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## The Fermi Gamma-ray Burst Monitor: Results from the first two years

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**Summary.** — In the first two years since the launch of the Fermi Observatory, the Gamma-ray Burst Monitor (GBM) has detected over 500 Gamma-Ray Bursts (GRBs), of which 18 were confidently detected by the Large Area Telescope (LAT) above 100 MeV. Besides GRBs, GBM has triggered on other transient sources, such as Soft Gamma Repeaters (SGRs), Terrestrial Gamma-ray Flashes (TGFs) and solar flares. Here we present the science highlights of the GBM observations.

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### 1. – Introduction

The Fermi Gamma-ray Space Telescope, which was successfully launched on June 11, 2008, is an international and multi-agency space observatory. The payload comprises two science instruments, the Large Area Telescope [1], a pair conversion telescope operating in the energy range between 20 MeV and 300 GeV and the Gamma-Ray Burst Monitor [2], which extends the Fermi energy range to lower energies (from 8 keV to 40 MeV). The primary role of the GBM is to augment the science return from Fermi in the study of GRBs by discovering transient events within a larger field of view (FoV) and performing time-resolved spectroscopy of the measured burst emission.

### 2. – The GBM detectors

The GBM flight hardware comprises 12 thallium activated sodium iodide (NaI(Tl), hereafter NaI) scintillation detectors and two bismuth germanate (BGO) scintillation detectors. The individual NaI detectors ( $\sim 8$ –1000 keV) are mounted around the spacecraft and their axes are oriented such that the positions of GRBs can be derived from the measured relative counting rates. With their energy range extending between  $\sim 0.2$  and  $\sim 40$  MeV, two BGO detectors provide the overlap in energy with the LAT instrument

and are crucial for in-flight inter-instrument calibration [3]. They are mounted on opposite sides of the Fermi spacecraft covering a net  $\sim 8$  sr FoV.

A burst trigger occurs when the flight software detects an increase in the count rates of two or more detectors above an adjustable threshold specified in units of the standard deviation of the background rate. 28 different trigger algorithms operate simultaneously, each with a distinct threshold. The trigger algorithms currently implemented include four energy ranges: 50–300 keV, which is the standard GRB trigger range, 25–50 keV to increase sensitivity for SGRs and GRBs with soft spectra,  $> 100$  keV, and  $> 300$  keV to increase sensitivity for hard GRBs and TGFs. When a burst trigger occurs, onboard software determines a direction to the source using the relative rates in the 12 NaI detectors. These rates are compared to a table of calculated relative rates. The location with the best chi-squared fit is converted into right ascension and declination using spacecraft attitude information and transmitted to the ground. Improved locations are automatically computed on the ground in near real-time by the Burst Alert Processor (BAP) and later interactively by the GBM Burst Advocate.

The Fermi Observatory incorporates the capability to autonomously alter the observing plan to slew to and maintain pointing at a GRB for a set period of time, nominally 5 hours, subject to Earth limb constraints. This allows the LAT to observe delayed high-energy emission, as has been previously observed by instruments on the Compton Gamma-Ray Observatory [4]. Either the GBM or the LAT can generate an Autonomous Repoint Request (ARR) to point at a GRB. A request originating from GBM is transmitted to the LAT. The LAT either revises the recommendation or forwards the request to the spacecraft. The LAT software may, for example, provide a better location to the spacecraft, or cancel the request due to operational constraints. The GBM flight software specifies different repoint criteria depending on whether or not the burst is already within the LAT FoV, defined as within  $70^\circ$  of the  $+Z$  axis. An ARR is generated by GBM if the trigger exceeds a specified threshold for peak flux or fluence. These thresholds are reduced if the burst spectrum exceeds a specified hardness ratio.

### 3. – Two years scientific results

**3.1. GRB observations.** – During its two years of operations since trigger enabling (July 13th, 2009–September 6th, 2010), GBM detected  $\sim 540$  GRBs, with  $\sim 270$  bursts placed inside the LAT FoV. In 45 cases, an ARR was positively issued by GBM to repoint the LAT and follow particularly bright events. Moreover, 18 GRBs were detected at energies above 100 MeV. The most energetic events include GRB 080916C [5], GRB 090510 [6], GRB 090902B [7], and GRB 090926A [8]. In all four cases, the LAT detected photons with energies  $> 10$  GeV, with GRB 090902B being the record holder with 33 GeV, the highest photon energy reported so far for a GRB. Moreover, GRB 090510 was the first short GRB showing emission up to 31 GeV. For this burst, no evidence was found for the violation of Lorentz invariance, thus disfavoring quantum-gravity theories in which the quantum nature of space-time on a very small scale alters the speed of light in a way that depends linearly on photon energy. From the spectral point of view, joint GBM-LAT observations uncovered the presence of two spectral components in GRB 090902B. For this burst, a power law component dominates the Band component at both low ( $< 50$  keV) and high ( $> 100$  MeV) energies and is significant within just the GBM data. Furthermore, GRB 090926A showed evidence for a high energy cutoff.

Recently, [9] presented an extremely detailed time-resolved spectroscopy at timescales as short as 2 ms for the three brightest short GRBs observed with GBM (GRB 090227B,

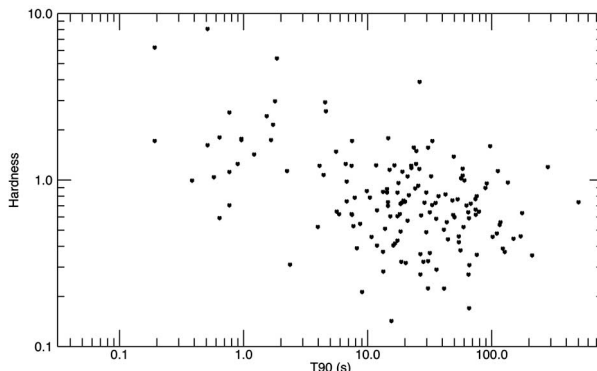


Fig. 1. – Distribution of spectral hardness *vs.* duration for a portion of the GBM bursts.

GRB 090228 and GRB 090510). The time-integrated spectra of the events deviate from the Band function, indicating the existence of an additional spectral component. The time-integrated  $E_{\text{peak}}$  values exceed 2 MeV for two of the bursts, and are well above the values observed in the brightest long GRBs. Their  $E_{\text{peak}}$  values and their low-energy power law indices confirm that short GRBs are harder than long ones. We find that short GRBs are very similar to long ones, but with light curves contracted in time and with harder spectra stretched towards higher energies.

Regarding common Fermi-*Swift* [10] GRB observations, the overlapping FoVs of GBM and of the Burst Alert Telescope (BAT) onboard *Swift* contributed to  $\sim 40$  common detections/y and resulted in 1 common GBM/LAT/BAT detection so far, namely in the case of the long-lived emission (from UV to GeV) of GRB 090510 [11]. The finer LAT localizations errors ( $< 0.4^\circ$ ) resulted in *Swift* follow-up of several Fermi bursts, providing 8 redshifts measurements (by ground-based observatories) so far.

**3.2. GRB catalog.** – Catalogs covering the first two years of GBM GRBs are currently being produced. The main catalog [12] summarizes basic parameters for all triggered GRBs, including sky location, fluence in two energy ranges (50–300 keV and 10–1000 keV), peak flux for the same two energy ranges and three timescales (64 ms, 256 ms and 1024 ms) and duration (T50 and T90 in the 50–300 keV range). The spectroscopy catalog [13] includes spectral fits using several standard functions for all sufficiently bright GRBs. The standard functions include power law, power law with exponential cut-off, Band function, and smoothly broken power law. For each burst two sets of spectral fits are performed: a  $3.5\sigma$  signal-to-background selection for the duration of the burst (fluence spectra), and a peak count rate selection (peak flux spectra). The peak count rate interval is 1 s for long bursts and 64 ms for short bursts, based on the burst T90 duration. Figure 1 shows the distribution of spectral hardness *versus* duration for a portion of the GBM bursts. Although the results are preliminary, the well-known tendency for short bursts to have harder spectra is clearly shown.

**3.3. Non-GRB science.** – Apart from GRBs, GBM triggered 170 times on SGR outbursts, mostly on soft, short trigger algorithms. Those triggers originated from four different active SGRs. Of those four, one is an already known source (SGR J1806–20), two are new sources discovered with *Swift* (SGR J0501+4516 and SGR J1550–5418) and one was discovered with GBM (SGR J0418+5729) [14]. An interesting finding by [15] was

the identification of a  $\sim 150$ -s-long enhanced persistent emission during the January 2009 outburst of SGR J1550–5418, which exhibited intriguing timing and spectral properties. The area of the blackbody-emitting region which could be estimated ( $\approx 0.046 (D/5 \text{ kpc})^2 \text{ km}^2$ , *i.e.* roughly a few  $\times 10^5$  of the neutron star area) is the smallest “hot spot” ever measured for a magnetar and most likely corresponds to the size of magnetically confined plasma near the neutron star surface.

GBM also triggered 93 times from TGF signals, all on hard, short trigger algorithms (see also [16]). First observations of a smaller sample of TGFs and their properties are reported in [17]. The temporal properties of a considerably larger sample of TGFs observed with GBM can be found in [18], who discuss several distinct categories of TGFs mainly identified by their time profiles. Moreover, [19] recently presented a search for correlations between TGFs detected by GBM and lightning strokes measured using the World Wide Lightning Location Network (WWLLN) [20]. In addition to gamma-ray TGFs, GBM has observed several TGFs by the propagation of charged particles along geomagnetic field lines. Strong 511 keV annihilation lines have been observed, demonstrating that both electrons and positrons are present in the particle beams [21].

Finally, GBM triggered 33 times on solar flares. Several other triggers were caused by well-known gamma-ray emitters, such as Cyg X-1, or by accidental particle events. Besides triggered transient sources, which are detected by the on-board trigger algorithm, GBM can be used to study hard X-ray pulsars with periods greater than a few seconds. These are monitored using Fourier transforms and epoch folding [22]. Moreover, GBM background data is extremely useful for a number of other studies, enabling a wide range of guest investigations. These data are currently used to monitor variable X-ray sources using the Earth occultation technique [23].

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