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The class of "disguised" short GRBs and its implications for the Amati relation

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Abstract. Within the fireshell model, canonical GRB light curves are made by two parts: the Proper GRB (P-GRB), emitted at the plasma transparency, and the extended afterglow (EA), due to the interaction with the CircumBurst Medium (CBM) of the left over ultrarelativistic baryonic matter. The "prompt emission" is formed by the P-GRB and the EA peak. There are 3 GRB classes: "genuine short", where the P-GRB is energetically predominant; "long", where the EA is energetically predominant; "disguised short", where the EA is energetically predominant over the P-GRB but has a lower peak flux due to a low CBM density typical of galactic halos. GRBs pertaining to this class are GRB 970228, GRB 060614, GRB 071227 and GRB 050509b. In these GRBs only the EA part alone follows the Amati relation. This fact may be used as a strong test for the theoretical framework or for the Amati relation itself.

Key words. Gamma-ray burst: general - black hole physics - binaries general

1. Introduction

The traditional classification of gamma ray bursts (GRBs) is based on the observed time duration of the prompt emission measured with the criterion of "T_{90}", which is the time duration in which the cumulative counts increase from 5% to 95% above the background, encompassing 90% of the total GRB counts. This parameter shows that there are two groups of GRBs, the short ones with $T_{90} < 2$ s, and the long ones with $T_{90} > 2$ s. This analysis motivated the standard classification in the literature of short and long GRBs (Klebesadel, 1992; Dezalay et al., 1992; Kouveliotou et al., 1993; Tavani, 1998). However, many "hybrid" sources hardly fitting this classification have been found today (see e.g. Norris & Bonnell, 2006; Gehrels et al., 2006; Xu et al., 2009).

In this paper we show that all these ambiguities and peculiarities can be explained in the framework of the fireshell model and we present the corresponding implications on the Amati et al. (2002) empirical correlation between the isotropic-equivalent radiated energy of the prompt emission E_{iso} and the cosmological rest-frame νF_ν spectrum peak energy $E_{p,i}$.

2. The Fireshell model

Within the fireshell model (Ruffini et al., 2009; Ruffini, 2011), all GRBs originate from an optically thick $e^\pm$ plasma of total energy $E^{e^\pm}_{tot}$ in the range 10^{49}–10^{54} ergs and a temperature T in the range 1–4 MeV. After an early expansion, the $e^\pm$-photon plasma reaches thermal equilibrium with the engulfed baryonic matter M_B described by the dimensionless parameter $B = M_B c^2/E^{e^\pm}_{tot}$, which must be $B < 10^{-2}$ to allow the fireshell to expand further. As the optically thick fireshell composed of $e^\pm$-photon-baryon plasma self-accelerates to ultrarelativistic velocities, it finally reaches the transparency condition. A flash of radiation is then emitted. This represents the proper-GRB (P-GRB). The amount of energy radiated in the P-GRB is only a fraction of the initial energy $E^{e^\pm}_{tot}$. The remaining energy is stored in the kinetic energy of the optically thin baryonic and leptonic matter fireshell that, by inelastic collisions with the CBM, gives rise to multiwavelength emission. This is the extended afterglow, whose light curve presents a rising part, a peak and a decaying tail. What is usually called “GRB prompt emission” is actually composed by both the P-GRB and the peak of the extended afterglow (Ruffini et al., 2001, 2009; Ruffini, 2011).

The value of B strongly affects the ratio of the energetics of the P-GRB to the extended afterglow phase. It also affects the time separation between the corresponding peaks (Ruffini et al., 2009; Ruffini, 2011). For baryon loading $B \lesssim 10^{-5}$, the P-GRB component is always energetically dominant over the extended afterglow (see Fig. 1). In the limit $B \to 0$, it gives rise to a “genuine” short GRB. Otherwise,

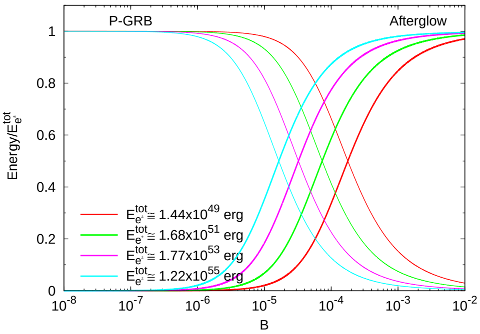

Fig. 1. At the fireshell transparency point, for 4 different values of $E^{tot}_{e^\pm}$, we plot as a function of B: the energy radiated in the P-GRB (thinner lines, rising when B decreases) and the one converted into baryonic kinetic energy and later emitted in the extended afterglow (thicker lines, rising when B increases), in units of $E^{tot}_{e^\pm}$. For details see Ruffini et al. (2000, 2001, 2009); Ruffini (2011).

when $3.0 \times 10^{-4} \lesssim B \leq 10^{-2}$, the extended afterglow emission predominates with respect to the P-GRB giving rise to a ‘long duration GRB. Since the “critical” value of B corresponding to the crossing point in Fig. 1 is a slowly varying function of the total energy $E^{e^\pm}_{tot}$, for $10^{-5} \lesssim B \lesssim 3.0 \times 10^{-4}$ the ratio of the total energies of the P-GRB and the extended afterglow is also a function of $E^{e^\pm}_{tot}$ (Ruffini et al., 2001, 2009; Ruffini, 2011).

The extended afterglow luminosity in the different energy bands is governed by two quantities associated with the environment: the CBM density profile, n_{CBM}, and the ratio of the effective emitting area A_{eff} to the total area A_{tot} of the expanding baryonic shell, $\mathcal{R} = A_{eff}/A_{tot}$ (Ruffini et al., 2004; Bernardini et al., 2005). This second parameter takes into account the CBM filamentary structure (Ruffini et al., 2005).

3. The “disguised” short GRB class

In the context of the fireshell model, we considered a new class of GRBs, pioneered by Norris & Bonnell (2006). This class is characterized by an occasional softer extended emission after an initial spike-like emission. The softer extended emission has a peak luminosity lower than the one of the initial spike-like emission. As shown in the prototypical case of GRB 970228 (Bernardini et al., 2007) and then in GRB 060614 (Caito et al., 2009), GRB 071227 (Caito et al., 2010) and in GRB 050509b (de Barros et al., 2011), we can identify the initial spike-like emission with the P-GRB and the softer extended emission with the peak of the extended afterglow. A crucial point is that the time-integrated extended afterglow luminosity (i.e. its total radiated energy) is much higher than the P-GRB one. This unquestionably identifies these GRBs as canonical long duration GRBs with $B > 10^{-4}$. The consistent application of the fireshell model allows us to infer the CBM filamentary structure and average density, which, in that specific case, is $n_{CBM} \sim 10^{-3}$ particles/cm^3, typical of a galactic halo environment (Bernardini et al., 2007). This low CBM density value explains the peculiarity of the low extended afterglow peak luminosity and its more protracted time evolution. These features are not intrinsic to the progenitor, but depend uniquely on the peculiarly low value of the CBM density. Hence we called these sources "fake" or "disguised" short GRBs. This led us to expand the traditional classification of GRBs to three classes: "genuine" short GRBs, "disguised" short GRBs, and the remaining "long duration" ones.

A CBM density $n_{CBM} \sim 10^{-3}$ particles/cm^3 is typical of a galactic halo environment, and GRB 970228 was indeed found to be in the halo of its host galaxy (Sahu et al., 1997; van Paradijs et al., 1997). We therefore proposed that the progenitors of this new class of disguised short GRBs are merging binary systems, formed by neutron stars and/or white dwarfs in all possible combinations, which spiraled out from their birth place into the halo (see Bernardini et al., 2007; Caito et al., 2009; Kramer, 2008). This hypothesis can also be supported by other observations. Assuming that the soft-tail peak luminosity is directly related to the CBM density, short GRBs displaying a prolonged soft tail should have a systematically smaller offset from the center of their host galaxy. Some observational evidence was found in this sense (Troja et al., 2008; Fong et al., 2010; Berger, 2011).

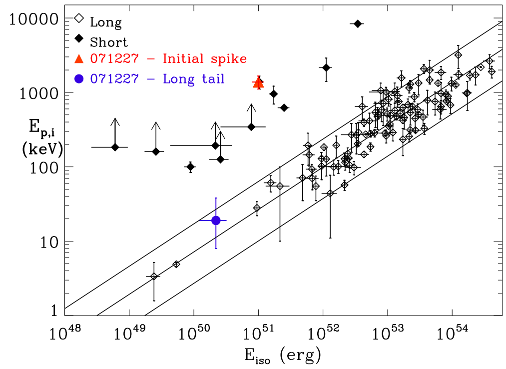

Fig. 2. Location of the initial short spike and soft long tail of GRB 071227 in the $E_{p,i} - E_{iso}$ plane. The data points of long GRBs are from Amati et al. (2008, 2009), the data points and limits of short GRBs are from Amati (2006); Amati et al. (2009); Piranomonte et al. (2008). The continuous lines show the best-fit power law and the 2σ confidence region of the correlation, as determined by Amati et al. (2008). Details in Caito et al. (2010).

4. Implications for the Amati relation

The most effective tool for determining the nature and, then, interpreting the different classes of GRBs, is the Amati relation (Amati et al., 2002; Amati, 2006; Amati et al., 2009). This empirical spectrum-energy correlation states that the isotropic-equivalent radiated energy of the prompt emission E_{iso} is correlated with the cosmological rest-frame νF_ν spectrum peak energy $E_{p,i}$: $E_{p,i} \propto (E_{iso})^a$, where $a \approx 0.5$ and a dispersion $\sigma(\log_{E_p}) \sim 0.2$. The Amati relation holds only for long duration bursts, while short ones, as it has been possible to prove after the "afterglow revolution" and the measurement of their redshift, are inconsistent with it (Amati, 2006; Amati et al., 2009). This dichotomy can naturally be explained by the fireshell model. As we recalled in Sect. 2, within this theoretical framework the prompt emission of long GRBs is dominated by the peak of the extended afterglow, while that of the short GRBs is dominated by the P-GRB. Only the extended afterglow emission follows the Amati relation (see Guida et al., 2008; Caito et al., 2010). Therefore, all GRBs in which the P-GRB provides a negligible contribution to the prompt emission (namely the long ones, where the P-GRB is at most a small precursor) fulfill the Amati relation, while all GRBs in which the extended afterglow provides a negligible contribution to the prompt emission (namely the short ones) do not (see Bernardini et al., 2007, 2008; Guida et al., 2008; Caito et al., 2009, 2010). As a consequence, for disguised short bursts the two components of the prompt emission must be analyzed separately. The first spikelike emission alone, which is identified with the P-GRB, should not follow the Amati relation; the prolonged soft tail, which is identified with the peak of the extended afterglow, should instead follow the Amati relation. This has been confirmed in the cases of GRB 060614, GRB 071227 and GRB 050509b (Caito et al., 2010; de Barros et al., 2011, see also Fig. 2).

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