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Time Profiles and Pulse Structure of Bright, Long Gamma-Ray Bursts Using BATSE TTS Data*

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The time profiles of many gamma-ray bursts observed by BATSE consist of distinct pulses, which offer the possibility of characterizing the temporal structure of these bursts using a relatively small set of pulse-shape parameters. This pulse analysis has previously been performed on some bright, long bursts using binned data, and on some short bursts using BATSE Time-Tagged Event (TTE) data. The BATSE Time-to-Spill (TTS) burst data records the times required to accumulate a fixed number of photons, giving variable time resolution. The spill times recorded in the TTS data behave as a gamma distribution. We have developed an interactive pulse-fitting program using the pulse model of Norris *et al.* and a maximum-likelihood fitting algorithm to the gamma distribution of the spill times. We then used this program to analyze a number of bright, long bursts for which TTS data is available. We present statistical information on the attributes of pulses comprising these bursts.

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BATSE TIME-TO-SPILL DATA

The BATSE Time-to-Spill (TTS) burst data records the time intervals to accumulate a fixed number of photons, usually 64 photons, in each of four energy channels. Relatively little analysis has been done with the TTS data, because it is less convenient to use with standard algorithms than binned data or time-tagged event (TTE) data. However, TTS data offers variable time resolution, ranging from under 50 ms at low background rates to under 1 ms in the peaks of the brightest bursts. In contrast, the finest time resolution available for binned data is 16 ms for the medium energy resolution (MER) data, and then only for the first 33 seconds after the burst trigger. The TTS data usually allows the complete time profiles of bright, long bursts—up to 16,384 spill events (over 10^6 photons) for each channel—to be stored in the limited memory on board the CGRO. This is unlike the TTE data, which is limited to 32,768 photons in all four energy channels combined (see Fig. 1). For short bursts, the TTE data has the advantages of finer time resolution, and of containing data from before the burst trigger time. Some of the shortest bursts are nearly over by the time burst trigger conditions have been met.

The spill times recorded in the TTS data behave as a gamma distribution, for which the probability of observing a spill time t is

$$P(t) \;=\; \frac{t^{N-1}R^N e^{-t}}{\Gamma(N)} \;,$$

where N is the number of events per spill and R is the individual event rate. This probability distribution is closely related to the Poisson distribution. For large N, the gamma distribution approaches a normal distribution, while for $N = 1$, it is the exponential distribution for individual time-tagged events.

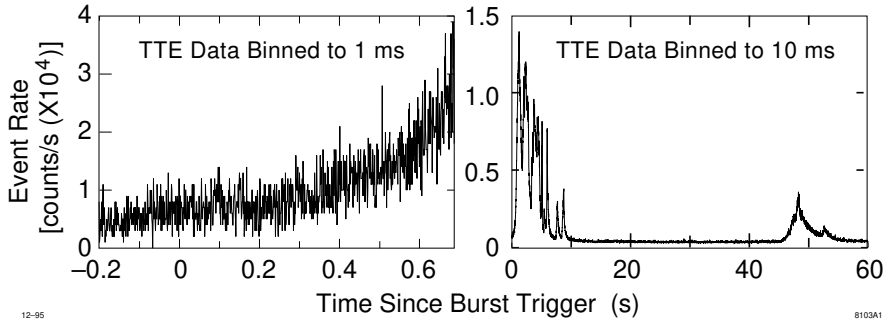

FIG. 1. BATSE Trigger Number 143, a bright, long burst.

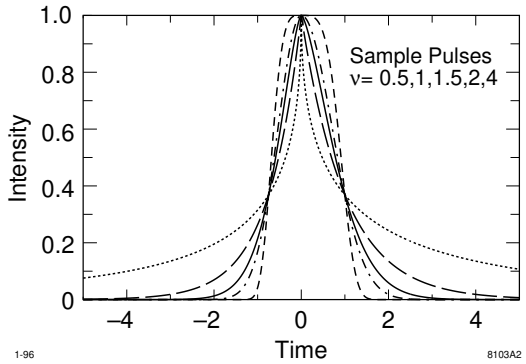

FIG. 2. Sample Pulses, $\nu = 0.5$, 1.0, 1.5, 2.0, 4.0.

THE PULSE MODEL

We have used the phenomological pulse model of Norris *et al.* to fit burst time profiles. In this model (see Fig. 2), each pulse is described by five parameters with the functional form

$$I(t) \;=\; A \exp\left(- \left| \frac{t - t_{\max}}{\sigma_{r,d}} \right|^{\nu} \right) ,$$

where $t_{\max}$ is the time at which the pulse attains its maximum, σ_r and σ_d are the rise and decay times, respectively, A is the pulse amplitude, and ν (the "peakedness") gives the sharpness or smoothness of the pulse at its peak. For $\nu = 1$, the rise and decay are both simple exponentials, and for $\nu = 2$, the rise and decay are Gaussian. Pulses can, and frequently do, overlap.

PULSE-FITTED BURSTS

We have developed an interactive pulse-fitting program, written in IDL. When fitting pulses to a gamma-ray burst time profile, the user sets the initial pulse parameters, along with the initial parameters for a background with constant slope, graphically. The fitting routine uses a version of the standard IDL routine CURVEFIT, modified to perform a maximum-likelihood fit for the gamma distribution that the TTS spill times follow, rather than the usual χ^2 fit. The algorithm used by this routine is the Levenberg-Marquardt gradient-expansion method.

Each spill time in the TTS data file gives the inverse rate at the time of the spill. The program displays the burst time profile in one window, and a second window normally displays the pulse-fit residuals; that is, the difference between the observed and fitted rates for both the recorded individual spill times and after smoothing. We show only the smoothed data. Instead of the

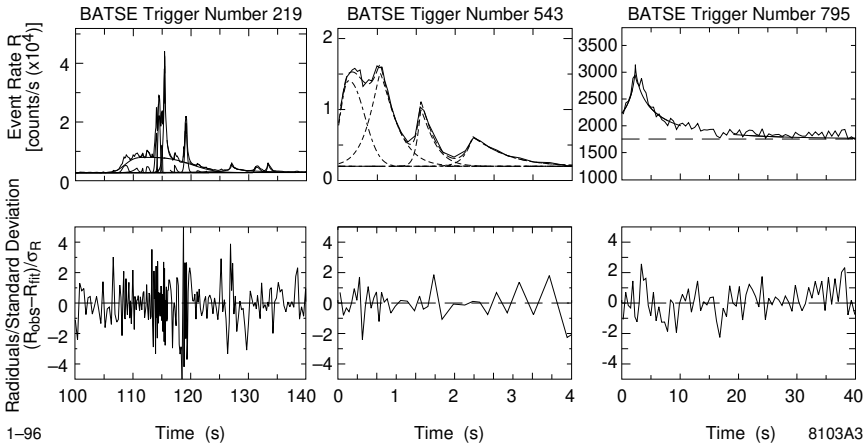

FIG. 3. Gamma-Ray Burst Time Profiles, Energy Channel 3, 100-300 keV.

pulse fit residuals, we show the residuals divided by the standard deviation of the data (see Fig. 3).

BURST AND PULSE CHARACTERISTICS

To date, we have fitted pulses to 109 gamma-ray bursts from the BATSE 2B catalog in energy channel 3, which covers approximately 100–300 keV, for a total of 756 pulses. Of these pulses, we considered to be statistically significant only those with amplitudes that differed from zero by at least three standard deviations, as reported by the fitting routine. Sixteen pulses failed this test, and only the remaining 740 pulses were used to obtain the statistics shown. The results are consistent with those found by Norris *et al.,* fitting all four energy channels to binned BATSE data for 40 gamma-ray bursts. (See Figs. 4, 5, 6, and 7.)

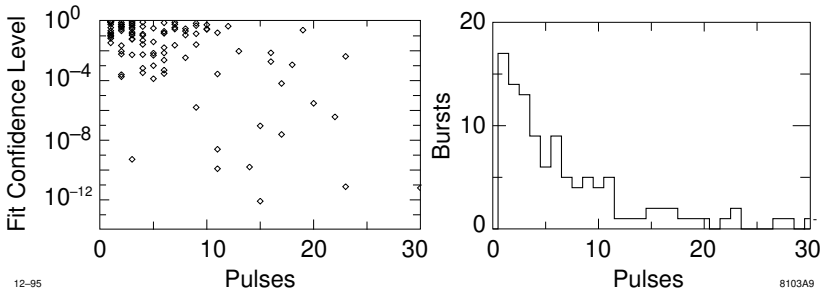

FIG. 4. (left) Fits to complex bursts requiring large numbers of pulses are more likely to have poorer confidence levels.

FIG. 5. (right) Average number of pulses per burst is 6.9 ± 6.5; the median is 5.

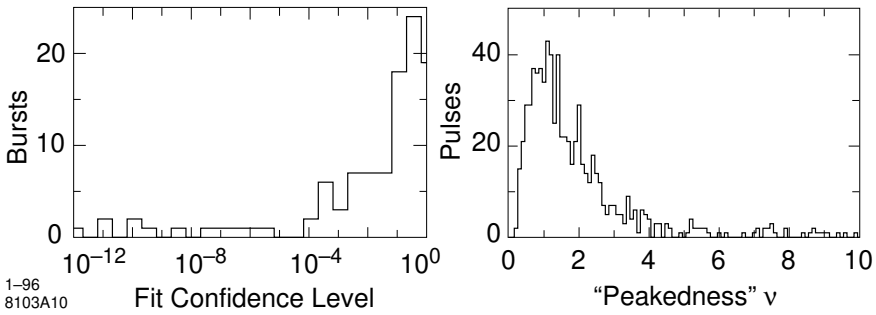

FIG. 6. Average value of "peakedness" parameter ν: 2.0 $\pm$ 1.9 Median: 1.4.

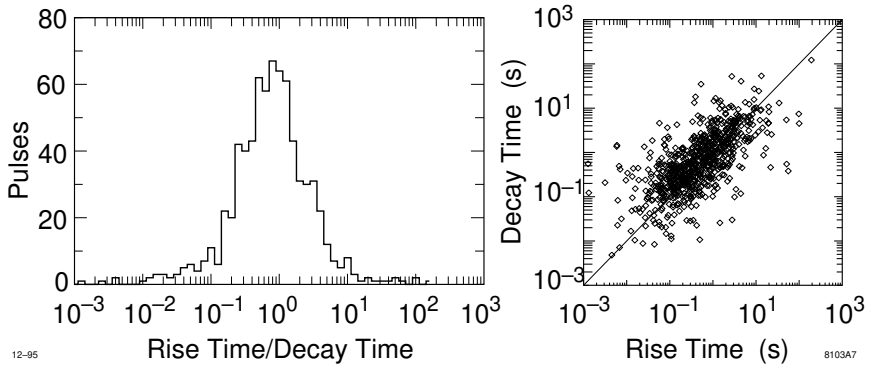

FIG. 7. The ratio of rise to decay times covered a very broad range. The geometric mean of the ratio is 0.74 with a one standard deviation range of 0.19 - 2.9, and the median is 0.77. (The usual arithmetic mean of the ratio is 2.2 ± 8.3, and of the inverse ratio is 5.5 ± 34.)

CONCLUSIONS

This phenomenological pulse model gives an accurate and compact representation of the time profiles of many of the simpler gamma-ray bursts, allowing statistical studies of their characteristics. Some issues arise for more complex bursts that must be fit using many pulses. One issue is the uniqueness of the pulse decomposition when there is large overlap between different pulses. Another is the low confidence levels of many of the fits. It would be possible to obtain fits with higher confidence levels by simply adding more pulses, but this eventually defeats the goal of a compact representation for the burst time profile. In addition, as smaller pulses are added, the statistical significance of the fit parameters decreases, eventually becoming statistically insignificant.

FUTURE WORK

We plan to complete this pulse analysis for all bright, long BATSE bursts for which TTS data is available, and for all four energy channels, comparing the characteristics of the different energy channels. We will also analyze the pulse-fit residuals to see if they differ from white noise, which would indicate temporal behavior not represented in this pulse model. We will also examine the use of other pulse models.

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