Where is the 3rd subgroup of GRBs?

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Abstract. It is shown that in the duration-hardness plane the GRBs of the third intermediate subgroup are well defined. Their durations are intermediate (i.e. roughly between 2 and 10 seconds), but their hardnesses are the smallest. They are even softer than the long bursts.

Key words: gamma rays: bursts

1. Introduction

It is widely accepted that the short and long gamma-ray bursts (GRBs) are really different phenomena (see, for example Norris et al. (2001) and the references therein). In 1998 Horváth made a trimodal fit of the BATSE Catalog bursts’ duration distribution and found a third subclass of GRBs’ (Horváth 1998). Later papers (Mukherjee et al. 1998, Hakkila et al. 2000, Rajaniemi & Mähönen 2002, Horváth 2002) used more parameters (e.g. peak fluxes, fluences, hardness ratios), and in this multidimensional space studies all of them confirmed that the third bursts population was statistically necessary.

Bagoly et al. (1998) showed that in this high dimensional parameter spaces only two main parameters were necessary to characterize all the BATSE Catalog bursts’ properties. Hence, a two dimensional space looks like a good characterisation of the GRB subgroups. Therefore, here we use $T_{90}$ and the hardness $H_{32}$ ratio in our newest analysis. Figure 1. shows the observed BATSE bursts’ distribution on the $\log(T_{90}) - \log(H_{32})$ plane.
2. The fits

This distribution can be fitted at the first step by the sum of two two-dimensional normal distributions in the \(\log T_{90} - \log H_{32}\) plane. If one were fitting simultaneously the values of \(\log T_{90}\) and \(\log H_{32}\) by one single two-dimensional (bivariate) normal distribution, then the distribution would have five independent parameters (two means, two dispersions, and the correlation coefficient). The standard form of such a bivariate distribution is given by

\[
f(x, y)dx dy = \frac{Ndx dy}{2\pi\sigma_x\sigma_y\sqrt{1-r^2}} \times \\
\exp \left[ -\frac{1}{2(1-r^2)} \left( \frac{(x-a_x)^2}{\sigma_x^2} + \frac{(y-a_y)^2}{\sigma_y^2} - \frac{C}{\sigma_x\sigma_y} \right) \right],
\]

where \(x = \log T_{90}\), \(y = \log H_{32}\), \(C = 2r(x-a_x)(y-a_y)\), \(a_x\), \(a_y\) are the means, \(\sigma_x\), \(\sigma_y\) are the dispersions, and \(r\) is the correlation coefficient. \(N\) is the number of GRBs, and \(f(x, y)dx dy\) the theoretically expected numbers of GRBs at the inf. surface at the \([x, y]\) plane given by intervals \([x, (x + dx)]\) and \([y, (y + dy)]\). In other words, \((f(x, y)/N)dx dy\) defines the probability of finding a GRB at the given inf. surface.

This fit was done by a standard search for 11 parameters with \(N = 1929\) measured points. Each GRB defines a point in the \(x, y\) plane with coordinates \(x_i, y_i\) \((i = 1, 2, ..., N)\). The theoretical curve \(f_2(x, y, a_{xk}, a_{yk}, \sigma_{xk}, \sigma_{yk}, r_k, W)\) \((k = 1, 2)\) is a sum of two normal distributions as given in Eq.1. The normalization constant of the first [second] term is \(NW [N(1-W)]\), where \(W\) is the weight of the first normal distribution. For the first (second) term the parameters are \(a_{x1}, a_{y1}, \sigma_{x1}, \sigma_{y1}, r_1\) \((a_{x2}, a_{y2}, \sigma_{x2}, \sigma_{y2}, r_2)\).

Table 1. Best fit with two bivariate normal distributions for \(\log T_{90}\) and \(\log H_{32}\).

| \(a_{x1}\) | -0.35 | \(a_{x2}\) | 1.47 |
| \(a_{y1}\) | 0.70 | \(a_{y2}\) | 0.39 |
| \(\sigma_{x1}\) | 0.52 | \(\sigma_{x2}\) | 0.47 |
| \(\sigma_{y1}\) | 0.33 | \(\sigma_{y2}\) | 0.24 |
| \(r_1\) | 0.1 | \(r_2\) | 0.1 |
| \(W\) | 0.28 |
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We obtain the best fit to the 11 parameters through a maximum likelihood (ML) estimation. We search for the maximum of the formula

$$L_2 = \sum_{i=1}^{N} \ln f_2(x_i, y_i)$$

(2)

using a simplex numerical procedure; the index ”2” in $L_2$ shows that we have a sum of two log-normal distributions of type given by Eq.1.

The results of this fit are shown in Table 1. One can calculate a density distribution of the observed data on the log($T_{90}$)-log($H_{32}$) plane. The values of Table 1 define the theoretical distribution of GRBs, if there is any theory, which suggests lognormal $H_{32}$ and $T_{90}$ distributions, in the $T_{90}$ - $H_{32}$ plane under the assumption that there are only two subgroups.

Hence, one can make the difference between the actual distribution and the theoretical distribution. If there were only two components, which distributed lognormally, one would find only some noise being proportional to the square root of the actual value of the burst density function. Surprisingly the biggest deviation is not there where the observed (or the theoretical) burst density function is the biggest, not even the dense core of the two subgroup population, rather then between the two groups in $T_{90}$ but in $H_{32}$ softer then either groups.

This deviation is shown by Figure 2. The widest contour has the half intensity then the highest deviation. In order to be sure that this difference is not a chance and is not given by the random noise, we proceeded as follows. We take this part of the log $T_{90}$ - log $H_{32}$ plane. This part contains 145 bursts. The integral over this area of the theoretical distribution gives 63.

Depends on which number is the Poisson parameter one can calculate the probability $10^{-17}$-$10^{-14}$. Of course there are so many different area and shapes, which we can probe. However if we take
10 different shapes 100 different sizes and try 1000 different positions in the plane the probability is still very low. Therefore one can say the deviation which the Figure 2. shows is very unlikely can cause by chance.

Unfortunately, the possible third group members are mixed with the long ones (partially also with the short ones, too).

3. Conclusions

We have argued that both the duration and also the hardness should be distributed log-normally - of course, in any subclass separately. We also provided in the $\log T_{90} - \log H32$ plane a fit with the sum of two bivariate normal distributions. The idea for this fitting was given by the observational fact that the short and long subclasses are different both at hardnesses and durations. Finally we obtained the difference between the actual distribution of GRBs and the theoretical one. The difference, not being a Poissonian noise, shows another subgroup, the third subgroup.

As the result we obtained the intermediate subclass having approximately the same number of bursts than it was previously predicted (Horváth 1998, Mukherjee et al. 1998, Hakkila et al. 2000, Rajaniemi & Mähönen 2002 and Horváth 2002). We also confirm that their hardnesses are low.

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