

## What SWIFT has Taught us about X-ray Flashes and Long-duration Gamma-Ray Bursts

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**Abstract** Recent data gathered and triggered by the SWIFT satellite have greatly improved our knowledge of long-duration gamma ray bursts (GRBs) and X-ray flashes (XRFs). This is particularly the case for the X-ray data at all times, and for UV and optical data at very early times. I show that the optical and X-ray observations are in excellent agreement with the predictions of the “cannonball” model of GRBs and XRFs. Elementary physics and just two mechanisms underlie these predictions: inverse Compton scattering and synchrotron radiation, generally dominant at early and late times, respectively. I put this result in its proper context and dedicate the paper to those who planned, built and operate SWIFT, a true flying jewel.

**Key words:** GRB — XRF — supernova — compton scattering — synchrotron radiation

### 1 PROLEGOMENA

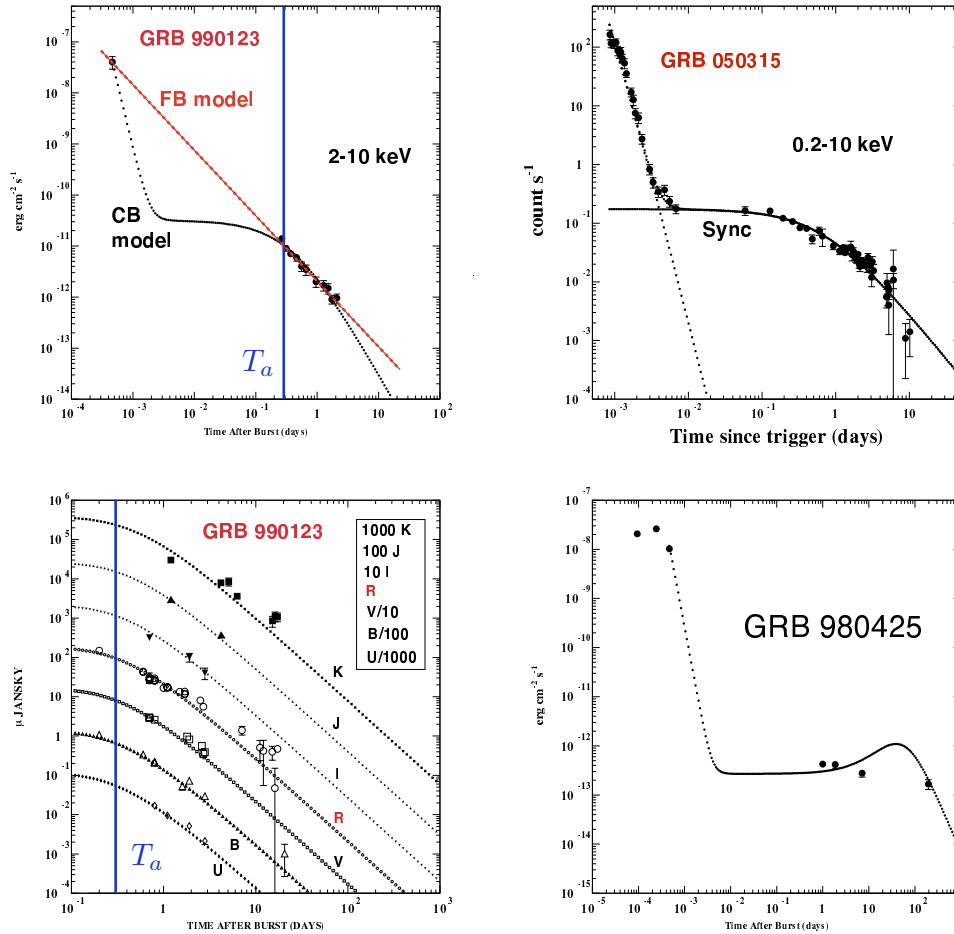
With predestined celerity, the observations made or triggered by the SWIFT satellite have resulted in a wealth of information on Gamma Ray Bursts (GRBs), in particular on the early X-ray and optical afterglows (AGs) of X-ray flashes (XRFs) and long-duration GRBs. The data pose severe problems to the ‘standard’ Fireball models, whose ‘microphysics’ (see, e.g. Panaitescu et al. 2006), reliance on shocks (see, e.g. Kumar et al. 2007), and correlations based on the ‘jet-opening angle’ (see, e.g. Sato et al. 2007; Burrows & Racusin 2007), may have to be abandoned.

The said recent observations agree remarkably well with the predictions of the ‘Cannon Ball’ (CB) model (Dar & De Rújula 2004; Dado, Dar & De Rújula 2002, 2003, hereafter DD04; DDD02; DDD03, respectively). Some examples are given in Figure 1. The predicted light-curve of the X-ray AG is shown in Figure 1a for the Fireball (see e.g. Maiorano et al. 2005) and CB (DDD02) models. Many X-ray AGs have a ‘canonical behaviour’ (e.g. Nousek et al. 2006; Zhang 2006; O’Brien et al. 2006), in impressive agreement with the CB-model predictions, as in the example of Figure 1b. The evolution of the AG around the time,  $T_a$ , ending the ‘plateau phase’ is predicted to be achromatic in the optical to X-ray range (DDD02), see and compare Figures 1a,c (sometimes  $T_a$  precedes the end of the fast prompt decline and no plateau is seen). Examining SWIFT data, Curran et al. (2006) found that ‘X-ray and optical AGs demonstrate achromatic breaks at about one day which differ significantly from the usual jet break in the [Fireball] blastwave model of AGs’. In our model these observed ‘breaks’ are ‘deceleration bends’: As a CB collides with interstellar matter (ISM), its Lorentz factor,  $\gamma(t)$ , typically begins to diminish significantly after one observer’s day and, consequently, so does its fluence (DDD02).

The ‘plateau’ is nowadays generally interpreted as a ‘continued activity of the engine’, yet a new surprise. In the CB model it is just the result of the initial, almost inertial motion of the CBs: inevitable, not surprising. Even our closest neighbour to date, GRB980425, associated with SN1998bw, is canonical, not

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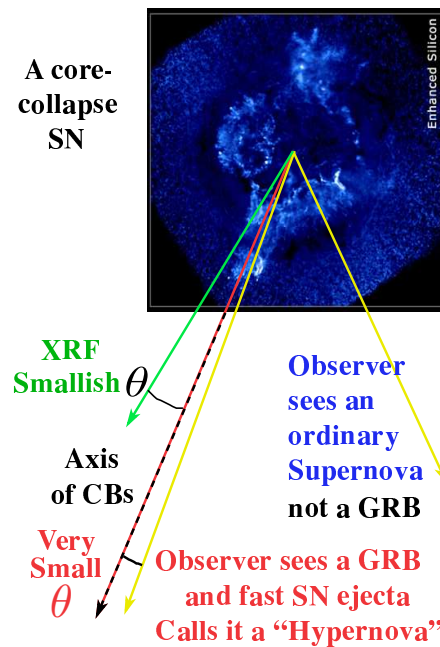


**Fig. 1** (a) **Top left**: Pre-SWIFT predictions for the 2–10 keV X-ray AG in the CB (DDD02) and fireball (e.g. Maiorano et al. 2005) models, compared to data for GRB 990123.  $T_a$  is the time ending the ‘plateau’ phase. (b) **Top right**: Comparison between the CB model prediction and the canonical 0.2–10 keV X-ray light curve of GRB 050315 (Vaughan et al. 2006). (c) **Bottom left**: Broad band optical data on GRB 990123, fit in the CB model (DDD03). After the onset of the plateau, the predicted and observed evolution is achromatic from optical to X-ray energies, as seen in this figure and its comparison with (a). (d) **Bottom right**: The X-ray light curve of GRB 980425 (DDD02) showing a ‘canonical’ behaviour and what we called a ‘plateau’ (long and hilly in this case, given the large observer’s angle). The last (red) point postdates the original figure. The other properties of this GRB and its SN are also not exceptional, in the CB model (DDD03).

exceptional. Its X-ray light curve (DDD02, DDD03) is shown in Figure 1d; its last data point (Pian et al. 2004; Kouveliotou et al. 2004) was predicted, not fit.

In the CB model there are two basically identical radiation mechanisms: inverse Compton scattering (ICS) and synchrotron radiation (SR).

For the scores of cases we have studied, the  $\gamma$  and X-ray emissions are dominated by ICS until the end of their fast-declining phase. The X-ray production, from the ‘plateau’ onwards, is dominated by SR. All other general statements equating the two mechanisms to the two phases (prompt and afterglow) have exceptions.



**Fig. 2** Long GRBs and XRFs are seen close to the axis of their associated supernova. The nonrelativistic ejecta of a fairly ordinary SN may be faster than average in its axial directions. Thus, *hypernovae* (a hypothetical class of SNe associated with GRBs) may be in the eyes of the beholder. Cas A picture by NASA/CXC/GSFC/U.Hwang et al. After decades of computing effort, no ‘first-principled’ code explodes SNe, spherically or not, nor generates relativistic ejecta. In this situation, it may be wise to rely on observations, which are advancing fast (see e.g., Mazzali et al. 2005).

In DDD02/03 we showed that reality and the CB model share some significant features. The hypotheses and physics underlying the prediction for the synchrotron-dominated phase were simple: equipartition of the magnetic field energy within a CB with that of the intercepted ISM particles, energy-momentum conservation for the CBs’ deceleration law, an initial relativistic expansion of a CB in its rest system, followed by  $F = m a$ , for the evolution of its radius. The resulting expressions provided good fits to the broad-band AGs of *all* localized GRBs known at the time, and allowed us to demonstrate, to our entire satisfaction, that a supernova (SN) akin to SN1998bw was seen in the data in all cases where it could be observed, and unseen in all cases where it couldn’t (the distinction occurred at a redshift  $z \sim 1.2$ ). This corroborated the model’s original hypothesis (Dar & Plaga 1999) that core-collapse SNe are the engines of long GRBs, and gave us the necessary confidence to predict the night in which SN2003dh, associated with GRB030329, would be discovered (Dado et al. 2003b). Since that night, everybody ‘had always known’ that the SN/GRB association was for real, see Figure 2 and its caption.

Given the information extracted from our AG analyses on the typical Lorentz factors, observation angles and cannonball masses of pre-SWIFT GRBs, the observed properties of pre-SN winds, and the early luminosity of a core-collapse SN (such as SN1987A), we could, in DD04, go one step forward. The early light of a SN scatters in its semi-transparent ‘circumburst material’, previously blown by the wind of the progenitor. This creates a *glory*: a light-reservoir of non-radially directed photons. In DD04 we studied the outcome of ICS of the light of the SN’s glory by the electrons enclosed in a CB. The mechanism correctly predicts all the established properties of GRB pulses, their typical values, and the distributions around them. These include their peak-energies, equivalent isotropic energy, pulse shape, spectrum and temporal evolution. As Sidney Coleman would put it: ‘Modesty restrains me, but honestly compels me’ ... to admit that, as of then, I am convinced that long GRBs have been understood. After all, even in astrophysics, a problem

is occasionally solved, e.g. the energy source of stars. GRBs are a small fraction of the energy budget of a supernova, nothing like the advertised ‘biggest explosions after the Big Bang’. Originally, the solutions to the grand problem of stars and the modest problem of GRBs were incomplete: Hans Bethe did not have a decent theory of the weak interactions, nor do we have a predictive theory of the ‘cannon’ (the accreting compact object resulting from a star’s core-collapse). In both cases, related observations filled these theoretical gaps.

Most of the rest of this note is devoted to how precisely ICS describes the early X-ray and optical data. As an appetizer, I shall demonstrate that ICS is indeed the prompt mechanism of GRBs and XRFs. Many correlations between GRB observables have been studied with the help of the new data on GRBs of measured  $z$  (e.g. Schaefer 2006). All of the successful correlations are appallingly simple predictions of the CB model: The typical Lorentz factor of the CBs of GRBs is  $\gamma = \mathcal{O}(10^3)$ . Expanding in its rest system at a speed comparable to that of light, a CB is quasi-point-like: the angle it subtends from its point of emission (in the SN frame) is comparable or smaller than the opening angle,  $1/\gamma$ , characterizing its beamed radiation. Let  $\theta$  be the viewing angle of an observer of a CB, relative to its direction of motion, typically of  $\mathcal{O}(1 \text{ mrad})$ , and let  $\delta$  be the corresponding Doppler factor:  $\delta \equiv 1/[\gamma(1 - \beta \cos \theta)] \simeq 2\gamma/[1 + \gamma^2 \theta^2]$ . To correlate two GRB observables, all one needs to know is their functional dependence on  $\delta$  and  $\gamma$ . This is because the  $\theta$  dependence of  $\delta(\gamma, \theta)$  is so pronounced, that it should be the largest source of the case-to-case spread in the measured quantities. In the CB model, the  $(\gamma, \delta, z)$  dependences of the spherical equivalent energy of a GRB,  $E_\gamma^{\text{iso}}$ ; its peak isotropic luminosity  $L_p^{\text{iso}}$ ; its peak energy,  $E_p$  (Dar & De Rújula 2001a); its pulse rise-time  $t_{\text{rise}}$ ; its variability,  $V$ ; and its ‘lag-time’,  $t_{\text{lag}}$  (Dado et al. 2007a); are<sup>1</sup>:

$$E_\gamma^{\text{iso}} \propto \delta^3; \quad L_p^{\text{iso}} \propto \frac{\delta^4}{(1+z)^2}; \quad E_p \propto \frac{\gamma \delta}{1+z}; \quad t_{\text{rise}} \propto \frac{1+z}{\gamma \delta}; \quad V \propto \frac{\gamma \delta}{1+z}; \quad t_{\text{lag}} \propto \frac{(1+z)^2}{\delta^2 \gamma^2}. \quad (1)$$

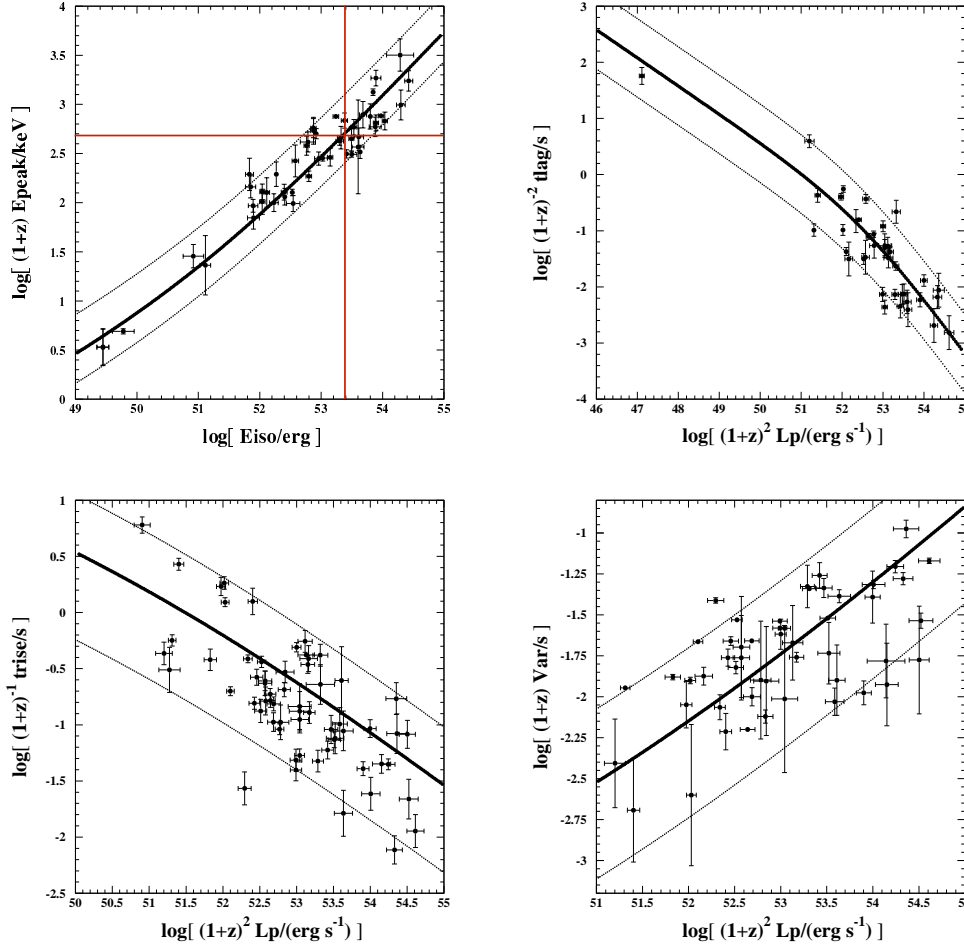
One obvious consequence is  $E_\gamma^{\text{iso}} \propto [(1+z)^2 L_p^{\text{iso}}]^{3/4}$ , see Figure 4a. The most celebrated correlation is the  $[E_p, E_\gamma^{\text{iso}}]$  one, shown in Figure 3a as a test of our prediction (Dado et al. 2007 and references therein). It evolves from  $E_p \propto [E_\gamma^{\text{iso}}]^{1/3}$  for small  $E_p$ , to  $E_p \propto [E_\gamma^{\text{iso}}]^{2/3}$  for large  $E_p$ . This is because for  $\theta \ll 1/\gamma$ ,  $\delta \propto \gamma$ , while in the opposite case  $\delta$  and  $\gamma$  are independent. The correlations are specific to the ICS by the CB’s electrons (comoving with it with a Lorentz factor  $\gamma$ ) of the glory’s photons, that are approximately isotropic in the supernova rest system, and are Doppler-shifted by the CB’s motion by a factor  $\delta$  (the result would be different, for instance, for SR from the GRB’s source, or self-Compton scattering of photons comoving with it). Five correlations between the six observables in Equation (1) are independent, three more, shown in Figures 3b,c,d, complete a set. The data agree with the predicted correlations. QED.

Another tell-tale signal of ICS is the polarization, predicted to be  $\Pi = 2\theta^2 \gamma^2 / (1 + \theta^4 \gamma^4)$  (Shaviv & Dar 1995). With limited sensitivity, the most probable observation angle of a GRB is  $\theta \sim \mathcal{O}(1/\gamma)$ , resulting in  $\Pi \sim 1$ . In the CB model XRFs and long GRBs are the same objects, viewed at different  $\theta$ . The former (conventionally defined by their low  $E_p$ ) are observed at larger  $\theta$  than the latter (DD04). Thus, for XRFs,  $\Pi$  is predicted to be smaller. Four GRB polarization measurements have been reported, all compatible with  $\Pi = 100\%$ . But the data have large statistical and (possibly) systematic errors (Coburn & Boggs 2003; Willis et al. 2005; Kalemci et al. 2006; Dado et al. 2007b, and references therein).

## 2 MORE RECENT AND DETAILED RESULTS

The XRF060218/SN2006aj pair provides one of the best testing grounds of theories, given its proximity ( $z = 0.033$ ), its excellent sampling and statistics, and its simplicity: it had just one X-ray flare. The X-ray and optical data, shown in Figure 4b, have been modeled by a sum of a black body emission with a time-declining temperature and a cut-off power-law, allegedly the result of the core-collapse shock breaking out from the stellar envelope and of the stellar wind of the SN’s progenitor (Campana et al. 2006; Blustin 2007; Liang et al. 2007; Waxman, Meszaros & Campana 2007). No novelties are required to understand this XRF/SN pair in the CB model. I use it next as an exemplar to introduce and test some very specific predictions.

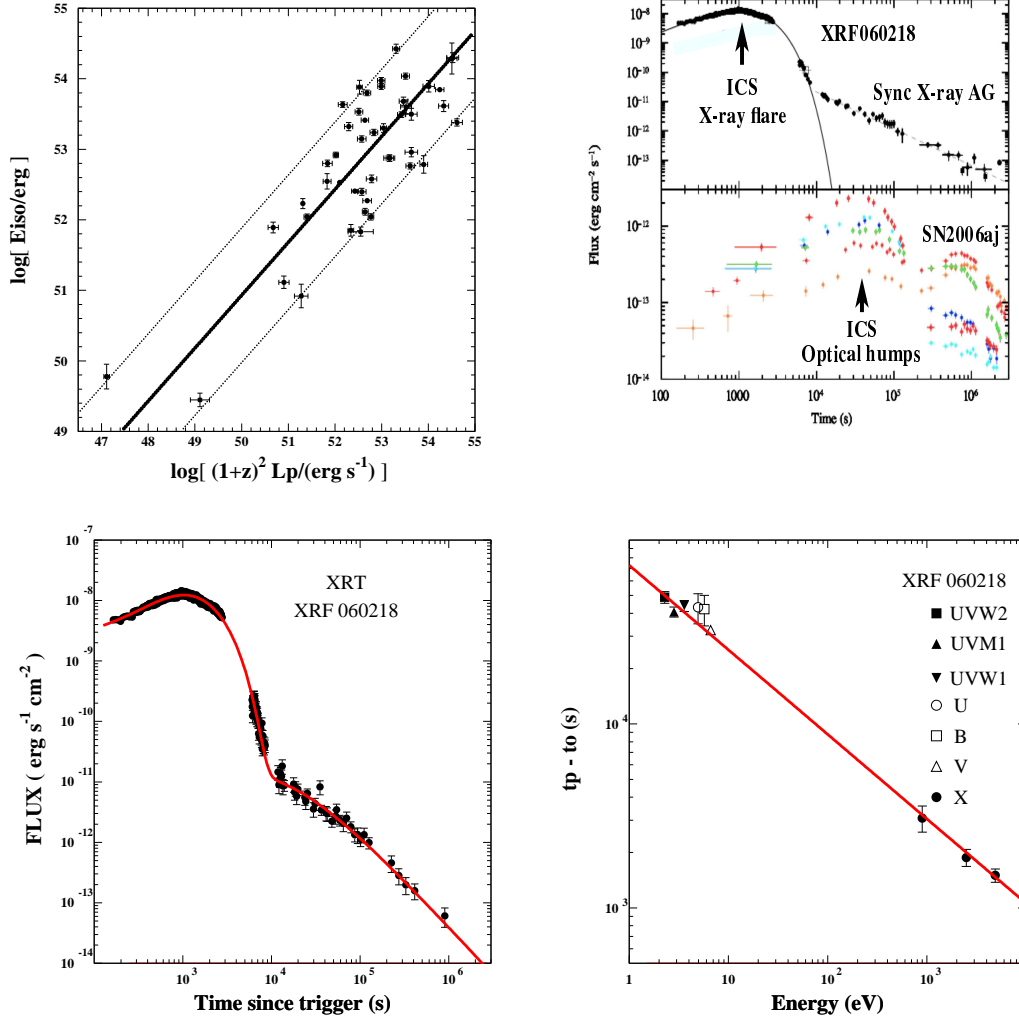
<sup>1</sup> The coefficients of proportionality in Eq. (1) have explicit dependences on the number of CBs in a GRB, their initial expansion velocity and baryon number. With typical values fixed by the analysis of GRB afterglows, the predictions agree with the observations, see DD04, Dado et al. (2007a), and the crossed lines in Fig. 3a.



**Fig. 3** (a) **Top left:** The  $(E_p, E_\gamma^{\text{iso}})$  correlation, compared with its predicted trend in the CB model. The crossed red lines are the predicted typical or average values. (b) **Top right:** The  $[t_{\text{lag}}, L_p^{\text{iso}}]$  correlation. (c) **Bottom left:** The  $[t_{\text{rise}}, L_p^{\text{iso}}]$  correlation. (d) **Bottom right:** The  $[V, L_p^{\text{iso}}]$  correlation. The definition and measurement of the rise-time of a pulse and, more so, its variability, are debatable. Correlations involving these quantities are the loosest. The  $(E_p, E_\gamma^{\text{iso}})$  correlation compares two observables averaged over pulses (as opposed to an averaged observable and a single-pulse one). It is expected and observed to be the tightest: strictly speaking Eq. (1) are for single pulses (Dado et al. 2007a).

A typical CB has  $E_\gamma^{\text{iso}} \approx 0.8 \times 10^{44} \delta^3$  erg and its *early*  $E_p$  is  $E_p(0) \approx 2 \gamma \delta T_g / [3(1+z)]$ , with  $T_g \sim 1$  eV the (pseudo)-temperature of the glory's thin-brestrahlung spectrum  $E_i dN_i/dE_i \sim \exp[-E_i/T_g]$  (DD04). Thus, the reported  $E_{\text{iso}} \approx (6.2 \pm 0.3) \times 10^{49}$  erg and  $E_p(0) = 54$  keV result in the estimates  $\delta_0 \sim 92$ ,  $\gamma_0 \sim 910$  and  $\theta \sim 4.8 \times 10^{-3}$ . Using these parameters and a fit value for the ISM density we can predict the SR contribution to the X-ray AG in the 0.3–10 keV band. It is shown in Figure 4c, it dominates after  $t \sim 10^4$  s. The shape of the initial ICS-dominated X-ray peak is a prediction, its normalization and width are fitted, but they are totally compatible with the expectations for the above  $\gamma$  and  $\theta$  values (Dado et al. 2007c).

A quick look at the ‘prompt’  $\gamma$ -ray count-rates and X-ray light curves of SWIFT GRBs reveals that the  $\gamma$ -ray ‘pulses’ and X-ray ‘flares’ are coincident. In the CB-model this relation is very well understood. The derived ICS spectrum bears a striking resemblance to the observed ‘Band’ spectrum. A spectrum  $E dN/dE \sim \exp[-E/E_p]$  generally suffices to describe the SWIFT X-ray data (that extend up to 350 keV).



**Fig. 4** (a) **Top left:** The  $[E_{\gamma}^{\text{iso}}, L_p^{\text{iso}}]$  correlation (Dado et al. 2007a). (b) **Top right:** Data on XRF 060218/SN2006aj. Upper part: the 0.3–10 keV SWIFT-XRT light curve, with fits by Campana et al. (2006b). Lower part: UVO light curves. The ICS X-flare and UV/optical ‘humps’ are our interpretation (Dado et al. 2007c). (c) **Bottom left:** The X-ray light curve of XRF 060218, fit in the CB model. (d) **Bottom right:** Results of the ‘ $E \times t^2$ ’ law for this XRF (Dado et al. 2007c).

Such a spectrum is simply the one generated by electrons comoving with a CB, Compton up-scattering the glory’s photons. In more detail, a single GRB pulse or X-ray flare obeys a ‘master formula’ (DD04, Dado et al. 2007c):

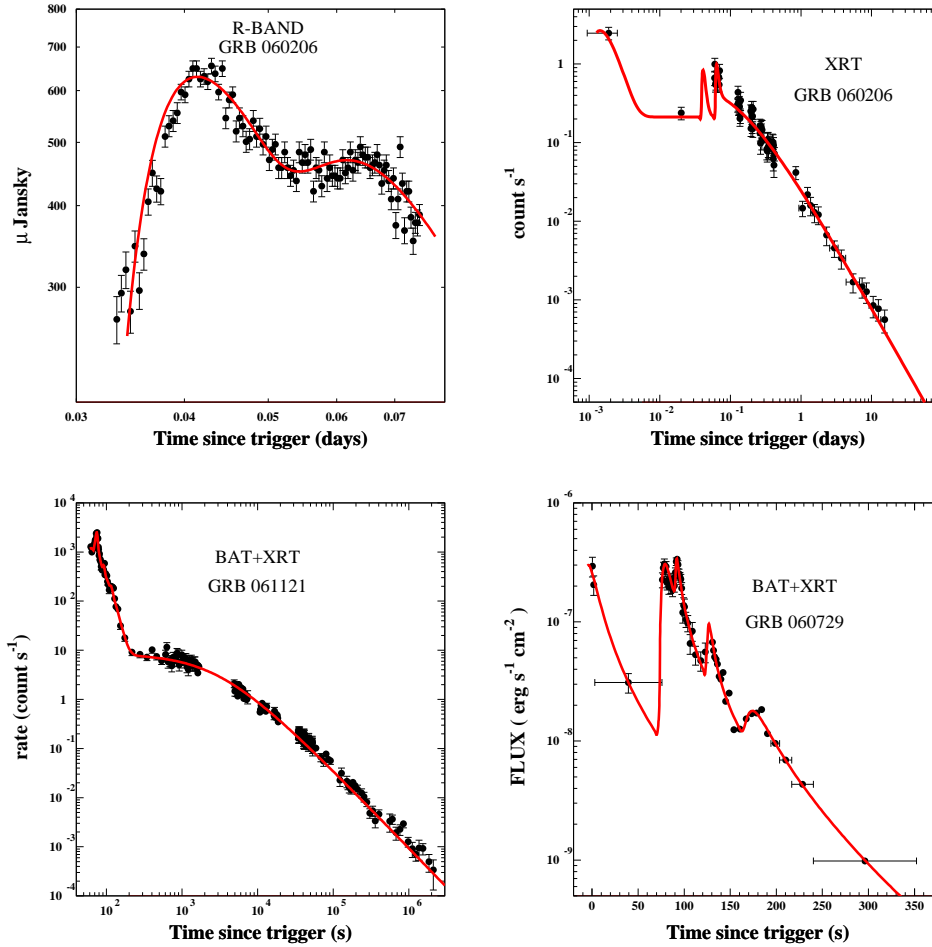
$$E \frac{d^2 N_{\gamma}}{dt dE} \approx F[E t^2] \approx \Theta[t] e^{-[\Delta t(E)/t]^2} \left\{ 1 - e^{-[\Delta t(E)/t]^2} \right\} e^{-E/E_p(t)},$$

$$E_p(t) \approx E_p(0) \left( 1 - t/\sqrt{\Delta t^2 + t^2} \right), \quad \Delta t(E) \approx t_{\text{tr}}^w (E_p/E)^{\frac{1}{2}}, \quad (2)$$

where  $t_{\text{tr}}^w$  is the observer’s time at which the remaining ‘wind’ material becomes transparent, of  $\mathcal{O}(1\text{s})$ , for typical parameters. The energy fluence  $F$  of Equation (2) is predicted to be approximately a function of the

combination  $E \times t^2$  of its two variables (DD04). This is mainly due to the fact that a glory's photon incident on a CB (in the supernova rest system) at an angle  $\alpha$  is Compton scattered to an energy  $E \propto 1 + \cos \alpha \rightarrow 1/r^2 \propto 1/t^2$ . The limit is for the large times,  $t \gg t_{\text{tr}}^w$  [or radial distances,  $r \gg c \gamma \delta t_{\text{tr}}^w / (1+z)$ ] for which the glory's light appears to the escaping CB to be radially distributed. But even at  $t \sim t_{\text{tr}}^w$ , by definition, the wind material is semitransparent and the distribution of the light it scatters is such that  $\langle \cos \alpha \rangle \approx -1 + 1/r^2$ , making the  $E \times t^2$  'law' a good approximation at all  $t$ . The predicted  $E_p(t)$  evolution is observed in the time-resolved spectra of well isolated pulses (see, for instance, the insert in fig. 8 of Mangano et al. 2007).

For XRF060218, Equation (2) describes very well the flare and the fast-decay of the X-ray light curve, see Figure 4c, and the fast softening of its spectrum during this phase. As soon as SR dominates over ICS (at  $t \sim 9000$  s) the spectrum becomes a harder power-law with an observed index  $\beta_X \sim -1.1$ , the prediction of the CB model for the unabsorbed synchrotron spectral energy density in the X-ray band (DDD02).



**Fig. 5** (a) **Top left:** The very early R-band light curves of GRB 060206 (Wozniak et al. 2006). (b) **Top right:** The less-well sampled X-ray light curves (Evans et al. 2007), inferred from SWIFT BAT and XRT data for GRB 060206. The properties of the last two prominent X-ray flares are predicted from those of their optical counterparts in a. (c) **Bottom left:** The extensive X-ray light curve of GRB 061121 (Page et al. 2007). (d) **Bottom right:** The complex decay of the X-ray light curve of GRB 060729 (Grupe et al. 2007), with the progressively dying pangs of its accreting engine. All data are accompanied by their CB-model description (Dado et al. 2007c).

The most impressive CB-model result concerning XRF060218 is the prediction of the properties of its optical emission. We contend that the ‘optical humps’ in Figure 4b are nothing but the X-ray flare, seen at much lower frequencies. This we prove by fitting the 15–150 keV band data to Equation (2) to extract the peak time,  $t_{\text{peak}}(E_X) = 425 \pm 25$  s, and peak energy flux,  $\text{PEF} = 1.30 \pm 0.07$  erg cm<sup>-2</sup> s<sup>-1</sup>. The peak times in 2 other X-ray energy intervals and in 6 UV and optical frequencies are then predicted:  $t_{\text{peak}}(E_j) \approx t_{\text{peak}}(E_X) \sqrt{E_j/E_X}$ ,  $j = 1, 8$ . The results are shown in Figure 4d, an extension by > 3 orders of magnitude of similar results in DD04. The (spectral) results for the PEFs are equally simple and successful (Dado et al. 2007c). Recall that all these results follow from the elementary physics of ICS on the glory’s light of a supernova. Finally, this XRF is indeed associated with a SN, since it is simply a (long) GRB seen at a relatively large  $\theta$ . Sometimes a single observation, e.g. the  $\Omega^-$ , or data set, e.g. the spectrum of charmonium, suffices to definitely establish a theory. The XRF060218/SN2006aj pair would be such a case... if astrophysics was more akin to particle physics, or to today’s cosmology.

In Dado et al. (2007c) we have analyzed a sample of GRBs and XRFs which includes the brightest SWIFT GRBs, the one with the longest measured X-ray emission, a couple with canonical X-ray light curves (with and without late X-ray ‘mini-flares’) and some of the ones considered most puzzling from the point of view of fireball models. In Figure 5 I show some of the results. In the case of GRB060206, the very early optical data, shown in Figure 5a, are exceptionally good. We fit it, and use Equations (2) to predict the X-ray light curve from  $t \sim 0.03$  s onwards, see Figure 5b. The complete X-ray light curve of GRB061121, was measured over a record seven orders of magnitude in intensity and five orders of magnitude in time. It is impressively well described by the simple predictions of the CB model for ICS followed by SR, as shown in Figure 5c. In some cases, during the rapidly decreasing phase of the X-ray light curve, there are ‘mini-flares’ not seen in the corresponding  $\gamma$ -ray light curve. One example is GRB060729, shown in Figure 5d. In the CB model, CBs are ejected in delayed accretion episodes of matter from a ring or torus (Dar & De Rújula 2000). As the accretion material is consumed, one may expect the ‘engine’ to have a few progressively-weakening dying pangs, seen as miniflares. We now know that, indeed, SNe ‘may bang more than once’ (De Rújula 1997). They do it at least as many times as we see  $\gamma$ -ray peaks and X-ray flares in a GRB or an XRF.

### 3 CONCLUSIONS

The data on GRBs gathered after the launch of SWIFT, as interpreted in the CB model, has taught us five things:

- The relatively narrow pulses of the  $\gamma$ -ray signal, the somewhat wider prompt flares of the X-rays, and the much wider humps sometimes seen at UVO frequencies, have a common origin. They are generated by inverse Compton scattering.
- Relatively weak ‘dying pang’ episodes of accretion are seen as X-ray ‘mini-flares’ in the declining phase of the previous mightier pulses, which are seen both in  $\gamma$  and X-rays.
- The historical distinction between prompt and afterglow phases is obsolete. It is replaced by a physical distinction: the relative dominance of the Compton or synchrotron mechanisms at different times, which are frequency-dependent.
- The two quoted mechanisms suffice to provide a very simple and accurate description of XRFs and long-duration GRBs at all frequencies and times. They generate the rich structure of the light curves at all frequencies, and their chromatic or achromatic ‘breaks’.
- To date, as the quality of the data improves, so does the quality of its agreement with the CB-model’s predictions.

The above ‘SWIFT teachings’ are not the ones most specialists in the field would list. The fast decline, ‘continued engine activity’ and misplaced ‘break’ of the ‘canonical’ behaviour are no doubt the most important recognized new challenges to the orthodox –but ductile– views. In the CB model they are predictions. Some other SWIFT teachings are also indisputable, e.g. the average  $z$  of SWIFT GRBs is 2.8, and its current record is 6.29.

When their collimated radiation points to the observer, GRBs are the brightest sources in the sky. In the simple-physics context of the CB model, GRBs are not persistent mysteries, and a constant source of

surprises, exceptions and new requirements. Instead, they are well-understood and can be used as cosmological tools, to study the history of the intergalactic medium and of star formation up to large redshifts, and to locate SN explosions at an early stage. In the CB model GRBs are not ‘standard candles’, their use in ‘Hubble-like’ analyses would require further elaboration. The GRB conundra have been reduced to just one: ‘how does a SN manage to sprout mighty jets?’ The increasingly well-studied CBs ejected by quasars and microquasars, no doubt also fired in catastrophic accretion episodes on compact central objects, provide observational hints with which, so far, theory and simulations cannot compete.

The CB model underlies a unified theory of high energy astrophysics. The information gathered in our study of GRBs can be used to understand, also in very simple terms, other phenomena. The most notable is (non-solar) Cosmic Rays. We allege (Dar et al. 1992; Dar & Plaga 1999) that they are simply the charged ISM particles scattered by CBs, in complete analogy with the ICS of light by the same CBs. This results in a successful description of the spectra of all primary cosmic-ray nuclei and electrons at all observed energies (Dar & De Rújula 2006a). The CB model also predicts very simply the spectrum of the gamma background radiation and explains its directional properties (Dar & De Rújula 2001b, 2006b). Other phenomena understood in simple terms include the properties of cooling core clusters (Colafrancesco, Dar & De Rújula 2003) and of intergalactic magnetic fields (Dar & De Rújula 2005). The model may even have a say in ‘astrobiology’ (Dar et al. 1998; Dar & De Rújula 2001b).

Finally, if the cannonballs of GRBs are so pervasive, one may ponder why they have not been directly seen. After all, particularly in astrophysics, *seeing is believing*. The answer is simple. Cannonballs are tiny astrophysical objects: their typical mass is half of the mass of Mercury. Their energy flux at all frequencies is  $\propto \delta^3$ , large only when their Lorentz factors are large. But then, the radiation is also extraordinarily collimated, it can only be seen nearly on-axis. Typically, observed SNe are too far to *photograph* their CBs with sufficient resolution.

Only in two SN explosions that took place close enough, the CBs were in practice observable. One case was SN1987A, located in the LMC, whose approaching and receding CBs were photographed by Nisenson and Papaliolios (2001). The other case was SN2003dh, associated with GRB030329, at  $z = 0.1685$ . In the CB model interpretation, its two approaching CBs were first ‘seen’ as the two-peak  $\gamma$ -ray light curve and the two-shoulder AG (Dado et al. 2003b). This allowed us to estimate the time-varying angle of their superluminal motion in the sky. Two sources or ‘components’ were indeed clearly seen in radio observations at a certain date, coincident with an optical AG rebrightening. We claim that the data agree with our expectations<sup>2</sup>, including the predicted inter-CB superluminal separation (Dar & De Rújula 2000, DD04). The observers claimed the contrary, though the evidence for the weaker ‘second component’ is  $> 20\sigma$ , and it is ‘not expected in the standard model’ (Taylor et al. 2004). The no-doubt spectacular-discovery picture of the two superluminally moving sources has, to my knowledge, never been published. This is too bad, for *a picture is worth a thousand words*.

More often than not, an insufficient but necessary condition for an astrophysical theory to eventually survive as part of the truth is that it be long opposed, despised, and authoritatively pronounced wrong by the community. The CB model passes this final test with flying colours.

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<sup>2</sup> The size of a CB is small enough to expect its radio image to scintillate, arguably more than observed (Taylor et al. 2004). We only realized a posteriori that the ISM electrons a CB scatters, synchrotron-radiating in the ambient magnetic field, would significantly contribute at radio frequencies, somewhat blurring the CB’s radio image (Dado, Dar & De Rújula 2004; Dado & Dar 2005).

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