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A Restriction on the Duration and Peak Energy of Gamma-Ray Bursts

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Abstract Two dimensional distributions of T_{90} versus $E_{\rm peak}$ (or $E_{\rm break}$) for three bright GRB samples have been investigated. The result shows that although both T_{90} and $E_{\rm peak}$ (or $E_{\rm break}$) each span over a wide range, they are restricted to the region $\log(T_{90}) \leq -\log(E_{\rm peak}) + 5.24$. This cannot be explained by the current fireball model. It may represent a constraint on the fireball model.

Key words: gamma rays: bursts

1 INTRODUCTION

Gamma-ray bursts (GRBs), first discovered three decades ago (Klebesadel et al. 1973), have extremely peculiar observed properties whose nature still remains mysterious. The BeppoSAX satellite (Boella et al. 1997) first detected a GRB afterglow on 1997 Feb 28 (Costa et al. 1997), which has revolutionized GRB observations. The observations of afterglow have greatly improved our knowledge of the phenomenon, and the modelling of the theoretical models (Dai & Lu 1998a, 1998b, 1999, 2000; Huang & Lu 1999; Huang et al. 1999; Chevalier & Li 1999, 2000; Li & Chevalier 2001). However, we still know very little about the intrinsic characteristics of the sources and of the emission regions of GRBs. The large range of their duration and the great variety of their spectral behavior were not predicted by the theoretical models proposed so far. Statistical analysis of the observed properties is helpful for understanding the nature of the phenomenon and leads to constraints on the theoretical models. For example, the bimodal distribution of burst durations (Kouveliotou et al. 1993; Qin et al. 2000) and the significant differences in the pulse timescale and fluence-hardness correlation between two classes of GRBs (Liang et al. 2002; Liang & Xie 2002) may indicate the existence of two different kinds of progenitors (Wang 1996); and the possible evidence of beaming effect in GRBs (see Fan et al.

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1997; Wei & Lu 2000) may suggest that the burst fireball is anisotropic. In this work we investigate three samples given by previous authors (Band et al. 1993; Schaefer et al. 1994; Preece et al. 1998) for their two dimensional distribution of $E_{\rm peak}$ (or $E_{\rm break}$) versus burst duration. The samples are described in Section 2. The analysis of the two dimensional distributions is described in Section 3. In section 4 we present a discussion and our conclusions.

2 DESCRIPTION OF THE SAMPLES

Spectral studies so far have only been made on GRBs with a sufficiently large signal-to-noise ratio and most of the bursts are long, bright GRBs. Three samples were selected from the literature (Band et al. 1993; Schaefer et al. 1994; Preece et al. 1998). The durations, T_{90}, defined as the time for the integrated photon count to increase from 5% to 95% of the total, are taken from the BATSE burst catalogs (see Fishman et al. 1994; Meegan et al. 1994, 1996; Paciesas et al. 1997).

Sample 1 is taken from Band et al. (1993) and consists of 54 bursts. The chosen bursts are those bursts observed by BATSE up to the end of 1992 May, with peak count rates (summed over all triggered LADs and accumulated in 64 ms time bins) exceeding 10 000 count s^{-1} above the background, 42 of the 54 sources have both T_{90} and $E_{\rm break}$ available.

Sample 2 was presented by Schaefer et al. (1994). It consists of all bright bursts observed by BATSE prior to 1992 March 6 with peak count rates greater than 4 photons cm^{-2}s^{-1} in the 64 ms time bins. The values of $E_{\rm break}$ and T_{90} are available for 28 of the 30 GRBs in the sample.

Sample 3 is quoted from Preece et al. (1998). The sample contains bright bursts selected from the beginning of the BATSE mission up to early 1997 with a fluence (> 20 keV) greater than 4×10^{-5} erg cm^{-2} or a peak flux in $50 - 300$ keV on 256 ms timescale above 10 photon cm^{-2} s^{-1}. The values of T_{90} and $E_{\rm break}$ are available for 96 of 126 GRBs in the sample.

3 TWO DIMENSIONAL DISTRIBUTIONS OF T_{90} vs. $E_{\rm peak}$ (or $E_{\rm break}$)

The two dimensional distribution of T_{90} versus $E_{\rm peak}$ for the three samples is displayed in Figure 1, where T_{90} is in second and $E_{\rm peak}$ (or $E_{\rm break}$) is in keV. One can see from Figure 1 that T_{90} is not at all correlated with $E_{\rm peak}$ or $E_{\rm break}$.

On a further inspection of Figure 1, it is interesting to note that although T_{90} and $E_{\rm peak}$ (or $E_{\rm break}$) each spans over a wide range, a large area in the top right region of the plot appears to be a clearly defined forbidden region for the sources. The boundary for this forbidden region seems to be

$$\log(T_{90}) = -\log(E_{\rm peak}) + 5.24\,. \tag{1}$$

This boundary is also drawn in Figure 1 (solid line). Below this boundary, the distribution is scattered for the three samples: the two quantities, T_{90} and $E_{\rm peak}$ (or $E_{\rm break}$), are not correlated at all, T_{90} apparently having no effect on $E_{\rm peak}$ (or $E_{\rm break}$). This can be understood by the fireball model. However, the existence of the boundary cannot be so understood and it may represent a constraint on the fireball model.

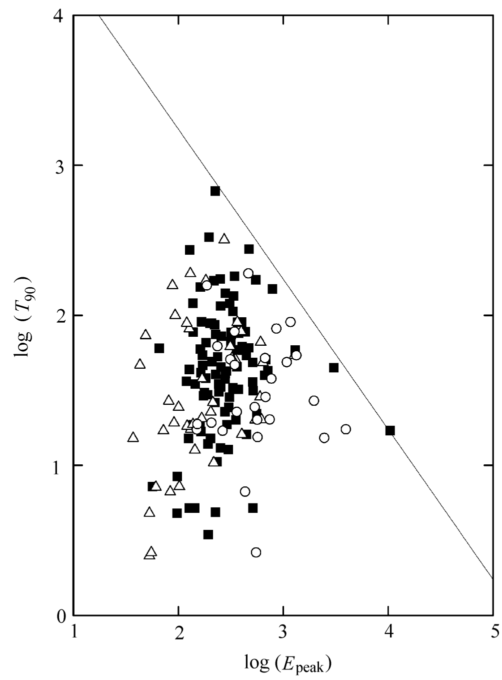

Fig. 1 Two dimensional distribution of T_{90} versus $E_{\rm peak}$ or $E_{\rm break}$ for three samples. T_{90} in second and $E_{\rm peak}$ (or $E_{\rm break}$) in keV. Sources from the Samples 1, 2, 3 are represented respectively by open circles, open triangles, and filled squares. The solid line is $\log T_{90} = -\log(E_{\rm peak}) + 5.24$.

4 DISCUSSION AND CONCLUSIONS

The two dimensional distributions of T_{90} versus $E_{\rm peak}$ (or $E_{\rm break}$) for three bright GRB samples have been investigated. The result shows that although both T_{90} and $E_{\rm peak}$ (or $E_{\rm break}$) each span over a wide range, they are restricted to the region, $\log(T_{90}) \leq -\log(E_{\rm peak}) + 5.24$.

It is well known that, for a source at redshift z, the observed peak energy, $E_{\rm peak}$, or break energy, $E_{\rm break}$, is related to the emitted peak energy, $E_{\rm p,emit}$, or emitted break energy, $E_{\rm b,emit}$, by (see, e.g., Mallozzi et al. 1995)

$$E_{\rm peak} = \frac{E_{\rm p,emit}}{1+z} \qquad \text{or} \qquad E_{\rm break} = \frac{E_{\rm b,emit}}{1+z}\,, \tag{2}$$

while the observed duration, T_{90}, is related to the proper duration, $T_{\rm prop}$, by

$$T_{90} = (1+z)T_{\rm prop}\,. \tag{3}$$

From Eqs. (2) and (3) we have

$$T_{90} = \frac{K}{E_{\rm peak}} \qquad \text{or} \qquad T_{90} = \frac{K}{E_{\rm break}}\,, \tag{4}$$

where

$$K = T_{\rm prop}E_{\rm p,emit} \qquad \text{or} \qquad K = T_{\rm prop}E_{\rm b,emit}\,. \tag{5}$$

Accordingly, we have

$$\log T_{90} = -\log E_{\rm peak} + k \qquad \text{or} \qquad \log T_{90} = -\log E_{\rm break} + k, \tag{6}$$

where k is a constant independent of the redshift. This constant should be intrinsic to the burst. The boundary in Figure 1 corresponds to $k_{\rm max} = 5.24$. The figure shows that, for the sources observed, the value of k can vary, but can never exceed $k_{\rm max}$.

If k represents an intrinsic aspect of GRBs, then Figure 1 shows a spread of k values without any classifying signatures. Considering a set of GRBs with similar values of k: for this set, one can derive from Eq. (6) that longer bursts tend to have softer spectra. This is consistent with the most accepted GRB classification of "long-soft and short-hard " (Kouveliotou 1993).

The cosmological effect can also lead to a trend of "long–soft and short–hard". For a set of GRBs with different redshifts, from Eqs. (2) and (3) one can see that a burst with a higher redshift tends to have a lower $E_{\rm peak}$ (or $E_{\rm break}$) and a longer T_{90}. However, it can also be seen in Figure 1 that some sources with approximate the same value of k can have T_{90} values differing by factors of $10 - 100$. This cannot be accounted for by the cosmological effect. For the bursts that have been measured, the redshifts of the sources span from $z = 0.0085$ (Tinney et al. 1998) to $z = 5.0$ (Fruchter 1999). The effect of redshift could not lead to such a difference.

However, it should be noted that the conclusion of "long-soft and short-hard" was derived from all of the observed bursts (Kouveliotou 1993), whereas here, we only considered long, intense bursts. A provocative idea now arises: could there be a systematic difference in k in the two classes of GRBs? We will study this issue in our next paper.

The most accepted theoretical model of GRB is the relativistic fireball shock model (e.g., Rees & Meszaros 1992; Meszaros & Rees 1993a, 1993b). According to the model, the emission region is far away from the source ($\sim 10^{13}$ cm). The characteristics of gamma-ray emission, such as $E_{\rm peak}$ or $E_{\rm break}$ and hardness ratios, rely on some unexpected parameters of the emission region, such as the Lorentz factor of the shells, the distribution of relativistic electrons, and the power density of magnetic field. The observed duration of a burst is likely related to the time interval that the source of the burst continually releases its energy into space, i.e., it mainly depends on the characteristics of the source. The characteristics of gamma-ray emission seem to have no effect on burst durations according to the model. The result of this work presents a restriction on the two quantities. This restriction cannot be explained by the current fireball model and may be a constraint on it.

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