

MEASUREMENTS OF GAMMA-RAY BURSTS WITH GLAST

G. G. Lichti¹, M. Briggs², R. Diehl¹, G. Fishman³, J. Greiner¹,
R. M. Kippen⁴, C. Kouveliotou³, C. Meegan³, W. Paciesas²,
R. Preece², V. Schönfelder¹ and A. von Kienlin¹

¹ *Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstrasse,
D-85748, Garching, Germany*

² *University of Alabama, Huntsville, AL 35899, U.S.A.*

³ *NASA/Marshall Space-Flight Center, 320 Sparkman Drive, Huntsville,
AL 35812, U.S.A.*

⁴ *Los Alamos National Laboratory, ISR-2, Mail Stop B244, Los Alamos,
NM 87545, U.S.A.*

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Abstract. One of the scientific goals of the main instrument of *GLAST* is the study of gamma-ray bursts (GRBs) in the energy range from ~ 20 MeV to ~ 300 GeV. In order to extend the energy measurement towards lower energies, a secondary instrument, the *GLAST* Burst Monitor (GBM), will measure GRBs from ~ 10 keV to ~ 25 MeV and will therefore allow the investigation of the relation between the keV and the MeV–GeV emission from GRBs over six energy decades. These unprecedented measurements will permit the exploration of the unknown aspects of the high-energy burst emission and the investigation of their connection with the well-studied low-energy emission. They will also provide new insights into the physics of GRBs in general. In addition, the excellent localization of GRBs by the Large-Area Telescope will stimulate follow-up observations at other wavelengths which may yield clues about the nature of the burst sources.

Key words: instruments – GLAST space mission – gamma-rays: bursts

1. INTRODUCTION

Gamma-ray burst astronomy is one of the most active fields of modern astronomy since it deals with the physics of compact objects

and of black holes, with stellar evolution and supernovae, with star formation and cosmology and with particle acceleration and cosmic-ray physics. Since the outstanding discoveries of *BeppoSAX*, the cosmological distance scale for long (>2 s) bursts has been established. In the recent years also a basic understanding of the central engine has emerged. However still a lot of open questions exist.

One of these concerns the generation of delayed high-energy gamma-ray emission which was observed by EGRET in 1994 (Hurley et al. 1994). The interesting finding was that these high-energy gamma-rays were observed till ~ 1.5 hours after the start of the burst. The interesting and not yet answered question is how these gamma-rays are produced and how this high-energy emission is related to the low-energy emission. Two emission processes come into question. The first one is inverse-Compton scattering of photons by relativistic electrons either in external shocks (Meszaros et al. 1994) or in internal shocks (Papathanassiou & Meszaros 1996) during the prompt phase of the gamma-ray burst. The second one are proton-neutron collisions with production of π^0 -mesons which decay to gamma-rays of ~ 80 MeV which are boosted to GeV energies (Boettcher & Dermer 1998). Estimations show that the 1–10 GeV flux of this process should be detectable for the Large-Area Telescope on *GLAST* for bursts which are closer than $z \approx 0.1$.

2. THE LAT OF GLAST

In order to tackle these questions NASA plans the *GLAST* mission which will continue the successful observations of EGRET. The *GLAST* spacecraft carries two instruments: a main instrument, the Large-Area Telescope (LAT) (Michelson 2003), and a secondary instrument, the *GLAST* Burst Monitor (GBM) (Lichti et al. 2002). The LAT uses basically the same physical process as EGRET to measure gamma-rays in the energy range from ~ 15 MeV to ~ 300 GeV, the pair-production process, but employing a more advanced detection technology. Instead of using a spark chamber, silicon-strip detectors will be used to measure the tracks of the electron-positron pairs. With this technique a sensitivity which is more than 30 times better than the one of EGRET will be obtained. The LAT will also have a good energy resolution of $\sim 10\%$ and a field of view (FoV) of 2–3 sr. Within this FoV it will be able to localize gamma-ray point sources with an accuracy between $30''$ and $5'$. The LAT is devoted to study gamma-rays which are the result of particle acceleration which takes place in the nuclei of active galactic nuclei, near pulsars

and in supernova remnants. In addition, the diffuse Galactic and extragalactic gamma-ray emission will be studied. Another interesting topic for the LAT is the exploration of the dark matter and of the early Universe. And finally, the LAT will also observe between 50 and 150 bursts/year, and new knowledge about the sources of GRBs can be expected from the LAT observations.

However the LAT alone is not an optimal burst detector since the high-energy measurements alone do not allow a unique classification of GRBs because the break energy E_b which characterizes a burst spectrum is below the LAT's energy threshold of 15 MeV. Therefore no link to the BATSE data archive is possible where most of the information and knowledge about GRBs is concentrated. Another disadvantage of the LAT is that a precise determination of the high-energy power-law index β is difficult with the LAT data alone and that low-energy measurements are favorable for this purpose. Also the determination of a possible cut-off energy is better possible when low-energy data are available because of the longer lever arm. And finally the trigger conditions for weak bursts are unfavorable because of the background of the LAT. If one succeeds to reduce this background which is possible by binning the gamma-ray events then one could obtain a much better sensitivity of the LAT for weak bursts.

3. THE GLAST BURST MONITOR

It will be the task of the GBM to cure these deficiencies. The purpose of the GBM is to augment *GLAST's* capabilities to study GRBs by extending the spectral response towards lower energies and to increase the number of bursts observed by the LAT by performing an on-board localization of the arrival direction of a GRB. This position will be communicated to the LAT to allow a repoint of it to observe bursts which occur outside its own FoV thus increasing the number of observed GRBs.

The GBM will be built by a collaboration of people who work at MSFC, UAH and MPE. The group from MSFC/UAH is responsible for the Digital-Processing Unit and the management of the whole project, whereas the group from MPE is responsible for the manufacturing of the detectors and the low-voltage and high-voltage power supplies. Both groups share equally the data rights and will analyze the data in a common effort.

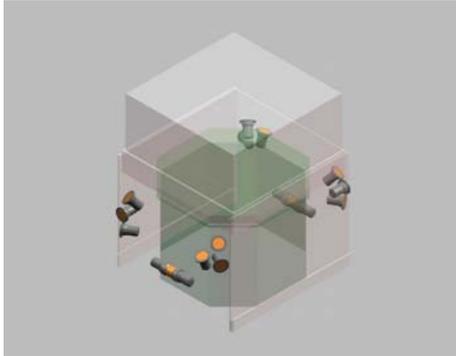


Fig. 1. The GBM detector positions around the *GLAST* spacecraft.

3.1. The GBM approach

The main goals of the GBM are to measure gamma-rays at low energies within a larger FoV than the one of the LAT, to localize the GRBs occurring in this FoV, to communicate this position to the LAT to allow a repointing of the main instrument and to perform time-resolved spectroscopy. These goals can be achieved by an arrangement of 12 thin NaI detectors which are inclined to each other to derive the position of GRBs from the measured relative counting rates (BATSE principle) and to get the low-energy spectrum. In order to get a spectral overlap with the LAT two BGO detectors will be mounted on two opposite sides of the *GLAST* spacecraft. The NaI crystals have a diameter of 12.7 cm (5") and a thickness of 1.27 cm (0.5") with a 0.22 mm thick radiation-entrance window made from Be. Each crystal is viewed by one photomultiplier tube. The NaI crystals measure gamma-rays from 10 keV to 1 MeV.

The two BGO crystals are sensitive to gamma-rays from ~ 150 keV to ~ 25 MeV. This energy range overlaps on the low side with the one of the NaI detectors and on the high side with the one of the LAT which is important for inter-instrument calibration. The two BGO crystals have a diameter and a length of 12.7 cm (5"). They are viewed on both sides by PMTs whose analogue signals are summed. The planned arrangement of the GBM detectors is shown in Figure 1.

3.2. Performance and properties of the GBM

Over the full energy range an effective area between 100 cm² and 200 cm² per detector is achieved (see Figure 2). The energy spectrum of a burst can be measured with $\sim 60\%$ FWHM at 6 keV and $\sim 3\%$ at 20 MeV. Based on background estimations one can expect an on-

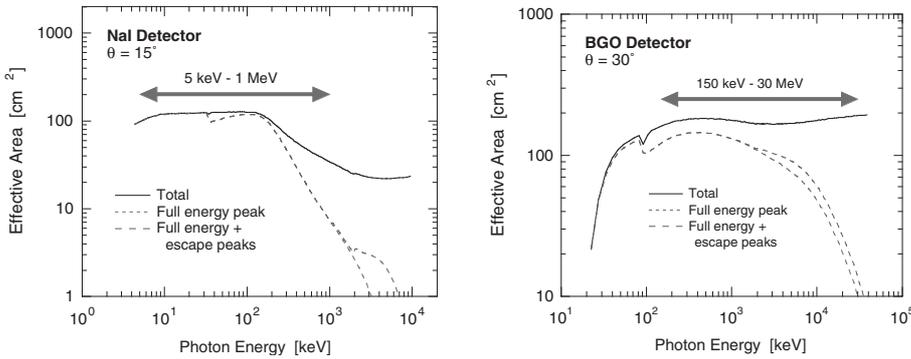


Fig. 1. The effective areas of GBM NaI (left) and BGO (right) as a function of energy.

board sensitivity of $<0.6 \gamma/(\text{cm}^2 \text{ s})$. With this sensitivity the GBM will trigger on ~ 150 bursts/year. A much higher sensitivity of $\sim 0.35 \gamma/(\text{cm}^2 \text{ s})(5\sigma)$, however, will be reached on ground. The localization accuracy on board for most of the bursts will be $<15^\circ$. The ultimate limiting location accuracy for bright bursts due to systematic errors will be $<1.5^\circ$ after a detailed analysis on ground.

3.3. The trigger criteria and the interaction with LAT

The GBM detectors' counting rates measured with multiple time intervals (>16 ms) and multiple energy ranges will be searched for significant increases. When a fast and sudden count-rate increase has been detected, this event will be time tagged and a burst alert will be created if the following conditions are met:

- the count-rate increase above background must be detected with a statistical significance of at least 4.5σ ;
- such counting-rate increases must be observed in at least two neighbouring NaI crystals;
- the light curves measured in the different detectors must be similar;
- the on-board software must be able to calculate an unambiguously position from the relative counting rates of the different detectors;
- the estimated position must lie in the sky and not on the Earth.

Whenever the criteria of Section 3.3 are fulfilled and a burst has triggered, a trigger signal will be sent to the LAT within 5 ms. Using the highest-energy photons of the LAT a highly accurate position (~ 1 arcmin) will be computed in near-real time (~ 16 minutes) and this

position as well as the one derived by the GBM will be broadcasted to interested observers via the GCN.

4. SCIENTIFIC GOALS AND EXPECTED RESULTS

From BATSE observations the characteristic features of GRBs at energies below ~ 1 MeV are known, where in most cases the maximum of the emission lies. However, the information at higher energies is sparse. Since only very few GRBs were detected by EGRET, the high-energy power-law index β is poorly known. With the LAT and the GBM β can be measured for the first time quite accurately because of the long lever arm. This will allow the classification of these bursts and will answer the question of how they fit into the complete burst population. It may also help to entangle the problem how these high-energy gamma-rays can escape their source region without being absorbed via γ - γ interactions with lower-energy photons.

By measuring the relation between the low-energy and high-energy emission the questions of the hard-to-soft evolution of the low-energy power-law index α and the hardness-intensity correlation can be investigated. The *GLAST* measurements will also allow the investigation of the evolution of the high-energy power-law index β .

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