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An Analysis of the Structure of Gamma-Ray Burst Time Histories

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ABSTRACT

If gamma-ray bursts arise from a small number of distinctly different physical phenomena, then this might be revealed by a clustering of time profile characteristics into a small number of groups. We have applied a "spike" counting algorithm to 107 GRB profiles. Here we present graphs of spike frequency and spike amplitude versus burst intensity and duration. So far, we see no evidence of grouping.

INTRODUCTION

One of the challenges for both theorists and experimentalists in the field of gamma-ray bursts is to explain the seemingly disparate results of recent observations. One of the pressing questions in the ongoing debate is whether or not the majority of bursts originate from a single or multi-component source distribution.

If bursts arise from a small number of distinctly different physical phenomena, then this might be revealed by a clustering of time profile characteristics into a small number of groups. In this paper, we analyze the amplitude and frequence of occurrence of spikes in GRB time profiles. Our goal is to see if these characteristics divide the GRB population into groups which could indicate the presence of a multi-component source population.

Previous attempts to characterize gamma-ray bursts by their time histories have met with very limited success. Barat et al.[1] calculated a wide range of burst profile characteristics with no apparent groupings nor trends. They also found no correlation of time profiles with spectral character.

Belli,[2] analyzing five Venera 11 and 12 GRB time profiles from the Mazets catalog, found that the non-Poissonian "noise" could be explained by shot noise processes with characteristic shot frequencies of 0.5 ± 1 shots per second. (The relatively large error being due to the poor statistics provided by only 5 bursts.)

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ALGORITHM

In a previous paper[3] we presented the idea that a reasonable statistic that measures the structure or "spikiness" of a time profile is the number of times the profile shows a run of monotonically increasing (or decreasing) bin-to-bin differences of a pre-determined length. The algorithm that we use permits a definition of a "spike" as a monotonic increase of at least N bin differences followed by at least M monotonically decreasing bin differences. (The mirror image can also be counted, if desired, i.e., N decreasing followed by M increasing.)

In that paper we showed that runs of 7 or more bin differences were effective in differentiating profiles with different amounts of structure and also separating the weakest bursts from background profiles. This algorithm is also sensitive, as it should be, to spikes riding on top of a broad emission feature and insensitive to the broad feature itself. In order for this method to work, we found it necessary to first smooth the profile with a 5-point moving average. This does not alter the number of spikes in the post-burst background but it does enhance the spikes in the burst.

In addition to the width of the spike (length of the "run"), we have added another variable to the algorithm. This second variable is the peak height, equal to the difference in the number of counts between the last bin in the run and the first bin. This variable, called the "peak height filter" or, filter, is measured as a number of σ above the post-burst background.

In this paper, we apply these criteria to 107 burst time histories. The data that we use are the BATSE 64-ms DISCSC data ($E > 20$ keV). Thus, a monotonic run of 8 bins spans a time of 1/2 second. The 107 profiles were chosen because their durations were greater than 12 seconds.

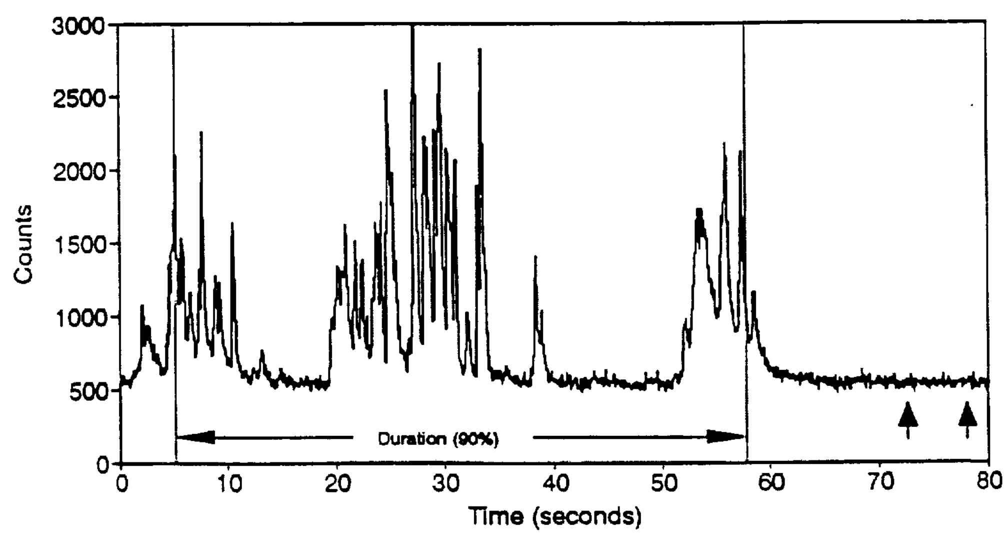

Figure 1. Time history of BATSE GRB #1676 (1B 920627, at 46956 secs). Indicated are the duration, T_5^{95}, and the region of the post-burst profile used to calculate the average background.

Figure 1 presents a sample time profile. Superimposed on the figure is a measure of duration, T_5^{95}. An average background level is calculated in the post-burst region between the small arrows on the right side of the figure. This average background is subtracted and the T_5^{95} duration begins after 5% of the burst counts are recorded and ends after 95%.

Figure 2 shows histograms of the average spike frequency (spikes/sec) seen in the 107 profiles for three different values of spike size, N. Notice that as the spike size is decreased, the number of spikes increases. In this paper we use a spike size of $N = 7$. The average frequency in this case is about 0.2 spikes/sec.

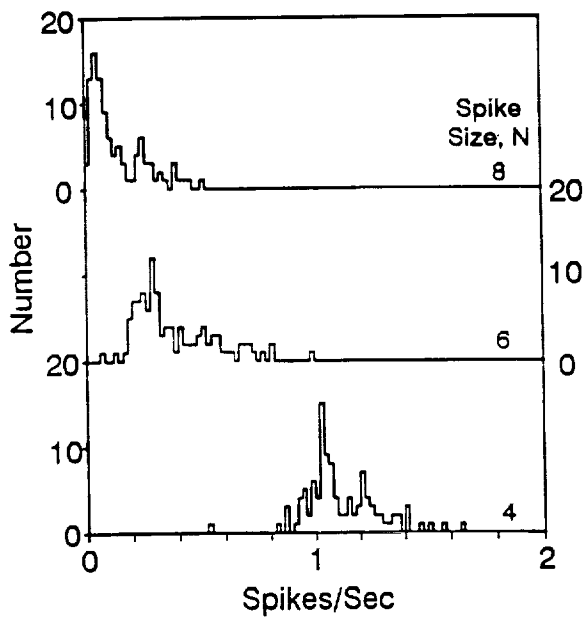

Figure 2. Spike frequencies for all 107 profiles for 3 different spike sizes.

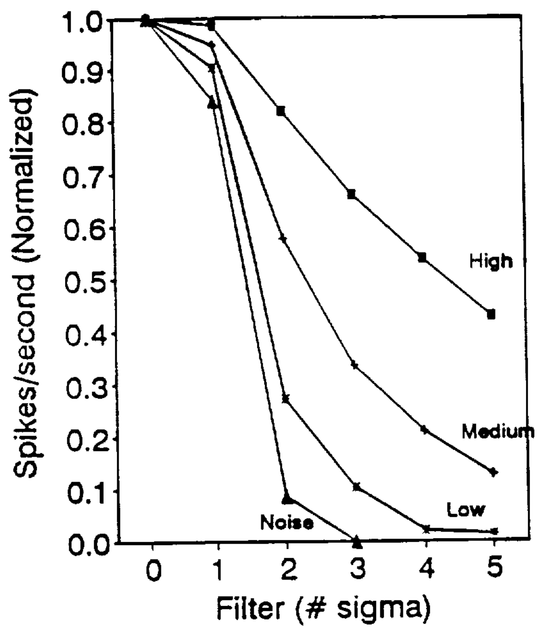

Figure 3. Spike frequency versus filter for 3 profile types (high, medium, and low structure and background.)

To demonstrate the effect of the filter on the measured spike frequency, Figure 3 presents the frequency as a function of filter (σ). We have divided the 107 bursts into three groups according to their structure. In addition, we include the results of measurements on ten theoretically-generated noise profiles, each one with a duration of 250 seconds. Notice that the spike frequency in the profiles with high structure do not decrease as rapidly with increasing filter as do the others.

RESULTS

Here we present graphs of profile structure and several other parameters in the hope of finding unexpected correlations or groupings of data points. The presence of groups may indicate the presence of different causal phenomena and/or a multi-component source distribution.

Figures 4, 5, and 6 present i) the values of $C_{\mathbf{max}}$ (i.e., the largest count in a 64-msec bin) versus the T_5^{95}, ii) the spike frequency vs. T_5^{95}, and iii) the spike frequency vs. $C_{\mathbf{max}}$, respectively. As might be expected, there is no correlation in the first two graphs. In Figure 4, long bursts have the same maximum intensity as short bursts†. In Figure 5 the frequency of spikes evidently does not depend on burst duration. Figure 6 does show an expected correlation. Brighter bursts have small peaks that stand out above the background and are therefore counted thus increasing the spike frequency. However, dimmer bursts lose spike counts because of the background noise and therefore have a lower frequency.

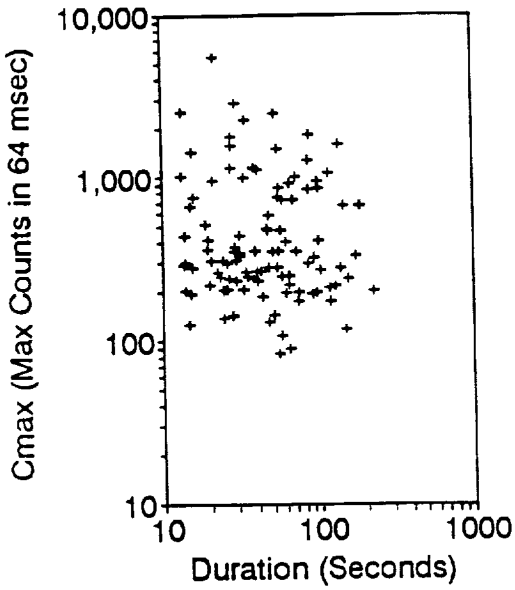

Figure 4. $C_{\mathbf{max}}$ vs. Duration

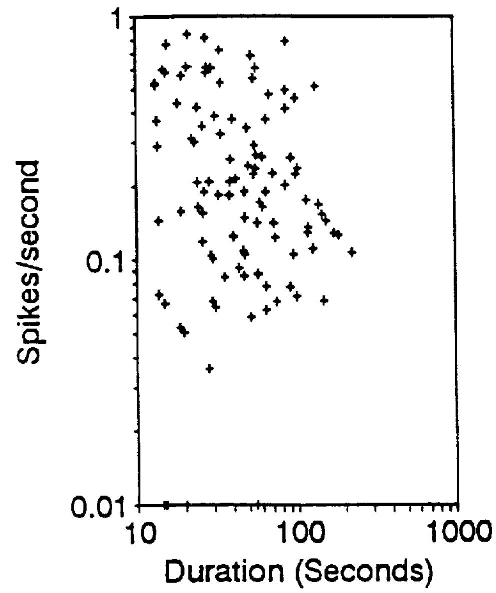

Figure 5. Spike Frequency vs. Duration.

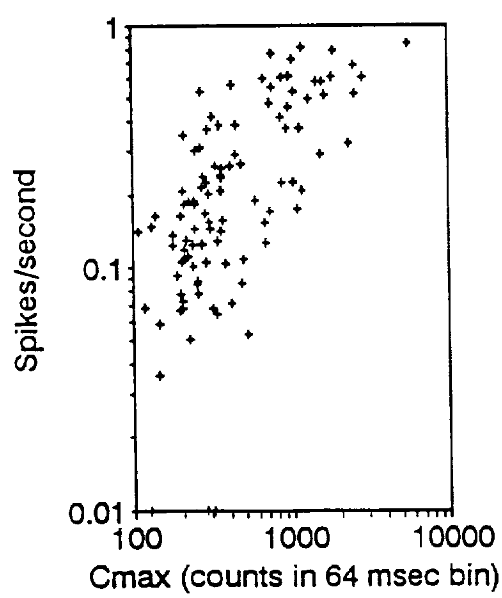

Figure 6. Spike Frequency vs. $C_{\mathbf{max}}$

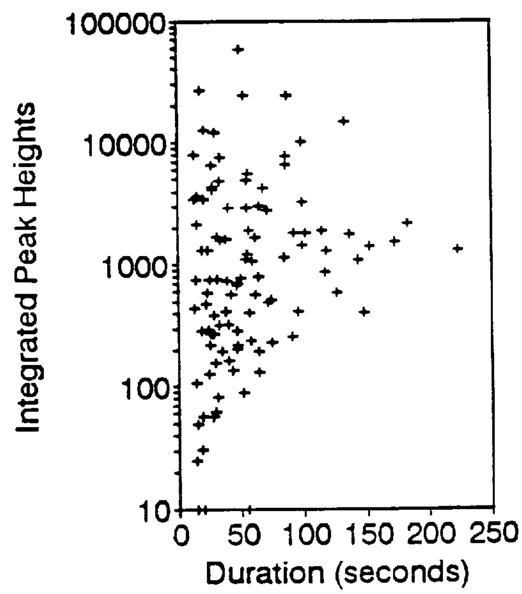

Figure 7. Integrated peak heights vs Duration.

† A cosmological effect, if present, would at most change the durations by a factor of 2 or 3. In Figure 4 the ratio of maximum to minimum duration is 25.

Figure 7 presents the integrated peak heights vs. duration. The integrated peak height is the sum of all heights for qualified spikes in a profile. It is interesting that the longest bursts do not show the same spread in this parameter as do the shorter bursts. However, we see no evidence of separate components in this figure.

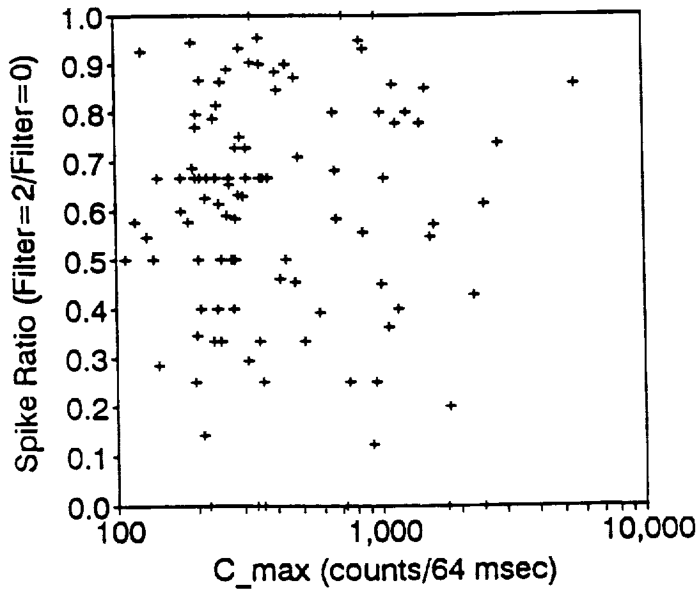

Figure 8. Ratio of spike frequency at a filter of 2 σ to that at 0 σ vs. $C_{\max}$.

Finally, we present in Figure 8 the graph of the ratio of spikes seen with a filter equal to 2 σ to that at 0 σ versus $C_{\max}$. The abscissa here reflects the absence of smaller spikes in a profile. If a profile has no small peaks, this ratio will be unity; if most of its spikes are small (i.e., less than 2 σ) then its ratio will be close to zero. As before, there is no evidence for grouping nor the presence of subsets in these data.

CONCLUSIONS

At this stage we see no evidence in burst time profiles that would suggest that gamma-ray bursts originate from a small number of distinctly different phenomenological sources. The distributions of profile characteristics that we measure, such as spike frequency and spike amplitude, are homogeneous and show no unexpected correlations. We are continuing this line of investigation and will include correlations with other parameters such as spectral hardness. Furthermore, since our algorithm provides us with not only the number of spikes in a profile but also the time between spikes, we will extend the analysis to investigate spike clustering.

REFERENCES

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2. B. M. Belli, Ap. J. **393**, 266 (1992).
3. J. P. Lestrade, et. al., Gamma-Ray Bursts (AIP Conf. Proc. 265, 1992).