THE FIRST SWIFT BAT GAMMA-RAY BURST CATALOG

T. Sakamoto,1,2 S. D. Barthelmy,3,4 L. Barbier,1 J. R. Cummings,3,4 E. E. Fenimore,5 N. Gehrels,1 D. Hullinger,2 H. A. Krimm,5,6 C. B. Markwardt,5,6 D. M. Palmer,5 A. M. Parsons,1 G. Sato,1,9 M. Stamatikos,1,2 J. Tueller,1 T. N. Ukwatta,1,10 and B. Zhang11

Received 2007 July 30; accepted 2007 September 4

ABSTRACT

We present the first Swift Burst Alert Telescope (BAT) catalog of gamma-ray bursts (GRBs), which contains bursts detected by the BAT between 2004 December 19 and 2007 June 16. This catalog (hereafter the BAT1 catalog) contains burst trigger time, location, 90% error radius, duration, fluence, peak flux, and time-averaged spectral parameters for each of 237 GRBs, as measured by the BAT. The BAT-determined position reported here is within 1.75′ of the Swift X-Ray Telescope (XRT; Burrows et al. 2005a) or the Swift UV/Optical Telescope (UVOT; Roming et al. 2005) within a few hundred seconds after the trigger. Swift opens a new opportunity to study the host galaxies and the distance scale of the mysterious short-duration GRBs (e.g., Gehrels et al. 2005; Barthelmy et al. 2005b). Swift allows us to use GRBs as a tool for investigation of the early universe (see detection of GRB 050904 at a redshift of 6.29; 2006). Furthermore, which is securely associated with a supernova (Campana et al. 2006) that give us insight into details of the fireball model and to the nature of the central engine.

Subject headings: gamma rays: bursts

Online material: color figures, machine-readable tables

1. INTRODUCTION

The Swift mission (Gehrels et al. 2004) has revolutionized our understanding of gamma-ray bursts (GRBs). Because of the sophisticated on-board localization capability of the Swift Burst Alert Telescope (BAT; Barthelmy et al. 2005a) and the fast spacecraft pointing of Swift, more than 90% (30%) of Swift GRBs have an X-ray (optical) afterglow observation from the Swift X-Ray Telescope (XRT; Burrows et al. 2005a) or the Swift UV/Optical Telescope (UVOT; Roming et al. 2005) within a few seconds after the trigger. Swift opens a new opportunity to study the host galaxies and the distance scale of the mysterious short-duration GRBs (e.g., Gehrels et al. 2005; Barthelmy et al. 2005b). Swift allows us to use GRBs as a tool for investigation of the early universe (see detection of GRB 050904 at a redshift of 6.29; Cusumano et al. 2006). Swift found the fourth GRB, GRB 060218, which is securely associated with a supernova (Campana et al. 2006). Furthermore, Swift is providing X-ray afterglow data (e.g., Zhang et al. 2006) that give us insight into details of the fireball model and to the nature of the central engine.

Here we present the first BAT GRB catalog, including 237 GRBs detected by BAT from 2004 December 19 to 2007 June 16. In § 2, we describe the BAT instrument. In § 3, we show the current status of the on-orbit calibration of the BAT based on the Crab observations. In § 4, we describe the analysis methods for the catalog. In § 5, we describe the content of the tables of the catalog and show the results of the prompt emission properties of the BAT GRBs based on the catalog. Our conclusions are summarized in § 6. All quoted errors in this work are at the 90% confidence level.

2. INSTRUMENTATION

The BAT is a highly sensitive, large field of view (FOV) (1.4 sr for >50% coded FOV and 2.2 sr for >10% coded FOV), coded-aperture telescope that detects and localizes GRBs in real time. The fast and accurate BAT GRB positions with 1′–3′ error radii are the key to autonomously slewing the spacecraft to point the XRT and the UVOT. The BAT GRB position, light curves, and the detector plane image (BAT scaled map) are transmitted through TDRSS to the ground within 20–200 s after the burst trigger. The BAT detector plane is composed of 32,768 pieces of CdZnTe (CZT: 4 × 4 × 2 mm), and the coded-aperture mask is composed of ~52,000 lead tiles (5 × 5 × 1 mm) with a 1 m separation between mask and detector plane. The energy range is 15–150 keV for imaging or mask-weighting13 with a noncoded response up to 350 keV.

The CZT pixels are biased to −200 V with a nominal operating temperature of 20°C. The energy scale calibration is performed automatically on the front-end electronics (XA1) by injecting calibration pulses. This electronic calibration task is executed every ~5000 s during spacecraft slews. In addition to the electronic calibration, there are two 241Am tagged sources mounted below the mask for calibrating the absolute energy scale and the detector efficiency for each CZT pixel in-flight.

13 Mask-weighting is a background-subtraction technique based on the modulation resulting from the coded mask.
There are three types of triggers in the BAT flight software. Two of these are rate triggers looking for excesses in the count rate from the background, and one is an image trigger based on new significant sources found in the sky images. The rate triggers are divided into short-rate (foreground period ≤ 64 ms) and long-rate triggers (foreground period ≥ 64 ms). Each trigger criterion is a specific combination of choices of foreground interval, number of background samples, energy band, and one of nine different regions of the detector plane. Currently, 494 trigger criteria have been running on-board for a long-rate trigger, 36 for the short-rate trigger, and 1 for the image trigger. Once a rate trigger has occurred, the BAT creates a sky image using the triggered foreground and background intervals in the specified energy band to find a significant source in the image. Failing to produce a significant image excess, the BAT will check for trigger criteria that produce a more statistically significant image. When a rate or image trigger finds a significant source in the image, a location match to the on-board source catalog is executed to exclude activity from known hard X-ray astronomical sources.

For each GRB trigger, the photon-by-photon data (event data) are available with a time resolution of 100 μs. The duration of the event data was primarily from T = 300 s to T + 300 s (T is the BAT trigger time). After 2006 March 17, we have extended the duration of the event data that are downlinked to from T − 300 s to T + 1000 s. We also transmit 10 s of the event data for failed triggers. In the survey mode, the BAT produces detector plane histograms (DPHs). These histograms have an 80 channel spectrum for each detector integrated typically over 5 minutes. The DPHs are the primary data product when the GRB prompt emission lasts longer than the stop time of the event data collection (e.g., GRB 060124; Romano et al. 2006).

3. ON-ORBIT CALIBRATION

The Crab nebula data collected for various positions in the BAT field of view were used for the on-orbit calibration. We analyzed the DPH data for this purpose. The standard BAT software (HEASoft 6.2) and the latest calibration database (CALDB: 20061014) were used for processing the data. We first made the Good Time Interval (GTI) file for each observation segment (each observation ID) excluding the periods when (1) the spacecraft was not settled, (2) the spacecraft was in the South Atlantic Anomaly (SAA), and (3) the Crab was occulted by the Earth, Moon, and/or Sun. The batoccultgti software was used for excluding the time periods for case 3. The batmerge software was applied to the DPH data to correct the energy scale.

A Detector Plane Image (DPI) file was created from the DPH using batbinevt for each individual row. The spacecraft attitude file was recreated using foals aspect by specifying the observation start and stop time of the DPI. The detector enable/disable map was created using batphotpix. The BAT sky image was created by batftimage using the DPI, the updated attitude file and the enable/disable map. The batcelldetect software was used to extract the position of the Crab. The mass weight map of the Crab was created by batmasking using the “true” Crab position from SIMBAD [R.A.(J2000.0) = 83.6332°, decl(J2000.0) = 22.0144°]. The spectrum (PHA file) was created by batbinevt using the mask weight map for each row of the DPH. All of the individual PHA files at the same sky coordinate were added to create a single PHA file if the Crab was detected >8σ in the image in the full energy band (15−350 keV). The detector energy response file was created by batdrmgen for each summed PHA file.

3.1. Position Accuracy

The histograms of the angular differences between the Crab detected position by batcelldetect and the “true” Crab position (the Crab position in SIMBAD) are shown in the top of Figure 1. The position differences are less than 1° for 95% of the Crab observations in both the right ascension (R.A.) and the declination (decl.). The bottom of Figure 1 shows the BAT position errors as a function of signal-to-noise ratio for the Crab. The signal-to-noise ratio and the position error are correlated with a power-law index of −0.7 (see § 5).

3.2. Energy Response

Immediately after the first attempt to fit the Crab spectrum with the prelaunch detector energy response matrices (DRM), we noticed that there were systematic errors in the prelaunch DRM at low energies (below 25 keV) and also at high energies (above 80 keV). The investigation of these problems is still in progress. To overcome these problems, we applied corrections to force the Crab to fit a canonical model, a power law with a photon index of 2.15 and a 15−150 keV energy flux of 2.11 × 10−8 erg s cm−2 s−1 (e.g., Jung 1989; Rothschild et al. 1998; Fiore et al. 1999; Olive et al. 2003; Lubiński et al. 2005). Due to these corrections, the BAT team has released the software tool, batphasyserr, and the CALDB file (swbysyserr20030101v002.fits) to apply the energy dependent systematic errors to the PHA file. The systematic errors that should be applied to the PHA file are shown in Figure 2. The Crab spectra were fitted by a simple power-law model using Xspec 11.3.2 including the systematic errors.

Figure 3 shows the Crab photon index and the flux in the 15−150 keV band as a function of the incident angle. In the current BAT DRM (batdrmgen v3.3 and CALDB: 20061014), the scatter of the photon index and the flux are about 5% and 10% of the canonical values. Figure 4 shows the contour maps of the Crab photon index and the flux in the 15−150 keV band over the BAT field of view. We note that the parameters tend to deviate from the canonical values toward the edge of the BAT field of view. Thus, the spectral parameters could have a larger systematic error when the source is at the edge of the field of view of BAT.

3.3. BAT GRB Response Time

Figure 5 shows the histogram of the time delay between the BAT GRB trigger time and the GCN BAT Position Notice. The highest peak of the distribution is around 15 s. The BAT position has been reported on the ground within 30 s after the burst trigger for half of the BAT GRBs. Most of the longer delays (>300 s) are due to interruptions in TDRSS transmissions during regular telemetry down links to the Malindi ground station.

4. ANALYSIS FOR THE GRB CATALOG

We used the standard BAT software (HEASoft 6.1.1) and the latest calibration database (CALDB: 20061014) to process the BAT GRBs from 2004 December (GRB 041217) to 2007 June (GRB 070616). The burst pipeline script, batgrbproduct,
Fig. 1.—Top: Difference in R.A. (top) and decl. (bottom) between the BAT detected (>8σ) and the SIMBAD ("true") Crab position. The dotted line is the best-fit Gaussian model. The centroid and sigma of the best fit Gaussian are −0.07" and 0.33" for R.A., and 0.08" and 0.27" for decl., respectively. **Bottom:** BAT position errors as a function of signal-to-noise ratio for the Crab. The dashed line is the position error ∝ SNR−0.7. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 2.—Systematic error as a function of energy. The systematic error vectors must be applied to the BAT spectral file created by the BAT software, HEASoft 6.2 and CALDB: 20061014, due to the current uncertainty in the energy calibration.

Fig. 3.—Power-law photon index (top) and the flux in the 15–150 keV band as a function of the incident angle (θ) of the Crab observed 2004 December–2005 April (black), 2005 November, and 2005 August. The horizontal dashed lines are the Crab canonical values of −2.15 for the photon index and 2.11 × 10−9 ergs cm−2 s−1 for the flux. The dashed dotted lines are ±5% of the photon index and ±10% of the flux canonical values. [See the electronic edition of the Supplement for a color version of this figure.]
was used to process the BAT event data. The Xspec spectral fitting tool (version 11.3.1) was used to fit each spectrum. Since our analysis is restricted to use only the event data, we present partial analysis based on the available event data for bursts that last longer than the end period of the event data (e.g., GRB 060124) or that have incomplete event data for various reasons (e.g., GRB 050507). In some cases, especially for weak short GRBs, battblocks, which is one of the tasks run in batgrbproduct, might fail to find the burst interval. In those cases, we fitted the mask-weighted light curve in the full BAT energy range by a liner-rise exponential decay model ("BURS" model in ftools qdp20) to find the burst time intervals (\(T_{100}, T_{90}, T_{50}\), and peak 1 s intervals) and created the \(T_{100}\) and peak 1 s PHA files based on these time intervals. We put

Fig. 4.—Contour maps (sparsely sampled) of the Crab photon index (top) and the flux in the 15–150 keV band in units of \(10^{-8}\) ergs cm\(^{-2}\) s\(^{-1}\) (bottom) in the BAT field of view in tangent plane coordinates (IMX and IMY). [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 5.—Time delay from the BAT trigger time to the GCN BAT Position Notice (the BAT burst sample from GRB 050215A to GRB 070616 excluding the GRBs found in ground processing).
comments on Table 1 for the bursts that have a problem in either the data or the processing.

For the time-averaged spectral analysis, we use the time interval from the emission start time to the emission end time ($T_{100}$ interval). Since the BAT energy response generator, batdrmgen, performs the calculation for a fixed single incident angle of the source, it will be a problem if the position of the source is moving during the time interval selected for the spectral analysis because of the spacecraft slew. In this situation, we created the DRMs for each 5 s period during the time interval taking into account the position of the GRB in detector coordinates. We then weighted these DRMs by the 5 s count rates and created the averaged DRM using addrmf. Since the spacecraft slewed about $1^\circ$ s$^{-1}$ in response to a GRB trigger, we chose 5 s intervals to calculate the DRM for every $5^\circ$.

The spectrum was fitted by a simple power-law (PL) model,

$$f(E) = K_{50}^{PL} \left(\frac{E}{50 \text{ keV}}\right)^{\alpha_{PL}},$$

(1)

where $\alpha_{PL}$ is the power-law photon index and $K_{50}^{PL}$ is the normalization at 50 keV in units of photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$, and by a cutoff power-law (CPL) model,

$$f(E) = K_{50}^{CPL} \left(\frac{E}{50 \text{ keV}}\right)^{\alpha_{CPL}} \exp\left[-\frac{E}{E_{\text{peak}}^{CPL}}\right],$$

(2)

where $\alpha_{CPL}$ is the power-law photon index, $E_{\text{peak}}$ is the peak energy in the $\nu F_{\nu}$ spectrum, and $K_{50}^{CPL}$ is the normalization at 50 keV in units of photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$. We also systematically fitted the spectrum with the Band function (Band et al. 1993). However, none of the BAT spectra show a significant improvement in $\chi^2$ with a Band function fit compared to that of a CPL model fit. Note that this is equivalent to saying that a CPL model and a Band function represent equally well the observed spectrum. However, we only present the results based on a CPL model throughout the paper due to its simplicity in the functional form. The best-fit spectral model is determined based on the difference in $\chi^2$ between a PL and a CPL fit. If $\chi^2_{\text{PL}}$ is greater than 6 ($\Delta \chi^2 = \chi^2_{\text{PL}} - \chi^2_{\text{CPL}} > 6$), we determined that a CPL model is a better representative spectral model for the data. To quantify the significance of this improvement, we performed 10,000 spectral simulations taking into account the distributions of the power-law photon index in a PL fit, the fluence in the 15–150 keV band in a PL fit, and the $T_{100}$ duration of the BAT GRBs, and we determined in how many cases a CPL fit gives $\chi^2$ improvements of equal or greater than 6 over a PL fit. The BAT DRM used in the simulation was for an incident angle of 30$^\circ$, which was an averaged incident angle of the BAT GRB sample (see Fig. 7). We found equal or higher improvements in $\chi^2$ in 62 simulated spectra out of 10,000. Thus, the chance probability of having an equal or higher $\chi^2$ of 6 with a CPL model when the parent distribution is a case of a PL model is 0.62%.

The fluence and the peak flux are derived from the spectral fits. The fluences are calculated fitting the time-averaged spectrum by the best-fit spectral model. The peak fluxes are calculated fitting the spectrum of the 1 s interval bracketing the highest peak in the light curve (hereafter the peak spectrum). Again, we used the best-fit spectral model for calculating the peak fluxes. To correctly reflect the incident angle of the source during the period of the peak spectrum, the DRM for the peak spectrum was created updating the keywords of the peak spectrum file by batupdatephakw and running batdrmgen using this updated spectral file.

5. THE CATALOG

The first BAT catalog includes the time period between 2004 December 19 and 2007 June 16. The total number of GRBs including five untriggered GRBs and four possible GRBs is 237. 237 GRBs are listed in Table 1. The first column is the GRB name. The next column is the BAT trigger number. The next column specifies the BAT trigger time in UTC in the form of YYYY-MM-DD hh:mm:ss, where YYYY is year, MM is month, DD is day of month, hh is hour, mm is minute, and ss is second. Note that the definition of the BAT trigger time is the start time of the foreground time interval of the image from which the GRB is detected on board.

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\footnote{A Band function has four parameters, whereas a CPL model has three parameters.}

\footnote{GRBs that were found in ground processing.}

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### TABLE 1

**BAT GRB SUMMARY**

| GRB Name          | Trigger Number | Trigger Time | R.A. (deg) | Decl. (deg) | $\text{SN}_\text{avg}$ ($\sigma$) | Error (arcmin) | $T_{00}$ (s) | $T_{50}$ (s) | Start (s) | Stop (s) | Comment |
|-------------------|----------------|--------------|------------|------------|-------------------------------|---------------|-------------|-------------|-----------|----------|---------|
| 041217.............| 100116         | 2004 Dec 17 07:28:25.236 | 164.793 | -17.942 | 20.4 | 1.3 | 5.8 | 2.7 | -2.2 | 17.8 | No data$^a$ |
| 041219A............| 100318         | 2004 Dec 19 01:42:18.000 | 6.154   | 62.847   | ... | 7.0 | ... | ... | ... | ... | No data$^a$ |
| 041219B............| 100367         | 2004 Dec 19 15:38:48.000 | 167.674 | -33.458 | ... | 7.0 | ... | ... | ... | ... | No data$^a$ |
| 041220.............| 100380         | 2004 Dec 19 20:30:34.000 | 343.926 | -76.744 | 34.2 | 1.0 | 4.8 | 1.4 | -3.0 | 17.1 | No data$^a$ |
| 041220.............| 100433         | 2004 Dec 20 22:58:26.599 | 291.288 | 60.598  | 33.8 | 1.0 | 5.6 | 2.2 | -299.9 | 302.1 |
| 041223.............| 100585         | 2004 Dec 23 14:06:17.956 | 100.204 | -37.068 | 87.5 | 1.0 | 109.1 | 29.3 | -299.3 | 302.8 |
| 041224.............| 100703         | 2004 Dec 24 20:57:69.956 | 56.192  | -6.663  | 11.3 | 2.0 | 177.2 | 37.5 | -299.0 | 303.0 |
| 041226.............| 100815         | 2004 Dec 26 20:34:18.976 | 79.689  | 73.329  | 6.2 | 3.0 | 89.7 | 52.8 | -299.3 | 302.7 |
| 041228.............| 100970         | 2004 Dec 28 10:49:14.142 | 336.642 | 5.032   | 37.7 | 1.0 | 55.4 | 19.8 | -299.5 | 302.6 |

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\*Note: — Table 1 is available in its entirety in the electronic edition of the Supplement. A portion is shown here for guidance regarding its form and content.\*
The next four columns give the locations by the ground process in equatorial (J2000.0) coordinates, the signal-to-noise ratio of the BAT image at the location, and the radius of the 90% confidence region in arcmin. The 90% error radius is calculated based on the signal-to-noise ratio of the image using the following equation, which is derived from the BAT hard X-ray survey process.

\[ r_{90\%} = 10.92 \times \text{SNR}^{-0.7} \text{ (arcmin)} \]

where SNR is the signal-to-noise ratio of the BAT image. However, due to the limitation of the BAT point-spread function, we decided to quote the minimum allowed value of \( r_{90\%} \) as 1’ in the catalog. The next two columns specify the burst durations that contain from 5% to 95% \((T_{90})\) and from 25% to 75% \((T_{50})\) of the total burst fluence. These durations are calculated in the 15–350 keV band.

The next two columns are the start and stop time from the BAT trigger time that the BAT trigger time that were used to calculate the fluences. Note that since our analysis is based on the available event data, 6 bursts with the incomplete data (see the twelfth column of Table 1) might not include the whole burst emission.

Table 3 and 4 summarize the 1 s peak photon and energy fluxes in various energy bands. The first column is the GRB name. The next column specifies the spectral model used in deriving the 1 s peak flux. The next five columns are the 1 s peak photon and energy fluxes in the 15–25, 25–50, 50–100, 100–150, and 15–150 keV bands. The unit of the fluence is \(10^{-8} \text{ erg cm}^{-2} \). The last two columns specify the start and the stop time from the BAT trigger time that were used to calculate the peak fluxes. The time-averaged spectral parameters are listed in Table 5. The first column is the GRB name. The next three columns are the photon index, the normalization at 50 keV, and \( \chi^2 \) of the fit for a PL model. The degree of freedom is 57 for all bursts in a PL fit. The next four columns are the photon index, \( E_{\text{peak}} \), the normalization at 50 keV, and \( \chi^2 \) of the fit in a CPL model. The degree of freedom is 56 for all bursts for a CPL fit. The spectral parameters in a CPL are only shown for the bursts that meet the criteria described in the §4.
In the following subsections of investigating the relationship among fluences, peak fluxes, and the spectral parameters, we excluded 10 GRBs based on an incomplete data set and also those labeled as possible GRBs/SGRs (see the twelfth column of Table 1).

5.1. BAT GRB Position and Sky Locations

Figure 6 shows the angular difference between the BAT ground position and the first reported XRT position. The BAT ground position is within 0.95° and 1.75° from the XRT position for 68% and 90% of the bursts, respectively. The distribution of the incident angles (θ) is shown in Figure 7. The θ distribution is peaked around 30° with a spread from 0° to 60°. The sky map of the BAT 237 GRBs in galactic coordinates is shown in Figure 8.

5.2. Durations and Hardness

The histograms of T_{90} and T_{50} measured by the mask-weighted light curve in the BAT full energy band are shown in Figure 9. The BAT T_{90} and T_{50} durations are peaked around 80 and 20 s, respectively. The BAT duration distributions do not show the clear bimodality seen in the BATSE sample (e.g., Kouveliotou et al. 1993) due to the smaller samples of short-duration bursts (hereafter short GRBs). This is a well-known selection effect for an imaging GRB instrument like the BAT. For most of the GRB imaging instruments, two triggering processes have to be met for a GRB trigger to be determined. The first step is the increase in the count rate from the background level, and the second step is the significant signal in the image. Although the short-duration bursts would have triggered as an excess in the count rate, it could be very difficult to meet the criterion for a significant signal in the image because of the smaller number of photons to do the imaging compared to those of the long duration bursts (hereafter long GRBs). However, because of the large effective area and also the sophisticated flight software, the BAT has been triggering and localizing short GRBs in a much higher fraction than other GRB imaging instruments (e.g., BeppoSAX, HETE-2).

Figure 10 shows the T_{50} and T_{90} durations versus the fluence ratio between the 50–100 keV and the 25–50 keV bands. Although the short GRBs tend to be systematically harder than the long GRBs, the separation in the hardness between these two classes is not obvious, at least in the BAT GRB sample. Note that there are several works that question the hardness of the BATSE short GRBs reported on the BATSE catalog (Sakamoto et al. 2006; Ohno et al. 2008; Donaghy et al. 2007). Therefore, as mentioned in Donaghy et al. (2007) and also seen in the BAT short GRB samples, the duration and the hardness are insufficient to resolve the long and short populations, since the two components have so much overlap.

5.3. Peak Fluxes and Fluences

Figure 11 shows the distribution of the fluence versus the peak photon flux in the 15–150 keV band. The positive correlation is

| BAT GRB 1 s Peak Energy Flux |
|-----------------------------|
| GRB NAME | SPECTRAL MODEL | F_{p,mc}^{(15−25)} (10^{-8} ergs cm^{-2} s^{-1}) | F_{p,mc}^{(25−50)} (10^{-8} ergs cm^{-2} s^{-1}) | F_{p,mc}^{(50−100)} (10^{-8} ergs cm^{-2} s^{-1}) | F_{p,mc}^{(100−150)} (10^{-8} ergs cm^{-2} s^{-1}) | START (s) | STOP (s) |
|-----------------------------|
| 041217.................. | PL | 6.5 ± 0.8 | 12.8 ± 1.0 | 19.4 ± 1.7 | 15.7 ± 2.1 | 54.4 ± 4.2 | +3.3 | +4.3 |
| 041219A.................. | PL | 2.9 ± 0.5 | 4.6 ± 0.5 | 5.4 ± 0.7 | 3.6 ± 0.7 | 16.6 ± 1.8 | +1.5 | +2.5 |
| 041219B.................. | PL | 1.6 ± 0.2 | 3.3 ± 0.3 | 5.4 ± 0.5 | 4.6 ± 0.7 | 15.0 ± 1.3 | -0.0 | +1.0 |
| 04121200.............. | PL | 4.6 ± 0.4 | 12.3 ± 0.7 | 26.9 ± 1.2 | 28.8 ± 2.1 | 72.6 ± 3.3 | +35.0 | +36.0 |
| 041224.................. | PL | 2.5 ± 0.5 | 5.4 ± 0.6 | 9.1 ± 1.0 | 8.0 ± 1.4 | 25.0 ± 2.6 | -0.1 | +0.9 |
| 041226.................. | PL | 0.3 ± 0.1 | 0.6 ± 0.2 | 1.1 ± 0.4 | 1.1 ± 0.5 | 3.1 ± 0.9 | +3.3 | +4.2 |
| 041228.................. | PL | 1.9 ± 0.5 | 3.0 ± 0.5 | 3.8 ± 0.8 | 2.6 ± 0.8 | 11.2 ± 1.8 | +22.0 | +23.0 |

Notes.—Table 4 is available in its entirety in the electronic edition of the Supplement. A portion is shown here for guidance regarding its form and content. Dagger (†) signifies that the signal-to-noise ratio of the peak spectrum is too low to perform a spectral fit.
seen in these two parameters (correlation coefficient of +0.912 in a 220 burst sample). The peak photon flux of about 70% of the BAT GRBs is less than 2 photons cm$^{-2}$ s$^{-1}$ in the 15–150 keV band. If we assume a GRB detector with a sensitivity of 1 photons cm$^{-2}$ s$^{-1}$ in the 50–300 keV band (trigger band of BATSE), the peak photon flux in the 15–150 keV band is 2.5 photons cm$^{-2}$ s$^{-1}$ assuming the Band function parameters of $\alpha = -1$, $\beta = -2.5$, and $E_{\text{peak}}^{\text{obs}} = 100$ keV. Thus, the majority of the BAT GRBs might be too weak to trigger a typical GRB detector, which is sensitive at $>50$ keV. This rough estimate is consistent with the observation that only 20%–30% of the BAT GRBs are simultaneously triggered successfully by the currently active GRB detectors such as Konus-Wind and Suzaku-WAM.

Figure 12 shows the fluence in the 15–50 keV band versus that in the 50–150 keV band. The dash-dotted line is the case of the Band function parameters of $\alpha = -1$, $\beta = -2.5$, and $E_{\text{peak}}^{\text{obs}} = 100$ keV. The dotted line is the case of the Band function parameters of $\alpha = -1$, $\beta = -2.5$, and $E_{\text{peak}}^{\text{obs}} = 30$ keV. With the assumption of the Band parameters of $\alpha = -1$ and $\beta = -2.5$, the fraction of the long GRBs ($T_{90} > 2$ s) with $E_{\text{peak}}^{\text{obs}} < 100$ keV can be estimated to be about 60% of the total long GRB samples. On the other hand, according to the BATSE spectral catalog (Kaneko et al. 2006), there are only 3% of the long BATSE GRBs with $E_{\text{peak}}^{\text{obs}} < 100$ keV. Therefore, the $E_{\text{peak}}^{\text{obs}}$ distribution of the BAT GRBs could be systematically lower than the BATSE $E_{\text{peak}}^{\text{obs}}$ distribution because of the relatively lower energy coverage of the BAT.\(^{27}\)

5.4. Time-averaged Spectral Parameters

The histogram of the photon index in a PL fit is shown in Figure 13. The photon index distribution has a single broad peak that is centered around $-1.6$. The peak value of the PL photon index of $-1.6$ is close to the mean value of the low-energy photon index of $-1.0$ and the high-energy photon index of $-2.5$ of the typical GRB spectrum (Kaneko et al. 2006; Sakamoto et al. 2005). Since we would expect a photon index based on a PL model to be $-1.0$ or $-2.5$ if $E_{\text{peak}}^{\text{obs}}$ is above or below the BAT energy band, this result clearly demonstrates that the majority of $E_{\text{peak}}^{\text{obs}}$ of the BAT GRBs is likely to be within the BAT energy band. The reason why the BAT cannot measure $E_{\text{peak}}^{\text{obs}}$ for the majority of GRBs is due to its narrow energy band (Sakamoto et al. 2007). Although the sample of bursts is very limited, the short GRBs tend to have a harder PL photon index than the long GRBs. However, the PL photon index distributions have a significant overlap between the short and long GRBs.

The top panel of Figure 14 shows the photon index versus the fluence in the 15–150 keV band in a PL fit. There is a correlation between these two parameters for the long GRBs. The correlation coefficient is +0.458 for the sample of 206 bursts. The probability of such a correlation occurring by chance is <0.001%. If we include the short-duration bursts, however, the correlation becomes weaker (correlation coefficient of +0.228 for the sample of 220 bursts). Therefore, we have confirmed the fluence-hardness correlation (e.g., Lloyd et al. 2000) especially for the BAT long GRB sample. The bottom panel of Figure 14 shows the time-averaged photon index in a PL fit versus the 1 s peak energy flux in the 15–150 keV band. The correlation coefficient of these two parameters are +0.397 for the GRB sample without the short bursts (total 206 GRBs) and +0.376 for the sample with the short bursts (total 220 GRBs). The probabilities of a chance coincidence of the correlation between parameters are <0.001% for both cases. Therefore, we also confirmed the correlation between the peak flux and the hardness either with or without the short GRBs (e.g., Lloyd et al. 2000). Note that both the fluence and the peak flux measured by the BAT are not the bolometric values and may introduce the systematic errors in the correlations.

For the limited number of GRBs (32 GRBs) that have a significant improvement in $\chi^2$ by a CPL fit, we investigated the relationship between $E_{\text{peak}}^{\text{obs}}$ and other parameters. The top panel of Figure 15 shows the distribution of $E_{\text{peak}}^{\text{obs}}$ and the energy fluence in the 15–150 keV band. The correlation coefficient between these two parameters is +0.580 (a chance probability of 0.2%). The bottom panel of Figure 15 shows the distribution of $E_{\text{peak}}^{\text{obs}}$ and the 1 s peak energy flux in the 15–150 keV band. The correlation coefficient is +0.563 (a chance probability of 0.2%). Note that the fluence and the peak flux are calculated from the BAT energy

\(^{27}\) Note that the estimated number of Swift GRBs with $E_{\text{peak}}^{\text{obs}} < 100$ keV depends on the assumption of $\alpha$. If we estimate the number of Swift GRBs of $E_{\text{peak}}^{\text{obs}} < 100$ keV for $\alpha = -1.6$, which is the peak of the PL photon index distribution of BAT (Fig. 13), and $\beta = -2.5$, it will be 10% of the total population. However, based on the Band $\alpha$ distribution of the BATSE spectral catalog (Kaneko et al. 2006) and also on the detailed spectral simulation study of the BAT data (Sakamoto et al. 2007), the BAT PL photon index very likely does not correspond to $\alpha$ of the Band function (see § 5.4).

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**Figure 6.** Histogram (top) and the cumulative fraction (bottom) of the angular difference between the BAT ground position and the XRT position; 68% and 90% of BAT ground positions are within 0.95° and 1.75° from the XRT position, respectively.

**Figure 7.** Incident angle (θ) distribution of the BAT GRBs. The line shows the calculated θ distribution in the case of the uniform sky distribution. [See the electronic edition of the Supplement for a color version of this figure.]
range. Therefore, these values are not bolometric. Figure 16 shows the relationship between the photon index in a CPL model and $E_{\text{peak}}$. The $E_{\text{peak}}$ distribution is spread from 10 to 500 keV for the BAT GRB sample. There is no correlation between the photon index and $E_{\text{peak}}$. This is consistent with the measurements of other missions (e.g., Kippen et al. 2001; Sakamoto et al. 2005).

Figure 17 shows the correlation between the photon index in a PL fit and $E_{\text{peak}}$ derived from a CPL fit. As we mentioned in the first paragraph of this section, the variation in the photon indices derived from a PL fit is very likely to reflect the differences in $E_{\text{peak}}$ energies that are within the BAT energy band. This correlation between the PL photon index and $E_{\text{peak}}$ was also recognized by Zhang et al. (2007), and their best-fit correlation is shown as a dashed line in Figure 17. Since the correlation found by Zhang et al. (2007) is based on $E_{\text{peak}}$ derived from a Band function, the slight offset between the dashed line and the data could be due to
Fig. 11.—Distribution of the energy fluence in the 15–150 keV band vs. 1 s peak photon flux in the 15–150 keV band.

Fig. 12.—Distribution of the energy fluence in the 15–50 keV band vs. that in the 50–150 keV band. Long GRBs ($T_{90} \geq 2$ s) are in black and short GRBs ($T_{90} < 2$ s) are in gray. The dash-dotted line is the case of the Band function of $\alpha = -1$, $\beta = -2.5$, and $E_{\text{peak}}^\text{max} = 100$ keV. The dashed line is the case of the Band function of $\alpha = -1$, $\beta = -2.5$, and $E_{\text{peak}}^\text{max} = 30$ keV. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 13.—Histogram of the photon index in a PL fit for long GRBs (black) and short GRBs (gray). The short GRB that has a PL photon index of $-2.5$ is GRB 050906. [See the electronic edition of the Supplement for a color version of this figure.]

Fig. 14.—Top: Distribution of the PL photon index vs. the energy fluence in the 15–150 keV band for long GRBs (black) and short GRBs (gray). Bottom: Distribution of the PL photon index vs. the 1 s peak energy flux in the 15–150 keV band for long GRBs (black) and short GRBs (gray). [See the electronic edition of the Supplement for a color version of this figure.]
Fig. 15.—Top: Distribution of $E_{\text{peak}}$ vs. the energy flux in the 15–150 keV band. Two GRBs that are located in $\sim 7 \times 10^{-8}$ erg cm$^{-2}$ are GRB 050815 and GRB 050925. One GRB that has $E_{\text{peak}}$ of $\sim$ 20 keV is GRB 060428B. Bottom: Distribution of $E_{\text{peak}}$ vs. the 1 s peak energy flux in the 15–150 keV band.

Fig. 16.—Distribution of $E_{\text{peak}}$ vs. the CPL photon index for 32 GRBs that have a significant improvement in $\chi^2$ by a CPL fit over a PL fit.

Fig. 17.—Distribution of $E_{\text{peak}}$ vs. the PL photon index for 32 GRBs. The dashed line is the PL photon index-$E_{\text{peak}}$ correlation of Zhang et al. (2007): 

$$\log E_{\text{peak}} = 2.76 - 3.61 \log (\alpha_{\text{PL}}).$$
the systematic difference of $E_{\text{peak}}$ based on the choice of the spectral model (e.g., Kaneko et al. 2006). The detailed study of this correlation based on the spectral simulations will be presented elsewhere (Sakamoto et al. 2007).

6. SUMMARY

The first BAT catalog includes 237 GRBs detected by BAT during 2.5 years of operation. The BAT ground positions are <1.75° from the XRT position for 90% of GRBs. We presented the observed temporal and spectral properties of the prompt emission based on the analysis of the BAT event data. Taking into account the difficulty in triggering short GRBs with the imaging instrument like BAT, the duration distributions are consistent with other missions. We showed that the BAT long GRB sample is systematically softer than that of the BATSE bright GRB sample. The correlations such as the fluence hardness and the peak flux hardness have been confirmed by the BAT GRB samples.

We would like to thank J. A. Nousek, J. P. Osborne, G. Chincarini, Y. Kaneko, and D. Malesani for valuable comments. We also would like to thank the anonymous referee for comments and suggestions that materially improved the paper. This research was performed while T. S. held a NASA Postdoctoral Program administered by Oak Ridge Associated Universities at NASA Goddard Space Flight Center formerly the National Research Council program.

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