The GLAST Burst Monitor (GBM)

R. M. Kippen[*], M. S. Briggs[*], R. Diehl[†], G. J. Fishman[**], R. H. Georgii[†],
C. Kouveliotou[**], G. G. Lichti[†], C. A. Meegan[**], W. S. Paciesas[*],
R. D. Preece[*], V. Schönfelder[†] and A. von Kienlin[†]

[*] *University of Alabama in Huntsville, Huntsville, AL 35899, USA*
[†] *Max-Planck-Institut für extraterrestrische Physik, 85748 Garching, Germany*
[**] *NASA/Marshall Space Flight Center, Huntsville, AL 35812, USA*

Abstract. The study of gamma-ray bursts (GRBs) is one of the primary scientific objectives of the Gamma-ray Large Area Space Telescope (GLAST) mission. With its high sensitivity to prompt and extended 20 MeV to 300 GeV burst emission, GLAST's Large Area Telescope (LAT) is expected to yield significant progress in the understanding of GRB physics. To tie these breakthrough high-energy measurements to the known properties of GRBs at lower energies, the GLAST Burst Monitor (GBM) will provide spectra and timing in the 10 keV to 25 MeV energy range. The GBM will also have the capability to quickly localize burst sources to $\sim 15^\circ$ over more than half the sky, allowing the LAT to re-point at particularly interesting bursts which occur outside its field of view. With combined LAT/GBM measurements GLAST will be able to characterize the spectral behavior of many bursts over nearly six decades in energy. This will allow the unknown aspects of high-energy burst emission to be explored in the context of well-known low-energy properties. In this paper, we present an overview of the GBM instrument, including its technical design, scientific goals, and expected performance.

GAMMA-RAY BURSTS AND GLAST

Recent breakthrough discoveries, along with decades of observations and theoretical speculations, have brought gamma-ray bursts (GRBs) into the forefront of astrophysics research. The enigmatic GRB phenomenon — the most powerful in the Universe yet discovered — has captured the wonder and imagination of a broad audience, such that any future high-energy observatories are bound to have GRBs as a major scientific objective. The Gamma-ray Large Area Space Telescope (GLAST), planned for launch in 2006, is no exception.

The GLAST Large Area Telescope [LAT; see 1] will provide particularly important insight into the physics of gamma-ray bursts as it will probe — with high sensitivity over a wide field of view — the relatively unknown aspects of GRB emission above 20 MeV, where the effects of high-energy particle acceleration, relativistic beaming, and intergalactic attenuation are most clearly observed. Measurements obtained with the GLAST-LAT will build on the handful of bursts detected by CGRO-EGRET in this energy range [2, 3], which have supplied unique and important constraints on the energy release and photon production mechanisms [see e.g., 4, 5]. In addition to providing high-quality spectral and temporal measurements, the GLAST-LAT will also be able to localize more than 100 GRB sources per year with $\sim 10'$ precision [6], and provide these locations to follow-up observers within minutes of burst onset. Thus, GLAST will be an important component in the new science of tracking GRB afterglow emission at different wavelengths over extended periods of time. This approach promises to yield fruitful scientific return, as it probes the GRB phenomenon in vastly different physical regimes.

Although the GLAST-LAT holds great promise for future GRB research, there are important limitations to its effectiveness as a burst detector. Foremost among these is the problem of continuity with the current knowledge of GRBs, which is based mainly on measurements of low-energy gamma rays below 1 MeV. With the LAT alone it will be difficult to evaluate how the ground-breaking high-energy observations fit into the known low-energy characteristics of GRB behavior. This problem is most evident in terms of GRB energy spectra, where the most characteristic known feature — a break typically in the energy range 100–500 keV [7, 8] — occurs at energies well below the LAT threshold. The EGRET observations of extended or delayed high-energy flux [2, 3] suggest different or evolving emission processes that will be difficult to evaluate in a limited energy range. Other significant concerns for the LAT as a burst detector are the technical problems associated with autonomous triggering and rapid source localization given the large on-orbit background rate and small number of detected source photons for weak bursts. In order to overcome or mitigate these problems, GLAST will include a secondary instrument: the GLAST Burst Monitor (GBM[1]). This paper [see also 9] provides a brief introductory description of the GBM instrument, and how it will perform to enhance the GLAST mission in the study of GRBs.

GBM ROLE AND REQUIREMENTS

The primary role of the GBM is to enhance the scientific return of GLAST GRB observations by providing simultaneous low-energy spectral and temporal measurements for all GRBs that occur within the LAT field of view. This requires an effective energy range extending low enough to measure well-below the typical GRB spectral break, and high enough to overlap with LAT measurements for inter-instrument calibration. Furthermore, the GBM sensitivity and field of view (FoV) must be commensurate with the LAT capabilities 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 in its ability to rapidly detect and localize bursts by providing prompt burst trigger notification information. The secondary GBM objective is to provide coarse burst locations over a wide FoV that can be used to re-point the LAT at particularly interesting bursts for performing afterglow observations, or to notify external follow-up observers.

The GBM instrument performance requirements to achieve its scientific objectives are listed in Table 1. In this context, a requirement is a key capability that the instrument will be designed to achieve, while a goal represents a capability to strive for that enhances the scientific measurement performance. Also listed in the table is the key item that drives each requirement. It is important to note that a fundamental requirement not included in

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[1] `http://gammaray.msfc.nasa.gov/GBM`

TABLE 1. Summary of GBM Scientific Performance Requirements

Parameter	**Requirement**	**Goal**	**Main Driver**
Low Energy Limit	10 keV	5 keV	Characterize spectra below break
High Energy Limit	25 MeV	30 MeV	Overlap LAT energy range
Energy Resolution[a]	<25%	<18%	Continuum spectroscopy
Field of View[b]	>8 sr	>10 sr	Match, exceed LAT FoV
Time Accuracy[c]	<10 μs	<2 μs	Measure rapid variability
Average Dead Time	<10 μs/count	<3 μs/count	Measure intense pulses
Burst Sensitivity[d]	<0.5	<0.3	Consistent with LAT GRB sensitivity
Burst Alert Locations[e]	—	<15°	Sufficient to re-point LAT
Burst Alert Time Delay[f]	<2 s	<1 s	Less than typical GRB duration

[a] FWHM, 0.1–1 MeV

[b] Co-aligned with LAT field of view

[c] Relative to spacecraft time

[d] Peak flux for 5σ detection in $\mathrm{ph} \cdot \mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ (50–300 keV)

[e] 1σ systematic error radius

[f] Time from burst trigger to spacecraft notification. Used to notify ground or LAT.

the table is that the GBM is constrained to consume only a small fraction ($\lesssim$5%) of the overall GLAST mission resources (e.g., mass, power, cost), and shall in no way detract from the LAT's operation or performance.

GBM INSTRUMENT DESIGN

Given the stringent resource limits, the GBM is forced to be a relatively modest instrument. To fit the required performance within the limitations, the design and technology borrow heavily from previous GRB instruments, particularly from CGRO-BATSE. Like BATSE, the GBM design is based on the use of two types of cylindrical crystal scintillation detectors, whose light is read out by photomultiplier tubes (PMTs).

An array of 12 sodium iodide (NaI) detectors (0.5-in thick, 5-in diameter) are employed to cover the lower end of the energy range up to $\sim$1 MeV. 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 1) with different orientations so as to provide the required sensitivity and FoV. The thin NaI detectors produce a cosine-like off-axis response that will be used to localize burst sources by comparing the counting rates from detectors with different viewing angles. To cover higher energies, the GBM will also include two 5-in thick, 5-in diameter bismuth germanate (BGO) detectors. The BGO detectors have a combination of high-density (7.1 g cm^{-3}) and large effective $Z \approx 63$ that results in good stopping power up to the start of the LAT energy range $\sim$20 MeV. They 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 will have two PMTs, located at opposite ends of the crystal.

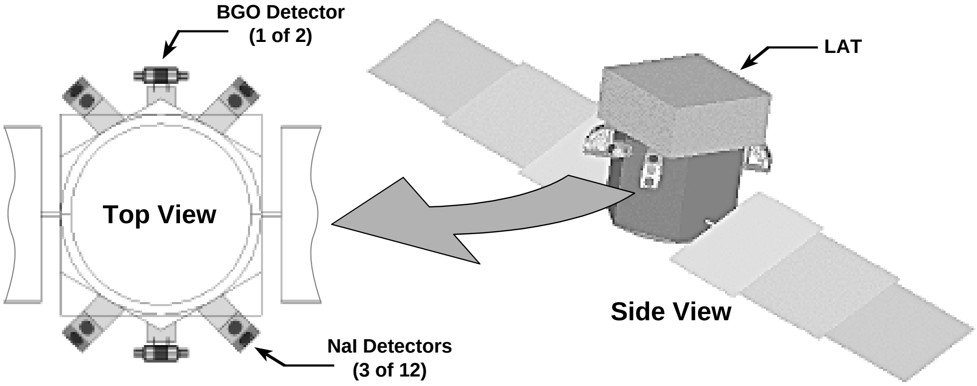

FIGURE 1. Preliminary concept for placement of the GBM detectors on the GLAST spacecraft.

The signals from all 14 GBM detectors will be collected by a central Data Processing Unit (DPU). This unit will digitize and time-tag the detector pulse height signals, package the resulting data into several different types for transmission to the ground (via the GLAST spacecraft), and perform various data processing tasks such as autonomous burst triggering. In addition, the DPU will be the sole means of controlling and monitoring the instrument. Included in this function is the ability to control adjustable detector power supplies to enable automatic control of the gain of each PMT.

There will be three basic types of science data: (1) continuous data will consist of the counting rates from each detector with various (selectable) energy and time integration bins; (2) burst trigger data will contain lists of individually time-tagged pulse height events from selected detectors for periods before and after each on-board burst trigger; (3) burst alert data will contain computed information from a burst trigger, such as intensity, location, and classification. The burst alert data will receive priority telemetry that will allow transmission to the ground at any time in less than 7 s. Alerts will also be made available to the LAT and to the spacecraft to aide in LAT burst detection and for making re-pointing decisions. The remaining data types will be transmitted via discrete ground contacts with a typical latency of $\lesssim$12 hours.

EXPECTED PERFORMANCE

We have performed simulations to assess the GRB measurement performance of the GBM instrument. These, include Monte Carlo simulations of the physical detector response, measured detector performance properties, and background rates scaled appropriately from BATSE measurements. With these assumptions, and using detection criteria similar to those of BATSE ($>4.5\sigma$, 50–300 keV, in at least two detectors in 1.024 s), the predicted GBM burst detection rate ranges from 150–225 per year, depending on the pointing schedule of GLAST (i.e., the fraction of time Earth blocks the GBM FoV). This rate is commensurate with that expected for the LAT [6]. In practice, a higher GBM burst detection rate will be achieved with a more flexible trigger algorithm that provides improved background estimates, and uses several different energy ranges and time-scales.

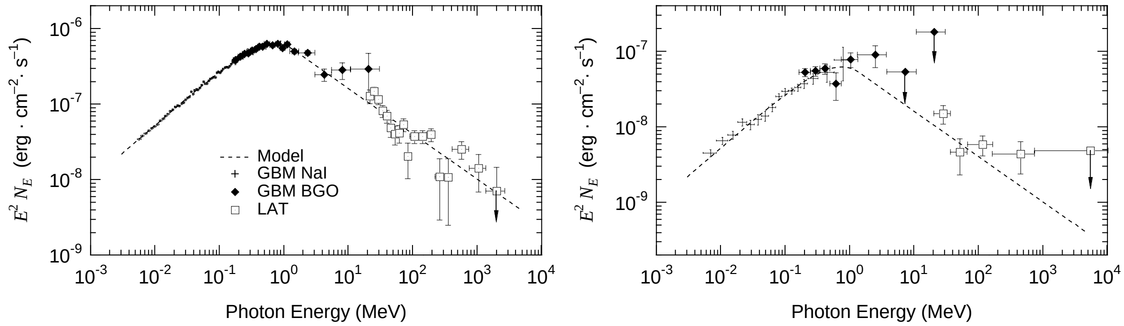

FIGURE 2. Simulated GBM and LAT spectral measurements of the bright GRB 940217 (*left*), and the same burst dimmed by a factor of ten (*right*).

The average GBM statistical location uncertainty for all triggered bursts is estimated to be $\sim$15° (1σ radius), and improves to $\sim$9° ($\sim$1.5°) for the brightest 40% (5%) of the bursts. The systematic location error is estimated to be $\sim$1–2° for final ground processed data, and $\sim$5–10° for on-board processing.

To evaluate the spectroscopic performance of the GBM, detailed simulations were performed for a variety of different spectral characteristics, burst intensities, and observing conditions, including joint observations with the LAT. Figure 2 shows examples of simulated observations of the bright GRB 940217 (as characterized by CGRO measurements [3]). For this burst the joint GBM+LAT measurements constrain the time-averaged burst spectrum over more than five decades in energy with typical statistical uncertainties in the spectral parameters of less than 1% ($\sim$2–10% when the burst is dimmed by a factor of ten). In addition to measuring the low-energy spectral regime below the LAT threshold, the GBM significantly improves the constraints on high-energy spectral behavior compared to those of the LAT alone. For instance, in the simulation of GRB 940217 the uncertainty in the high-energy spectral index improves by a factor of four compared to a fit of the LAT data alone. The combination of GBM and LAT will thereby provide a powerful tool to study GRB spectra and their underlying physics.

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