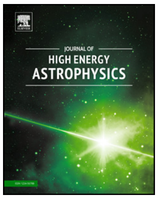
Journal of High Energy Astrophysics 7 (2015) 81–89

Contents lists available at ScienceDirect

Journal of High Energy Astrophysics

www.elsevier.com/locate/jheap



Review

Are short Gamma Ray Bursts similar to long ones?

G. Ghirlanda*, M.G. Bernardini, G. Calderone, P. D'Avanzo

INAF–Osservatorio Astronomico di Brera, Via E. Bianchi 46, I-23807 Merate (LC), Italy

ARTICLE INFO

Article history:
Received 5 March 2015
Accepted 8 April 2015

ABSTRACT

The apparent separation of short and long Gamma-Ray Bursts (GRBs) in the hardness ratio vs duration plot has been considered as a direct evidence of the difference between these two populations. The origin of this diversity, however, has been only confirmed with larger GRB samples but not fully understood. In particular, the hardness ratio is only a proxy of the shape of the spectra of GRBs and itself, together with the observed duration, does not consider the possible different redshift distribution of short and long bursts, which might arise from their different progenitors' nature. By correcting the spectral shape of short and long GRBs for the redshift effects, short GRBs are harder than long ones due to a harder low energy spectral component while the two populations have similar (rest frame) peak energy. In the rest frame, the temporal break of the long/short duration distribution is blurred away and short and long GRBs have a continuous differential duration distribution. Moreover, they show similar luminosities but their energetics differ by a factor proportional to their different average duration. The spectral evolution of long GRBs shows that the initial phase (of the order of 0.3 s rest frame) has similar spectral properties of that of short GRBs. As a consequence, the different hardness at low energies might be due to a prolonged spectral evolution of long GRBs with respect to short ones. Finally, we show that long GRBs can have a null lag similarly to short bursts. Moreover, we find that a considerable fraction of long (and most of short) GRBs are inconsistent with the lag-luminosity relation which could be a boundary in the corresponding plane, rather than a correlation.

1. Introduction

Gamma Ray Bursts (GRBs) are typically divided into two classes of short and long events based on their observed duration in the γ-ray band. The bimodal distribution of T_{90}, i.e. the timescale in which from 5% to 95% of the counts are recorded, suggested a possible separation at $\sim$2 s (Kouveliotou et al., 1993). For a recent review of Short GRBs see Berger (2014). This was assumed for years as the dividing line between short (SGRB with $T_{90} \leq 2$ s) and long (LGRB with $T_{90} > 2$ s) GRBs. A statistically significant (10^{-4}) intermediate duration population was also claimed (Horváth, 1998; Řípa et al., 2009) although it showed similar properties to the class of long GRBs (de Ugarte Postigo et al., 2011).[1] The apparent separation between SGRBs and LGRBs, discovered in the GRB population detected by BATSE/CGRO, was confirmed by Hete-2 (Sakamoto et al., 2005; Pélangeon et al., 2008), BeppoSAX (Frontera et al., 2009), Integral (Bošnjak et al., 2014; Savchenko et al., 2012), Swift (Sakamoto et al., 2005) and Fermi (von Kienlin et al., 2014). However, the comparison of the duration distributions of bursts detected by different instruments suffers from instrumental biases induced by the energy range where they operate, the trigger method (image triggers are less sensitive to short/spiky bursts) and the energy range where the T_{90} is computed (on average a smaller T_{90} is estimated with light curves of higher energy photons – Qin et al., 2013).

What, observationally, does distinguish short and long bursts in addition to their duration? It was early realised that SGRBs might have different spectral properties. The hardness ratio (HR), defined as the ratio of the flux in two separated energy bands (i.e. the counts in the harder energy band divided by those in the softer), showed that short GRBs have *on average* a larger HR than long bursts (Kouveliotou et al., 1993; Tavani, 1998). However, no correlation between HR and duration was found within the individual classes (Qin et al., 2001). Fig. 1 (Sakamoto et al., 2005) shows the HR-T_{90} plot of GRBs detected by Swift (five year catalog of 476 events – grey symbols), compared with BATSE (red symbols), Beppo/SAX (green symbols) and Hete-2 (blue symbols) bursts. For Swift bursts, the Kolmogorov–Smirnov (KS) test of the HR between SGRBs and LGRBs has a probability of 8.3×10^{-20} that

---

* Corresponding author.
E-mail address: giancarlo.ghirlanda@brera.inaf.it (G. Ghirlanda).

[1] Recently, it has also been claimed the existence of a distinct population of ultra-long GRBs (Levan et al., 2014).

http://dx.doi.org/10.1016/j.jheap.2015.04.002

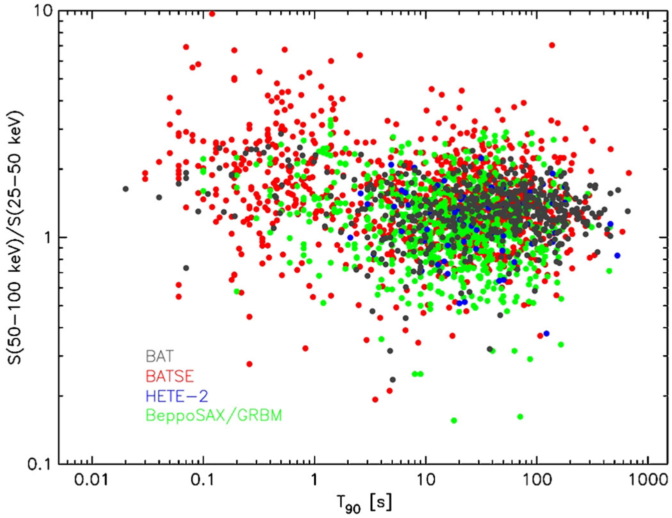


Fig. 1. HR-T_{90} plot of GRBs detected by different missions (as shown in the legend) from Sakamoto et al. (2011). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

the two populations are drawn from the same parent distribution. In general, the populations of GRBs detected by different instruments overlay in the HR-T_{90} plane although the relative number of short and long GRBs differ among different instruments. The four year catalog of 954 Fermi bursts (von Kienlin et al., 2014) contains between 13% and 20% of SGRB with average duration ∼0.7 s and average HR>1 (LGRBs have an average duration of 25 s and HR<1).[2]

Other possible differences in the temporal properties are the smaller minimum variability timescale (MacLachlan et al., 2012, 2013) of SGRBs (on average 10 ms) with respect to LGRBs (200 ms); see also Nakar and Piran (2002) and Golkhou and Butler (2014). What links temporal and spectral properties is the lag: this is the delay (either positive or negative) between the light curves in two different energy bands. It was early found in the BATSE GRB sample that LGRBs have positive lags with the high energy light curve lagging the low energy one, while typically SGRBs have null lag (Cheng et al., 1995; Norris et al., 2001; Norris and Bonnell, 2006).

Overall, the comparison of the prompt γ-ray emission properties of short and long GRBs shows that short GRBs have (a) harder spectra (as shown by the HR, Fig. 1), (b) smaller variability timescale and (c) null lag. However, there are some caveats: T_{90} and HR are computed in the *observer frame* through the light curves accumulated by a given detector. Most often, HR has been computed as the ratio of the instrumental counts recorded in two different energy bands. With the launch of Swift in 2004 (Gehrels et al., 2004) the possible different redshift distribution of short and long bursts was disclosed. BATSE and Fermi data allowed us to characterise the spectra of GRBs over a wide (few keV to several MeV) energy range with tens of ms time resolution. We now know that GRB spectra might have different shapes (typically represented by curved models, i.e. more complicated than simple powerlaw) and strongly evolve with time within individual GRBs. Therefore, (1) the redshift, (2) the overall shape of the spectrum and (3) its evolution within the burst should all be considered when comparing the temporal and spectral properties of SGRB and LGRB. The possible different redshift distributions of short and long GRBs might change the results, i.e. blur away or exacerbate the differences between the two classes. The HR represents only a proxy of the real spectral diversity of short and long events which should instead be searched in the difference of the spectral parameters of these classes (Ghirlanda et al., 2004, 2009, 2011).

In the following sections we will progressively probe deeper into the consolidated differences of short and long GRBs exploring the origin of the different HR by searching for differences in the spectral shape (Section 2), including the redshift corrections (Section 3) and the temporal evolution of the spectrum (Section 4) and, finally, revisiting the lag as a discriminator between short and long events (Section 5).

2. The observed spectrum of GRBs

Spectral analysis of samples of short and long GRBs showed that this is typically represented by a curved function (Preece et al., 2000; Ghirlanda et al., 2002, 2004; Kaneko et al., 2006; Frontera et al., 2009; Nava et al., 2011a; Goldstein et al., 2013, 2012; Gruber et al., 2014). In particular, a smoothly broken power law (Band et al., 1993) or a power law with a high energy cutoff suffice to reproduce the observed spectra of most short and long GRBs with the former being more often fitted by a cutoff power law function (Ghirlanda et al., 2004, 2009). The common feature of these functions is the presence of a low energy power law (parametrised by its photon spectral index α) and a characteristic energy $E_{\rm peak}$ where the νF_ν spectrum peaks. The smoothly broken power law model has an additional high energy power law component (parametrised by the photon spectral index β).

Spectral analysis of samples of short and long GRBs detected by BATSE and Fermi (Ghirlanda et al., 2004, 2009) shows that short and long GRBs have slightly different $E_{\rm peak}$ distributions (with a KS probability of 10^{-2} of being drawn from the same parent population) while the main difference is in the low energy spectral index (α) distribution (with a KS probability of 10^{-4}). From the distributions of these two spectral parameters (Ghirlanda et al., 2009) it *appears* that SGRBs are harder than LGRBs due both to a combination of their peak energy (on average $E_{\rm peak} \sim 400$ keV for SGRBs with respect to 220 keV for long events) and of a harder low energy spectral index (on average $\alpha \sim -0.4$ for SGRBs with respect to -0.92 for long ones). These results, found in the BATSE short and long populations (Ghirlanda et al., 2009), are confirmed by the Fermi data (Nava et al., 2011a). Fig. 2 shows the distributions of the low energy spectral index (top panel) and peak energy (bottom panel) of Fermi long (blue hatched histogram) and short (red hatched histogram) bursts (from Nava et al., 2011a).[3] The top panel of Fig. 2 also shows that all short GRBs have a low energy spectral index violating (i.e. harder than) the synchrotron limit of -1.5 in case of electron cooling.

We further test these results with the most updated sample of GRBs from the GBM/Fermi catalog[4] (von Kienlin et al., 2014; Gruber et al., 2014). We selected all the GRBs (up to Feb. 2015) detected by the GBM on board Fermi with a time integrated spectrum well fitted by either a Band function or a power law with exponential cutoff. Fig. 3 (top panel) shows the low energy spectral index (α) versus the peak energy ($E_{\rm peak}$) *in the observer frame* for the 982 GRBs. Red and blue symbols show the population of short and long events, respectively, considered separating the sample at 2 s. The KS test probabilities of $E_{\rm peak}$ and α for the two populations are 10^{-30} and 10^{-24}, respectively. We also verified if the KS probability depends on the 2 s short/long divide. Indeed, it has been suggested (Bromberg et al., 2012, 2013) that there could be a contamination of collapsars (i.e. long GRB progenitors) in the

---

[2] The HR values may change according to the energy ranges selected for their computation.

[3] For a comparison of the spectral properties of short and long GRBs detected by Fermi and BATSE see Nava et al. (2011b).

[4] http://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html.