and delivered to the other ground system elements. The command products will be delivered first to the GSSC, which usually sends them on to the MOC; the GSSC to MOC transfer is not treated as a new data product, and the data product is shown in this table as being delivered to both the GSSC and the MOC.

Table 8-2: LAT Operations Data Products

Product	Description	Delivered	Latency	Size	Deliver to
Data Retransmission Requests	Request for retransmission of data because the original transmission was corrupted	As needed			MOC
LAT Anomaly Incident Reports	Reports by LAT team on the cause and resolution of a LAT anomaly	As needed			MOC GSSC
LAT Instrument Loads and Commands	All commands to be uploaded within the weekly ATS submitted by the LISOC to the MOC through the GSSC, whether or not they were executed. In Phase 0 or in an emergency may bypass the GSSC.				GSSC MOC
LAT Instrument Memory Loads and Commands	All commands submitted by the LISOC to the MOC through the GSSC, whether or not they were executed. In Phase 0 or in an emergency may bypass the GSSC.				GSSC MOC

LAT FSW Loads	All FSW loads submitted by the LISOC to the MOC through the GSSC. In Phase 0 may bypass the GSSC.				GSSC MOC
SAA Definition Updates	An update to the LAT's definition of the SAA. Differs from the standard LAT memory load in that the SAA definition is used by the spacecraft FSW. The GSSC will use the SAA definition in the science planning. In Phase 0 may bypass the GSSC.				GSSC MOC

8.6.3 GBM

The following data products will be produced by the GIOC and delivered to the other ground system elements. The command products will be delivered first to the GSSC, which usually sends them on to the MOC; the GSSC to MOC transfer is not treated as a new data product, and the data product is shown in this table as being delivered to both the GSSC and the MOC.

Table 8-3: GBM Operations Data Products

Product	Description	Delivered	Latency	Size	Deliver to
Data Retransmission Requests	Request for retransmission of data because the original transmission was corrupted	As needed			MOC
GBM Anomaly Incident Reports	Reports by GBM team on the cause and resolution of a GBM anomaly	As needed			MOC GSSC
GBM Instrument Loads and Commands	All commands to be uploaded within the weekly ATS submitted by the GIOC to the MOC through the GSSC, whether or not they were executed. In Phase 0 or in an emergency may bypass the GSSC.				GSSC MOC
GBM Instrument Memory Loads and Commands	All commands submitted by the GIOC to the MOC through the GSSC, whether or not they were executed. In Phase 0 or in an emergency may bypass the GSSC.				GSSC MOC

GBM FSW Loads	All FSW loads submitted by the GIOC to the MOC through the GSSC. In Phase 0 may bypass the GSSC.				GSSC MOC
SAA Definition Updates	An update to the GBM's definition of the SAA. Differs from the standard GBM memory load in that the SAA definition is used by the spacecraft FSW. The GSSC will use the SAA definition in the science planning. In Phase 0 may bypass the GSSC.				GSSC MOC

8.6.4 GSSC

The following data products will be produced by the GSSC and delivered to the other ground system elements.

Table 8-4: GSSC Operations Data Products

Product	Description	Delivered	Latency	Size	Deliver to
Data Retransmission Requests	Request for retransmission of data because the original transmission was corrupted	As needed			MOC ISOC GIOC
Preliminary Science Timeline	Preliminary timeline for science observations, created ~a month before implementation	Weekly			MOC ISOC GIOC
Final Science Timeline	Final timeline for science observations, created a few days before implementation	Weekly			MOC
TOO Orders	Order for a TOO including the target coordinates and the observation duration	As needed			MOC

9 CALIBRATIONS AND LEVEL 1 PROCESSING

9.1 LAT

9.1.1 LAT CALIBRATION

In calibrating the LAT before and after launch, the instrument team will characterize the response of the instrument to external photon sources. Before launch experimental data isused to verify and validate the mathematical model of the instrument that is then used for Monte Carlo simulations of the LAT's response. The Monte Carlo simulations and experimental data determine the instrument response as a function of relevant photon parameters such as incident direction and energy. These simulations produce lists of events that are formatted as if they were real data and used to test the analysis software. The functional form of the Instrument Response Functions (IRFs) is abstracted from these simulations. These calibrations will be tested after launch, and if necessary, the IRFs will be updated. For details of the calibration of the LAT see the LAT Calibration Plan. The LISOC will provide the IRFs to the GSSC, and will update these IRFs as needed. The LISOC will archive calibration data derived from experiment and computer simulations.

Because most LAT data will be acquired while the spacecraft is scanning the sky, most observations will result in counts with different photon incident directions relative to the LAT; each detected photon will require its own IRF. Thus the analysis of LAT data requires a compact yet accurate representation of the IRFs that can be utilized rapidly, particularly by the average investigator. Currently the IRFs are separated into three functions that depend on the photon energy and its direction relative to the LAT's z-axis: the effective area, the point-spread function (PSF) and the energy redistribution. Photons may be classified by where they first interact within the LAT and by other selection cuts, and the resulting photon classes will have their own IRFs. The IRF functions are parameterizations whose constants are stored in FITS files within the HEASARC's Calibration Database (CALDB).

9.1.2 LAT LEVEL 1 PROCESSING

The Level 0 data will consist of the position and pulse heights of interactions in different parts of the LAT induced both by gamma rays and by cosmic rays that survived the initial analysis cuts aboard the spacecraft. The Level 1 data will be lists of events characterized by quantities such as the apparent direction, energy, and time. The Level 1 processing will consequently be quite involved, and will be implemented by a software pipeline consisting of a series of programs. The LISOC will be responsible for developing the programs for the Level 1 processing; the GSSC will install a backup copy of the basic Level 1 processing software. Although this software will ultimately be archived at the HEASARC, its internal data used in processing need not conform to the standards of the astrophysical community; the final products are FITS files. Once real data become available after launch, the Level 1 processing will undoubtedly have to be refined: calibration parameters may change, different fitting tolerances may be necessary, data cuts may be modified, etc. The LISOC will update the Level 1 processing software maintained by the GSSC, particularly during the first year after launch. During this first year the Level 0 data will be reprocessed a number of times; the processing version is identified in the resulting data product files. The GSSC's backup Level 1 processing software will be updated to mirror the current state of the LISOC's software. The GSSC's backup software will be tested to ensure that it duplicates the processing by the LISOC's software.

During all mission phases the LISOC will operate the Level 1 processing pipeline for both the scientific community and the LAT team. The GSSC will activate its backup pipeline only in an emergency and with the concurrence and consultation of the LAT team. As part of its Automated Standard Processing (ASP) pipeline, the LISOC will scan the Level 1 data for transients; new sources or significant variability of known sources will be reported on LAT and GSSC public websites. In addition, the LISOC will monitor ~20 (or more) sources, and post their lightcurves and spectra. The list of sources is posted on the GSSC website. During all phases standard Level 2 data products will become public as soon as available. A significant transient may be reported by an IAU circular, and may initiate a TOO. As part of its routine processing, the LISOC will screen and classify burst triggers, and will provide the GSSC with GRB parameters such as intensity, fluence, spectrum, and duration. The LISOC will provide updated burst locations and parameters to the scientific community through the GCN system.

In conjunction with the other ground elements, the LISOC will test the ground system software before launch. Thus the LISOC will participate in various tests of this software to ensure that data will flow properly within and among the various ground organizations, and that the software packages perform properly.

9.2 GBM

9.2.1 GBM CALIBRATION

GBM calibration activities at the GIOC fall into two categories: channel-to-energy conversion and detector response. The conversion of pulse height channels to energy as a function of operating temperature are determined for each detector prior to launch based on laboratory calibrations with standard sources and electronic test pulses. In-flight variations are monitored by measuring the pulse height channel of one or more emission lines in the background spectra, and corrections are applied as needed to the pre-launch algorithms.

Since the GBM detectors are unshielded, the incident photons consist of three components: direct, spacecraft-scattered, and atmospheric-scattered. The direct and spacecraft-scattered components depend on the location of the source relative to the detector. The atmospheric-scattered component is also dependent on the relative location of the geocenter. Storing a set of response matrices for every possible combination of source and geocenter angles is inefficient. Fortunately, various symmetries simplify the problem. Using a combination of pre-launch laboratory measurements and Monte Carlo simulations, the GBM response will be parameterized as a set of fiducial tables and algorithms from which a response matrix may be generated for an arbitrary set of source and geocenter angles, and energy bins. The response matrices will be validated in-flight by the GIOC. The GIOC will provide both the files of simulated events and the IRFs to the GSSC. The GIOC will archive all calibration data, whether derived from experiment or computer simulations. The GSSC and GIOC will establish the standards for the representation of the GBM’s IRFs. The calibration files will be stored within the CALDB system and will conform to HEASARC FITS standards.

In conjunction with the other ground system elements, the GIOC will test the ground system software before launch. Thus the GIOC will participate in various tests of this software to ensure that data will flow properly within and among the various ground system elements, and that the software packages perform properly.

9.2.2 GBM LEVEL 1 PROCESSING

GBM Level 1 data processing consists of decoding the telemetry data packets, scaling all engineering data to engineering units, separating and assembling time-resolved spectra, time-tagged events and necessary related information, classifying triggers, and calculating standard parameters for selected trigger types. The Level 1 processing pipeline will produce two sets of standard data products: continuous data files and burst trigger data files. Additional products will include catalogs of triggered GRBs, selected other trigger types, and energy spectra. As part of its routine processing, the GIOC will screen and classify GBM triggers, and will provide the GSSC with updated GRB parameters, such as location, intensity, fluence, spectrum, and duration. The GIOC will provide updated positions and burst parameters to the scientific community through the GCN system.

The GIOC will be responsible for developing the programs for the Level 1 processing, which will be provided to the GSSC. Once real data become available after launch, the Level 1 processing may have to be refined because calibration parameters may have changed. Reprocessing of the Level 0 data is anticipated, particularly during the first year. The GSSC's backup pipeline will be modified to reflect the refinements made by the GIOC. The GIOC and GSSC will compare the results of their processing pipelines to ensure they agree. During the mission the GIOC will operate its Level 1 processing pipeline for both the astronomical community and the GBM team. The GSSC will activate its pipeline only in an emergency with the concurrence and supervision of the GIOC.

DRAFT—09/02/15

10 DATA ANALYSIS

10.1 APPROACH

GLAST's Level 1 data will be analyzed by the Standard Analysis Environment (SAE), which is not a new analysis system but an addition to the HEASoft tools (e.g., FTOOLS) familiar to the high energy astrophysics community. Thus, the software will conform to the standards of the HEASARC by using FITS format files for I/O, utilizing PIL parameter files, and being mainly built of simple programs that can be run from a command line. The scientific tools will not require expensive proprietary software, and will run on the computer platforms common to the astronomical community. In addition to the various flavors of UNIX (e.g., different variants of LINUX and Mac OS X), Windows will also be supported.

The SAE will add to the HEASoft system the tools that the GLAST data require. In particular, a likelihood tool will analyze the LAT photon data in space and energy. The GLAST tools are written in object-oriented C++, and the libraries developed for GLAST will be used by future HEASoft tools. A GUI interface is included.

The SAE has been developed primarily for the LAT data, but where applicable the tools have been extended to analyze GBM data. Thus only a few GBM-specific tools are necessary, although the GBM team may contribute additional tools based on their burst analysis experience. Where possible, the tools have been designed to permit multimission analysis.

During the early part of the mission these tools will be provided to GLAST investigators through the GSSC's website, but later in the mission the HEASARC will integrate them into the general HEAsoft system. Regardless of the website, the HEASARC's installation methodology will be used. Users may choose either binary executables or source code. The IOCs will provide the software to the instrument teams.

The software will be accompanied by basic documentation (see §10.4) describing the applicability of the underlying methodology, the algorithms implemented, and the use of the code.

10.2 RESPONSIBILITY

The instrument teams and the general scientific community will use the same basic analysis tools. The instrument teams are responsible for managing the development of the analysis tools and for procuring the necessary resources, but ultimately the GSSC is responsible for ensuring that the full set of tools defined is available at launch, and that these tools conform to the I/O standards and data formats (e.g., FITS) of the HEASARC. Consequently, the GSSC and the IOCs have collaborated in defining the SAE. Therefore, the LISOC and GSSC have convened a software working group with HEASARC representation—with a co-lead and equal representation from each organization—to maintain the list of required software packages, establish standards for this software, and set release dates for the required software produced by members of the LAT team and by GSSC scientists. Similarly, the GSSC and the GIOC have collaborated in formulating the analysis tools for the GBM.

10.3 DESCRIPTION OF THE ANALYSIS SOFTWARE

Because the LAT PSF will be broad, particularly at low energy where most of the photons will be detected, the photons from nearby sources will overlap spatially, and the analysis of most persistent sources must be spatial and spectral. The likelihood tool, gtlikelihood, will use the likelihood for the spatial and spectral distribution of the observed photons for analyses such as source detection and spectral fitting.

Listed below are the Level 2 software tools that the GSSC will provide to the scientific community. These GLAST tools begin with the prefix 'gt.' The tools are grouped by their primary use.

Table 10-1: SAE Tools

Name	**Description**
	Utilities
gtselect	Creates a new FITS file of selected rows in an input event data file based on cuts that are applied to the values in each row of the input file. This application enables more detailed selections to be made on data obtained from the data server
gtmktime	This tool creates Good Time Intervals (GTIs) based on selections applied to a spacecraft file; event files can also be filtered using the selection criteria.
gtvcut	This tool prints out the selection criteria used for an event file.
gtsrcid	This tool creates a counterpart candidate catalogue by correlating the objects from a source catalogue (e.g., the LAT source catalogue) with the objects of a counterpart catalogue.
	Likelihood
gtexpmap	This tool computes the exposure maps for use in an unbinned likelihood analysis.
gtdiffrsp	This tool computes the event-specific response for each diffuse source in the input source model. A column containing these data is added to the event file for each source.
gtlike	LAT data can be analyzed with this tool using an unbinned or binned formulation of the log-likelihood.
gtltcube	Using the spacecraft data file and the time range and GTI selections in the event file, this tool integrates the livetime as a function of sky position and off axis angle. The sky is represented using a nested HEALPix array.
gtltsum	This tool sums livetime cubes.
gtmodel	This tool creates a model counts map by summing up convolved source maps that have been scaled by the spectral parameters given in the source model XML file.
gtbkg	This tool creates a background count spectrum (for use in a spectral modeling program such as XSPEC) calculated from a model of a region of the sky.
gtpsf	This tool calculates the effective point spread function, as a function of energy at a given source location, averaged over an observation.
gtsrcmaps	This tool convolves the components of the specified source model with the instrument response for a given observation. The geometry in sky and energy coordinates of the output maps match

	that of the input counts map.
gttsmap	This tool computes a test statistic map for source localization and detection in an unbinned likelihood analysis.
gtfindsrc	This tool optimizes a point source location using unbinned likelihood analysis.
Gamma-Ray Burst Analysis	
gtbin	This tool bins an event list in time, energy, or space and results in spectra, lightcurves, or a count map.
gtbindef	This utility reads in an ASCII file with the time or energy bin definitions, and produces the appropriately-formatted FITS file that can be used by gtbin to bin an event list.
gtrspgen	This tool creates a standard RSP FITS file required to analyze a binned spectrum with a spectral analysis tool such as XSPEC.
gtburstfit	This tool analyzes burst light curves by applying a Bayesian algorithm to determine the optimum set of blocks to follow the burst profile shape; blocks may also be used by gtburstfit to construct a pulse model, which gtburstfit can fit to the data.
Pulsar Analysis	
gtbary	This tool performs a barycentering time correction to FITS files using GLAST orbit files.
gtpsearch	This tool searches for pulsation frequencies near to a known, guessed or estimated reference frequency.
gtpspec	This tool performs a blind period search using an FFT.
gtpphase	This tool operates on an event file to compute the spin (pulse) phase for the time of each event, and writes this phase to the PULSE_PHASE column of the event file.
gtophase	This tool operates on an event file to compute the orbital phase for the time of each event, and writes this phase to the ORBITAL_PHASE column of the event file.
gtephem	This tool presents the user with the best ephemeris available in a pulsar database for a given pulsar and instant of time.
gtpulsardb	This tool creates, filters, and/or combines pulsar ephemerides database files.
Observation Simulation	
gtorbsim	This tool generates spacecraft orbit and attitude data for a variety of pointing strategies.
gtobssim	This tool generates photon events from astrophysical sources and processes those photons according to the specified instrument response functions.
ModelEditor	This tool creates source models in the appropriate XML format.

10.4 DOCUMENTATION

The documentation for the SAE consists of four components. The first describes how the SAE tools should be installed on the user's system. The second component consists of a series of analysis threads that demonstrate how the tools can be used together for a number of typical analyses. These analysis threads are grouped topically, such as data access, point source analysis, GRB analysis and pulsar analysis. As time progresses additional analysis threads will be added, some contributed by users. The third component is a reference manual describing each tool and its input parameters. The resulting sections are similar to unix 'man' pages.

Finally, the fourth component, called the ‘Cicerone’ (a cicerone is a sophisticated guide for an intelligent user), is a detailed manual that explains the nature of the data and the methods behind the tools. This set of documentation should support and assistance users with different learning styles and different initial knowledge.

10.5 EVALUATION

The SAE will be tested and used by different groups before it is released to the general scientific community. Periodically during development scientists and programmers associated with the tool development exercise the tools by analyzing simulated data; this is called a ‘checkout.’ The simulated data is created by folding a model of the sky through the instrument response functions.

Two progressively more sophisticated ‘Data Challenges’ were undertaken for the development phase of the scientific software. In these data challenges a team of scientists created a model of the gamma-ray sky, including gamma-ray bursts, solar flares, pulsars, transient sources and the diffuse background. The interaction in the LAT of photons from this model and background events were modeled using Monte Carlo simulation software, resulting in the expected measurements by the LAT’s various components (e.g., from the different layers of silicon-strip detectors). The simulated readout from the LAT was then ‘reconstructed’ by the software that will ultimately be used to reconstruct the actual data. One purpose of the data challenge was to develop and refine the ‘cuts’ used to differentiate between astrophysical photons and background events; a product of this analysis was the instrument response functions applicable to the cuts. The resulting list of astrophysical photons was then analyzed using the SAE. Simulated GBM data were included in the second data challenge. . In these data challenges, the GLAST scientists testing the SAE did not know what sources were included in the simulated data. Documentation was developed in conjunction with the data challenges.

The LAT instrument team is currently in the midst of a series of Service Challenges, modified data challenges. In these exercises various simulated data sets are created, and the LISOC tests its ability to process the data under realistic conditions. Scientists testing the SAE tools know the model of the sky used to simulate the data.

Finally, the GLAST Users’ Group (GUG) beta tested the SAE after the second data challenge; a second GUG beta test is planned. Members of the committee were presented with the SAE tools, documentation and simulated data, and were asked to comment upon both the tools and the documentation.

11 USER SUPPORT

11.1 DATA ACCESS

The data access policies of the GLAST mission, including the policies guiding the GI program, are presented in detail in the Science Policy Document (which is the controlling document), and therefore are only summarized briefly here.

During Phases 0 and 1 the LAT event data are restricted to the LAT team and the interdisciplinary scientists (IDSs) while the observatory carries out a sky survey and the instrument teams calibrate their instruments; Cycle 1 GIs will not have access to the LAT event data, nor may they propose observations that will disrupt the sky survey. The Phase 1 data will be provided to the GSSC at the end of Phase 1 so that the relevant databases will be operational when the data become public at the beginning of Phase 2. During Phase 1 the LAT team will make public fluxes, lightcurves and spectra characterizing transients and lightcurves from ~20 sources interesting to the scientific community.

During Phase 2 all LAT science data will be public as soon as they are loaded into the GSSC's databases.

All GBM science data will be publicly available through the GSSC's website from the beginning of Phase 1.

11.2 ORGANIZATION OF THE GUEST INVESTIGATOR PROGRAM

The GSSC is responsible for assisting NASA HQ in preparing the NRAs for each GI cycle, organizing the proposal process, supporting NASA HQ by organizing the evaluation of guest investigation proposals, and implementing the guest investigations selected by NASA HQ.

The GSSC will prepare the text for each NRA based on requirements from NASA HQ. Thus the GSSC will write, and subsequently revise, the text describing the policies of the GLAST GI program that will be included in the Research Opportunities in Space and Earth Sciences (ROSES), NASA's yearly compendium of NRAs in space science (or the equivalent given NASA's internal structure), as well as the supplementary descriptions of the instruments, data, and analysis software that will be posted on the GSSC website. In particular, the GSSC will prepare and maintain the "GLAST Technical Handbook." The NRAs will be revised, reviewed, ratified and released by NASA HQ.

The GSSC will make available to proposers a variety of tools with differing levels of sophistication to evaluate the feasibility of their proposed observations. The simplest tools will estimate the time necessary to achieve a detection of a desired significance given the underlying background. The more advanced tools will simulate observations that can then be analyzed with the standard analysis software as if they were real data; this software may use simplified IRFs to speed up the simulations. As the mission progresses, the GSSC will develop analytic estimates of the instruments' sensitivities that can be used to estimate the detectability of sources of a given intensity. The GSSC will also provide tools to evaluate the efficacy of different observing modes for the proposed observations. Finally, the GSSC will maintain a library of scientific results from GLAST and past gamma-ray missions.

The GSSC will organize the evaluation of the submitted proposals. Thus the GSSC will assist NASA HQ by receiving and cataloging the proposals, evaluating the technical feasibility (where relevant), recommending peer reviewers, distributing the proposals to the peer reviewers, convening the peer review panels, and collating the evaluations of the peer review panels. The GSSC will advise the panels on the impacts of proposals on the timeline. NASA HQ will select the peer review committees and make the final proposal selection. Following guidelines from NASA HQ, the GSSC will establish the policies governing the peer review (e.g., conflict-of-interest rules).

11.3 GUEST INVESTIGATOR SUPPORT

The GSSC will make data available to a GI as the GI's Phase 2 observations occur. Analysis software, ancillary data, and related documentation will be available on the GSSC's website. The GSSC will furnish online and human expertise in analyzing the data. The GSSC will also support a library with catalogs and other ancillary information to assist the investigator community.

Once an observation requested by a GI has undergone Level 1 processing and has been placed into the GSSC's database, the GI will extract the relevant observational data from the database, and may transmit it electronically to his/her home institution (e.g., via FTP). Given the universal availability of computer resources and internet access, the GSSC will not operate a dedicated facility to which investigators come to analyze data, nor will the GSSC distribute the data via physical media (e.g., tapes or CDs) except by special request.

The GSSC will make available analysis software (described in §10) that the GIs can download from the GSSC's website early in the mission and from the HEASARC's website later in the mission. This software will also generate the necessary IRFs. The software will be accompanied by extensive documentation about its use and about the algorithms implemented. The GSSC will also provide ancillary data necessary for the data analysis such as the diffuse emission model (maintained and updated by the LAT team) and the pulsar timing database (with ephemerides obtained by the Pulsar Committee). The GSSC website will make accessible to GIs (and all interested scientists) the GLAST point source catalog, other relevant catalogs, and a library of GLAST and previous gamma-ray results.

Finally, GSSC scientists will provide expertise and advice, as needed. Investigators will request and receive assistance through the GSSC Helpdesk; all communication will be logged. It is anticipated that the need for human assistance will be greatest early in the mission, and will taper off as on-line documentation is developed to answer the most frequently asked questions.

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12 ARCHIVING

The GSSC will load all the data products provided by the other ground system elements (see §5) into databases that will conform to the standards of the HEASARC (§4.6). During the mission these databases will be used for GLAST research by the Project, the instrument teams and the scientific community. The databases will be on GSSC-provided computer disks mounted on servers that are part of the HEASARC system. In most cases the science data products will be ingested into the HEASARC's data system and served to the scientific community through the HEASARC's Browse interface; thus, from early in the mission most of the GLAST data will be accessed through the HEASARC. When the GLAST GSSC is disbanded after the end of the GLAST mission, the databases will remain as part of the HEASARC archives. The GSSC bears the ultimate responsibility for ensuring that all GLAST scientific data are archived, and the HEASARC is the permanent archive. The GSSC's databases will in general conform to HEASARC standards, both in architecture and format. Specifically, the data will be in FITS files with metadata cataloging the data (and pointing to the FITS files) in a non-proprietary format (e.g., tables accessible to users through a web interface). Note that the HEASARC refers to the FITS data files as "archives" and to the metadata as "databases," while the GLAST project uses the term "database" interchangeably to describe FITS-formatted data tables along with non-FITS formatted metadata tables used to catalog GLAST data.

In a few cases the GSSC may maintain a non-archival architecture for operational use. For example, the GSSC may create "optimized databases" which distribute HEASARC-format data files over multiple nodes for access speed; the access software will be able to read the data from one or multiple nodes. In all cases, the GSSC will provide databases acceptable for the HEASARC archives without conversion by the end of the mission, as described in the GSSC-HEASARC MOU. Similarly, the integration of the GSSC's access software with the HEASARC's will be described in the GSSC-HEASARC ICD. The data products extracted from the GSSC databases will always conform to HEASARC standards.

The GLAST Project will ensure that Level 0 data is preserved during and after the mission. The Level 0 data will be archived at the NSSDC approximately a year after they are taken. The MOC will preserve the raw telemetry during the mission. Archived GLAST data sets will be discarded only after review by the GSSC, the SWG and the GLAST Users' Committee.

While the IOCs will transmit the data listed in §6 to the GSSC in FITS files, the IOCs may elect to store and use these data in other formats. They may also maintain institutional archives.