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Sequences in the Hardness Ratio-Peak Energy Plane of Gamma-Ray Bursts *

Xiao-Hong Cui[1,4], En-Wei Liang[1,2,3] and Rui-Jing Lu[1,2,4]

[1] National Astronomical Observatories/Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011; *ciwei8008@163.com*

[2] Department of Physics, Guangxi University, Nanning 530004

[3] Department of Astronomy, Nanjing University, Nanjing 210093

[4] Graduate School of the Chinese Academy of Sciences, Beijing 100039

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Abstract The narrowness of the distribution of the peak energy of the νF_ν spectrum of gamma-ray bursts (GRBs) and the unification of GRB populations are great puzzles yet to be solved. We investigate the two puzzles based on the global spectral behaviors of different GRB populations, the long GRBs, the short GRBs, and the X-ray flashes (XRFs), in the $HR - E_{\rm p}$ plane (HR the spectral hardness ratio) with BATSE and HETE-2 observations. It is found that the long GRBs and the XRFs observed by HETE-2 seem to follow the same sequence in the $HR-E_{\rm p}$ plane, with the XRFs at the low end of this sequence. We fit the sequence by a universal Band function, and find that this sequence is mainly defined by the low energy index α, and is insensitive to the high energy index, β. With fixed $\beta = -5$, a best fit is given by $\alpha = -1.00$ with $\chi^2_{\rm min}/{\rm dof} = 2.2$. The long and short GRBs observed by BATSE follow significantly different sequences in the $HR - E_{\rm p}$ plane, with most of the short GRBs having a larger hardness ratio than the long GRBs at a given $E_{\rm p}$. For the long GRBs a best-fit yields $\alpha = -0.30$ and $\beta = -2.05$. For the short GRBs, a best fit gives $\alpha = -0.60$ with $\chi^2_{\rm min} = 1.1$ (with β fixed at -2.0 because it is numerically unstable). The α value for the short GRBs is significantly greater than that for the long GRBs. These results indicate that the global spectral behaviors of the long GRB sample and the XRF sample are similar, while that of the short GRBs is different. The short GRBs seem to be a unique subclass of GRBs, and they are not the higher energy extension of the long GRBs.

Key words: gamma ray: bursts – gamma ray: observations – methods: statistical

1 INTRODUCTION

Gamma-Ray Bursts (GRBs) are short and intense gamma-ray radiation from cosmological distances. Much progress on GRBs and their afterglows has been made in the past decade (Fishman

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& Meegan 1995; Piran 1999; van Paradijs et al. 2000; Cheng & Lu 2001; Mészáros 2002; Zhang & Mészáros 2004; Piran 2005). It is believed today that GRBs are produced by conical ejecta (jets) powered by central engines at cosmological distances. Numerous observations have been successfully explained by the popular fireball model. However, this phenomenon is still mysterious. A great number of puzzles are still to be solved.

Unification of the GRB population is one of the puzzles. Based on their distribution in the burst duration-harness ratio (HR) plane, Kouveliotou et al. (1993) suggested there are two subclasses of GRBs, long GRBs and short GRBs separated at ~ 2 seconds (see also Qin et al. 2001). In recent years, a new subclass of GRBs, the X-ray flashes (XRFs), was also identified (e.g., Heise et al. 2001). Are the different subclasses of GRBs the same phenomenon? How to provide a unified description for the GRB population? These questions have roused much attention (Heise et al. 2001; Kippen et al. 2003; Sakamoto et al. 2004a, 2004b; Lamb et al. 2003; Yamazaki et al. 2003a, 2003b, 2004a, 2004b; Lloyd-Ronning et al. 2004; Zhang et al. 2004; Dai & Zhang 2004; Liang & Dai 2004).

The peak energy of the νF_ν spectrum, $E_{\rm p}$, is an important quantity of the GRB. Liang et al. (2002a) showed a limitation of E_p with burst duration. This limitation cannot be explained by the current fireball model. It may represent a constraint on the fireball model. The narrowness of the $E_{\rm p}$ distribution is also a great puzzle. The distribution based on a time –resolved spectral catalog of bright BATSE GRBs (Preece et al. 2000) shows that $E_{\rm p}$ is narrowly clustered at 200–400 keV. It might be caused by some selection effects of the BATSE, which is sensitive to photons in the energy band of 50–300 keV. HETE-2 is sensitive to photons in an energy band of ∼10–400 keV, and it is suitable for observations to XRFs. It is found that the spectra of XRFs are well fitted by the Band function (Band et al. 1993) with similar spectral indices as long GRBs (e.g., Kippen et al. 2003; Barraud et al. 2003), and they obey the same relations of $E_{\rm p}$ to equivalent-isotropic energy (Amati et al. 2002; Lloyd-Ronning & Ramirez-Ruiz 2002; Sakamoto et al. 2004a; Lamb et al. 2003; Liang, Dai & Wu 2004; Yonetoku et al. 2004) and to jet energy (Ghirlanda, Ghisellini & Lazzati 2004b; Dai, Liang & Xu 2004). The duration distributions of long GRBs and XRFs are also similar (Heise et al. 2001). These facts suggest that long GRBs and XRFs are the same phenomenon, and XRFs are a lower peak-energy extension of long GRBs (e.g., Kippen et al. 2003; Sakamoto et al. 2004a). Therefore, XRFs extend the $E_{\rm p}$ distribution to a few keV. Whether or not the $E_{\rm p}$ distribution can be broadened to a higher energy is still uncertain. Short GRBs tend to have a harder spectrum. Are short GRBs a higher energy extension of long GRBs? Ghirlanda, Ghisellini & Celotti (2004a) presented an analysis of the short GRBs. They found that the spectra of the short bursts are well fitted by a single power law with an exponential cutoff at high energies. The statistics in the high energy channels of the spectra is too poor to constrain the high energy power law component of the Band function. They also found that the spectral properties of the short GRBs are similar to the first 1 second of long GRBs. Yamazaki et al. (2004b) proposed a unified description for long GRBs, short GRBs, and XRFs based on an off-axis jet model. If long and short GRBs are the same phenomenon, one may expect that short GRBs are a higher energy extension of long GRBs, and long GRBs, short GRBs, and XRFs form a sequence in the $HR - E_{\rm p}$ plane, since the short GRBs tend to have a harder spectrum. In this work we investigate this issue with the current GRB samples observed by BATSE and HETE-2.

This paper is arranged as follows. The method of analysis is presented in Section 2. The global spectral behaviors of the long GRB and XRF samples observed by HETE-2 are shown in Section 3, and those of the long and short GRB samples observed by BATSE, in Section 4. A discussion and conclusions are presented in Section 5.

2 ANALYSIS METHOD

It is well known that the GRB spectrum can be well fitted by the Band function (Band et al. 1993),

$$N(E) = A \begin{cases} (\frac{E}{100\,\mathrm{keV}})^{\alpha} \exp(-E/E_0)\,, & E \leq (\alpha-\beta)E_0, \\ (\frac{(\alpha-\beta)E_0}{100\,\mathrm{keV}})^{\alpha-\beta} \exp(\beta-\alpha)(\frac{E}{100\,\mathrm{keV}})^{\beta}\,, & E \geq (\alpha-\beta)E_0, \end{cases} \tag{1}$$

where A is a normalization parameter, E_0 the break energy (in keV), α and β the low and high band spectral indices, respectively. For the case of $\beta < -2$ and $\alpha > -2$, the peak energy can be derived by $E_{\rm p} = (2+\alpha)E_0$, which corresponds to the energy at the maximum flux in νf_ν spectrum. For a spectrum with $\alpha > -1$ and $\beta > -2$, the "true" $E_{\rm p}$ lies at an unknown energy beyond the high end of the data, and only a lower boundary, $E_{\rm b}$, to the energy of the high-energy power-law component characterized by β is known. The observed fluence at a given bandpass (E_1, E_2) as a function of $E_{\rm p}$ is given by

$$S_{E_1-E_2}(E_{\rm p}) = \int_{E_1}^{E_2} EN(E)dE. \tag{2}$$

The hardness ratio is defined as

$$HR(E_{\rm p}) \equiv \frac{S_{E_1-E_2}(E_{\rm p})}{S_{E_3-E_4}(E_{\rm p})}, \tag{3}$$

and its error caused by $E_{\rm p}$ is (without considering the errors of α and β in our analysis),

$$\sigma_{HR} = HR\sqrt{\Big(\frac{\sigma_{S_{E_3-E_4}}}{S_{E_3-E_4}}\Big)^2 + \Big(\frac{\sigma_{S_{E_1-E_2}}}{S_{E_1-E_2}}\Big)^2}, \tag{4}$$

where

$$\sigma_{S_{E_i-E_j}} = \begin{cases} \frac{|2+\alpha|}{E_{\rm p}}\frac{\sigma_{E_{\rm p}}}{E_{\rm p}}\int_{E_{\rm i}}^{E_{\rm j}} E^2 N dE\,, & E \leq (\alpha-\beta)E_0, \\ \frac{|\alpha-\beta|\sigma_{E_{\rm p}}}{E_{\rm p}}\int_{E_{\rm i}}^{E_{\rm j}} EN(E)dE\,, & E \geq (\alpha-\beta)E_0. \end{cases} \tag{5}$$

GRBs with similar spectral behaviors should trace out a sequence in the $HR - E_{\rm p}$ plane. In this paper we investigate whether or not different subclasses of GRBs are in a $HR - E_{\rm p}$ sequence characterized by a universal Band function by using the GRBs observed by BATSE and HETE-2.

3 LONG GRBS VS. XRFS

HETE-2 is sensitive to photons in the energy band $\sim 10 - 400\,$keV. It is suitable for observing GRBs and XRFs. We examine the sequence of long GRBs and XRFs in the $HR-E_{\rm p}$ plane with the bursts observed by HETE-2. Of the 63 HETE-2 bursts (to the end of June, 2004), 34 are long GRBs and 22 are XRFs. We include only the long GRBs and the XRFs in our analysis. The values of $E_{\rm p}$, fluences ($S_{30-400\,\mathrm{keV}}$ and $S_{2-30\,\mathrm{keV}}$, in energy bands of 30–400 keV and $2-30\,$keV, respectively) and their errors for 40 bursts are taken from Sakamoto et al. (2004b). The other bursts are taken from HETE-2 burst home page[1] and G. Ricker's report (private communication), but no errors of $E_{\rm p}$ and fluences are available for these. The errors of GRB 030324

[1] http://space.mit.edu/HETE/Bursts/

and GRB 030723 given by Sakamoto et al. (2004b) are extremely large. We calculate the average percentages of the errors for the bursts from Sakamoto et al. (2004b) not including GRB 030324 and GRB 030723, and obtain $\langle \sigma_{E_\mathrm{p}}/E_\mathrm{p}\rangle \simeq 0.19$, $\langle \sigma_{S_{30-400\mathrm{keV}}}/S_{30-400\,\mathrm{keV}}\rangle \simeq 0.26$, $\langle \sigma_{S_{2-30\,\mathrm{keV}}}/S_{2-30\,\mathrm{keV}}\rangle \simeq 0.09$. Thus, for those bursts with no errors available, and for the two bursts, GRB 030324 and GRB 030723, we take $\sigma_{E_\mathrm{p}} = 0.19E_\mathrm{p}$, $\sigma_{S_{30-400\,\mathrm{keV}}} = 0.26S_{30-400\,\mathrm{keV}}$, $S_{2-30\,\mathrm{keV}} \simeq 0.09S_{2-30\,\mathrm{keV}}$. HR^ob is calculated by $HR^\mathrm{ob} = S_{30-400\,\mathrm{keV}}/S_{2-30\,\mathrm{keV}}$, and its error is given by Eq. (4) with measured errors of the fluences in the two energy bands. HR^ob as a function of E_p for the HETE-2 bursts is shown in Fig. 1. From Fig. 1 we find that the GRBs and XRFs seem to form a well-defined sequence. We fit this sequence with Eq. (3) by minimizing χ^2,

$$\chi^2 = \sum_i \frac{(HR_i^\mathrm{ob} - HR_i^\mathrm{th})^2}{\sigma^2_{HR_i^\mathrm{ob}} + \sigma^2_{HR_i^\mathrm{th}}}\,, \tag{6}$$

where $\sigma_{HR_i^\mathrm{th}}$ is the error of HR caused by the uncertainty of E_p, which is calculated by Eqs. (4) and (5). In our calculations, we find that this sequence is characterized by α, while β is numerically unstable (varying it from -5 to -10 gives comparable values of χ^2_min (~ 118)). So we fix $\beta = -5$, and then make a best fit to the sequence, and obtain $\alpha = -1.00$ with $\chi^2_\mathrm{min}/\mathrm{dof} = 2.2$. The best fit curve is also plotted in Fig. 1 (the solid curve). These results show that both the GRBs and the XRFs can be described by a universal Band function with E_p ranging from a few keV to hundreds of keV. The XRFs are at the lower end of the sequence of long GRBs, suggesting that XRFs are the lower energy extension of the long GRB sequence.

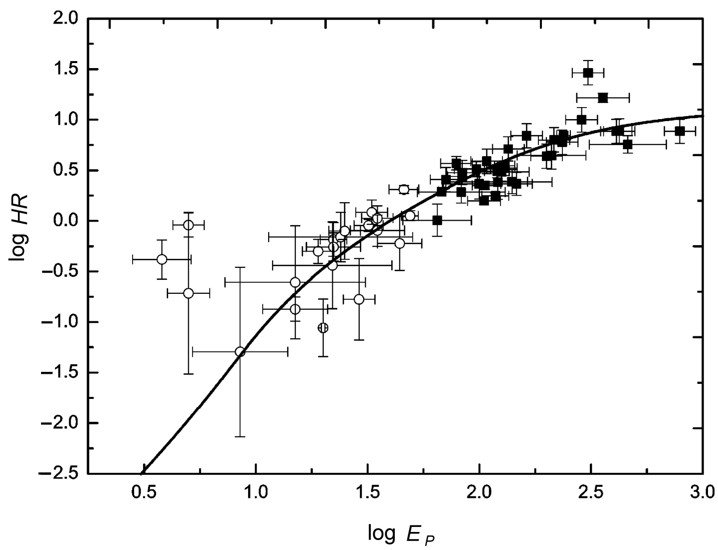

Fig. 1 HR as a function of E_p for the long GRBs (solid circles) and XRFs (open circles) observed by HETE-2. The solid curve is the best fit with Eq. (3) by fixing $\beta = -5$.

4 LONG GRBS VS. SHORT GRBS

In the present GRB sample, most of the short GRBs were observed by BATSE. To investigate whether or not both short and long GRBs can be characterized by a universal Band function, we use the long BATSE GRB sample (149 GRBs) given by Lloyd-Ronning & Ramirez-Ruiz

(2002) and the short BATSE GRB sample (28 GRBs) given by Ghirlanda et al. (2004a). The fluences and their errors are available at the FLUX TABLE of the Current BATSE Catalog [2]. We calculate the hardness ratios using the observed fluences in channel 3 ($110 - 320$ keV) and channel 2 ($55 - 110$ keV), and their errors are derived by Eq. (4) with the errors of the fluences in channels 2 and 3. The HR versus $E_{\rm p}$ plot for the long BATSE GRB sample is shown in Fig. 2. Since no $E_{\rm p}$ errors of these bursts are available in Lloyd-Ronning & Ramirez-Ruiz (2002), we fit the long GRB sequence by Eq. (3) without considering the errors. The result shows that the minimum residual square, $\mu^2 = \sum_i (HR_i^{\rm ob} - HR_i^{\rm th})^2$, is 131 at $(\alpha, \beta) = (-0.3, -2.05)$, which is also shown in Fig. 2.

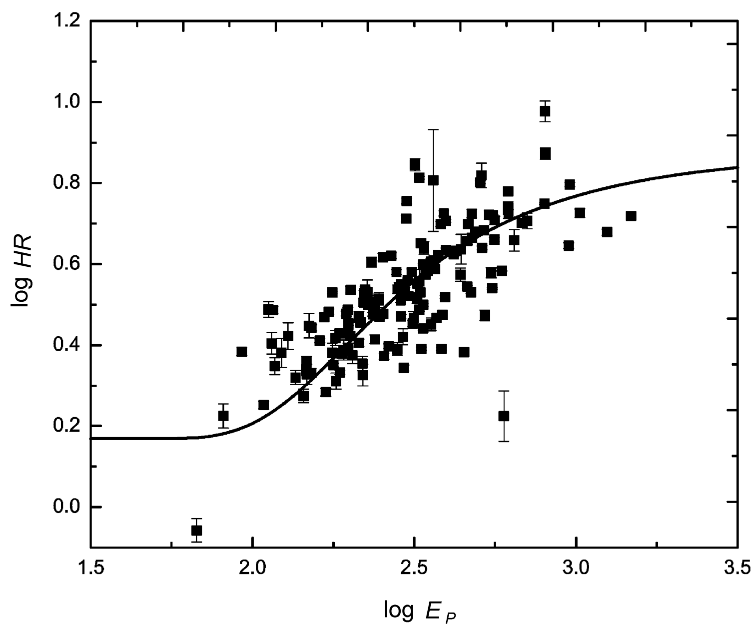

Fig. 2 HR as a function of $E_{\rm p}$ for the long BATSE GRBs. The solid curve is the best fit with Eq. (3).

The HR versus $E_{\rm p}$ plot for the short BATSE GRB sample is shown in Fig. 3. The spectrum of these short bursts is well fitted by a single power law with an exponential cutoff at high energies. Besides, the statistics in the high energy channels of the spectra is too poor to constrain the high energy power law component of the Band model (Ghirlanda et al. 2004a). We make a best fit to the short GRB sequence with Eq. (3). We find that β is again ill-defined. So we fix $\beta = -2$ (similar to the long BATSE GRBs), and then make a best fit to the sequence, and derive $\alpha = -0.60$ with $\chi^2_{\rm min}/{\rm dof} = 1.1$. The α value is quite similar to the mean value of α in Ghirlanda et al. (2004a) (–0.58). The best fit curve is plotted in Fig. 3 (the solid curve). For comparison, the best fit for the long BATSE GRB sample is also plotted in Fig. 3 (dotted curve). It is found that the two best fits are quite different. Most of the short GRBs are above the long GRB sequence, indicating that the short GRBs tend to have a larger HR than the long GRBs at a given $E_{\rm p}$. Short GRBs are unlikely to be a higher energy extension of long GRBs.

[2] http://cossc.gsfc.nasa.gov/batse/

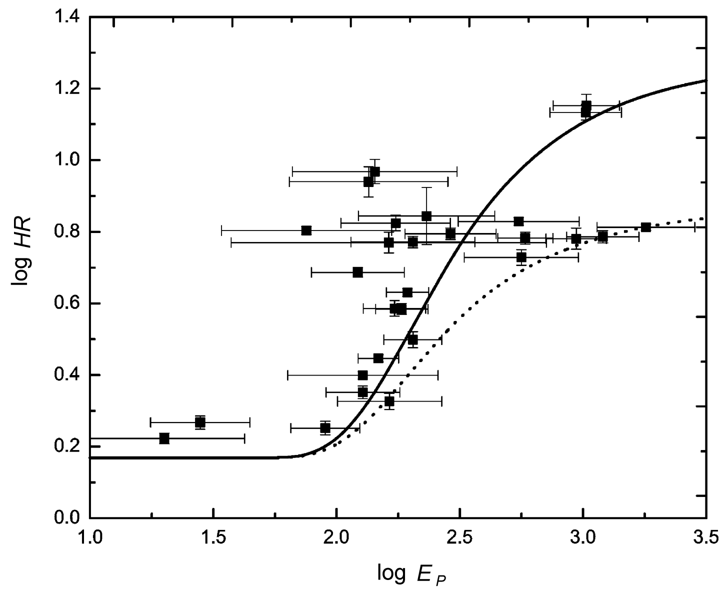

Fig. 3 HR as a function of $E_{\rm p}$ for the short BATSE GRBs. The solid curve is the best fit with Eq. (3) with fixed $\beta = -2.0$, and the dotted curve is the best fit for the long BATSE GRB sample.

5 CONCLUSIONS AND DISCUSSION

We have investigated the global spectral behaviors of long GRBs, short GRBs, and XRFs in the $HR - E_{\rm p}$ plane with BATSE and HETE-2 observations. It is found that the long GRBs and the XRFs observed by HETE-2 seem to follow the same sequence in the $HR - E_{\rm p}$ plane, with the XRFs at the low end of this sequence. We fit the sequence by a universal Band function, and find that this sequence is mainly fixed by α, while β is numerically unstable, with $\chi^2_{\rm min}$ remaining at ~ 118 for β varying from -5 to -10 . So we fix $\beta = -5$, and then make a best fit to the sequence, and derive $\alpha = -1.00$ with $\chi^2_{\rm min}/{\rm dof} = 2.2$. The sequences of the long and short GRBs observed by BATSE in the $HR - E_{\rm p}$ plane are significantly different from that of the long GRBs. In the $HR - E_{\rm p}$ plane, most of the short GRBs are above the long GRB sequence, indicating that the short GRBs tend to have a larger HR than the long GRBs at a given $E_{\rm p}$. A best-fit gives $\alpha = -0.30$ and $\beta = -2.05$ for the long BATSE GRBs. For the short GRBs, a best fit is obtained with $\alpha = -0.60$, with $\chi^2_{\rm min} = 1.1$ (β is fixed at -2.0 since it is again numerically unstable). The α value of the short GRB sequence is significantly greater than that of the long GRBs. These results suggest strongly that the global spectral behaviors of the long GRBs and the XRFs are similar, and the XRFs are the lower energy extension of the long GRBs, while the global spectral behaviors of the short GRBs are different from the long GRBs: the short GRBs seem to be a unique subclass of GRBs, and they are not the higher energy extension of the long GRBs.

The unified model description of long GRBs and XRFs has been widely discussed. Zhang et al. (2004) showed that current GRB/XRF prompt emission/afterglow data can be described by a quasi-universal Gaussian-like (or similar structure) structured jet with a typical opening angle of $\sim 6^\circ$ and with a standard jet energy of $\sim 10^{51}$ erg. Based on HETE-2 observations, Lamb et al. (2003) proposed that the uniform jet model nicely describes the prompt emission data of GRBs/XRFs, but this model fails to account for the afterglow jet break time data of GRBs. Liang & Dai (2004) found a bimodal distribution of the observed $E_{\rm p}$ of GRBs/XRFs and suggested that the two-component jet model (Berger et al. 2003) can explain this distribution, proposed that two-component jet seems to be universal for GRBs/XRFs. The results of this paper further confirm the view that long GRBs and XRFs are the same phenomenon.

We show that short GRBs are not the higher energy extension of GRBs, although they tend to have a harder spectrum than long GRBs. Please note that this result is based on the BATSE observations. Whether or not the $E_{\rm p}$ distribution can be broadened to a higher energy is still uncertain. This possibility cannot be ruled out by the BATSE observations.

The observed association of long GRBs with star formation regions (e.g., Djorgovski et al. 2001), and the possible supernova components in afterglow light curves (e.g., Bloom et al. 1999; Rechart et al. 2001; Stanek et al. 2003; Hjorth et al. 2003) indicate that the central engines of the long GRBs might be the collapse of supermassive stars to black holes (e.g., Wooseley 1993; Berger, Kulkarni & Frail 2003). Our results suggest that the short GRBs are not the same phenomenon as the long GRBs and the XRFs. So far no afterglows of short GRBs have been observed. It is not clear whether this is an observational artifact or a real feature. Furthermore, we do not know of any direct evidence relating to the origin of short GRBs. The results in this paper hint that short and long GRBs might come from different progenitors. Liang et al. (2002b, c) made the same argument based on the the differences of the variability time scales and the total fluences of long and short GRBs.

From Fig. 1 it is found that the sequences in the $HR - E_{\rm p}$ plane are mainly characterized by the value of α, indicating that the GRB spectra in our analysis are dominated by photons with energies lower than $E_{\rm p}$. In our calculations we find that $\chi^2_{\rm min}$ is sensitive to α, but not to β. The β value significantly affects the low end of the sequence at $\log E_{\rm p}/{\rm keV} < 1$. However, there are only four XRFs in our GRB sample in this range. Thus, we cannot well constrain the low tail of the GRB sequence (and hence the value of β). In fact, the β value is ill-defined. This indicates that the statistics in the high energy channels of the spectra is too poor to constrain the high energy power law component of the Band model (Ghirlanda et al. 2004a).

It should be noted that our best fit to the GRB sequence in the $HR - E_{\rm p}$ plane is related to the definition of HR. Different definitions can lead to different best fit results for the same GRB sample. This is the reason why the best fits shown in Figs. 1 and 2 for the HETE-2 long GRB sample and for the BATSE long GRB sample are quite different. For the BATSE sample, HR is calculated by the fluences in Channels 3 and 2 (energy bands 110–320 keV and 55–110 keV) while the HR of the HETE-2 GRB sample is calculated by the fluences in the energy bands 30–400 keV and 2–30 keV. Therefore, the best-fits to the HETE-2 GRB sample and to the BATSE GRB sample are different. However, this difference does not affect the results of our analysis because we separately investigated the long GRB-XRF sequence and the long GRB-short GRB sequence given by the two instruments.

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References

Amati L., Frontera F., Tavani M. et al., 2002, A&A, 390, 81
Band D., Matteson J., Ford L. et al., 1993, ApJ, 413, 281
Barraud C., Olive J. F., Lestrade J. P. et al., 2003, A&A, 400, 1021
Berger E., Kulkarni S. R., & Frail D. A. 2003, ApJ, 590, 379
Berger E., Kulkarni S. R., Pooley G. et al., 2003, Nature, 426, 154
Bloom J. S., Kulkarni S. R., Djorgovski S. G. et al., 1999, Nature, 401, 453
Cheng K. S., Lu T., 2001, Chin. J. Astron. Astrophys., 1, 1
Dai X. Y., Zhang B., 2004, ApJ, 621, 875
Dai Z. G., Liang E. W., Xu D., 2004, ApJ, 612, L101
Djorgovski S. G., Frail D. A., Kulkarni S. R. et al., 2001, ApJ, 562, 654
Fishman G., Meegan C., 1995, ARA&A, 33, 415
Ghirlanda G., Ghisellini G., Celotti A. 2004a, A&A, 422, L55
Ghirlanda G., Ghisellini G., Lazzati D., 2004b, ApJ, 616, 331
Heise J., in't Zand J., Kippen R. M., Woods P. M., 2001, In: E. Costa, F. Frontera, J. Hjorth, eds., Gamma- Ray Bursts in the Afterglow Era, Berlin: Springer, 16
Hjorth J., Møller P., Gorosabel J. et al., 2003, ApJ, 597, 699
Huang Y. F., Wu X. F., Dai Z. G., Ma H. T., Lu T., 2004, ApJ, 605, 300
Kippen R. M., Woods P. M., Heise J. et al., 2003, AIPC, 662, 244
Kouveliotou C., Meegan C. A., Fishman G. J. et al., 1993, ApJ, 413, 101
Lamb D. Q., Donaghy T. Q., Graziani C., 2005, ApJ, 620, 355
Liang E. W., Qin Y. P., Dong Y. M. et al., 2002a, Chin. J. Astron. Astrophys., 2, 347
Liang E. W., Xie G. Z., Su C. Y., 2002b, PASJ, 54, 1
Liang E. W., Xie G. Z., 2002c, PASJ, 54, 359
Liang E. W., Dai Z. G., 2004, ApJ, 608, L9
Liang E. W., Dai Z. G., Wu X. F., 2004, ApJ, 606, L29
Lloyd-Ronning N. M., Ramirez-Ruiz E., 2002, ApJ, 576, 101
Lloyd-Ronning N. M., Dai X. Y., Zhang B., 2004, ApJ, 601, 371
Mészáros P., 2002, ARA&A, 40, 137
Piran T., 1999, Phys. Rep., 314, 575
Piran T., 2005, Reviews of Modern Physics, 76, 1143
Preece R. D., Briggs M. S., Mallozzi R. S. et al., 2000, ApJS, 126, 19
Qin Y. P., Xie G. Z., Liang E. W. et al., 2001, A&A, 369, 537
Reichart D. E., Lamb D. Q., Fenimore E. E. et al., 2001, ApJ, 552, 57
Sakamoto T., Lamb D. Q., Graziani C. et al., 2004a, ApJ, 602, 875
Sakamoto T., Lamb D. Q., Graziani C. et al., 2004b, ApJ, Submitted, (astro-ph/0409128)
Stanek K. Z., Matheson T., Garnavich P. M. et al., 2003, ApJ, 591, L17
van Paradijs J., Kouveliotou C., Wijers R. A. M. J., 2000, ARA&A, 38, 379
Woosley S. E., 1993, ApJ, 405, 273
Yamazaki R., Yonetoku D., Nakamura T., 2003a, ApJ, 594, 79
Yamazaki R., Ioka K., Nakamura T., 2003b, ApJ, 593, 941
Yamazaki R., Ioka K., Nakamura T., 2004a, ApJ, 607, 103
Yamazaki R., Ioka K., Nakamura T., 2004b, ApJ, 606, 33
Yonetoku D., Murakami T., Nakamura T. et al., 2004, ApJ, 609, 935
Zhang B., Mészáros P., 2004, IJMPA, 19, 2385
Zhang B., Dai X. Y., Lloyd-Ronning N. M., Mészáros P., 2004, ApJ, 601, 119