SPECTRAL EVOLUTION OF SHORT GRBS ON SUB-MILLISECOND TIME SCALE

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Abstract. There has been growing consensus that short and long GRBs are associated with two different populations of astrophysical sources: mergers and SN explosions, respectively. While temporal properties of short and long GRBs could be considered with similar depth and accuracy, patterns of spectral variability of the 2 classes of GRBs are much harder to compare. This is due to the fact, that short GRBs exhibit variability on time scales shorter than 1 ms and count rate, measured at such short time scales, is not sufficient for reliable spectroscopy even for the brightest events.

In this situation, any new possibility to look at spectral evolution of short GRBs on sub-millisecond time scales in terms of spectral parameters, may provide more solid background for theoretical analysis. In this paper we present analysis of spectral evolution of short GRBs in terms of Band spectral function parameters, using the earlier developed Global Fit approach (GFA).

1 Introduction

Doing spectroscopy of transient or variable gamma-ray sources an observer normally finds himself dealing, even with modern large area detectors, with low count rate data that considerably limits the time resolution. This is because spectral functions used for spectroscopy of gamma-ray emission are normally non-linear in any parameter space and the number of approximated spectral parameters $n \gg 1$. Any nonlinear approximation procedure for such a function becomes unstable even for moderately noisy data.

Fortunately, for a fine time resolution spectroscopy, there have been numerous indications that spectral parameters of GRB spectra manifested a high degree of correlation along a given GRB (*e.g.* Ford 1995). If one assumes that some of the spectral parameters are not independent ones but rather are functions of the other

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parameters, then the dimension of the optimization procedure could be reduced and one could sample the emission to smaller S/N ratios, which means either better time resolution or fainter sources. The improvement may be estimated having in mind that $\Delta t_{min} = \frac{S/N^2}{R}$, where R is count rate. For example, reducing the number of adjustable parameters from typical value of 3 to 1, one could improve time resolution by an order of magnitude. As a result, spectral evolution and variations of the integrated flux could be investigated with a comparable a time resolution.

2 Sub-millisecond spectroscopy with global fit analysis

Mathematical formulation and statistical justification of the hypothesis of functional interrelation between spectral shape parameters, which we use for time resolved spectroscopy of GRBs is described in details in (Chernenko 2002).

In short, we assume that 1) instantaneous spectra of GRBs in keV–MeV domain are of the Band shape (Band *et al.* 1993) and 2) the parameters of this spectral shape are functionally depended as follows:

$$\begin{cases} \alpha = \alpha_0 + \alpha_R \cdot \lg(R) + \alpha_E \cdot \lg(E_0) \\ \beta = \beta_0 + \beta_R \cdot \lg(R) + \beta_E \cdot \lg(E_0). \end{cases} \quad (1)$$

The method of Global Fit Analysis (GFA) being allows one to estimate, for the entire duration of a GRB, the time history of E_0 and the set of global parameter of Equation (1). An example GFA application is presented in Figure 1.

Fig. 1. Time history of count rate R is presented for BATSE GB 930905 by thick line. Overplotted by thin lines with error bars is time history of E_0 derived from GFA. The data had been re-binned with the threshold $S/N = 15$ per time interval in the range $25 \sim \text{keV} - 2 \sim \text{MeV}$, which allowed us to sample spectral evolution with time resolution down to $450 \mu\text{s}$.

3 Patterns of spectral evolution in short GRBs

As it was shown in Chernenko (2002), the GFA can be universally used for spectral analysis of GRBs in keV–MeV range. GFA allows one to reduce spectral variability to 2 independent parameters, $\mathbf{R}(t)$ and $\mathbf{E}_0(t)$. Therefore, scatter plots of $\mathbf{E}_0(t)$ vs. $\mathbf{R}(t)$ become natural tool for analysing and comparing spectral evolution across different GRBs. Figure 2 presents such a *GFA scatter plot* for BATSE GB 930905, the burst also presented in Figure 1.

Fig. 2. Scatter plot of E_0 vs. count rate $\mathbf{R}$ is presented for BATSE GB 930905. The data points correspond to Figure 1. Most of the points lay along a line which is characteristic to hardness-intensity correlation, while some points form clouds above this line that are typical for hard-to-soft evolution across individual peaks.

Detailed analysis of short GRB, using GFA scatter plots is beyond the scope of this paper. However, even from this example one may conclude that, despite being a classical short GRB, GB 930905 manifests, in terms of $\mathbf{E}_0(t)$ vs. $\mathbf{R}(t)$ both patterns of spectral evolution, typical for long GRBs: hardness intensity correlation, and hard-to-soft evolution. And it manifests this on sub-millisecond time scale.

4 Conclusions

While analysis of GRB hosts and their afterglows give us hints to the astronomical nature of their progenitors, it is investigation of prompt gamma-ray emission that brings us closer to understanding physical processes of GRB generation. The similarity of patterns of spectral evolution of prompt gamma-ray emission in short and long GRBs indicate that while progenitors of short and long GRBs are different, physical conditions at the engines may be similar.

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References

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