Gamma-Ray Burst Groups Observed by Different Satellites

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Abstract. Two classes of gamma-ray bursts have been identified in the BATSE catalogs characterized by durations shorter and longer than about 2 seconds. There are, however, some indications for the existence of a third one. Swift satellite detectors have different spectral sensitivity than pre-Swift ones for gamma-ray bursts. Therefore it is worth to reanalyze the durations and their distribution and also the classification of GRBs. In this paper we are going to analyze the bursts’ duration distribution and also the duration-hardness bivariate distribution, published in The First BAT Catalog, whether it contains two, three or maybe more groups. Similarly to the BATSE data, to explain the BAT GRBs duration distribution three components are needed. Although, the relative frequencies of the groups are different than they were in the BATSE GRB sample, the difference in the instrument spectral sensitivities can explain this bias in a natural way. This means theoretical models may have to explain three different type of gamma-ray bursts.

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INTRODUCTION

It was always challenging to classify gamma-ray bursts (GRBs). Using The First BATSE Catalog, Kouveliotou et al. [1] found a bimodality in the distribution of the logarithms of the durations using \( T_{90} \) (the time in which 90% of the fluence is accumulated) to characterize the duration of GRBs. Today it is widely accepted that the physics of these two groups are different, and these two kinds of GRBs are different phenomena [2, 3]. The sky distribution of the short bursts is anisotropic [4, 5]. In the Swift database the two groups have a different redshift distribution, for short burst the median is 0.4 [6] and for the long ones it is 2.4 [7].

Using the Third BATSE Catalog we have shown [8] that the duration \( (T_{90}) \) distribution of GRBs observed by BATSE could be well fitted by a sum of three log-normal distributions. We find it unlikely (with a probability \( \sim 10^{-4} \)) that there are only two groups. At the same time, [9] report the finding (in a multidimensional parameter space) of a very similar group structure of GRBs. Several authors [10, 11, 12, 13, 14, 15] included more physical parameters into the analysis of the bursts (e.g. peak-fluxes, fluences, hardness ratios, etc.). A cluster analysis in this multidimensional parameter space suggests the existence of the third (“intermediate”) group as well [9, 10, 16, 17, 15]. The physical existence of the third group is, however, still not convincingly proven. The celestial distribution of the third group is anisotropic [18, 19, 20]. All these results mean that the existence of the third intermediate group in the BATSE sample is acceptable, but its physical meaning, importance and origin is less clear than those of the other groups. Thus, it is important to investigate the presence of the third group in the Swift sample as well.

DURATION AND DURATION-HARDNESS FITS

As in [21] we fit the log \( T_{90} \) distribution using Maximum Likelihood (ML) method with a superposition of \( k \) log-normal components. Each of the components have 2 unknown parameters to be fitted and the total number of measured points is \( N = 222 \) (in the Swift First BAT Catalog there are 237 GRBs, of which 222 have duration information [22]). For the distribution see Fig. 1. Our goal is to find the minimum value of \( k \) suitable to fit the observed distribution. Assuming a weighted superposition of \( k \) log-normal distributions one has to maximize the following likelihood function:

\[
L_k = \sum_{i=1}^{N} \log \left( \sum_{l=1}^{k} w_l f_l(x_i, \log T_i, \sigma_l) \right)
\]
where $w_i$ are the weights, $f_i$ a log-normal function with $\log T_i$ mean and $\sigma_i$ standard deviation having the form of
\[
f_i = \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left(-\frac{(x - \log T_i)^2}{2\sigma_i^2}\right)
\]

The three-Gaussian fit is shown in Figure 1. The best parameters were published in [23]. Here in Table 1, we present the comparison of the parameters of the GRB groups observed by CGRO BATSE and Swift BAT. BAT sensitivity is different than BATSE sensitivity was [24, 25]. BAT is more sensitive at low energies which means it can observe more X-ray flashes and soft bursts and probably fails to detect many hard bursts (typically short ones). Therefore one expects more long and intermediate bursts and less short GRBs. In the BAT data set there are only a few short bursts. Our analysis could only find 16 short bursts (7%). The robustness of the ML method is demonstrated here because a group with only 7% weight is identified. Previously, in the BATSE database the intermediate bursts were identified by many research groups. However, in this class different frequencies were found representing 10-20% of BATSE GRBs [9, 10, 16, 17, 26].

We can use more parameters for classification. The analysis of the clustering properties of GRBs in the BATSE 3B Catalog [9] identified duration, total fluence and hardness as the relevant quantities for classification. Fitting the observed distribution with the superposition of Gaussian components one had to keep the number of estimated parameters as small as possible to ensure the stability of the Maximum Likelihood procedure, therefore we decided to use two dimensional Gaussians with the logarithmic duration and hardness. This work for the BATSE data was done by [26] (Figure 2, left panel shows the result).

Here we use the Swift First BAT catalog and fit 2D Gaussians on the duration hardness plane. Figure 2 right panel shows the result (black=short, light gray=intermediate and dark gray=long bursts). In Table 1, we compare the results of the Swift and BATSE data.

### TABLE 1. The parameters of the three groups of GRBs

| centroid in log(Duration) | $w$ (Swift BAT) | centroid in log(Duration) | $w$ (CGRO BATSE) |
|--------------------------|-----------------|--------------------------|------------------|
| -0.479                   | 7.5% short      | -0.301                   | 20-26%           |
| 1.754                    | 65% long        | 1.565                    | 60-66%           |
| 0.991                    | 27.5% intermediate | 0.637               | 10-20%           |

**FIGURE 1.** Duration distribution of the First BAT Catalog gamma-ray bursts with a three-Gaussian fit.
FIGURE 2. Classification in the duration-hardness plane (left BATSE, right Swift).

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