

Confirming the γ -ray burst spectral-energy correlations in the era of multiple time breaks

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ABSTRACT

We test the spectral-energy correlation including the new bursts detected (mostly) by *Swift* with firm measurements of their redshifts and peak energy. The problem of identifying the jet breaks in the complex and multibreak/flaring X-ray light curves observed by *Swift* is discussed in the complex and multibreak/flaring X-ray light curves observed by *Swift*. We use the optical data as the most reliable source for the identification of the jet break, since the X-ray flux may be produced by a mechanism different from the external shocks between the fireball and the circumburst medium, which are responsible for the optical afterglow. We show that the presence of an underlying SN event in XRF 050416A requires a break to occur in the afterglow optical light curve at around the expected jet break time. The possible presence of a jet break in the optical light curve of GRB 050401 is also discussed. We point out that, for measuring the jet break, it is mandatory that the optical light curve extends after the epoch where the jet break is expected. The interpretation of the early optical breaks in GRB 050922C and GRB 060206 as jet breaks is controversial because they might instead correspond to the flat-to-steep decay transition common in the early X-ray light curves. All the 16 bursts coming from *Swift* are consistent with the $E_{\text{peak}} - E_{\gamma}$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation. No outlier is found to date. Moreover, the small dispersion of the $E_{\text{peak}} - E_{\gamma}$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation, confirmed also by the *Swift* bursts, strengthens the case of using GRBs as standard candles.

Key words. gamma rays: bursts – gamma rays: observation – X-rays: general

1. Introduction

Since the launch of the *Swift* satellite (Gehrels et al. 2004) we are witnessing the discovery of new properties of Gamma Ray Bursts (GRBs), thanks to the “prompt” follow up of the GRB emission from the X-ray to the optical and NIR band (see e.g. Zhang 2007, for a recent review).

In the pre-*Swift* era several correlations involving the prompt and afterglow properties of long Gamma-Ray Bursts with measured redshifts were reported. Amati et al. (2002), with 12 GRBs detected by *BeppoSAX* found that the prompt emission (rest frame) spectral peak energy (i.e. the peak of the νF_{ν} spectrum) is correlated with the isotropic energy released during the prompt phase ($E_{\text{peak}} \propto E_{\text{iso}}^{1/2}$ – so called “Amati” correlation). The inclusion of more bursts detected by BATSE(CGRO), Integral and Hete-II (Ghirlanda et al. 2004 – GGL04 hereafter; Lamb et al. 2004; Nava et al. 2006 – N06 hereafter) confirmed this correlation. Recently, Amati (2006) confirmed his correlation by adding the 17 bursts, detected in the *Swift* era (up to GRB 061007), with firm measurements of their E_{peak} and redshift z .

The possible jetted nature of GRBs implies that, when the fireball is decelerated by the circumburst medium up to $\Gamma \sim 1/\theta_{\text{jet}}$ (where θ_{jet} is the jet opening angle), an achromatic break should appear in the GRB afterglow light curve at a characteristic time t_{jet} (e.g. Rhoads 1997; Sari et al. 1999). By correcting the GRB prompt emission energy for the collimation factor ($f = 1 - \cos \theta_{\text{jet}}$), Frail et al. (2001; see also Bloom et al. 2003) showed that the large dispersion of E_{iso} is reduced. Then GGL04 discovered (with a sample of 15 GRBs with jet break times

measured from the optical light curves) a tight correlation (so called “Ghirlanda” correlation) between the GRB peak energies and the collimation corrected energy, i.e. $E_{\text{peak}} \propto E_{\gamma}^{0.7}$ (where $E_{\gamma} = E_{\text{iso}} \cdot f$) if the circumburst medium has a constant density (homogeneous medium – HM) and the radiative efficiency of the prompt phase is the same for all bursts (a value of 20% was used – e.g. Frail et al. 2001). In the case of a stratified circumburst density (e.g. $\rho \propto r^{-2}$ – wind medium, WM), N06 showed that this correlation (computed with the 17 GRBs of the pre-*Swift* era plus the *Swift* burst GRB 050525A) becomes linear: $E_{\text{peak}} \propto E_{\gamma}$. Furthermore, Liang & Zhang (2005) discovered a completely phenomenological correlation (so called “Liang-Zhang” correlation) involving the three observables E_{peak} , E_{iso} and t_{jet} (all quantities computed in the source frame and t_{jet} estimated from the optical light curve) whose consistency with the model dependent $E_{\text{peak}} - E_{\gamma}$ correlations has been demonstrated in N06.

The quantities needed to test the $E_{\text{peak}} - E_{\gamma}$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations are the redshift z , the peak energy E_{peak} and the jet break time t_{jet} . Despite ~ 50 (i.e. about $\sim 1/4$) of the *Swift* GRBs have a measured redshift, both the $E_{\text{peak}} - E_{\gamma}$ and the $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations were hardly tested with new bursts due to: (i) the difficulty to measure the peak energy E_{peak} with the relatively small energy band (15–150 keV) of the BAT instrument on-board *Swift*; and (ii) the unexpected (and unforeseen in the pre-*Swift* era) complexity of the early (≤ 1 d) afterglow light curves (Nousek et al. 2006; O’Brien et al. 2006; Borrows et al. 2005).

A typical *Swift* X-ray light curve, in fact, presents at least three phases (Nousek et al. 2006): (a) a steep initial decay

followed by (b) a flat phase and finally (c) by a steeper decay (similar to what observed in the the pre-*Swift* afterglow light curves). These phases are separated by corresponding breaks at ~ 500 s (from (a) to (b)) and between 10^3 and 10^4 s (from (b) to (c)). Also, an intense (long-lasting) flaring activity is superposed to the typical bare power law decay of the afterglow X-ray light curve (Burrows et al. 2007). The optical light curve tracks the X-ray light curve in some cases, but more often it is different. Also in the optical light curve there can be a multiplicity of breaks, also not simultaneous with those of the X-ray light curve (e.g. Panaitescu 2007).

In a recent paper, Willingale et al. (2007, W07 hereafter), studied the *Swift* GRB X-ray emission and suggested that both the very early and the late (up to 10^5 – 10^6 s) emission can be reproduced with a model having the same functional form, i.e. an exponential smoothly connected with a power law. For the afterglow phase, this functional form allows to define the characteristic time T_a where the power law sets in and dominates the emission, which W07 estimated for a large number of *Swift* bursts. Intriguingly, they found that if T_a is treated as a jet break time (i.e. with the same formalism which is used to derive the collimation angle θ_{jet} from the measure of t_{jet}), then the collimation corrected energetics correlates strongly with E_{peak} , for those *Swift* bursts of known E_{peak} and z .

Trying to explain the different optical and X-ray behavior, Uhm & Beloborodov (2007) and Genet et al. (2007) have proposed that the X-ray flux may be dominated by the reverse shock emission in slow shells, while the optical flux is instead due to the standard forward external shock. In this case only the optical light curve (and even not always, if the reverse shock contributes also in the optical) can show a jet break time. Another possibility is that the X-ray flux is dominated by a late activity of the central engine (late prompt emission model, see Ghisellini et al. 2007).

This complexity requires care when identifying a break with the jet break time. Since the pre-*Swift* $E_{\text{peak}} - E_\gamma$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ relations made use of break times found in the optical light curves (typically starting several hours after the GRB trigger), it is safer to use *only* the optical light curves to find t_{jet} , and relax the requirement that the break should be present also in the X-ray light curve which, as mentioned above, could be produced by a different mechanism. In addition, an early optical break should be tested for being the jet break: if the light curve does not extend to (and even after) the epoch when the jet break is expected (according to the $E_{\text{peak}} - E_\gamma$ correlation), this early break cannot be claimed to be the jet break. This is, indeed, the case of GRB 050922C and 060206 (discussed below).

The relevance of the $E_{\text{peak}} - E_\gamma$ (and of its phenomenological form, i.e. the $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation) is twofold: (1) they represent a new tool to understand the GRB physics and some interpretations have already been proposed (see e.g. Eichler & Levinson 2005; Thompson 2006; Thompson et al. 2007); (2) the tightness of these correlations makes them a new tool to standardize the GRB energetics for a cosmological use (e.g. Ghirlanda et al. 2006, for a review). More recently, Firmani et al. (2006c, F06 hereafter) discovered a new correlation which is based only on prompt emission properties and is a new tool to use GRBs as standard candle which does not require the use of the jet break time (Firmani et al. 2006a,b).

In this paper we update the $E_{\text{peak}} - E_\gamma$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation by including all the possible GRBs detected in the *Swift* era. With a sample which is doubled with respect to the original one (GGL04) we find no new outlier with respect to these correlations, despite previous claims of the contrary

(Sato et al. 2006, S06 hereafter; Mundell et al. 2007). We will then discuss these cases in more detail.

In Sect. 2 we present and discuss the sample of GRBs, in Sect. 3 we find (GRB 050416A and GRB 050401) and discuss (GRB 050922C and GRB 060206) some jet break times derived in the optical, while in Sect. 4 we present the results of the statistical analysis of the $E_{\text{peak}} - E_\gamma$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation. In Sect. 5 we discuss our results.

We use a standard cosmology with $\Omega_M = 0.3$ and $\Omega_\Lambda = h = 0.7$.

2. The sample

Before the *Swift* mission the jet break time t_{jet} was measured from the optical light curves of GRB afterglows. Since it should be achromatic, we were hoping that the *Swift* capability to localize and promptly follow the X-ray emission of the burst would greatly help to easily measure several t_{jet} from the X-ray light curve. Indeed, *Swift* has observed several X-ray afterglows starting ~ 100 s after the GRB onset. In a few cases the X-ray emission was measured also simultaneously with the prompt γ -ray emission (e.g. Butler & Kochevski 2007). But, unexpectedly, these light curves are complex (steep-flat-steep structure with multiple breaks and several superposed early and late time flares). As a consequence, *the jet break can be hardly identified using the X-ray data.* It is therefore reasonable to rely on the optical light curves to search for possible jet breaks. Also in this case, however, we should keep in mind that the optical emission often shows a complexity similar to what seen in the X-rays.

After having selected all *Swift* GRBs with measured redshift, we have searched for any published information on their prompt emission spectral properties in order to obtain E_{peak} and to estimate E_{iso} . Finally, we searched for evidence of jet breaks in the optical light curves. In several cases we could only set a lower limit on t_{jet} although the optical emission was fairly well sampled. For the reasons discussed above we did not include in our sample the GRBs for which a jet break was claimed only in the X-ray light curve. We present our sample in Table 1 dividing the pre-*Swift* GRBs from those identified in the *Swift* era and added in this paper (from GRB 050525A to GRB 061121).

The typical time-averaged spectrum of GRBs (e.g. Preece et al. 2000; Kaneko et al. 2006) is best fitted by a smoothly joint double power law model (the Band model – Band et al. 1993). However, for some bursts detected by HETE-II and included in the pre-*Swift* sample of N06 and F06, the time-averaged spectrum reported in the literature was fitted with a power law ending with a high-energy exponential cutoff (CPL model). The isotropic energy used to define the Amati correlation as well as the $E_{\text{peak}} - E_\gamma$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations is derived by extrapolating the best fit spectral model in the rest frame 1 – 10^4 keV energy band (e.g. see Eq. (1) in GGL04). As a consequence those bursts whose spectrum is fitted with a CPL model underestimate the value of E_{iso} (see also F06). The same happens for most of the *Swift*-BAT bursts whose spectra, due to the limited energy range of this instrument, are typically fitted with a CPL model.

In all these cases (i.e. GRB 011211, 020813, 021004, 030226, 030429, 041006, 050318, 050525A, 050820A, 050922C, 051109A, 060124, 060206, 060418, 060927) we estimated E_{iso} as the (logarithmic) average between the value obtained assuming the cutoff-power law model that was reported in the literature and the value obtained with the same spectral parameters but with a Band model having the high energy spectral component fixed, i.e. $\beta = -2.3$ (photon spectral index) which is the average value found from the spectral analysis of

GRBs (e.g. Kaneko et al. 2006). In these cases we adopted an error on E_{iso} which accounts for these two extreme values.

Note that, among the pre-*Swift* bursts, we have updated the values of E_{iso} with respect to the sample of N06 and F06 (for GRB 011211, 020813, 021004, 030226, 030429, 041006). Moreover, we have updated the jet break time of GRB 030226 with the most recently published estimate (Klose et al. 2004) and we have corrected a typo in the N06 table on the rest frame value of E_{peak} for GRB 030328 and GRB 050525A. For GRB 061121 and GRB 061007 we averaged the E_{peak} and E_{iso} values found by the analysis of the Konus-Wind and RHESSI spectra (Golenetskii et al. 2006b,c; Bellm et al. 2006). For GRB 050416A we adopted the spectral parameters (and E_{iso}) calculated by S06.

Finally, in a recent work, Schaefer (2007) used some other bursts with published z and E_{peak} which we do not include in our sample. The breaks of GRB 050318, 050505, 051022 and 060210 were in fact identified in the X-ray light curve, so we do not include these cases for the reasons explained above. However, Schaefer (2007), by adopting the jet breaks observed in the X-ray light curves of the bursts above, found that they are consistent with the $E_{\text{peak}} - E_{\gamma}$ correlation. Only GRB 060526 (present in the sample of Schaefer 2007) is included in our sample because Dai et al. (2007) have shown the presence of an achromatic optical/X-ray jet break at 2.77 d^1 . We also considered the most distant GRB 050904 (also included in Schaefer 2007) at $z = 6.29$ which has an achromatic jet break (Tagliaferri et al. 2006). We did not include this burst in our sample because its E_{peak} estimate is still uncertain: Amati (2006) lists a lower limit of 1100 keV (rest frame) while Schaefer (2007) lists a value of 3178 keV (rest frame). Using the latter value and the density inferred in the homogeneous case ($n = 680 \text{ cm}^{-3}$ – Frail et al. 2006), this burst is consistent with the $E_{\text{peak}} - E_{\gamma}$ correlation.

In this search we found two more bursts (i.e. GRB 060115 and GRB 060707, listed by Amati 2006) which, having a firm estimate of E_{peak} and z , are candidates to be included in the present sample. However, for these bursts the optical light curves (publicly available at present only in form of GCNs) are poorly sampled². Note finally that we did not include in the present sample GRB 060218 (associated with SN2006aj, see e.g. Mazzali et al. 2006; Campana et al. 2006) because the SN dominates the optical emission, making impossible to estimate t_{jet} . It is consistent with the $E_{\text{peak}} - E_{\text{iso}}$ correlation (Amati et al. 2007), and its possible jet opening angle is discussed in Ghisellini et al. (2006).

3. Optical breaks

In order to rely on published data we have considered all bursts with a published optical light curve and we have checked for the presence of jet breaks. In two cases (GRB 050401 and GRB 050416A), discussed below, we present our estimate of the jet break time from the fitting of the available optical data. Sato et al. (2006), based on the X-ray afterglow behaviour, claimed that these two bursts are outliers for the $E_{\text{peak}} - E_{\gamma}$ correlation. We show that, instead, our estimate of the jet break time makes them consistent with this correlation.

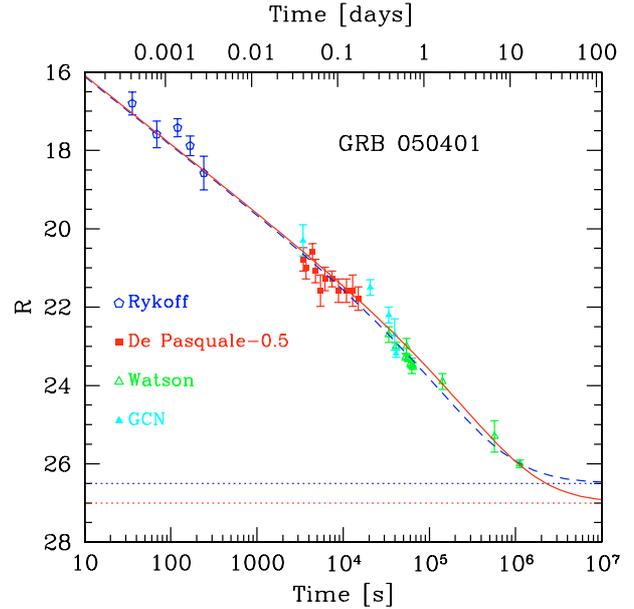


Fig. 1. The optical light curve of GRB 050401. Data from: D’Avanzo et al. (2005); De Pasquale et al. (2006); Greco et al. (2005); Kahharov et al. (2005); McNaught et al. (2005); Misra et al. (2005); Rykoff et al. (2006); Watson et al. (2006). The dashed and solid lines are two fits with break time set at 1 and 2 days, respectively. The dotted lines correspond to the magnitude assumed for the host galaxy.

3.1. GRB 050401

We have collected the photometric data for this bursts from the literature, including the $R = 26 \pm 0.1$ mag Subaru observation reported in Watson et al. (2006). In that paper, it is not specified if this magnitude is inclusive or not of the host galaxy. We have assumed this magnitude corresponds to the sum of the afterglow plus the host galaxy fluxes. De Pasquale et al. (2006) pointed out that the data in their list, while internally consistent, may have up to 0.5 mag uncertainty in absolute normalization when compared with data of other sources, due to the differences in the used reference stars. We have then “renormalized” these data to have a rough agreement with other observations made close in time. In addition, the magnitudes given in De Pasquale et al. (2006) were de-reddened by galactic extinction. For consistency with the other data, we have instead taken the observed magnitudes. We have then fitted a broken power law plus a constant to the data:

$$F(t) = F_{\text{host}} + \frac{F_b (t/t_b)^{-\alpha_1}}{1 + (t/t_b)^{\alpha_2 - \alpha_1}}. \quad (1)$$

The dashed line in Fig. 1 corresponds to $t_b = 1 \text{ d}$; $R_{\text{host}} = 26.5$; $\alpha_1 = 0.7$ and $\alpha_2 = 1.4$; while the solid line corresponds to $t_b = 2 \text{ d}$; $R_{\text{host}} = 27$; $\alpha_1 = 0.7$ and $\alpha_2 = 1.4$.

These results do not greatly change by adopting a different renormalization for the data of De Pasquale et al. (2006). We conclude that the data show the existence of a possible break in the optical light curve of GRB 050401, and set $t_b = 1.5 \pm 0.5$ days.

3.2. GRB 050416A

In Fig. 2 we show the optical and near IR light curve of GRB 050416A, with data taken from Soderberg et al. (2006) and Holland et al. (2007). Since the rebrightening at ~ 10 days is most likely due to an underlying supernova

¹ GRB 060526 is present also in the sample of Schaefer (2007) but he adopted the early jet break observed in the X-ray light curve (Moretti et al. 2006).

² See also <http://grad40.as.utexas.edu/grblog.php>.

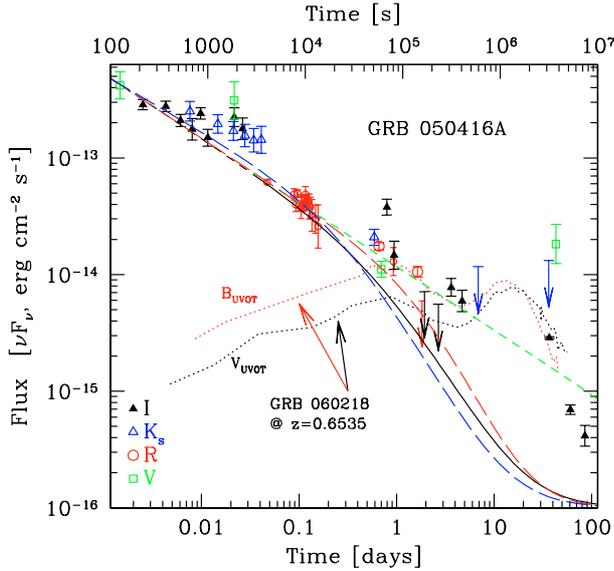


Fig. 2. The optical and near IR light curve of GRB 050416A. Data from Soderberg et al. (2006) and Holland et al. (2007). These data have been fitted with a smoothly broken power law plus a constant (see Eq. (1)), assuming three different break times: 0.3 and 2 days (long dashed lines) and 0.8 day (solid line). The short dashed line is an example of unbroken power law, which clearly exceeds late time data. In this burst the rebrightening at ~ 10 days is most likely due to an underlying supernova. The flux associated to the supernova is likely to contribute to the light curve even for earlier times, as shown by the light curve of GRB 060218 (from Campana et al. 2006, dotted lines), assuming to lie at the same redshift of GRB 050416A ($z = 0.6535$).

(Soderberg et al. 2006), in Fig. 2 we also show the light curve of GRB 060218 (from Campana et al. 2006, dotted lines), assuming to lie at the same redshift of GRB 050416A ($z = 0.6535$). It can be seen that its flux can contribute to the light curve of the afterglow even much earlier than 10–20 days. Note that the rest frame wavelengths of the R and I filters for GRB 0504016A roughly corresponds to the rest frame wavelengths of the B and V bands for GRB 060218 ($z = 0.033$).

Using Eq. (1), we have fitted these data assuming three different break times: 0.3 and 2 days (long dashed lines) and 0.8 day (solid line). The values of the decay indices changes little in all cases, being in the ranges $0.48 < \alpha_1 < 0.55$ and $1.5 < \alpha_1 < 1.8$. Note that an unbroken power law clearly exceeds late time data (short-dash line).

We conclude that the data require the light curve to break, but the uncertainties due to the paucity of data and to the contribution from the supernova allow to determine t_b only with a large error, therefore we set $t_b = 1.0 \pm 0.7$ days.

3.3. GRB 050922C and GRB 060206

These two bursts have an optical light curve showing early breaks at 0.11 ± 0.03 (Li et al. 2005) for GRB 050922C and ~ 0.6 days (Monfardini et al. 2006; Stanek et al. 2006) for GRB 060206. The jet breaks predicted by the $E_{\text{peak}} - E_\gamma$ correlation are instead $t_{\text{jet}} = 8.0^{+5.7}_{-3.3}$ days for GRB 050922C and $t_{\text{jet}} = 10.3^{+7.4}_{-4.3}$ days for GRB 060206 (in the HM case – to be consistent with the $E_{\text{peak}} - E_\gamma$ correlation within its 1σ scatter) and $t_{\text{jet}} = 8.7^{+6.8}_{-3.8}$ for GRB 050922C and $t_{\text{jet}} = 11.2^{+8.7}_{-4.9}$ for GRB 060206 (in the WM case). The available optical light curve, in both cases, does not extend to such epochs and therefore it is

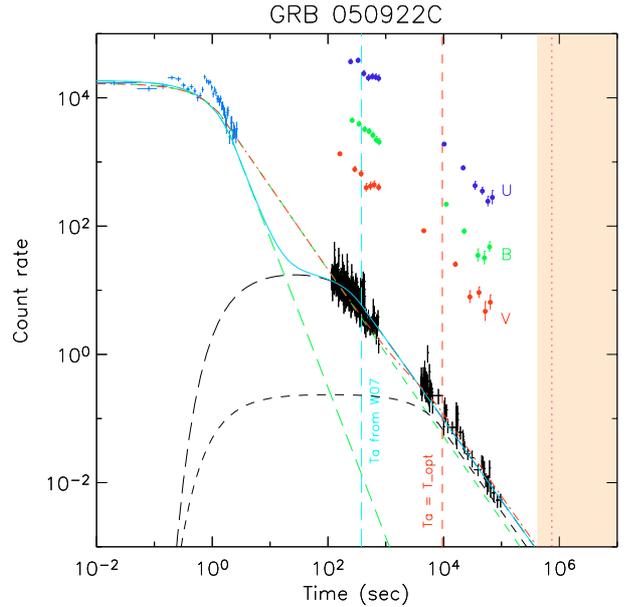


Fig. 3. Early BAT and XRT light curve of GRB 050922C obtained from the Butler archive <http://astro.berkeley.edu/~nat/swift/>. The data points are the count rate at 1 keV. In the case of the early light curve these have been obtained by extrapolating at this energy the BAT spectrum. The solid line corresponds to the double component model of W07 (with the parameters listed in their Table 1) with the two components shown by the long-dashed lines. The value of $T_a = 380$ s derived by W07 is shown by the vertical long-dashed line. The dot-dashed line show our fit to the data (the two model components are represented by the dashed lines) by assuming a flatter early component (i.e. $\propto t^{-1.3}$) and $T_a = t_{\text{opt}} = 0.11$ days. The dotted vertical line marks where the jet break is expected based on the $E_{\text{peak}} - E_\gamma$ correlation (in the WM case) and the shaded region its 1σ interval. Optical fluxes (in arbitrary units, UVOT/Swift, U , B , V bands, from top to bottom, displaced for clarity, data from Li et al. 2005) are also shown.

not possible to say if they really have a jet break when it is expected according to the $E_{\text{peak}} - E_\gamma$ correlation.

For this reason these two bursts cannot be considered outliers of the $E_{\text{peak}} - E_\gamma$ correlation (as they would be, adopting the early optical break as the jet break) nor as lower limits for this correlation (by adopting the latest optical observation available).

3.3.1. On the possible nature of the optical breaks in GRB 050922C and GRB 060206

The early optical break in GRB 050922C (at 0.11 ± 0.03 days after the BAT trigger) is 25 times larger than the break that W07 derive ($T_a = 380$ s) from a multi-component fit to the BAT-XRT light curve up to 10^5 s (solid line in Fig. 3).

With $T_a = 380$ s the burst is an outlier with respect to the $E_{\text{peak}} - E_\gamma$ correlation derived by the same authors, which uses T_a as a jet break time.

In Fig. 3 we show the early BAT light curve and the XRT light curve starting 100 s and extending to 1 day after the trigger³.

We tried to “match” the X-ray light curve with the functional form proposed by W07 by assuming T_a equal to the break observed in the optical light curve ($t_{\text{opt}} = 0.11$ days – Li et al. 2005). This is shown by the dot-dashed curve in Fig. 3 (while

³ Data are taken from the public archive of Butler <http://astro.berkeley.edu/~nat/swift/>.

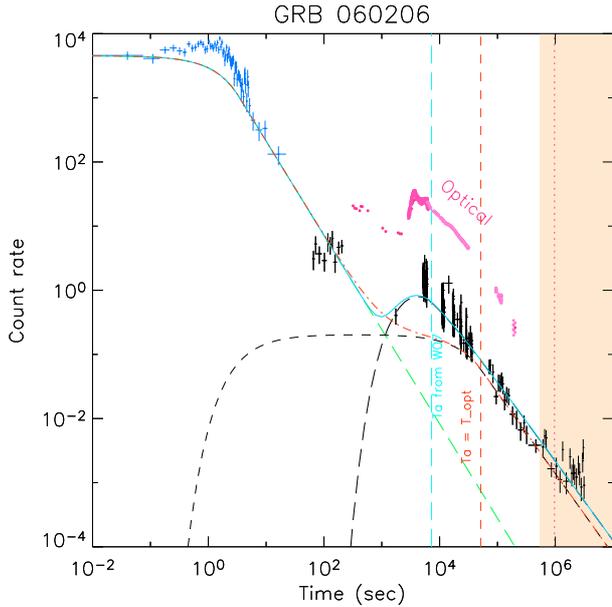


Fig. 4. Early BAT and XRT light curve of GRB 060206. The solid line corresponds to the double component model of W07 (with the parameters listed in their Table 1) with the two components represented by the long-dashed lines. The value of $T_a = 7244$ s derived by W07 is shown by the vertical long-dashed line. The dot-dashed line shows our fit to the data (the two model components correspond to the dashed lines) by assuming $T_a = t_{\text{opt}} = 0.6$ days and by excluding the X-ray flare at 10^4 s. The optical R-band data are shown (Monfardini et al. 2006; Stanek et al. 2006; Wozniak et al. 2006). The dotted vertical line marks where the jet break is expected, based on the $E_{\text{peak}} - E_\gamma$ correlation (in the WM case) and the shaded region its 1σ interval.

the functional form fitted by W07 is the solid line in the same figure). We note that the two fits are consistent with the available data and suggest that T_a might lie between the two values, i.e. 380 s (derived by W07) and the break observed in the optical (at 0.11 days). With $T_a = t_{\text{opt}} \sim 10^4$ s GRB 050922C is not an outlier with respect to the $E_{\text{peak}} - E_\gamma$ correlation defined by W07.

The published optical data of GRB 050922C end at $t = 1.2$ days (Covino et al. 2005). If, according to the above interpretation, the early optical break is T_a , we are authorized to assume $t_{\text{jet}} > 1.2$ days and treat this as a lower limit for the $E_{\text{peak}} - E_\gamma$ correlation.

For GRB 060206 the observed early optical break (Monfardini et al. 2006; Stanek et al. 2006) is only 10 times larger than the T_a derived by W07. However, as shown by Monfardini et al. (2006) and Stanek et al. (2006), the optical light curve presents a strong flare peaking at $3-4 \times 10^3$ s. The same flaring structure is present in the X-ray light curve.

We show the X-ray and optical light curve of GRB 060206 in Fig. 4 and the model function of W07 (solid line) which gives $T_a \sim 7000$ s. Similarly to the case of GRB 050922C we fitted the X-ray data by assuming $T_a = t_{\text{opt}} = 0.6$ days (dot-dashed line in Fig. 4) but excluding the X-ray flare coincident with that observed in the optical.

The optical data of GRB 060206 (Stanek et al. 2006) end at 2.33 days, i.e. before the epoch at which the jet break is predicted by the $E_{\text{peak}} - E_\gamma$ correlation (shaded region in Fig. 4). Therefore we assume this value as a lower limit on the jet break time of this burst.

3.4. GRB 061007

Mundell et al. (2007) claim that GRB 061007 is an outlier with respect to the $E_{\text{peak}} - E_\gamma$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations because no break is observed up to 10^6 s in the X-ray light curve. For the arguments detailed above (see also Sect. 5) we do not consider the X-ray light curve. We instead take the lower limit on the jet break set by the latest optical observation at 1.7 d (Mundell et al. 2007; Schady et al. 2006). In this case the $E_{\text{peak}} - E_\gamma$ correlation predicts a jet break between 0.7 and 2.2 days (1σ in the HM case) and 0.8 and 2.4 days (1σ in the WM case).

4. Results

We first recomputed the $E_{\text{peak}} - E_\gamma$ correlation in the case of a homogeneous and wind-like medium and then the phenomenological $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation following the method described in N06.

To the pre-*Swift* bursts included in the N06 sample (17 GRBs – excluding GRB 050525A which is a *Swift* burst – with measured jet break time) we add 16 new *Swift* GRBs. The results using our total sample of 33 GRBs are presented in Figs. 5–7: *all points and lower limits are consistent with these correlations and there are no outliers.*

Following the discussion of Sects. 2 and 3 we found 9 (out of 16) bursts which have only a lower limit on their jet break (as discussed at the end of Sect. 3 we include in the subsample of lower limits also GRB 050922C and GRB 060206). Among these 9 lower limits there are 2 GRBs (i.e. 061007 and 060418) which lie on the right side of the $E_{\text{peak}} - E_\gamma$ correlation (see Figs. 5–7). These 2 bursts were used for the statistical analysis of the correlations.

In 7 cases (out of 16) the jet break was measured in the optical light curve (in 5 cases t_{jet} was already published in the literature and in 2 bursts it is found for the first time in this work, Sect. 3). However, we did not consider in the statistical analysis GRB 060614. This burst, in fact, although fully consistent with both these correlations⁴ (as shown by the open square symbol in Figs. 5–7), was claimed to represent a new class of bursts (see Gehrels et al. 2006; Della Valle et al. 2006b). Therefore, the sample of *Swift* GRBs added to the correlations and effectively used in their statistical analysis is composed by 6 bursts with firm jet break measurements (GRB 050401, 050416A, 050525A, 050820A, 060124, 060526) and 2 bursts with lower limits on t_{jet} (GRB 060418 and 061007). These, added to the pre-*Swift* sample of 17 bursts, bring to 25 the total number of GRBs used for the statistical analysis.

We fitted the correlations by weighting for the errors on the involved quantities (with the *fitxy* routine of Press et al. 1999). We also evaluated the scatter of the data points computed perpendicularly to the best fit line.

4.1. The $E_{\text{peak}} - E_\gamma$ correlation in the HM case

We recomputed the $E_{\text{peak}} - E_\gamma$ correlation in the homogeneous medium case. The jet opening angle is:

$$\theta_{\text{jet}} = 0.161 \left(\frac{t_{\text{jet,d}}}{1+z} \right)^{3/8} \left(\frac{n \eta_\gamma}{E_{\text{iso},52}} \right)^{1/8} \quad (2)$$

⁴ Note that the published spectral parameters of GRB 060614 make its peak energy poorly constrained. This is the reason of the shown large uncertainties.

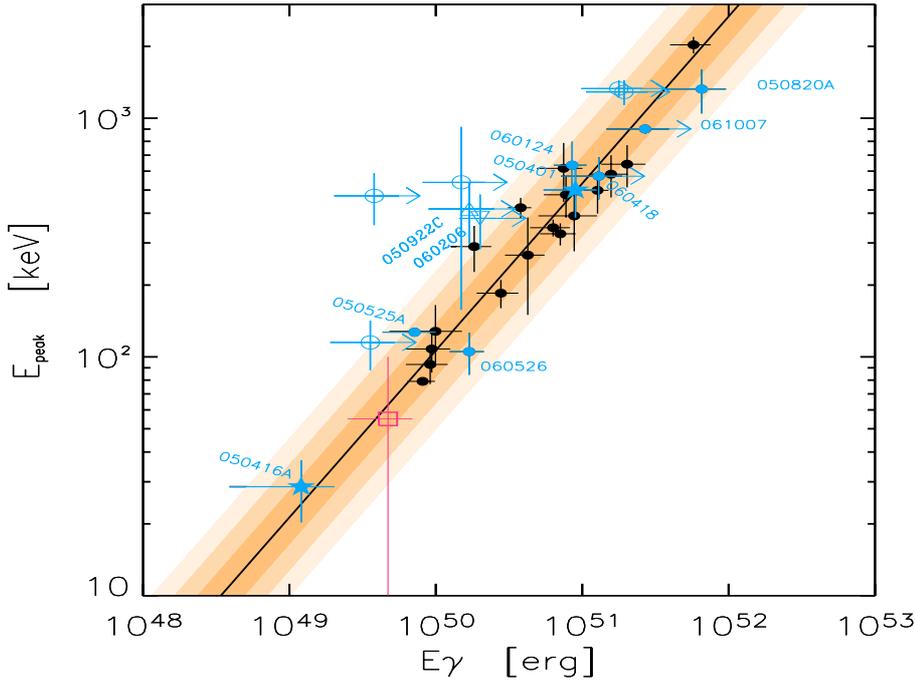


Fig. 5. The $E_{\text{peak}}-E_{\gamma}$ correlation with the inclusion of 16 *Swift* GRBs for a homogeneous circumburst medium case. The best fit correlation (solid line) and its 1, 2, and 3 σ scatter (solid filled regions) are reported. The names of the 8 *Swift* bursts used in the fit are reported. The open triangles and open circles are the burst not included in the fit because only a lower limit on their jet break was found. The open square corresponds to GRB 060614 which is not included in the fit. GRB 050401 and GRB 050416A whose jet break time was estimated in this work are shown with filled star symbols. Note that we did not show, in this figure, GRB 980425 and GRB 031203 which are outliers not only of the $E_{\text{peak}}-E_{\gamma}$ correlations, but also of the Amati correlation (but see Ghisellini et al. 2006). GRB 060218, instead, obeys the Amati correlations, but the presence of the SN lightcurve made any estimate of t_{jet} impossible.

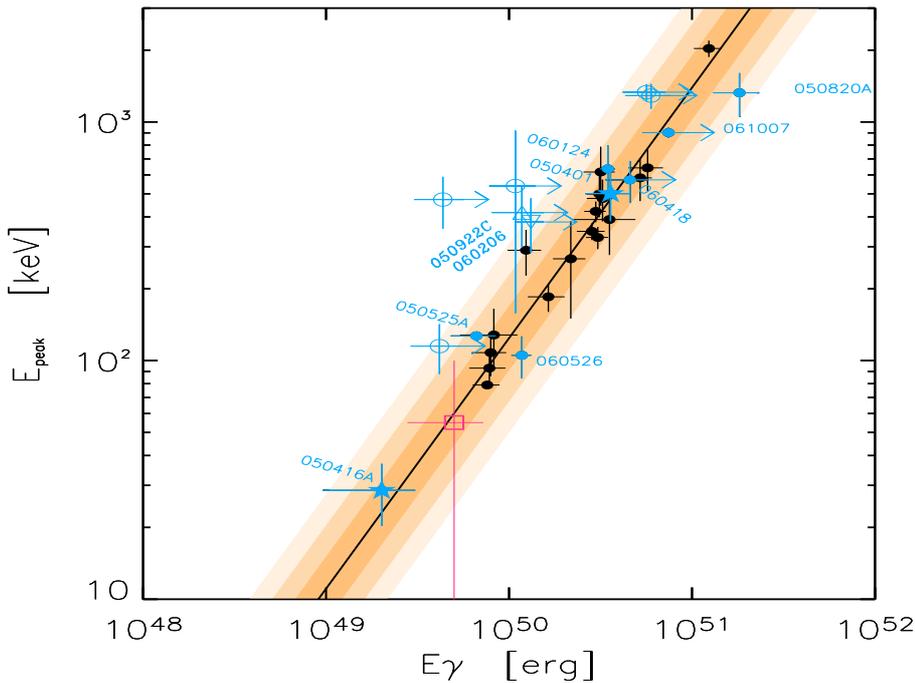


Fig. 6. The $E_{\text{peak}}-E_{\gamma,w}$ correlation with the inclusion of *Swift* GRBs for a wind circumburst medium case. The filled symbols (black circles and grey circles and stars) are the 25 GRBs considered for the fit of the correlation. Symbols are as in Fig. 5.

where z is the redshift, η_{γ} is the radiative efficiency and $t_{\text{jet,d}}$ is the break time measured in days of the afterglow light curve⁵. The efficiency η_{γ} relates the isotropic kinetic energy of the fireball after the prompt phase, $E_{k,\text{iso}}$, to the prompt emitted energy E_{iso} , through $E_{k,\text{iso}} = E_{\text{iso}}/\eta_{\gamma}$. This implicitly assumes that $\eta_{\gamma} \ll 1$ otherwise the remaining kinetic energy after the prompt emission is instead $E_{k,\text{iso}} = E_{\text{iso}}(1 - \eta_{\gamma})/\eta_{\gamma}$. This efficiency, in principle, could be different from burst to burst, but in the absence of any hints of how its value changes as a function of other properties of the bursts and favored by its low power in Eq. (2), one

assumes a constant value for all bursts, i.e. $\eta_{\gamma} = 0.2$ (after its first use by Frail et al. 2001, following the estimate of this parameter in GRB 970508).

The values of θ_{jet} and E_{γ} in the HM case are reported, for all GRBs, in Table 1. With these values the $E_{\text{peak}} - E_{\gamma}$ correlation (shown in Fig. 5) is

$$\left(\frac{E_{\text{peak}}}{100 \text{ keV}} \right) = (3.02 \pm 0.14) \left(\frac{E_{\gamma}}{4.4 \times 10^{50} \text{ erg}} \right)^{0.70 \pm 0.04} \quad (3)$$

with a reduced $\chi_r^2 = 1.08$ for 23 degrees of freedom. The errors on its slope and normalization are calculated in the ‘‘barycenter’’ of E_{peak} and E_{γ} , where the slope and normalization errors are uncorrelated (Press et al. 1999). The scatter of the

⁵ Here we adopt the notation $Q = 10^x Q_x$, and use cgs units unless otherwise noted.

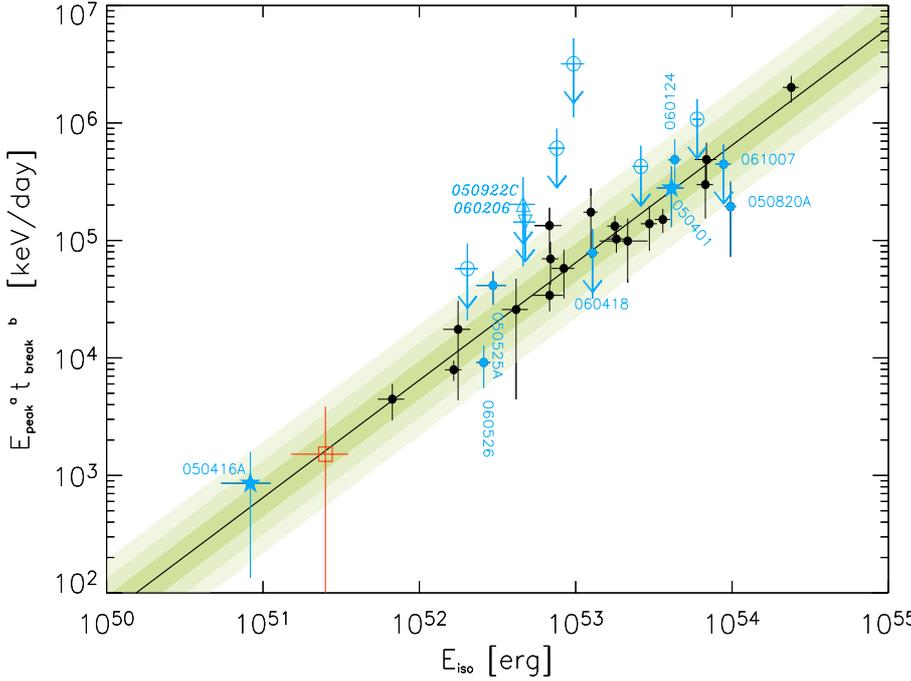


Fig. 7. The phenomenological $E_{\text{peak}} - E_{\text{iso}} - t'_{\text{jet}}$ correlation with the inclusion of Swift GRBs. Symbols are as in Fig. 5.

data points around this correlation is distributed as a Gaussian with $\sigma = 0.09$.

4.2. The $E_{\text{peak}} - E_{\gamma}$ correlation in the WM case

If the external medium is distributed with an r^{-2} density profile the semiaperture angle of the jet is related to the achromatic jet break through (Chevalier & Li 2000):

$$\theta_{\text{jet,w}} = 0.2016 \left(\frac{t_{\text{jet,d}}}{1+z} \right)^{1/4} \left(\frac{\eta_{\gamma} A_*}{E_{\text{iso},52}} \right)^{1/4} \quad (4)$$

where we assume $n(r) = Ar^{-2}$ and A_* is the value of A ($A = \dot{M}_{\text{w}}/(4\pi v_{\text{w}}) = 5 \times 10^{11} A_* \text{ g cm}^{-1}$) when setting the mass loss rate due to the wind $\dot{M}_{\text{w}} = 10^{-5} M_{\odot} \text{ yr}^{-1}$ and the wind velocity $v_{\text{w}} = 10^3 \text{ km s}^{-1}$, according to the typical Wolf-Rayet wind physical conditions. Given the few still uncertain estimates of the A_* parameter, we assume a constant value (i.e. $A_* = 1$) for all bursts neglecting the unknown uncertainty on this parameter.

The fit with a power law model gives

$$\frac{E_{\text{p}}}{100 \text{ keV}} = (3.34 \pm 0.18) \left(\frac{E_{\gamma,w}}{2.6 \times 10^{50} \text{ erg}} \right)^{1.05 \pm 0.06} \quad (5)$$

with a reduced $\chi^2_{\text{r}} = 0.89$ for 23 degrees of freedom (see Fig. 6). Note that the slope of this relation is entirely consistent with unity. The scatter of the points around the best fit correlation is fitted by a Gaussian with $\sigma = 0.08$.

4.3. The $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation

We have extended the 2D fit which weights for the errors on two quantities to the 3D case for the $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation. This fit weights the multidimensional errors on the three independent variables E_{iso} , E_{peak} and t_{jet} , where the peak energy and the jet break time are computed in the source rest frame. We find

$$E_{\text{iso},53} = (1.33 \pm 0.10) \left(\frac{E_{\text{peak}}}{299 \text{ keV}} \right)^{1.88 \pm 0.15} \left(\frac{t_{\text{jet}}}{0.53 \text{ d}} \right)^{-0.92 \pm 0.13} \quad (6)$$

with a reduced $\chi^2_{\text{r}} = 1.33$ for 22 degrees of freedom. The scatter of the data points around the correlation is $\sigma = 0.1$.

4.4. The Amati versus Ghirlanda correlation

Since we have discussed the most updated $E_{\text{peak}} - E_{\gamma}$ correlation we also compare it with the most updated (up to Jan. 2007) $E_{\text{peak}} - E_{\text{iso}}$ correlation. Besides the GRBs in Table 1 we have added those GRBs with z and E_{peak} known (excluding upper/lower limits) taken from the lists of Amati (2006) and Nava et al. (2007). We found a total of 64 GRBs. They are shown in Fig. 8 (squares) with the $E_{\text{peak}} - E_{\gamma}$ correlation in the wind case. The fit of the $E_{\text{peak}} - E_{\text{iso}}$ correlation (using the *fitexy* routine and excluding the two outliers GRB 980425 and GRB 031203) is:

$$\frac{E_{\text{p}}}{100 \text{ keV}} = (2.88 \pm 0.10) \left(\frac{E_{\text{iso}}}{6.9 \times 10^{52} \text{ erg}} \right)^{0.57 \pm 0.01} \quad (7)$$

with a reduced $\chi^2 = 7.2$ for 60 d.o.f. The scatter of the data points around the best fit is distributed as a Gaussian with $\sigma = 0.2$.

From the comparison of the two correlations and their scatter it is noticeable how the dispersion of the data points is reduced from the Amati to the Ghirlanda relation, especially considering bursts with similar E_{peak} . Note that the different slopes of the Amati and Ghirlanda correlation imply that they intersect at some small value of $E_{\gamma} = E_{\text{iso}}$ corresponding to truly isotropic bursts. The intersection value, however, depends on the circumbursts density profile: it is below 10^{48} erg in the WM and smaller for the HM case.

5. Discussion and conclusions

In the era of multiple breaks of the X-ray and optical afterglow light curves the identification of the jet break time is complex. Even more so when flares (more often in the X-rays, but sometimes also in the optical) occur, and the lightcurve is not densely sampled. In the following, for clarity, we list some points which

Table 1. Bursts with firm estimates of the redshift and of the spectral peak energy E_{peak} (rest frame). Bursts of the pre-*Swift* era (from GRB 970828 to GRB 041006) and bursts of the *Swift* era (from GRB 050525A) added in this work are separated by the horizontal line. For each burst we report the value of the jet opening angle θ_j ($\theta_{j,w}$) and of the collimation corrected energy E_γ ($E_{\gamma,w}$) computed in the case of a homogeneous (wind) external medium. For those bursts with only a lower limit on t_{jet} we adopted a 50% uncertainty on its value to compute the error on the collimation corrected energy.

GRB	z	t_{jet} days	E_{peak} keV	Ref. ^a	$E_{\gamma,\text{iso}}$ erg	θ_j deg	E_γ erg	$\theta_{j,w}$ deg	$E_{\gamma,w}$ erg
970828	0.958	2.2 (0.4)	583 (117)		2.96e53 (0.35)	5.91 (0.80)	1.57e51 (0.46)	3.40 (0.18)	5.21e50 (0.84)
980703	0.966	3.4 (0.5)	499 (100)		6.90e52 (0.82)	11.02 (0.80)	1.27e51 (0.24)	5.45 (0.26)	3.12e50 (0.47)
990123	1.600	2.04 (0.46)	2031 (161)		2.39e54 (0.28)	3.98 (0.57)	5.76e51 (1.78)	1.84 (0.12)	1.24e51 (0.21)
990510	1.619	1.6 (0.2)	422 (42)		1.78e53 (0.19)	3.74 (0.28)	3.80e50 (0.70)	3.31 (0.14)	2.98e50 (0.40)
990705	0.843	1.0 (0.2)	348 (28)		1.82e53 (0.23)	4.78 (0.66)	6.33e50 (1.92)	3.20 (0.19)	2.84e50 (0.49)
990712	0.433	1.6 (0.2)	93 (16)		6.72e51 (1.29)	9.46 (1.20)	9.15e49 (2.90)	8.74 (0.50)	7.81e49 (1.74)
991216	1.02	1.2 (0.4)	642 (129)		6.75e53 (0.81)	4.44 (0.70)	2.03e51 (0.68)	2.36 (0.21)	5.72e50 (1.22)
011211	2.140	1.56 (0.16)	185 (25)		6.64e52 (1.32)	5.25 (0.65)	2.78e50 (0.88)	4.03 (0.23)	1.64e50 (0.37)
020124	3.198	3.0 (0.4)	390 (113)		2.15e53 (0.73)	5.19 (0.69)	8.82e50 (3.80)	3.29 (0.30)	3.54e50 (1.36)
020405	0.695	1.67 (0.52)	617 (171)		1.25e53 (0.13)	6.27 (1.03)	7.47e50 (2.57)	4.08 (0.33)	3.17e50 (0.62)
020813	1.255	0.43 (0.06)	478 (95)		6.77e53 (1.00)	2.74 (0.35)	7.74e50 (2.28)	1.77 (0.10)	3.24e50 (0.58)
021004	2.335	4.74 (0.5)	267 (117)		4.09e52 (0.71)	8.27 (1.02)	4.25e50 (1.28)	5.91 (0.30)	2.18e50 (0.44)
030226	1.986	0.84 (0.10)	290 (63)		6.7e52 (1.2)	4.23 (0.53)	1.83e50 (0.56)	3.49 (0.19)	1.24e50 (0.26)
030328	1.520	0.8 (0.1)	328 (35)		3.61e53 (0.40)	3.59 (0.45)	7.08e50 (1.93)	2.36 (0.10)	3.06e50 (0.42)
030329	0.169	0.5 (0.1)	79 (3)		1.66e52 (0.20)	5.67 (0.50)	8.13e49 (1.75)	5.49 (0.32)	7.60e49 (1.28)
030429	2.656	1.77 (1.0)	128 (37)		1.73e52 (0.31)	6.15 (1.49)	9.95e49 (5.13)	5.60 (0.83)	8.26e49 (2.86)
041006	0.716	0.16 (0.04)	108 (22)		8.3e52 (1.3)	2.72 (0.41)	9.38e49 (3.17)	2.51 (0.18)	7.94e49 (1.71)
050318	1.44	>0.26 (0.13)	115 (27)	[1]1	2.00e52 (0.31)	>3.42 (0.76)	>3.57e49 (1.67)	>3.70 (0.48)	>4.17e49 (1.27)
050401	2.9	1.5 (0.5)	501 (117)	[2]2	4.1e53 (0.8)	3.8 (0.65)	9.0e50 (3.5)	2.40 (0.23)	3.59e50 (0.98)
050416A	0.653	1.0 (0.7)	28.6 (8.3)	[3]3	8.3e50 (2.9)	9.77 (2.83)	1.2e49 (0.8)	12.66 (2.47)	2.02e49 (1.05)
050525A	0.606	0.3 (0.1)	127 (5.5)	[4]4	2.89e52 (0.57)	4.03 (0.69)	7.16e49 (2.83)	3.88 (0.38)	6.63e49 (1.83)
050603	2.821	>2.5 (1.25)	1333 (107)	[5]5	5.98e53 (0.4)	>4.42 (0.97)	>1.78e51 (0.79)	>2.49 (0.31)	>5.65e50 (1.47)
050820A	2.612	15.2 (8)	1325 (277)	[6]6	9.75e53 (0.77)	6.65 (1.53)	6.55e51 (3.05)	3.50 (0.47)	1.82e51 (0.51)
050922C	2.198	>1.2 (0.6)	417 (118)	[7]7	4.53e52 (0.78)	>4.95 (1.09)	>1.69e50 (0.80)	>4.13 (0.55)	>1.18e50 (0.37)
051109A	2.346	>0.64 (0.32)	539 (381)	[8]8	7.52e52 (0.88)	>3.61 (0.80)	>1.49e50 (0.68)	>3.08 (0.39)	>1.08e50 (0.31)
060124	2.297	1.1 (0.1)	636 (162)	[9]9	4.3e53 (0.34)	3.61 (0.43)	8.55e50 (2.15)	2.30 (0.06)	3.47e50 (0.34)
060206	4.048	>2.3 (0.11)	381 (98)	[10]10	4.68e52 (0.71)	>5.31 (0.63)	>2.00e50 (0.6)	>4.3 (0.2)	>1.32e50 (0.23)
060418	1.489	>5.0 (2.5)	572 (114)	[11]11	1.28e53 (0.10)	>8.16 (1.80)	>1.30e51 (0.58)	>4.85 (0.61)	>4.58e50 (1.21)
060526	3.21	2.77 (0.30)	105 (21)	[12]12	2.58e52 (0.3)	6.56 (0.80)	1.70e50 (0.5)	5.47 (0.20)	1.18e50 (0.15)
060614	0.125	1.38 (0.04)	55 (45)	[13]13	2.5e51 (1.0)	11.12 (1.4)	4.71e49 (2.22)	11.47 (1.15)	5.01e49 (2.23)
060927	5.6	>0.16 (0.08)	473 (116)	[14]14	9.55e52 (1.48)	>1.62 (0.36)	>3.79e49 (1.78)	>1.73 (0.23)	>4.35e49 (1.32)
061007	1.261	>1.74 (0.87)	902 (43)	[15]15	8.82e53 (0.98)	>4.47 (1.00)	>2.69e51 (1.22)	>2.35 (0.30)	>7.4e50 (2.1)
061121	1.314	>3.87 (1.9)	1289 (153)	[16]16	2.61e53 (0.3)	>6.97 (1.52)	>1.93e51 (0.87)	>3.87 (0.49)	>5.96e50 (1.65)

^a References in square parenthesis are for the jet break time: [1] Still et al. (2005); [2] this paper; [3] this paper; [4] Blustin et al. (2005); Mirabal et al. (2005); Della Valle et al. (2006a); [5] Grupe et al. (2006); [6] Cenko et al. (2006); [7] this paper; Covino et al. (2005); [8] Pavlenko et al. (2005); <http://grad40.as.utexas.edu/grblog.php>; [9] Romano et al. (2006); Curran et al. (2006); [10] this paper; Stanek et al. (2006); [11] Karimov et al. (2005); Vergani et al. (2007); [12] Dai et al. (2007); [13] Della Valle M. et al. (2006b); [14] Atoniuk et al. (2006); <http://grad40.as.utexas.edu/grblog.php>; [15] Schady et al. (2006); [16] Halpern & Armstrong (2006). Following references are for E_{peak} and the spectral properties (in case of asymmetric errors on E_{peak} we computed the logarithmic average value): (1) Perri et al. (2005); (2) Golenetskii et al. (2005a) (we computed the weighted average of the values reported in this reference); (3) Sato et al. (2006); (4) Blustin et al. (2006); (5) Golenetskii et al. (2005b); (6) Cenko et al. (2006); (7) Crew et al. (2005); (8) Golenetskii et al. (2005c); (9) Romano et al. (2006); (10) Palmer et al. (2006); (11) Golenetskii et al. (2006a) (20% error on E_{peak} is assumed); (12) Schaefer (2007); (13) Amati (2006); (14) Stamatikos et al. (2006); (15) Golenetskii et al. (2006c); (16) Golenetskii et al. (2006b); Bellm et al. (2006) (we computed the weighted average of the values reported in these references).

we believe are particularly important for the correct identification of the jet break time.

- The jet break should be observed in the optical.
- The light curve in the optical should extend up to a time longer than the jet break time predicted by the $E_{\text{peak}} - E_\gamma$ correlation.
- The host galaxy and a possible supernova flux should be subtracted off.
- The break should be achromatic in the optical, but we should relax the requirement of a simultaneous break in the X-ray light curve, since the X-ray flux may be due to another component.
- If a simultaneous X-ray and optical break is present, one should check that this is not the time break ending the plateau phase (T_a in Willingale et al. 2007). If this is the case, and the optical and X-ray flux continue to track one another, it is possible that the component dominating the X-ray flux is also contributing in the optical, hiding any jet-break.
- A steep (i.e. $F(t) \propto t^{-\alpha}$, with $\alpha > 1.5$) optical decay in a limited time interval is not necessarily an indication of a jet break occurred earlier. A steep decay can in fact be the tail of a flare. A densely sampled light curve is required to disentangle this case from a post-break light curve.
- The bolometric luminosity should be calculated between 1 keV and 10 MeV in the rest frame of the GRB, using the spectral parameters. It is also useful, when a cut-off power law is used instead of the Band function, to give limits by using a Band model with a fixed β -value.

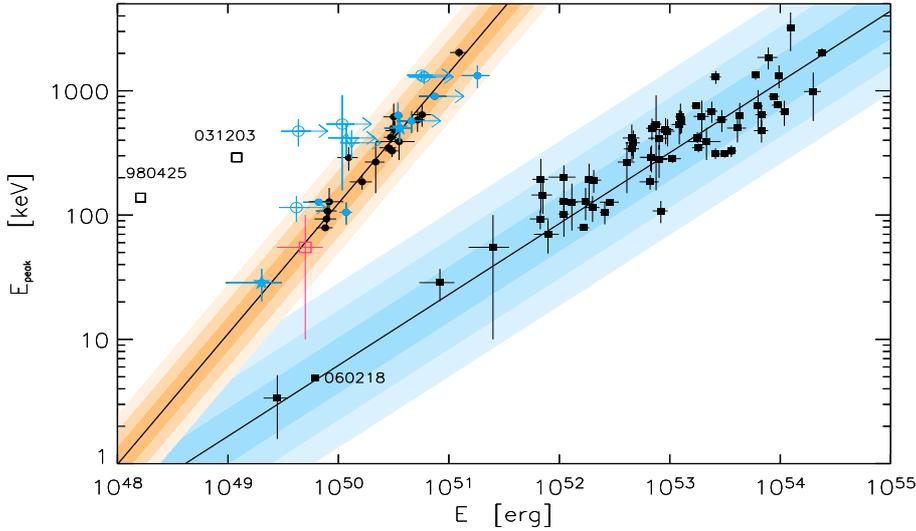


Fig. 8. The correlation between the rest frame peak energy and the bolometric isotropic energy (62 GRBs – square symbols) with the most updated (up to Jan. 2007) burst sample is compared with the $E_{\text{peak}} - E_{\gamma}$ correlation (in the WM case). The two outliers GRB 980425 and GRB 031203 are shown. The solid lines represent the best fit to the data and the shaded regions the 1, 2, 3 σ scatter of the data points around these correlations.

- Sometimes the Swift/BAT and the Konus-Wind data give different spectral fits. Given the limited energy range of BAT, one should take the result of spectral fitting the BAT data with care.
- An outlier for the $E_{\text{peak}} - E_{\gamma}$ correlation which is also an outlier for the $E_{\text{peak}} - E_{\text{iso}}$ correlation, while being an outlier, is “recognizable” and should be put in the same category of GRB 980425 and GRB 031203.
- When deriving jet-angles from the jet break times, the same values of the efficiency η should be used. One should also allow for a range in possible densities of the interstellar medium (taken in the range 1–10 cm⁻³ in GGL04), when this is not derived by other means. Of course this does not apply to the $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation.

Following these rules we have selected, among all *Swift* long bursts with firm redshift measurements (46 long GRBs up to Dec. 2006), those with measured peak energy and some information about a jet break in the optical light curve. We have found 16 *Swift* bursts that can be added to the pre-*Swift* sample of 17 GRBs (N06). In the present sample of 33 events there is no outlier with respect to the $E_{\text{peak}} - E_{\gamma}$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations (besides GRB 980425 and GRB 031203 – but see Ghisellini et al. 2006, for the possibility that even these two GRBs are not outliers). Indeed, these correlations are strengthened by the new *Swift* bursts. In particular we added 6 firm bursts (i.e. with defined E_{peak} , z and t_{jet}) and 2 lower limits (on t_{jet}) which enlarge to 25 the original sample of pre-*Swift* bursts used to fit these correlations. With this sample we re-analyzed the $E_{\text{peak}} - E_{\gamma}$ correlation in the two possible scenarios of a homogeneous and wind medium (HM and WM). The updated correlations are completely consistent with those found in the pre-*Swift* era and their fits are statistically improved (i.e. $\chi^2 = 1.08$ and $\chi^2 = 0.89$ in the HM and WM case, respectively). We also re-analyzed the phenomenological $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlation which turns out to be consistent with what found before *Swift* (Liang & Zhang 2005; N06). The dispersion around these correlations (computed with 25 GRBs) is described by a Gaussian with $\sigma = 0.08$ –0.1 in all the three cases. Such dispersions are consistent with being due to measurement errors only.

The confirmation of the $E_{\text{peak}} - E_{\gamma}$ and $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations by the *Swift* GRBs also supports the possibility, with an increasingly larger sample of GRBs, to use them as standard

candles to constrain the cosmological parameters (e.g. Ghirlanda et al. 2006).

The complexity of the afterglow light curves, disclosed by the *Swift* observations, certainly makes less direct and unambiguous the determination of the jet break time, with respect to the pre-*Swift* era. There are GRBs with multiple breaks and flares, even in the optical band, and this makes mandatory to have well sampled light curves beyond the jet break timescale predicted by the $E_{\text{peak}} - E_{\gamma}$ and the $E_{\text{peak}} - E_{\text{iso}} - t_{\text{jet}}$ correlations.

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