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# Long gamma-ray bursts without visible supernovae: a case study of redshift estimators and alleged novel objects

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## ABSTRACT

There is an ongoing debate on whether or not the observational limits on a supernova (SN) associated with GRB060614 convincingly exclude a SN akin to SN1998bw as its originator, and provide evidence for a new class of long-duration GRBs. We discuss this issue in the contexts of indirect 'redshift estimators' and of the fireball and cannonball models of GRBs. The latter explains the unusual properties of GRB060614: at its debated low redshift (0.125) they are predicted, as opposed to exceptional, if the associated SN is of 'Pastorello's class'. Long-baseline radio data and deep optical data may test the proposed alternatives.

## 1. Introduction

There is mounting evidence (e.g., Galama et al. 1998; Dado et al. 2002, 2003a,b, Dar 2004; Dado & Dar 2005 and references therein) sometimes stricking (Dado et al. 2003b, Stanek et al. 2003; Hjorth et al. 2003; Malesani et al. 2003; Campana et al. 2006; Pian et al. 2006), that long-duration gamma-ray bursts (GRBs) and cosmological X-ray flashes (XRFs) are produced by core-collapse supernovae (SNe), as advocated in the Cannonball (CB) model of GRBs (e.g., Shaviv & Dar 1995; Dar & Plaga 1999; Dar & De Rújula 2000; Dado et al. 2002, 2003a,b; Dar and De Rújula 2004, Dar 2004 and references therein). Recently, three different groups (Gal-Yam et al. 2006; Della Valle et al. 2006 and Fynbo et al. 2006) reported that they have failed to detect a SN to a deep limit in the optical afterglow (AG) of the allegedly nearby ($z = 0.125$) long-duration ($\sim 100$ s) GRB060614 (Parsons et al. 2006; Golenetskii et al. 2006). They concluded that this requires a new class of long-duration GRBs not associated with bright SNe.

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For 40 years, simulations of the core-collapse of massive stars have resulted in a black hole without matter ejection and not in a compact object and a bright SN. Arguing against a GRB–SN association (Goodman et al. 1987; Dar et al. 1992) Woosley (1993) proposed that, as suggested by simulations, the nearly-total collapse of a very massive *'collapsar'* star into a black hole may eject a broadly beamed fireball of $e^+e^-$ pairs, resulting in a GRB without an accompanying SN. These GRB-producing *'failed supernovae'* would explain the then favoured GRB–SN *dissociation.* Following the mounting evidence for a GRB–SN association, a *hypernova* hypothesis was introduced, wherein GRBs would be made by a postulated class of very bright and energetic core-collapse SNe of Type Ib/c (MacFadyen et al. 2001).

Though observations do not require it at the moment, the gravitational collapse of very massive stars may produce faint GRBs without a visible SN, or even explain some of the 'dark' GRBs without an observable AG. Other types of SN-less GRBs may be induced by the collapse of a neutron star, a strange 'hyper-star' or a quark star into a more compact object, the collapse being induced by cooling, or accretion from a companion star.

In this note we argue that the limit on an underlying SN in the optical AG of GRB060614 neither excludes a SN1998bw-like origin for this burst, nor provides evidence for a new class of GRBs. We discuss and compare three alternative explanations why the SN progenitor of this GRB may have been undetectable:

- The GRB was produced by a very faint SN, akin to the ones observed by Pastorello et al. (2004), located in the outskirts of a dwarf galaxy at $z = 0.125$, near the GRB's sky position (Della-Valle et al. 2006). To agree with the HST limit (Gal-Yam et al. 2006, 2006b), extinction in the host galaxy must dim such a SN by a factor $\sim 5$; we argue that this is supported by SWIFT data (Mangano et al. 2006). The GRB's small isotropic energy and peak luminosity resulted from the relatively low density of photons in the glory of the SN, illuminated by its explosion. In the CB model these photons are Compton upscattered —into a narrow beam of $\gamma$ rays— by the electrons in the jet of CBs ejected in the SN explosion (Shaviv and Dar 1995; Dar & De Rújula, 2004).
- The GRB was produced in the putative host galaxy at $z = 0.125$, within a dense molecular cloud. The EUV and soft X-rays of the GRB destroyed the dust. In the CB model this occurs only inside an extremely narrow cone along the jet axis. Through this cone only a very small fraction of the SN light could be seen. Most of the SN light in the direction of the observer travelled outside this cone and encountered a large column density of dust, suffering strong extinction.
- The GRB was a normal long GRB produced in a SN explosion at a large redshift ($z \sim 2$) wherefrom the SN was well below the detection limits. The proximity of the

sightline to GRB060614 to a foreground galaxy at $z = 0.125$ was a chance coincidence, as advocated by Schaefer & Xiao (2006) and Cobb et al. (2006) and debated by Gal-Yam et al. (2006b) and Gehrels et al. (2006).

The locations of a particular GRB of undetermined redshift in the scatter plots reflecting correlations between pairs of GRB observables are used as redshift estimators. GRB060614 is a good case to study this issue both within and without the CB model. We argue that, so far, this procedure is insufficiently precise to determine the redshift of this particular GRB.

## 2. The CB model

In the CB model (Dar & De Rújula 2000, 2004; Dado et al. 2002, 2003), *long-duration* GRBs and their AGs are produced by bipolar jets of CBs, ejected in core-collapse SN explosions (Dar & Plaga 1999). An accretion disk is hypothesized to be produced around the newly formed compact object, either by stellar material originally close to the surface of the imploding core and left behind by the explosion-generating outgoing shock, or by more distant stellar matter falling back after its passage (De Rújula 1987). As observed in microquasars, each time part of the disk falls abruptly onto the compact object, a pair of CBs made of *ordinary plasma* are emitted with high bulk-motion Lorentz factors, $\gamma$, in opposite directions along the rotation axis, wherefrom matter has already fallen onto the compact object, due to lack of rotational support. The $\gamma$-rays of a single pulse in a GRB are produced as a CB coasts through the SN glory –the SN light scattered by the SN and pre-SN ejecta. The electrons enclosed in the CB Compton up-scatter glory's photons to GRB energies. Each pulse of a GRB corresponds to one CB. The baryon number, Lorentz factor, and emission time of the individual CBs reflect the chaotic accretion process and are not currently predictable, but given these parameters (which we extract from the analysis of GRB AGs), all properties of the GRB pulses follow (Dar & De Rújula 2004).

The rapid expansion of the CBs stops shortly after ejection (Dado et al. 2002, Dar & De Rújula 2006) by their interaction with the inter-stellar medium (ISM). During this initial rapid expansion and cooling phase, their AG is dominated by thermal bremstrahlung and line emission. Later, their AG becomes dominated by synchrotron radiation from swept-in ISM electrons spiraling in the CBs' inner magnetic fields (Dado et al. 2002, 2006) and from ISM electrons scattered to higher energies by the moving CBs (Dado & Dar 2005).

Let $\theta = \mathcal{O}(1\ \mathrm{mrad})$ be the typical viewing angle of an observer of a CB that moves with a typical Lorentz factor $\gamma = \mathcal{O}(10^3)$. Let $\delta = \mathcal{O}(10^3)$ be the corresponding Doppler factor:

$$\delta \equiv \frac{1}{\gamma\,(1-\beta\, cos\theta)} \simeq \frac{2\,\gamma}{1+\gamma^2\,\theta^2}\,, \tag{1}$$

where the approximation is excellent for $\theta \ll 1$ and $\gamma \gg 1$. For a typical angle of incidence (Dar & De Rújula 2004), the energy of a Compton up-scattered photon from the SN glory is Lorentz and Doppler boosted by a factor $\sim\gamma\,\delta/2$ and redshifted by $1{+}z$. The peak energy $E_p$ of the GRB's $\gamma$-rays is related to the peak energy, $\epsilon_p \sim 1$ eV, of the glory's light by:

$$E_p \simeq \frac{\gamma\,\delta\,\epsilon_p}{2\,(1{+}z)} \simeq (250\ \mathrm{keV})\,\frac{\gamma\,\delta}{10^6}\,\frac{2}{1+z}\,\frac{\epsilon_p}{1\ \mathrm{eV}}\,. \tag{2}$$

The upscattered radiation, emitted nearly isotropically in the CB's rest frame, is boosted by its highly relativistic motion to a narrow angular distribution whose number density is:

$$\frac{dn_\gamma}{d\Omega} \simeq \frac{n_\gamma}{4\,\pi}\,\delta^2 \simeq \frac{n_\gamma}{4\,\pi}\,\frac{4\,\gamma^2}{(1+\gamma^2\,\theta^2)^2}\,, \tag{3}$$

and, for a GRB of known $z$, the spherical equivalent energy, $E_\gamma^{\rm iso}$, is (Dar & De Rújula 2004):

$$E_\gamma^{\rm iso} \simeq \frac{\delta^3\,L_{\rm SN}\,N_{\rm CB}\,\beta_s}{6\,c}\,\sqrt{\frac{\sigma_{\rm T}\,N_b}{4\,\pi}} \sim (3.8\times 10^{53}\,\mathrm{erg})\,\frac{\delta^3}{10^9}\,\frac{L_{\rm SN}}{L_{\rm SN}^{\rm bw}}\,\frac{N_{\rm CB}}{6}\,\beta_s\sqrt{\frac{N_b}{10^{50}}}\,, \tag{4}$$

where $L_{\rm SN}$ is the mean SN optical luminosity just prior to the ejection of CBs, $N_{\rm CB}$ is the number of CBs in the jet, $N_b$ is their mean baryon number, $\beta_s$ is the comoving early expansion velocity of a CB (in units of $c/\sqrt{3}$), and $\sigma_{\rm T}$ is the Thomson cross section. The early SN luminosity required to produce the mean isotropic energy, $E_\gamma^{\rm iso} \sim 4{\times}10^{53}$ erg, of ordinary long GRBs is $L_{\rm SN}^{\rm bw} \simeq 5\times 10^{42}\,\mathrm{erg\,s^{-1}}$, the estimated early luminosity of SN1998bw. The observed peak isotropic luminosity, reached in the rise-time of a GRB's pulse ($\sim 1/2$ the time it takes a CB to become transparent to radiation) is:

$$L_p^{\rm iso} \sim \frac{\delta^4\,\beta_s^2\,L_{\rm SN}}{48\pi\,(1{+}z)^2} \sim (8.3\times 10^{51}\,\mathrm{erg\,s^{-1}})\,\frac{\delta^4}{10^{12}}\,\frac{4\,\beta_{\rm s}^2}{(1+\mathrm{z})^2}\,\frac{\mathrm{L_{SN}}}{\mathrm{L_{SN}^{bw}}}\,. \tag{5}$$

## 3. A faint SN parent of GRB060614?

Pastorello's new type of SNe are $\sim 100$ times less luminous than the SNe associated with normal GRBs. If that is the main difference between the two SN types, the GRBs associated with Pastorello's SNe should have $E_\gamma^{\rm iso}$ and $L_p^{\rm iso} \sim 100$ times smaller than usual, see Eqs.(4,5). SN1999br, for instance, had a peak luminosity $L_{\rm SN} \simeq 6{\times}10^{40}\,\mathrm{erg\,s^{-1}}$, resulting —if its early and plateau luminosities were similar— in $E_\gamma^{\rm iso}\sim 5{\times}10^{51}$ erg and $L_p^{\rm iso}\sim 3{\times}10^{50}$ erg s$^{-1}$, at $z=0.125$. If, otherwise, the initial luminosity of core-collapse SNe is proportional to the kinetic energy of their ejecta, SN1999br —whose expansion velocity was 1073 km/s, $\sim$25 times slower than that of 1998bw-like SNe— should have had an initial luminosity $L_{\rm SN}\simeq 10^{40}$ erg s$^{-1}$, implying $E_\gamma^{\rm iso}\sim 10^{51}$ erg, and $L_p^{\rm iso}\sim 5\times 10^{49}$ erg s$^{-1}$. These numbers bracket the data for GRB060614 for, at $z=0.125$, $E_\gamma^{\rm iso}\simeq 1.58^{+0.07}_{-0.13}\times 10^{51}$ erg and $L_p^{\rm iso}\sim 2.19^{+0.3}_{-0.6}\times 10^{50}$ erg s$^{-1}$, for the standard cosmology ($\Omega=1$; $\Omega_M=0.27$; $\Omega_\Lambda=0.73$; $h=0.7$). The 'downscaling' of $L_{\rm SN}$ also explains the short lag-time, $t_{\rm lag}\sim 3$ ms, of GRB060614, emphasized by Gehrels et al. (2006) as requiring a new class of GRBs, since $t_{\rm lag}$ is linearly anticorrelated to peak luminosity, see Schaefer and Xiao (2006). At $z=0.125$, Eq. (2) predicts $E_p\simeq 444$ keV, also in agreement with the observed $E_p\simeq 302^{+214}_{-85}$ keV (Golenetskii et al. 2006).

The above expectations for $E_p$, $E_\gamma^{\rm iso}$ and $L_p^{\rm iso}$ are shown in Figs. (1,2) as rectangles. The plotted (FWHM) range of $E_p$ values is also a prediction (Dar & De Rújula 2004). Some 4-5% of Type II SNe are of Pastorello type. There are $\sim$85 GRBs of known $z$. In the CB model, seldom towards us, between $\sim$15% (Type Ib/c) and $\sim$100% (Types II and Ib/c) of core-collapse SNe emit a GRB. The numbers agree with $\sim$1 GRB like 060614 seen to date.

The HST data of Gal-Yam et al. (2006b) rule out a SN brighter than $M_{\rm V}=-12.3$, while SN1999br had a plateau absolute magnitude of $M_{\rm V}=-13.7$, dimmer by a factor $\sim$3.6. Though there is no reason for the faintest of 4 Pastorello SNe to be a lower limit, we attribute the $\sim$1.5 magnitude difference to extinction, consistent with SWIFT data on the early AG (Mangano et al. 2006). These authors state "The WT data show strong spectral evolution with time, with average photon index 1.65±0.04 in the time interval 90-270 s from the trigger and 2.95±0.11 in the time interval 270-460 s. WT spectra show evidence of absorption at the level of $(1.3\pm0.3)\,10^{21}$ cm$^{-2}$, in excess with respect to the Galactic $N_H$ of $3\,10^{20}$ cm$^{-2}$. The PC spectrum extracted from the second orbit of data is well fitted by an absorbed power law with photon index 1.8±0.2 and $N_H$ consistent with the Galactic value."

The CBs are the source of the AG and their motion may result in the observed decreasing absorption. During the 90-270 s they are already at a distance $\gamma\delta c\, t/(1+z)\sim 1$ pc from the SN whose radius after a day is $\sim 10^{16}$ cm (for an expansion velocity of $\sim$1000 km/s). Thus the dust column density to the SN and the corresponding extinction of the SN light can be much larger than that estimated from the WT photon spectrum during the 90-270 s interval. This could dim a SN1999br-like SN beyond the HST detectability limit. To conclude, this GRB may have occurred at $z=0.125$ and be otherwise normal, but for the low luminosity of its progenitor SN, if it was 'Pastorello-like'.

## 4. A GRB inside a molecular cloud?

A molecular cloud (MC) is a region of dense gas and dust ($n_{\rm MC} \simeq 10^3\,{\rm cm}^{-3}$) which shields its contents against the ambient ultraviolet radiation. In such a cold, protected environment, the predominant form of matter, atomic hydrogen, preferentially associates into molecular hydrogen. Star formation is presumed to begin in the cores of MCs, when they become gravitationally unstable and fragment into smaller clouds that collapse into proto-stars. The very massive stars evolve rapidly and end up in SNe, which produce shock waves that trigger more star formation and SNe. The optical light from the first SNe in the MC is strongly extinct by the dust. Later, the winds from massive stars and the SN ejecta sweep up the ISM and eventually form a superbubble transparent to optical light.

The radiation of GRBs is intense enough to destroy the dust on its way out of a MC (Waxman & Draine 2001). But, in the CB model, the angular size of a GRB's beaming cone subtends only a small fraction $\sim 1/\gamma^2$ of the SN photosphere, see Eq. (3). Most of the SN light pointing to the observer passes through the region of the MC lying outside the beaming cone, and is strongly extinct by dust. Hence, while most of the beamed AG from CBs is visible to an observer with a typical viewing angle $\theta \sim 1/\gamma$, only a fraction $\sim 1/\gamma^2$ of the SN light reaches the observer. This fraction is too faint to be detectable. The decrease of the column density in front of the jet as a function of time —inferred from the prompt and early-time X-ray AG of GRB060614— and the initially rising light-curve of its optical AG (Mangano et al. 2006) are consistent with the MC interpretation [the estimates of extinction along the sight-line to the GRB from the spectrum of its late AG (Gal-Yam et al. 2006) are only valid for light within the beaming cone, emitted by CBs already far away from the SN, at a distance $\sim\gamma^2\, c\, t \sim 10$ pc. These estimates are invalid for lines of sight from the SN].

The CB model predicts a strong extinction of the SN light in a GRB originating in a MC, without a comparable extinction of the late GRB's AG. But it cannot explain without further ado, in the case of GRB060614 at $z=0.125$, the large $E_p$ and the small $E_\gamma^{\rm iso}$ and $L_p^{\rm iso}$: the first implies a typical $\delta$, the two others favour a significantly smaller one, see Eqs. (2,4,5).

## 5. Correlations and red-shift estimators; a normal GRB at a typical $z$?

GRB061604 had 'normal' duration, fluence, spectrum, peak energy and energy flux, pulse widths, variability, and X-ray and optical AGs. This suggests a redshift near the average for long GRBs (the mean $z$ of 40 GRBs with secured redshift of BeppoSAX, HETE, IPN and INTEGRAL, is $\bar z \simeq 1.4$; it is $\bar z \simeq 2.5$ for 45 GRBs seen by SWIFT). If GRB060614 originated at the average of these means ($z_{\rm av} \simeq 1.95$) its proximity to a $z = 0.125$ galaxy

(Price et al. 2006) was a coincidence. At $z_{\rm av}\simeq 1.95$, the isotropic energy and peak luminosity of GRB060614 were also normal: $E_\gamma^{\rm iso}\simeq 3.7\times 10^{53}$ erg and $L_p^{\rm iso}\simeq 1.2\times 10^{53}\,{\rm erg\,s^{-1}}$. Its early X-ray AG was similar in magnitude, spectrum and shape to the 'canonical' ones (Nousek et al. 2006, Dado et al. 2006) of distant GRBs, such as GRB 050315, also at $z=1.95$, and with similar duration, $T\simeq 90$ s. At such a redshift, neither a 1998bw-like SN, nor a dwarf host galaxy behind the foreground galaxy at $z=0.125$ are likely to be visible.

Gal-Yam et al. (2006, 2006b) and Gehrels et al. (2006) argue that $z>1$ is excluded for three reasons. No Lyman-limit break in the spectrum of the AG of GRB 060614 was detected by the SWIFT UVOT filters. The probability that the line of sight to GRB 060614 passes so close to a dwarf foreground galaxy at $z=0.125$ is very small. There is no evidence from the HST spectrum obtained by Gal-Yam et al. (2006) for any absorption due to dust along the line of sight in the foreground galaxy. Although these arguments make $z\sim 2$ less likely, they do not exclude it: some quasars with $1<z<2$ in the HST quasar absorption line key project (Jannuzi et al. 1998) show no Lyman limit breaks redward of 1800 Å. The column density of dust along the line of sight to GRB 060614 in the foreground galaxy may be small. A-posteriori estimates of a sky coincidence probability for single events are unreliable.

Schaefer and Xiao (2006) used 8 GRB redshift estimators (single power-law fits to correlations between pairs of GRB observables) to argue that GRB061604 took place at $z=1.97\pm^{0.84}_{0.53}$. But since it had all the properties of normal GRBs, any estimator yields for this GRB a redshift comparable to the mean. These authors argue that the estimators are accurate, well understood (a-posteriori) and predictive. But the estimators are based on arbitrary power laws and the data have a large dispersion around the best fits. The inevitable dispersion is due to the case-by-case variability of the parameters determining the properties of a GRB, whatever these *hidden variables* may be. Suppose that a GRB of known $z$ is an 'outlier': it is relatively far from one or more of the mean trends of the correlations. No doubt that is due to an atypical value of one or more hidden variables. Without a deeper understanding, no averaging over large sets of data and estimators would bring this GRB to the redshift where 'it should be'. An estimate of its 'best' $z$ from the estimators' mean trends would necessarily be wrong. Often, outliers of known $z$ (typically GRB980425, but also others) are eliminated from the fits leading to redshift estimators. Their subsequent use to determine $z$ for a single debatable case is then a logical inconsistency, unless the 'misbehaviour' of the outliers is understood (like for Andromeda, at $z<0$ in Hubble's plot).

The origin of the established correlations between GRB properties, and the 'hidden variables' responsible for their dispersion, are well specified in the CB model. This may help to asses the reliability of redshift estimators for individual GRBs. Most of these correlations stem from the CB-model's trivial beaming properties, see Eqs. (1-5). They were first proposed by Shaviv & Dar (1995) for the $\gamma$-ray polarization, used to predict many correlations in Dar & De Rújula (2001), and shown to agree with the data in Dar & De Rújula (2004).

One of the best established GRB correlations is the 'Amati correlation', whose latest version is $(1{+}z)E_p \simeq 77 \times (E_\gamma^{\rm iso}/10^{52}\,{\rm erg})^{0.57}$ keV. But the observed values of $\log[(1{+}z)E_p]$ are spread around the central fit by $\pm 0.4$ (Amati et al. 2006) implying that the correlation yields a poorly determined redshift with $\Delta[\log(1+z)] = \pm 0.4$. E.g., for a central value $z \sim 1.95$ the uncertainty range is $0.18 \lesssim z \lesssim 6.5$. Without understanding the origin of the spread, one cannot pin-down individual redshifts from this correlation, or a cumulation of similar ones.

A 'pre-Amati' correlation was predicted [and tested] in Dar & De Rújula (2001, [2004]). According to Eqs. (2,4), $(1{+}z)\,E_p \propto \gamma\delta$ and $E_\gamma^{\rm iso} \propto \delta^3$. If most of the variability is attributed to the fast-varying $\theta$-dependence of $\delta$ in Eq. (1), $(1+z)E_p \propto [E_\gamma^{\rm iso}]^{1/3}$. This prediction is compared to current data in Fig. 1a (the 'variability lines' are not symmetric about the best-fit, because most data have similar relative errors: the lower-$E_p$ ones have smaller absolute errors and 'attract' the best-fit line). The agreement can be further improved by exploiting another prediction. A typical observer's angle is $\theta \sim 1/\gamma$. A relatively large $E_p$ implies a relatively large $\delta$, and a relatively small viewing angle, $\theta < 1/\gamma$. For $\theta^2 \ll 1/\gamma^2$, $\delta \simeq 2\gamma$, implying that $(1{+}z)E_p \propto [E_\gamma^{\rm iso}]^{2/3}$ *for the largest observed values* of $E_\gamma^{\rm iso}$. On the other hand, for $\theta^2 \gg 1/\gamma^2$, the 'pre-Amati' correlation is unchanged: it should be increasingly accurate *for smaller values* of $E_\gamma^{\rm iso}$. We interpolate between these extremes by positing:

$$(1{+}z)\,E_p = A\,[E_\gamma^{\rm iso}]^{1/3} + B\,[E_\gamma^{\rm iso}]^{2/3}\,. \tag{6}$$

A best fit to Eq. (6) is shown in Fig. 1b, an a-posteriori improvement over Fig. 1a. The variability is due to potentially varying intrinsic parameters. In Eq. (4), for instance, there are four of them, besides $\delta$. The fit to Eq. (6) has $\chi^2/{\rm dof} = 11.4$, similar to that of Amati's arbitrary-power correlation ($\chi^2/{\rm dof} = 11.7$). Yet, the correlations are not reliable estimators for the redshift of *individual* GRBs: in Figs. 1, GRB060614 at $z = 0.125$ is not a convincing outlier. GRB060614 would not be an outlier, had the 'variability line' encompassed GRB980425 (a maverick outlier, but for an allegedly good reason, see Dado & Dar 2005).

Another estimator is based on the correlation $(1{+}z)\,E_p \propto [L_p^{\rm iso}]^{0.51}$ (Yonetoku et al. 2004). Paraphrase our discussion of the $[(1{+}z)E_p, E_\gamma^{\rm iso}]$ case, using Eqs. (1-5), to find that $(1{+}z)E_p \propto [(1{+}z)^2 L_p^{\rm iso}]^c$, with $c = 1/4\,(1/2)$ for small (large) $L_p^{\rm iso}$. In Fig. 2a we test our 'pre-Yonekotu' prediction ($c = 1/4$, Dar & De Rújula 2004). In Fig. 2b, the prediction is improved, positing:

$$(1+z)\,E_p \simeq C\,[(1+z)^2\,L_p^{\rm iso}]^{1/4} + D\,[(1+z)^2\,L_p^{\rm iso}]^{1/2}\,. \tag{7}$$

The corresponding fit has $\chi^2/{\rm dof} = 6.8$; for Yonenotu's relation it is 8.0. Once more, the variability is too large to pin-down the redshift of GRB060614.

Some redshift estimators are pre-improved by employing Frail's[1] 'true' GRB energy, $E_\gamma$, and the ensuing 'true' luminosity, $L_p$, in the correlations, e.g. $[(1+z)E_p - L_p]$ (Ghirlanda et al. 2005) and $[(1+z)E_p - E_\gamma]$ (Schaefer & Xiao 2006). This procedure may be unreliable:

1) Even if GRBs were produced by conical ejecta, the opening angle, $\theta_j$, of the jet during the GRB and AG phases may not be the same. Analogous jets from quasars and microquasars are not conical shells, but plasmoids (CBs) whose rapid expansion stops shortly after ejection (Dar & De Rújula 2004 and references therein). Their radiation is beamed into a narrow cone, not a good reason to spouse conical jets. Moreover, the CBs of quasars (Sambruna et al. 2006) and microquasars (Namiki et al. 2003 and references therein) appear to be made of ordinary-matter plasma (Dar & De Rújula 2000) and not of $e^+e^-$ pairs.

2) The break in the AG, argued to occur when the observer begins to see the full front of the conical jet, must be achromatic, but it is not (e.g. Panaitescu et al. 2006).

3) The break time depends not only on $\theta_j$ and $E_\gamma^{\rm iso}$ but also on the chosen circumburst density distribution (a constant, or the $\sim 1/r^2$ profile of the wind of a Wolf-Rayet progenitor), on its normalization, and on the efficiency for converting kinetic energy to radiation. These 'hidden variables' may on occasion be chosen to converge on the desired result: a fixed 'true' energy. If so, it is not surprising that the ensuing correlations appear to be tighter.

4) For all XRFs of known $z$, $E_\gamma^{\rm iso}$ is much smaller than the Frail 'standard candle' value $E_\gamma$, implying that XRFs cannot be simply GRBs viewed far off axis, while all the observations support that they are, including the predicted (Dar & De Rújula 2000, 2004; Dado et al. 2002, 2003, 2004) and observed (Pian et al. 2006) SN1993bw-like progenitors[4].

5) All published attempts to *predict* the AG's break time of a GRB, using the measured values of $z$, $E_p$ and $E_\gamma^{\rm iso}$, have failed. For instance, Rhoads et al. (2003) predicted $t_{\rm break} > 10.8$ days for GRB 030226, while Greiner et al. (2003), shortly after, observed $t_{\rm break} \sim 0.8$ day.

6) The Frail relation and most of its consequences are derived for observers placed on the firecone's axis, to within a beaming angle $\sim 2/\gamma$. The ratio of the probability of being on-axis to that of being 'on-edge' (to within the same angle) is $\theta_j/\gamma$. The on-axis/off-axis probability ratio is quadratic in $\theta_j/\gamma$. For typical firecone parameters these probability ratios are tiny.

7) In most fireball models, the GRB's $\gamma$-rays are synchrotron-generated. Most GRB spectra are harder than consequently predicted (Ghirlanda et al. 2003). A GRB pulse originates in a collision of $\gamma \gg 1$ shells moving in the same direction; the AG is due to the collision

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[1] The Frail relation (Frail et al. 2001), though used extensively in the literature, has a trivial geometrical error. It should read $E_\gamma = E_\gamma^{\rm iso}(1-\cos\theta_j)/2 \simeq E_\gamma^{\rm iso}\theta_j^2/4$.

of the ensemble of shells with the ISM at rest. This implies that there must be at least one order of magnitude more energy in the AG than in the GRB. The contrary is always observed. It may not be a surprise that these models also have difficulties in relating other GRB properties to AG observables, such as the break time.

## 6. Conclusions

The limit on an underlying SN in the optical afterglow of GRB060614 neither excludes a core-collapse SN origin of this burst, nor provides evidence for a new class of GRBs. This GRB offers a good case to discuss correlations as redshift indicators. We argued that current indicators are not reliable for single GRBs, even in the CB-model, wherein the correlations are predictions based on trivial physics and geometry, and are supported by the data.

We discussed three reasons why a SN progenitor of GRB060614 may have avoided detection: strong extinction of the SN light in a molecular cloud, a fake sky coincidence with a galaxy at $z = 0.125$, and a dimmed associated 'Pastorella-like' SN. The first possibility we disfavoured, the second is perfectly consistent but not decisively provable, the third is the most natural, if the GRB indeed originated at $z = 0.125$. Very long baseline radio observations, if they have been made, may resolve the remaining dichotomy. It the GRB is far, they may be useless. But, if it is at $z=0.125$, the data may reveal a trail of hyperluminal CBs, as they arguably revealed the two CBs of the two-pulse GRB030329 (Dado et al. 2004b). Very faint SNe may have a very late peak or a long plateau, like Pastorello's SNe, a deep optical search may still be advisable.

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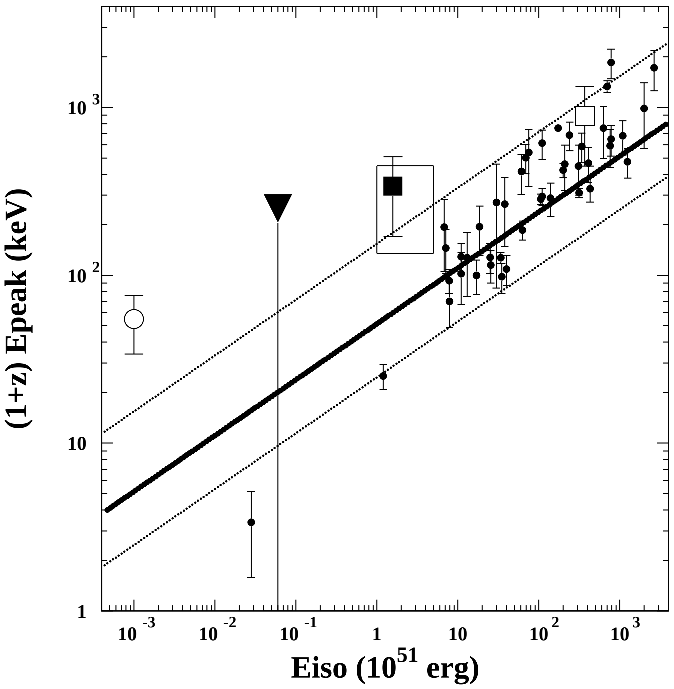

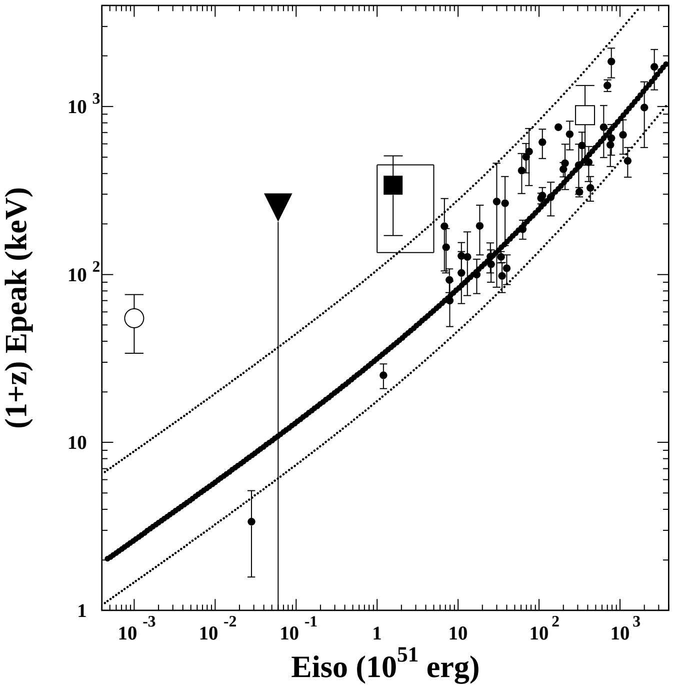

Fig. 1.— $(1+z)\,E_p$ as function of $E_\gamma^{\rm iso}$ for a sample of 46 GRBs with secured redshift, compiled by Amati (2006) and Ghirlanda et al. (2004). The rectangle is the CB-model's expectation for a Pastorello-like parent SN at $z = 0.125$. Top: Our 'pre-Amati' prediction. Bottom: the improvement of Eq. (6). The 'variability' lines are the lightly-dotted ones. GRB060614, for $z = 1.95$ (0.125) is the open (filled) square. The open circle (GRB 0980425) is convincingly an outlier. A CB-model's explanation is discussed in Dado & Dar (2005).

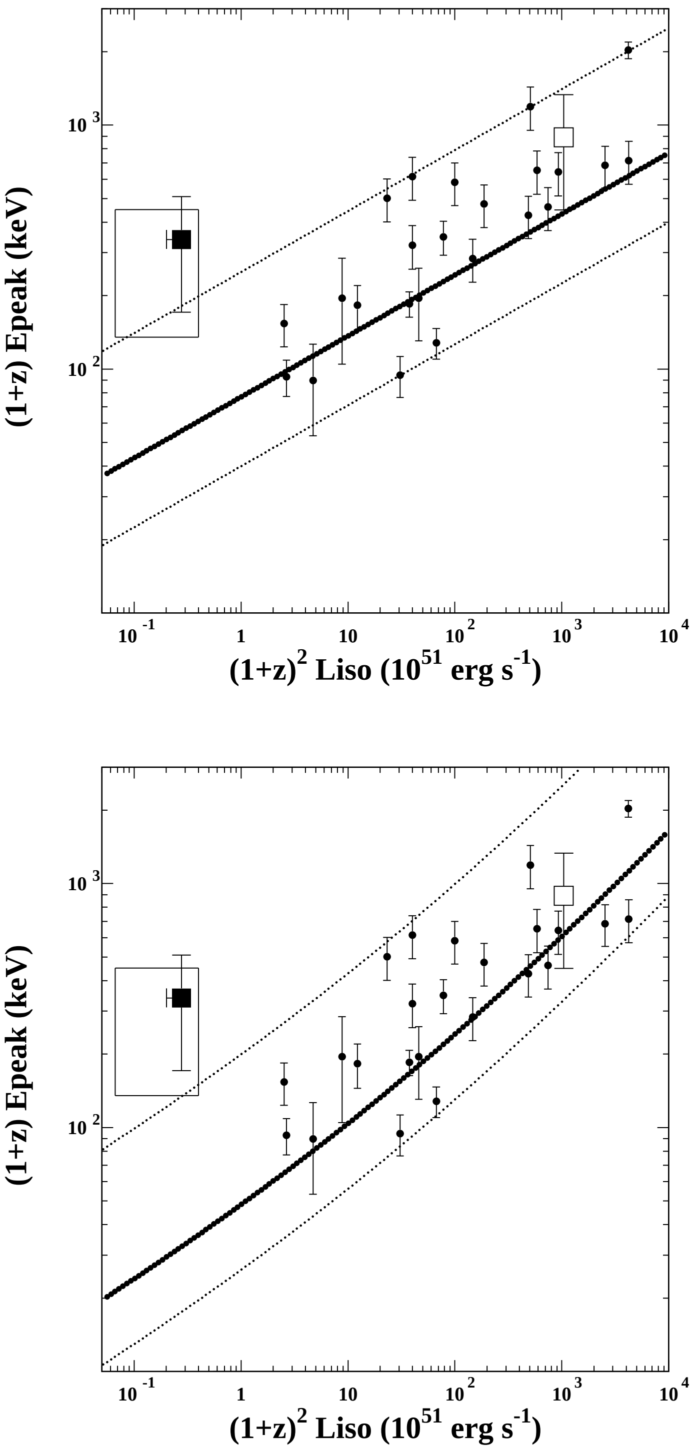

Fig. 2.— $(1+z)E_p$ as function of $(1+z)^2 L_p^{\rm iso}$ for a sample of GRBs with secured redshift, compiled by Yonekotu et al. (2004) and Ghirlanda et al. (2005). The rectangle is the CB-model's expectation for a Pastorello-like parent SN at $z = 0.125$. Top: Our 'pre-Yonetoku' prediction. Bottom: The improvement of Eq. (7). Notation and comments are as in Fig. 1.