Temporal properties of short and long gamma-ray bursts

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Abstract. A temporal analysis was performed on a sample of 100 bright short GRBs with $T_{90}<2s$ from the BATSE Current Catalog along with a similar analysis on 319 long bright GRBs with $T_{90}>2s$ from the same catalog. The short GRBs were denoised using a median filter and the long GRBs were denoised using a wavelet method. Both samples were subjected to an automated pulse selection algorithm to objectively determine the effects of neighbouring pulses. The rise times, fall times, FWHM, pulse amplitudes and areas were measured and their frequency distributions are presented. The time intervals between pulses were also measured. The frequency distributions of the pulse properties were found to be similar and consistent with lognormal distributions for both the short and long GRBs. The time intervals between the pulses and the pulse amplitudes of neighbouring pulses were found to be correlated with each other. The same emission mechanism can account for the two sub-classes of GRBs.

INTRODUCTION

It has been recognised that GRBs may occur in two sub-classes based on spectral hardness and duration with $T_{90}>2s$ and $T_{90}<2s$ [2, 6, 7]. The bimodal distribution can be fit by two Gaussian distributions to the logarithmic durations [3]. A variety of statistical methods have been applied to the temporal properties of the long GRBs with $T_{90}>2s$. It is important to compare the temporal properties of the long and short GRBs to determine the similarities and differences between the two classes in an objective way. Detailed temporal analyses have been performed on a large sample of short and long bright GRBs. The results from the long sample [8] can be used as templates for comparison with a similar analysis of short GRBs.

DATA ANALYSIS

The sample of 100 short GRBs was selected from the Time Tagged Event data at 5 ms from the BATSE Current Catalog. The four energy channels were combined to maximise the signal to noise ratio. The sample of 319 long GRBs was selected from the “discsc” 64ms data also from the BATSE Current Catalog. The energy channels were combined as for the short GRBs. Bursts from both samples were background subtracted by selecting a pre- and/or post-burst section.

A median filter was used to denoise the short GRBs [4] and a wavelet method [8] was used to denoise the long GRBs. The same pulse selection method was applied to each sample of denoised GRBs. The pulses selected had a threshold of 5 $\sigma$ above background ($\tau_{\sigma} \geq 5$) and were isolated from adjacent pulses by at least 50% ($\tau_{i} \geq 50\%$). A value of $\tau_{i} \geq 50\%$ implies that the two minima on either side of the pulse maximum must be at or below half the maximum value. A total of 313 pulses were selected from the sample of short GRBs with $\tau_{\sigma} \geq 5$ and 181 of these had $\tau_{i} \geq 50\%$. A total of 3358 pulses with $\tau_{\sigma} \geq 5$ were selected from the sample of long GRBs, 1575 of which had $\tau_{i} \geq 50\%$.

RESULTS

The distributions of rise times ($t_{r}$), fall times ($t_{f}$) and full width at half maxima (FWHM) for the isolated pulses ($\tau_{i} \geq 50\%$) are presented in Fig. 1. The distribution of time intervals between the pulses ($\Delta T$) with $\tau_{\sigma} \geq 5$ is also given in Fig. 1. The distributions of pulse amplitudes and areas are given in Figs. 2 and 3 for the isolated pulses observed by two BATSE large area detectors. The median values of the distributions are presented in Table 1. The Spearman Rank Order correlation coefficients $\rho$ along with associated probabilities for the time intervals separated by N pulses are given in Table 2. The $\Delta T$ values are normalised by $T_{90}$ for each burst and show that there is a high degree of correlation over many intervals for the long GRBs. The Spearman Rank Order correlation
coefficients for the pulse amplitudes with N are listed in Table 3 for the short and long bursts.

**TABLE 1.** The median values of the pulse properties in GRBs. All pulses with \( \tau_0 \geq 5 \) were used for the time intervals, not just isolated pulses as for the pulse properties.

| Pulse Property          | Short GRBs | Long GRBs |
|-------------------------|------------|-----------|
| Rise Time (sec)         | 0.035      | 0.64      |
| Fall Time (sec)         | 0.056      | 1.10      |
| FWHM (sec)              | 0.045      | 0.58      |
| Time Interval (sec)     | 0.095      | 1.34      |
| Pulse Area (count rate) | \( 1.5 \times 10^5 \) | \( 1.5 \times 10^5 \) |
| Pulse Amplitude (count rate) | \( 1.0 \times 10^4 \) | \( 8 \times 10^3 \) |

**TABLE 2.** Spearman Rank Order correlation coefficients \( \rho \) for time intervals between pulses. The value of N indicates the number of pulses between the correlated time intervals. The two values for \( \rho \) and the probability are for unnormalised/normalised time intervals. The values are normalised by \( T_{90} \). The first two lines refer to the short GRBs and the remaining lines refer to the long GRBs.

| N | Number of Intervals | \( \rho \) | Probability |
|---|---------------------|---------|-------------|
| 1 | 140                 | 0.42/0.30 | \( 1.7 \times 10^{-12} / 3.4 \times 10^{-4} \) |
| 2 | 84                  | 0.48/0.32 | \( 4.9 \times 10^{-6} / 3.0 \times 10^{-3} \) |
| 1 | 2751                | 0.42/0.56 | \( < 10^{-48} \) |
| 2 | 2499                | 0.34/0.48 | \( < 10^{-48} \) |
| 5 | 1929                | 0.24/0.37 | \( 5 \times 10^{-26} / < 10^{-48} \) |
| 10| 1395                | 0.20/0.29 | \( 3 \times 10^{-13} / 6 \times 10^{-27} \) |
| 15| 890                 | 0.16/0.25 | \( 3 \times 10^{-6} / 4 \times 10^{-14} \) |

**TABLE 3.** Spearman Rank Order correlation coefficients \( \rho \) for the pulse amplitudes of neighbouring pulses (N=1) and pulses separated by N pulses. The two values for \( \rho \) and the probability are for unnormalised/normalised pulse amplitudes. The later are normalised by the maximum pulse amplitude in the burst. The first two lines refer to the short GRBs and the remaining lines refer to the long GRBs. The maximum peak was removed for the short GRBs in the normalised sample.

| N | Number of Pulses | \( \rho \) | Probability |
|---|------------------|---------|-------------|
| 1 | 213/107          | 0.39/0.24 | \( 5 \times 10^{-9} / 1.1 \times 10^{-2} \) |
| 2 | 140/84           | 0.13/-0.09 | 0.13/0.42 |
| 1 | 3039             | 0.72/0.57 | \( < 10^{-48} \) |
| 3 | 2499             | 0.55/0.32 | \( < 10^{-48} \) |
| 5 | 2098             | 0.52/0.24 | \( < 10^{-48} / 3 \times 10^{-29} \) |
| 7 | 1777             | 0.48/0.15 | \( < 10^{-48} / 6 \times 10^{-11} \) |

**DISCUSSION**

There are remarkable similarities between the statistical properties of the two sub-classes of GRBs. The distributions of the \( t_r \), \( t_f \), FWHM, pulse amplitude, pulse area

**FIGURE 1.** Normalised distributions of \( t_r \), \( t_f \), FWHM, and \( \Delta T \) (a-d).
and $\Delta T$ for GRBs with $T_{90}<2$ s and $T_{90}>2$ s are very similar and both are well described by lognormal distributions [4, 8]. In long GRBs with $T_{90}>2$ s the values of $\Delta T$ are not random but consistent with a lognormal distribution with a Pareto-Levy tail for a small number of long time intervals in excess of 15 s. The values of the time intervals between pulses and the pulse amplitudes were found to be correlated over most of the long GRBs (Tables 2 and 3). In the short GRBs adjacent and subsequent time intervals and pulse amplitudes were found to be correlated at a lower significance level due to the smaller number of pulses.

The clear conclusion is that the same emission mechanism can account for the two types of GRBs. This conclusion is in agreement with a very different analysis of the temporal structure of short GRBs [5]. The external shock model [1] has serious difficulties in accounting for GRBs with $T_{90}<2$ s and with the non-random distribution of correlated time intervals between pulses. The results presented here provide considerable support for the internal shock model [9]. The internal shock model can account for the results obtained for long and short GRBs provided the cause of the pulses and the correlated values of $\Delta T$ can be attributed to the central engine.

**CONCLUSIONS**

Samples of short and long bright GRBs have been denoised and analysed by an automatic pulse selection algorithm. The results show that in both cases the distribution of the properties of isolated pulses and time intervals between all pulses are similar and compatible with lognormal distributions. The same mechanism seems to be responsible for both long and short GRBs and may be attributable to the internal shock model.

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**FIGURE 2.** Pulse Amplitude distributions for the long GRBs (a) and the short GRBs (b). The dashed lines indicate lognormal fits to the data. The resolution of the long sample is 64 ms and the resolution of the short sample is 5 ms.

**FIGURE 3.** Pulse Area distributions for the long GRBs (a) and the short GRBs (b). The dashed lines indicate lognormal fits to the data.