

The prompt-afterglow connection in Gamma-Ray Bursts: a comprehensive statistical analysis of Swift X-ray light-curves

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on behalf of the Swift-XRT team

We present a comprehensive statistical analysis of *Swift* X-ray light-curves of Gamma-Ray Bursts (GRBs), with more than 650 GRBs. Two questions drive this effort: (1) Does the X-ray emission retain any kind of memory of the prompt phase? (2) Where is the dividing line between long and short GRBs? We show that short GRBs decay faster, are less luminous and less energetic than long GRBs, but are interestingly characterized by very similar intrinsic absorption. Our analysis reveal the existence of a number of relations that link the X-ray to prompt parameters in long GRBs; short GRBs are outliers of the majority of these 2-parameter relations. Here we concentrate on a 3-parameter ($E_{\rm pk} - E_{\gamma,\rm iso} - E_{\rm X,iso}$) scaling that is shared by the GRB class as a whole (short GRBs, long GRBs and X-ray Flashes -XRFs): interpreted in terms of emission efficiency, this scaling may imply that GRBs with high $E_{\rm pk}$ are more efficient during their prompt emission.

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1. Introduction

The extremely fast re-pointing capabilities of the Swift spacecraft enabled the GRB community to sample the X-ray emission that follows the prompt phase in exquisite detail starting as early as ~ 60 s after the trigger. After ~ 7 years of operation (and more than 700 GRBs observed by the X-ray telescope on board Swift -XRT), we have now the possibility to discuss the properties of the X-ray light-curves of GRBs from a statistical perspective. We analyze more than 650 GRBs (38 are short GRBs) detected by Swift -XRT during the first 6 years of operation. For the subsample of 437 GRBs with complete light-curve (i.e. promptly re-pointed by Swift-XRT and for which we have been able to follow the fading of the source down to a factor 5-10 from the background limit) we are able to constrain the properties of their X-ray light-curves (decaying slopes, temporal break times, fluxes, fluences) together with the properties (duration, peak flux, statistical significance, fluence) of the X-ray flares superimposed. Our approach benefits from the largest sample of GRBs with redshift measurement analyzed in the literature (165 GRBs) in the common rest-frame energy band 0.3-30 keV: this gives us the possibility to measure their *intrinsic* properties (time-scales, energetics). Furthermore, we combine the results from our analysis in the X-rays with the prompt γ -ray emission parameters from the literature [12, 1, 11], and look for correlations that bridge the gap between the prompt and afterglow emission.

The results from our X-ray flare project can be found in [10, 8, 9, 4, 3]. Here we focus on the major results we obtained from the study of the smoothly decaying X-ray afterglow component. We refer the reader to [7] for a detailed description of our findings.

2. Major Results

2.1 Short vs. long GRB X-ray afterglow properties

Short GRBs are traditionally classified from their properties during the prompt γ -ray phase: a short duration ($T_{90} < 2$ s), a hard γ -ray emission and a negligible spectral time lag during the prompt emission are considered suggestive of a "short"-GRB nature. Do short GRBs show a distinct behavior during their X-ray afterglow as well? Our study reveals that:

- (1) Short GRB X-ray afterglows are less luminous of a factor $\sim 10-30$ when compared to long GRB afterglows (Fig. 1). However, Figure 1 demonstrates that the two samples slightly overlap, especially at early ($t_{\rm rest} < 300$ s) times, when short GRBs typically show a luminosity comparable to the low luminosity edge of the long GRB distribution.
- (2) On average, short GRB afterglows decay faster (average decay in the rest-frame time interval $10^2-10^4~{\rm s} \propto t^{-1}~{\rm vs.} \propto t^{-1.3}$ for long and short GRBs, respectively. The uncertainty associated to the decay index is $\lesssim 0.05$).
- (3) The average 0.3-30 keV (rest-frame) isotropic energy released during the afterglow of a short GRB is \sim 100 times lower than a long GRB (see Fig. 2): in particular, $E_{\rm X,iso}^{short} < 10^{51}\,{\rm erg}$.
- (4) For long GRBs, the X-ray energy emitted after the prompt emission correlates with the isotropic equivalent prompt γ -ray energy (Fig. 3). With the exception of GRB 050724, short GRBs fall off the $E_{X,iso}$ vs. $E_{\gamma,iso}$ relation established by long GRBs: when compared to long GRBs, short GRBs emit less energy in the X-rays than expected.
- (5) Short GRBs map the low end of the intrinsic neutral hydrogen $NH_{\rm HG}$ distribution of GRBs (Fig.

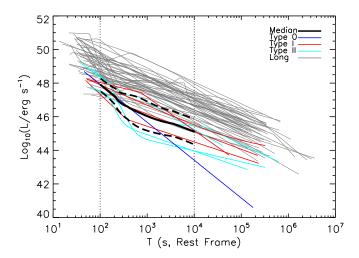


Figure 1: Grey lines: 0.3-30 keV (rest-frame) best fitting profiles of 77 long GRBs of our sample with complete light-curve (i.e. promptly re-pointed by *Swift* and whose follow-up has not been truncated). Color lines: sample of 9 short GRBs satisfying the same criteria. Different colors refer to different light-curve morphological types as defined by [7]. The black thick line marks the median light-curve for the short sample.

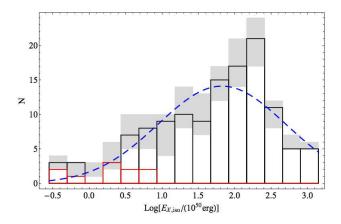


Figure 2: 0.3-30 keV (rest-frame) isotropic energy emitted after the prompt emission is over. Black (red) solid line: long (short) GRBs. The grey area is derived using Monte Carlo simulations and marks the 99% confidence interval. Blue dashed line: best-fitting Gaussian profile with central value $E_{X,iso} \sim 6 \times 10^{51}$ erg.

4, panel c), with an average absorption $NH_{\rm HG}^{short}=10^{21.4}{\rm cm}^{-2}$ (the median value for the entire distribution is $NH_{\rm HG}=10^{21.8}{\rm cm}^{-2}$.) However and more importantly, short GRBs are consistent with the intrinsic absorption of long GRBs in the same redshift bin: A KS-test comparing the $NH_{\rm HG}$ distribution of long and short GRBs with 0 < z < 1 reveals no statistical evidence for a distinct parent population (p(KS)=34%).

2.2 $E_{\rm pk} - E_{\gamma,\rm iso} - E_{\rm X,iso}$ universal scaling

Long and short GRBs are known to be *not* consistent with the *same* E_{pk} vs. $E_{\gamma,iso}$ scaling (where E_{pk} is the spectral peak energy during the prompt emission, [1]); in this work we show

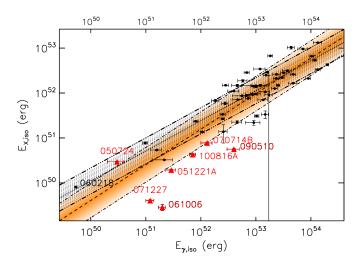


Figure 3: Isotropic X-ray (0.3-30 keV, rest frame) energy emitted after the prompt emission is over vs. prompt γ-ray (1 – 10⁴) energy. Black (red) points: long (short) GRBs. Dashed line: best-fitting relation for the entire sample: $E_{\rm X,iso} \propto E_{\gamma,\rm iso}^{0.8}$. Excluding the short GRBs, we obtain $E_{\rm X,iso} \propto E_{\gamma,\rm iso}^{0.7}$. The shaded areas mark the 68% confidence region around the best-fitting relations.

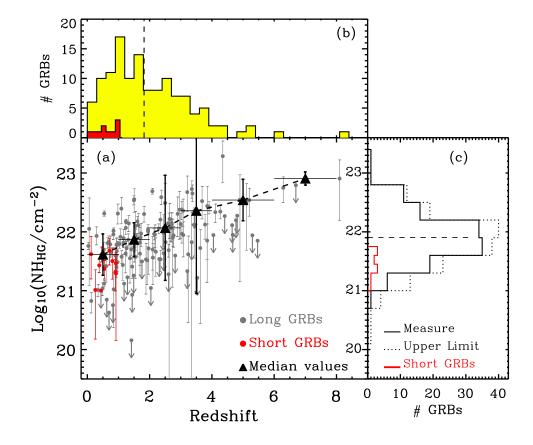


Figure 4: (a): Intrinsic neutral hydrogen absorption vs. redshift for long and short GRBs (grey and red dots, respectively). 90% upper limits are marked with arrows. Median $NH_{\rm HG}$ values in different redshift bins are indicated with filled triangles. In panels (b) and (c) a dashed line indicates the median value for the entire distributions ($z = 1.82, NH_{\rm HG} = 10^{21.8} {\rm cm}^{-2}$).

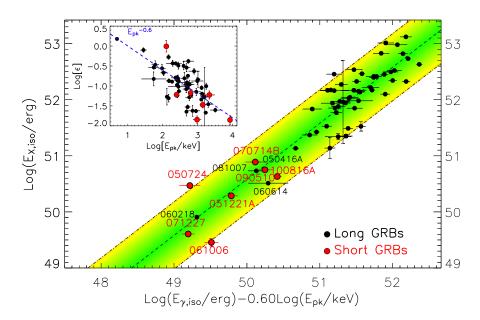


Figure 5: Three parameter correlation involving $E_{\rm pk}$, $E_{\gamma,\rm iso}$ and $E_{\rm X,iso}$. Dashed line: best-fitting relation; dot-dashed lines mark the 95% confidence area around the best-fitting law. Notably, long and short GRBs share the same scaling, with short and sub- energetic GRBs (like GRB 060218) occupying the same area of the plot. Inset: evolution of $\varepsilon \equiv E_{\rm X,iso}/E_{\gamma,\rm iso}$ as a function of the spectral peak energy of the prompt emission $E_{\rm pk}$. Blue dashed line: $\varepsilon \propto E_{\rm pk}^{-0.6}$ scaling.

that this is also true when we consider the $E_{X,iso}$ vs. $E_{\gamma,iso}$ correlation. However, when the three quantities are considered, we find evidence for a universal $E_{pk} - E_{\gamma,iso} - E_{X,iso}$ scaling shared by "normal" long GRBs, XRFs and short GRBs (Fig. 5, see also Bernardini et al., this volume). Computing the X-ray energy in the 0.3-30 (rest-frame) energy band, the best fitting relation reads:

$$E_{\rm X,iso} \propto \frac{E_{\gamma,\rm iso}^{1.00\pm0.06}}{E_{\rm pk}^{0.60\pm0.10}}$$
 (2.1)

We note that:

- (1) GRBs seem to divide into two groups with "normal" long GRBs occupying the upper-right area; short and peculiar GRBs together with XRFs share the same lower-left region of the plot.
- (2) The scaling above implies: $E_{\gamma,iso}/E_{X,iso} \propto E_{pk}^{0.60}$. The prompt GRB efficiency reads: $\eta_{\gamma} = E_{\gamma}/(E_{\gamma} + E_{K})$, where E_{K} is the kinetic energy of the outflow. For $E_{\gamma} < E_{K}$, $\eta_{\gamma} \approx E_{\gamma}/E_{K}$. Since E_{K} is proportional to the X-ray energy in the afterglow, we find $\eta_{\gamma} \propto E_{pk}^{0.60}$ (see the inset of Fig. 5, where we plot $\varepsilon = 1/\eta_{\gamma}$): GRBs with high spectral peak energy during the prompt emission tend to be more efficient. This result has been shown to naturally arise in the context of the "photospheric" emission model (Lazzati contribution, this volume; see also [6]). Alternatively, this correlation has also been interpreted in the context of the "cannon-ball" model: we refer the reader to [5] for details.

3. Conclusions

Our comprehensive statistical analysis of more than 650 GRBs (165 with measured redshift)

allowed us to perform the first characterization of the X-ray afterglow of short GRBs as a class: short GRB afterglows are less luminous, less energetic and show a faster decay. This study furthermore revealed the existence of a universal GRB scaling. Interpreted in terms of prompt emission efficiency, this scaling may be used to shed light on the still elusive emission mechanism which powers the prompt phase of GRBs as a whole.

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