Relation between the hardness ratio and time in the first 2 seconds for compatible samples of short and long gamma-ray bursts

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ABSTRACT
In this paper, we randomly selected a sample (sample 1) of long gamma-ray bursts, with its size being the same as that of the short burst group (sample 2) (N=500), from the Current BATSE Bursts Catalog. We randomly selected a short burst and assigned its T90 to each of these long bursts. We thus constructed a long burst sample with both the sample size and the distribution of T90 being the same as those of the short burst sample obtained from the Current BATSE Bursts Catalog. Then we calculated the hardness ratio ($h_{RT}$) over the assigned T90 for the long bursts and over their own T90 for the shout bursts, and studied the relation between the hardness ratio and the corresponding T90 for these two samples. We also calculated the hardness ratio ($h_{RT}$) over the randomly selected 64 ms time intervals within the T90, and investigated the relation between this hardness ratio and the selected 64 ms time interval. In addition, the $h_{RT}$ within and beyond the first 2 seconds for all the long bursts (sample 3; N=1541) were also investigated. We found that the KS probabilities of the distributions of the $h_{RT}$ (7.15337E-15) and $h_{RT}$ (9.54833E-10) for samples 1 and 2 are very small, and the average value of $h_{RT}$ and $h_{RT}$ of short bursts are obviously larger than that of the long bursts. The correlations between log$h_{RT}$ and logT90, and between log$h_{RT}$ and log t, for samples 1 and 2 are different. These show that short and long bursts in the first 2 seconds have different characters and they probably originate

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from different progenitors. For sample 3, for the two time intervals, the KS probability is 5.35828E-5, which suggests that the hardness ratios in different time intervals for long bursts are also different.

**Key words:** gamma rays:bursts– methods:statistical

1 INTRODUCTION

Gamma-ray bursts (GRBs) are the brightest astronomical phenomena since they were firstly detected in the late 1960’s (klebesadel et al, 1973). They almost remained thereafter mysteries for more than thirty years, largely due to the fact that during this period they remained detectable only for the high energy–gamma-ray energies and with short durations. In 1997, the first x–ray afterglow (GRB970228) (Costa, Frontera & Heise et al. 1997), optical afterglow (van Paradijs, Groot & Galama et al, 1997) and radio afterglow (GRB 970508)(Frail, Kulkarni & Nicastro et al. 1997) were detected, which led the study of GRBs into GRB afterglow era. The discoveries of the GRB afterglows proved that the GRBs were at cosmological distances. So far, Over forty GRB afterglows have been detected [http://www.mpe.mpg.de/~jcg/grb.html](http://www.mpe.mpg.de/~jcg/grb.html). But all the detected afterglows belong to the long burst class and there is not any detected afterglow which is a short burst. This probably indicates that the two classes of GRBs are intrinsically distinct. Statistical studies revealed that these two classes have different distributions of the hardness ratio (short bursts being harder), pulse width, separation time scale, number of pulses per bursts, different anti–correlations between the spectral hardness and duration. It suggests that the two classes might be intrinsically different (Hurley et al. 1992; Kouveliotou et al. 1993; Fishman & Meegan 1995; Norris et al. 2000; Qin et al. 2000, 2001; Nakar & Piran 2002). A generally accepted scenario is that short bursts are likely to be produced by the merger of compact objects while the core collapse of massive stars is likely to give rise to long bursts (see, e.g., Zhang & Mésazáros, 2003; Piran, 2004).

Recently, Ghirlanda, Ghisellini & Celotti (2004) have shown that the emission properties of short bursts are similar to that of the first 2 seconds for long events and concluded that the central engine of long and short bursts is the same, only working for a longer time for long GRBs. Based on this work, Yamazaki, Ioka & Nakamura (2004) proposed a unified model of short and long GRBs and suggested that the jet of GRB consists of multiple subjets or subshells, where the multiplicity of the subjets along the line of sight \( n_s \) is an important parameter. They showed that if \( n_s \) is large (\( \gg 1 \)), the event looks like a long GRB, while if \( n_s \) is small (\( \sim 1 \)), the event looks like a short GRB. Based on the unified model of Yamazaki et al. (2004), Toma, Yamazaki & Nakamura
Relation between the hardness ratio and time in the first 2 seconds for compatible samples of short and long gamma-ray bursts

Dong & Qin (2004) have successfully explained the bimodal distribution of T90 of the GRBs. Thus, it is still unclear whether the short and long bursts are intrinsically the same. In this paper, we will adopt the definition of the hardness ratio associated with time, \( h_{rt} \), presented in Dong & Qin (2004), and pay our main attention to the differences of the quantity within the first 2 seconds for these two groups of GRBs. Owing to the observed event rate of short bursts being \( \sim 1/3 \) of that of the long bursts, we randomly selected a sample from the whole long bursts, with its number being the same as that of the short burst group.

This paper is organized as follows. In section 2, we described a long burst sample with both the sample size and the distribution of T90 being the same as those of the short burst sample obtained from the Current BATSE Bursts Catalog. Then we calculated the hardness ratio \( h_{rT} \) over the assigned T90 for the long bursts and over their own T90 for the short bursts, and studied the relation between the hardness ratio and the corresponding T90 for these two samples. We also calculated the hardness ratio \( h_{rt} \) over the randomly selected 64 ms time intervals within the T90, and investigated the relation between this hardness ratio and the selected 64 ms time interval for these two samples. In section 3, we investigated the \( h_{rt} \) in different time intervals for all the long bursts. A brief discussion was presented in section 4.

2 RELATION BETWEEN THE HARDNESS RATIO AND TIME FOR SHORT AND RANDOMLY SELECTED LONG BURSTS

In the duration table of the Current BATSE Bursts Catalog (http://cossc.gsfc.nasa.gov/batse/), 1541 long bursts and 500 short bursts are presented. The 64 ms temporal resolution and four-channel spectral resolution GRB data (Concatenated 64-ms Burst Data in ASCII Format) observed by BATSE can also be available via anonymous ftp in the web site (ftp://cossc.gsfc.nasa.gov/compton/data/batse/). The data type of Concatenated 64-ms Burst Data in ASCII Format is a concatenation of three standard BATSE data types, DISCLA, PREB, and DISCSC. All three data types are derived from the on-board data stream of BATSE’s eight Large Area Detectors (LADs), and all three data types have four energy channels, with approximate channel boundaries: 25-55 keV, 55-110 keV, 110-320 keV, and >320 keV. These data were used to calculate the hardness ratios in this paper. Owing to the observed event rate of short bursts is \( \sim 1/3 \) of that of long bursts, we randomly selected a long bursts sample (sample 1), with its size being the same as that of the short burst group (sample 2, N=500), from all the long bursts (sample 3, N=1541) available in the duration table. But when performing the calculation of the hardness ratio in this paper, we found that some bursts presented...
in the duration table do not have the corresponding 64 ms temporal resolution and four-channel spectral resolution GRBs data in the Concatenated 64-ms Burst Data in ASCII Format. Thus, in this paper, only 462 short bursts and 467 long bursts were employed to calculate the following hardness ratio.

The durations of long bursts are larger than 2 seconds, while they are less than 2 seconds for short bursts. In order to investigate the hardness ratio of the two GRBs classes within the first 2 seconds, we considered two definitions of the hardness ratio. First, we assigned a duration T90 of a randomly selected short burst from sample 2 to each of the long bursts in sample 1, and calculated the hardness ratio with the sum of the counts within this assigned T90, \( hr_T \), for each long burst, and calculated the hardness ratio with the sum of the counts within its own T90 for every short burst. Second, the hardness ratio is calculated with the count in a randomly selected 64 ms time interval, \( hr_t \), within the assign T90 for long bursts and within their own T90 for short bursts. The time intervals defining \( hr_T \) is from the beginning of the T90 to the end of the T90 considered here. The \( hr_T \) is determined by

\[
hr_T = \frac{\sum_{0}^{T90} \text{Count3}}{\sum_{0}^{T90} \text{Count2}}
\]

where count3 is the count of the third channel of the Concatenated 64-ms Burst Data in each 64 ms time intervals, and count2 is that of the second channel.

The plot of the \( \log hr_T - \log T90 \) for the short and selected long bursts is presented in Fig. 1. In this plot, all data points are presented and the regression lines for the two classes are drawn. Presented in the plot are also two data points standing for the average values of the two quantities for the two classes. The corresponding distributions of the \( hr_T \) of the two classes are shown in Fig. 2, and the probability of KS test to the two distributions is 7.15337E-15. We find : (1) the correlation coefficient between the two quantities for short bursts is \( r = -0.19 \), where the size of the short bursts is \( N = 462 \); and for the selected long bursts it is \( r = -0.15 \), where the size of the long bursts is \( N = 467 \). This shows that for the two classes the \( \log hr_T \) and the \( \log T90 \) are correlated, but the correlation of the two classes is different. As the KS probability is very small, which is only 7.15337E-15, it shows that the distributions of the \( hr_T \) of the two GRBs classes are obviously different, indicating that they are likely to arise from different distributions. Meanwhile, we also find in Fig. 1 the average value of the \( \log hr_T \) for the short bursts (0.0146) is larger than that of the long bursts (-0.037), which is consistent with the previous results (Dezalay, Lestrade & Barat et al. 1996).
In the second situation, the way of calculating the hardness ratio over a randomly selected 64 ms time intervals for short and long bursts is as follows. We firstly randomly, and not repeatedly, selected a short and long burst, then randomly selected a 64 ms time intervals within the T90 of this short burst. Secondly, we calculated the hardness ratio with the count in this 64 ms time interval for this short and long bursts. Thus, for any of short and long bursts, we can calculate their hardness ratio associated with the randomly selected 64 ms time interval. The $hr_t$ is determined by

$$hr_t = \frac{\text{count3}}{\text{count2}}$$

where count3 is the count of the third channel of the Concatenated 64-ms Burst Data in the randomly selected time intervals, count2 is that of the second channel, and t is the corresponding time of the selected time interval measured from the beginning of the T90.

The plot of the log $hr_t$–log $t$ for the short and selected long bursts is shown in Fig. 3. In this plot, all data points are presented and the regression lines for the two classes are drawn. Presented
Figure 2. The distributions of $h_{rT}$ of the short bursts and selected long bursts. The dashed line represent the short bursts and the solid line represent the selected long bursts. The probability of the KS test to the two distributions is 7.1537E-15

in the plot are also two data points standing for the average values of the two quantities for the two classes. At the same time, the distributions of $h_{rT}$ for the selected long bursts and short bursts are presented in Fig. 4, and the probability of the KS test to the two distributions is 9.54833E-10, which is also very small. In Fig. 3, we can find: the correlation coefficient between the two quantities for the short bursts is $r=-0.17$, and for the long bursts it is $r=0.046$. They are correlated for the short bursts but not correlated for the long bursts. The average value of the log $h_{rT}$ for the short bursts (0.0049) is larger than that of the long bursts (-0.039). Thus, from these two situations we can find that short bursts are obviously different from long bursts. This shows that the two GRB classes should be intrinsically distinct, and they should originate from different progenitors.

3 RELATION BETWEEN THE HARDNESS RATIO AND TIME WITHIN AND BEYOND THE FIRST 2 SECONDS FOR THE LONG BURSTS

Ghirland et al. (2004) suggested that the central engine of short and long bursts is the same, just working for a longer time for long bursts and they showed that the emission properties of short
bursts are similar to that of the first 2 seconds of long bursts. Thus, in section 2, we investigated the $hr_T$ and the $hr_t$ for short and randomly selected long bursts within the first 2 seconds, and found that they are obviously different, indicating that they should not arise from a same physical process. In this section, we will investigate the hardness ratio for all the long bursts (sample 3) in different time intervals. We divided the duration of a long burst into two time intervals. The first time interval is from the beginning of T90 to the first 2 seconds, and the second time interval is from the first 2 seconds to the end of T90. In each time interval, we randomly selected a 64 ms time interval and calculated the corresponding hardness ratio $hr_t$ with the count in this 64 ms time interval. We therefore obtained two set of $hr_t$ for long bursts. The two set of $hr_t$ will be used to investigate whether there are important differences between the two time intervals for long bursts.

The plot of the $\log hr_t - \log t$ in the two different time intervals for long bursts is shown in Fig. 5a, and the plot of the $\log hr_t - \log t$ for short bursts (sample 2) within the first 2 seconds and for long bursts (sample 3) beyond the first 2 seconds is shown in Fig. 5b. In Fig. 5a, all data points
are presented and the regression lines for the two time intervals are drawn. Presented in Fig. 5a are also two data points standing for the average values of the two quantities for the two time intervals. In Fig. 5b, the symbols are the same as those in Fig. 5a, but they represent two groups of GRBs (samples 2 and 3). In Fig. 6 we present the distributions of $h_{rt}$ within and beyond the first 2 seconds for the long bursts. The probability of the KS test to the two distributions is 5.35828E-5. This probability is so small that we can not think they are the similar distributions for the two time intervals, which shows that the hardness ratios in different time intervals for long bursts are
Relation between the hardness ratio and time in the first 2 seconds for compatible samples of short and long gamma-ray bursts.

![Figure 5](image)

**Figure 5.** a: The plot of $\log hr_t - \log t$ for long bursts within (open circles) and beyond (open squares) the first 2 seconds, respectively. The dashed line is the regression line for the data within the first 2 seconds and the solid line is the regression line for that beyond the first 2 seconds. The solid circles represent the two data points standing for the average values of the two quantities for the two classes respectively. b: The plot of $\log hr_t - \log t$ for the data of short bursts (sample 2; open circles) within the first 2 seconds and for that of long bursts (sample 3; open squares) beyond the first 2 seconds. The dashed line is the regression line for the short bursts and the solid line is the regression line for the long bursts. The solid circles represent the two data points standing for the average values of the two quantities for the two classes, respectively.

different. From Fig. 5a we can find: the correlation coefficient between the two quantities in the first 2 seconds is $r=-0.0286$ and it is $r=0.0237$ beyond the first 2 seconds for the long bursts. This shows that for the two time intervals the $\log hr_t$ and $\log t$ are not correlated. We also find that the regression lines of the two quantities within and beyond the first 2 seconds are almost parallel, and the average value of the $\log hr_t$ in the first 2 seconds (-0.043) is appreciably larger than that beyond the first 2 seconds (-0.061). But from Fig. 5b, we find that the difference of the $\log hr_t - \log t$ correlation between the short and long bursts is obvious. Firstly, the average value of $\log hr_t$ of short bursts (0.0049) is obviously larger than that of the long bursts (-0.061) beyond the first 2 seconds. Secondly, the regression lines of the short within the first 2 seconds and of the long bursts beyond the first 2 seconds are obviously different. This shows clearly that the difference between the two classes of bursts is not at all due to time interval (if due to time interval, the two regression lines within the first 2 seconds in Figs 5a and 5b should be almost the same). The two class are likely to be distinct groups.
4 DISCUSSIONS AND CONCLUSIONS

In this paper, we randomly selected a long bursts sample, with its size being the same as that of the short burst group, from all the long bursts available in the Current BATSE Bursts Catalog. We randomly, and not repeatedly, selected a short burst and assigned its T90 to one of these long bursts as its new T90. Then we investigated the hardness ratio \( hr_T \) over the assigned T90 for the long bursts and over their own T90 for the short bursts. Meanwhile, we also investigated the hardness ratio associated with the randomly selected 64 ms time intervals \( hr_t \) within the T90 of short bursts for both short and long bursts. In addition, the \( hr_t \) within and beyond the first 2 seconds for all the long bursts were also investigated. The main aim of this work is to find whether the hardness ratio of short and long bursts in the first 2 seconds possess the same character.

In section 2, one can find for short and randomly selected long bursts that, the KS probabilities of the distributions of the \( hr_T \) (7.15337E-15) and \( hr_t \) (9.54833E-10) are very small, and the average value of \( hr_T \) and \( hr_t \) of short bursts are obviously larger than that of the long bursts. The correlations between \( \log hr_T \) and \( \log T90 \), and between \( \log hr_t \) and \( \log t \), for short and randomly

Figure 6. The distributions of \( hr_t \) for long bursts in different time intervals. The dashed line represent the data of long bursts in the first 2 seconds and the solid line stands for that of the long bursts beyond the first 2 seconds. The possibility of KS test to the two distributions is 5.35828E-5
Relation between the hardness ratio and time in the first 2 seconds for compatible samples of short and long gamma-ray bursts. Selected long bursts are different. These show that short and long bursts in the first 2 seconds have different characters and they probably originate from different progenitors. In section 3, for the long bursts, the correlations between log $hr_t$ and log $t$ in different time intervals are similar and the average values of $hr_t$ do not show an obvious difference. But the ks probability of distributions of the $hr_t$ (5.35828E-5) for long bursts in the two time intervals is small. These suggest that the hardness ratios in different time intervals for long bursts are similar in some aspect, but meanwhile, to a certain extent, they also show some differences. When replacing the data of long burst with that of short burst within the first 2 seconds, the situation becomes much different: the regression line now deviates obviously from that of the long bursts beyond the first 2 seconds. This suggests that the difference between long and short bursts is intrinsical and the two class are likely to be distinct groups. Thus, we can draw these conclusions: (1) the distributions of the $hr_T$ or $hr_t$ of short bursts and the long bursts in the first 2 seconds can not arise from the same parent population and the two classes probably originate from different progenitors; (2) the average value of $hr_T$ or $hr_t$ for short bursts and the long bursts is different and that of the short bursts is larger than that of the long bursts, in agreement with previous study; (3) for the short and long bursts, the correlation between the hardness ratio and the corresponding time is different; (4) the hardness ratios in different time intervals for long bursts are not the same, in consistent with the well-known hard-to-soft character observed previously.

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