Current Status of the GBM Project

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Abstract. One of the scientific goals of the Large-Area Telescope (LAT) on 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 ~30 MeV and will therefore allow the investigation of the relation between the keV and the MeV-GeV emission from GRBs over more than six energy decades. These unprecedented measurements will furthermore permit the exploration of the unknown aspects of the high-energy burst emission. The status of the GBM project approximately one year before launch is reported here.

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INTRODUCTION

Since their discovery ~35 years ago gamma-ray bursts (GRBs) challenged the astronomical community in many ways. They stimulated the experimentalists to develop new and more sensitive instruments and the theoreticians to find convincing explanations for the puzzling observations. But until 1996 theoretical modelling was hindered by the lack of the distance scale to these enigmatic objects. This changed with the outstanding discoveries of BeppoSAX in 1997 which allowed for the first time the determination of their distance. It was found that long GRBs (>2 s) are located at far (or cosmological) distances (an observation which was already inferred from the BATSE observation that the GRBs were isotropically distributed on the sky [1]). These large distances have the consequence that a huge energy release (~10^{51} ergs) is needed to explain the observed fluxes. It is now widely accepted that this energy release has its origin in a collapse of the central region of a supermassive star to a black hole (BH) with a succeeding fast accretion of matter onto this BH (collapsar model [2]). Nearly perpendicular to the accretion flow a jet of relativistic particles is expelled and accelerated. In this jet, shock fronts moving at different speeds are colliding, producing the γ-rays of the prompt γ-ray emission. Later, when the particles of the jet hit the circum- or interstellar medium the afterglow emission at longer wavelengths is produced.

This general emission scenario is now commonly accepted and can explain the bulk of the observations. But among others there is one observation which lacks until now a convincing explanation. It concerns the delayed emission of high-energy γ-rays as it was observed by EGRET [3]. The remarkable finding was that these high-energy γ-rays were observed as long as ~1.5 hours after the start of the burst. The interesting and not yet answered question is how these γ-rays are produced, especially at such a late time, and how they can escape their production site without being absorbed via γγ interactions. Furthermore it is unclear how this high-energy emission is related to the low-energy (hard X-ray) emission.

It is one aim of the Large-Area Telescope (LAT), the main instrument on GLAST, to continue these EGRET observations with much better sensitivity thus enhancing the observational facts about this long-lasting emission. In order to put these facts in the context of the observations at low energies, where the bulk of information about GRBs exists, a secondary instrument, the GLAST Burst Monitor (GBM), will be flown on GLAST which will measure the spectra of GRBs below the energy range of the LAT. The state of the GBM especially with respect to its scientific performance is briefly presented here.

THE GLAST BURST MONITOR

The main goals of the GBM are therefore to measure γ-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 of the measured burst emission. 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 the range ~10 keV to ~1 MeV. The cylindrical NaI crystals have a diameter of 12.7 cm (5") and a thickness of 1.27 cm (0.5") with a radiation-entrance window composed of a 0.22 mm thick Be sheet and a 0.7 mm thick silicone layer. Each crystal is viewed by one 5" Hamamatsu photo-multiplier tube of the type R877.

In order to get a spectral overlap with the LAT two BGO detectors will be mounted on two opposite sides of the GLAST spacecraft consisting of BGO crystals which are sensitive to γ-rays from ~150 keV to ~30 MeV. This energy range overlaps on the low-energy part with that of the NaI detectors and on the high-energy side with that of the LAT which is important for inter-instrument calibration. The two cylindrical BGO crystals have a diameter and a length of 12.7 cm (5"). They are viewed on both sides by PMTs (of the same type as given

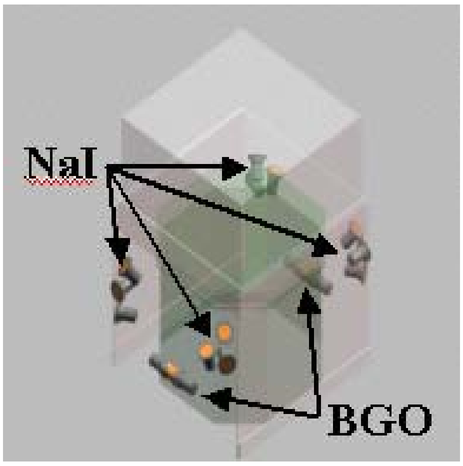

FIGURE 1. The arrangement of the GBM detectors around the GLAST spacecraft.

above) whose analogue signals are summed. The planned arrangement of the GBM detectors and pictures of the two detector types are shown in Fig. 1, 2 and 3. More detailed descriptions of the GBM can be found in [4-11].

The GBM is being built by a collaboration of 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 and test of the detectors and the low- and high-voltage power supplies. Both groups share equally the data rights and will analyse the data in a common effort.

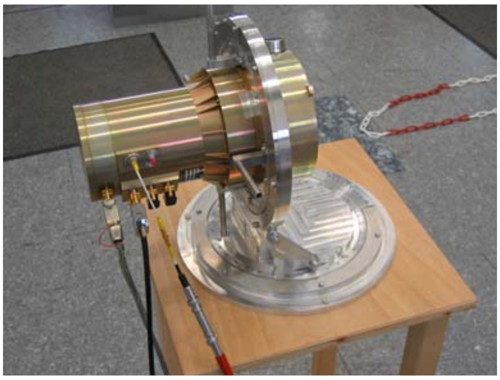

FIGURE 2. A NaI detector in its calibration setup.

FIGURE 3. A BGO detector in its Ti holding structure.

PRELIMINARY RESULTS OF THE DETECTOR CALIBRATION

In 2005 the Jena-Optronik GmbH in Jena, Germany completed the manufacturing of the GBM detectors and Astrium in Friedrichshafen, Germany completed the fabrication of the power-supply box (PSB). In the time-frame June – September 2005 the detectors were delivered to MPE where an extensive calibration with radioactive sources was performed. The energy of these sources ranged from ~14 keV up to 4.43 MeV thus covering the whole energy range of the NaI detectors (10 keV – 1 MeV), but only the low-energy range of the BGO detectors (150 keV – 30 MeV). A high-energy calibration with the BGO engineering-qualification model

(EQM) was performed during autumn 2006 using a Van-de-Graaff accelerator at SLAC.

Due to the Iodine K-shell absorption edge at ~33 keV the response of the NaI detectors is non-linear at low energies. Since not enough radioactive sources with γ-ray lines in this energy range are available it was not possible to determine this non-linearity with radioactive sources. Therefore it was decided to calibrate one NaI detector very precisely with γ-rays from a synchrotron accelerator. For this calibration the BESSY synchrotron in Berlin was chosen with which photons in the energy range 8 – 60 keV could be produced.

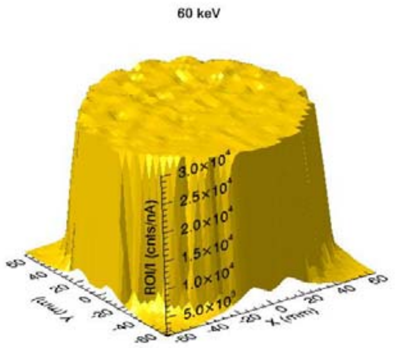

FIGURE 4. The homogeneity of the response of a NaI detector.

The aim of the calibration was the measurement of the channel-energy relation, the energy resolution and the effective area as a function of energy and the relative off-axis response. At Bessy it was in addition possible to scan a NaI detector with a pencil beam and to determine the spatial homogeneity of its response to mono-energetic γ-rays. An example of this measurement at 60 keV is shown in Fig. 4. It is seen that the response of the NaI detectors is fairly homogeneous across the crystal.

In Figs. 5 & 6 the energy resolutions of the NaI-EQM and of the BGO-EQM detectors are compared with the requirements. It is obvious that for the NaI detectors all requirements and even the goal of <35% at 14 keV are met. In the

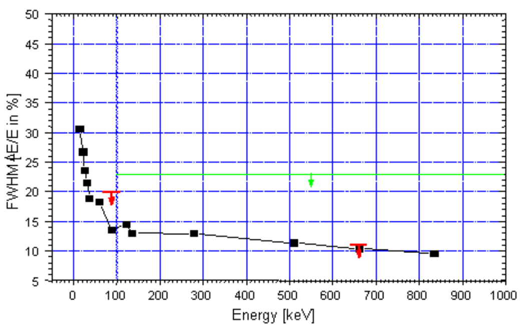

FiGURE 5. The energy resolution of a NaI detector (green line: top-level requirement; red lines: GBM-internal requirements).

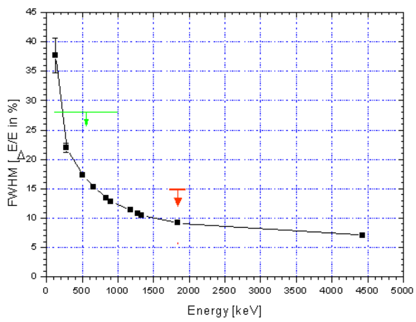

FIGURE 6. The energy resolution of a BGO detector (green line: top-level requirement; red line: GBM-internal requirement).

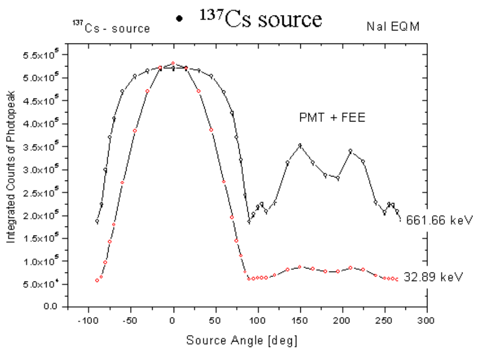

FIGURE 7. The off-axis response of a NaI detector for two γ-ray line energies.

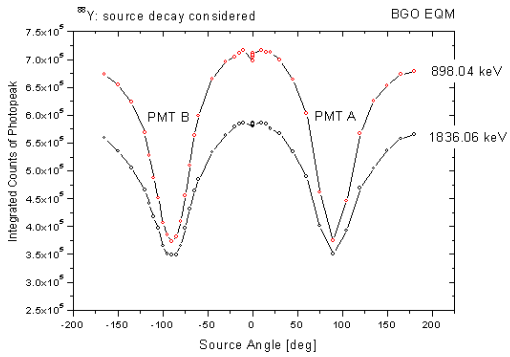

FIGURE 8. The off-axis response of a BGO detector for two γ-ray line energies.

case of the BGO detector the FWHM resolution meets also the requirement below ~200 keV since the point at the lowest energy is below the low-energy limit of the BGO detectors of 150 keV!

In Figs. 7 & 8 the off-axis response for both detector types is shown in both cases for two different energies. The response of the NaI differs for the two energies. At low energies the X-rays are absorbed in the first few mm and the response follows the well-known cosine law, whereas at high energies the crystal is semi-transparent and one sees a combined effect between the decrease of the projected area and the increasing effective crystal thickness leading to a flatter response around 0°. Also nicely seen are the differences when the crystals were illuminated from the rear side through the electronics and the photomultiplier tubes. All X-rays are absorbed in the intervening material, whereas up to ~70% of the higher-energy γ-rays are still penetrating. The response of the BGO for the two energies is very

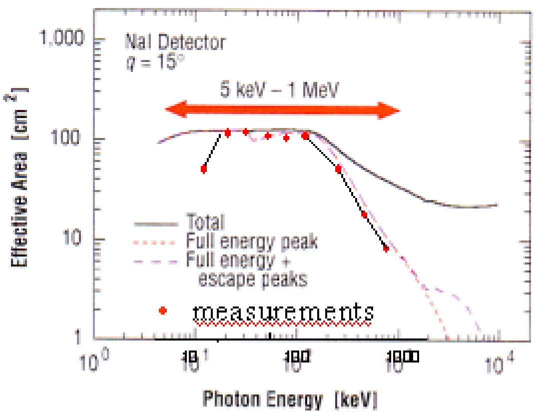

FIGURE 9. The photopeak (or full-energy peak) effective area of a NaI detector.

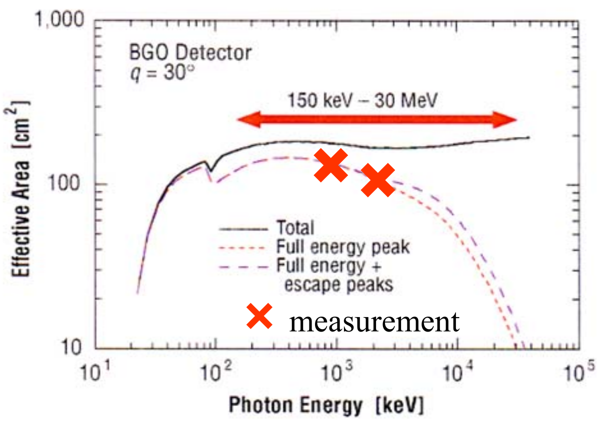

FIGURE 10. The photopeak (or full-energy peak) effective area of a BGO detector.

similar as it can be expected from the high absorption efficiency of this scintillator.

The measured effective areas are compared with the simulated predictions of the original proposal in Figs. 9 & 10. The measured effective areas of the photo-peak events of the NaI detectors follow closely the prediction with one exception at low energies. The effective area at 14 keV is only ~50 cm² instead of the expected ~100 cm². This is due to a 0.7 mm thick silicone layer in front of the entrance window of the crystal. This layer unfortunately absorbs most of the in-falling low-energy X-rays (the transmission at 14 keV is only ~60%) and was not considered in the simulations for the proposal. Only at higher energies does this layer become transparent. For the BGOs the effective areas measured at two energies compare well with the prediction.

SIMULATION OF CALIBRATED SPECTRA

In order to estimate the instrument response of the GBM in orbit, simulation software is being developed based on Monte-Carlo simulations of the physical detector response. This software models the detectors and the GLAST spacecraft in sufficient detail and takes into account, when calculating the instrument response function, the scattering of γ-rays from a burst in the spacecraft and in the Earth's atmosphere. Once the response function is known one can determine the true γ-ray spectrum from the measured data via a deconvolution. Since the matter in which the γ-rays are scattered is more important the closer it is to the detectors themselves, it is very important to have a very accurate mass model of the detectors.

Such a mass model has been developed for the two different detector types [12]. In order to adapt these mass models to reality, the simulated spectra are compared with the measured data. For this comparison the environment around the detector (i. e. the laboratory) had to be modelled as well. This was done and spectra for the different energies were simulated.

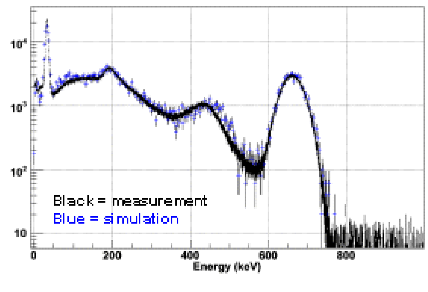

FIGURE 11. Comparison between a measured and a simulated Cs^{137} spectrum.

In Fig. 11 a NaI spectrum measured with a Cs^{137} source is compared with the corresponding simulation. The agreement between the two spectra is excellent suggesting that the detector mass model is nearly perfect. Only between ~450 keV and ~500 keV a small discrepancy is visible. Work is in progress to determine the cause of this discrepancy and then to improve the mass model so that even this deviation disappears. The result of this optimisation process will be an improved overall mass model of the GBM.

THE PERFORMANCE OF THE GBM

In Table 1 the scientific-relevant parameters are summarized and compared with the requirements. It can be seen that all level-1 (NASA top level) requirements are met.

TABLE 1. Comparison of the expected GBM performance with the requirements.

Parameter	**Level-1 requirement**	**Intra-Project Goal**	**Expected Performance**
Energy range	10 keV – 25 MeV	5 keV – 30 MeV	8 keV – 30 MeV
Energy resolution	<10% (1σ; 0.1 – 1 MeV)	7% (1σ; 0.1 – 1 MeV)	<8% at 0.1 MeV <4.5% at 1 MeV
Effective area	none	NaI: >50 cm² at 6 keV BGO: none	NaI: 48-78 cm² at 14 keV; BGO: >95 cm²
On-board GRB location	none	15° accuracy (1σ radius) within 2 s	<15° in 1.8 s (<8° for SC zenith angle <60°)
On-ground GRB sensitivity	<0.5 photons/(cm² s) (peak flux; 50-300 keV)	0.3 photons/(cm² s) (peak flux; 50-300 keV)	0.47 photons/(cm² s) (peak flux; 50-300 keV)
On-board GRB trigger sensitivity	1 photon/(cm² s) (peak flux; 50-300 keV)	0.75 photons/(cm² s) (peak flux; 50-300 keV)	0.7 photons/(cm² s) (peak flux; 50-300 keV)
Field of view	>8 steradian	10 steradian	9 steradian

With the sensitivity shown in Table 1 the GBM will detect ~200 bursts/year. About 60 of these bursts will be within the 55° FoV of the LAT.

SUMMARY

In the year 2006 the GBM was successfully tested and calibrated and its integration to the GLAST spacecraft is in progress. All scientific requirements have been met . So the GBM is ready for flight which is scheduled for November 2007.

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