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GLAST: GeV Astronomy in a Multiwavelength Context

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Abstract

The GLAST Large Area Telescope (LAT), successor to EGRET on the Compton Observatory, will play an important role in multiwavelength studies during the second half of this decade. Operating at energies between 20 MeV and greater than 300 GeV with sensitivity 30 or more times greater than that of EGRET, the LAT will offer good spatial and time resolution over a large (>2 sr) field of view. The LAT will bring insight to the whole range of high-energy gamma-ray phenomena, including bursts, active galactic nuclei, pulsars, supernova remnants, diffuse emission, and unidentified sources. In essentially all cases, the maximum scientific return will come from coordinated (although not necessarily simultaneous) multiwavelength observations. Particularly with its planned scanning mode of operation, GLAST will have full sky coverage on relatively short time scales. The LAT team looks forward to cooperating with observers at other wavelengths.

1 Introduction

As the highest-energy photons, gamma rays have an inherent interest to astrophysicists and particle physicists studying high-energy, nonthermal processes. Gamma-ray telescopes complement those at other wavelengths, especially radio, optical, and X-ray, providing the broad, mutiwavelength coverage that has become such a powerful aspect of modern astrophysics. EGRET, the high-energy telescope on the Compton Gamma Ray Observatory, led the way, contributing to broad-band studies of blazars, gamma-ray bursts, pulsars, and unidentified sources. The next major advance in high-energy gamma-ray astrophysics is GLAST, the Gamma-ray Large Area Space Telescope. The Large Area Telescope (LAT) on GLAST will have $\sim$30 times the sensitivity of EGRET at 100 MeV and more at higher energies, including the largely-unexplored 30–100 GeV band. Multiwavelength observations are a central feature of the plans for GLAST.

This paper is organized around three topics:

• Past. Results from CGRO illustrate the value of multiwavelength observations.

• Present. The design and expected performance of the GLAST instruments will be a powerful complement to other ground-based and space telescopes.

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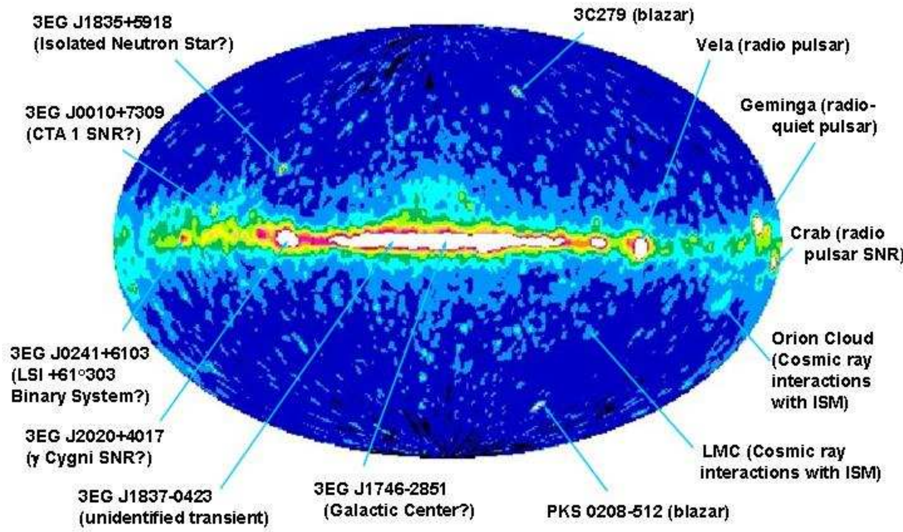

Figure 1: The gamma-ray sky above 1 GeV as seen by EGRET

• Future. GLAST operational planning incorporates multiwavelength cooperation as a keystone of its effort.

2 Lessons from the Compton Observatory

In the MeV range and above, astrophysical sources are non-thermal, i.e. produced by interactions of energetic particles. Nonthermal sources are inherently multiwavelength objects, for several reasons:

1. Nature rarely produces monoenergetic particle beams. A broad range of particle energies leads to a broad range of photon energies.

2. Charged particles rarely interact by only one process. Different processes radiate in different energy bands.

3. High-energy particles, as they lose energy, can radiate in lower-energy bands.

The Compton Gamma Ray Observatory[1], especially the Energetic Gamma Ray Experiment Telescope (EGRET), provided a comprehensive overview of the sky at gamma-ray energies. A summary of the EGRET data above 1 GeV, including notations for some sources and possible identifications, is shown in Fig. 1. Gamma-ray source identifications rely almost exclusively on multiwavelength observations, because the gamma-ray observations by themselves provided too little information to make unique identifications. Some examples of multiwavelength studies involving CGRO, including science topics and implications for future multiwavelength studies, are shown on the next page.

2.1 Pulsars

For these rapidly-rotating neutron stars, some of the science topics include neutron star population studies, the location and nature of particle acceleration and interaction (model testing), physics in extreme magnetic and electric fields, matter state at high densities, and relativistic effects. Except for the pulsations themselves, time variability is not significant for pulsars. Simultaneous multiwavelength observations are not essential.

2.2 Active Galactic Nuclei

Thought to be supermassive black holes with accretion disks and relativistic jets, AGN explore a wide variety of scientific phenomena, including location and nature of particle acceleration and interaction in jets, confirmation of unified models, cosmological probes using high-energy cutoff due to absorption by Extragalactic Background Light, and contribution to the diffuse background. Due to variability on short time scales, AGN require simultaneous multiwavelength observations for maximum scientific return. A key multiwavelength approach for AGN is measuring the strength and phasing of flaring at different wavelengths for modeling emission. This method requires observations before and after a flare, with a duration several times that of the flare itself, to be sure it is the same flare.

2.3 Supernova Remnants

Supernova remanants are an excellent astrophysical laboratory for such topics as comparing electron vs. proton acceleration in SNR, studying interactions with the interstellar medium, and determining the upper energy limit of SNR acceleration of cosmic rays. The time scale for variability in SNR is long; therefore simultaneity is not critical for multiwavelength observations.

2.4 Unidentified Sources

Unidentified high-energy gamma-ray sources represent discovery science which can uncover new source classes or new insight about known objects. Variability such as was seen in some unidentified EGRET sources can help probe the nature of non-blazar transients. Although many unidentified soures are steady and require only contemporaneous multiwavelength observations, for transients or other variable unidentified gamma-ray sources, having simultaneous observations may be the only viable means of positive identification.

3 Preparations for the LAT and GBM on GLAST

The GLAST observatory will carry two scientific instruments: the Large Area Telescope (LAT, which orignally was called GLAST by itself) and the GLAST Burst Monitor (GBM). These two instruments span an energy range from about 10 keV to greater than 300 GeV. The observatory, which is managed by NASA

Figure 2: Artist's concept of the Gamma-ray Large Area Space Telescope

Goddard Space Flight Center, is scheduled for launch in late 2006 and is planned for a minimum lifetime of at least five years.

The GBM[2] is a collaboration between the National Space Science Technology Center(NSSTC) in Huntsville, Alabama, and the Max Planck Institute for Extraterrestrial Physics in Garching, Germany. The Principal Investigator is C. Meegan of NSSTC. It includes Sodium Iodide (NaI) detectors that provide low-energy spectral coverage and rough burst locations in the typical GRB energy regime over a wide Field of View (FoV)and Bismuth Germanate (BGO) detectors that provide high-energy spectral coverage to overlap the LAT range over a wide FoV. The GBM provides spectra for bursts from 10 keV to 30 MeV, connecting frontier LAT high-energy measurements with more familiar energy domain; it provides wide sky coverage (8 sr) and enables autonomous repoint requests for exceptionally bright bursts that occur outside LAT FOV for high-energy afterglow studies (an important question from EGRET); and it provides burst alerts to the ground.

The LAT[3] is a partnership between NASA and the Department of Energy, with international hardware contributions from France, Italy, Japan and Sweden. The Principal Investigator is P. Michelson of Stanford, and the project is managed at the Stanford Linear Accelerator Center (SLAC). The LAT is a pair-production telescope, a greatly-improved successor to EGRET. It has a precision Si-strip Tracker (TKR)with 18 XY tracking planes (to measure the photon direction and identify gamma rays), a hodoscopic CsI Calorimeter(CAL)array of 1536 CsI(Tl) crystals in 8 layers (to measure the photon energy and image the shower), a segmented Anticoincidence Detector (ACD) with 89 plastic scintillator tiles (to reject background of charged cosmic rays), and an electronics system that includes a flexible, robust hardware trigger and software filters.

The LAT has a large FoV (∼20% of the sky), operates across 4 decades in energy (including the largely unexplored region from 10-100 GeV), has a Point Spread Function (PSF) for gamma rays a factor > 3 better than EGRET for E>1 GeV, and combines these features with a large effective area (factor > 4 better than EGRET) to give a factor > 30 improvement in sensitivity. As a result, during the all-sky survey LAT will have sufficient sensitivity after about one day to detect (5σ) the weakest EGRET sources.

AGN offer an example of the expected capabilities of the LAT. EGRET detected ∼70-90 AGN of the blazar class. Extrapolation to the GLAST LAT sensitivity depends on the detailed assumptions, but GLAST should expect to see dramatically more, up to thousands of these sources. In addition to the number of AGN seen, the GLAST energy range is broad, overlapping those of ground-based experiments for good multiwavelength coverage, and the wide field of view will allow GLAST to monitor AGN for time variability on many scales.

Supernova remnants illustrate the value of the improved sensitivity and spatial resolution of the LAT compared to EGRET. For SNR candidates, the LAT sensitivity and resolution will allow mapping to separate extended emission from the SNR from possible pulsar components. Energy spectra for the two emission components may also differ. Resolved images will allow observations at other wavelengths to concentrate on promising directions.

Unidentified sources benefit especially from the improved source location capability of the LAT. EGRET source position error circles are ∼0.5°, resulting in counterpart confusion. GLAST will provide much more accurate positions, with ∼30 arcsec - ∼5 arcmin localizations, depending on brightness. Better positions facilitate multiwavelength comparisons.

An important aspect of GLAST is its complementarity with the ground-based telescopes that extend to even higher energies. The source detection sensitivities for the space-based and ground-based telescopes are comparable. The fact that their energy ranges overlap is an important advance over the previous generations of telescopes. In addition, specific aspects of source detections provide some synergy. Table 1 shows the comparison of telescope characteristics.

4 Plans for GLAST Operations

The details of the GLAST operating plans are flexible. Because GLAST is considered a facility, a Users Group is planned to help advise on the best scientific use of the mission. Nevertheless, some basic priciples for GLAST operations have been established. Key features of this plan were included in the NASA Announcement of Opportunity for GLAST[4]

The first year will be an all-sky survey. Unlike CGRO, the survey will be carried out primarily in a scanning mode, keeping the instruments always pointed away from the Earth (which is bright in gamma rays). This approach

Table 1: Comparison of Ground- and Space-Based Gamma-Ray Telescopes

	Ground Cerenkov	Ground Air Shower	Space
Angular resolution	good	fair	good
Duty cycle	low	high	high
Area	large	large	small
Field of view	small	large	large
Energy resolution	good	fair	good
Limiting factor	background	background	photon statistics

takes maximum advantage of the large fields of view of the LAT and the GBM, allowing a full sky survey on short (day) timescales. After the first year, the scientific program will be determined by peer-reviewed proposals. Proposals can request pointed observations, based on scientific requirements. A pointed observation can obtain about 3 times as many photons from a source per unit time as the scanning mode. Target of Opportunity (TOO) proposals can also be included.

There will be essentially no constraints on GLAST Operations. Any non-occulted source can be observed at any time.

For the two best-known classes of variable gamma-ray sources, bursts and AGN, preliminary approaches have been established for the first year of operation. Because bursts are much brighter and shorter than AGN flares, special provisions have been made for the possiblity of re-pointing the observatory.

4.1 Burst Operations

Gamma-ray bursts may be handled as follows:

• If a burst is bright enough that an on-board analysis provides >90% certainty that a burst occurred within the LAT FOV, the observatory will slew to keep the burst direction within about 30 degrees of the LAT z axis during >80% of the entire non-occulted viewing period (neglecting South Atlantic Anomaly effects). Such events are estimated to occur approximately once per week.

• If the burst is exceptionally bright, the observatory will slew to bring the burst direction within about 30 degrees of the LAT z axis during >80% of the entire non-occulted viewing period (neglecting SAA effects). Such events are likely to occur a few times per year.

• After six months, this repointing strategy will be re-evaluated. In particular, the brightness criterion for case 2 and the stare time, nominally five hours, will be revisited and possibly adjusted by command, based on what has been learned about the late high-energy emission of bursts.

4.2 AGN Planning

Gamma-ray-bright AGN planning includes:

• Most AGN science can be best addressed by the all-sky scan.

• Unusually large flares will be treated as Targets of Opportunity, and studied in a coordinated multiwavelength campaign, for those where a multiwavelength campaign is feasible. Autonomous repointing of the spacecraft is not required for AGN science during the first year.

• This survey approach to AGN studies will be re-evaluated after the first year, because new knowledge about AGN might demand a new strategy.

5 Plans for GLAST Data Processing and Distribution

As for the operations planning, the planning for handling of the GLAST data is tentative and will be updated before launch. It should be strongly emphasized that information in the present paper is unofficial and subject to change. The AO did provide a working concept for GLAST data management:

• During the all-sky survey. The LAT team will use the early data for instrument calibration and preparation of an initial source catalog. At the end of the survey, all the data will be made public. The GLAST Science Support Center will be providing user-friendly software to enable all types of standard analysis.

• After the first year. All data will be made public. Guest Investigator proposals will be awarded for scientific ideas, not images or other data. Use of data will be handled on an honor system. No data will be proprietary.

• At all times, data from transient sources, including burst data from the GBM, will be made public immediately, in order to facilitate multiwavelength observations. These quicklook data may be uncalibrated, especially early in the mission, but the uncertainities will be quantified. On-board processing will produce alerts for bursts within seconds.

• A LAT source catalog will be released at the end of the first year and then updated at the end of the second and fifth years (tentative schedule); an early release version of the catalog may be made available during the first year to aid proposal preparation.

The pointing and livetime history will be released with the Level 1 data, along with the instrument response functions. Pulsar ephemerides, which come primarily from radio timing information, will be updated during the mission, coordinated by a Pulsar Working Group through the GLAST Science Support Center.

To facilitate the multi-mission interpretation of the GLAST data, the GLAST Science Support Center is located in Goddards Laboratory for High Energy Astrophysics. The SSC and the instrument teams are defining the analysis software. The instrument teams will manage the software development, but SSC staff will assist. The SSC is responsible for:

1. managing the the guest investigator program
2. coordinating the mission timeline (includes support for TOOs, commands)
3. providing data and analysis software to the scientific community
4. archiving data and software in the HEASARC

5. supplying the Italian mirror site with data and software

6. supporting (logistically and scientifically) the Project Scientist, the Science Working Group, and the Users Committee

7. some data processing (e.g., exposure maps)

6 GLAST Contributions to Multiwavelength Astrophysics

As a facility-class mission, GLAST is dedicated to the principles of multiwavelength support and cooperation. Some aspects of the opportunities and challenges for GLAST in multiwavelength studies are:

1. GLAST can monitor the sky for variable sources. Especially in scanning mode, but even if pointed, GLAST will see a large fraction of the sky with good sensitivity every day. GLAST can serve as a trigger for observations at other wavelengths. Flaring sources probably require some processing on the ground and will require a day or more (depending on intensity) for quicklook recognition. How the GLAST instrument teams communicate this information is under discussion. Proposals include a Web site showing bright sources, updated regularly. Bursts will give an on-board trigger that can be sent immediately to the ground. The current plan is to use the existing GCN.

2. Selecting the sources for multiwavelength study will rely largely on other wavelengths. Availability of telescope time, coordinated plans, and observational constraints will limit the number and choice of sources. The GLAST science teams want to cooperate in multiwavelength programs with the broadest coverage. The LAT team is encouraging small optical observatories and even amateurs to help monitor sufficiently bright sources. We will try to support ongoing programs that contribute to multiwavelength studies.

3. Multiwavelength observation programs are needed even when sources are not flaring. The broad-band shape of the spectrum is often critical in determining the nature of an unidentified source. The fluctuation (power density) spectrum is an important part of understanding flares. Determining blazar radio properties and redshifts is also important, since GLAST expects to detect many blazars that are not yet identified as such.

As with many developing projects, much of the current information about GLAST is most easily found on Web sites. Some of these of particular interest to multiwavelength studies are listed in Table 2. In particular, the GLAST Science Working Group fully supports the agreement made at this workshop to provide information that will assist in multiwavelength planning.

7 Conclusions

Multiwavelength observations are essential for GLAST science. Both previous observations and theoretical considerations show that gamma-ray sources are usually broad-band objects. GLAST will address many important astrophysical questions, including topics such as black holes and other particle accelerators, unidentified gamma-ray sources, the diffuse gamma-ray background, gamma-ray

Table 2: Some Web Sites with Information about GLAST

http://glast.gsfc.nasa.gov/science/multi/	GLAST Project Multiwavength Page
http://glast.gsfc.nasa.gov/ssc/	GLAST Science Support Center
http://glast.sonoma.edu/	GLAST Education and Public Outreach Site
http://www-glast.stanford.edu/	GLAST Large Area Telescope
http://f64.nsstc.nasa.gov/gbm/	GLAST Burst Monitor

bursts at high energies, and new gamma-ray discoveries. GLAST operations will contribute to a wide range of cooperative, multiwavelength observations.

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References

[1] Gehrels, N. and Shrader, C., in Gamma 2001: Gamma-Ray Astrophysics, Edited by Steven Ritz, Neil Gehrels, and Chris R. Shrader. AIP Conference Proceedings, Vol. 587. Melville, NY: American Institute of Physics, 2001., p.3.

[2] Kippen, R.M. et al., in Gamma 2001: Gamma-Ray Astrophysics, Edited by Steven Ritz, Neil Gehrels, and Chris R. Shrader. AIP Conference Proceedings, Vol. 587. Melville, NY: American Institute of Physics, 2001., p.801

[3] Michelson, P.F., in Gamma 2001: Gamma-Ray Astrophysics, Edited by Steven Ritz, Neil Gehrels, and Chris R. Shrader. AIP Conference Proceedings, Vol. 587. Melville, NY: American Institute of Physics, 2001., p.713

[4] Announcement of Opportunity, Gamma-Ray Large Area Space Telescope (GLAST), Flight Investigations, NASA AO 99-OSS-03