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The GLAST burst monitor instrument response simulation system(*)

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Summary. — The GLAST Burst Monitor (GBM) is designed to provide wide field of view observations of gamma-ray bursts from 10 keV to 25 MeV. The GBM is composed of twelve NaI and two BGO detectors that are widely dispersed about the GLAST spacecraft. Reconstructing burst locations and energy spectra from these separated detectors requires detailed knowledge of the response to direct and scattered burst radiation. A simulation software package based on the GEANT4 Monte Carlo toolset is being developed to fulfill this requirement. We will discuss the architecture of our simulation system and evaluate the scientific capabilities of the GBM.

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1. – Introduction

The Gamma-ray Large Area Space Telescope (GLAST) [1] will study the cosmos in the 10 keV–300 GeV energy range. The Large Area Telescope (LAT) is the main instrument, and will cover the 20 MeV–300 GeV range. A second instrument, the GLAST Burst Monitor (GBM), will complement the LAT at lower energies, allowing for comparison of gamma-ray bursts between the well understood low-energy region and the unknown high-energy region. Figure 1 shows the simulated response of the GBM and LAT to the time-averaged spectrum emitted by GRB 940217, a bright burst observed with BATSE

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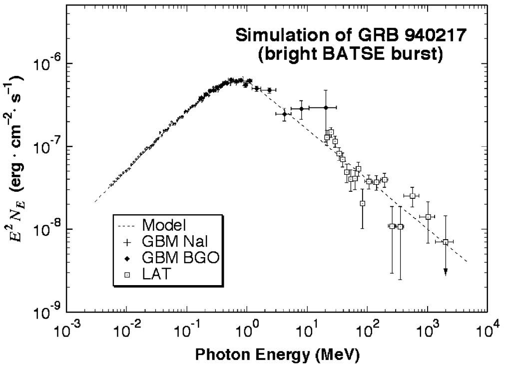

Fig. 1

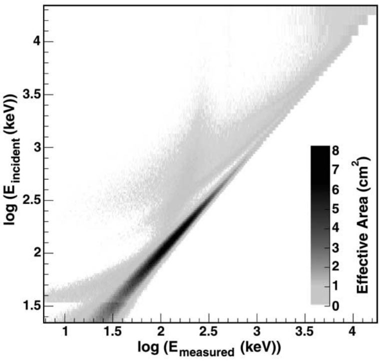

Fig. 2

Fig. 1. – Simulation of GRB 940217.

Fig. 2. – Response matrix for NaI detector, normal incidence. Effective area is plotted.

(peak flux = 36.2 ph/ cm^2/ s in the 50–300 keV range, fluence = 6.6×10^{-4} erg/ cm^2 at >20 keV; both of these measures are in the top 0.5% of all BATSE bursts). The combination of the GBM NaI and BGO detectors produces continuous coverage from 10 keV to the lower end of the LAT energy range.

A detector response matrix (DRM) describes how the detector responds to a source photon spectrum. Accurate simulation of the DRM is critical for the data analysis process, where the DRM is used to unfold the original source spectrum from the measured spectrum. The quality of scientific return from the GBM relies on this simulation. The simulation software must determine the response of the GBM detectors from several possible sources: 1) source photons that hit the detector directly and may scatter inside the detector itself, 2) source photons that scatter off the spacecraft before entering the detector, 3) source photons that scatter off the Earth's atmosphere (and possibly the spacecraft also) before entering the detector. The simulation uses full-scale, detailed models of the NaI and BGO detectors, the spacecraft (currently in preparation), and the Earth's atmosphere. When full-scale simulation production begins, we will simulate the detector, spacecraft, and atmospheric response for a range of energies and incident directions. We will verify the simulation performance by comparing to data collected from radioactive sources in the laboratory.

The simulation relies on GEANT4 [2] for radiation transport Monte Carlo, the ROOT [3] data analysis package for data files and data analysis, and FITS [4] files for database storage. The NaI and BGO instrument simulation is separate from the Earth atmosphere simulation. After calibration and instrumental effects (*e.g.,* energy resolution and thresholds) are applied to the instrument data, a database stores the detector and atmospheric response matrices. For data analysis, a database tool will access the database, combine the detector and atmospheric responses, and generate a DRM for a particular burst event, based on its location.

2. – Detector simulation

The NaI and BGO detector simulation models were constructed with great care to achieve good agreement between the model and the dimensions and materials specified by the detector design drawings. The main components are the photo-multiplier tube(s), the scintillation crystals and wrappings, and the exterior shell. Figures 2 and 3 show

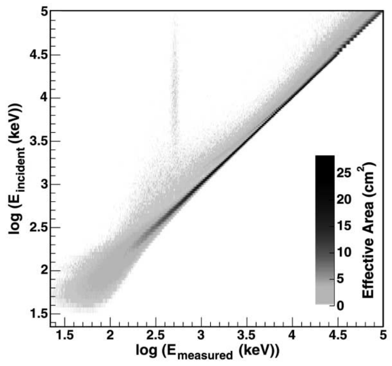

Fig. 3

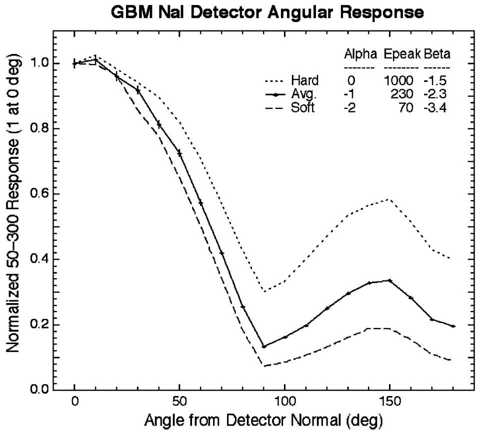

Fig. 4

Fig. 3. – Response matrix for BGO detector, normal incidence. Effective area is plotted.

Fig. 4. – Angular dependance of NaI detector sensitivity for hard, average, and soft bursts, assuming the Band model parameters shown.

examples of what the DRMs might look like for the two types of detectors. These DRMs were generated at normal incidence angle. Very simple energy resolution effects were added. After laboratory testing with radioactive sources, the real energy resolution parameters will be known and used for DRM production.

Figure 4 shows how the sensitivity of the NaI detector varies as a function of the photon incidence angle. The sensitivity is shown for three different types of bursts (hard, average, and soft) in the 50–300 keV range. The curves plotted are normalized such that the sensitivity is 1 at zero degrees. The sensitivity seen at large angles will likely be reduced when the spacecraft body is included in the simulation, which will obscure the rear view of the detectors.

3. – Atmosphere simulation

A full-scale simulation of the Earth's atmosphere was constructed from concentric spherical shells, with each shell having a unique temperature, density, pressure and elemental composition. The number and thickness of the layers is arbitrary and easily changed. For each layer, the temperature, pressure, density, and composition is homogeneous and these quantities are computed from the NRLMSISE-00 atmospheric model [5], which can cover altitudes from 0–1000 km. The altitude at the middle of each homogeneous layer is used to compute the properties for that layer. By choosing many layers, one can create an atmosphere model that is very accurate.

An imaginary collection surface is created at the altitude of the spacecraft. The energy and momentum of photons crossing the surface in the outward direction is recorded. Together with the incident photon momentum, the scatter angle can be computed. Figure 5 shows an atomspheric response matrix for a model comprised of 20 layers from 0 to 500 km altitude. The effective area is plotted as a function of the indicent energy (vertical axis) and the energy of photons crossing the collection surface (horizontal axis). Only photons which have non-zero scatter angle are plotted.

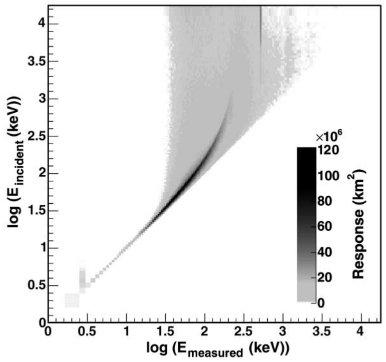

Fig. 5

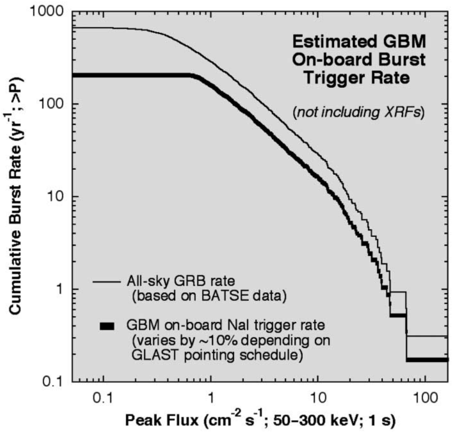

Fig. 6

Fig. 5. – Atmospheric response matrix. Effective area is plotted.

Fig. 6. – Estimated on-board GBM burst trigger rate.

4. – Expected performance

We expect the GBM to trigger on approximately 200 bursts per year, and determine the burst location for the brightest bursts with an error of less than 15° after on-board analysis and 3° after ground-based analysis. We expect time resolution of at least 10 μs, and a field of view of about 10 steradians. Figure 6 shows the expected yearly trigger rate versus peak burst flux for GBM, assuming an all sky GRB rate based on BATSE data. Bursts were distributed isotropically on the sky, assuming typical Band model spectra ($\alpha = -1$, $\beta = -2.3$, $E_{peak} = 230\,\text{keV}$). For each burst, the number of photons incident on the GBM detectors (including contribution from a background model and corrections for spacecraft blockage) was computed and the angular efficiency curve in fig. 4 was applied to determine if the detector would trigger.

5. – Conclusions

Accurate simulation of the GBM detectors is critical to achieving the best scientific return. We are well underway in the development of a GEANT4-based simulation system which includes the GBM detectors, the spacecraft, and the Earth's atmosphere. In the near term we anticipate tuning the simulation to achieve agreement with real detector data collected in the laboratory with radioactive sources. We will also begin to work on the spacecraft model. In the longer term we will begin a massive simulation effort to populate the detector and atmospheric response matrix databases.

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