Temporal Evolution of the Pulse Width in GRBs

Abstract: Many cosmological models of GRBs explain the pulse width in the GRB prompt emission in the following way: the pulse width is due to the expansion of the shell of the core of the 

Introduction

Fig. 1. Average peak luminosity of GRBs as a function of redshift.
2. Pulse width evolution obtained from time histories

A visual inspection of the BATSE catalog of multiplet-peaked time histories reveals that peaks usually have about the same duration at the beginning of the burst as near the end of the burst. Our aim is to characterize and measure the pulse shape as a function of arrival time.

The aligned peak method measures the average pulse temporal structure, each burst contributes to the average by aligning the largest peak (Mitrofanov 1997). We used all 53 bursts from the BATSE 4B Catalog that were longer than 20 s and brighter than 5 photons cm$^{-2}$ s$^{-1}$. Each burst must have at least one peak, as determined by a peak-finding algorithm (similar to Li & Fenimore 1996), in each third of its duration. The largest peak in each third was normalized to unity and shifted in time, bringing the largest peaks of all bursts into common alignment. This method was applied in each third of the duration of the bursts. Thus, we obtained one curve of the averaged pulse shape for each different section of the bursts (as shown in Figure 1). The average profile is notably identical in each 1/3 of $T_{90}$ (we estimate the differential spread, S, to be $\sim 1\%$).

We have shown the lack of temporal evolution of the peak width in the context of an average of many bursts. Now, we expand our analysis to individual bursts. An excellent analysis has been provided by Norris et al. 1995, where they examined the temporal profiles of bright GRBs by fitting those profiles with pulses. From the set of bursts that they analysed, we used the 28 bursts with the characteristic of having seven or more fitted pulses within their duration. To obtain the temporal dependency of the pulse width, we selected the five largest peaks in each burst and fitted their FWHM to a function of the arrival time, $\Delta T = k \left( \frac{T - T_{90}}{T_{90}} \right)^{\alpha}$. We chose this model because the expected dependency from the “external” shock model scales as $T^{-\alpha}$ (if a relativistic shell is responsible for the shape in the time histories, $T_{90}$ should be proportional to $T_{90}$; see Fenimore et al. 1996). The purpose of the $T_{90}$ parameter is to correct the BATSE time to time since the beginning of the explosion. Figure 2 shows the distribution of the power law indexes ($\alpha$) for the set of bursts analysed. The distribution shows that in individual bursts the pulse width does not increase throughout their duration as predicted by the external shock model, for which $\alpha = 1$ (or larger if deceleration is occurring). In fact, most bursts show a diminution in pulse width.

3. Discussion

We have uncovered that the width of the peaks remains remarkably constant throughout a burst. The width should scales as $1 - \beta \cos \theta$. In the external shock model, such lack of temporal evolution implies that $\Gamma$ must be nearly constant. Peaks occur late in the burst because they are from regions off axis where the delay is caused by the curvature of the shell. The later peaks would be wider and delayed because off axis regions have larger $\beta$'s. A constant peak width indicates that all emitting entities must have similar $\theta$. Since the maximum angular size of the shell allowed by a differential spread of $S$ is $ST^{-1}$, the entire size of the shell must be a few percent of $\Gamma^{-1}$. Thus, the only external shock model that is consistent with the observations is one where the overall size of the shell is much smaller than $\Gamma^{-1}$, and there is no deceleration during the classic GRB phase. This adds to our previous arguments (Fenimore et al. 1996, Fenimore et al. 1998) that a central engine (internal shocks) is the more likely explanation for the observed chaotic time history. In the context of the internal shock model, we cannot place a limit on angular extent but the lack of evolution of the peak width indicates that $\Gamma$ must be remarkably constant throughout the internal shock phase.

References


