A Complete Sample of Long Bright *Swift* GRBs

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Starting from the *Swift* sample we define a complete sub-sample of 58 bright long Gamma Ray Bursts (GRB), 55 of them (95%) with a redshift determination, in order to characterize their properties. Our sample (BAT6) allows us to study the properties of the long GRB population and their evolution with cosmic time. We focus in particular on the GRB luminosity function, on the spectral-energy correlations of their prompt emission, on the nature of dark bursts, on possible correlations between the prompt and the X-ray afterglow properties, and on the dust extinction.

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1 Introduction

Long Gamma Ray Bursts (GRBs) are powerful flashes of high energy photons occurring at a rate of a few per day throughout the universe. They are firmly associated with the death of massive stars and therefore with star forming regions. Thanks to their brightness, GRBs can be detected up to extremely high redshifts (so far we have a secure spectroscopic redshift of $z = 8.2$ [1, 2]) allowing us to study them and the environment in which they explode from the local universe to the epoch in which the first stars form.

2 Sample selection

About one third of the bursts detected by Swift has a measured redshift. While this represents an enormous improvement with respect to the pre-Swift situation, this is still too low to provide a complete sample in redshift. Therefore we start from the criteria proposed by [3] selecting those burst that have favorable observing conditions for ground-based telescopes. We then restrict to GRBs that are relatively bright in the 15-150 keV Swift/BAT band, i.e. with a 1-s peak photon flux $P \geq 2.6 \text{ ph s}^{-1} \text{ cm}^{-2}$ (BAT6 sample). This corresponds to an instrument that is $\sim 6$ times less sensitive than Swift, which give us a high level of confidence that all GRBs with a flux higher then our limit and that are inside the FOV of BAT when they explode will be detected. Therefore, our sample is complete with respect to our selection criteria and provide an unbiased view of the bright end of the GRB log $N - \log P$. 58 GRBs match our selection criteria [4] and 55 of them have a measured redshift (95% completeness in redshift). The mean (median) redshift is $1.84 \pm 0.16$ ($1.60 \pm 0.10$) with a long tail extending at least up to $z = 5.47$ (Fig. 1, left-panel).

3 Results

We briefly summarize here the results obtained on the basis of the BAT6 sample.

GRB redshift distribution and luminosity function [4]. We derive the GRB luminosity function (LF) by jointly fitting the observed differential number counts in the 50–300 keV band of BATSE and the observed redshift distribution of bursts in our sample. As shown in Fig. 1 top-left panel, a no-evolution scenario (dashed line, i.e. GRBs trace the cosmic SFR and their LF do not evolve) can not reproduce the observed redshift distribution of the BAT6 sample. We find that our data are well reproduced if we assume: (i) a luminosity evolution model, in which the GRBs at higher redshift are typically brighter than those at lower redshift with the typical luminosity increasing as $(1 + z)^{2.3 \pm 0.6}$; (ii) a density evolution model, in which the
GRB formation rate increases with redshift as $(1+z)^{1.7\pm0.5}$ on the top of the known cosmic evolution of the SFR, or (iii) GRBs form preferentially in low-metallicity environments with $Z < 0.3 \, Z_\odot$. Adopting these models we expect that 3–5% of bursts detected by Swift should lie at $z > 5$.

**Prompt emission correlations** [5]. A strong correlation is found between the spectral peak energy, $E_{\text{peak}}$, and the isotropic energy, $E_{\text{iso}}$, or the isotropic luminosity, $L_{\text{iso}}$, for the bursts in the BAT6 sample (see Fig. 1, bottom panel), with only one outlier, GRB061021, for the $E_{\text{peak}} - E_{\text{iso}}$. Their slopes, normalizations and dispersions are consistent with those found with the whole sample of bursts with measured $z$ and $E_{\text{peak}}$, and therefore the biases present in the total sample commonly used to study these correlations do not affect their properties. We also find no evolution of the correlations with $z$. Finally, we investigated the possible effects caused by the flux-
limit selection in our complete sample on the $E_{\text{peak}} - L_{\text{iso}}$ correlation [6]. If we assume that this correlation does not exist, we are unable to reproduce it as due to the flux limit threshold of our complete sample. The null hypothesis can be rejected at more than 2.7 $\sigma$ level of confidence.

**X-ray afterglow** [7]. We find that the rest frame afterglow X–ray luminosity strongly correlates with $E_{\text{iso}}$, $L_{\text{iso}}$ and $E_{\text{peak}}$. These correlation decreases over time suggesting that the X-ray light curve can be due to a combination of different components whose relative contribution and weight change with time, with the prompt and afterglow emission dominating at early and late time, respectively. In particular, we found evidence that the plateau and the shallow decay phases often observed in GRB X–ray light curves are powered by activity from the central engine. The existence of the $L_X - E_{\text{iso}}$ correlation at late times (see Fig. 1, right panel) suggests a similar radiative efficiency among different bursts with on average about 6% of the total kinetic energy powering the prompt emission.
X-ray absorption \[8\]. For the full sample of X-ray afterglows, using the Swift X-ray Telescope data, we find that the distribution of their intrinsic absorbing X-ray column densities has a mean value of \(\log(N_H/cm^{-2}) = 21.7 \pm 0.5\), consistent with the one derived from the total sample of GRBs with redshift \[9\]. Contrarily with previous results, we find that the low-\(z\), high-\(N_H\) region of the \(N_H - z\) plane is now populated by low redshift dark bursts. Still we find a lack of high-\(z\), low-\(N_H\) GRBs suggesting a mild increase of the intrinsic column density with redshift (Fig. 2 left-panel). This can be due to the contribution of intervening systems along the line of sight (shadow area in Fig. 2 left-panel; see \[8\] for details).

Dark bursts \[10\]. “Dark”-GRBs are defined on the basis of the ratio between the optical and the X-ray fluxes (or their upper limits). About one third of the bursts in the BAT6 sample have optical-to-X-ray spectral index, \(\beta_{ox} < 0.5\), i.e. they are dark according to the definition of \[11\]. Their redshift distribution and prompt properties are very similar to those of the whole sample. The major cause of the optically dark events is the dust extinction as also shown by the very tight correlation between \(\beta_{ox}\) and \(N_H\) \[8\] (see Fig. 2 top-right panel). Indeed, this correlation shows that dark-GRBs form in a metal-rich environment where dust must be present.

Dust extinction \[12\]. We find that 87% of events in the BAT6 sample are absorbed by less than 2 mag (50% with \(A_V < 0.4\)), the remaining being highly absorbed (Fig. 2 bottom panel). The latter appears to follow a different distribution being inconsistent with a simple extrapolation of the low-extinction events. No clear evolution of the dust extinction properties is evident within the redshift range of our sample. As discussed before, dark bursts are characterized on average by higher extinctions. Finally we find a correlation between \(A_V\) and \(N_H\) although with a gas-to-dust ratio well above that observed in Local Group environments.

4 Conclusions

We have presented here a complete sub-sample of bright Swift long GRBs that is characterized by a high level of completeness in redshift (95%). This sample has been used to study the properties of the long GRB population and their evolution with redshift. Apart from the results highlighted here, the BAT6 sample has also been used to study the distributions of the GRB jet opening angle \(\theta_{jet}\) and the bulk Lorentz factor \(\Gamma_0\) \[13\], the properties of precursors \[14\], and the distribution of GRB afterglow radio fluxes \[15\].

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