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The Hardness–Duration Correlation in the Two Classes of Gamma-Ray Bursts

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Abstract

The well-known hardness–duration correlation of gamma-ray bursts (GRBs) is investigated using data from the 4B catalog. We find that, while the hardness ratio and the duration are obviously correlated for the entire set of the 4B catalog, they are not at all correlated for the two subsets divided at the duration of 2 seconds. However, for other subsets with comparable sizes, the two quantities are significantly correlated. The following conclusions are thus reached: (1) the existence of two classes of GRBs is confirmed; (2) the hardness ratio and the duration are not at all correlated for any of the two classes; (3) different classes of GRBs have different distributions of the hardness ratio and the duration, and it is this difference that causes the correlation between the two quantities for the entire set of bursts.

Key words: cosmology: observations — gamma rays: bursts — gamma rays: theory — methods: statistical

1. Introduction

Since the discovery of the events of gamma-ray bursts (GRBs) about thirty years ago (Klebesadel et al. 1973), although many achievements have been obtained, full comprehension of the objects seems still to be a long-standing problem. Among the many efforts, investigating the statistical properties of the events is as necessary as poking into the details of the bursts. Since even more data of GRBs have become available (e.g., Fishman et al. 1994; Meegan 1994; Meegan et al. 1996, 1998; Paciesas et al. 1999), statistical results have become even more reliable. Possible correlations among various parameters of GRBs were previously studied (e.g., Golenetskii et al. 1983; Barat et al. 1984; Belli 1993). Investigations of the issues were recently continued with more sizable sets of data (e.g., Mallozzi et al. 1995; Dezalay et al. 1997; Belli 1999). With a large number of bursts observed with BATSE, Fishman (1999) found that the hardness–duration correlation, which had been described previously, was confirmed. In the following, we further consider this issue.

2. The Hardness–Duration Correlation of GRBs

It is well-known that there are two classes of bursts with different distributions of duration, divided at around 2 seconds (e.g., Dezalay et al. 1992; Kouveliotou et al. 1993; Fishman et al. 1994; Meegan et al. 1996; Paciesas et al. 1999). We wonder if the hardness–duration correlation is caused by different distributions of the hardness ratio and the duration for the two classes. In other words, we want to know if the correlation still holds for either of the two classes.

To investigate this issue, the burst data of the 4B catalog (Paciesas et al. 1997) were employed. We divided the bursts into two subsets with a division at the duration of 2 seconds. That is, those bursts with $T_{90} < 2$ s were defined as short-duration bursts and those with $T_{90} \geq 2$ s as long-duration bursts. The hardness ratio of a burst was defined as the fluence in channel 3 (~ 100 to ~ 300 keV) divided by the fluence in channel 2 (~ 50 to ~ 100 keV).

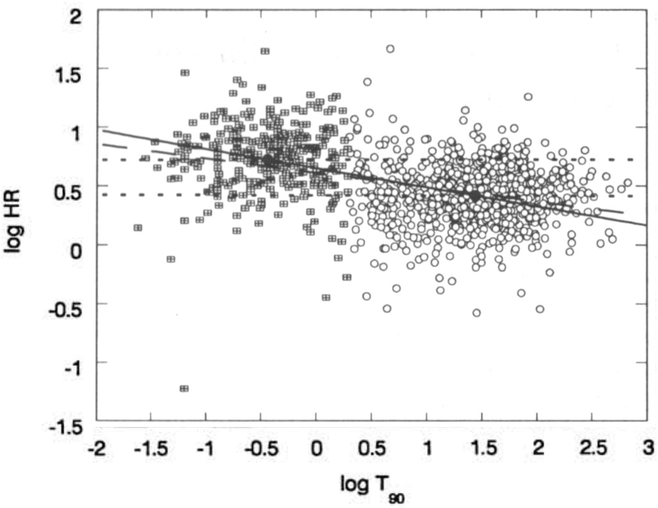

Fig. 1. The plot of $\log HR$–$\log T_{90}$ for sample 1 (including samples 2 and 3), where, T_{90} is in units of s. In the plot, a plus overlapping an open square represents a source of sample 2, while an open circle stands for a source of sample 3. The solid line is the regression line for sample 1, while the two dotted lines are the regression lines for samples 2 and 3, respectively. Filled circles represent the two data points standing for the average values of the two quantities for the two classes respectively. The dash line is a straight line connecting these two data points.

There are 1179 bursts in the catalog with available values of T_{90} and the fluences in both channels 2 and 3. This set was called sample 1. Of the 1179 sources, 304 belong to the short-duration burst class and 875 constitute the long duration-burst class. The two subsets were called samples 2 and 3, respectively. The correlation between $\log HR$ and $\log T_{90}$ were calculated for the three samples, where HR denotes the hardness ratio defined above. We find: (1) the correlation coefficient between the two quantities for sample 1 is $r = -0.391$, where the size of the sample is $N = 1179$; (2) for sample 2, $r = 0.002$, where $N = 304$; (3) for sample 3, $r = -0.050$, where $N = 875$. This shows that, while the hardness ratio and the duration are obviously correlated for the entire set of the 4B catalog, they are not at all correlated for any of the two classes. The correlation shown in sample 1 must be caused by the different distributions of the hardness ratio and the duration of the two classes.

To obtain an intuitive view of this point, we make a plot of $\log HR$–$\log T_{90}$ for the sources (shown in figure 1). In the plot, all data points are presented and the regression lines for the three samples are drawn. Presented in the plot are also two data points standing for the average values of the two quantities for the two classes. A straight line connecting these two data points is also drawn. We find in figure 1 that, the regression line of the entire set of the 4B catalog is very close to the straight line, but obviously deviates from the two other regression lines, suggesting that the correlation shown in sample 1 is indeed caused by the different distributions of the two classes.

3. Discussion and Conclusions

In last section, we consider whether the well-known hardness–duration correlation is caused by different distributions of the hardness ratio and the duration for the two classes of GRBs. To investigate this issue, we employed the burst data of the 4B catalog (Paciesas et al. 1997) and divided the bursts into two subsets with a division at duration of 2 seconds. We find that, while the hardness ratio and the duration are obviously correlated for the entire set of the 4B catalog, they are not at all correlated for the two classes. The correlation shown in sample 1 must be caused by the different distributions of the hardness ratio and the duration of the two classes.

Before reaching any conclusion, we must clarify whether any subsets of the catalog would produce an incorrelation between the two quantities. We selected a subset of the 4B catalog by constraining the duration in the range $1 \le T_{90} < 10$. This subset contained 217 sources (called sample 4). For sample 4, the correlation coefficient between the two quantities is $r = -0.343$, where $N = 217$. Secondly, we selected another subset of the 4B catalog by constraining the duration in the range $0.1 \le T_{90} < 100$ (note that the range of the duration for the entire set of the 4B catalog is $0.01 \le T_{90} < 1000$). We then obtained a 1045 source sample (called sample 5). The correlation coefficient between the two quantities for sample 5 is $r = -0.413$, where $N = 1045$. The two quantities are significantly correlated for these two subsets. One should notice that the sizes of samples 4 and 5 are comparable with that of samples 2 and 3, but the two former contain the 2 second division point. This clearly indicates that only for those subsets belonging to one of the two classes of GRBs there would show any incorrelation between the two quantities; subsets containing sufficiently numbers of sources of both classes would present an obvious correlation between the two quantities. This analysis not only reinforces the above conclusion, but, in turn, also confirms the existence of two classes of GRBs.

We thus come to the conclusion that there indeed exist two classes of GRBs. The hardness ratio and the duration concerned are not at all correlated for any of the two classes. Different classes of GRBs have different distributions of the hardness ratio and the duration. It is this difference that causes the correlation between the two quantities for the entire set of the bursts.

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