Constraints on the bulk Lorentz factor of gamma-ray bursts with the detection rate by *Fermi* LAT

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ABSTRACT

The bulk Lorentz factor (Γ) of the outflow is an essential parameter for understanding the physics of gamma-ray burst (GRB). Informations about the Lorentz factors of some individual GRBs have been obtained from the spectral features of the high-energy gamma-ray emissions (>100 MeV), assuming that the spectral breaks or cutoffs are due to the pair-production attenuation (i.e. $\gamma\gamma \rightarrow e^+e^-$). In this paper, we attempt to interpret the dependence of the Large Area Telescope (LAT) detection rate of GRBs on the number of high-energy gamma-rays, taking into account the attenuation effect. We first simulate a long-GRB sample with Monte Carlo method using the luminosity function, rate distribution with redshift, and properties of the GRB spectrum. To characterize the distribution of the Lorentz factors, we assume that the Lorentz factors follow the relation $\Gamma = \Gamma_0 E_{\text{iso},52}^k$, where $E_{\text{iso},52}$ is the isotropic photon energy in unit of 10^{52} erg. After taking into account the attenuation effect related with the above Lorentz factor distribution, we are able to reproduce the LAT-detected rate of GRBs as the function of the number of gamma-rays for suitable choice of the values of Γ_0 and k . The result suggests that the distribution of the bulk Lorentz factor for the majority of GRBs is in the range of 50–250.

Key words: radiation mechanisms: non-thermal – gamma-rays: general.

1 INTRODUCTION

Detection of high-energy gamma-rays from gamma-ray burst (GRBs) requires that these photons (>100 MeV) escape the source without suffering from attenuation due to pair production ($\gamma\gamma \rightarrow e^+e^-$) (e.g. Krolik & Pier 1991; Fenimore, Epstein & Ho 1993; Woods & Loeb 1995; Baring & Harding 1997). Requiring that the absorption optical depth $\tau_{\gamma\gamma} \lesssim 1$ within the source for high-energy photons, one can deduce a lower limit on the bulk Lorentz factor (Γ) of the emitting region, which is usually $\gtrsim 100$ (Lithwick & Sari 2001). Recently, thanks to wide energy coverage and good sensitivity of Large Area Telescope (LAT) on *Fermi*, the spectral cutoffs or breaks have been observed in several GRBs (Ackermann et al. 2011; Tang et al. 2015; Vianello et al. 2017; Yassine et al. 2017). Assuming that the spectral breaks are caused by the attenuation effect, the bulk Lorentz factors of these GRBs are obtained (e.g. Ackermann et al. 2011), which are in the range of 200–1000. However, for the vast majority of GRBs, we still do not know the values of their bulk Lorentz factors.

Using the GRB sample detected in the first 3 yr by *Fermi*/LAT, Ackermann et al. (2013) obtained the detected number of GRBs as a function of the number of gamma-rays. The detection rate by *Fermi*/LAT is about 8 yr^{-1} , which is smaller than the expected one derived from the extrapolation of the empiric Band function to high energy (Band et al. 2009). Additionally, the difference between the predicted and observed numbers of GRBs increases for bursts with increasing number of gamma-rays in the LAT data. The lack of GRBs detected by *Fermi*/LAT has been interpreted as arising from the attenuation effect that suppress the high-energy emission (Guetta, Pian & Waxman 2011). To consider the attenuation in each GRB, we assume that the Lorentz factor follows the relation $\Gamma \propto E_{\text{iso}}^k$, motivated by some recent studies (Liang et al. 2010; Ghirlanda et al. 2012; Tang et al. 2015). In this paper, we attempt to interpret the dependence of the number of detected GRBs on the number of gamma-rays by considering the attenuation effect. As this deals with the whole population of GRBs, such an approach could reveal the information about the Lorentz factors of the major population of GRBs.

Our paper is organized as follows. In Section 2, we first simulate a sample of GRBs according to the luminosity function, the event rate distribution with redshift, and the properties of prompt GRB

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spectrum. Then in Section 3, we consider the attenuation effect on the spectra of high-energy gamma-rays and try to reproduce the relation between the number of GRBs detected per year and the number of gamma-rays detected in one GRB. Then we give our conclusion and discussion in Section 4.

2 SIMULATION OF A GRB SAMPLE

In this work, we assume that the distributions of GRBs in luminosity and in redshift are independent. We adopt the luminosity function and the redshift evolution function of GRBs given by Wanderman & Piran (2010), which are obtained directly from the redshift-luminosity distribution of long GRBs detected by Swift, i.e.

$$\phi(L_{\text{iso}}) = \begin{cases} \left(\frac{L_{\text{iso}}}{L_b}\right)^{-a_1}, & L_{\text{iso}} < L_b \\ \left(\frac{L_{\text{iso}}}{L_b}\right)^{-a_2}, & L_{\text{iso}} \geq L_b \end{cases} \quad (1)$$

and

$$\rho(z) = \rho_0 \begin{cases} (1+z)^{n_1}, & z < z_b \\ (1+z)^{n_2}(1+z_b)^{n_1-n_2}, & z \geq z_b \end{cases} \quad (2)$$

where $a_1 = 1.17$, $a_2 = 2.44$, $L_b = 10^{52.5} \text{ erg s}^{-1}$, $n_1 = 2.1$, $n_2 = -1.4$, $z_b = 3.1$, and $\rho_0 = 1.3 \text{ Gpc}^{-3} \text{ yr}^{-1}$. Here L_{iso} is the peak bolometric luminosity of GRB in 1–10 000 keV. Setting L_{iso} from 10^{50} to $10^{54} \text{ erg s}^{-1}$ and the redshift $z \leq 8$, we use a Monte Carlo simulation to generate a sample of GRBs with luminosity and redshift following equations (1) and (2). The generated luminosity distribution and the redshift distribution are shown in Fig. 1. We then obtain the isotropic-equivalent photon energy of each GRB following the relation between the luminosity and the total energy given by Ghirlanda et al. (2012), i.e.

$$\log E_{\text{iso},52} = 1.07 \log L_{\text{iso},52} + (0.66 \pm 0.54). \quad (3)$$

As is well accepted, the Band function (Band et al. 1993) can describe the photon spectra of GRBs as

$$N(E) = N_0 \begin{cases} \left(\frac{E}{E_0}\right)^\alpha e^{-E/E_0}, & E < (\alpha - \beta)E_0 \\ \left(\frac{E}{E_0}\right)^\beta (\alpha - \beta)^{\alpha-\beta} e^{\beta E/E_0}, & E \geq (\alpha - \beta)E_0 \end{cases} \quad (4)$$

where N_0 is a normalization constant. Here α and β are the photon indexes below and above the break energy $(\alpha - \beta)E_0$, respectively. We generate their values based on the statistical distribution of these two quantities obtained from *Fermi*/GBM GRBs of the first 2 yr (Goldstein et al. 2012),¹ as shown in Fig. 2. The peak energy in the energy spectrum is related with E_0 by $E_{\text{peak}} = (2 + \alpha)E_0$ for GRBs with $\beta_0 < -2$ (which is usually the case). So, to obtain E_0 what we need is E_{peak} for each GRB.

To determine E_{peak} of each GRBs, we study the relation between E_{peak} and the burst bolometric fluence,² following the treatment of

Lloyd, Petrosian & Mallozzi (2000), Ghirlanda et al. (2008), and Nava et al. (2008), but with the latest *Fermi*-GBM sample of 72 long GRBs with measured redshifts (see Table A1). We extrapolate the measured fluences in the energy range of 10–1000 to 1–10 000 keV, in order to comply with the energy range used for the luminosity function. We find that there is a good correlation between E_{peak} and the fluence F (see Fig. 3), which is, with 95 per cent confidence bounds,

$$\log \left(\frac{E_{\text{peak}}}{\text{keV}} \right) = (0.28 \pm 0.04) \log \left(\frac{F}{\text{erg cm}^{-2}} \right) + (3.56 \pm 0.21). \quad (5)$$

Here both E_{peak} and the fluence are the values in the observer's frame. Based on the above relation, the peak energy of each generated GRB in our sample can be obtained from the fluence which is determined by the generated E_{iso} and redshift z . We set the trigger threshold of GRB detector in our simulation to be $0.74 \text{ photons cm}^{-2} \text{ s}^{-1}$ in 50–300 keV, the same as that of GBM (Meegan et al. 2009). Finally, we generate a sample of 1000 triggered GRBs, and compare the fluence distribution (in the energy range of 10–1000 keV) and E_{peak} distribution of the simulated GRB sample to those in the observed sample, respectively, in Fig. 4. The K-S tests return an accepting probability of 15 per cent and 22 per cent, respectively, for fluence distribution and for E_{peak} distribution.

3 CONSTRAINTS ON THE BULK LORENTZ FACTORS OF GRBS

3.1 Extension of the Band function to high energy

The properties of the generated GRBs include isotropic luminosity in 1–10 000 keV, isotropic photon energy in 1–10 000 keV, redshift, spectral indices, and peak energy of each GRB, based on which one can get differential fluence of the GRB at the Earth. We extrapolate the fluence of each GRB up to 100 GeV to obtain the high-energy photon flux at Earth (in unit of photons cm^{-2}) if there is no absorption, and calculate the expected number of high-energy photons (100 MeV to 100 GeV) detected by LAT. We treat the effective area of LAT as a product of two independent functions of photon energy and incidence angle, respectively, where the former function follows the response of the effective area to energy at normal incidence ($\theta = 0$) and the latter one follows the response of the effective area to incidence angle for 10 GeV photons. Based on the assumption of an isotropic distribution of GRBs in the celestial sphere, we generate the incidence angle for each GRB. A GRB is regarded as being detected by LAT if its 100 MeV to 100 GeV flux at the Earth can lead to detection of ≥ 5 events at LAT. Given all these necessary information (the effective area of LAT, the spectrum of simulated GRBs, and their incidence angle), we find that 145 GRBs in our sample can be detected by LAT, which translates to a detection rate of ~ 29 GRBs per year. This means that ~ 15 per cent of the total triggered GRBs would be detected by LAT, while the observed rate is only about 5 per cent (Ackermann et al. 2013). We also calculate the expected number of GRBs detected by LAT per year as a function of the number of > 100 MeV photons detected, as shown

¹Note that there is a peak around -6 in the distribution of β . This is because Goldstein et al. (2012) put all the GRBs with $\beta < -6$ into the bin of -6 . So the function used to fitting the distribution, of course, is not a realistic distribution for β at the very soft side. But adopting this function will not introduce error in our simulation, because extrapolating the spectrum to > 100 MeV with $\beta = -6$ will already result in a very low flux of the GRB at high energies, with no chance of being detected by LAT. It makes no difference if we extrapolate the spectrum with a smaller β .

²Here, one can also find E_{peak} of each GRB, in principle, through some empirical $E_{\text{peak}} - L_{\text{iso}}$ and $E_{\text{peak}} - E_{\text{iso}}$ relations (e.g. Amati et al. 2002; Ghirlanda et al. 2012) which is usually adopted in previous studies (e.g. Kakuwa et al.

2012; Liu & Wang 2013). However, the generated E_{peak} distribution in our sample with such relations is rejected by K-S test when compared with the E_{peak} distribution of observed GRBs. Therefore, we use an empirical $E_{\text{peak}} - \text{fluence}$ relation instead.

Figure 1. The normalized distribution of GRBs appearing with a bolometric luminosity L (left-hand panel) and appearing at redshift z (right-hand panel). The solid curves are the theoretical distribution based on the luminosity function and the redshift evolution function. For luminosity distribution, the solid curve $\propto \varphi(L)$ while for redshift distribution, the solid curve $\propto \rho(z) 4\pi D_c(z)^2/(1+z)/H(z)$ with D_c the comoving distance at z and $H(z)$ the Hubble parameter at z . The histograms are the distributions of luminosity L and redshift z of the total simulated GRBs. Note that not all the simulated GRBs can trigger GBM, so the luminosity distribution and the redshift distribution of triggered GRBs should be different from those shown here.

Figure 2. Distributions of the low-energy spectral index α (left) and high-energy spectral index β (right) from fluence spectral fits. The histograms, which are taken from Goldstein et al. (2012), represent the distributions of the observed GRB sample. Our fitting to the observed distributions are shown as solid curves. The distribution of α is fitted by the superposition (black curve) of a Gaussian distribution with the mean value of 0 and deviation of 0.6 (blue) and a skew normal distribution with the mean value of -0.6 , deviation of 0.45, and skewness of -2 (green). The distribution of β is fitted by the superposition (black curve) of a Gaussian distribution with the mean value of -5.9 and deviation of 0.15 (blue), a Gaussian distribution with the mean value of -3.5 and deviation of 1 (yellow) and a skew normal distribution of the mean value of -1.8 , deviation of 0.5, and skewness of -2.5 (green). These functions are used to generate the values of α and β for our simulated GRB sample.

by the red dashed line in each graph of Figs 5 and 6. It is significantly larger than the observed rate, which is shown by the black dashed line. Such an inconsistency between the simulated sample and the observed sample may imply an internal absorption of those high-energy photons, as we will discuss below.

3.2 Internal absorption

The pair production process ($\gamma\gamma \rightarrow e^-e^+$) is relevant for high-energy photons in a radiation field of compact astrophysical objects, leading to the possible attenuation of high-energy photons. This process has a kinematic threshold which is given by

$s \equiv \epsilon\epsilon_1(1 - \cos \theta)$, with ϵ and ϵ_1 being the energies of soft target photon and high-energy incidence photon, respectively, in units of $m_e c^2$ while θ is the colliding angle of the two photons (in the lab frame). During the prompt emission phase of a GRB, a huge amount of X/ γ -ray photons are produced in the compact fireball, which may in principle lead to absorption to the GeV photons. However, the ultrarelativistic bulk motion of the fireball would result in nearly parallel propagation of all the emitted photons (i.e. a large $\cos \theta$) and hence suppress the interaction or the optical depth of GeV photons. Thus, the detection rate of GeV emissions from GRBs may give a clue to the bulk Lorentz factor of the fireball. We note that the extragalactic background light (EBL) will also attenuate >10 GeV

Figure 3. Peak energy (E_{peak}) as a function of bolometric fluence F . The solid line shows the least-squares fit with a power law to the $E_{\text{peak}}-F$ correlation to the sample of 72 *Fermi*/GBM GRBs with measured redshift (filled blocks), while the shadow shows the 95 per cent C.L. bound.

photons when these photons are propagating in the intergalactic space. We ignore this effect in this work because most of high-energy photons of GRBs detected by LAT are around hundreds of MeV, given that the high-energy spectral indices of most GRBs (i.e. β) are less than -2 . Hence, the high-energy photon detection rate of LAT would be barely changed whether we consider the attenuation by EBL or not.

Considering the high-energy photons are emitted on-axis and all the photons are emitted from the same radius, the $\gamma\gamma$ optical depth can be given by (Granot, Cohen-Tanugi & Silva 2008; Hascoët et al. 2012)

$$\tau_{\gamma\gamma}(\epsilon_1) = 2^{1+2\beta} I(\beta) \frac{(-2-\beta)\sigma_T L_\gamma(\epsilon > E_{\text{peak}}) \Delta T \Gamma^{2(1+\beta)}}{4\pi R^2 E_{\text{peak}}(1+z)} \times \left[\frac{m_e^2 c^4}{\epsilon_1 E_{\text{peak}}(1+z)^2} \right]^{1+\beta}, \quad (6)$$

where ϵ_1 is the energy of an observed high-energy photon, σ_T is the Thomson cross-section. $I(\beta) = \int_0^1 y g(y) dy / (1-y^2)^{2+\beta}$ with $g(y) = \frac{3}{16} (1-y^2) [(3-y^4) \ln \frac{1+y}{1-y} - 2y(2-y^2)]$. Here we assume that only photons with energy beyond the spectral E_{peak} are energetic enough to annihilate with high-energy photons, and hence the low-energy spectral slope α does not show up in the expression. The radius of the fireball is given by $R = 2\Gamma^2 c \Delta T$ with ΔT being the variability time-scale of a single pulse. We can see the value of $\tau_{\gamma\gamma}$ is sensitively dependent on Γ , i.e. $\tau_{\gamma\gamma} \propto \Gamma^{2\beta-2}$, given $\beta < -2$ in most cases. Note that this formula gives a smaller optical depth than that obtained from the simple model assuming an isotropic radiation field in the comoving frame of the fireball. If one further considers that photons are emitted at different radius, the obtained optical depth will further decrease, as is indicated in previous studies (e.g. Granot et al. 2008; Zou, Fan & Piran 2011; Hascoët et al. 2012).

The bulk Lorentz factor of GRB fireball is thought to be related with the isotropic luminosity or energy (Liang et al. 2010; Ghirlanda et al. 2012; Lü et al. 2012; Tang et al. 2015). We employ a relation given by $\Gamma = \Gamma_0 E_{\text{iso},52}^k$, with Γ_0 and k being free parameters, instead of using the relations obtained in the previous literatures which have large uncertainties. Here, we consider $k = 0$ as the lower limit of k , since the previous studies all indicate a positive relation between the total energy and the bulk Lorentz factor. Then, we obtain optical depths for high-energy photons in each simulated GRB, and the

flux after absorption can be given by $f_{\text{abs}}(\epsilon_1) = f(\epsilon_1) \exp^{-\tau(\epsilon_1)}$. By tuning the values of k and Γ_0 , we can obtain the predicted LAT detection rate that matches the observed one. The feasible combinations of Γ_0 and k are so many that we cannot exhaust them. Thus, we present the LAT detection rate for three representative combinations of Γ_0 and k in the case of $\Delta T = 100$ ms in Fig. 5. The black dashed lines represent the observed rate and the red dashed lines represent the case without considering $\gamma\gamma$ absorption. Solid lines of different colours represent the results after considering the absorption for different values of k , while the black solid lines represent the solutions. In general, we see that the solid lines approach the red dashed lines (the no absorption case) more closely for larger Γ_0 , implying that the absorption is less important for larger Γ_0 , as it leads to a larger dissipation radius and consequently a smaller density of target photons. On the other hand, a larger k also leads to less absorption, because the energetic GRBs ($E_{\text{iso}} > 10^{52}$ erg) will then have larger Lorentz factors and, in consequence, smaller opacities. A larger k , in the meantime, results in smaller Lorentz factors for less energetic ($E_{\text{iso}} < 10^{52}$ erg) GRBs, which results in stronger internal absorption. But these ‘dim’ GRBs are mostly undetectable to LAT unless appearing in our vicinity, so the high opacity does not affect the LAT detection rate for these dim GRBs. The feasible range for k is about $k < 0.3$. A larger k will result in a small optical depth for high-luminosity GRBs and overpredict the LAT detection. Although the optical depth can be increased by choosing a small Γ_0 , the optical depth for $\lesssim 10$ MeV photons in low-luminosity GRBs would then be larger than unity, which is not consistent with observation. This sets a lower bound for Γ_0 to be about 50. The upper bound of Γ_0 can be obtained with $k = 0$. Given the uncertainty in the variability time-scale, we also consider a case with $\Delta = 10$ ms and the results are shown in Fig. 6. Given a smaller variability time, we need a larger bulk Lorentz factor to achieve the same opacity. However, since the opacity sensitively depends on the bulk Lorentz factor, the later one does not need to increase much.

In Fig. 7, we show the distributions of the Lorentz factors of simulated GRBs for the solutions of Γ_0 and k that can reproduce the LAT detection rate with $\Delta T = 100$ and 10 ms, respectively, in the upper panel and the lower panel. Interestingly, we can see the Lorentz factors for most GRBs lie between 50 and 250 for all these solutions. We note that, however, some bright GRBs present a hard extra-component spectrum at GeV which is not considered in this work. The presence of the extra-component would increase the detectability, leading to the detection rate obtained here is a lower limit and the Lorentz factor is an upper limit. But the fraction of GRBs that have a significant extra component is small, so this correction should not be large. We also check the Thomson opacity for each GRB. For the given combinations shown in Fig. 7. The Thomson optical depths for almost all the GRBs are smaller than unity, and 60–90 per cent GRBs have optical depth smaller than 0.1 in the case of $\Delta T = 100$ ms and that fraction in the case of $\Delta T = 10$ ms is 40–80 per cent, unless the baryon loading factor is $\gg 1$. Thus, the Thomson opacity is less constraining than the $\gamma\gamma$ opacity on the bulk Lorentz factor.

4 DISCUSSIONS AND CONCLUSIONS

In this work, we studied the properties of the bulk Lorentz factors of GRBs from the viewpoint of the LAT detection rate. Taking advantage of various empirical relations of GRBs, we first generated a GRB sample with information about the burst distances and spectra. We then calculate the LAT detection rate as a function of the

Figure 4. *Left:* Comparison of the fluence (in the energy range of 10–1000 keV) distributions of simulated GRBs (solid line) to that of *Fermi*/GBM GRBs with measured redshift (dashed line). The K–S test gives a probability of 15 per cent for the agreement of the two distributions. *Right:* Same as the left-hand panel but for E_{peak} distributions. The K–S test gives a probability of 22 per cent for the agreement of the two distributions.

Figure 5. Predicted number of GRB detected by LAT per year as a function of the number of high-energy (>100 MeV) photons detected from each burst in the case of $\Delta t = 100$ ms. Note that we set the detection threshold of LAT to be receiving ≥ 5 high-energy photons from a GRB. Γ_0 is different in each panel. As shown, The black dashed lines represent the realistic LAT detection rate averaged over the period from 2008 August 25 to 2011 July 31. The red dashed lines represent the case of no absorption. Solid lines with different colours represent cases for different values of k and black solid lines represent the solutions that can match the observation.

Figure 6. The same as Fig. 5 but for $\Delta t = 10$ ms.

Figure 7. The number fraction of GRBs in the simulated sample as a function of the bulk Lorentz factors for various combinations of γ_0 and k that can match the *Fermi*/LAT observation, in the case of $\Delta t = 100$ ms (upper panel) and $t = 10$ ms (lower panel).

number of high-energy photons, considering the attenuation effect on the burst spectra at high energies. As the attenuation optical depth is highly sensitive to the bulk Lorentz factors of GRBs, we further constrain the properties of the Lorentz factors of GRBs. We find that to get a consistent LAT detection rate with the observed one, the distribution of Lorentz factors of the vast majority of GRBs should be in an appropriate range with 50–250 given variability time-scales of both $\Delta t = 100$ and 10 ms for the prompt emissions of GRBs.

In this work, the Band function, an empirical function that has been fairly successful in fitting the spectra of most GRBs, is used to describe the GRB spectra. This empirical function may reflect the physics of the synchrotron emission (Zhang et al. 2016). There are some other functions available to fit the spectrum, such as the ‘Comptonized’ model and the smoothly broken power-law model which are preferred for fitting some GRBs (e.g. Kaneko et al. 2006; Kienlin et al. 2014; Bhat et al. 2016). Particularly, the ‘Comptonized’ model suggests an exponential cutoff in the spectrum at high energy and hence the extrapolated fluence at 100 MeV is very low. However, we note that the uncertainty in the choice of the spectral function for GRB will not introduce much error in our results. This is because that GRBs that favour the ‘Comptonized’ model tend to have low fluence and/or soft spectrum above the peak energy. Thus, even if we extrapolate the fluences of these GRBs to high-energy energies with the ‘Comptonized’ model instead of the Band function, the predicted LAT detection rate will not change (see the Appendix for a detailed analysis).

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APPENDIX A: SPECTRAL FUNCTION FOR THE PROMPT EMISSION OF GRBS: BAND VERSUS COMP

We look up into the GBM GRB catalogue³ and collect a sample of 2099 GRBs with complete spectral information from 2008 August 14 to 2017 December 30. Among the sample, there are 1234 GRBs whose best-fitting model are labelled as ‘COMP’ (abbreviation for the ‘Comptonized’ model), 313 are labelled as ‘BAND’ (abbreviation for the Band function) or ‘SBPL’ (abbreviation for the smoothly broken power law), and the rest are labelled as ‘PLAW’

³<https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html>

Figure A1. Distribution of the reduced χ^2 when all the GRBs in the sample are fitted by COMP and BAND, respectively.

(abbreviation for power law). Extrapolating the flux to high energy with SBPL or PLAW does not result in significant difference from that with BAND, while extrapolating the flux with COMP leads to big difference, since it introduces an exponential cutoff in the high-energy spectrum. Thus, in what follows, we mainly discuss the difference between BAND and COMP and show that employing the BAND model as the intrinsic spectrum for all the simulated GRBs will not introduce much error in our results.

First, from the point of view of the χ^2 test, BAND is preferred to COMP for the spectrum fitting. In the sample, there are 1425 GRBs with a smaller reduced χ^2 value when fitted by BAND than fitted by COMP. This can be seen in the attached Fig. A1, in which we plot the respective distribution of the reduced χ^2 value fitted by these two different models for all the GRBs in the sample. We can also see that, for the majority of GRBs, the reduced chi-square values are smaller than 1.5 for the BAND fitting, implying that BAND is nevertheless a quite acceptable model for the spectral fitting.

In the GBM GRB catalogue, the best-fitting model is determined by the Castor C-statistics instead of the χ^2 test. The former one has a better performance than the latter one when there are a few counts in data bins, because the former one constructs a maximum-likelihood

estimator C based on the Poisson distribution of detected counts. Note that for a spectrum with many counts per bin, $C \rightarrow \chi^2$. Thus, for most GRBs which have a high fluence and a relatively hard spectrum above the peak energy, BAND is usually the best choice, or the improvement of the fitting with COMP with respect to that with BAND is not significant. To look into this issue, we show the 2D distribution of GRBs in the plane of β (when GRBs are fitted by BAND) and the 1–1000 keV fluence in Fig. A2. Most GRBs that are located at top-right region, the favoured region for LAT detection when extrapolating the spectrum up to 100 MeV, are best fitted by BAND or SBPL. Since the simulated GRB sample is consistent with the observed one in terms of both the β distribution and the fluence distribution, we expect that the predicted LAT detection rate will not change even if we use COMP (instead of BAND) for the spectral extrapolation for those GRBs that are best fitted by COMP.

Besides, we calculate the LAT detection rate of the simulated GRB sample with the same method introduced in Section 2 and 3, but using COMP instead of BAND. It results in null detection of LAT, suggesting that COMP cannot describe all the GRBs.

Figure A2. 2D distribution of GRBs in the β – fluence plane. Red filled circles represent GRBs best fitted by COMP while blue filled squares represent GRBs best fitted by BAND.

Table A1. Spectral properties of 72 long *Fermi*/GBM GRBs with measured redshifts, which are taken from Jochen Greiner's collection^a.

Name	z	α	β	E_{peak}^b (keV)	Fluence (10^{-6} erg cm $^{-2}$)	Energy range (keV)	Bolometric fluence ^c (10^{-6} erg cm $^{-2}$)	GCN number
080810	3.35	-0.91 ± 0.12		313.5 ± 73.6	6.9 ± 0.5	50–300	20.49	8100
080916A	0.689	-0.9 ± 0.1		109 ± 9	15 ± 5	25–1000	21.60	8263
080916C	4.35	-0.91 ± 0.02	-2.08 ± 0.06	424 ± 24	190 ± 0	8–30000	161.14	8278
081007	0.5295	-1.4 ± 0.4		40 ± 10	1.2 ± 0.1	25–900	2.28	8369
081109	0.9787	-1.28 ± 0.09		240 ± 60	6.53 ± 0.43	8–1000	9.06	8505
081221	2.26	-0.42 ± 0.03	-2.91 ± 0.08	77 ± 1	37 ± 1	8–1000	39.98	8704
081222	2.77	-0.55 ± 0.07	-2.1 ± 0.06	134 ± 9	13.5 ± 0.8	8–1000	20.99	8715
090323	3.57	-0.89 ± 0.03		697 ± 51	100 ± 1	8–1000	175.84	9035
090328	0.736	-0.93 ± 0.02	-2.2 ± 0.1	653 ± 45	80.9 ± 1	8–1000	150.46	9057
090423	8.26	-0.77 ± 0.35		82 ± 15	1.1 ± 0.3	8–1000	1.39	9229
090424	0.544	-0.9 ± 0.02	-2.9 ± 0.1	177 ± 3	52 ± 1	8–1000	59.01	9230
090516	4.109	-1.51 ± 0.11		$185.6^{+98.4}_{-42.5}$	23 ± 5	8–1000	32.16	9415
090618	0.54	$-1.26^{+0.06}_{-0.02}$	$-2.5^{+0.15}_{-0.33}$	$155.5^{+11.1}_{-10.5}$	270 ± 6	8–1000	343.78	9535
090902B	1.822	-0.70 ± 0.01	$-3.85^{+0.21}_{-0.31}$	775 ± 11	374 ± 3	50–10000	386.10	9866
090926A	2.1062	-0.75 ± 0.01	$-2.59^{+0.04}_{-0.05}$	314 ± 4	145 ± 4	8–1000	190.29	9933
090926B	1.24	-0.13 ± 0.06		91 ± 2	8.7 ± 0.3	10–1000	11.01	9957
091003A	0.8969	-1.13 ± 0.01	-2.64 ± 0.24	486.2 ± 23.6	37.6 ± 0.4	8–1000	52.58	9983
091127	0.49	-1.27 ± 0.06	-2.2 ± 0.02	36 ± 2	18.7 ± 0.2	8–1000	27.04	10204
091208B	1.063	$-1.48^{+0.05}_{-0.05}$		$144.2^{+18}_{-13.9}$	5.8 ± 0.2	8–1000	7.99	10266
100414A	1.368	-0.58 ± 0.01		$627.6^{+12.5}_{-12.1}$	129 ± 2	8–1000	228.33	10595
100615A	1.398	$-1.24^{+0.08}_{-0.06}$	$-2.27^{+0.11}_{-0.12}$	$85.73^{+7.82}_{-9.33}$	8.64 ± 0.17	8–1000	11.81	10851
100728A	1.567	-0.75 ± 0.01	$-3.04^{+0.23}_{-0.57}$	$344.3^{+9.1}_{-7.9}$	129.1 ± 0.8	8–1000	153.33	11006
100728B	2.106	-0.9 ± 0.1		131 ± 15	2.4 ± 0.1	8–1000	3.12	11015
100802A	<4	$-1.17^{+0.21}_{-0.25}$		149^{+41}_{-96}	2.24 ± 0.28	10–1000	3.02	11046
100814A	1.44	$-0.64^{+0.14}_{-0.12}$	$-2.02^{+0.09}_{-0.12}$	$106.4^{+13.9}_{-12.6}$	19.8 ± 0.6	10–1000	32.60	11099
100906A	1.727	$-1.34^{+0.08}_{-0.06}$	$-1.98^{+0.06}_{-0.07}$	$106^{+17.5}_{-20.2}$	26.4 ± 0.3	10–1000	43.80	11248
101219B	0.55	0.33 ± 0.36	-2.12 ± 0.12	70 ± 8	5.5 ± 0.4	10–1000	8.05	11477
110213A	1.46	-1.44 ± 0.05		$98.4^{+8.5}_{-6.9}$	10.3 ± 0.3	10–1000	14.36	11727
110731A	2.83	-0.80 ± 0.03	-2.98 ± 0.30	304 ± 13	22.18 ± 0.06	10–1000	26.26	12221
110818A	3.36	-1.33 ± 0.08		256.3 ± 55.3	8.2 ± 0.6	10–1000	11.64	12287
111107A	2.893	-1.38 ± 0.21		108 ± 32	1.392 ± 0.197	10–1000	1.91	12545
111228A	0.714	-1.9 ± 0.1	-2.7 ± 0.3	34 ± 3	18 ± 0	10–1000	29.47	12744
120119A	1.728	-0.98 ± 0.03	-2.36 ± 0.09	189.2 ± 8.3	38.7 ± 0.1	10–1000	52.51	12874
120326A	1.798	-0.98 ± 0.14	-2.53 ± 0.15	46.45 ± 3.67	3.539 ± 0.174	10–1000	4.46	13145
120624B	2.1974	-0.85 ± 0.01	-2.36 ± 0.08	566 ± 20	191.6 ± 0.2	10–1000	318.46	13383
120711A	1.405	-0.94 ± 0.01	-2.40 ± 0.04	973 ± 35	194.2 ± 0.2	10–1000	381.89	13437
120716A	2.486	-0.48 ± 0.22	-2.19 ± 0.17	115 ± 19	14.7 ± 0.1	10–1000	21.09	13498
120907A	0.97	-0.75 ± 0.25		154.50 ± 32.90	0.78 ± 0.11	10–1000	1.03	13721
120909A	3.93	-1.3 ± 0.1		370 ± 140	21 ± 2	10–1000	31.01	13737
120922A	3.1	1.6 ± 0.7	-2.3 ± 0.1	37.7 ± 3.5	6.5 ± 0.4	10–1000	8.03	13809
121128A	2.2	-0.80 ± 0.12	-2.41 ± 0.10	62.2 ± 4.6	10.4 ± 0.4	10–1000	13.06	14012
121211A	1.023	-0.30 ± 0.34		95.96 ± 12.60	0.4825 ± 0.0507	10–1000	0.61	14078
130420A	1.297	1.00 ± 0.13		56 ± 3	14 ± 0.5	10–1000	17.11	14429
130427A	0.3399	-0.789 ± 0.003	-3.0 ± 0.02	830 ± 5	1975 ± 3	10–1000	3161.17	14473
130518A	2.488	-0.86 ± 0.01	-2.27 ± 0.04	396 ± 9	93 ± 0.6	10–1000	148.35	14674
130610A	2.092	-1.0 ± 0.1		294.9 ± 42.9	6.1 ± 0.4	10–1000	8.73	14858
130612A	2.006	-1.3 ± 0.3		61.9 ± 10.5	0.57 ± 0.06	10–1000	0.78	14896
130925A	0.347	-1.50 ± 0.05		107 ± 3	0.283 ± 0.006	10–1000	0.40	15261
131011A	1.874	-0.79 ± 0.08	-2.0 ± 0.1	220 ± 30	66 ± 0.3	10–1000	108.35	15331
131108A	2.4	-0.91 ± 0.02	-2.6 ± 0.1	373 ± 14	36.5 ± 0.4	10–1000	49.30	15477
131231A	0.642	-1.10 ± 0.01	-2.14 ± 0.01	146 ± 3	2.51 ± 0.01	10–1000	3.82	15644
140206A	1.98	0.2 ± 0.1	-2.4 ± 0.1	120 ± 6	14.7 ± 0.3	10–1000	18.72	15796
140213A	1.2076	-1.01 ± 0.03	-2.41 ± 0.04	80 ± 2	20.4 ± 0.3	10–1000	26.09	15833
140304A	5.3	-1.1 ± 0.1		185 ± 35	2.6 ± 0.2	10–1000	3.54	15923
140423A	3.26	-0.25 ± 0.11	-1.97 ± 0.06	125 ± 9	20 ± 1	10–1000	34.09	16152
140506A	0.889	-0.9 ± 0.2	-2.0 ± 0.1	141 ± 36	3.5 ± 0.2	10–1000	5.47	16220
140508A	1.027	-1.07 ± 0.02	-2.38 ± 0.09	256.2 ± 11.8	62.4 ± 0.7	10–1000	86.77	16224
140512A	0.725	-1.33 ± 0.03		588 ± 84	43 ± 1	10–1000	68.73	16262

Table A1. – continued

Name	z	α	β	E_{peak}^b (keV)	Fluence (10^{-6} erg cm $^{-2}$)	Energy range (keV)	Bolometric fluence ^c (10^{-6} erg cm $^{-2}$)	GCN number
140606B	0.384	-1.22 ± 0.04		473.00 ± 82.60	9.018 ± 0.369	10–1000	13.88	16363
140620A	2.04	-1.1 ± 0.1		77 ± 5	5.3 ± 0.2	10–1000	6.98	16426
140623A	1.92	-1.46 ± 0.1		350^{+220}_{-100}	6.8 ± 0.6	10–1000	10.07	16450
140703A	3.14	-1.10 ± 0.06		177 ± 14	0.74 ± 0.04	10–1000	1.00	16512
140801A	1.32	-0.40 ± 0.04	-3.6 ± 0.4	122 ± 3	12.2 ± 0.1	10–1000	12.71	16658
140808A	3.29	-0.4 ± 0.1	-2.9 ± 0.3	115.2 ± 7.7	3.2 ± 0.2	10–1000	3.51	16669
140907A	1.21	-0.97 ± 0.08		113 ± 7	5.5 ± 0.2	10–1000	7.20	16798
141004A	0.573	-1.3 ± 0.1		147 ± 28	2.2 ± 0.2	10–1000	3.00	16900
141220A	1.3195	-0.80 ± 0.05		180 ± 9	5.23 ± 0.15	8–1000	7.00	17205
141221A	1.452	-1.07 ± 0.13		152.4 ± 28.5	3.4 ± 0.4	8–1000	4.50	17216
141225A	0.915	-0.35 ± 0.17	-2.0 ± 0.1	187 ± 29	6.5 ± 0.3	10–1000	10.66	17241
150301B	1.5169	-1.1 ± 0.1	-2.0 ± 0.2	180 ± 38	4.4 ± 0.2	10–1000	6.52	17525
150314A	1.758	-0.60 ± 0.01	-2.32 ± 0.04	311 ± 5	85.3 ± 0.4	10–1000	128.06	17579
150514A	0.807	-1.34 ± 0.07	-2.51 ± 0.17	73 ± 6	4.9 ± 0.2	10–1000	6.44	17819

Notes: ^a<http://www.mpe.mpg.de/~jcg/grbgen.html>^bIn the observer's frame.^cIn the energy range of 1–10 000 keV.This paper has been typeset from a $\text{\LaTeX}$ file prepared by the author.