

## FIRST-YEAR RESULTS OF BROADBAND SPECTROSCOPY OF THE BRIGHTEST *FERMI*-GBM GAMMA-RAY BURSTS

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### ABSTRACT

We present our results of the temporal and spectral analysis of a sample of 52 bright and hard gamma-ray bursts (GRBs) observed with the *Fermi* Gamma-ray Burst Monitor (GBM) during its first year of operation (2008 July–2009 July). Our sample was selected from a total of 253 GBM GRBs based on the event peak count rate measured between 0.2 and 40 MeV. The final sample comprised of 34 long and 18 short GRBs. These numbers show that the GBM sample contains a much larger fraction of short GRBs than the *CGRO*/BATSE data set, which we explain as the result of our (different) selection criteria, which favor collection of short, bright GRBs over BATSE. A first by-product of our selection methodology is the determination of a detection threshold from the GBM data alone, above which GRBs most likely will be detected in the MeV/GeV range with the Large Area Telescope on board *Fermi*. This predictor will be very useful for future multi-wavelength GRB follow-ups with ground- and space-based observatories. Further, we have estimated the burst durations up to 10 MeV and for the first time expanded the duration–energy relationship in the GRB light curves to high energies. We confirm that GRB durations decline with energy as a power law with index approximately  $-0.4$ , as was found earlier with the BATSE data and we also notice evidence of a possible cutoff or break at higher energies. Finally, we performed time-integrated spectral analysis of all 52 bursts and compared their spectral parameters with those obtained with the larger data sample of the BATSE data. We find that the two parameter data sets are similar and confirm that short GRBs are in general harder than longer ones.

**Key words:** gamma-ray burst: general – methods: data analysis

**Online-only material:** color figures

### 1. INTRODUCTION

The most exciting results in the last decade of gamma-ray burst (GRB) science at MeV–GeV energies came from the combined observations of the Burst And Transient Source Experiment (BATSE; Fishman et al. 1993) with the Energetic Gamma-Ray Experiment Telescope (EGRET; Fichtel et al. 1994). Both instruments operated between 1991 and 2000 on board the *Compton Gamma-Ray Observatory* (*CGRO*) and covered the energy bands from 20 keV to 20 MeV and from 20 MeV to 30 GeV, respectively. BATSE observed 2704 bursts (Paciesas et al. 1999), providing the largest GRB database from a single experiment thus far. Out of this sample, only five bursts were detected with EGRET above 100 MeV and only one of these, GRB 930131 (Sommer et al. 1994), had high-energy emission that was consistent with an extrapolation from its spectrum obtained with BATSE between 25 keV and 4 MeV (see also Dingus 2003). However, in later analysis of the combined data from the BATSE/Large Area Detectors and the EGRET

calorimeter, the total absorption shower counter (TASC) uncovered an MeV component in GRB 941017 described by a power law with photon index approximately  $-1$  up to about 200 MeV (González et al. 2003). González et al. (2009) subsequently searched the TASC data for a response to 68 bright BATSE bursts. They found that only 21 showed emission detectable by TASC and of these, only three contained spectra with peak energy,  $E_{\text{peak}} > 2$  MeV. As these spectra were only found in a time-resolved analysis, González et al. (2009) claimed that the high-energy component could be hidden in the brightness of the synchrotron emission in a time-integrated spectrum. They suggested that the existence of the high-energy component indicated additional nonthermal processes at the source.

With the successful launch on 2008 June 11 of the *Fermi* Gamma-ray Space Telescope (*FGST*, hereafter *Fermi*), it is now possible to search and confirm the spectral signatures from GRBs up to very high energies. *Fermi* is an international and multi-agency space observatory that studies the cosmos over an unprecedented broad energy range (10 keV to 300 GeV). The Gamma-ray Burst Monitor (GBM) is the secondary instrument on board *Fermi*, operating between  $\sim 8$  keV and  $\sim 40$  MeV. The search for higher energy GRB emission is carried

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out with the primary instrument, the Large Area Telescope (LAT; Atwood et al. 2009), a pair conversion telescope, like EGRET, operating in the energy range between 20 MeV and 300 GeV. GBM alone provides a much wider energy coverage than any other current GRB mission, such as *Swift* (Gehrels et al. 2004). As of 2010 November, joint high-energy GBM/LAT observations have been carried out for 19 GRBs above 100 MeV. This number represents  $\sim 3\%$  of the total number of GRBs observed with GBM.

The small number of LAT GRB detections may be due to instrumental bias. The combined GBM/LAT GRB spectra are usually well described in the MeV–GeV range by a single power law with an index in the approximate range of  $-1$  to  $-3$  (see, e.g., Abdo et al. 2009a). This result is in agreement with the distributions of the high-energy power-law indices observed with BATSE in the  $\sim 30$  keV to  $\sim 2$  MeV energy range (Kaneko et al. 2006, hereafter K06). Consequently, photon counts above  $\sim 1$  MeV are usually very low, and this, combined with the limited field of view (FoV) of the LAT, results in much fewer GRBs observed in the multi MeV band than in the keV band. Currently, detailed calculations of LAT upper limits are being performed for the brightest bursts detected with GBM.

In this paper, we establish a well-defined sample of 52 bright GBM GRBs with broadband spectral coverage and with statistically significant high spectral resolution. All events were collected during the first year of GBM operations (2008 July 14–2009 July 15) and were detected up to MeV energies with GBM alone. In Section 2, we discuss the GBM instrumentation and data types and in Section 3 we describe the selection methodology for our sample, mainly based on the peak count rates measured above 500 keV. In Section 4, we present the temporal analysis of our sample over several energy bands. In Section 5, we describe the results of our time-integrated spectral analysis using different photon models to fit each spectrum, and discuss the distributions and correlations of the spectral parameters for the best models. Our conclusions are presented in Section 6.

## 2. INSTRUMENTATION AND DATA TYPES

The primary role of GBM was to augment the science return from *Fermi* in the study of GRBs by making observations at lower energies ( $\sim 8$  keV to  $\sim 40$  MeV) and thus bridging the gap with those of the LAT. The GBM flight hardware comprises a set of 12 Thallium-doped Sodium Iodide crystals (NaI(Tl), hereafter NaI) and two Bismuth Germanate crystals ( $\text{Bi}_4\text{Ge}_3\text{O}_{13}$ , commonly abbreviated as BGO). The individual NaI detectors are mounted around the spacecraft in four groups of three. Their arrangement results in an exposure of the whole sky unocculted by the Earth in orbit. The NaI detectors are able to detect  $\gamma$ -rays in the energy range between  $\sim 8$  keV and  $\sim 1$  MeV. The two BGO detectors are mounted on opposite sides of the *Fermi* spacecraft. With their energy range between  $\sim 0.2$  and  $\sim 40$  MeV, they provide the overlap in energy with the LAT instrument and are crucial in the study of high-energy hard bursts.

To trigger the GBM flight software (FSW), two or more NaI detectors must have a simultaneous statistically significant rate increase above the background rate (usually  $>5\sigma$ ). This requirement increases the threshold against statistical fluctuations and suppresses triggering due to non-astrophysical events that appear in only one detector, such as phosphorescence spikes. Before performing any spectral analysis, the detector geometry with respect to the GRB direction must be carefully taken into account. Detectors which see the burst at an angle  $>50^\circ$ , or

which suffer from blockages (by the solar panels, by the LAT, or by the spacecraft itself) were excluded. Sometimes these criteria result in a single NaI detector to be chosen for the spectral analysis, which is then fitted together with the mostly illuminated BGO detector. The best detector combination for each burst is given in Columns 4 (NaIs) and 5 (BGO) of Table 1.

All three GBM data types, namely CSPEC, CTIME, and TTE data, were used for the analysis presented in the following sections. A detailed description of these data types can be found in Meegan et al. (2009). CTIME and CSPEC data were used in burst mode, i.e., at 64 ms and 1.024 s temporal resolution, respectively. The BGO peak count rate analysis and the determination of the burst durations in the integrated BGO energy range are based on CTIME files, which have the finest temporal resolution (64 ms) with modest energy resolution consisting of eight energy channels. For the determination of the duration dependence on energy, we used TTE data both for the NaI and the BGO detectors. CSPEC and TTE data provide an energy resolution consisting of 128 energy channels and were used for all spectral analyses. The coarse time resolution CSPEC data are normally used as pre-trigger background data for the TTE data, since the latter only include  $\sim 30$  s before the trigger time. TTE data are then collected up to 300 s post-trigger, and in all cases discussed hereafter cover the whole burst duration. For each GRB, the data type used for spectral analysis is listed in Column 7 of Table 1.

## 3. SAMPLE SELECTION METHODOLOGY

We selected our sample based on two requirements: (1) a significant count rate excess above background ( $>3\sigma$ ) measured by the most illuminated NaI detectors in the 50–300 keV energy range, to ensure good statistics and (2) a significant count rate excess above background measured by the most illuminated BGO detector in the 500 keV–1 MeV during the main burst emission episode ( $T_{90}$ ). This combination allows a broadband spectral analysis of GBM data, which spans about three decades in energy (10 keV–10 MeV). It also represents a significant difference from previous selection criteria adopted by K06, which were mainly based on peak photon flux and fluence values measured in the 50–300 keV energy range. Criterion (2) was afforded by the good performance of the BGO detectors at those energies ( $>400$  keV), where the effective area of the NaI detectors rapidly decreases (Bissaldi et al. 2009). Below we discuss the methodology employed for the burst sample selection.

The first coarser burst selection was based on the analysis of the GBM telemetry packets, which are automatically produced during a trigger and contain all trigger information such as locations, classifications, and accumulated rates (Meegan et al. 2009). The so-called GBM maximum rates observed over a short period after trigger time ( $<4$  s) are produced from the accumulations made for the trigger algorithms and are evaluated as statistical significance (signal-to-noise ratio, S/N) versus the background. Typically, the FSW background interval ranges from about  $-36$  s to  $-4$  s with respect to the trigger time, thus excluding the most recent few seconds of data and avoiding in most cases the contamination by pre-trigger data from the burst. We automatically selected bursts showing an increase of more than 80 counts  $\text{s}^{-1}$  over background in at least one BGO detector over the full BGO energy range ( $\sim 250$  keV to  $\sim 40$  MeV).

The refined burst selection was based on the analysis of BGO CTIME light curves. As previously mentioned, CTIME

**Table 1**  
Basic Properties of 52 Bright GRBs

GBM	GRB	Trigger Time	NaI	BGO	LAT Angle	Data	Time Interval <sup>a</sup>	
Trigger	Name	( $T_0$ , MET)	Detector	Detector	(deg)	Type	Start	Stop
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
080723.557	080723B	238512142	4	0	107	CSPEC	0.004	60.161
080723.985	—	238549063	5,2	0	113	CSPEC	-2.304	50.945
080725.541	—	238683564	6,7	1	50	TTE	-0.064	0.384
080802.386	080802	239361311	4,5	0	125	TTE	-0.064	0.448
080807.993	080807	239845833	0,1,2	0	74	CSPEC	-1.376	21.152
080816.989	080816B	240623035	b,7	1	70	TTE	-0.064	4.480
080817.161	080817A	240637931	2,5	0	80	CSPEC	0.004	60.417
080825.593	080825C	241366429	9,a	1	60	CSPEC	0.004	25.216
080905.499	080905A	242308736	6,7	1	28	TTE	-0.064	1.024
080906.212	080906B	242370312	0,1,3	0	32	CSPEC	0.004	3.712
080916.009	080916C	243216766	3,4	0	52	CSPEC	0.004	70.145
080925.775	080925	244060556	6,7	1	38	CSPEC	0.004	25.856
081006.604	081006	244996175	0,3	0	16	TTE	-0.384	3.392
081009.690	—	245262818	8,b	1	96	CSPEC	-2.688	40.321
081012.045	081012B	245466323	9,a	1	66	TTE	-0.128	0.768
081024.891	081024B	246576161	6,9	1	16	TTE	-0.128	0.128
081101.532	081101B	247236325	5,2	0	116	CSPEC	0.003	8.704
081110.601	081110	248019944	7,8	1	67	TTE	-0.192	12.096
081121.858	081121	248992528	a,b	1	140	CSPEC	0.003	21.504
081122.520	081122	249049693	0,1	0	21 (ARR)	CSPEC	0.002	25.600
081125.496	081125	249306820	a,b	1	126	CSPEC	0.003	10.368
081126.899	081126	249428050	0,1	0	18	CSPEC	-12.160	40.065
081129.161	081129	249623525	a,b	1	118	CSPEC	-2.944	28.800
081207.680	081207	250359527	9,a	1	56	CSPEC	0.003	100.354
081209.981	081209	250558317	8,b	1	107	TTE	-0.056	0.256
081215.784	081215A	251059717	9,a	1	89	CSPEC	0.004	7.424
081216.531	081216	251124240	8,b	1	99	TTE	-0.128	0.960
081224.887	081224	251846276	6,9	1	17 (ARR)	CSPEC	0.002	16.544
081226.509	081226B	251986391	6,7	1	22	TTE	-0.064	0.192
081231.140	081231	252386462	6,9	1	21	CSPEC	0.003	28.672
090102.122	090102	252557732	a,b	1	87	CSPEC	0.003	28.928
090131.090	090131	255060563	9	1	40	CSPEC	0.003	38.145
090217.206	090217	256539404	6,9,7	1	34	CSPEC	0.003	29.824
090219.074	090219	256700780	5,2	0	137	TTE	-0.064	0.576
090227.310	090227	257412359	0,3	0	20	CSPEC	0.003	15.232
090227.772	090227B	257452263	1,2,5	0	72 (ARR)	TTE	-0.128	0.384
090228.204	090228	257489602	0,1,3	0	16	TTE	-0.128	0.512
090305.052	090305B	257908477	0,3,1	0	40	TTE	-0.128	1.344
090308.734	090308B	258226586	3,7,4	0,1	50	TTE	0.000	1.536
090323.002	090323	259459364	9	1	53 (ARR)	CSPEC	0.003	71.681
090328.401	090328	259925808	7,8	1	63 (ARR)	CSPEC	0.003	30.720
090328.713	090328B	259952826	9,10	1	74 (ARR)	TTE	-0.064	0.128
090330.279	090330	260088144	7,9,b	1	50	CSPEC	-38.913	31.745
090424.592	090424	262275130	7,8,b	1	71	CSPEC	0.002	14.592
090429.753	090429D	262721039	0,1	0	33	TTE	-0.128	0.512
090510.016	090510	263607781	6,7,9	1	13 (ARR)	TTE	0.512	1.024
090528.516	090528B	265206153	7,8	1	65	CSPEC	0.003	80.897
090531.775	090531B	265487758	6,7,9	1	26	TTE	-0.128	0.832
090618.353	090618	267006508	4	0	130	CSPEC	8.704	125.442
090620.400	090620	267183385	6,7,b	1	60	CSPEC	0.003	11.520
090623.107	090623	267417259	7,8,b	1	73	CSPEC	-1.920	49.281
090626.189	090626	267683530	0	0	15	CSPEC	0.003	48.897

**Note.** <sup>a</sup> The time range values are given in  $s$  relative to the trigger time  $T_0$ . They represent the interval used for the time-integrated spectral analysis.

data have a 64 ms temporal resolution during burst mode and spectral resolution of eight energy channels. Channel edges are controlled using the specific lookup tables, which map the 4096 raw channels into the eight energy channels (Meegan et al. 2009). Exact channel boundaries can vary from detector to detector (BGO 0 or 1) and from burst to burst. The BGO CTIME

background was computed, including pre- and post-trigger time intervals, usually from  $-300$  s to  $+300$  s in the case of long bursts and from  $-50$  s to  $+50$  s for short bursts, excluding the interval of the burst itself. The background-subtracted light curve was then examined for the maximum or “peak” count rate on the 64 ms timescale over each individual CTIME energy channel.

The resulting total number of GRBs included in this spectral analysis is 52, which approximately represents  $\sim 20\%$  of all bursts detected during the first year of GBM operation. These bursts are listed in Table 1. The first three columns list the GBM trigger number, the GRB name,<sup>9</sup> and the burst trigger time (in MET). The numbers of the NaI (from 0 to 11) and BGO (0 and 1) detectors used for the temporal and spectral analysis are reported in Columns 4 and 5, respectively. Column 6 gives the angle ( $\theta$ ) of the burst with respect to the LAT boresight. The LAT FoV covers those events which are located at  $\theta < 65^\circ$ . This value represents the initial angle from the source calculated at trigger time and can vary during the burst in the case of a slew of the spacecraft (the so-called autonomous repoint recommendation or ARR). The GBM data type and time interval (with respect to the burst trigger time,  $T_0$ ) adopted for the spectral analysis are listed in the last three columns.

The full sample of 52 bursts was further subdivided according to the detection significance of the event peak in a BGO energy channel. GRBs detected with more than  $3\sigma$  significance in the first six BGO energy channels constitute the corresponding *Channel* sample. All bursts in the full sample are detected in *Ch.0* ( $\sim 200$ – $500$  keV) and *Ch.1* ( $\sim 500$ – $1000$  keV), 28 bursts are detected in *Ch.2* ( $\sim 1$ – $2$  MeV), 14 bursts are detected in *Ch.3* ( $\sim 2$ – $5$  MeV), and 6 bursts are detected in *Ch.4* ( $\sim 5$ – $10$  MeV).

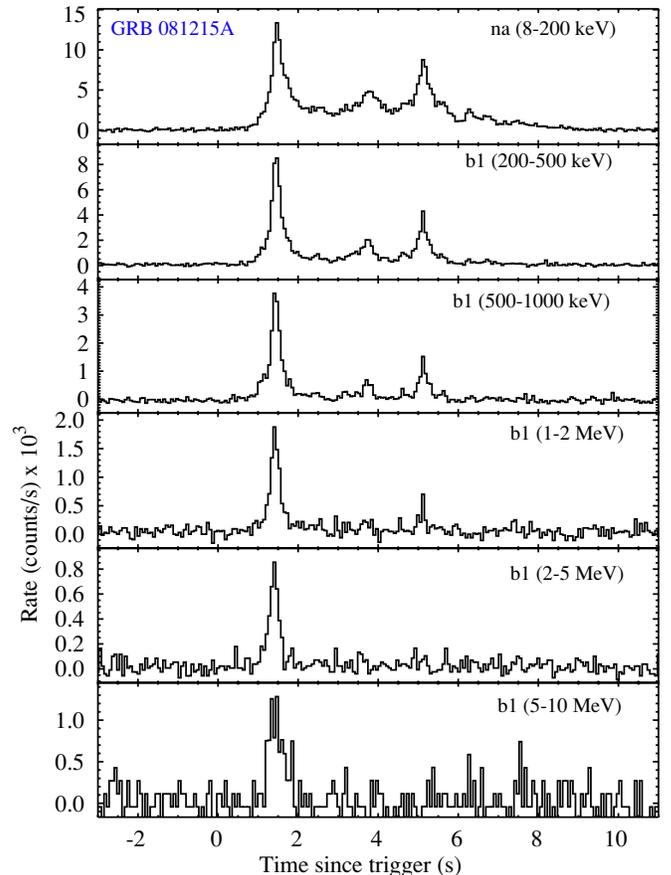
Figure 1 shows an example light curve of one of the brightest GBM bursts in our sample, namely the long GRB 081215A, which is detected up to  $>5$  MeV in BGO. The top panel shows the 8–200 keV band, covered by the most illuminated NaI detector(s). The other panels show the BGO light curve in different energy ranges, covering five CTIME energy channels (*Ch.0*–*Ch.4*). This very bright burst was also marginally detected by the LAT (McEnery et al. 2008a). Indeed,  $\theta$  was  $\sim 86^\circ$ , which means that neither directional nor energy information could be obtained with the standard analysis procedures. Using non-standard data selection, McEnery et al. (2008a) reported the detection of over 100 events above background within a 0.5 s interval in coincidence with the main GBM peak. The significance of this excess is greater than  $8\sigma$ .

### 3.1. BGO Effective Area Correction

In order to correct for the dependence of the BGO effective area on the incidence angle, we calculated an additional scaling factor accounting for the angle between the burst position and the BGO detectors. This was mainly necessary since the peak count rate analysis was performed on data without taking the instrument response into account. In Bissaldi et al. (2009), the off-axis response of the BGO detectors was measured at different energies for both flight module detectors at various angles between  $0^\circ$  (i.e., on-axis) and  $90^\circ$ . A scaling factor could be calculated for each incident direction and then used to correct the peak count rates. The correction factors are relatively small out to  $\sim 40^\circ$  and strongly increase toward  $90^\circ$ . At higher energies, the correction factor is not as high as at lower energies. This mainly reflects the strong absorption of low-energy photons by the BGO photomultiplier tubes.

### 3.2. LAT Detections

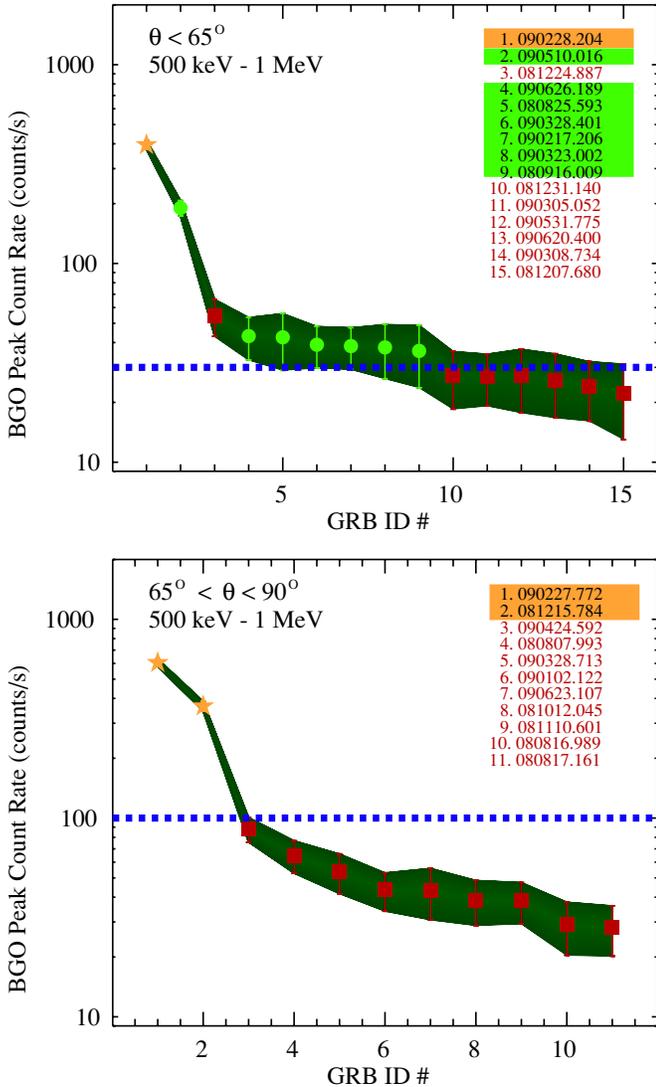
An interesting result of the BGO peak count rate analysis emerges by considering only those bursts, which are located



**Figure 1.** Background-subtracted light curves of the long GRB 081215 observed with the GBM detectors. The panels show the sum of the counts in different energy bands as seen by (top histogram) the most illuminated NaI detector in the 8–200 keV energy range, and (bottom five histograms) the BGO detectors covering the first five CTIME energy channels. The bin width is 128 ms.

either inside or at the edge of the LAT FoV. (i.e.,  $\theta < 65^\circ$  or  $65^\circ < \theta < 90^\circ$  from the LAT boresight, respectively). Figure 2 shows the BGO peak count rate measured in *Ch.1* for 15 and 11 bursts, which respectively fulfill these conditions. The GBM trigger IDs and numbers for both subsamples are listed on the top right corner of each plot. Circles (green), stars (orange), and squares (red) represent firm, marginal, or no LAT detections, respectively. All firm LAT detections are discussed in dedicated publications (see, e.g., Abdo et al. 2009a, 2009b). The marginal detection of GRB 081215 is reported in McEnery et al. (2008a), while a preliminary analysis of GRB 090227B and GRB 090228 can be found in Connaughton et al. (2010). The detection of GRB 081224 was claimed in Wilson-Hodge et al. (2008), and later retracted by McEnery et al. (2008b). The final LAT GRB results will be presented in the forthcoming GRB Catalog by the LAT Team. The dotted line marks a “detection limit,” which was arbitrarily placed at 30 (top panel) and 100 counts  $s^{-1}$  (bottom panel) in the *Ch.1* peak count rate. For those bursts with lower rates in *Ch.1* no detection has been yet reported from the LAT. Pelassa et al. (2010) recently presented a new technique to recover the signal from the GRB prompt emission between  $\sim 30$  MeV and 100 MeV, which differs from the standard LAT analysis (the so-called LAT Low-Energy technique, or LLE). This very promising technique may recover the signal to confirm the LAT marginal detections and even reveal undiscovered emission from some of the Figure 2 BGO bursts lying below these arbitrary thresholds. Another technique which could act as a

<sup>9</sup> The naming convention follows the Gamma-ray bursts Coordinates Network (GCN) publication policy. Bursts which were not reported in a GCN circular are not given a name in Column 2.



**Figure 2.** BGO peak count rate measured in *Ch.1* (500 keV–1 MeV) for those bursts inside (top panel) and at the edge (bottom panel) of the LAT FoV. Circles (green), stars (orange), and squares (red) represent firm, marginal, or no LAT detections, respectively. The dotted line marks the arbitrary “detection limit” placed at 30 (top panel) and 100 (bottom panel) counts  $s^{-1}$ .

(A color version of this figure is available in the online journal.)

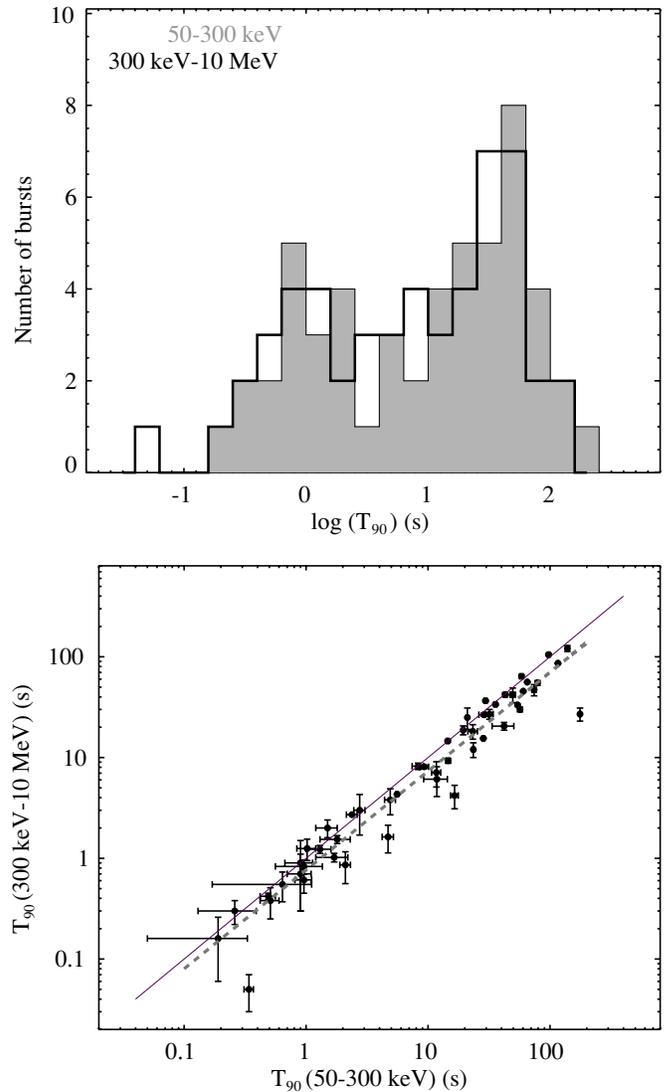
possible source for future confirmation of LAT GRB detections is the one presented in Akerlof et al. (2010) and Akerlof et al. (2011).

The significance of the above analysis lies in its potential to provide a good predictor for LAT detections of GBM GRBs. Indeed, the relevant changes were recently made to the GBM ground software and new information was added to the GBM ground location GCN notices (GCN/FERMI\_GBM\_GND\_POSITION; see also Connaughton et al. 2011 for more details). This change, based on the above presented BGO peak count rate analysis, will send an alert that a bright, hard burst has occurred in the LAT FoV to other space- and ground-based GRB observatories.

## 4. TEMPORAL ANALYSIS

### 4.1. Duration Distributions

We used the CTIME data of the most illuminated NaI detector for each GRB to compute the  $T_{90}$  duration (Kouveliotou



**Figure 3.** Top panel: burst duration distributions in the 50–300 keV (gray filled histogram) and in the 300 keV–10 MeV (black empty histogram) energy ranges for 52 bursts of our bright-burst sample. Both distributions show a bimodal shape. Bottom panel: scatter plot of the burst duration distributions. The continuous line represents perfect linearity, while the dotted line represents the fit applied to the data.

et al. 1993) in the BATSE energy range of 50–300 keV (for comparison reasons). The background model was determined by fitting a low-order ( $\leq 4$ ) polynomial function over at least a few hundred seconds before and after the trigger time. All standard  $T_{90}$  durations in the 50–300 keV energy range were computed with the spectral analysis software RMfit<sup>10</sup> (version 3.8; see, e.g., Mallozzi et al. 2005), which was also employed for the spectral analysis presented in Section 5. The resulting durations were thus estimated in photon space (i.e., the time it took to collect 90% of the burst photons). A different approach (since the BGO data were not yet programmed in RMfit at that time) was adopted to compute the burst durations in the 300 keV–10 MeV energy range, where we estimated the  $T_{90}$ ’s in count space using software developed at MPE, thus obtaining a measure of the so-called BGO duration. Figure 3 includes

<sup>10</sup> An ad hoc version of RMFIT for GBM and LAT analysis was developed by the GBM Team and is publicly available at <http://fermi.gsfc.nasa.gov/ssc/data/analysis/>.

**Table 2**  
Duration versus Energy Parameters

Energy Range	Number of Bursts			$\langle T_{90}(50\text{--}300\text{ keV}) \rangle$		$\langle \alpha_{90} \rangle$	
	T	L	S	L	S	L	S
300 keV–2 MeV	9	6	3	$43.1 \pm 0.7$	$1.08 \pm 0.18$	$-0.41 \pm 0.04$	$-0.42 \pm 0.17$
300 keV–5 MeV	4	2	2	$52.9 \pm 0.5$	$0.92 \pm 0.15$	$-0.38 \pm 0.04$	$-0.42 \pm 0.17$
300 keV–10 MeV	6	4	2	$76.7 \pm 0.6$	$2.24 \pm 0.16$	$-0.32 \pm 0.02$	$-0.40 \pm 0.12$

both data sets for demonstration purposes. Although these are not directly comparable (photon versus count durations) they serve as qualitative trend indicators as we discuss below.

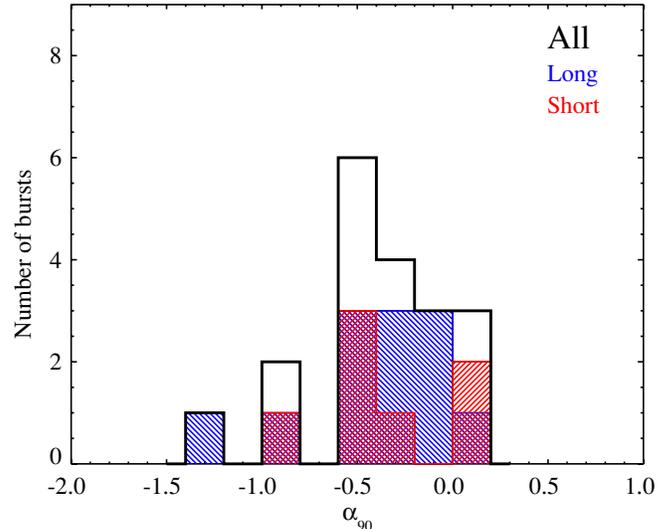
The initially selected sample of 52 GRBs includes 18 bursts with a duration  $T_{90} < 3$  s (50–300 keV, *short GRBs*) and 34 bursts with a duration  $T_{90} > 3$  s (50–300 keV, *long GRBs*). The three longest bursts in the sample, with durations greater than 100 s, are GRB 081009, GRB 090323, and GRB 090618, while the three shortest ones are GRB 081226B, GRB 090328B, and GRB 090228. The top panel of Figure 3 shows the distribution of  $T_{90}$ , calculated in the 50–300 keV and in the 300 keV–10 MeV energy ranges, for all 52 bursts. We note that the duration bimodality found in the BATSE data (Kouveliotou et al. 1993) is evident even in this small sample of GBM data and in both count and photon-space durations. We fitted each distribution with a double Gaussian function to estimate the medians and deviations. We found that short bursts peak at  $1.2 \pm 0.3$  s ( $1.04 \pm 0.16$  s) in the 50–300 keV (300 keV–10 MeV) bands, while long bursts peak at  $33 \pm 5$  s ( $25 \pm 8$  s), respectively. In the bottom panel of Figure 3 we plot the  $T_{90}$  distributions against each other. The dashed line represents a linear fit applied to the data. It has a slope of  $0.98 \pm 0.03$ , and lies below the bisector (continuous line), indicating that on the average, the BGO durations are smaller than the NaI’s. This result agrees qualitatively with the earlier findings of Richardson et al. (1996) that GRB durations decline with energy. In Section 4.2, we explore and expand this relationship to the MeV range for the first time.

#### 4.2. Evolution of Duration with Energy

We followed the approach described by Richardson et al. (1996), who presented the analysis of 72 intense GRBs from the BATSE 3B catalog. They measured their  $T_{90}$  in four broad energy channels, namely 25–50 keV, 50–100 keV, 100–300 keV, and  $>300$  keV. The bursts used for their study were uniformly selected by their peak photon flux on the 64 ms timescale. Thanks to the broader BGO energy coverage, we can measure  $T_{90}$  over the five additional energy channels described in Section 3 (the only exception is *Ch.0*, which is here defined between 300 and 500 keV, to match the upper edge of the BATSE  $T_{90}$  values, for comparison reasons). The  $T_{90}$  calculated using only NaI data in the 50–300 keV energy band represents our lowest measurement; this energy interval was not further subdivided.

The energy intervals used for our analysis are listed in the first column of Table 2. Columns 2–4 give the number of bursts detected over the different energy intervals, where T indicates the total number of GRBs, and L and S indicate long and short bursts, respectively. The average  $T_{90}$  values calculated using NaI only data in the 50–300 keV for each subgroup (again in photon space) are given in Columns 5 and 6. It is worth noting that the bursts detected up to higher energies are systematically longer. This behavior is seen for both long and short GRBs.

We then fitted the energy versus duration values for each burst in the sample, excluding the NaI data points (to ensure a



**Figure 4.** Distribution of the best-fit indexes  $\alpha_{90}$  of power-law fits to the burst durations over different energy channels. Blue and red histograms represent the distributions of long and short GRBs, respectively. The black histogram represents the entire sample.

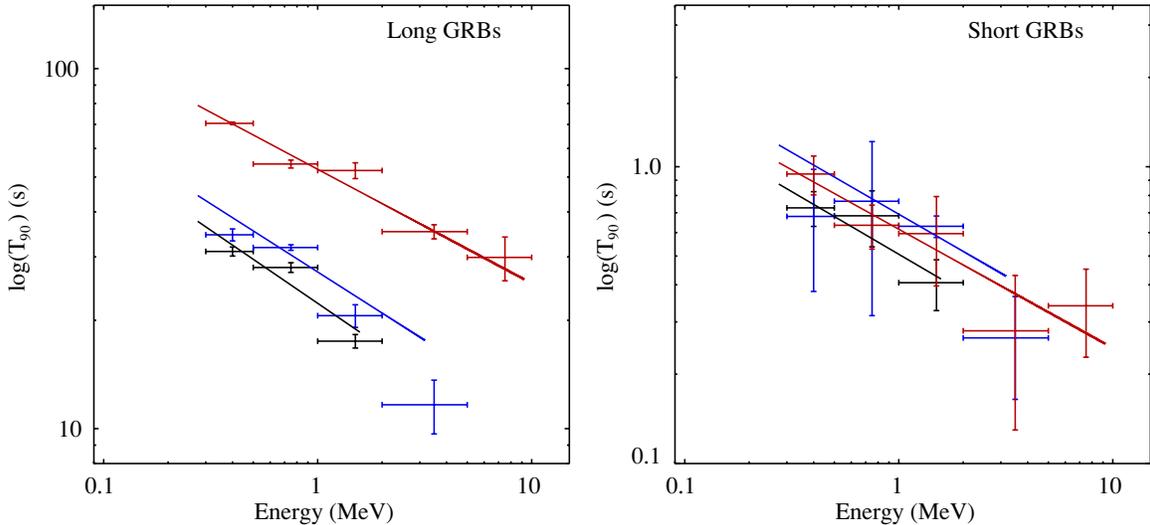
(A color version of this figure is available in the online journal.)

homogeneous set), to a power-law function given by

$$T_{90} = A_{90} E^{\alpha_{90}} \quad (1)$$

using a  $\chi^2$  minimization technique. We used the central energy value to represent each energy channel in the fit. The distribution of the best-fit indexes,  $\alpha_{90}$ , over all energy intervals is shown in Figure 4. Blue and red shaded histograms represent the distributions of long and short GRBs, respectively. The average value of  $\alpha_{90}$  calculated with this technique is  $-0.39 \pm 0.04$  (0.34), where the first error is the error in the mean and the error given in parenthesis is the standard deviation of the distribution. This value is in good agreement with the result of Richardson et al. (1996) and indicates that the same overall trend of declining duration versus energy in the GRB light curves continues up to at least 10 MeV.

We now proceed to explore the duration–energy relation in subsamples of our 52 GRBs selected according to their highest detection in each of the 5 BGO channels described above. The sample sizes are defined in Table 2; e.g., 22 long GRBs are detected up to *Ch.1* and a mere 4 up to *Ch.5*. For each subsample, we first average the values of  $T_{90}$  for each energy channel, and then fit a power law to these data as we did in the total sample. These fits were computed separately for long and short bursts and are shown in two panels of Figure 5. The values of their  $\alpha_{90}$  are given in Columns 7 and 8 of Table 2. The left panel of Figure 5 clearly exhibits the trend for the longest subsample to extend to higher energies; we can see the same trend in the short GRB subsample albeit with lesser statistical significance. Whether this trend is simply a selection effect or an



**Figure 5.** Evolution of the  $T_{90}$  duration with respect to energy for four subsamples of 12 long GRBs (left panel) and 7 short GRBs (right panel). Energy bands are over the 5 BGO CTIME channels. Different curves correspond to different burst sets for which such duration measurements were possible (see also text and Table 2). (A color version of this figure is available in the online journal.)

intrinsic GRB property remains to be determined with a larger GRB sample, including events with LAT detections possibly extending this relation to higher energies. We find evidence for slight curvature of  $T_{90}$  versus energy in both duration modes indicating a potential cutoff. The detailed study of these relations using a uniform data set and time-resolved binning of the NaI durations is the subject of another publication, currently in preparation. We note here that the red subsamples include GRBs that have indeed been detected with the LAT in GeV energies.

## 5. SPECTRAL ANALYSIS

During the BATSE era, GRB spectra were well represented by a broken power law (the empirical *Band* function; Band et al. 1993) in the BATSE energy band (K06). In our spectral analysis, we fitted the time-integrated spectra of the 52 bright bursts in Table 1 with two functions: (1) the *Band* function and (2) the *Comptonized (Comp)* model. The second represents a low-energy power law with an exponential high-energy cutoff, which is equivalent to the *Band* function without a high-energy power law (i.e.,  $\beta \rightarrow -\infty$ ). More details regarding both spectral functions can be found in K06. Since we excluded faint or soft GRBs from our sample, the simple power-law model was not used. Moreover, no additional extra components were fitted to both spectral models. For a detailed time-integrated spectral analysis of a subsample of three short GRBs exploring several multi-component emission models, see Guiriec et al. (2010). Guiriec et al. (2011) have also identified an additional spectral component in the time-integrated analysis of GRB 100724B; the appearance of these components in the high-energy part of the GBM spectrum could be another predictor for the bursts expected to be seen with the LAT.

We performed broadband spectroscopy simultaneously on the  $\sim 8$  keV to 1 MeV NaI data and the  $\sim 250$  keV to  $\sim 38$  MeV BGO data. In some cases an effective area correction had to be fit to the BGO data (see, e.g., Abdo et al. 2009b) to match the model normalizations given by the NaI data; this correction is usually consistent with the uncertainties in the GBM detector responses ( $<10\%$ ). Columns 8 and 9 of Table 1 list the time

intervals used for each burst. All times are referred to the burst trigger time  $T_0$ .

The time-integrated spectral best-fit results are presented in Table 3 for each burst. The GRB trigger number is given in Column 1, while the best model for the spectral fit is listed in Column 2. The spectral parameters are given in Columns 3–7. Column 8 lists the effective area correction factors. The quality of fit in terms of CSTAT<sup>11</sup> over degrees of freedom (DOF) is listed in Column 9. The *Band* function was preferred for those bursts for which an improvement of  $>10$  was observed in the CSTAT statistic over the *Comp* function. This assures that the spectra have a well-identifiable high-energy power-law component. We find that the *Band* function is preferred over the *Comp* model in 27 out of 52 cases (52%). Most short bursts are best fit by a *Comp* model: only five out of 18 short GRBs are best fit by the *Band* function. Three of those are the brightest bursts in our sample, for which Guiriec et al. (2010) have reported the presence of an extra power-law component in the GBM data. We proceed below in the description of the spectral parameter distributions, their correlations and their comparisons with empirical relationships in the literature.

### 5.1. Distributions of Spectral Parameters

The distribution of the two parameters of the *Comp* model (index  $\lambda$  and  $E_{\text{peak}}$ ) are shown in Figure 6; those of the *Band* function parameters are displayed in Figure 7. In both figures, the  $E_{\text{peak}}$  parameter distribution is plotted at the bottom. In Figure 7, the two top panels show the low-energy index  $\alpha$  and the high-energy index  $\beta$ . In all plots of the following sections, blue, red, and black histograms represent the distributions of 34 long, 18 short, and the entire sample of 52 bright GRBs, respectively.

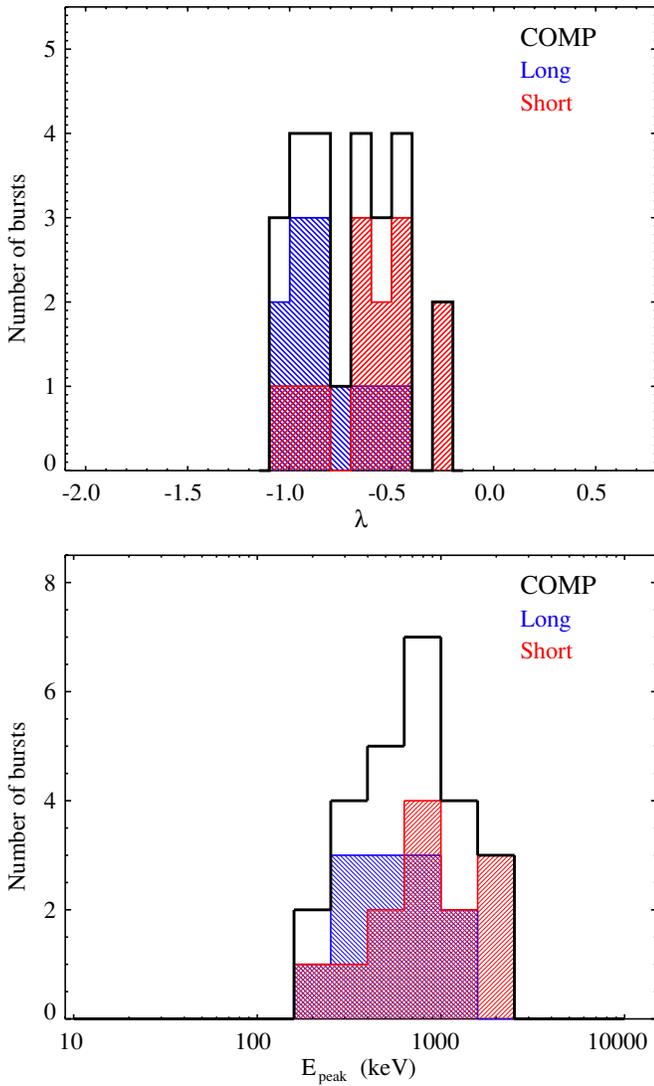
The spectral parameter distributions show that short bursts tend to have larger  $\alpha$  ( $\lambda$ ) and smaller  $\beta$  values. The five short bursts best fitted with a *Band* function show higher  $E_{\text{peak}}$  than long bursts (Figure 7, bottom panel); in three of them we found a value of  $\beta < -2.6$ . The *Comp* model is preferred for the other

<sup>11</sup> The CSTAT statistics is equivalent to the XSPEC (Arnaud 1996) implementation of the Cash statistic (Cash 1979).

**Table 3**  
Summary of Time-integrated Spectral Fit Results of 52 Bright GRBs

GBM Trigger (1)	Best Model (2)	$A$ ( $\text{phs}^{-1} \text{cm}^{-2} \text{keV}^{-1}$ ) (3)	$E_{\text{peak}}$ (keV) (4)	Index (5)	$\alpha$ (6)	$\beta$ (7)	$A_{\text{eff}}$ Correction (8)	CSTAT/ DOF (9)
080723.557	Band	$0.035 \pm 0.0008$	$219^{(+9)}_{(-8)}$	...	$-0.858^{(+0.023)}_{(-0.023)}$	$-2.63^{(+0.12)}_{(-0.15)}$	0.83	384/235
080723.985	Comp	$0.0111 \pm 0.0003$	$445^{(+24)}_{(-22)}$	$-0.949^{(+0.027)}_{(-0.026)}$	...	...	...	496/359
080725.541	Comp	$0.0135 \pm 0.0009$	$1670^{(+760)}_{(-540)}$	$-0.89^{(+0.14)}_{(-0.11)}$	...	...	...	362/359
080802.386	Comp	$0.0166 \pm 0.0025$	$600^{(+150)}_{(-150)}$	$-0.65^{(+0.21)}_{(-0.18)}$	...	...	...	402/358
080807.993	Comp	$0.0043 \pm 0.0002$	$790^{(+260)}_{(-170)}$	$-1.01^{(+0.07)}_{(-0.06)}$	...	...	...	577/481
080816.989	Comp	$0.0039 \pm 0.0002$	$1550^{(+300)}_{(-280)}$	$-0.51^{(+0.12)}_{(-0.11)}$	...	...	...	390/360
080817.161	Band	$0.0147 \pm 0.0004$	$425^{(+26)}_{(-25)}$	...	$-0.99 \pm 0.02$	$-2.31^{(+0.10)}_{(-0.14)}$	...	544/361
080825.593	Band	$0.0617 \pm 0.0033$	$176 \pm 7$	...	$-0.64 \pm 0.04$	$-2.52^{(+0.10)}_{(-0.14)}$	0.80	418/357
080905.499	Comp	$0.0090 \pm 0.0016$	$500^{(+180)}_{(-110)}$	$-0.20^{(+0.4)}_{(-0.29)}$	...	...	...	471/361
080906.212	Band	$0.1152 \pm 0.0110$	$147^{(+8)}_{(-7)}$	...	$-0.37 \pm 0.06$	$-2.39^{(+0.10)}_{(-0.12)}$	...	522/479
080916.009	Band	$0.0166 \pm 0.0002$	$540^{(+32)}_{(-30)}$	...	$-1.06 \pm 0.02$	$-2.24^{(+0.08)}_{(-0.10)}$	...	533/358
080925.775	Band	$0.0272 \pm 0.0016$	$138 \pm 8$	...	$-0.96 \pm 0.04$	$-2.27^{(+0.08)}_{(-0.10)}$	...	430/359
081006.604	Comp	$0.0038 \pm 0.0004$	$840^{(+520)}_{(-240)}$	$-0.43^{(+0.3)}_{(-0.26)}$	...	...	...	423/362
081009.690	Band	$0.0296 \pm 0.0143$	$63^{(+15)}_{(-11)}$	...	$-0.53^{(+0.3)}_{(-0.24)}$	$-1.76^{(+0.04)}_{(-0.05)}$	0.70	502/358
081012.045	Comp	$0.0123 \pm 0.0011$	$750^{(+300)}_{(-160)}$	$-0.44^{(+0.23)}_{(-0.20)}$	...	...	...	368/355
081024.891	Comp	$0.0096 \pm 0.0014$	$1300^{(+540)}_{(-410)}$	$-0.46^{(+0.3)}_{(-0.22)}$	...	...	...	326/359
081101.532	Comp	$0.0251 \pm 0.0008$	$290 \pm 30$	$-0.686 \pm 0.04$	...	...	...	360/360
081110.601	Comp	$0.0105 \pm 0.0004$	$470^{(+70)}_{(-50)}$	$-1.064^{(+0.046)}_{(-0.043)}$	...	...	...	410/359
081121.858	Band	$0.0266 \pm 0.0049$	$158^{(+18)}_{(-17)}$	...	$-0.47^{(+0.14)}_{(-0.12)}$	$-1.94^{(+0.06)}_{(-0.07)}$	...	456/356
081122.520	Comp	$0.0093 \pm 0.0006$	$207^{(+21)}_{(-17)}$	$-0.90 \pm 0.07$	...	...	...	435/360
081125.496	Band	$0.0932 \pm 0.0051$	$164 \pm 7$	...	$-0.48 \pm 0.05$	$-2.86^{(+0.18)}_{(-0.26)}$	0.76	408/358
081126.899	Comp	$0.0040 \pm 0.0004$	$330^{(+50)}_{(-40)}$	$-1.00 \pm 0.07$	...	...	...	488/360
081129.161	Band	$0.0114 \pm 0.0007$	$250 \pm 30$	...	$-0.96^{(+0.06)}_{(-0.05)}$	$-2.20^{(+0.15)}_{(-0.22)}$	...	454/356
081207.680	Band	$0.0095 \pm 0.0002$	$430^{(+30)}_{(-28)}$	...	$-0.67 \pm 0.03$	$-2.11^{(+0.08)}_{(-0.09)}$	...	501/356
081209.981	Band	$0.0347 \pm 0.0021$	$1100^{(+400)}_{(-300)}$	...	$-0.68^{(+0.14)}_{(-0.11)}$	$-2.23^{(+0.26)}_{(-0.5)}$	...	349/357
081215.784	Band	$0.1074 \pm 0.0014$	$458 \pm 13$	...	$-0.71^{(+0.02)}_{(-0.02)}$	$-2.36^{(+0.04)}_{(-0.05)}$	...	519/356
081216.531	Band	$0.0200 \pm 0.0009$	$1270^{(+260)}_{(-300)}$	...	$-0.81^{(+0.07)}_{(-0.05)}$	$-2.54^{(+0.40)}_{(-0.80)}$	...	453/357
081224.887	Comp	$0.0378 \pm 0.0007$	$380 \pm 11$	$-0.73 \pm 0.02$	...	...	0.87	442/358
081226.509	Comp	$0.0311 \pm 0.0044$	$350^{(+100)}_{(-70)}$	$-0.41^{(+0.24)}_{(-0.20)}$	...	...	...	414/360
081231.140	Band	$0.0149 \pm 0.0006$	$234^{(+26)}_{(-20)}$	...	$-1.06 \pm 0.04$	$-2.26^{(+0.17)}_{(-0.50)}$	...	472/358
090102.122	Comp	$0.0180 \pm 0.0003$	$412^{(+16)}_{(-15)}$	$-0.86 \pm 0.02$	...	...	0.87	442/357
090131.090	Band	$0.0321 \pm 0.0030$	$61 \pm 4$	...	$-1.21^{(+0.08)}_{(-0.06)}$	$-2.42^{(+0.09)}_{(-0.10)}$	...	348/236
090217.206	Comp	$0.0125 \pm 0.0002$	$633^{(+35)}_{(-32)}$	$-0.91 \pm 0.02$	...	...	...	659/479
090219.074	Comp	$0.0289 \pm 0.0115$	$214^{(+100)}_{(-55)}$	$-0.2^{(+0.8)}_{(-0.5)}$	...	...	...	353/361
090227.310	Comp	$0.0055 \pm 0.0002$	$1000^{(+200)}_{(-160)}$	$-0.86 \pm 0.06$	...	...	...	383/360
090227.772	Band	$0.0762 \pm 0.0016$	$2100 \pm 100$	...	$-0.51^{(+0.03)}_{(-0.02)}$	$-3.33^{(+0.27)}_{(-0.40)}$	...	548/479
090228.204	Comp	$0.0755 \pm 0.0016$	$840 \pm 50$	$-0.60 \pm 0.03$	...	...	...	540/480
090305.052	Comp	$0.0126 \pm 0.0006$	$890^{(+150)}_{(-120)}$	$-0.58^{(+0.11)}_{(-0.09)}$	...	...	...	570/480
090308.734	Comp	$0.0193 \pm 0.0080$	$664^{(+60)}_{(-50)}$	$-0.53^{(+0.08)}_{(-0.07)}$	...	...	...	688/600
090323.002	Band	$0.0178 \pm 0.0003$	$530^{(+26)}_{(-24)}$	...	$-0.81 \pm 0.02$	$-2.42^{(+0.09)}_{(-0.12)}$	...	568/237
090328.401	Band	$0.0173 \pm 0.0003$	$660 \pm 40$	...	$-0.93 \pm 0.02$	$-2.44^{(+0.14)}_{(-0.19)}$	...	534/360
090328.713	Comp	$0.0319 \pm 0.0016$	$2000^{(+680)}_{(-520)}$	$-0.96 \pm 0.07$	...	...	...	376/356
090330.279	Band	$0.0068 \pm 0.0005$	$198 \pm 19$	...	$-0.92^{(+0.07)}_{(-0.06)}$	$-2.28^{(+0.15)}_{(-0.21)}$	...	747/477
090424.592	Band	$0.1419 \pm 0.0026$	$146.2^{(+2.8)}_{(-2.9)}$	...	$-0.86 \pm 0.02$	$-2.76 \pm 0.08$	0.78	843/478
090429.753	Comp	$0.0150 \pm 0.0008$	$1400^{(+700)}_{(-400)}$	$-1.06^{(+0.09)}_{(-0.08)}$	...	...	...	372/360
090510.016	Band	$0.0427 \pm 0.0009$	$4400^{(+400)}_{(-380)}$	...	$-0.79 \pm 0.03$	$-2.74^{(+0.26)}_{(-0.40)}$	...	486/479
090528.516	Band	$0.0170 \pm 0.0070$	$170^{(+12)}_{(-11)}$	...	$-1.10 \pm 0.04$	$-2.21^{(+0.08)}_{(-0.10)}$	...	553/358
090531.775	Comp	$0.0094 \pm 0.0006$	$1750^{(+370)}_{(-320)}$	$-0.63^{(+0.11)}_{(-0.09)}$	...	...	...	632/481
090618.353	Band	$0.0717 \pm 0.0011$	$150.2 \pm 2.7$	...	$-1.12 \pm 0.01$	$-2.50 \pm 0.03$	0.78	532/233
090620.400	Band	$0.0920 \pm 0.0045$	$150 \pm 4$	...	$-0.174 \pm 0.05$	$-2.77^{(+0.11)}_{(-0.13)}$	0.70	580/479
090623.107	Band	$0.0084 \pm 0.0004$	$307^{(+36)}_{(-30)}$	...	$-0.63^{(+0.07)}_{(-0.06)}$	$-2.29^{(+0.17)}_{(-0.3)}$	0.72	607/478
090626.189	Band	$0.0440 \pm 0.0014$	$160^{(+8)}_{(-7)}$	...	$-1.04 \pm 0.03$	$-2.30^{(+0.05)}_{(-0.06)}$	0.74	353/240

**Note.** <sup>a</sup> The time range values are given in  $s$  relative to the trigger time  $T_0$ . They represent the interval used for the time-integrated spectral analysis.

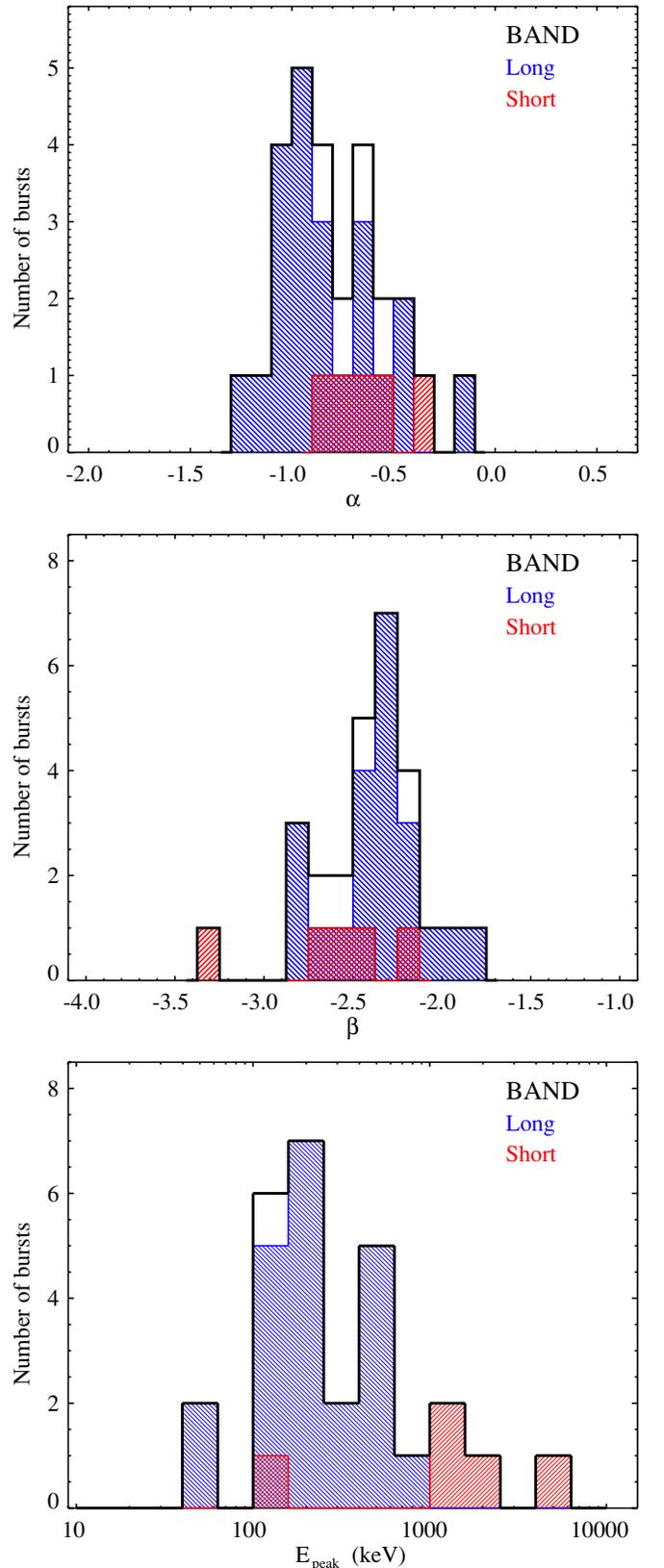


**Figure 6.** Index  $\lambda$  (top panel) and  $E_{\text{peak}}$  (bottom panel) distribution of the time-integrated spectra which are best fitted with the *Comp* model. Blue and red histograms represent the distributions of long and short GRBs, respectively. (A color version of this figure is available in the online journal.)

13 short bursts. The *Comp*  $E_{\text{peak}}$  distribution of the total sample peaks at  $\sim 800$  keV, while the *Band*  $E_{\text{peak}}$  is much lower, around 200 keV. Below we compare our results with those of K06.

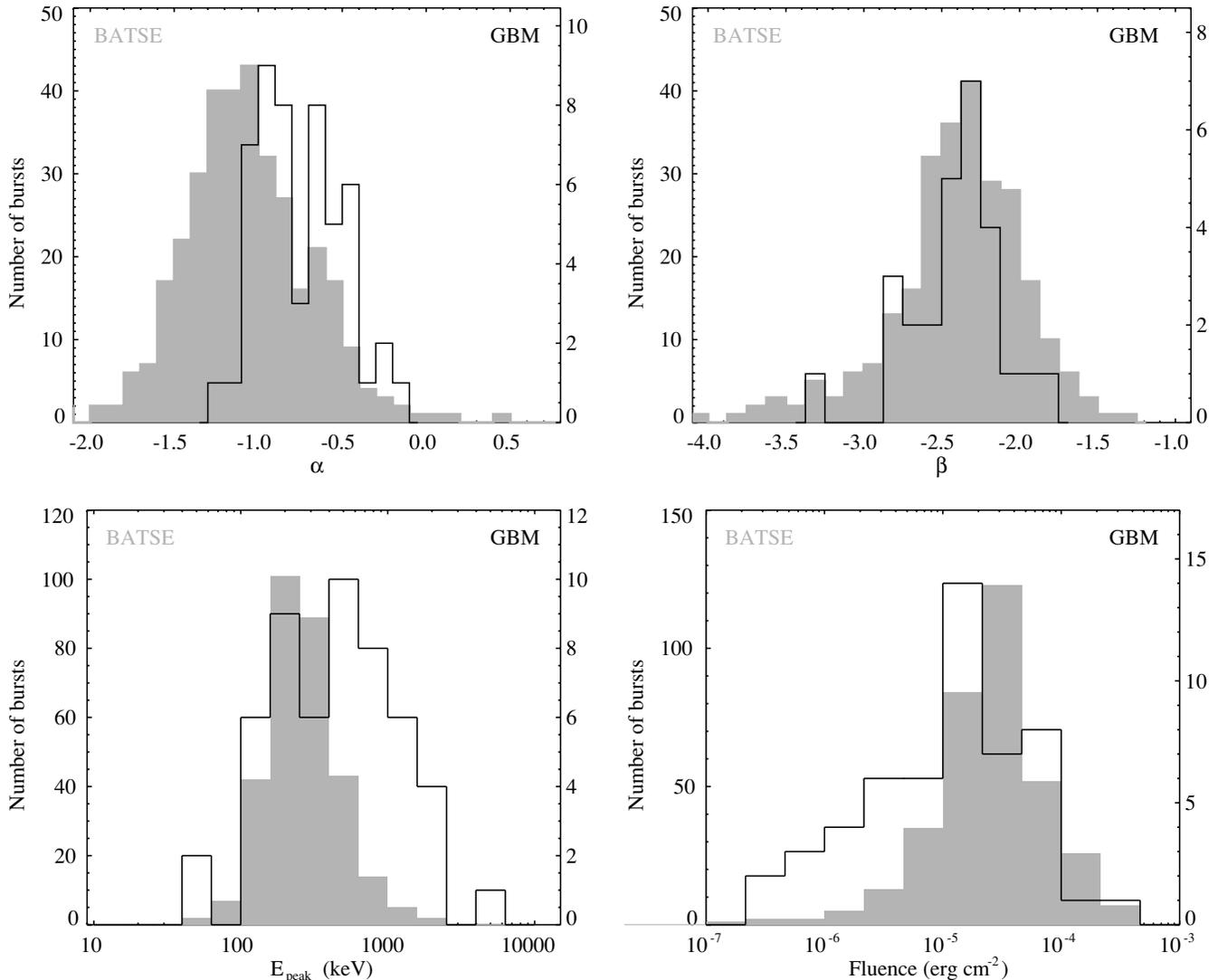
### 5.2. Comparison to the BATSE Bright Burst Catalog

We compare the spectral parameter distributions of our 52 bright GBM bursts with the distributions of bursts from the BEST<sup>12</sup> sample of K06. Our sample is much smaller than the one recently used by Nava et al. (2011), which comprises the entire GBM GRB database. The K06 spectral catalog comprises 350 bright GRBs observed with BATSE ( $\sim 20$  keV–2 MeV) and is the most comprehensive study of spectral properties of GRB prompt emission to date, thus representing a perfect sample for comparing with GBM burst properties. Comparison histograms of GBM and BATSE low-energy ( $\alpha$ ), high-energy ( $\beta$ ), and  $E_{\text{peak}}$  spectral parameter distributions are shown in Figure 8. The GBM distributions (black empty histograms) are overlapped



**Figure 7.** Low-energy index  $\alpha$ , high-energy index  $\beta$  (top panels), and  $E_{\text{peak}}$  (bottom panel) distribution of the time-integrated spectra best fitted with the *Band* function. Blue and red histograms represent the distributions of long and short GRBs, respectively. (A color version of this figure is available in the online journal.)

<sup>12</sup> Kaneko et al. (2006) designated the model with the more constrained parameters as the best-fit (BEST) model.



**Figure 8.** Low-energy index  $\alpha$  (top left panel), high-energy index  $\beta$  (bottom left panel),  $E_{\text{peak}}$  (top right panel), and energy fluence (bottom right panel) distributions of time-integrated spectra from 350 bright BATSE bursts (gray filled histogram) from K06 (BEST sample) and 52 bright GBM bursts (black histogram). The GBM energy fluence is computed in the standard BATSE energy range, namely between 25 and 2000 keV. The GBM parameter distributions follow the right y-axis.

on the BATSE ones (gray filled histograms). The former follow the right y-axis and are rescaled for comparison purposes.

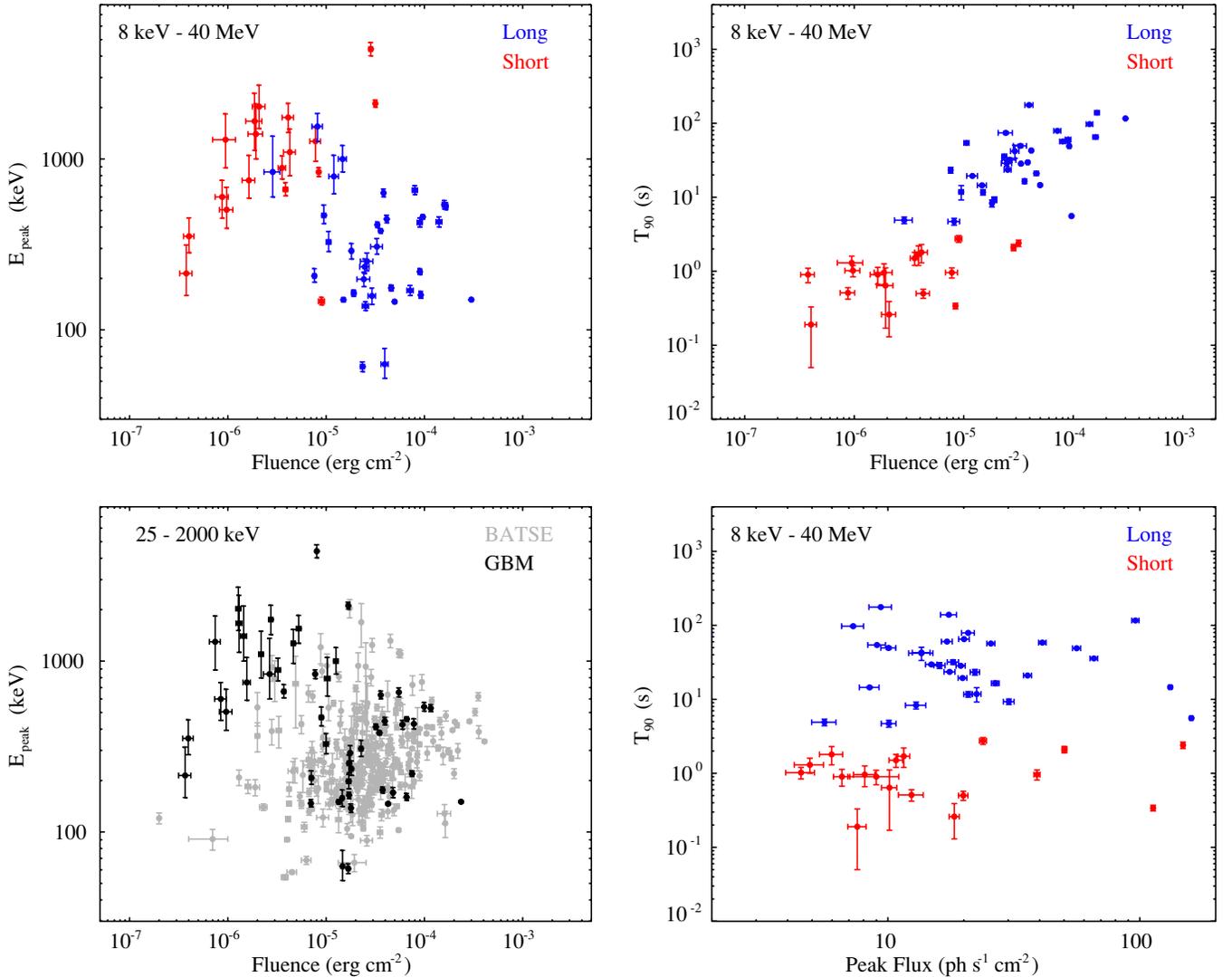
While the two  $\beta$  distributions look similar, differences appear in the  $\alpha$  and  $E_{\text{peak}}$  distributions. After one year of operations, GBM detected a sample of bright bursts which tend to have larger  $\alpha$  and higher  $E_{\text{peak}}$  values than what was observed in 10 years with the BATSE instrument. Note however that Lloyd & Petrosian (1999) made a prediction that there may exist a significant number of high- $E_{\text{peak}}$  bursts that were not detected by BATSE.

The energy fluence distribution for both samples is calculated in the (BATSE) energy range of 25–2000 keV and is also shown in the bottom right panel of Figure 8. It becomes immediately evident that the two samples were selected following different criteria. The K06 sample comprises more GRBs with higher fluence than the GBM sample. This difference is even more clearly demonstrated in Figure 9, where we plot the GBM burst  $T_{90}$  durations versus their fluences (top right panel) and peak fluxes (calculated over 128 ms, bottom right panel) between 8 keV and 40 MeV. A comparison of the two panels shows that a high-fluence criterion would have included by far less short

GRBs in our sample, as their total energies are much smaller than those of the long events, while their peak fluxes span a broader range. With 18 short GRBs out of 52 selected bright bursts ( $\sim 30\%$ ), the first year of GBM sample contains many more bright short and hard bursts than K06. In fact, only 17 out of 350 BATSE bright bursts are short, representing  $\sim 5\%$  of the sample. We conclude that the reason for this discrepancy is indeed the different selection criteria implemented in the K06 catalog—flux and fluence cutoff—while we are only selecting on peak count rates and hardness. In fact, the GBM short/long GRB ratio is approximately the same as for BATSE (about 20%). The main advantage we exploit here is the wider energy coverage (above 1 MeV) provided by the BGO, which allows us to further explore in detail the high-energy part of short GRBs.

### 5.3. Correlation Among Spectral Parameters—Empirical Relations

Empirical correlations among spectral parameters have been previously found with smaller GRB samples either within individual bursts or for collections of time-resolved parameters of multiple events. K06 found no indication of global correlations



**Figure 9.** Left panels: distribution of  $E_{\text{peak}}$  vs. energy fluence calculated over the entire GBM energy range (top left panel, 8 keV–40 MeV) and over the BATSE energy range (bottom left panel, 25–2000 keV). Blue and red data points represent long and short GRBs, respectively; Gray data points represent 350 GRBs from the K06 sample. Right panels: distribution of  $T_{90}$  (50–300 keV) vs. energy fluence (8 keV–40 MeV, top right panel) and vs. 128 ms peak photon fluxes (8 keV–40 MeV, bottom right panel).

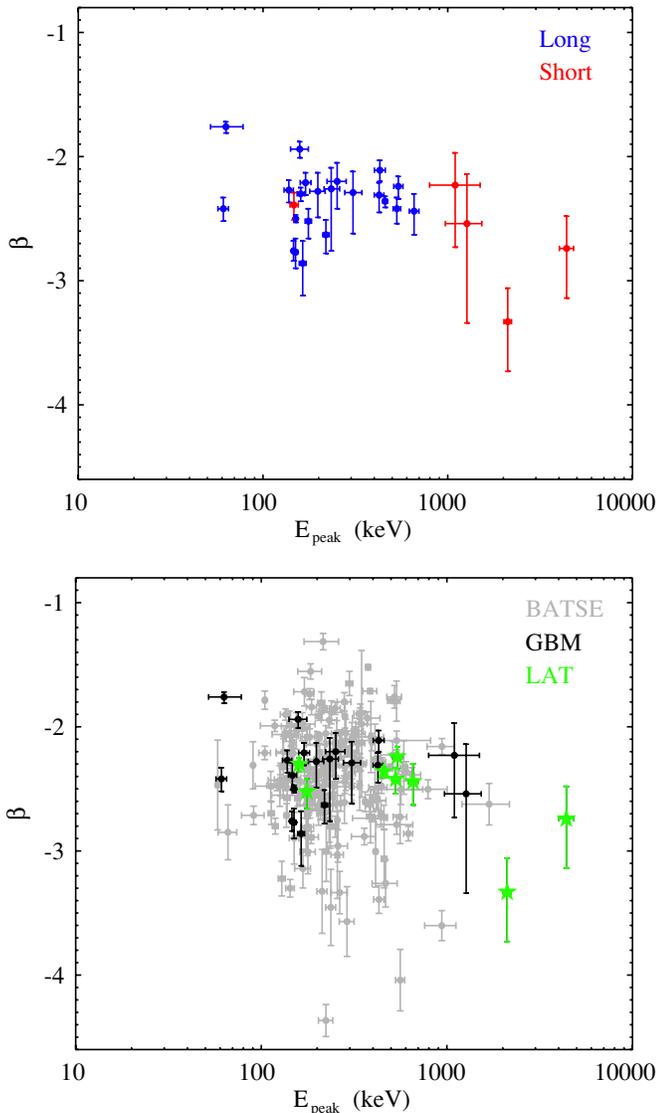
(A color version of this figure is available in the online journal.)

among the time-integrated spectral parameters of their BEST sample (discussed in Section 5.2), while they found strong correlations among the time-resolved spectral parameters. They also noted that it is best to look for parameter correlations within individual bursts to eliminate possible effects due to cosmological redshift that varies from burst to burst. Since no time-resolved spectral analysis was performed in this work, we limit our correlation analysis to comparisons of the low- and high-energy spectral parameters against  $E_{\text{peak}}$  values and against each other.

Figure 10 shows the scatter plot of the *Band* function high-energy index  $\beta$  versus  $E_{\text{peak}}$  for the GBM data alone (top panel), and for the combined data sets of GBM and BATSE (bottom panel). The most distinct differences between the two samples is the larger  $E_{\text{peak}}$  span of the GBM data, and the larger  $\beta$  spread of the BATSE data. The reasons for the former have been elaborated in Section 5.2; the latter is the effect again of the K06 selection for fluence and not for hardness (as in the GBM sample) and constitutes, therefore, a more representative

characteristic of the GRB population as a whole. The GBM subsample of the bright, hard events, also includes—not quite unexpectedly—the majority of the LAT GRBs, and falls well within the BATSE  $\beta$  range (see also Ghisellini et al. 2010; Guetta et al. 2011).

Figure 9 displays the  $E_{\text{peak}}$  and  $T_{90}$  distributions against energy fluences and peak fluxes measured over the entire GBM energy band, i.e., 8 keV–40 MeV.  $E_{\text{peak}}$  is plotted against fluences for short and long GBM GRBs (red and blue data points, top left panel) and for GBM and BATSE bright GRBs (black and gray data points, bottom left panel). Short, low-fluence bursts show higher  $E_{\text{peak}}$  values, while long, high-fluence bursts tend to have lower  $E_{\text{peak}}$  values. The distribution of  $T_{90}$  measured in the standard BATSE energy range of 50–300 keV versus energy fluence in the GBM 8 keV–40 MeV band is shown in the top right panel of Figure 9. This panel clearly exhibits the trend already shown with the *Swift* data that short bursts have lower fluences than longer ones and that high fluences unambiguously correspond to longer durations (Pizzichini et al. 2009). The

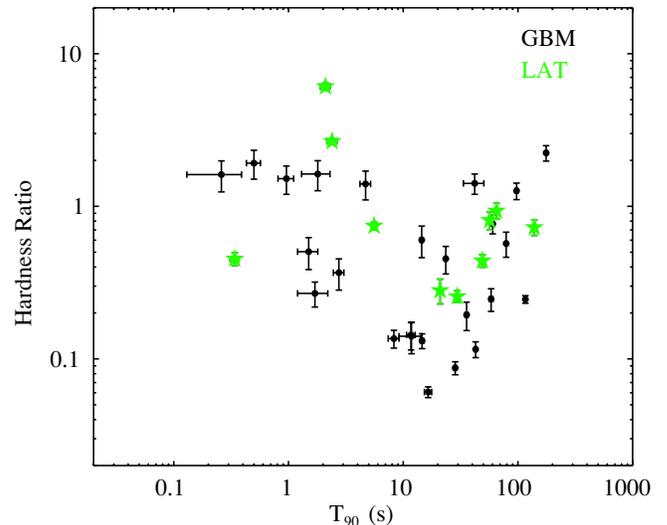


**Figure 10.** Scatter plot of the GBM spectral parameter pair  $E_{\text{peak}}-\beta$  for 22 long GRBs and 5 short GRBs (blue and red data points in the top panel). Gray data points in the bottom panel represent 350 GRBs from the K06 sample. Bursts fully or marginally detected by the LAT are marked with green stars. (A color version of this figure is available in the online journal.)

lower right panel exhibits that both long and short GRBs have a similar (broad) peak flux range.

Finally, we plot in Figure 11 the distribution of hardness ratios versus  $T_{90}$ . The hardness ratios are defined by the ratio of counts collected in the BGO energy range over those collected in the NaI energy range (1000–40000/8–1000, in keV units). Although the current sample is not very large, it allows us to distinguish that shorter bursts in general tend to have harder spectra than the long ones.

Amati et al. (2002) reported a relation of  $E_{\text{iso}}$  versus  $E_{\text{peak}}$  using the BATSE data set. However, Nakar & Piran (2005) and Band & Preece (2005) showed that their results may have suffered from strong selection effects and were inconsistent with a larger set of GRB data obtained with BATSE. We tested here the Amati relation for those bursts included in the BGO-bright burst sample with a redshift measurement. We only had seven cases, namely six long GRBs (GRB 080916C,  $z = 4.35$ , Greiner et al. 2009; GRB 090102,  $z = 1.55$ , de Ugarte Postigo



**Figure 11.** Distribution of hardness ratios vs.  $T_{90}$  (50–300 keV). The hardness ratios are defined as the ratio of counts collected between 1 and 40 MeV over those collected between 8 and 1000 keV. Bursts fully or marginally detected by the LAT are marked with green stars. (A color version of this figure is available in the online journal.)

et al. 2009; GRB 090323,  $z = 3.57$ , Chornock et al. 2009a; GRB 090328,  $z = 0.74$ , Cenko et al. 2009a; GRB 090424,  $z = 0.54$ , Chornock et al. 2009b; GRB 090618,  $z = 0.54$ , Cenko et al. 2009b) and one short burst (GRB 090510,  $z = 0.90$ ; Rau et al. 2009). We note that long bursts nicely follow the  $E_{\text{peak}}-E_{\text{iso}}$  relation, as was also recently pointed out by Amati (2010), and the only outlier is the short burst. A recent study by Goldstein et al. (2011) explores the Amati relationship in detail using the entire GBM data set.

## 6. CONCLUSIONS

We have studied here a sample of 52 bright and hard GRBs collected during the first year of the GBM operation. We have performed temporal and time-integrated spectral analysis of all these events and studied the distributions and evolution of the derived parameters. The new spectral capabilities afforded by the GBM BGO detectors have enabled us to produce a predicting filter using GBM data alone of potential GRB detections with the LAT on *Fermi*. This filter will be implemented in the GBM FSW and alerts will be distributed to the wide scientific community to allow timely multi-wavelength follow-up observations and thus, broadband spectral energy distribution studies in GRBs.

Our temporal evolution analysis has, for the first time, extended the duration–energy relationship (found earlier in the BATSE data) to the MeV energy range. Although the LAT GeV detections seem to be longer in some GRBs (even up to hundreds of seconds, as in the case of GRB 090323 and GRB 090328; see Ohno et al. 2009 and Cutini et al. 2009), there seems to be a single power-law relation (of index  $-0.4$ ) between duration and energy in the keV to MeV prompt gamma-ray emission. Whether the GeV emission seen with the LAT in several of these GRBs is related to the prompt or the afterglow emission is still an open question, which requires more data for definite conclusions. We confirm that their spectral parameter distributions are overall similar to those of the K06 sample, and that short GRBs are in general harder than longer events. The small subsample of GRBs with known distances in our data

is not sufficient to test the various empirical relations in the literature.

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