Classification of BeppoSAX’s Gamma-Ray Bursts

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Abstract

The BeppoSAX Catalog has been very recently published. In this paper we analyze - using the Maximum Likelihood (ML) method - the duration distribution of the 1003 GRBs listed in the catalog with duration. The ML method can identify the long and the intermediate duration groups. The short population of the bursts is identified only at a 96% significance level. MC simulation has been also applied and gives a similar significance level; 95%. However, the existence of the short bursts is not a scientific question after the Compton Gamma-Ray Observatory’s observation. Our minor result is this well-known fact that in the BeppoSAX data the short bursts are underrepresented, mainly caused by the different triggering system. Our major result is the identification of the intermediate group in the BeppoSAX data. Therefore, four different satellites (CGRO, Swift, RHESSI and BeppoSAX) observed the intermediate type Gamma-Ray Burst.

Keywords Gamma rays: bursts, theory, observations

1 Introduction

(Kouveliotou et al. 1993) identified two types of Gamma-Ray Bursts (GRBs) based on durations, for which the value of $T_{90}$ (the time during which 90% of the fluence is accumulated) is smaller or larger than 2 s, respectively. (Mukherjee et al. 1998) and (Horváth 1998) made a suggestion about the third type of GRBs, which have intermediate (2-9 s) duration. Later several papers confirmed this suggestion (Hakkila et al. 2003). All of these works were based on BATSE observations.

Lately, analysis of Swift (Horváth et al. 2008) and RHESSI (Ripa et al. 2007; Ripa et al. 2009) data have found a similar group structure (for RHESSI the $\chi^2$ method found only two groups, however, the Maximum Likelihood (ML) method reveals a significant intermediate group (Ripa et al. 2009)). Since The Gamma-Ray Burst catalog obtained with the Gamma Ray Burst Monitor (GRBM) aboard BeppoSAX (Frontera et al. 2009a) has been published recently, this catalog is worth to be analyzed, whether the statistical methods can show us similar or different groups of GRBs.

In Sect. 2 we analyze the duration distribution of the GRBs observed by BeppoSAX. In Sect. 3 we discuss the instrumental details of our analysis. In Sect. 4 we present the conclusions.

2 Analysis of the duration distribution

In the BeppoSAX catalog (Frontera et al. 2009a; Frontera et al. 2009b) there are 1082 GRBs, of which 1003 have duration information (see Figure 1. for the distribution).

2.1 Maximum Likelihood calculations

Similarly to (Horváth 2002) we fit the log $T_{90}$ distribution using Maximum Likelihood (ML) method with a superposition of $k$ log-normal components, each of them having 2 unknown parameters to be fitted with $N = 1003$ measured points in our case. 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:

\[ L_k = \sum_{i=1}^{N} \log \left( \sum_{l=1}^{k} w_l f_l(x_i, \log T_l, \sigma_l) \right) \]  

(1)

where \( w_l \) is a weight, \( f_l \) a log-normal function with \( \log T_l \) mean and \( \sigma_l \) standard deviation having the form of

\[ f_l = \frac{1}{\sigma_l \sqrt{2\pi}} \exp \left( -\frac{(x-\log T_l)^2}{2\sigma_l^2} \right) \]  

(2)

and due to a normalization condition

\[ \sum_{l=1}^{k} w_l = N. \]  

(3)

We used a simple C++ code to find the maximum of \( L_k \). Assuming only one log-normal component the fit gives \( L_{1\text{max}} = 5951.895 \) but in the case of \( k=2 \) one gets \( L_{2\text{max}} = 6011.355 \). See Table 1. for the best parameters.

In (Horváth et al. 2008) we summarize the ML method and refer to (Kendall & Stuart 1976) the confidence region of the estimated parameters, which is given by the following formula, where \( L_{\text{max}} \) is the maximum value of the likelihood function and \( L_0 \) is the likelihood function at the true value of the parameters:

\[ 2(L_{\text{max}} - L_0) \approx \chi_k^2 \]  

(4)

Based on this equation we can infer whether the addition of a further log-normal component is necessary to significantly improve the fit. We make the null hypothesis that we have already reached the true value of \( k \). Adding a new component, i.e. moving from \( k \) to \( k+1 \), the ML solution of \( L_{k\text{max}} \) has changed to \( L_{(k+1)\text{max}} \), but \( L_0 \) remained the same. In the meantime we increased the number of parameters with 3 (\( w_{k+1} \),

**Table 1** The best parameters for the two log-normal fit of the GRB (observed by BeppoSAX) duration distribution.

| Duration | \( \log T_{90} \) | \( \sigma(\log T_{90}) \) | \( w \) |
|----------|-----------------|-----------------|-----|
| shorter  | 0.62            | 0.62            | 306.2 |
| long     | 1.45            | 0.40            | 696.8 |
logT_{k+1} and \sigma_{(k+1)}). Applying Eq. (3) on both L_{kmax} and L_{(k+1)max} we get after subtraction

\[ 2(L_{(k+1)max} - L_{kmax}) \approx \chi^2_3. \tag{5} \]

For \( k = 1 \), \( L_{2max} \) is greater than \( L_{1max} \) by more than 59, which gives for \( \chi^2_3 \) an extremely low probability. It means the two log-normal fit is a really better approximation for the duration distribution of GRBs than one log-normal. The longer duration group (with a centroid about 28 seconds) has 69\% of the burst population and the shorter one (with a centroid about 4.2 seconds) has 31\%.

Thirdly, a three-log-normal fit was made combining three \( f_k \) functions with eight independent parameters (three means, three standard deviations and two weights). The highest value of the logarithm of the likelihood \( (L_{3max}) \) is 6015.585. For two log-normal functions the maximum was \( L_{2max} = 6011.355 \). The maximum thus improved by 4.23. Twice of this is 8.46 which gives us the probability of 3.7\% for the difference between \( L_{2max} \) and \( L_{3max} \) is being only by chance.

2.2 Monte Carlo simulations

One can check the 0.037 probability, using a Monte-Carlo (MC) simulation. Take the two-log-normal distribution with the best fitted parameters of the observed data, and generate 1003 numbers for \( T_90 \) whose distribution follows the best fit of the two-log-normal distribution. Find the best likelihood with five free parameters, two means, two dispersions and two weights (only one is independent). Make a fit with a three-log-normal distribution (eight free parameters, three means, three dispersions and two independent weights). Take the difference between the two logarithms of the maximum likelihoods and that gives one number in our MC simulation.

This procedure have been carried out for 1000 simulations. There were 49 cases when the log-likelihood difference was more than the one obtained for the BeppoSax data (4.23). Therefore, the MC simulations do not confirm exactly the numerical result obtaining by Eq. (3), however, it gives a similar (4.9\%) probability for the statement that a third group is only a statistical fluctuation (for more details see (D’Agostini 2003; D’Agostini 2004)).

The conclusion is the same; the third group population is not confirmed in high significance level. Therefore, there is a chance the third log-normal is not needed. This third population is the shortest duration GRB group. However we already know from the BATSE sample the short duration group is exist. Therefore from the SAX data, using only the duration information we can confirm the existence of the short bursts with only 95-96\% significance level.

3 Discussion

There is no question that the short bursts exist, since many satellites identified short (less than two seconds long) and spectrally harder bursts. In this paper we are using only the duration information of the bursts. The ML method was not able to identify all the three subgroups in the BeppoSax data at a high significance level (once again, using only \( T_90 \)). The third group in our analysis was the shortest in duration. As (Frontera et al. 2009a) pointed out short bursts are less pronounced and displaced toward higher durations with respect to BATSE. This discrepancy is due to the lower efficiency of the GRBM trigger system to short GRBs, which, for almost the entire BeppoSax mission duration, used 1 s as short integration time. More details can be seen in (Band 2003; Guidorzi et al. 2001; Frontera et al. 1997).

However, in the duration distribution two components were found at a very high significance level. Surprisingly, analyzing the duration distribution observed by BeppoSax GRBM one can find the long and the intermediate duration population. The short population can be seen only with low significance level.

4 Conclusions

In the BATSE data many scientific groups identified three types of bursts; short hard, long soft and intermediate duration very soft bursts (Mukherjee et al. 1998; Horváth 1998; Hakkila et al. 2000; Balastegui et al. 2001; Rajaniemi & Mähönen 2002; Horváth 2002; Hakkila et al. 2003; Horváth et al. 2006; Chattopadhyay et al. 2007). In the Swift (Horváth et al. 2008) and RHESSI (Rípa et al. 2007; Rípa et al. 2008) data recent works identified the same group structures.

In this paper we analyzed a fourth data set - observed by the BeppoSAX satellite. The duration distribution cannot be well fitted with one Gaussian component. The two Gaussian fit is much better and the three Gaussian fit is better only at a 95-96\% significance level. However, we surely know from previous works that short (third group in our analysis) bursts exist.

The existence of the intermediate type burst is still not widely accepted. In this paper we showed that in order to fit the BeppoSAX data duration distribution a
second component of intermediate duration is needed. However, the physical existence of the intermediate GRBs can be still questionable. (Hakkila et al. 2003) argued that the statistical existence of the intermediate group in the BATSE sample is caused by instrumental effects. Instrumental biases can play a relevant role in shaping the observed duration distribution and the different fractions of short GRBs observed in the various catalogues reflects this. In the case of the GRBM, an important bias is given by the relatively long (1 s) short integration time adopted throughout most of the mission lifetime (Frontera et al. 2009a). Due to this, the claim for a physically separate class of intermediate GRBs requires a word of caution and the upcoming catalogues of new missions, such as Fermi/GBM, will help to clarify this issue.

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