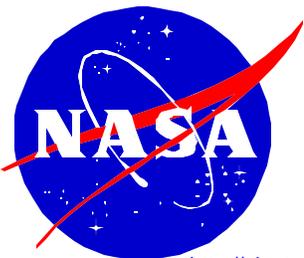


**GAMMA-RAY LARGE AREA  
SPACE TELESCOPE  
(GLAST)  
PROJECT**

**SCIENCE REQUIREMENTS  
DOCUMENT (SRD)**

**SEPTEMBER 23, 2000**



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**GODDARD SPACE FLIGHT CENTER  
GREENBELT, MARYLAND**

GAMMA-RAY LARGE AREA SPACE TELESCOPE  
(GLAST) PROJECT

SCIENCE REQUIREMENTS DOCUMENT (SRD)

SEPTEMBER 23, 2000

NASA Goddard Space Flight Center  
Greenbelt, Maryland

## GLAST Project Science Requirements Document (SRD)

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**ACRONYM LIST**

AGN	active galactic nucleus
BATSE	Burst and Transient Source Experiment
CGRO	Compton Gamma Ray Observatory
DOE	Department of Energy
GBM	GLAST Burst Monitor
GCN	Gamma-ray Coordinates Network
GLAST	Gamma Ray Large Area Telescope
GRAPWG	Gamma Ray Astronomy Program Working Group
GRB	Gamma Ray Bursts
EGRET	Energetic Gamma Ray Experiment Telescope
LAT	Large Area Telescope
PBH	Primordial Black Hole
SRD	Science Requirements Document
SSC	Synchrotron Self-Compton
TOO	Target of Opportunity
UGO	unidentified gamma-ray object

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## 1 INTRODUCTION

The Gamma-ray Large Area Space Telescope (GLAST) mission is a high-energy gamma-ray observatory designed for making observations of celestial sources in the energy band extending from 20 MeV to 300 GeV with complementary coverage between 10 keV and 25 MeV for gamma-ray bursts. This mission will:

- 1) Identify and study nature's high-energy particle accelerators through observations of active galactic nuclei, pulsars, stellar-mass black holes, supernova remnants, gamma-ray bursts, Solar and stellar flares, and the diffuse galactic and extragalactic high-energy radiation.
- 2) Use these sources to probe important physical parameters of the Galaxy and the Universe that are not readily measured with other observatories, such as the intensity of infrared radiation fields, magnetic fields strengths in cosmic particle accelerators, and 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 fundamentally new phenomena, such as particle dark matter, quantum gravity, and evaporating black holes.

The GLAST mission's scientific objectives require a main instrument with large collecting area, imaging capability over a wide field of view, ability to measure the energy of gamma rays over a broad energy range, and time resolution sufficient to study transient phenomena. The instrument shall also achieve sufficient background discrimination against the large fluxes of cosmic-rays, earth albedo gamma rays, and trapped radiation that are encountered in orbit. A secondary instrument is required to simultaneously observe gamma-ray bursts in the classical low-energy gamma-ray band and provide rapid burst location information.

## 1.1 PURPOSE

This document defines the scientific objectives and corresponding measurement requirements for the GLAST mission. An earlier version was written in 1999 for the GLAST instrument AO (99-OSS-03) with final signed copy dated July 9, 1999. This version was called the "AO Science Requirements Document (SRD)" and was prepared by the GLAST Science Facility Team, co-chaired by Peter Michelson and Neil Gehrels. It has now been updated by the GLAST Science Working Group, chaired by Project Scientist Jonathan Ormes, and named the GLAST Science Requirements Document (SRD).

## 1.2 GLAST INSTRUMENTS

As a result of the GLAST flight investigations AO, two instruments were selected. The main instrument is the Large Area Telescope (LAT) with Peter Michelson as Principal Investigator covering the high energy gamma-ray band. The secondary instrument is the GLAST Burst Monitor (GBM) with Charles Meegan as Principal Investigator covering the low energy and medium energy gamma-ray band with particular emphasis on gamma-ray burst science.

## 1.3 OBSERVING MODES

After instrument checkout and calibration, the GLAST mission shall perform a one-year all-sky survey. During this period the spacecraft will be oriented in "rocking zenith" mode to point the LAT instrument in a general zenith direction with some rocking motion around the orbit to improve the uniformity of the sky coverage.

There may be occasional interruptions of the survey for pointed observations of particular transient sources. This "pointed" mode has the LAT instrument oriented toward a position of interest to within 30° while it is above the Earth's limb.

After the one-year survey, the mission will have a mixture of rocking zenith and pointed mode observations.

#### 1.4 TERM DEFINITIONS

**Requirements** are those mission and instrument capabilities that are needed to achieve the stated science goals, and represent objectives to be met in the design of the instruments and spacecraft.

**Goals** are also given in this document, and indicate performance parameter values that would significantly enhance the scientific return from the mission. For most parameters a **minimum** is given. This is the value that, if not met, has serious negative scientific consequences and would trigger a Project review.

#### 1.5 APPLICABLE DOCUMENTS

Documents that are relevant to the development of the GLAST mission concept and its requirements include the following:

1. "Recommended Priorities for NASA's Gamma Ray Astronomy Program 1996-2010", Report of the Gamma Ray Astronomy Program Working Group, April 1997.
2. "The Evolving Universe: Structure and Evolution of the Universe Roadmap 2000 - 2020", roadmap document for the SEU theme, NASA Office of Space Science, June 1997.
3. "The Space Science Enterprise Strategic Plan: Origins, Evolution, and Destiny of the Cosmos and Life", NASA Office of Space Science, November 1997.
4. "Gamma Ray Large Area Space Telescope Instrument Technology Development Program", NRA 98-217-02, NASA Office of Space Science, January 16, 1998.
5. "Astronomy and Astrophysics in the New Millennium", NRC review of U.S. priorities in astronomy and astrophysics, National Academic Press, May 18, 2000.
6. GLAST Flight Investigations AO, NASA AO 99-OSS-03.
7. "HEPAP Subpanel Report on Planning for the Future of US HEP", DOE/ER0718, February 1998.

## 1.6 BACKGROUND

High-energy gamma-ray astronomy is currently in a period of discovery and vigor unparalleled in its history. In particular, the Energetic Gamma-Ray Experiment Telescope (EGRET) on the Compton Gamma-Ray Observatory (CGRO) has moved the field from detection of a small number of sources to detailed studies of several classes of Galactic and extragalactic objects. The CGRO/EGRET discoveries of gamma-ray blazars, pulsars, high-energy gamma-ray bursts, and a large class of unidentified high-energy sources have given us a new view of the high-energy gamma-ray sky, while raising fundamental new questions about the origin and evolution destiny of nature's highest energy sources of radiation.

High-energy gamma rays probe the most energetic phenomena occurring in nature. These typically involve dynamical non-thermal processes such as the interactions of high-energy particles (electrons, positrons, protons, ions, etc.) and photons with matter, radiation and magnetic fields; high-energy nuclear interactions; matter-antimatter annihilation; and other fundamental elementary plasma and radiation processes. High-energy gamma rays are emitted over a wide range of angular scales from diverse populations of astrophysical sources including: stellar-mass objects, in particular, isolated neutron stars and pulsars; high-energy cosmic rays that interact with interstellar gas in the Galaxy; unknown contributions of localized and extended sources and diffuse emission that make up the diffuse extragalactic background; supernovae that are predicted to be sites of cosmic-ray hadron acceleration; and gamma-ray bursts. EGRET has shown that these are copious sources of gamma rays, and often radiate the bulk of their power at gamma-ray energies. The Sun is also known to produce high-energy gamma rays during flaring periods. Many of the sources exhibit transient phenomena, ranging from the sub-second timescales of the fastest gamma-ray bursts to AGN flares lasting days or more. The Milky Way and other galaxies also produce a persistent glow from cosmic ray interactions.

The basic instrument requirements are defined in a two step process. First, major science themes are identified. These themes are largely based upon the science goals for a high-energy gamma-ray mission

as outlined by NASA's Gamma-ray Astronomy Programs Working Group (the GRAPWG). A summary of the GRAPWG's work can be found at <http://universe.gsfc.nasa.gov/grapwg.html>. In addition to the NASA GRAPWG, there has been corresponding work in the high energy physics community and the international science community. GLAST science was presented to the DOE High Energy Physics Advisory Panel (HEPAP) and the Scientific Assessment Group for Experiments in Non-Accelerator Physics (SAGENAP), a joint DOE and NSF reviewing body. As a result, the DOE is participating in the GLAST mission. GLAST science and instrument participation was also approved by international bodies in Italy (INFN), France (CNES and CNRS), Japan (US-Japan Collaboration Committee in High Energy Physics), and Sweden.

The second step in the requirement definition process is, for each of the major science themes, an estimate of the basic telescope properties that are most relevant to reaching the science goals are listed. In many cases, it is natural to make direct comparisons with the EGRET instrument as the most recent and successful experiment for high energy gamma-ray astronomy and the BATSE instrument for gamma-ray bursts. An overview of the science themes and the requirements they impose on the instrumentation is given in Section 2. A summary of technical requirements is given in Section 3.

## **2 GLAST SCIENCE 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 instrument and mission. Even so, the clear and compelling science goals for the GLAST mission make definite requirements possible. The following sub-sections describe the main science goals of GLAST in seven areas of current research. In each area the most relevant instrument requirements are stated.

### **2.1 ACTIVE GALACTIC NUCLEI**

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To date over 70 active galactic nuclei (AGN) of the “blazar” class have been detected at high gamma-ray energies. Blazars are defined by large amplitude, rapidly variable emission, prominent optical polarization, and strong, flat-spectrum, core-dominated radio flux. Gamma-ray observations have yielded interesting results on individual sources, and have initiated high-energy study of AGN as a class. The gamma-ray band has become an integral part of the multiwavelength approach to studying blazars. Despite this progress, fundamental questions about the formation of AGN jets, particle acceleration, and broadband radiation mechanisms remain. The study of gamma-ray emission from blazars (and possibly other AGN classes) and the study of correlated multiwavelength observations will create a new understanding of the AGN phenomenon.

Greatly increased numbers of gamma-ray AGN and more sensitive observations of individual sources are key to answering fundamental questions about blazars: What is the global structure of the AGN jet? What are the sources of variability? Are the radiating particles leptons or hadrons? Is the broad-band energy distribution consistent with Synchrotron Self-Compton (SSC), or could the seed photons come from the accretion disk, either directly or after being scattered off broad-line region clouds? Is a one-zone model adequate or is an inhomogeneous jet model required? Is there a redshift dependence of blazar emission due to evolutionary effects on supermassive black hole formation? How do the target photon sources and radiation processes differ between different classes of BL Lac objects and flat- and steep-spectrum radio quasars? Why do some supermassive black holes form collimated plasma outflows, and what does this mean for the role of the host galaxy in fueling the central engine?

To answer these questions, a sensitive high-energy instrument that can measure wide-band spectral energy distributions across a range of variability timescales is required. A gamma-ray telescope with a large field of view is needed to monitor many AGN and to examine their unexpected flaring behavior. Greatly improved point-source sensitivity is crucial to understand the relationship between different classes of AGNs, and will increase the number of detected AGNs by at least an order of magnitude. GLAST observations will address questions concerning the nature and location of relativistic particle

acceleration and gamma-ray production in jets, the black hole/jet symbiosis, and the physics of particle acceleration and high-energy radiation in the inner jet.

Improved gamma-ray time variability and temporal correlations are important for understanding blazar activity. For example, at TeV energies, the blazar Mkn 421 has been shown to vary on timescales as short as 15-30 minutes. Given the sparse photon numbers and constrained detector areas, gamma-ray instruments generally require long observation times to detect significant source variability. Temporal correlation analysis involving the gamma-ray data alone, or in conjunction with multiwavelength monitoring campaigns, will strongly constrain the relationship between SSC components and target photons. These measurements can also be used to infer bulk Lorentz factors and magnetic field strengths. GLAST will be able to measure variability for bright AGN on a timescale of a few hours or less. This will be accomplished by a large increase in effective telescope area over EGRET, which generally detected variability on timescales of days for blazars. An increase in energy range and spectral sensitivity for GLAST is also required for further progress in this field. Studies of spectral evolution during gamma-ray flares and measurements of spectral breaks at both low and high energies can give important clues to particle acceleration mechanisms and the location of emission regions. It is vitally important to understand the intrinsic blazar spectrum separately from the interaction of source gamma rays with the intergalactic medium. Precise determinations of redshift vs. spectral cutoff energy allow us to measure the intensity of the intergalactic infrared background radiation. These measurements will provide information on the epoch of galaxy and AGN formation, on the radiation byproducts of star formation in the early universe, and on dark matter candidates. A broad energy range and good spectral response is needed to achieve these goals. Overlap and good inter-calibration with other ground-based, high-energy gamma-ray Cherenkov telescopes (100 GeV- TeV range) will be important for definitive studies of spectral cutoffs.

**Key Elements:**

- LAT shall have broad energy response from 20 MeV to at least 300 GeV to explore the low-energy spectrum where many AGN have peak emission, to measure high-energy cutoffs, and to overlap with

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ground-based gamma-ray observations. LAT shall have an energy range goal of 10 MeV to 500 GeV. LAT shall have an energy range minimum of 30 MeV to 100 GeV.

- LAT shall have spectral resolution of 10% or better (100 MeV - 10 GeV) to facilitate studies of spectral breaks at both low and high energies.
- LAT shall have effective area of at least 8000 cm<sup>2</sup> (approx. 5 times EGRET) over the central part of the energy range to allow for variability studies of bright sources down to the sub-day timescales.
- LAT shall have a field of view at least 2 steradians (approx. 4 times EGRET) for significant sky coverage to monitor large numbers of AGN and their variability.
- LAT shall have clean separation of at least 1000 sources on the sky to minimize source confusion.
- LAT shall have flux sensitivity better than  $6 \times 10^{-9}$  cm<sup>-2</sup> s<sup>-1</sup> for the 1-year sky survey to measure the AGN logN-logS function to a factor of 16 fainter than EGRET.
- GLAST shall have a mission life of many years (> 5 years requirement, > 10 years goal) to allow long-term studies of AGN variability.

## 2.2 ISOTROPIC BACKGROUND RADIATION

Improvements in AGN studies will have a direct bearing on measurements of the isotropic gamma-ray background radiation. Deep surveys of high galactic latitude fields are important to determine if the high-energy background is completely resolvable into point sources, or if there is a true diffuse cosmic component. The identification of a diffuse cosmic background would have profound implications on studies of the early Universe. Spatial studies of the isotropic emission and the search for anisotropies will couple nicely with AGN class studies to fully describe the diffuse radiation. It is important that the GLAST sensitivity extends to high energies since air Cherenkov instruments cannot study large-scale diffuse emission. Also, the measurement of blazar cutoffs due to pair production of gamma rays on the infrared background, mentioned in Section 2.1, is an important technique for exploring the Universe around the epoch of galaxy formation.

### Key Elements:

- LAT shall have a background rejection capability such that the contamination of the observed high latitude diffuse flux (assumed to be  $1.5 \times 10^{-5} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ ) in any decade of energy (>100 MeV) is less than 10% (goal of 1%).
- LAT shall have broad energy range from 20 MeV to 300 GeV to extend diffuse spectral measurements to energy ranges that have not been well explored. LAT shall have an energy range goal of 10 MeV to 300 GeV. LAT shall have an energy range minimum of 30 MeV to 100 GeV.
- LAT shall have a broad (> 2 sr) field of view for sensitive full-sky maps

### 2.3 GAMMA RAY BURSTS

Gamma ray burst (GRB) studies have come a long way in the past few years with the detection of GRB counterparts at X-ray and optical energies, and the recognition of the cosmological distance scale for GRBs. GLAST can provide measurements over an otherwise inaccessible energy range. Although EGRET has detected only a handful of bursts, with each being relatively poorly studied, a major discovery by EGRET is the existence of a high-energy burst afterglow implying particle acceleration lasting for more than an hour. This has important implications for the physics of the source region and the activity of GRB engines, which might be associated with newly formed black holes. By detecting high-energy radiation from approximately 100 bursts per year (as compared to ~1 per year for EGRET) GLAST will provide constraints on physical mechanisms for GRBs and allow studies of the relationship between GeV emission and keV-MeV emission as a function of time during the burst. This sample will allow for a more thorough evaluation of the importance of the temporally extended emission found with EGRET. Do most bursts exhibit this behavior? How does the high-energy spectral form and peak energy change with time? Is there evidence for two components in the high-energy gamma-ray spectrum? The EGRET bursts are consistent with a spectrum extending to GeV energies. Measurements of intrinsic burst spectra at these energies can constrain bulk Lorentz factors of relativistic fireball models and provide measurements of cutoffs due to absorption on the circumburst radiation field and the extragalactic background light at energies as low as 100 GeV for large redshifts. A large field of view and effective area are important for these advances. Also important is the capability for GLAST to continue observations of a burst for long periods of time (hours) after the burst has occurred. This can be

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achieved by having a large field of view for the GLAST instrument and/or by rapidly (minutes) repointing the spacecraft to orient the instrument toward the burst.

Since GRBs are the most intense and rapidly changing gamma-ray sources known, deadtime effects could hinder a true measurement of the intrinsic variability timescales which constrain the size of the emission region of the highest energy gamma rays. Low system deadtime for high event rates is important.

Highly desirable is the capability to provide rapid (few seconds) notification of the burst and its position from GLAST to the ground. This will allow for rapid ground-based observations of the burst. It is also useful for burst notifications to be rapidly (few 10's of seconds) sent from the ground to GLAST. The purpose of this capability is to allow GLAST to point at gamma-ray bursts discovered by other missions.

GLAST will be making the first comprehensive observations of high-energy gamma-ray emission from bursts. Since very little is known about the relationship of the high-energy emission to the better studied low-energy gamma-ray and X-ray emission, it is required that there be a capability to simultaneously measure the low and high-energy components. Low-energy and medium energy measurements are also important for the most rapid determination of the existence of a gamma-ray burst, which can be used to provide notification to observers at other wavelengths. It is a GLAST requirement to have on-board low-energy and medium-energy measurements by the secondary GBM instrument for gamma-ray bursts. The key objectives of the GBM are to 1) provide lower energy and medium energy context measurements of the light curve and spectrum of bursts for comparison with high energy measurements of the LAT; 2) provide positions for bursts over a wide field of view to few-degree accuracy to allow repointing of the spacecraft to position the LAT on the burst source, 3) provide the rapid burst positions to the spacecraft for transmission to the ground for correlated observations by other ground-based and space-based telescopes.

**Key Elements:**

- LAT shall have the ability to quickly (< 5 seconds) recognize and localize GRBs.
- LAT shall have a field of view 2 sr to monitor a substantial fraction of the sky at any time. LAT shall have a field-of-view goal of 3 sr. LAT shall have a field-of-view minimum of 1.5 sr.
- LAT shall have spectral resolution better than 20%, especially at energies above 1 GeV, for sensitive spectral studies and searches for breaks.
- LAT shall have deadtime of less than 100  $\mu$ sec per event for determining correlations between low energy and high energy gamma-ray burst time structure.
- LAT shall have single photon angular resolution of 10 arcmin at high energies (>10 GeV) for good source localization.
- GBM shall have an energy range from 10 keV to 25 MeV to cover the classical gamma-ray band where most of the burst photons are emitted.
- GBM shall have a field of view of 8 sr to cover all of the visible sky from low-Earth orbit. The GBM field of view shall overlap that of the LAT.
- GBM shall have a capability as a goal to rapidly (< 2 seconds) determine burst positions  $\pm 0.15^\circ$  accuracy (goal: < 15 degrees) for purposes of notifying other observers and repointing the spacecraft to optimize LAT observations.
- The spacecraft shall have the capability to rapidly (< 7 seconds) transmit GRB coordinates to the ground.
- The spacecraft shall have the capability to autonomously repoint the LAT to positions of gamma-ray bursts within 10 minutes.
- The spacecraft shall have the capability to downlink GRB information to the ground in near realtime.
- The spacecraft shall have the capability to obtain notification of GRBs and other transients in near realtime from the ground.

**2.4 SOLAR FLARES**

Particle acceleration is fundamental to high energy astrophysics. It is also one of the principal channels of energy release in solar flares. The Sun is an excellent laboratory for studying astrophysical particle acceleration. GLAST will be able to observe the gamma-ray emission produced by the particles in the solar flare and, for the same flare, the particles that escape can be observed in interstellar space.

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Gamma rays from solar flares have been extensively observed at energies mostly below 10 MeV, a region dominated by nuclear lines. At higher energies, evidence for pion decay emission has been seen from several flares. The most exciting observation was the discovery by EGRET of pion decay emission lasting for 8 hours after the impulsive phase of the flare. A full understanding of the phenomenon, whether it is from particles continuously accelerated for hours or from particles accelerated in the impulsive phase and subsequently trapped in closed magnetic structure, is still not available. Both interpretations have important implications on theories of particle acceleration and confinement, processes of fundamental importance to high energy astrophysics. GLAST, with its higher sensitivity than EGRET, will be able to observe a larger sample of GeV events and answer the question of acceleration mechanism. In particular, the extension of the spectrum to higher energies will determine the upper limit on the accelerated particle energy, and the higher sensitivity will reveal the structure of the time profiles, all of which will lead to a better understanding of the basics on the underlying processes.

**Key Elements:**

- GLAST shall have a mission lifetime of at least 5 years with a goal of 10 years to provide solar flare observations over a range of solar cycle activity.
- LAT shall have an energy band of 20 MeV to 300 GeV to observe high energy emission from solar flares
- LAT shall have a deadtime of less than 100  $\mu$ sec to allow operation during intense solar flares
- GBM and LAT shall have a goal to provide data that allow rapid determination of the likelihood of a transient event being a solar flare as compared to a GRB or AGN flare.

**2.5 INTERSTELLAR CLOUDS, SUPERNOVA REMNANTS AND NORMAL GALAXIES**

The nature of the sites and mechanisms of cosmic ray production is an unsolved problem in astronomy. EGRET observations of the Small and Large Magellanic Clouds have shown that cosmic rays are likely Galactic in origin. X-ray and TeV observations have demonstrated cosmic-ray electron acceleration in

supernova remnants. GLAST gamma-ray mapping and spectral measurements should provide direct evidence of both cosmic-ray hadron and electron acceleration in supernova remnants.

GLAST will further contribute to these efforts by probing the cosmic-ray distribution in dense molecular clouds and in nearby galaxies (LMC, SMC, M31) both by mapping the gamma-ray flux and by measuring the spectrum of diffuse emission from these objects. In addition, GLAST should be able to resolve questions about the diffuse high-energy galactic emission, which is inconsistent with a spectrum radiated by cosmic rays which have the same energy distribution as measured locally. GLAST will look for variations in the X-ratio ( $N(H_2)/W_{CO}$ ) and the cosmic-ray/matter coupling scale from object to object. Finally, GLAST will provide important measurements to confirm the existence and establish the nature of the gamma-ray halo hinted at by EGRET. These efforts will benefit from a large effective area and good angular resolution to allow for fine mapping of diffuse features.

#### **Key Elements:**

- LAT shall have an angular resolution of better than  $3.5^\circ$  at 100 MeV at normal incidence, improving to better than  $0.5^\circ$  at 1 GeV, for mapping of diffuse features and extended sources.
- LAT shall have a point source localization less than  $\sim 1$  arcmin to identify supernova remnants.

## **2.6 ENDPOINTS OF STELLAR EVOLUTION (NEUTRON STARS AND BLACK HOLES)**

While only roughly 1% of known pulsars are gamma-ray pulsars, these are key to the overall understanding of the pulsar phenomenon because the gamma-ray power is a significant fraction of the spin-down luminosity. It is important for GLAST to significantly increase the number of detected gamma-ray pulsars in order to extend the compilation of empirical trends that EGRET made possible, such as the relationships between gamma-ray efficiency, spectral hardness, and pulsar age. An order of magnitude increase in the number of detected gamma-ray pulsars is essential for our understanding of the basic structure of pulsar magnetospheres and identify the sites and nature of pulsar particle acceleration. The ability to detect and identify radio-quiet Geminga-type pulsars out to the Galactic Center distance will provide important new insights into the basic statistics of pulsar birthrates. A

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program of optical, radio, and X-ray follow-up observations will establish the period and pulse-phase spectra of gamma-ray pulsars detected with GLAST. This will also provide much better understanding of the pulsar contribution to the diffuse Galactic emission. Large effective area and good spectral resolution are vital for these discoveries.

Improved phase-resolved spectroscopy of new and previously known gamma-ray pulsars is important for distinguishing between various models for high-energy gamma-ray emission from pulsars. Polar cap and outer gap models can be effectively distinguished by studies of the spectral structure of the pulsed emission. Adequate low-energy response (10-100 MeV) will allow searches for breaks in the primary spectrum while the high-energy response (>10 GeV) will allow the detection of Compton cutoffs and radiation reaction limits. GLAST observations of pulsars will also guide TeV searches, since TeV emission is predicted to arise in outer gap models and should also be emitted by plerion nebulae.

For Galactic black hole candidates, the increasing number of known accreting Galactic sources that exhibit relativistic jets provides an important opportunity for studying the high-energy emission from such objects. Detections of significant high-energy gamma radiation, or severe limits on emission from these objects, can be coupled with AGN studies to learn about the astrophysical consequences of scaling by black-hole mass. An important goal of the GLAST mission is to determine if the 2-3 million Solar mass black hole at the center of the Galaxy is a high-energy gamma-ray source. Although EGRET detects a source at the Galactic Center, it did not have adequate angular resolution to uniquely identify it.

**Key Elements:**

- LAT shall have good spectral resolution of ~10%, especially in the range from 100 MeV to 10 GeV where pulsar spectral breaks occur
- GLAST shall have absolute timing knowledge to 10  $\mu$ sec and absolute position knowledge to 3.3 km to facilitate searches for pulsations from millisecond pulsars and characterization of pulse profiles of detected pulsars

## 2.7 UNIDENTIFIED GAMMA-RAY SOURCES

More than half of the sources that EGRET detects are unidentified. Determining the type of object(s) and the mechanisms for gamma-ray emission from the unidentified gamma-ray sources is a high priority for GLAST. By measuring precise positions of these sources, the possible relationship between unidentified sources and supernova remnants, pulsars, molecular clouds, and other candidates can be explored. Perhaps entirely new source populations are involved. Only source locations on the order of arcminutes or better can begin to answer these questions.

How many unresolved point sources are in the Galactic plane? What is the nature of the emission at the Galactic Center? What is the nature of the unidentified sources at high Galactic latitudes? Exploring these questions requires significantly improved single-photon and source localization capabilities as compared to EGRET. Such localizations, coupled with the broadest possible gamma-ray energy range, will enable effective multiwavelength observations of unidentified gamma-ray sources for the first time. In addition, long exposure times and large effective area will allow for sensitive searches for gamma-ray pulsations from possible radio-quiet pulsars.

### Key Elements:

- LAT shall provide source localization to less than 5 arc minutes for sources of strength  $>10^{-8}$  ph cm<sup>-2</sup> s<sup>-1</sup> (10 times fainter than EGRET) and less than 0.5 arcminute for strong sources ( $>10^{-7}$  ph cm<sup>-2</sup> s<sup>-1</sup>) to facilitate counterpart searches at other energies.
- LAT shall have a broad energy range to extrapolate GLAST spectra into the hard X-ray and TeV regimes to facilitate studies at other wavelengths.
- LAT shall have a large ( $> 2$  sr) field of view to allow high-duty-cycle monitoring of unidentified sources for time variability.

## 2.8 DARK MATTER

Aside from normal diffuse emission, GLAST will search for extended emission from cold dark-matter clouds that may exist in the Galaxy, and from galaxy clusters that could reveal unusual concentrations of

unseen gas or cosmic rays. Many models of cold dark matter feature heavy supersymmetric particles whose line emission can be detected in the 10's or 100's of GeV range. Good spectral response over a broad range of energies and a wide field of view is important to look for these dark matter signatures. Another form of dark matter may be primordial black holes (PBHs). While EGRET has already set important limits on PBH production, greater sensitivity and the ability to identify and distinguish between photons arriving simultaneously in the instrument would aid in further PBH studies.

**Key Elements:**

- LAT shall have a broad energy range with response up to at least 300 GeV to constrain cold dark matter candidates.
- LAT shall have a spectral resolution of 6% at energies above 10 GeV for side-incident event to identify relatively narrow spectral lines. LAT shall have a spectral resolution goal of 3% resolution for these events.

### **3 SUMMARY OF REQUIREMENTS**

Section 2 describes a broad range of scientific goals that define the ultimate technical requirements, which the LAT and GBM must meet. Often, these requirements are difficult to quantify without referring to other parameters. For instance, point source sensitivity can be improved by increasing effective area, by increasing observation times through larger field of views, or by decreasing the point-spread function width to reduce background. Improved spectra can be achieved both by reducing intrinsic energy resolution and by increasing source statistics that come from more effective area. Although the parameters are interrelated, the stated scientific expectations can effectively guide the requirements. Tables 1 and 2 are summaries of the basic requirements of the LAT and GBM instruments based upon the science outlined in Section 2. Table 3 is a summary of the derived requirements for the overall mission. Requirements, minimums and goals are listed.

**TABLE 1.** Summary of LAT Instrument Requirements.

	<i>Quantity</i>	<i>EGRET</i>	<i>LAT Requirement</i> <sup>1</sup>	<i>LAT Goal</i> <sup>1</sup>	<i>LAT Minimum</i> <sup>1</sup>	<i>Science Topic</i>
1	<b>Energy Range Low Limit</b>	20 MeV	< 20 MeV	< 10 MeV	< 30 MeV	ALL
2	<b>Energy Range High Limit</b>	30 GeV	> 300 GeV	> 500 GeV	> 100 GeV	ALL
3	<b>Effective Area</b> <sup>2</sup>	1500 cm <sup>2</sup>	> 8000 cm <sup>2</sup>	> 12,000 cm <sup>2</sup>	> 8000 cm <sup>2</sup>	ALL
4	<b>Energy Resolution</b> <sup>3</sup> (on-axis, 100 MeV - 10 GeV)	10%	< 10%	< 8%	< 20%	ALL
5	<b>Energy Resolution</b> <sup>3</sup> (on-axis, 10-300 GeV)		<20%	<15%	<30%	ALL
6	<b>Energy Resolution</b> (>60° incidence, >10 GeV) <sup>4</sup>		< 6%	< 3%	NA <sup>5</sup>	Dark Matter
7	<b>Single Photon Angular Resolution - 68%</b> <sup>6</sup> (on-axis, E>10 GeV)	0.5°	< 0.15°	< 0.1°	< 0.3°	ALL

8	<b>Single Photon Angular Resolution - 68%</b> <sup>6</sup> (on-axis, E=100 MeV)	5.8°	< 3.5°	< 3°	< 5°	ALL
9	<b>Single Photon Angular Resolution - 95%</b> <sup>6</sup> (on-axis)		< 3 x $\theta_{68\%}$	< 2 x $\theta_{68\%}$	< 4 x $\theta_{68\%}$	ALL
10	<b>Single Photon Angular Resolution</b> (off axis at 55°)		< 1.7 times on-axis	< 1.5 times on-axis	< 2 times on-axis	ALL
11	<b>Field of View</b> <sup>7</sup>	0.5 sr	> 2 sr	> 3 sr	> 1.5 sr	ALL
12	<b>Source Location</b> <sup>8,9</sup> <b>Determination</b>	5 arcmin	< 0.5 arcmin	< 0.3 arcmin	< 1 arcmin	UGOs , GRBs
13	<b>Point Source Sensitivity</b> <sup>9,10</sup> (> 100 MeV)	$\sim 1 \times 10^{-7}$ $\text{cm}^{-2} \text{s}^{-1}$	< $6 \times 10^{-9} \text{cm}^{-2} \text{s}^{-1}$	< $3 \times 10^{-9} \text{cm}^{-2} \text{s}^{-1}$	< $8 \times 10^{-9} \text{cm}^{-2} \text{s}^{-1}$	AGN, UGOs, Pulsars, GRBs
14	<b>Instrument Time Accuracy</b> <sup>11</sup>	0.1 ms	< 10 $\mu\text{sec}$	< 2 $\mu\text{sec}$	< 30 $\mu\text{sec}$	Pulsars, GRBs
15	<b>Background Rejection</b> <sup>12</sup> (Contamination of high latitude diffuse sample in any decade of energy for >100 MeV.)	<1%	<10%	<1%	<15%	Diffuse
16	<b>Dead Time</b>	100 ms /event	< 100 $\mu\text{s}$ /event	< 20 $\mu\text{s}$ /event	< 200 $\mu\text{s}$ /event	GRBs

17	<b>GRB Location Accuracy On-Board</b> 13		< 10 arcmin	< 3 arcmin	NA 5	GRBs
18	<b>GRB Notification Time To Spacecraft</b> 14		< 5 sec	< 2 sec	NA 5	GRBs

- 1 Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.
- 2 Maximum (as function of energy) effective area at normal incidence. Includes inefficiencies necessary to achieve required background rejection. Effective area peak is typically in the 1 to 10 GeV range.
- 3 Equivalent Gaussian 1 sigma, on-axis.
- 4 Effective area for side incidence is 0.1 to 0.2 that of normal incidence for high resolution measurements.
- 5 NA = Not Applicable. Minimum values are not applicable for parameters that were not Requirements in the AO 99-OSS-03 Announcement of Opportunity.
- 6 Space angle.
- 7 Integral of effective area over solid angle divided by peak effective area. Geometric factor is Field of View times Effective Area.
- 8 High latitude source of  $10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$  flux at >100 MeV with a photon spectral index of -2.0 above a flat background and assuming no spectral cut-off. 1 sigma radius. 1-year survey.
- 9 Derived quantities delimited by double-lined box.
- 10 Sensitivity at high latitudes after a 1-year survey for a 5 sigma detection.
- 11 Relative to spacecraft time.
- 12 Assuming a high-latitude diffuse flux of  $1.5 \times 10^{-5} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$  (>100 MeV) assuming a photon spectral index of -2.1 with no spectral cut-off.
- 13 For burst (< 20 sec duration) with > 100 photons above 1 GeV. This corresponds to a burst of  $\sim 5 \text{ cm}^{-2} \text{ s}^{-1}$  peak rate in the 50 - 300 keV band assuming a spectrum of broken power law at 200 keV from photon index of -0.9 to -2.0. Such bursts are expected to occur in the LAT FOV  $\sim 10$  times per year.
- 14 Time relative to detection of GRB.

**TABLE 2.** Summary of GBM Instrument Requirements.

	<i>Quantity</i>	<i>BATSE</i>	<i>GBM Requirement</i> <sup>1</sup>	<i>GBM Goal</i> <sup>1</sup>	<i>GBM Minimum</i> <sup>1</sup>	<i>Science Topic</i>
19	<b>Energy Range Low Limit</b>	25 keV	< 10 keV	< 5 keV	< 20 keV	ALL
20	<b>Energy Range High Limit</b>	10 MeV	> 25 MeV	> 30 MeV	> 20 MeV	ALL
21	<b>Field of View</b> <sup>2</sup>	4 $\pi$	> 8 sr	> 10 sr	> 6 sr	ALL
22	<b>Energy Resolution</b> <sup>3</sup> (0.1 - 1.0 MeV)		< 10%	< 7%	< 12%	GRBs
23	<b>GRB Alert Location</b> <sup>5</sup>		NA <sup>4</sup>	< 15 deg	NA <sup>4</sup>	GRBs
24	<b>GRB Notification Time To Spacecraft</b> <sup>6</sup>		< 2 sec	< 1 sec	< 5 sec	GRBs
25	<b>Dead Time Average</b>		< 10 $\mu$ sec/event	< 3 $\mu$ sec/event	< 50 $\mu$ sec/event	GRBs
26	<b>Instrument Time Accuracy</b> <sup>7</sup>	10 $\mu$ sec	< 10 $\mu$ sec	< 2 $\mu$ sec	< 30 $\mu$ sec	GRBs

27	<b>Burst Sensitivity Ground Analysis</b> <sup>8</sup>	$0.2 \text{ cm}^{-2} \text{ s}^{-1}$	$< 0.5 \text{ cm}^{-2} \text{ s}^{-1}$	$< 0.3 \text{ cm}^{-2} \text{ s}^{-1}$	$< 1.0 \text{ cm}^{-2} \text{ s}^{-1}$	GRBs	CH-01
46	<b>Burst Sensitivity On-Board Trigger</b> <sup>9</sup>	$0.3 \text{ cm}^{-2} \text{ s}^{-1}$	$< 1.0 \text{ cm}^{-2} \text{ s}^{-1}$	$< 0.75 \text{ cm}^{-2} \text{ s}^{-1}$	$< 2.0 \text{ cm}^{-2} \text{ s}^{-1}$	GRBs	CH-01

- 1 Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.
- 2 Integral of effective area over solid angle divided by peak effective area. Geometric factor is Field of View times Effective Area. Should overlap with LAT FOV.
- 3 Equivalent Gaussian. 1 sigma. On axis.
- 4 NA= Not Applicable. The addition of the GRB monitor was a "goal" in the AO 99-OSS-03. The broad-band spectroscopic capability of the GRB instrument is upgraded here to be a requirement. The location of the bursts is listed only as a goal.
- 5 1 sigma radius. For burst of brightness  $10 \text{ cm}^{-2} \text{ s}^{-1}$  in 50 - 300 keV band and a duration of 1 second or longer.
- 6 Time relative to a GBM GRB trigger. Used for both 'rapid ground notification' or 'burst alert' through TDRSS (or equivalent real-time link) and for 'LAT notification'.
- 7 Relative to spacecraft time.
- 8 GRB peak brightness sensitivity, 50 - 300 keV range, 5 sigma detection.
- 9 50% efficiency level for bursts occurring within the GBM FOV, excluding observational inefficiencies such as SAA passages and earth occultations, 50 - 300 keV range.

CH-01

**Table 3.** Science Requirements on the GLAST Mission

	<i>Quantity</i>	<i>GLAST Requirement</i> <sup>1</sup>	<i>GLAST Goal</i> <sup>1</sup>	<i>GLAST Minimum</i> <sup>1</sup>	<i>Science Topic</i>
28	<b>Mission Lifetime</b> ( $<20\%$ degradation) <sup>2</sup>	> 5 years	> 10 years	=2 years	ALL
29	<b>Telemetry Downlink Orbit Average</b>	> 300 kbps	> 1 Mbps	> 300 kbps	ALL
30	<b>Telemetry Downlink Realtime</b> <sup>3</sup>	> 1 kbps	> 2 kbps	> 0.5 kbps	GRBs
31	<b>Telemetry Uplink Realtime</b> <sup>3</sup>	> 1 kbps	> 2 kbps	> 0.5 kbps	GRBs, AGN
32	<b>Time to Respond to TOO's on Ground</b> <sup>4</sup>	< 6 hours	< 4 hours	< 12 hours	GRBs, AGN
33	<b>Spacecraft Repointing Times for Autonomous Slews</b> <sup>5</sup>	< 10 min	< 5 min	NA	GRBs, AGN
34	<b>GRB Notification Time to Ground by Spacecraft</b> <sup>6</sup>	< 7 sec	< 4 sec	< 10 sec	GRBs, AGN
35	<b>Pointing Accuracy Absolute</b> <sup>7</sup>	< 2°	< 0.5°	< 5°	ALL

CH-02

36	<b>Pointing Knowledge</b> <sup>7</sup>	< 10 arcsec	< 5 arcsec	< 20 arcsec	ALL	
37	<b>Observing Modes</b>	- Rocking zenith pointing <sup>15</sup> - Pointed mode <sup>8</sup>			ALL	CH-01
38	<b>Targeting</b>	No restrictions on Pointing <sup>8</sup> of axis normal to LAT			ALL	CH-01
39	<b>Uniformity of Sky Coverage during All-sky Survey</b> <sup>9</sup>	< ± 20%	< ± 10%	< ± 30%	ALL	CH-01
40	<b>Observatory Time Accuracy</b> <sup>10</sup>	< 10 μsec	< 3 μsec	< 30 μsec	Pulsars	CH-01
41	<b>Observatory Absolute Position Accuracy</b>	< 3.3 km	< 1 km	< 10 km	Pulsars	
42	<b>Observing Efficiency</b> <sup>11</sup>	> 90 %	> 95%	> 80%	ALL	
43	<b>Data Loss</b> <sup>12</sup>	< 2 %	< 1%	< 5%	ALL	
44	<b>Data Corruption</b> <sup>13</sup>	< 10 <sup>-10</sup>	< 3 x 10 <sup>-11</sup>	< 3 x 10 <sup>-10</sup>	ALL	
45	<b>Earth Avoidance</b> <sup>14</sup>	> 30°(adjustable)	N/A	N/A	ALL	CH-01

- |    |  |       |
|----|--|-------|
| 1  | Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.  |       |
| 2  | 20% degradation = no more than 20% loss of LAT science return.   |       |
| 3  | Uplink telemetry rate for at least 80% of time outside of SAA.   |       |
| 4  | Response time for the SSC and MOC to plan and send a spacecraft repointing command after the decision is made to respond to a Target of Opportunity (TOO).   | CH-01 |
| 5  | Time for 75 <sup>0</sup> slew, to be met 100% of the time under 4 reaction wheel (RWA) control and 75% of the time under 3 RWA control (single RWA failure) accounting for slew constraints (e.g. yaw flip). | CH-03 |
| 6  | Time from spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.                             |       |
| 7  | 1 sigma radius.  |       |
| 8  | Pointing of axis normal to LAT to within 30 <sup>0</sup> of source. (No science constraint on roll axis.)  |       |
| 9  | Sky coverage exposure uniformity integrating for 7 days, not including SAA effects.  |       |
| 10 | Relative to Universal Time, 1 sigma r.m.s..  |       |
| 11 | Fraction of time with data return, not including SAA effects.  |       |
| 12 | Fraction of data taken by the instruments but not delivered to the IOC. Not including SAA data loss. Not including instrument downtime.  |       |
| 13 | Fraction of undetected corrupted events.   |       |
| 14 | Axis normal to LAT shall be capable of remaining at an angle greater than this above the Earth's horizon during normal operations, with the possible exception of rapid slewing to acquire a GRB.            | CH-01 |
| 15 | The observatory shall be capable of scanning the LAT FOV (55° half-angle) over >90% of the celestial sphere repetitively on selectable timescales as short as every 2 orbits.                                |       |