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The spectral evolution in the 2–700 keV energy band of the entire sample of GRBs observed with WFC and GRBM aboard BeppoSAX

F. Frontera[1,2], L. Amati[2], C. Guidorzi[1], R. Landi[2], and V. La Parola[3]

[1] Università di Ferrara, Dipartimento di Fisica, Via Saragat 1, I-44100 Ferrara, Italy
e-mail: frontera@fe.infn.it

[2] Istituto Nazionale di Astrofisica – Istituto Astrofisica e Fisica Cosmica, Via Gobetti 101, I-40129 Bologna, Italy

[3] Istituto Nazionale di Astrofisica – Istituto Astrofisica e Fisica Cosmica, Via La Malfa, 153, I-90146 Palermo, Italy

Abstract. We present some preliminary results obtained from a systematic analysis of GRBs simultaneously observed with the Gamma Ray Burst Monitor and the Wide Field Cameras aboard the *BeppoSAX* satellite.

Key words. Gamma Ray Bursts – GRB spectral evolution – X-/gamma-ray Observations – GRB prompt emission – BeppoSAX satellite

1. Introduction

In spite of the huge advances in the knowledge ot the GRB afterglow properties, the GRB phenomenon is still poorly understood. Of crucial importance, it is recognized to be the study of the prompt emission, which is directly connected with the original explosion.

The radiation emission mechanisms at work are still matter of debate. Most best fit models are still empirical: power-law (PL), smoothly broken PL proposed by Band et al. (1993)(Band law, BL), power–law with high energy exponential cutoff (CPL). Physical models have also been proposed (e.g., synchrotron shock model (Tavani 1996), synchrotron self-Compton (Mészáros & Rees 2000), Compton up-scattering of low energy photons (Liang et al. 1997), superposition of blackbody spectra (Blinnikov et al. 1999), Compton drag emission (Lazzati et al. 2000), thermal emission plus a possible non-thermal tail (Lazzati et al. 2009)), but none of them is capable to describe all the aspects of the emission and its origin in a convincing way.

Relations between intrinsic peak energy $E_{p,i}$ and GRB released energy/luminosity (e.g., Amati relation Amati et al. (2002) or the Yonetoku relation Yonetoku et al. (2004)) could help to solve the radiation mechanism issue. However these relations, derived using the GRB time integrated spectral properties, are still debated, mainly due to the dispersion of the data points around the best fit power–law. It is well known that the spectral properties evolve with time. What happens about

Send offprint requests to: F. Frontera these relations when the time resolved properties are considered?

Recently several authors have concentrated their interest on the time resolved spectra, using mainly BATSE data (Ghirlanda et al. 2007; Ryde & Pe'er 2009; Peng et al. 2009). According to Ryde & Pe'er (2009), the time resolved spectra of GRB FRED-like pulses can be fit with a BB+PL, as also suggested by Lazzati et al. (2009). However the BATSE data cover the hard X-/soft gamma-ray energy band (20-2000 keV). What happens if the band is extended down to 2 keV?

We present here some preliminary results of the time resolved spectral analysis of the entire sample of GRBs observed with BeppoSAX WFC plus GRBM in the 2-700 keV band. Results on the time resolved properties of 8 GRBs were published by Frontera et al. (2000).

2. The GRB sample

The entire GRB sample is made of 55 events simultaneously detected with both the Gamma Ray Burst Monitor (GRBM) and the Wide Field Cameras (WFCs) aboard the BeppoSAX satellite. An exhausive description of the GRBM can be found in Frontera et al. (2009) and references therein, while that of the WFCs can be found in Jager et al. (1997). The main features of the GRBM were the following: an energy band from 40 to 700 keV, a Field of View (FOV) of about 2π sr, a time resolution, in the case of a GRB trigger, down to 0.5 ms in the 40-700 keV energy channel, and a continuous transmission of the counts integrated over 1 s in 2 energy channels (40-700 keV, ¿100 keV) and over 128 s in 240 energy channels to cover the 40–700 keV band. Concerning the WFCs, their main features were the following: an energy band from 2 to 28 keV, a FOV of 40x40 deg (FWZR), 31 energy channels with a time resolution of 0.5 ms.

The GRBM/WFC events were extracted from the population of 1082 GRBs detected with the GRBM (see GRBM catalog in the paper by Frontera et al. (2009)). The 2–700 keV time-resolved spectral analysis performed thus far concerns 45 GRBs.

3. Data analysis and fit models

Each GRB time profile is subdivided in time slices with duration that takes into account the GRB pattern and the statistics of the data. Background is properly subtracted.

Spectra are derived in each of the time slices. In the spectral fits, GRBM and WFC normalization factors were left free to vary in the range 0.8-1.3, found in extended cross-calibrations.

Many input models were tested. We found that a photoelectrically CPL (as called in the XSPEC spectral deconvolution software Arnaud (1996)) gives the best fits and the best constrained parameters of the derived spectra. Thus we adpoted this model. However a photoelectrically absorbed BL was used when the peak energy E_p of the $EF(E)$ spectrum derived from CPL is inconsistent with that derived from BL and, at the same time, BL gives a better fit and a constrained value of the high energy index β.

4. Preliminary results

4.1. Test of the blackbody plus power–law model

We have also tested the blackbody plus power-law (BB+PL) model recently proposed by Ryde & Pe'er (2009) for the fit of the time resolved spectra of 56 strong BATSE GRBs. If we use only BATSE data, we confirm their results for GRB 990123), the only GRB of their sample observed with *BeppoSAX*GRBM plus WFC. However this model is rejected when we fit the BATSE+WFC or WFC+GRBM time resolved spectra. In Fig. 1 we show the results obtained in the case of the 6 s duration count spectrum measured during the rise of GRB990123.

This issue is the subject of a paper in preparation (Frontera et al. 2010).

4.2. Evolution of the spectral parameters with time

Depending on GRB and its brightness, the time resolved spectral parameters have a different behavior with time. As far as the peak energy

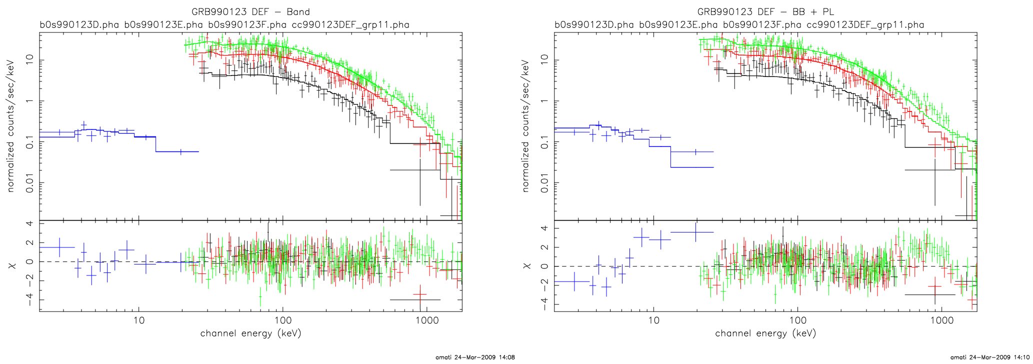

Fig. 1. Count spectrum of 6 s duration taken during the rise of GRB990123. *Left panel*: Fit with a BL model. *Right panel*: Fit with a BB+PL.

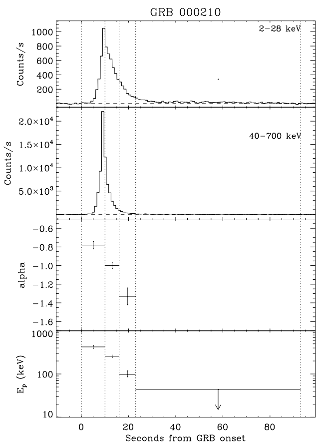

Fig. 2. Light curve in two energy bands and behavior of the spectral parameters with time in the case of the bright event GRB 000210.

E_p of the $EF(E)$ spectrum is concerned, its time behaviour is twofold: in some cases it mimics the GRB pattern of the prompt emission, in other cases it decreases with time (e.g., Fig 2). As far as the low energy photon index α is concerned, in general it decreases with time (i.e., the spectrum softens), but we also found some cases in which it mimics the GRB pattern. In any case, we do not find any correlation between α and E_p, with α mainly determined by the WFCs data.

4.3. Time resolved peak energy versus flux

As it is well known, a key importance relation is that found by us in 2002 Amati et al. (2002)(now known as Amati relation) between intrinsic time averaged peak energy $E_{p,i}$ and time averaged relased energy E_{iso} of the GRB prompt emission, derived assuming isotropy. This relation is now widely confirmed by all GRBs (about 100) with known redshift z Amati et al. (2009), detected thus far, except the nearest GRB ever observed (*BeppoSAX* GRB 980425, with $z = 0.0085$). A similar relation was later found by Yonetoku et al. (2004), using the peak luminosity $L_{p,iso}$, instead of the total released energy, evaluated from the time averaged spectrum of the prompt emission. Either the Amati relation or the Yonetoku relation are very robust, but they are characterized by a significant spread, that is inconsistent with the statistical uncertainty in the data points (see Fig. 3 for E_p vs. E_{iso}). Also due to this spread, the Amati relation is questioned by some authors Band & Preece (2005); Butler et al. (2007, 2009); Shahmoradi & Nemiroff (2009), who state that it could be the result of selection effects. However other authors Ghirlanda et al. (2005, 2008); Nava et al. (2008, 2009) find that these effects do not invalidate the relation. The time resolved spectra can help to settle this issue.

We find that, within each burst, the measured peak energy is related with the 2–700

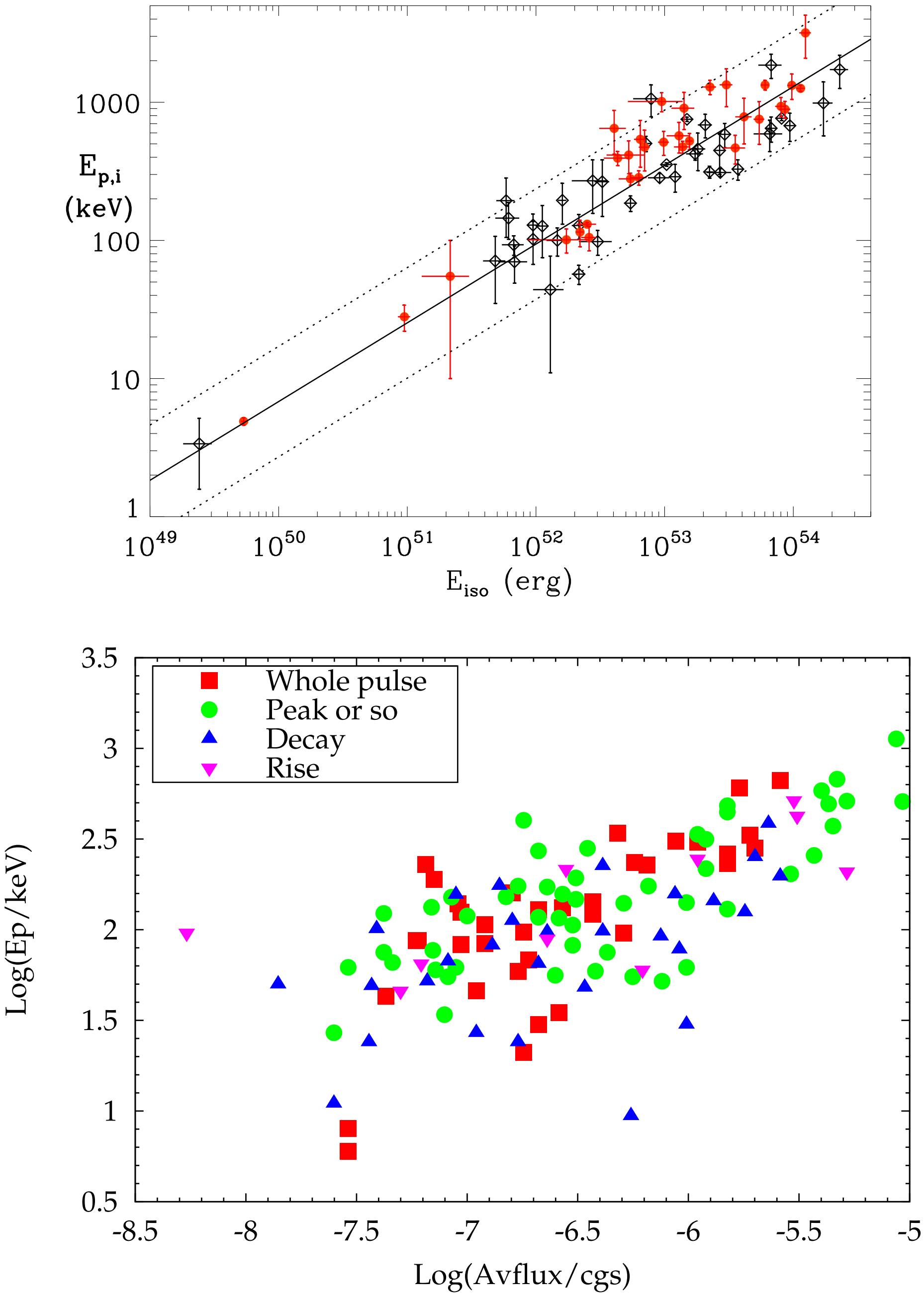

Fig. 3. *Left panel*: the $E_{p,i}$ vs. E_{iso} correlation based on the time averaged spectra of a sample of 70 GRBs with known redshift (Amati et al. 2008). *Right panel*: time resolved peak energy vs. 2–700 keV flux. Different colours and simbols are used for different subinterval types within each GRB.

keV flux and this dependence is clearly independent of the redshift or other selction effects. The E_p vs. 2–700 keV flux (F_{2-700}) is shown, for comparison with Amati relation, in Fig. 3 for those GRBs in our sample for which constrained values of E_p are possible. As it can be seen, like in the case of the Amati relation, a positive correlation between E_p and F_{2-700} is outstanding. The best fit is obtained with a power–law (PL) $E_p \propto F^{\alpha}_{2-700}$, with index $\alpha = 0.43 \pm 0.07$ and a significant extrinsic scatter ($\sigma_{logE_p} = 0.30$). This scatter is apparent in the figure above, especially for fluxes lower than 10^{-6} cgs. A higher contribution to the scatter seems to be due to the parameters derived during the event tail.

By limiting the analysis to the GRBs with known redshift z, we derived, in the z corrected plane, the intrinsic time resolved peak energies $E_{p,i}$ versus the corresponding bolometric (in the 1–10000 keV rest frame energy band) luminosities L_{bol}. As also expected, we find that the PL correlation between $E_{p,i}$ and L_{bol} is confirmed. The derived best fit PL index is consistent with 0.5, and the scattering of the (E_p, F_{2-700}) data points is almost unchanged.

Exhaustive results of our comparative analysis are the subject of a paper in preparation.

5. Conclusions

The 2-700 keV time resolved spectra of 55 GRBs detected with BSAX WFC+GRBM are being analyzed and compared.

A photoelectric absorbed power–law with a high energy exponential cutoff (CPL) appears to be the best model for the comparison of the time resolved spectra. A smoothly broken power–law (Band law) is used in a few controversial cases.

A blackbody + power–law model is inconsistent with the WFC data. The results found by Ryde & Pe'er (2009) and their consequences are not confirmed by our results.

No correlation between measure peak energy E_p and photon index of the CPL is found. This result strenghtens the E_p vs. Flux correlation.

A strong power–law correlation between the measured E_p and the 2-700 keV flux is observed, with a power–law index= 0.43 ± 0.07 and significant extrinsic scatter ($\sigma_{\log E_p} = 0.30$).

A power–law index consistent with 0.5 and a similar scatter is found in the case of $E_{p,i}$ vs. L_{iso}.

All these results strenghten the Amati correlation with a possible explanation of the spread of the data points around the best fit PL in terms of the spread of the time resolved E_p vs. Flux correlation within each GRB. The final analysis is in progress and will be published soon.

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