A GAMMA-RAY BURST MONITOR FOR GLAST

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ABSTRACT

The Gamma-Ray Large-Area Space Telescope GLAST is the next NASA mission in the high-energy γ-ray regime (10 MeV to about 500 GeV), with launch anticipated in 2006 (Gehrels, 1999). Recently a design using silicon strips for the electron-positron pair tracking was selected for the main instrument. One of the key scientific objectives of the GLAST mission is to determine the high-energy behaviour of gamma-ray bursts and transients. The importance of studying bursts with GLAST has been emphasized by choosing a burst monitor as the secondary instrument on GLAST. A proposal to the NASA AO for such a burst monitor was submitted jointly by a collaboration between the Marshall Space-Flight Center/University of Alabama (both in Huntsville / Alabama) and the Max-Planck-Institut für extraterrestrische Physik in Garching. This GLAST Burst Monitor will complement the main instrument information about bursts in the energy range between 5 keV and 30 MeV. It will provide real-time burst locations over a wide FOV with sufficient accuracy to repoint the GLAST spacecraft. Time-resolved spectra of many bursts recorded with GLAST and the burst monitor will cover unprecedented 6 decades of energy. This will help to advance our understanding of the mechanisms by which gamma-rays are generated in gamma-ray bursts. Mid of March 2000 this proposal for GLAST's burst monitor has been selected.

Key words: high-energy γ-rays; γ-ray bursts; burst monitor.

1. INTRODUCTION

The study of γ-ray bursts is one of the scientific objectives of the GLAST mission. This was motivated by observations of γ-ray bursts in the high energy range above 50 MeV by EGRET onboard NASA's Compton Gamma-Ray Observatory (CGRO): The delayed emission of γ-quanta more than 1 hour after the burst start time was unexpected. In GRB940217 a 18 GeV γ-event was found in this extended emission (Hurley et al., 1994). This delayed emission is in contrast to the characteristics of most of the bursts observed in the energy range of the Burst and Transient Source Experiment (BATSE) onboard CGRO, which have only a maximum duration of several 100 sec.

The main instrument on GLAST, the Large-Area Telescope (LAT), will itself detect bursts with high sensitivity, and locate them with a precision of about 10 arcmin. Within several minutes LAT's burst locations can be relayed to ground- and space-based observatories to search for afterglow emission. The expected LAT burst trigger rate is between 50 and 100 bursts/year. But there are important limitations to the effectiveness of the LAT as a burst detector operated in its current configuration. High-energy measurements alone do not reveal the full physical picture. In the GRB energy spectra the most important characteristic is a turnover or break (at break energy E_{break}) between two parts of the spectra, each described by a power law, with different spectral indices [with α as the low-energy power-law index and β as the high-energy power-law index (Band, 1993)]; this break occurs in the energy range between 100 and 500 keV, well below the LAT threshold of about 10 MeV. Furthermore, γ-ray bursts have their maximal luminosity around the break energy. The scientific return of the GLAST mission in the case of γ-ray bursts can be increased substantially by having simultaneous knowledge of the burst emission from GeV down to a few keV. This will help to answer the open questions of the relation between the high- and low-energy emission and especially the question if the high-energy γ-rays are a part of the burst-emission process itself or a kind of afterglow. The GLAST Burst Monitor called GBM, which is able to cover the whole low-energy part of the γ-ray burst emission down to about 5 keV and simultaneously overlapping the lower part of the LAT energy range, will

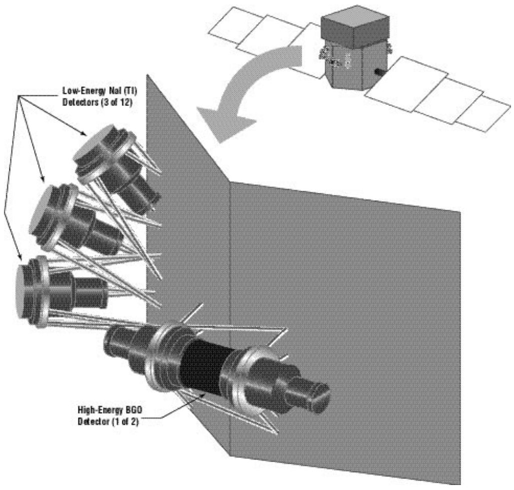

Figure 1. A schematic view of the GLAST satellite with the γ-ray burst monitor (GBM). The 12 NaI-detetectors are mounted in 4 banks, each equipped with 3 NaI-detectors. The two BGO-detectors will be mounted on opposite sides of the satellite. A group of 3 NaI- and 1 BGO-detector is shown enlarged. In contrast to the NaI-detectors the BGO-detector is viewed by two PMTs.

augment the capabilities of the LAT for γ-ray bursts. One of the important goals of the GBM is the continuation of the BATSE burst data base. A significant concern for GLAST as a burst detector are the technical problems associated with triggering, rapid source location and dead time. With GBM as an auxilliary, autonomous instrument these limitations can be mitigated.

2. INSTRUMENT DESCRIPTION

The GBM consists of 12 NaI and 2 BGO scintillation detectors mounted on the spacecraft as shown in Figure 1. The 12 NaI(Tl) detectors, 5 inches in diameter and 1/2 inch thick, are grouped into 4 banks, each containing 3 NaI-detectors viewing the sky at different angles (zenith angle: 30^0, 60^0, 90^0). This arrangement results in a large field of view for the GBM of about 8.6 steradian and gives the oportunity for locating the origin of the burst by comparing the count rates of different NaIs (same method as used by BATSE). The two bismuth germanate (BGO) scintillators, 5 inches in diameter and 5 inches in length, will cover the energy range of about 150 keV to about 30 MeV. This will provide a good overlap with the NaI at the low-energy and with the LAT at the high-energy end. The two BGO detectors will be mounted on opposite sides of the spacecraft, providing nearly a 4π steradian field of view. The expected response of the NaI- and BGO-detectors is summarized in Figure 2 and in Figure 3. All NaI scintillators are viewed by a single photomultiplier (PMT), each BGO scintillator by two PMTs from both ends. The 16 amplified PMT anode signals are fed to the Data Processing Unit (DPU) for digitalization (see Figure 4). The DPU software will search for a significant increase in the counting rates from the detectors. In case of a positive detection, a burst alert will be generated and transmitted to ground and to the main instrument. The DPU will calculate from the count rates of the NaI-detectors a rough direction of the burst and will deliver this information to the main instrument as well. The development and fabrication of the NaI- and BGO-detector modules and the power supplies (LVPS, HVPS) is under the responsibility of the MPE. The MSFC/UAH group is responsible for DPU hard- and software and the project management.

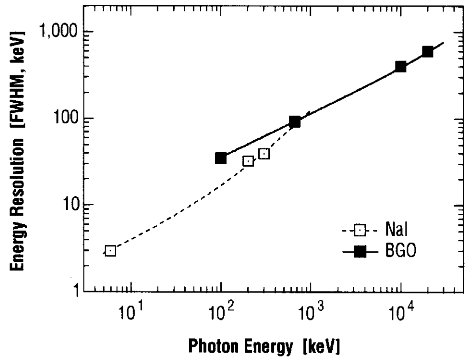

Figure 2. Energy resolution of the NaI- and BGO-detectors in dependence on the photon energy.

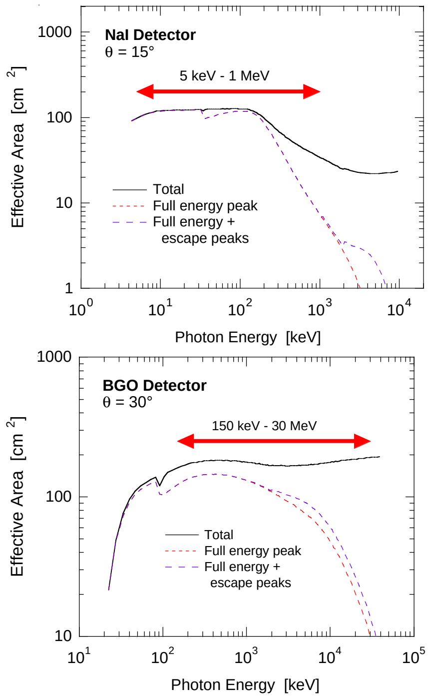

Figure 3. Effective area of a NaI- and BGO-detector in dependence on the photon energy, with Θ as angle of incidence. The double arrow shows the energy range of the NaI (top graph) and BGO (bottom graph) channels.

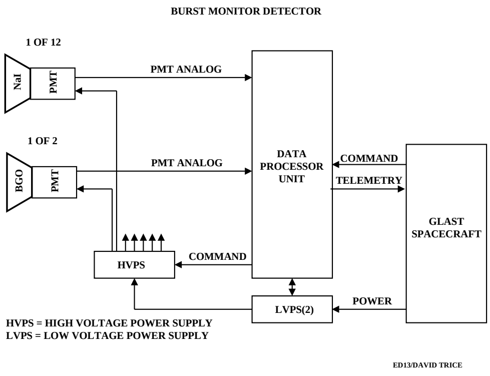

Figure 4. A block diagram of the main elements of the burst monitor.

3. EXPECTED GBM OUTPUT/RESULTS

The tasks of the GBM can be split up into three main topics each yielding an output important for various kinds of scientific analysis or for LAT support. The first output is certainly the GBM burst alert, which will be transmitted to LAT and ground. Next is the burst position, which will be provided by the GBM over a wide field of view. The last and most important output is the low-energy context measurement of the burst light curve and burst spectrum.

3.1. GBM burst trigger

The trigger scheme for the GBM will be similar to that one of BATSE. The trigger requirement will be an excess in count rate above a threshold, specified in standard deviations above background, simultaneously for two of the NaI-detector modules. The standard setting of the GBM threshold will be 4.5σ above background (energy interval: 50 keV to 300 keV, time interval for sensitivity calculations: 1.024 s), this will yield an absolute trigger sensitivity of < 0.57 photons $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (BATSE at 5.5σ threshold: ~ 0.2 photons $\mathrm{cm}^{-2}\mathrm{s}^{-1}$). Based on this and the burst intensity distribution determined by BATSE the GBM will trigger on about 150 bursts per year. It is also planned to search on ground for fainter bursts using more sophisticated algorithms. One method is the summing of rates of closely pointing detectors and the inclusion of the BGO detector count rates. The estimated sensitivity for untriggered bursts will be ~ 0.35 photons $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (5σ excess).

3.2. GBM burst localization

The GBM determines the γ-ray burst locations by comparing count rates of NaI-detectors, which are facing the sky in different directions. It is planned to increase the location accuracy in three stages: on board, automatic on ground and on ground manually. The burst location will be calculated on board in real time by the GBM-DPU, yielding an accuracy of about 15^0, which can be used as LAT trigger. If the burst occured in the LAT field of view, data reduction modes (reducing the LAT background by isolating the area of the GBM burst direction in the LAT dataspace) can be initiated in the LAT, which will increase the LAT sensitivity for weak bursts. The trigger conditions for weak burst of the LAT itself is unfavourable because of high background rates. If the burst occurred outside the LAT field of view (FoV), the spacecraft can be repointed to observe delayed high-energy γ-ray emission. This is possible because the GBM FoV with 8.6 sr is significantly larger than the LAT FoV with aprroximately 2.4 sr. After the transmission of the detector count rates to ground, the burst location can be computed with improved accuracy of less than 3^0. This will happen in near-real time, which means several seconds. This information can be used for the search of afterglow emission at other wavelengths, as input for the Gamma-Ray Coordinated Network (GCN) and as input for the Interplanetary Network (IPN). The ground manual algorithms, which means a detailed analysis of the data with human interaction, will yield an improved burst location $< 1.5^0$ after one or two days.

3.3. GBM burst spectra and light curves

The burst monitor will provide time-resolved spectra and energy-resolved lightcurves in the energy range between 5 keV and 30 MeV, overlapping with the LAT lowest energy range (low-energy threshold at $\sim$ 10 MeV). In order to fulfil the scientific goals the burst monitor will have four different data types. Two continuous background data types are designed for burst analysis, for extremly long-lasting bursts, search for non-triggered events and for the detection of bright sources via the Earth-occultation technique. The first backgound data type accumulates 128 energy channels with 8 s time resolution for each detector and the second background data type 4 energy channels every 0.256 s. In response to a burst trigger, the GBM will produce a third datatype with high temporal resolution (5 μs) and 128 channel spectral resolution. The fourth data type provides information on the burst location and spectral estimates determined on board.

3.4. Expected GBM results

The expected time resolved spectroscopy performance of GBM and LAT are shown in Figure 5. Simulations of GBM and LAT data were made assuming the BATSE parameter values of GRB990123. Looking at the results for parameter β one can see an excellent agreement between the assumed BATSE values and the value derived from a common GBM/LAT-fit. In comparision, the LAT-only

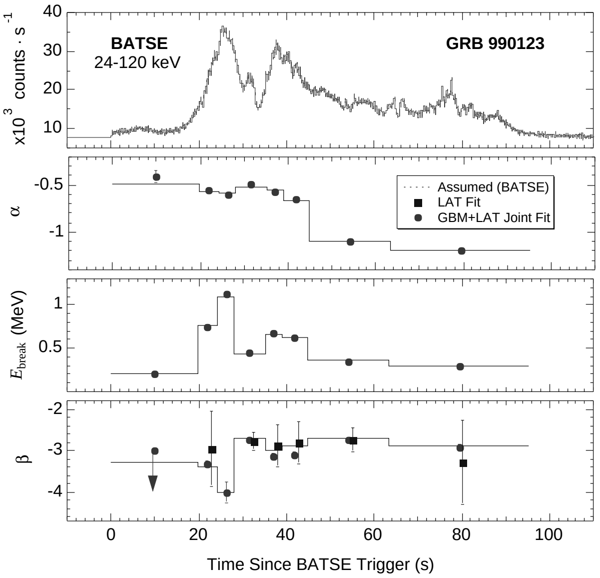

Figure 5. Time history of the simulated spectral parameters $E_{\rm break}$, α and β using the data of GRB990123.

fit shows larger uncertainties. Figure 6 shows the expected response of the GBM together with the LAT to a γ-ray burst like GRB 940217, which was recorded by the three CGRO instruments BATSE, COMPTEL and EGRET. The simulated spectrum covers over 6 energy decades from $\sim$ 5 keV up to $<$5 GeV

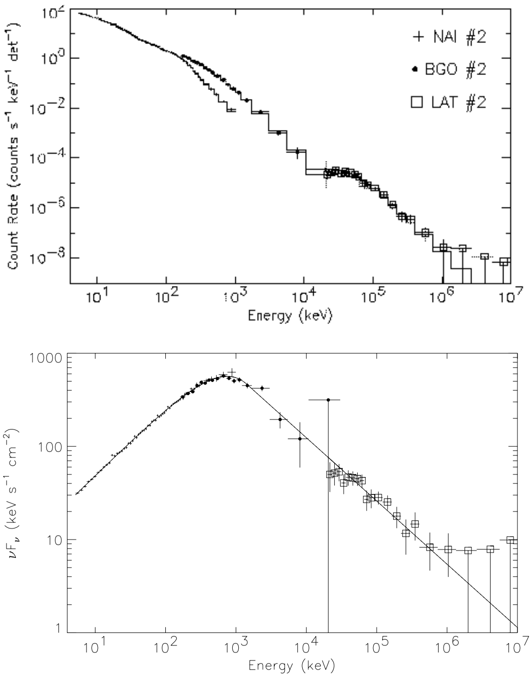

Figure 6. Simulated GBM-spectra using the data of GRB 940217 observed by BATSE, COMPTEL and EGRET.

4. OUTLOOK

The GBM together with the LAT will help to improve our understanding of the central engines and emission mechanisms of γ-ray bursts. Till now it is not understood how the high-energy emission observed by EGRET is related to the low-energy emission. Even the production mechanisms for these energetic γ-rays has not been explained by current models. How can they escape the source region without beeing absorbed via γ-γ interaction with lower-energy photons? The GBM will help to uncover how bursts, observed with LAT in the GeV regime, fit into the whole population. This is important, because the high-energy measurement alone do not allow a classification. It is one of the goals of the GBM team to produce a catalog of bursts that will include parameters such as location, duration, peak flux, and fluence, as well as spectral properties. These parameters will be defined as closely as possible to those in the BATSE catalog, so that the bursts observed by GLAST can be related to the large sample of the BATSE catalog. The continuation of the BATSE database will be one of the benefits of the GBM. In contrast to the simple spectral shape of bursts the observed temporal behaviour is varying strongly. Several common characteristic effects in the evolution of bursts have been observed, such as narrowing of pulses with increasing energy, a softening trend, and a hardness-intensity correlation. An interesting question for the GLAST mission will be how these temporal characteristics will behave when the energy band is increased. The investigation of the temporal behaviour and distribution of the spectral parameters ($\rm E_{break}$, α, β and the correlation beween $\rm E_{break}$ and the high-energy emission observed by the LAT) is one of the important tasks of the GBM. There are several other questions which will hopefully be answered with the help of GBM: In many spectra the power-law index β appears flatter than -2. Such spectra cannot continue to infinitely high energies without steepening; an expected high-energy break may, in a few cases, be measured by the LAT alone. But in many cases the constraints will be improved by fitting a wide-band spectrum, including the GBM spectra. Another interesting question is whether there exists a significant population of hard-spectrum bursts which have been missed or poorly sampled by BATSE. GLAST can settle this question only by sufficient simultaneous coverage of the BATSE energy range. The good temporal resolution will make GLAST an excellent detector for the 4^{th} GRB Interplanetary Network (IPN).

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