Mem. S.A.It. Vol. 79, 144

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Unveiling GRB hard X–ray afterglow emission with Simbol–X

L. Amati[1], E. Maiorano[1], E. Palazzi[1], R. Landi[1], F. Frontera[1,2], N. Masetti[1], and L. Nicastro[1]

[1] INAF – Istituto di Astrofisica Spaziale e Fisica cosmica di Bologna, Via P. Gobetti 101, I-40129 Bologna, Italy
[2] Dipartimento di Fisica, Università di Ferrara, I-44100 Ferrara, Italy

Abstract. Despite the enormous progress occurred in the last 10 years, the Gamma-Ray Bursts (GRB) phenomenon is still far to be fully understood. One of the most important open issues that have still to be settled is the afterglow emission above 10 keV, which is almost completely unexplored. This is due to the lack of sensitive enough detectors operating in this energy band. The only detection, by the *BeppoSAX*/PDS instrument (15-200 keV), of hard X-ray emission from a GRB (the very bright GRB 990123), combined with optical and radio observations, seriously challenged the standard scenario in which the dominant mechanism is synchrotron radiation produced in the shock of a ultra-relativistic fireball with the ISM, showing the need of a substantial revision of present models. In this respect, thanks to its unprecedented sensitivity in the 10–80 keV energy band, Simbol–X, through follow–up observations of bright GRBs detected and localized by GRB dedicated experiments that will fly in the >2010 time frame, will provide an important breakthrough in the GRB field.

Key words. X–rays: instrumentation – Gamma–rays: bursts

1. Introduction

Gamma–Ray Bursts (GRBs) are short and intense flashes of low–energy gamma–rays coming from random directions in the sky at unpredictable times and with a rate of ∼ 300/year as measured by all–sky detectors in low Earth orbit. In the last 10 years, observations allowed huge steps forward in the comprehension of these phenomena, such as their cosmological distance scale, their huge luminosities, their host galaxies, the likely association of "long" (∼2–1000 s) GRBs with the collapse of peculiar massive stars and of "short" (<∼2 s) GRBs with the merging of compact objects (NS—NS, NS–BH). See, e.g., Meszaros (2006) for a recent review. However, there are still several open issues, one of the most important being the emission mechanisms in play and their relative contribution to the total radiation. Follow–up observations at longer wavelengths (X–ray, optical, radio) of GRB fields generally lead to the detection of delayed, fading emission (the afterglow). According to the general interpretation, the afterglow emission is described reasonably well, in the framework of the fireball model (Cavallo & Rees 1978; Meszaros & Rees 1997), as synchrotron emission from accelerated electrons when a

Send offprint requests to: amati@iasfbo.inaf.it

relativistic shell collides with an external medium, the interstellar medium in our case. In this scenario the afterglow spectrum at any given time consists generally of a four segments power law. The spectral and temporal indices are linked together by relationships that depend on the geometry of the fireball expansion (Sari et al. 1998) and the properties of the circum–burst environment (density, distribution). The average temporal decaying index,$\sim$1.3, and spectral photon index, $\sim$2.2, obtained from observations (De Pasquale et al. 2006) give an electron spectral index p$\sim$2.2$-$2.5, which is indeed typical of shock acceleration.

2. Afterglow emission in hard X–rays

WHile the X–ray afterglow emission of GRB has been widely studied up to $\sim$10 keV, the upper bound of the energy band of past and presently flying X–ray telescopes (e.g., *BeppoSAX*, *Chandra*, *XMM–Newton*, *Suzaku*), in only one case, GRB 990123, the afterglow was detected, by the *BeppoSAX* Phoswich Detection System (PDS), in the hard X-rays, up to 60 keV. The multiwavelength observations of the afterglow emission (from radio to X–rays) of this event cannot be readily accomodated by basic synchrotron afterglow models (Maiorano et al. 2005). While the temporal and spectral behavior of the optical afterglow is possibly explained by a synchrotron cooling frequency between the optical and the X-ray energy band, in X–rays this assumption only accounts for the slope of the 2–10 keV light curve, but not for the flatness of the 0.1–60 keV spectrum. A possible solution to the problem was suggested by Corsi et al. (2005) including the contribution of Inverse Compton (IC) scattering to the hard X-ray emission. Anyway, even this IC component is not able to provide a self–consistent interpretation of the afterglow. On the other hand, leaving unchanged the emission mechanism requires modifying the hydrodynamics by invoking an ambient medium whose density rises rapidly with radius and by having the shock losing energy. Thus, GRB 990123 left us an open puzzle, showing the need and the importance of afterglow measurements above 10 keV.

3. Afterglow measurements with Simbol–X

The expected sensitivity of Simbol–X in the 15–60 keV energy band is of the order of 1 μCrab for a 1 Ms Observation (Ferrando et al. 2006), i.e. several hundreds times lower than that of any previous instrument operating in this energy range. Thus, in principle this mission can open a new observational window for the study of GRB afterglow emission and provide a big step forward in the comprehension of the physical mechanism(s) at play. For instance, at 11hr from the GRB onset about 1/3 of GRB afterglows show a flux > 100 μcrab (De Pasquale et al. 2006), and thus spectra of very good statistical quality up to several tens of keV can be obtained with Simbol–X. A serious concern for this kind of studies is the time required to Simbol–X to be on target since a GRB has been detected and localized by other space missions, together with the general observational strategy that will be adopted for this mission. However, even a 100 ks observation starting about 2 days from the GRB onset can provide sensitive spectral measurements in the 15–60 keV energy band for the bright afterglows. Indeed, the 10% brightest afterglows show a 2–10 keV flux >230 μCrab at 11hr from the burst onset; by assuming a typical photon index of 2.1 (i.e. Crab–like) and the average temporal decay index (1.3), the expected 15–60 keV flux at 48 hr is about 35 μCrab, and the average flux from 48hr to 76 hr (corresponding to a 100 ks long observation period) is about 25 μCrab. Fig. 1 shows the simulation of this observation performed with the public Simbol–X tools; as can be seen, the source is well detected in the image, with a significance of about 18 σ in the 15–60 keV energy band. We also show in Fig. 2 the simulation of the spectrum of GRB 990123, generated by assuming a sinchrotron + IC model similar to that adopted by Corsi et al. (2005) to fit the hard X–ray excess measured by the *BeppoSAX*/PDS, scaled to 48 hr from GRB onset. As can be seen, the

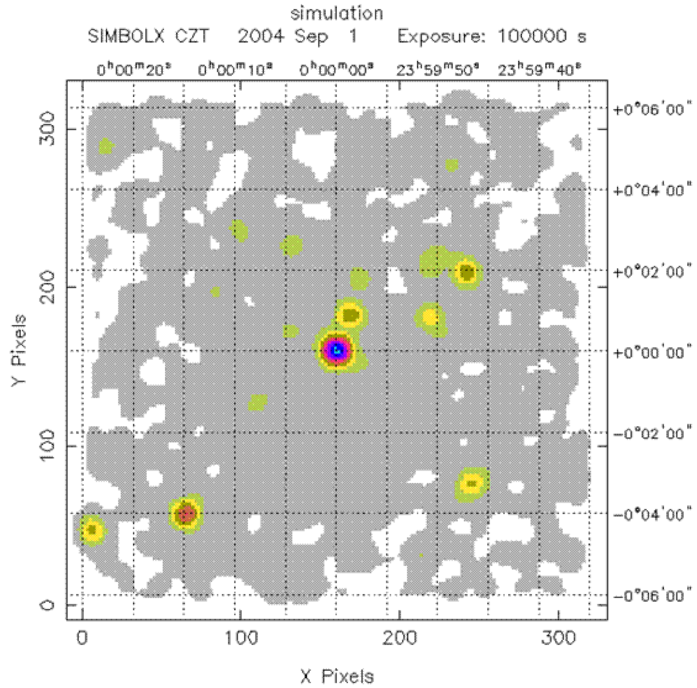

Fig. 1. Simulated Simbol–X 15–60 keV image of a bright afterglow (like GRB 990123) observed for 100 ks starting from 48 hrs since the GRB onset.

statistical quality of the data allows to characterize the spectrum up to about 60 keV and the deviation of the hard X–ray signal (due to the IC component) with respect to the simple power-law model (the synchrotron component) is clearly detected. The significance of the excess in the 15–60 keV range is about 6.5 σ . We stress that the assumption of an observation starting time at 2 days after the GRB is a very conservative one, and that pointings with 1 day delay, or even less, could be achievable. The simulated image and spectra shown in Fig. 1 and 2 hold also for an afterglow of medium intensity pointed at 12 hr from the burst. We also remark that, in light of the impact of the only one hard X-ray measurement available (GRB 990123), even a few of such observations can provide a significant contribution to the GRB science.

Finally, to do this kind of science, Simbol–X will need GRB detection and location to at least a few arcminutes by other satellites and/or optical telescopes. The GRB–related missions operating in the >2010 time frame may include: Swift (operating since December 2004, GRB detection and arcsec localization), SVOM (GRB detection and few arcmin localization), GLAST (GRB detection and possibly few arcmin localization), EDGE (GRB detection and a few arcsec localization) and possibly GRB detectors on other spacecrafts. Thus, also from this point of view GRB follow-up observations with Simbol–X are expected to be feasible.

4. Conclusions

Despite the enormous observational progress occurred in the last 10 years, the GRB phenomenon is still far to be fully understood.

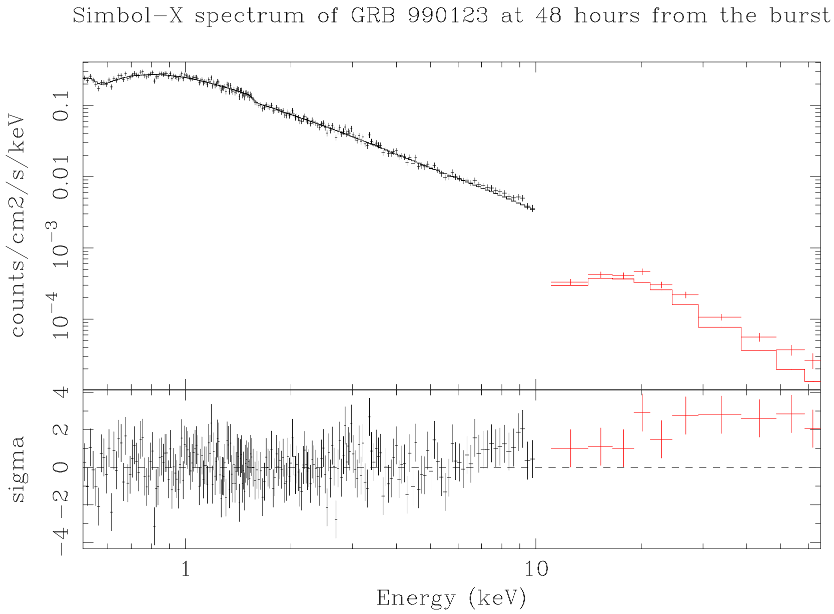

Fig. 2. Simulated Simbol–X 0.5–60 keV spectrum of the afterglow of GRB 990123 with an observation starting 48 hrs from the GRB onset and an exposure of 100 ks; the simulated spectrum (synchrotron + IC component) is fitted with a simple power-law.

One of the main open issues is the understanding of physical mechanisms at the basis of prompt and afterglow emission; the case of GRB 990123 shows that measurements of the nearly unexplored GRB hard (> 15 keV) X-ray afterglow emission can provide very stringent test to emission models. Thanks to its unprecedented sensitivity in the 15–60 keV energy band, Simbol–X can provide a significant step forward in this field. Simulations based on observed distribution of X–ray afterglow fluxes and spectral and decay indices show that even a 100 ks TOO observation of a bright GRB starting 2 days after the event can provide sensitive spectral measurements and allow to discriminate different emission components for a significant fraction of events. Moreover, it is likely that significantly lower TOO stat times (12/24 hr) will be possible for a few event/year, thus allowing sensitive hard X–rays measurements also for medium intensity GRB afterglows. The needed GRB detection and few arcmin localizations will be provided by space missions presently planned to be in flight in the >2012 time frame and by optical telescopes.

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