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Structure in Gamma-Ray Burst Time Profiles: Statistical Analysis I

Prepared by:	John Patrick Lestrade
Academic Rank:	Associate Professor
Institution and Department:	Mississippi State University Department of Physics and Astronomy
NASA/MSFC:	
Laboratory:	Space Science
Division:	Astrophysics
Branch:	High-Energy Astrophysics
MSFC Colleague:	G. J. Fishman

1. Introduction:

Since its launch on April 5, 1991, the Burst And Transient Source Experiment (BATSE) has observed and recorded over 500 gamma-ray bursts (GRB). The analysis of the time profiles of these bursts has proven to be difficult. An example profile is shown in Figure 1. Attempts to find periodicities through Fourier analysis have been fruitless except in one celebrated case (Mazets et al., 1979). The only meaningful results that have been derived are some general rise and fall times of the pulses. However, even these studies fail to show any significant trends or consistent classifications (Barat et al., 1984). The only definitive, agreed-upon, statement is that the positions and heights of the pulses in a gamma-ray burst time history appear to be completely stochastic in nature.

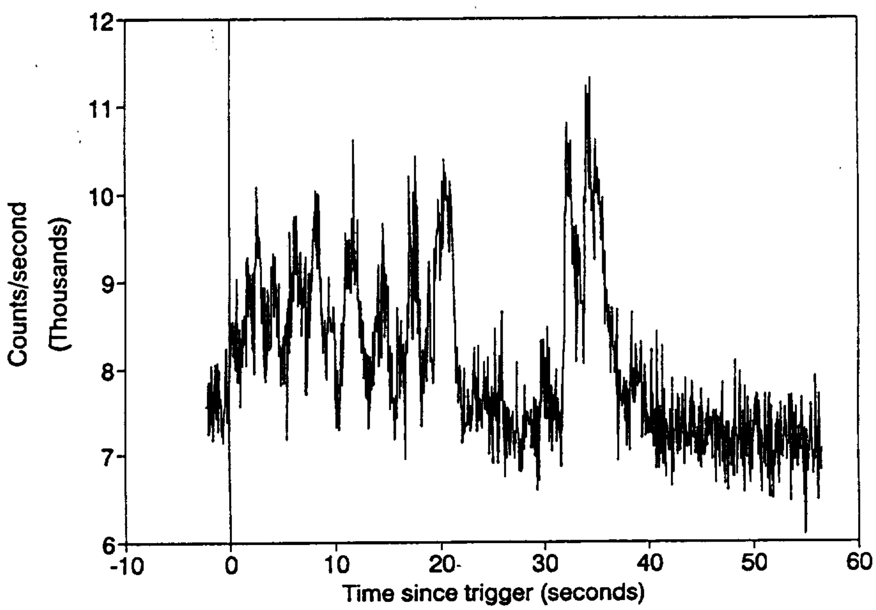

Figure 1. Time Profile of GRB #404

In a recent paper (Lestrade et al., 1991), we showed that a robust quantitative measure of a profile's structure is given by a count of the number of occurrences of monotonic "runs", similar to the standard "run test" (Eadie et al., 1971). This parameter (S_p) has several properties that make it attractive as a statistic: linearity with changing structure, independence from background fluctuations, independence from trigger time, and most importantly it is based upon a well-defined numerical recipe. The nominal recipe is 1) smooth the profile with a 5-point moving average, 2) choose a spike "size" $a|b$, and 3) scan through the profile counting "spikes". A spike is defined as $b+1$ successive bins with the first $a+1$ counts monotonically increasing and the following $b-a$ monotonically decreasing.

Our goal is to be able to quantify the observed time-profile structure. Before applying this formalism to bursts, we have tested it on profiles composed of random poissonian noise. This paper is a report of those preliminary results.

2. Spikiness:

The probability of observing x counts in a BATSE 64-msec bin is given by the normal p.d.f., viz,

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}, \qquad [1]$$

where μ is the mean (about 600 counts for BATSE discsc data) and σ is the standard deviation ($\approx \sqrt{\mu}$). The probability of finding n monotonically increasing bins is

$$P_n = \int_{-\infty}^{\infty} P(x_1) \int_{x_1}^{\infty} P(x_2) \ldots \int_{x_{n-1}}^{\infty} P(x) dx\, dx_{n-1} \ldots dx_1. \qquad [2]$$

Fortunately, we can avoid the integral in Equation [2] and use the algebra of permutations and combinations to calculate P_n.

As a test, we generated 10 artificial profiles of 3900 bins each from normal deviates (Press, 1986). Table 1 presents the observed number of spikes in these profiles as a function of spike duration. It should be kept in mind that a spike is recorded, if the *minimum* criterion is met. For example, an observed rising slope of 7 consecutive bins followed by 3 monotonically decreasing bins, would be counted as a spike for all criteria of sizes $a|b$ where $a \leq 6$ and $b-a \leq 3$.

Table 1: Number of Spikes in Random Profile

As a function of Spike Size.

Size (ab)	12	24	36	47	57	67	77	88	99
N_s/39k pts.	9545	2462	787	514	516	259	98	34	8

Figure 2 shows the distribution of spikes binned by their position in the profile. Since the possibility of a spike occurrence is equally likely in any of the ten intervals, any observed fluctuation is statistical (e.g., compare the 1|2 curve ($\mu = 1000$) and the 9|9 curve ($\mu = 0.8$)).

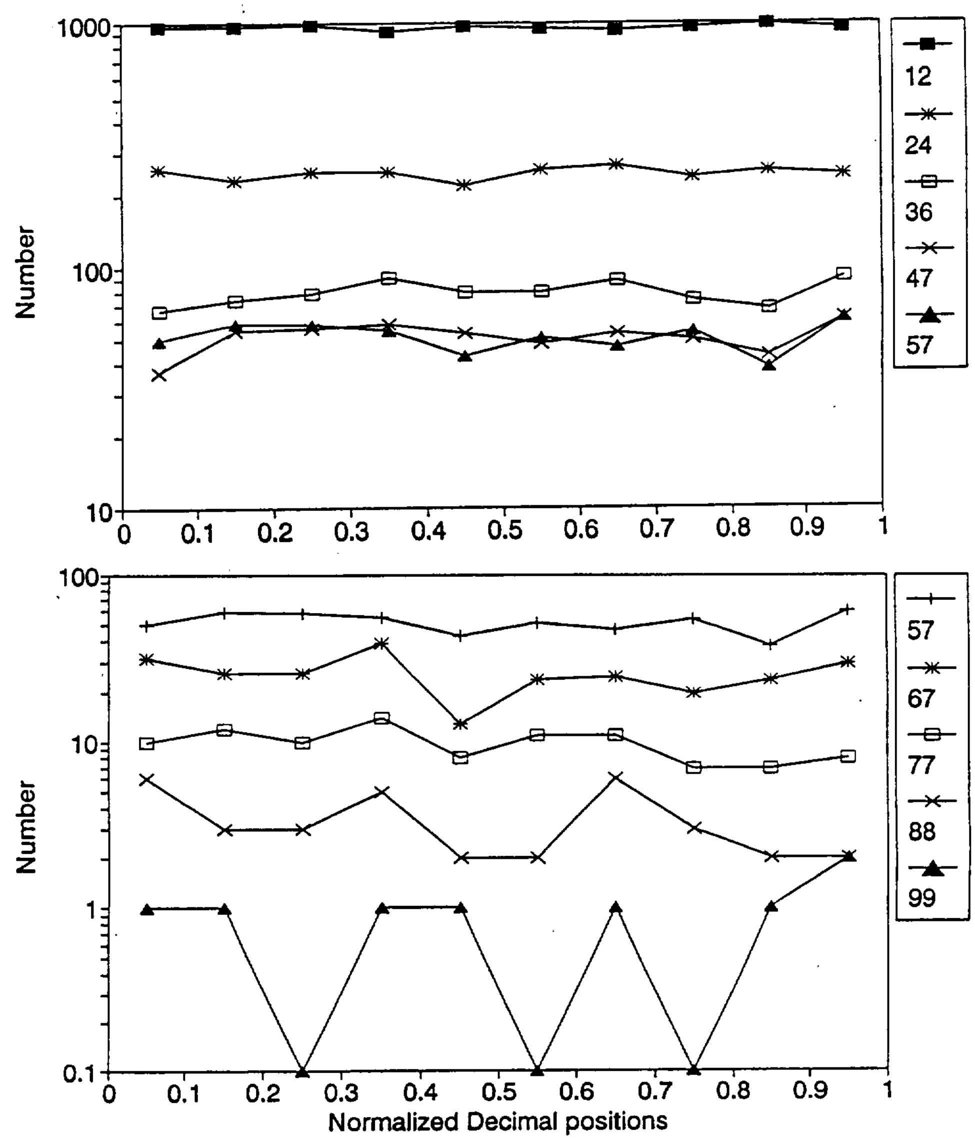

Figure 2. Distribution of Spikes in Normalized Duration.

Figure 3 presents a comparison of the total number of spikes versus spike size for the random data as well as for several real background profiles taken from BATSE data.

3. Conclusions:

We next plan to apply this program to the BATSE GRB profiles. At first, we will limit the analysis to long bursts which show a lot of structure. In addition, we have given the program the flexibility to include 1) a threshold, so that we count only spikes whose heights are greater than some number of sigma, 2) negative slopes, so that a peak criterion of 6|8, in addition to the normal spikes, would count 7 monotonically *decreasing* bins followed by two *increasing* bins as a spike, and 3) different smoothing criterion.

Furthermore, we will eventually look at higher resolution data, especially for the short bursts. We can apply these same criterion to the TTE data for those GRB's which show no structure on the 64-msec time scale.

In this way, we may find a characteristic of bursts that allows us to determine classes. This then could lead to a better understanding of the underlying physics.

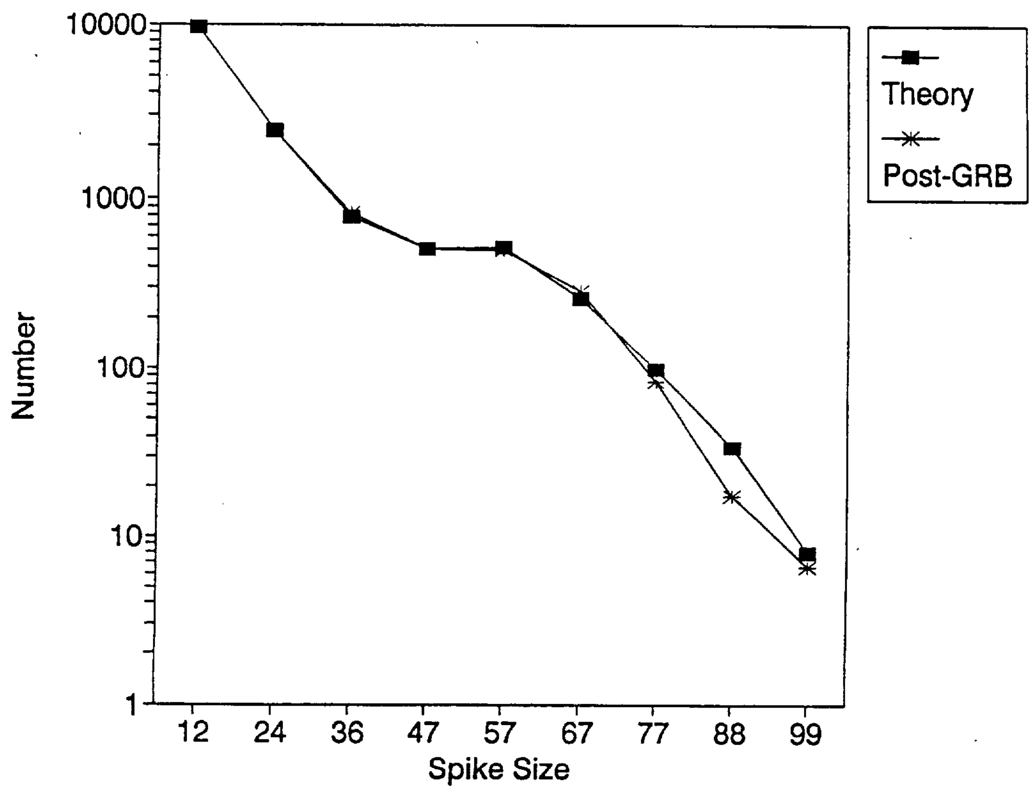

Figure 3. Number of Spikes versus Spike Size.

4. References:

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