ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **138**, 415–416 (1999)

Correlations between intensity and spectral hardness in GRBs

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Received January 21; accepted June 7, 1999

Abstract. We studied the distribution of the peak photon flux as a function of the spectral hardness (in this paper represented by the hardness-ratio) for the 4B BATSE catalog events. The maximum value of the peak distribution shows, for the first part of the hardness ratio variability range, clear positive correlation with the hardness-ratio up to a given value of the hardness-ratio. On the contrary, for higher hardness-ratio values, an anticorrelation is present. Possible interpretations of these peculiar behaviors are briefly discussed.

Key words: gamma-rays: bursts

1. Introduction

Since the discovery of the GRB (gamma-ray burst) phenomenon, about thirty years ago, the possible correlations among the known physical parameters of GRBs have been studied by several authors (Golenetskii et al. 1983; Barat et al. 1984; Belli 1984, 1993, etc.) and more recently by Mallozzi et al. (1995); Dezalay et al. (1997) etc. Some correlations have been put in evidence, e.g. rise-time and decay-time, rise-time and spectral hardness, and, the most important one, intensity - spectral hardness. But the lack of bursts allowed only fragmentary results. At present the available number of bursts is higher, due to the data provided by very powerful experiments like the BATSE experiment, on board of the US CGRO satellite, the French-Soviet PHEBUS satellites, the Japanese satellites as GINGA, ASCA etc. We use for this analysis the 1840 events of the 4B BATSE catalog. Not all the physical parameters provided by the catalog are available for all the events. We will specify every time the number of the events used in each reported analysis.

2. Spectral-hardness intensity correlation

We study the spectral hardness- intensity correlation with a direct approach. We plot 1191 events of the catalog on the intensity and spectral hardness plane (Fig. 1). The spectral hardness HR is given by the hardness-ratio, the ratio of the fluences in the energy ranges $100-300$ and $50-100$ keV; and the intensity $P_{\rm C}$ ($\rm s^{-1}$ $\rm cm^{-2}$) by the peak counting rate of the GRB light curve, evaluated in the energy range $50-300$ keV. Three values of this last parameter relative to three different bins of the accumulation time, 64, 256, 1024 ms respectively, are available in the catalog. Figure 1 shows the plot for 1024 ms acculation time. We observe that for each value of HR there are many possible values of the peak counting rate $P_{\rm C}$. One reason for this is the unknown distance at which the events occur. Another reason could be the presence of subsets with different luminosity functions for different light curve shapes and/or different spectral behaviors. As an example we recall the subset of GRBs without fluence over 300 keV (Pendleton et al. 1997), see the grey plot in Fig. 1. We consider for the analysis only the maximum and minimum value of the count rate for each HR. Observing the plot in Fig. 1, we can see that the intensity of GRBs (the maximum peak counting rate) can be represented as an increasing function of the spectral hardness HR below a

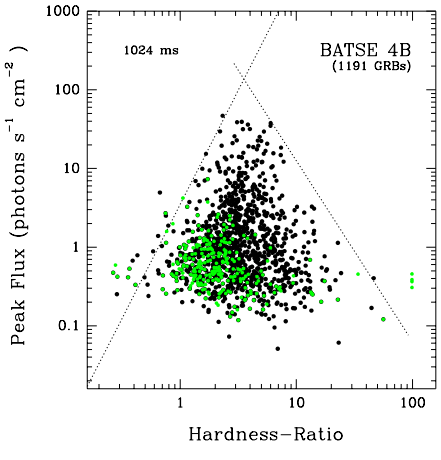

Fig. 1. Peak counting rate of 1191 GRBs of the BATSE catalog against hardness-ratio, for the 1024 s temporal bin reported in the catalog. The events signed in grey color are those of the Pendleton et al. class, without photons with energy higher then 300 keV

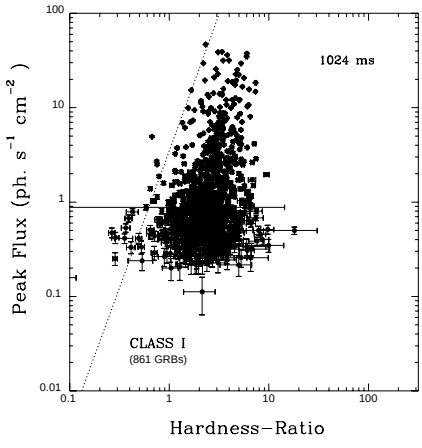

Fig. 2. Plots of peak photon flux ($cm^{-2}\,s^{-1}$) and hardness-ratio of the BATSE GRBs, for the 1024 s temporal bins of Class I; the error bars are reported in the catalog

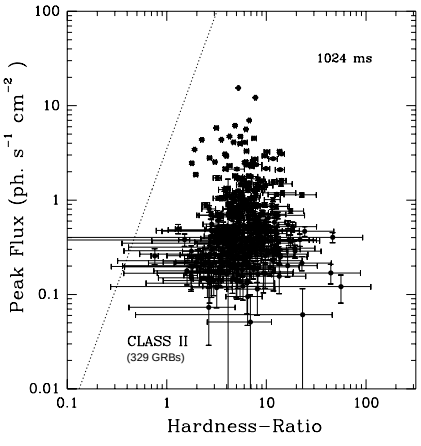

Fig. 3. Plots of peak photon flux ($cm^{-2}\,s^{-1}$) and hardness-ratio of the BATSE GRBs, for the 1024 s temporal bins of Class II; the error bars are reported in the catalog

given value of this parameter; for higher values it becomes a decreasing function. The best fit with a power law of the increasing part is: $P_C = 2.95\ HR^{2.3}$, and of the decreasing part is: $P_C = 2500\ HR^{-2.3}$, the best fits resulting the same for the three temporal bins. In a previous paper we devided GRBs in two Classes I and II in the plane D-HR, duration hardness-ratio. The two classes are at the right and at the left of the straight line $HR = 2\ D^{0.5}$ respectively. Class I is essentially composed of the longest events and Class II of the shortest ones but not only. The two classes are characterized by two parameters, duration and hardness-ratio (Belli 1995). The reported effect is evident in Class II, and not in Class I (Fig. 2 and Fig. 3).

3. Rise time and spectral hardness

The observed minimum peak count rate is determined by the experiment threshold. In the BATSE experiment the threshold is given by a trigger that enables the event detection when the counts accumulated in the selected temporal bin is higher than 5.5 σ over the current background. It is also clear that the minimum peak count rate is a function of HR, and it is not the same for the different temporal bins. The trend inversion occurs at about the same value of the HR, at which the maximum peak counting rate reaches the highest values. This minimum count rate is strongly influenced by the shape of the GRB light curve, more exactly by the rise time.

4. Discussion

This is the first time that the behaviour of the GRBs luminosity versus the hardness ratio has been completely analysed. The hardness ratio is a physical parameter which provides information (even if not complete) on the spectral behaviour of GRBs, avalaible for all the events. A deeper analysis obtained fitting a large energy bin number of GRBs spectra with several laws (Band et al. 1993; Tavani 1996; Briggs 1999, etc.) provides more detailed information for the whole energy range but for only a limited number of events, those with a sufficiently large signal-to noise ratio. The spectra of the less luminous GRBs, i.e. those GRBs which appear in the left and right tails of the figures, are excluded. For this reason, at present, it is not possible to perform a complete analysis of the correlations between luminosity and spectral parameters, obtained fitting the spectra with the proposed laws. Analysing the possible meaning of the obtained correlations between luminosity and hardness ratio, we note that the redshift effects alone cannot justify these results. In fact if the event low luminosity is due to redshift effects also the other parameters should be redshifted in the same way. But, for example, the events at the left of the plots, which have lower luminosities, are among the shortest ones (Belli 1995), and it is difficult to think that they are redshifted. So it seems that this luminosity behaviour is principally due to the intrinsic characteristics of the physical process at the origin of the phenomenon, to which possible redshift effects are added. For this reason these results can help us to select among the numerous models proposed for GRBs.

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