A COMPREHENSIVE ANALYSIS OF FERMI GAMMA-RAY BURST DATA. III.
ENERGY-DEPENDENT $T_{90}$ DISTRIBUTIONS OF GBM GRBs AND
INSTRUMENTAL SELECTION EFFECT ON DURATION CLASSIFICATION

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ABSTRACT

The durations ($T_{90}$) of 315 gamma-ray bursts (GRBs) detected with Fermi/GBM (8–1000 keV) up to 2011 September are calculated using the Bayesian Block method. We compare the $T_{90}$ distributions between this sample and those derived from previous/current GRB missions. We show that the $T_{90}$ distribution of this GRB sample is bimodal, with a statistical significance level comparable to those derived from the BeppoSAX/GRBM sample and the Swift/BATSE sample, but lower than that derived from the CGRO/BATSE sample. The short-to-long GRB number ratio is also much lower than that derived from the BATSE sample, i.e., 1:6.5 versus 1:3. We measure $T_{90}$ in several bands, i.e., 8–15, 15–25, 25–50, 50–100, 100–350, and 350–1000 keV, to investigate the energy-dependence effect of the bimodal $T_{90}$ distribution. It is found that the bimodal feature is well observed in the 50–100 and 100–350 keV bands, but is only marginally acceptable in the 25–50 keV and 350–1000 keV bands. The hypothesis of bimodality is confidently rejected in the 8–15 and 15–25 keV bands. The $T_{90}$ distributions in these bands are roughly consistent with those observed by missions with similar energy bands. The parameter $T_{90}$ as a function of energy follows $T_{90} \propto E^{-0.2 \pm 0.02}$ for long GRBs. Considering the erratic X-ray and optical flares, the duration of a burst would be even longer for most GRBs. Our results, together with the observed extended emission of some short GRBs, indicate that the central engine activity timescale would be much longer than $T_{90}$ for both long and short GRBs and the observed bimodal $T_{90}$ distribution may be due to an instrumental selection effect.

Key words: gamma-ray burst: general – methods: statistical

Online-only material: color figures, machine-readable table

1. INTRODUCTION

The gamma-ray burst (GRB) survey with Burst And Transient Source Experiment (BATSE) on board Compton Gamma-Ray Observatory (CGRO) revealed a clear bimodal distribution of the burst duration parameter $T_{90}$, which is measured with the time interval from 5% to 95% of the accumulated photon counts from the source, and two groups of GRBs, i.e., long versus short GRBs with a division line at $T_{90} = 2$ s, was identified (Kouveliotou et al. 1993). It has been long theoretically speculated that long GRBs (LGRBs) are related to the deaths of massive stars (Colgate 1974; Woosley 1993). This was confirmed observationally by the discoveries of supernova (SNe) association with some nearby LGRBs (for reviews see Zhang & Mészáros 2004; Piran 2005; Mészáros 2006; Woosley & Bloom 2006). The rapid localization capacity of the Swift GRB mission (Gehrels 2004) led to redshift measurements and host galaxy detections of short GRBs (SGRBs). Some nearby SGRBs were found in elliptical/early-type galaxies with very low star formation rates (Gehrels et al. 2005; Bloom & Bay Area GRB Group 2006; Barthelmy et al. 2005a; Berger et al. 2005) or in the regions with a low star formation rate in star-forming galaxies (Covino et al. 2006; Fox et al. 2005). These are consistent with a non-massive star origin of SGRBs, probably related to the mergers of two compact objects (e.g., Paczyński 1986, 1991; Eichler et al. 1989; Narayan 1992; Bloom et al. 1999; see Nakar 2007 for a review). The SGRB central engine in this model is a hot and dense torus of 0.01–0.3 $M_\odot$ that is accreted onto a stellar-mass black hole. The lifetime of an SGRB is expected to be typically shorter than 2 s (Popham et al. 1999; Narayan et al. 2001; Di Matteo et al. 2002). This is roughly consistent with the typical $T_{90}$ of SGRBs observed with BATSE.

It was surprising that two nearby LGRBs, i.e., GRB 060614 ($T_{90} = 103$ s at $z = 0.125$) and GRB 060605 ($T_{90} = 4$ s at $z = 0.089$), had no detection of an accompanying SN, different from other known nearby LGRBs such as GRB 980425/SN 1998bw (Galam et al. 1998; Kulikarni et al. 1998), GRB 030329/SN 2003dh (Stanek et al. 2003; Hjorth et al. 2003), GRB 031203/SN 2003lw (Malesani et al. 2004), GRB 060218/SN 2006aj (Modjaz et al. 2006; Pian et al. 2006; Sollerman et al. 2006; Mirabal et al. 2006; Cobb et al. 2006), and GRB 100316/D/SN 2010bh (Starling et al. 2011; Fan et al. 2011). The prompt emission and afterglow properties of GRB 060614 are similar to those of some nearby “short” GRBs that have a non-massive star origin (e.g., Gehrels et al. 2006; Zhang et al. 2007; Gal-Yam et al. 2006). This led to confusion concerning the long–short classification scheme and a new classification scheme, i.e., Type II (massive star origin) versus Type I (compact star origin), was proposed (Zhang 2006; Zhang et al. 2007). Note that some well-known Type I GRBs, such as GRB 050724 (Barthelmy et al. 2005; Tanvir et al. 2005; Berger et al. 2005) and GRB 050709 (Hjorth et al. 2005; Villasenor et al. 2005;
Fox et al. 2005), also have a long-lasting extended emission component, giving $T_{90} \sim 100$ s for these bursts. In fact, a handful of Type I GRBs show such a component in their light curves (Norris & Gehrels 2008; Lin et al. 2008; Zhang et al. 2009). GRB 060614-like nearby LGRBs are therefore likely Type I GRBs with a long, soft extended emission tail, similar to that observed in SGRB 050724 (Zhang et al. 2007). It is also interesting to note that some short-duration GRBs, such as GRB 090426 ($T_{90} = 1.28$ s in the 15–350 keV band; Levesque et al. 2010a, 2010b; Xin et al. 2010), likely originate from collapse of massive stars (Virgili et al. 2011; Zhang et al. 2009). Some high-redshift GRBs, such as GRB 080913 ($z = 6.7$; Greiner et al. 2009) and GRB 090423 ($z = 8.3$; Salvaterra et al. 2009; Tanvir et al. 2009), have a rest-frame short duration ($T_{90}/(1+z) < 2$ s) but they share a lot of common properties with LGRBs and are likely from collapse of massive stars (Zhang et al. 2009; Belczynski et al. 2010; Levesque et al. 2010a; Lin et al. 2010). These observations indicate that the long versus short GRB classification scheme does not always match the physical Type II versus Type I classification scheme. Liu et al. (2010) proposed a new observational parameter defined by the burst isotropic gamma-ray energy and the photon energy of the $\nu f_\nu$ spectral peak ($E_p$). Similarly, the ratio of the gamma-ray fluence to $E_p$ has also been suggested as a parameter for GRB classification (Goldstein et al. 2010).

As discussed above, $T_{90}$ is not always a good parameter to conduct GRB classification. It is essential to understand whether the observed bimodal $T_{90}$ distribution is intrinsic or just due to an instrumental selection effect. This is critical for GRB classification and theoretical modeling of GRB progenitors and central engines. Broadband energy band observations with the Fermi mission not only reveal the spectral components and their temporal evolution (Zhang et al. 2011; Lu et al. 2012; Papers I and II of this series), but also provide an opportunity to study the energy dependence of burst duration and possible instrumental selection effect on the $T_{90}$ distribution. In this paper, we present a detailed analysis of the $T_{90}$ distribution of the Fermi/GBM sample (in Section 2), and compare it with the $T_{90}$ distributions derived from the previous GRB missions (in Section 3). We next explore the instrumental selection effect on the $T_{90}$ distribution and the energy dependence of $T_{90}$ (in Section 4). We also discuss the burst duration by considering late X-ray and optical flares (in Section 5). We show that the bimodal distribution of $T_{90}$ is likely due to an instrumental selection effect and that the lifetime of the central engines of Type I GRBs is essentially longer than 2 s for most cases (in Section 6).

2. DATA REDUCTION AND CALCULATION OF $T_{90}$

We include all 315 GRBs detected by the GBM, as reported by the GBM team in GCN circulars up to 2011 September. We download the data from the Fermi Archive available at ftp://legacy.gsfc.nasa.gov/fermi/data/gbm/bursts/. The time-tagged event (TTE) data have excellent time resolution of 2 $\mu$s. The TTE data for the most illuminated NaI detector for each GRB are used for our analysis. The Nmfit (v3.7) package is used for data reduction.

We select two time intervals that are far before and far after the main burst as background and subtract it from the burst phase using a linear fit; then we calculate $T_{90}$ using the Bayesian Block method (Scargle 1998). Note that we do not adopt fixed intervals prior to or post the GRB trigger as the background, since some GRBs have significant emission prior to the trigger while others may have a long tail after the main burst. Therefore, the background intervals were visually selected by eye for each GRB. The background subtraction of the light curve alters the prior assumption used in the Bayesian Block method and adds additional error to the estimation of duration due to the propagation of errors from the background. However, it is found that this effect does not significantly affect our estimation of $T_{90}$ within the errors. To clarify the influence of interval selection on background subtraction in our calculation of $T_{90}$, we compare the derived $T_{90}$ by selecting different background intervals for three typical GRBs. The light curves and selection of background intervals for these GRBs are displayed in Figure 1. For GRB 091010, a bright burst, the derived $T_{90}$ values are $7.616 \pm 0.580$ s and $7.552 \pm 0.516$ s for two different selections of the time intervals for background subtraction, as shown in Figure 1. For GRB 090126B, a weak burst, we get $7.032 \pm 1.154$ s and $7.968 \pm 1.111$ s, respectively. For GRB 090227B, a short GRB, we get $1.248 \pm 0.601$ s and $1.184 \pm 0.544$ s, respectively. We see that the derived $T_{90}$ values are consistent with each other within the errors for different background selections.

For each GRB in our sample, we extract the 64 ms binned light curves from the TTE data and subtract the background for each energy band. We then calculate $T_{90}$ using the Bayesian Block method (Scargle 1998) for each light curve. Examples of light curve structure obtained using this method are also shown in Figure 1. Using this method, we derive the epochs of $t_5$ and $t_{95}$, where $t_5$ and $t_{95}$ are the times when 5% and 95% of the total count fluence is collected, respectively. In order to reduce fluctuation of $t_5$ and $t_{95}$ from a real light curve and estimate their errors, we generate a sample of $10^5$ mock light curve assuming that the error of light curve data has a Poisson distribution. The $t_5$ and $t_{95}$ values as well as their errors (1$\sigma$) are obtained from a Gaussian fit to their distributions from the mock light curve sample. Hence, we get $T_{90} = t_{95} - t_5$ and its error $\delta T_{90} = (\delta t_{95}^2 + \delta t_5^2)^{1/2}$. The derived $T_{90}$ values are reported in Table 1. Note that some light curves are too weak to calculate the values of $t_5$ and $t_{95}$ using the Bayesian Block method and thus $T_{90}$ values for these are not available.

The $T_{90}$ reported in the Fermi GBM Catalog by the GBM team are calculated by accumulating the photon fluence throughout the duration of the burst (Paciesas et al. 2012). In this method, a GRB is split into time bins and the spectrum of each bin is fitted with a model. The photon fluence from the best-fit spectral model for each time bin is accumulated to calculate $T_{90}$. This procedure factors in the detector response and the fact that the angle between the detectors and source is constantly changing. Figure 2 compares the derived $T_{90}$ in the 50–300 keV band using the Bayesian Block method with those derived from the photon fluence method as reported by Paciesas et al. (2012). It is found that the values are generally consistent with each other.

3. COMPARISON OF THE $T_{90}$ DISTRIBUTION WITH OTHER GRB MISSIONS

Since 1990, GRB surveys in different energy bands have been done with CGRO/BATSE (50–300 keV), HETE-2/FREGATE (6–80 keV), BeppoSAX/GRBM (40–700 keV), Swift/BAT

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8 Higher-order polynomial fits for background subtraction were also tried, but the $T_{90}$ derived from such fits is generally consistent with that derived from the linear fit within the errors.

9 Our calculation is done purely in count space. Since the GBM is constantly slewing in orbit, this method could skew the $T_{90}$ estimation for long GRBs.
ments. In Figure 3 and Table 2, we compare the $T_{90}$ distributions of our GBM sample in the 8–1000 keV band with those derived from the data collected by these missions. The data for HETE-2/FREGATE, BeppoSAX/GRBM, CGRO/BATSE, Swift/BAT, and INTEGRAL/SPI-ACS are taken from Pelangeon et al. (2008), Frontera et al. (2009), Paciesas et al. (1999), Sakamoto et al. (2011), and Savchenko et al. (2012), respectively. Note that the methods of $T_{90}$ calculation adopted by these instrumental teams may not be exactly the same. In the BeppoSAX, HETE-2, CGRO/BATSE, and INTEGRAL samples, the $T_{90}$ values were derived by using the accumulated count rate. The $T_{90}$ values for the Swift GRB sample were calculated using the Bayesian Block method. The $T_{90}$ values of the Fermi GRBs reported by the Fermi GBM team are calculated using the photon fluence method by considering the instrument response effect, as described in Section 2. The $T_{90}$ values derived using different methods for these instruments may have a small systematic bias which does not greatly affect our comparison of the $T_{90}$ distributions in our analysis.

As shown in Figure 3, the $T_{90}$ distributions of the LGRB groups observed with different missions are generally consistent with each other, but those of the SGRBs are dramatically different. The HETE-2 sample does not even have any GRB with $T_{90} < 2 \text{s}$. We fit the $T_{90}$ distributions with a model of two log-normal functions and find that the bimodal distribution feature is revealed only in the BATSE, GBM, BeppoSAX, and INTEGRAL samples. For the BATSE sample, the $T_{90}$ distribution peaks at $\log T_{90} = -0.02 \pm 0.73$ and $\log T_{90} = 1.57 \pm 0.41$. For the GBM sample, the peaks are at $\log T_{90} = -0.27 \pm 0.28$ and $\log T_{90} = 1.32 \pm 0.49$. For the BeppoSAX sample, the peaks are at $\log T_{90} = 0.27 \pm 0.41$ and $\log T_{90} = 1.41 \pm 0.40$. For the INTEGRAL sample, the peaks are at $\log T_{90} = -0.29 \pm 0.06$ and $\log T_{90} = 1.36 \pm 0.01$. For the Swift/BAT sample, two Gaussian components are fitted to the data, i.e., $\log T_{90} = -0.45 \pm 0.14$ and $\log T_{90} = 1.66 \pm 0.03$. For the HETE-2 sample, we get $\log T_{90} = 1.36 \pm 0.50$. The bimodal feature is apparently observed only in the CGRO/BATSE and Fermi/GBM-NaI samples, and is consistent with the result of Zhang et al. (2012), who measure $T_{90}$ with the observed fluence. The short-to-long GRB number ratios are also dramatically different, as reported in Table 2. In the HETE-2/FREGATE sample, no GRB with $T_{90} < 2 \text{s}$ was detected.\(^{10}\) The short-to-long GRB ratios in

(15–150 keV), and INTEGRAL/SPI-ACS (20 keV–8 MeV). The GBM roughly covers the energy bands of these instruments. In Figure 3 and Table 2, we compare the $T_{90}$ distribution of our GBM sample in the 8–1000 keV band with those derived from the data collected by these missions. The data for HETE-2/FREGATE, BeppoSAX/GRBM, CGRO/BATSE, Swift/BAT, and INTEGRAL/SPI-ACS are taken from Pelangeon et al. (2008), Frontera et al. (2009), Paciesas et al. (1999), Pelangeon et al. (2008), and GRB 060121 ($T_{90} = 2.6 \pm 0.1$; Pelangeon et al. 2008).
The results of a bimodal distribution test using the KMM algorithm are also reported. The deficit of SGRBs in samples observed with instruments other than LGRBs, where the spectral hardness ratio (HR) is defined as the fluence ratio of the 100–350 keV band to that of the 25–50 keV band of BATSE (Kouveliotou et al. 1993). The GBM-NaI sample is comparable to that of the BeppoSAX/GBM and Swift/BAT samples, but is much lower than the CGRO/BATSE sample. The hypothesis of a bimodal feature in the GBM-NaI sample is comparable to that of the BiGRBs in our sample with the spectral parameters reported in the GCN circulars for GBM GRBs in our sample, and examine the long–soft versus short–hard classification schemes. Figure 4 shows the comparison of the GRBs in our sample with the BATSE GRB sample in the HR–$T_{90}$ plane. We observe that they are consistent with each other.

### 4. ENERGY DEPENDENCE OF $T_{90}$

As shown above, the $T_{90}$ distribution is instrument dependent. The deficit of SGRBs in samples observed with instruments in a lower energy band, such as HETE-2/FREGATE and Swift/BAT, may be understood as a combination of the following two effects. First, since SGRBs are typically harder, there is a lower trigger probability with a soft instrument. Second, many SGRBs have longer soft tails, which are readily detectable in softer detectors. As a result, some GRBs that would be classified as “short” are detected as “long” in soft detectors. As seen in GRB 050724 and GRB 050709, the $T_{90}$ of Type I GRBs is energy dependent and could be much longer than 2 s. In this section, we investigate the energy dependence of $T_{90}$ using the GBM data. We derive the $T_{90}$ values in the following energy bands: 8–15, 15–25, 25–50, 50–100, 100–350, and 350–1000 keV. The short-to-long number ratios in each energy band are also reported in Table 2. The $T_{90}$ distributions are shown in Figure 5. Comparing the $T_{90}$ distributions with those observed by other instruments with similar energy bands, we find that they are roughly consistent with each other, i.e., 8–15 keV band versus HETE-2/FREGATE (6–80 keV), 15–25 and 25–50 keV bands.

| GBM ID | GRB Name | 8–15 keV (s) | 15–25 keV (s) | 25–50 keV (s) | 50–100 keV (s) | 100–350 keV (s) | 350–1000 keV (s) | 8–1000 keV (s) |
|--------|----------|--------------|---------------|---------------|----------------|-----------------|-----------------|----------------|
| 0807144754 | 080714 | … | 18.85 ± 0.62 | 8.86 ± 0.57 | 7.17 ± 0.54 | 6.37 ± 0.48 | 10.27 ± 0.62 | 32.29 ± 0.54 |
| 080725435 | 080725 | 21.79 ± 0.58 | 25.12 ± 0.44 | 31.58 ± 0.4 | 22.27 ± 0.46 | 22.88 ± 0.54 | 3.36 ± 0.66 | 22.21 ± 0.23 |
| 080727964 | 080727C | … | 25.7 ± 0.66 | 29.12 ± 0.66 | 32.77 ± 0.66 | 27.36 ± 0.69 | … | 35.55 ± 0.59 |
| 080804972 | 080804 | … | 20.35 ± 0.66 | 20.86 ± 0.7 | 16.45 ± 0.53 | 16.58 ± 0.46 | 106.5 ± 0.98 | 73.41 ± 0.93 |
| 080810549 | 080810 | 50.91 ± 0.99 | 51.39 ± 0.76 | 52.7 ± 0.83 | 25.92 ± 0.69 | 39.39 ± 0.88 | 125.28 ± 1.12 | 49.34 ± 0.63 |
| 080904886 | 080904 | 41.18 ± 0.88 | 18.72 ± 0.7 | 13.66 ± 0.49 | 17.28 ± 0.6 | 6.78 ± 0.65 | 51.87 ± 0.95 | 15.94 ± 0.47 |
| 080905499 | 080905A | 13.5 ± 0.57 | … | … | … | … | … | 1.06 ± 0.3 |
| 080905570 | 080905C | 23.26 ± 0.72 | 21.79 ± 0.53 | 19.2 ± 0.51 | 18.37 ± 0.51 | … | 78.82 ± 1 | 27.36 ± 0.56 |
| 080905705 | 080905B | 129.73 ± 1.48 | 204.64 ± 1.16 | 11.74 ± 0.48 | 21.12 ± 0.57 | 14.88 ± 0.53 | … | 158.02 ± 1.10 |
| 080906212 | 080906B | 5.15 ± 0.49 | 2.91 ± 0.3 | 14.98 ± 0.73 | 3.07 ± 0.34 | 2.82 ± 0.34 | 11.65 ± 0.7 | 3.26 ± 0.26 |

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
Comparison of the $T_{90}$ distributions observed with different instruments. The data from HETE-2/FREGATE, BeppoSAX/GRBM, CGRO/BATSE, Swift/BAT, and INTEGRAL/SPI-ACS are taken from Pelangeon et al. (2008), Frontera et al. (2009), Paciesas et al. (1999), Sakamoto et al. (2011), and Savchenko et al. (2012), respectively. The vertical dotted line marks $T_{90} = 2$ s. The fits to the distributions with two Gaussian functions or one Gaussian function are also shown.

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


discuss versus Swift/BAT (15–150 keV), 50–100 keV band versus BeppoSAX/GRBM (40–700 keV), and 100–350 band versus CGRO/BATSE (25–2000 keV). We also try to fit the $T_{90}$ distributions with the two log-normal component model. Similar results to those shown in Figure 3 are obtained. The most significant bimodal $T_{90}$ distribution is seen in the 100–350 keV band. We examine the bimodal feature in the $T_{90}$ distributions of these energy bands using the KMM algorithm and our results are also reported in Table 2. It is found that the bimodal hypothesis is rejected for the $T_{90}$ distributions in the 8–15 and 15–25 keV bands, similar to that observed with HETE-2/FREGATE. The hypothesis is marginally acceptable in the 25–50 and 350–1000 keV energy bands, and confidently accepted in the 50–100 and 100–350 keV bands. We note that BATSE is sensitive in the 50–350 keV band and conclude that the BATSE observation is consistent with the GBM observation in the 50–350 keV band, similar to that shown in Figure 4.

We compare the $T_{90}$ in the 8–1000 keV band with that in the sub-energy bands in Figure 6. We still adopt $T_{90} = 2$ s in the 8–1000 keV band as the division line to classify LGRBs and SGRBs. We find that some SGRBs in the 8–1000 keV band move to the LGRB group in softer bands. We investigate the energy dependence of $T_{90}$ for LGRBs only, since the SGRB sample is too small to give a robust statistical result. The typical value of $\bar{T}_{90}$ and its error $\Delta \log T_{90}$ for a given energy band are derived from a Gaussian fit to the log $T_{90}$ distribution. Figure 7 shows $\bar{T}_{90}$ as a function of the central value of the energy band. A clear correlation is found, and the best linear fit gives $\bar{T}_{90} \propto E^{-0.20 \pm 0.02}$. Note that the slopes are shallower than those observed in bright GRBs as reported by Richardson et al. (1996) and Bissaldi et al. (2011), who found $\bar{T}_{90} \propto E^{-0.4}$. This may be caused by a sample selection effect. A power-law index $\sim 0.2–0.3$ has also been reported in the literature for the energy dependence of GRB durations and pulse durations in some GRBs (e.g., Fenimore et al. 1995; Norris et al. 2005; Liang et al. 2006a, 2006b; Zhang 2008).

5. EXTENDED CENTRAL ENGINE ACTIVITY TIME IN THE X-RAY AND OPTICAL BANDS

As shown above, the burst duration is energy dependent and the bimodal $T_{90}$ distribution may be due to an instrumental
selection effect. This suggests that if one goes to even lower energy bands, the duration could be even longer. Robotic optical telescopes also detected significant optical flares in some GRBs. Li et al. (2012) presented a detailed analysis of the optical flares. They took 24 optical flares from 19 GRBs and found that the isotropic flare peak luminosity \( L_{R,\text{iso}} \) is correlated with that of gamma rays, i.e., \( L_{R,\text{iso}} \propto L_{\gamma,\text{iso}}^{1.11 \pm 0.27} \). The flares peak at from tens of seconds to several days after the GRB trigger. Later flares tend to be wider and dimmer, following the relations \( w \sim t_p/2 \) and \( L_{R,\text{iso}} \propto [t_p/(1 + z)]^{-1.15 \pm 0.15} \). These results suggest that the optical flares are also related to the erratic behavior of the central engine.

The rapid slewing capacity of the X-ray telescope (XRT) on board Swift makes it possible to catch the X-ray emission from very early to late episodes of GRBs. Erratic flares were detected for both LGRBs and SGRBs (Burrows et al. 2005; Chincarini et al. 2007; Margutti et al. 2010). The detection probability of X-ray flares is much larger than that of optical flares (Li et al. 2012). It is generally believed that these X-ray flares are due to extended central engine activity at late times (Burrows et al. 2005; King et al. 2005; Fan & Wei 2005; Zhang et al. 2006; Dai et al. 2006; Perna et al. 2006; Proga & Zhang 2006; Liang et al. 2006a, 2006b; Lazzati & Perna 2007; Maxham & Zhang 2009).

We take the peak time of the last X-ray flare to define the central engine duration of a burst (denoted as \( T_f \)). We make an extensive search for the significant flares in the Swift/XRT light curves using the following criteria. First, there are significant flares in the X-ray light curve, with \( \Delta F/F \geq 5 \) where \( \Delta F = F_p - F_i \) is the flux over the underlying flux level \( F_i \). Second, BAT and XRT light curves are well connected without a gap, or significant flares are observed after a gap. We show some examples of these light curves in Figure 8. We obtain a sample of 159 GRBs. Figure 9 shows \( T_f \) as a function of \( T_{90} \). We find that there is no significant flare after \( T_{90} \) in 49 GRBs. This suggests that the \( T_{90} \) of these bursts are comparable to the durations of the central engines. On the other hand, significant flares are observed in 110 GRBs after their \( T_{90} \), indicating the \( T_f \) of these bursts are much larger than \( T_{90} \). The X-ray emission of four GRBs, GRB 050502B, GRB 050724, GRB 050904, and GRB 060223, are dominated by flares (as shown in Figure 9), indicating that they may be super-LGRBs (Zou et al. 2006).

6. CONCLUSIONS AND DISCUSSION

We have calculated \( T_{90} \) for Fermi/GBM GRBs in various energy bands and compared the \( T_{90} \) distribution with those obtained from previous/current GRB survey missions. We show that the \( T_{90} \) distribution in the 8–1000 keV band is bimodal, roughly consistent with that of the CGRO/BATSE GRB sample, but the short-to-long GRB number ratio is 1:5, lower than that in the BATSE sample (1:3). We measure the \( T_{90} \) in several sub-bands, i.e., 8–15, 15–25, 25–50, 50–100, 100–350, and 350–1000 keV to investigate the energy band selection effect on the bimodal behavior of the \( T_{90} \) distribution. It is found that the bimodal feature is well recognized in the 50–100 and 100–350 keV bands and only marginally accepted in the 25–50 and 350–1000 keV energy bands. The hypothesis of bimodality is confidently rejected in 8–15 and 15–25 keV bands. We compare the \( T_{90} \) distributions in these sub-energy bands with those derived from other GRB detectors with similar energy bands and find that they are roughly consistent with each other. \( T_{90} \) as a function of energy band follows \( T_{90} \propto E^{-0.20 \pm 0.02} \) for LGRBs. Some GRBs fall into the short category in a
Figure 6. Comparisons between $T_{90}$ measured in the 8–1000 keV energy band and some sub-energy bands. The vertical dotted lines denote $T_{90} = 2$ s and the solid lines are the equality lines.

(A color version of this figure is available in the online journal.)
high-energy band, but move to the long category in a lower-energy band. Considering the erratic optical and X-ray flares that may have the same physical origin as the prompt gamma rays, the duration of a burst could be even longer for most GRBs. These results indicate that $T_{90}$ is energy dependent and the bimodal $T_{90}$ distribution is valid only for certain energy bands.

Burst duration is critical for both GRB classification and understanding the behavior of the GRB central engine. It is an indicator of the lifetime of the GRB central engine. Popular central engine models of GRBs are related to accretion onto a central black hole that is formed from collapse of a massive star or merger of a compact star binary. Current favored jet launching models for GRBs include a neutrinoannihilation mechanism from a neutrino-dominated accretion flow (e.g., Popham et al. 1999; Narayan et al. 2001; Kohri & Mineshige 2002; Di Matteo et al. 2002; Kohri et al. 2005; Gu et al. 2006; Chen & Beloborodov 2007; Liu et al. 2007, 2010; Xie et al. 2007; Lei et al. 2009) and Blandford–Znajek process (Blandford & Znajek 1977; Lee et al. 2000; Lei et al. 2007). It is theoretically expected that the accreting timescale for compact star mergers would be shorter than 1 s based on both analytical and numerical results (e.g., Narayan et al. 2001; Aloy et al. 2005). The $T_{90}$ distribution observed with CGRO/BATSE (Kouveliotou et al. 1993) seems to be consistent with the speculation that the two types of GRBs (long versus short) are consistent with two distinct progenitors, i.e., collapses of massive stars versus mergers of compact objects. However, as we have shown here, the bimodal $T_{90}$ distribution would be likely due to an instrumental selection effect. Our results, together with the observed extended emission of some short GRBs, not only challenge the long–short GRB classification scheme but also challenge the conventional GRB central engine models, and call for new mechanisms to account for extended GRB central engine activities (e.g., King et al. 2005; Fan & Wei 2005; Zhang et al. 2006; Dai et al. 2006; Perna et al. 2006; Proga & Zhang 2006; Metzger et al. 2008; Liu et al. 2012).
