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GRB 051210: *Swift* detection of a short gamma ray burst

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ABSTRACT

Aims. The short/hard GRB 051210 was detected and located by the *Swift*-BAT instrument and rapidly pointed towards by the narrow field instruments. The XRT was able to observe a bright, rapidly fading X-ray emission. We present the analysis of the prompt and afterglow emission of this event.
Methods. The BAT spectrum is a power-law with photon index 1.0 ± 0.3. The X-ray light curve decays with slope -2.58 ± 0.11 and shows a small flare in the early phases. The spectrum can be described with a power law with photon index 1.54 ± 0.16 and absorption $(7.5^{+4.3}_{-3.2}) \times 10^{20}$ cm^{-2}.
Results. We find that the X-ray emission is consistent with the hypothesis that we are observing the curvature effect of a GRB that occurred in a low density medium, with no detectable afterglow attributable to an external shock. We estimate the density of the circumburst medium to be lower than 3×10^{-3} cm^{-3}. We also discuss different hypothesis on the possible origin of the flare.

Key words. gamma rays: bursts – X-rays: bursts

1. Introduction

It has long been known that the T_{90} duration and hardness ratio of the population of gamma-ray bursts (GRBs) show a bimodal distribution, where two classes can be identified: long GRBs, with duration longer than 2 s and short GRBs lasting less than 2 s and showing a harder spectrum (Mazets et al. 1981; Norris et al. 1984; Kouveliotou et al. 1993). While long GRBs have been studied in good detail and their origin is now established in the explosion of massive stars leading to very energetic core collapse supernovae (e.g. Woosley 1993; Bloom et al. 1999; Stanek et al. 2003; Hjorth et al. 2003), very little was known about short GRBs, mainly because of the difficulty of localizing them with high precision. A good progenitor candidate for short GRBs has been identified in the merger of two compact objects in a tight binary (e.g. Eichler et al. 1989).

Thanks to the rapid repointing capability of the *Swift* satellite (Gehrels et al. 2004), that allows for an accurate localization of the afterglow within few minutes from the burst onset, this gap is now being filled, and up to now seven short GRBs have been localized and their afterglow detected (GRB 050509B: Gehrels et al. 2005; Bloom et al. 2005a; GRB 050709: Villasenor et al. 2005; Fox et al. 2005; GRB 050724: Barthelmy et al. 2005b; Campana et al. 2006; GRB 050813: Retter et al 2005; GRB 051210 Mangano et al. 2005a; GRB 051221A: Parsons et al. 2005; GRB 060121: Arimoto et al. 2006). The association of two of these events (GRB 050509B and GRB 050724) with late-type galaxies and the amount of energy involved (significantly lower than for long GRBs) support the hypothesis that short/hard bursts are the product of the merger of two compact objects in a binary system. The lack of any supernova signature in the identified host galaxies confirms this idea. On the other hand, the association of GRB 050709 and GRB 051221A with star forming galaxies is not at variance with this hypothesis, and merely extends the range of possible lifetimes of the progenitor system, which can be located both in early-type, old population galaxies, and in star-forming galaxies.

GRB 051210 triggered the *Swift*-BAT instrument (Barthelmy et al. 2005a) on December 12, 2005 at 05:46:21 UT (Mangano et al. 2005a). The BAT position calculated on-board was RA = $22^{h}00^{m}47^{s}$, Dec = $-57°38'01''$ (J2000), with a 90% uncertainty of 3′. The burst was classified as short after the on-ground analysis of the BAT data (Sato et al. 2005; Barthelmy et al. 2005c). Both its spectral lag ($-0.0010^{+0.0150}_{-0.0170}$ s, Barthelmy et al. 2005c, and its position on a T_{90} vs. hardness plot (Fig. 1) are typical of short GRBs (Norris & Bonnell 2006; Kouveliotou et al. 1993).

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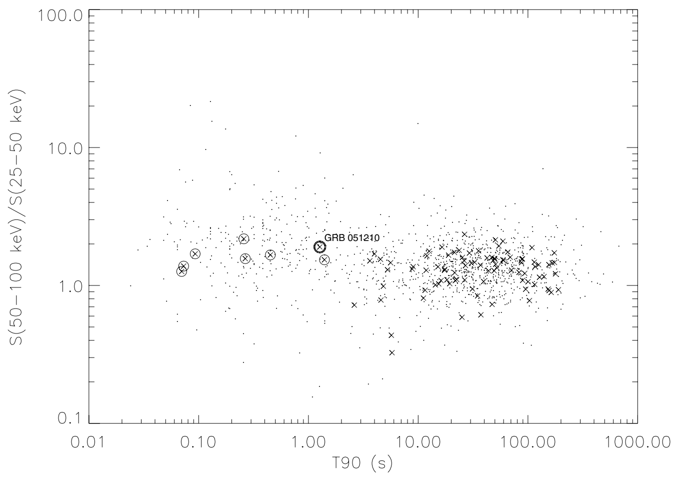

Fig. 1. Hardness ratio versus T_{90} for the BAT and BATSE bursts. The hardness ratio is defined as the ratio of flux in the 50−100 keV band to that in the 25−50 keV band. BATSE bursts are represented by dots and BAT bursts by the symbol "X." Short BAT bursts are circled in the figure and GRB 051210 is indicated. One can see that GRB 051210 falls well within the short burst distribution for both the BAT and BATSE samples.

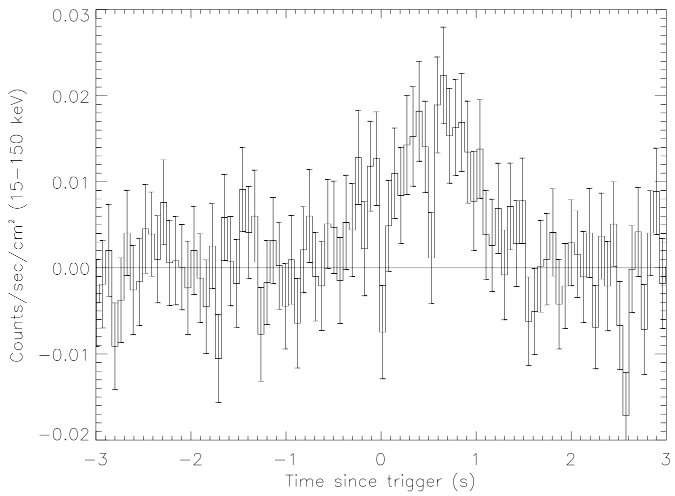

Fig. 2. BAT light curve of the prompt emission of GRB 051210 (15−150 keV). Each time bin is 64 ms long.

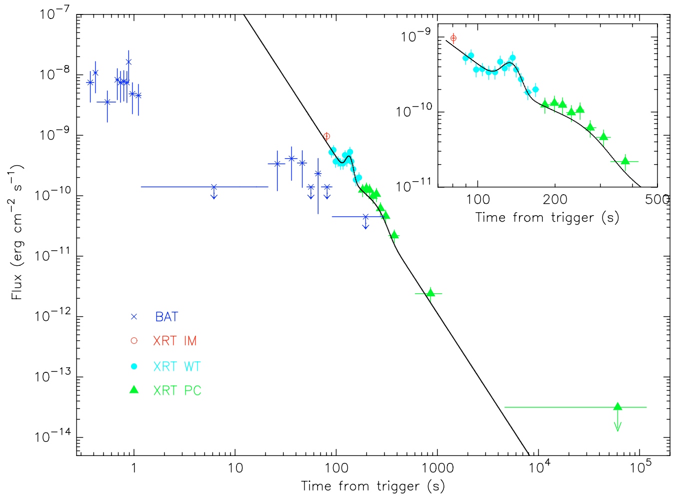

Fig. 3. XRT light curve decay of GRB 051210. The XRT count rate (0.2−10 keV) was converted into flux units by applying a conversion factor derived from the spectral analysis. The solid line represents the best fit model to the XRT data. The BAT light curve was extrapolated into the XRT energy band by converting the BAT count rate with the factor derived from the BAT spectral parameters.

The spacecraft slewed immediately and the XRT (Burrows et al. 2005) and UVOT (Roming et al. 2005) began observing the field 79.2 s and 70 s after the trigger, respectively. The XRT onboard centroiding procedure found a bright, fading, uncatalogued X-ray source. No source was detected in any of the UVOT filters (Blustin et al. 2005). Two sources were detected within the XRT error circle by the 6.5 m Clay/Magellan telescope using the LDSS3 instrument: Bloom et al. (2005b) report a clear detection of an apparently extended (north by north-east) source 2.″9 from the XRT position and a second marginal detection 1.″1 from the XRT position.

In this paper we report on the analysis of the prompt and afterglow emission of GRB 051210 as observed by the *Swift* X-ray instruments. Sections 2 and 3 describe the observations, the data reduction and the analysis of the BAT and XRT data respectively. The results are discussed in Sect. 4.

2. BAT observation

The BAT event data were re-analyzed using the standard BAT analysis software included in the HEASOFT distribution (v. 6.0.3), as described in the *Swift* BAT Ground Analysis Software Manual (Krimm et al. 2004), that incorporates post-launch updates to the BAT response and to the effective area and includes the systematic error vector to be applied to the spectrum. The light curve showed a double peak with T_{90} = 1.27 ± 0.05 s (Fig. 2). The BAT count rate falls to background levels after $\sim T + 1.4$ s. However, as seen in Fig. 3, there is a suggestion of emission centered at $\sim T + 35$ s, similar to what is described for other short bursts by Norris & Bonnell (2006). There is no detected hard X-ray emission coincident with the X-ray flare at $T + 150$ s. The average spectrum accumulated between $T + 0.184$ and $T + 1.088$ can be described by a power law with $\Gamma = 1.1 \pm 0.3$, with a total fluence of $(8.1 \pm 1.4) \times 10^{-8}$ erg cm^{-2} in the 15−150 keV band. A fit with a Band model is unconstrained.

3. XRT observation

3.1. Data reduction

The XRT is designed to perform observations in different read-out modes (see Hill et al. 2004, for a detailed description of the XRT modes), switching automatically between modes according to the count rate level of the source, in order to optimize the collected information and minimize the pile-up in the data. Currently, the Imaging (IM), Windowed Timing (WT) and Photon Counting (PC) modes are fully operating, while Photo-Diode (PD) mode is not in use.

XRT began observing the field of GRB 051210 in auto state and went through the correct sequence of read-out modes. The first IM frame (lasting 2.5 s) allowed for the on-board localization of the burst (Mangano et al. 2005a). This was followed by 85.1 s in WT mode and then by 37.0 ks in PC mode.

The data were calibrated, filtered and screened using the XRTDAS (v.2.3) software package to produce cleaned photon list files.

Table 1. Spectral fit results.

	BAT	XRT
NH (cm^{-2})	–	$(7.5^{+4.3}_{-3.2}) \times 10^{20}$
Γ	1.0 ± 0.3	1.54 ± 0.16
χ^2_{red} (d.o.f.)	1.0 (57)	0.78 (25)

The position of the source was recalculated on the ground using the task XRTCENTROID on the PC image and applying the boresight correction through the updated TELDEF file provided by the *Swift* Science Data Center (Angelini et al. 2005). The refined XRT coordinates are RA = $+22^h00^m41.3^s$, Dec = $-57°36'48''.2$ (J2000), with $4''.2$ uncertainty (Mangano et al. 2005b).

The photons for the timing and spectral analysis were extracted from a region with 20 and 30 pixels radii for WT and PC data, respectively. In order to account for the pile-up in the PC data, photons from a radius of 2.5 pixels around the source centroid were excluded from the analysis, and the remaining photons were then corrected by the fraction of point spread function lost. The presence of a hot column crossing the source close to the centroid was accounted for, both in the WT and PC data, using a correction factor derived from the ratio of the effective areas calculated for the same region with and without the hot column. The count rate of the source during the IM frame was estimated integrating the DN above the background in a 30 pixel radius circle and then following the procedure described in Goad et al. (2005).

3.2. Data analysis

Figure 3 shows the BAT and XRT light curve of GRB 051210. The BAT data (originally in the 15−150 keV band) were extrapolated into the XRT energy band (0.2−10 keV) and the source observed count rates converted into flux using the appropriate conversion factor derived from the spectral analysis. A fading X-ray source is detected only in the first 1000 s after the onset. At first order, the XRT light curve can be modelled with a single power law with decay index 2.47 ± 0.08. A flare in the early X-ray emission is evident over this simple fit, and can be well described by a Gaussian centered at 134 ± 2 s with $\sigma = 10 \pm 2$ s. The inclusion of this component in the fit improves the χ^2_{red}(d.o.f.) from 2.17(23) to 1.14(20), with F-test chance probability of 1×10^{-3}. A second Gaussian centered at 216 ± 44 s with $\sigma = 63 \pm 38$ s yields a further marginal improvement to the fit, with F-test chance probability of 4×10^{-2}. After including these two features, the best fit slope becomes 2.58 ± 0.11.

In order to compare the decay before and after the flares, we made an estimate of the decay slope before the flares by comparing the photon arrival times in the first 26 s of the WT mode observation with power laws with different slopes through a Kolmogorov-Smirnov test. We get $\alpha_{wt} = 2.35^{+0.30}_{-0.20}$, where the best value is the one that maximizes the probability that the photon arrival times follow a power law distribution, and the quoted errors define the interval of the slope values for which the test provides an "acceptance" probability higher than 90%. This slope is consistent both with the average decay and with the late time light curve.

The XRT spectrum (Fig. 4, Table 4) is relatively hard and can be well described with an absorbed power law ($\Gamma = 1.54 \pm 0.16$) with absorption slightly in excess with respect to the Galactic

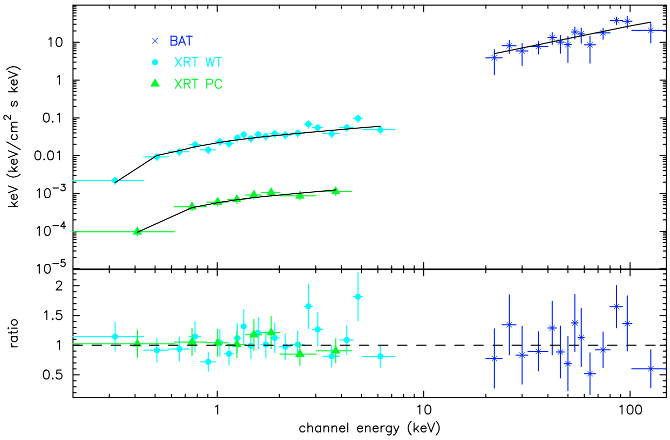

Fig. 4. XRT 0.2–10 keV and BAT 15–150 keV energy spectra of GRB 051210, with the best-fit absorbed power law model and residuals. The best fit parameters for the BAT and XRT data are reported in Table 1. The BAT and XRT data are not simultaneous: the BAT spectrum extends from $T - 0.184$ s to $T + 1.088$ s after the trigger, the WT spectrum spans from $T + 87$ s to $T + 173$ s and the PC spectrum spans from $T + 173$ s to $T + 7100$ s, where T is the time of the trigger.

value (2.2×10^{20} cm^{-2}, Dickey & Lockman 1990). All quoted errors are at 90% confidence level.

4. Discussion

GRB 051210 is one of the few short GRBs for which we have an X-ray detection and an accurate location. Its X-ray light curve decays rapidly and the X-ray counterpart is no longer detectable after ~1 ks. The X-ray light curve decays as a power law with slope $\alpha = 2.58 \pm 0.11$. Superimposed on it we detect a flare peaking at $T + 134$ s, and a less significant bump at $T + 216$ s. The BAT and XRT spectra can be described with a power law, with photon indices 1.0 ± 0.3 and 1.54 ± 0.16 respectively.

GRB 051210 is the third brightest short GRB observed by *Swift* until now, after GRB 050724 and GRB 051221A; the other short GRBs located to date are at least one order of magnitude fainter in count rate in the XRT band. With respect to GRB 050724 (Campana et al. 2006) and GRB 051221A (Soderberg et al. 2006), this GRB shows many differences both in the temporal behaviour and in the spectral distribution. The X-ray spectrum is harder than GRB 051221A (which has $\Gamma \sim 2$), and similar to that of GRB 050724 in its first 80 s. However, GRB 050724 shows significant spectral softening, while GRB 051210 does not show any spectral evolution.

The X-ray light curve of GRB 051210 does not show any flattening or break: it consists of a single steep power law, to be compared to the high complexity of GRB 050724 (several flares and a flattening after ~800 s) and to the slow decay of GRB 051221 ($\alpha \sim -1$). The shape of the light curve is very similar to that of GRB 050421 (Godet et al. 2006), a 10 s burst with a steep temporale decay ($\alpha \sim -3$) with two flares in the first 200 s. The rapid fading of the source and the lack of any flattening in the light curve after the initial decay may indicate that the GRB occurred in an extremely low density medium (naked GRB, Kumar & Panaitescu 2000; Page et al. 2005) where the radiation emitted by the forward shock, generated by the impact of the initial shock front with the surrounding interstellar medium, is expected to be undetectable. The steep decay of the X-ray emission is fully consistent with the hypothesis that we are observing a low energy tail of the prompt emission from an internal shock through the so-called curvature effect (Kumar & Panaitescu 2000; Dermer 2004; Zhang et al. 2006). The radiation observed as the tail of a peak is expected to be the off-axis emission of the shocked surface arriving at the observer at later times, due to the curvature of the emitting shell. This emission would decay as $t^{-\alpha} = t^{-(\Gamma+1)}$, where Γ is the photon index of the GRB emission. In the case of GRB 051210 we get $\alpha = \Gamma + 1 = 2.54$, in very good agreement with the observed slope (2.58 ± 0.11). However, the extrapolation of the XRT light curve back to the burst onset does not match the BAT points by a few decades. This could be explained if the XRT light curve is in fact the tail of a flare peaking at the time before the XRT observation and too weak to be detected by the BAT: extended emission, visible 10 to 60 s after the burst onset, has been reported by Norris & Bonnell (2006) for a few short bursts observed with BATSE. The few marginally significant points in the BAT light curve starting at $\sim T + 20$ s suggest that this could be the case. Within such an interpretation, the zero time point of the rapid decay component should be shifted to the beginning of the rising segment of the relevant flare (Zhang et al. 2006; Liang et al. 2006), which marks the reactivation of the central engine. We then re-fit for the decay index after such a shift. The temporal decaying slope changed to 2.2 ± 0.1, which is still marginally consistent with the theoretical predicted value, where $\alpha = \Gamma + 1 = 2.54 \pm 0.16$.

If we are seeing only the tail of the prompt emission, and the afterglow is not detectable, we can derive an estimation for the density of the interstellar medium n in the vicinity of the burst. For a limiting flux of $F_{\rm LIM} = 1 \times 10^{-14}$ erg cm^{-2} s^{-1}, and considering that we have no detectable emission at $T_0 + 10^4$, we can infer n from the expression of the expected afterglow flux according to the standard afterglow models (Sari & Esin 2001; Sari et al. 1998). We assume z to be the average redshift measured for short GRBs up to now (0.3), and estimate the energy of the afterglow ($E_{\rm a}$) from the 1−1000 keV fluence of the prompt emission, as indicated by (Frail et al. 2001). We account for the decay of the afterglow at a time $T_0 + 10^4$, assuming an electron index $p = 2.2$ and we assume this observation to be at a frequency between the peak frequency $\nu_{\rm m}$ and the cooling frequency $\nu_{\rm c}$. With these assumptions, we get $n < 3 \times 10^{-3}$, that confirms the trend put in evidence by Soderberg et al. (2006), that short GRBs tend to be in low-density environments. We note that the estimate of n is subject to uncertainties of z, $E_{\rm a}$ and p (e.g. it increases with z and p but decreases with $E_{\rm a}$). In any case, the inferred density is lower than the typical values inferred from long GRBs (Panaitescu & Kumar 2002).

Flaring activity has been previously observed in other short GRBs: GRB 050709 (Fox et al. 2005) shows a flare between 25 and 130 s and a late flare at about 16 d, and GRB 050724 (Barthelmy et al. 2005b; Campana et al. 2006) shows at least four flares. Interestingly, the epoch of the first flare is ∼100 s for both of those two events and for GRB 051210. Moreover, evidence for X-ray emission at this timescale has been reported in the stacked light curves of several BATSE short GRBs (Lazzati et al. 2001). Delayed activity from the inner engine has been generally invoked to interpret flares (Burrows et al. 2005; Zhang et al. 2006; Romano et al. 2006; Falcone et al. 2006). This is less problematic for long duration GRBs since in the collapsar scenario, there is a large reservoir of fuel and the fragmentation or gravity instability in the collapsing star may form clumps that are accreted at different times, leading to delayed X-ray flares (King et al. 2005). However, this cannot be applied to short GRBs, if we accept the hypothesis that they originate in the merger of two compact objects in a binary system (NS-NS or NS-BH), a scenario supported by the recent observations. Hydrodynamical simulations suggest that the central engine activity of merger events cannot last more than a few seconds (Davies et al 2005). Perna et al. (2006) suggest a common origin for flares in long and short GRBs: some kind of instability (likely gravitational instability) can lead to the fragmentation of the rapidly accreting accretion disc that forms after the GRB (both in the collapsar and in the merger model), creating blobs of material whose infall into the central object produces the observed flares. Proga & Zhang (2006) suggest that magnetic fields may build up near the black hole and form a magnetic barrier that temporarily block the accretion flow. The interplay between the magnetic barrier and the accretion flow can turn on and off the accretion episodes, leading to erratic X-ray flares at late epochs. This mechanism also applies to both long and short GRBs. Dai et al. (2006) propose that the postmerger product for the NS-NS system may well be a massive neutron star if the neutron star equation of state is stiff enough. The differential rotation of the neutron star would lead to wind-up of magnetic fields, leading to magnetic reconnection events that power X-ray flares. These scenarios are all consistent with a magnetic origin of the flares based on energetics arguments (Fan et al. 2005). Finally, an alternative hypothesis has been formulated by MacFadyen et al. (2005): the interaction of the GRB outflow with a noncompact stellar object is suggested as a natural explanation for a flare after the burst. This model is restricted to interpret only one flare (and therefore cannot be applied to GRB 050724 but may be relevant for GRB 051210) and the outflow is required to be not collimated. In any case, the presence of a flare at a similar epoch (around 100 s) in three out of five short bursts observed to date, if also confirmed by future short GRBs, is a point that is worth investigating and calls for better understanding.

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