GRB 120711A: A burst with long-lasting high-energy emission detected by *INTEGRAL*

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Long-lived hard X-ray/γ-ray emission from individual γ-ray bursts (GRBs) has been observed on several occasions lasting up to several thousand seconds, with characteristics suggestive of an external shock origin. On July 11$^{\text{th}}$ 2012, a long and intense GRB was detected by *INTEGRAL*, with a burst duration of $\sim$115 s and fluence of 2.8×10^{-4} erg cm^{-2} in the 20 keV–8 MeV energy range. Detailed analysis of the *INTEGRAL* IBIS/ISGRI data shows emission lasting $\sim$10 ks, in the 20–40 keV band. We present hard X-ray observations over 4 decades in time and hard X-ray to γ-ray spectra across 6 decades in energy with the use of *INTEGRAL* and *Fermi*/LAT data. This emission is modelled using the standard afterglow scenario, indicating a forward shock origin. At 1 hour post-trigger, the fluence (20–300 keV) over 1.2 ks, is an order of magnitude greater than the upper limit obtained for the most intense *INTEGRAL* burst, GRB 041219A.

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1. Introduction

Long-lived soft γ–ray emission, detected by the co-addition of large numbers of GRBs detected by BATSE and *Fermi*/GBM has been observed to extend to $\sim$ 1000 s post-trigger [1, 2, 3, 4]. Before the launch of *Fermi*, GeV emission was observed by EGRET from GRB 940217, 90 minutes after the burst onset, with no corresponding BATSE contribution at lower energies [5]. However, *Fermi* has now detected high-energy emission from several GRBs up to $\sim$1000 s after the trigger, that can be modelled by an external shock mechanism [6, 7].

2. GRB 120711A

At 02:44:48 UT on July 11$^{\text{th}}$ 2012 (denoted as T_0 throughout the paper), an extremely bright and long GRB (Fig. 1) was detected by *INTEGRAL* (RA = 06h18m48.7s, Dec = -71°00′04″, [8]). Most unusually, the burst also had long-lasting emission up to $\sim$1200 s after the trigger, detected by both IBIS/ISGRI and SPI in the 20–50 keV energy range [9, 10]. The burst was rapidly followed up by many other telescopes. *Fermi*/LAT observations started $\sim$300 s after the trigger and emission was detected up to 2 GeV [11, 12], while robotic optical telescopes detected a rapidly brightening and decaying optical counterpart, peaking at magnitude $\sim$12 (R and V bands, [13]) when the burst was still in progress. A tentative spectroscopic redshift of 1.405 was made using Gemini-S [14], while a photometric determination of $z \sim 3$ was suggested by *GROND* [15].

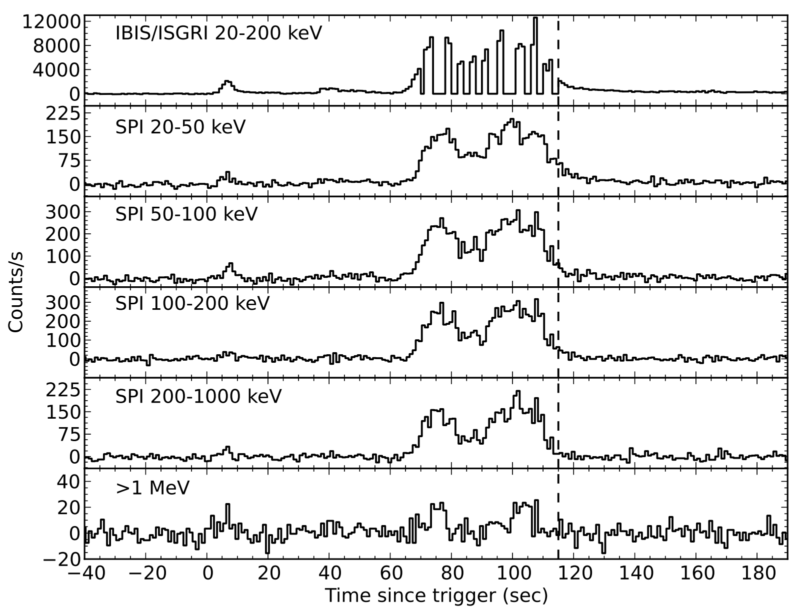

Figure 1: Energy resolved light curves of GRB 120711A. The top panel shows the 20–200 keV IBIS/ISGRI light curve severely affected by telemetry gaps. The lower panels show the SPI light curves in different energy bands. In all cases, the light curves are binned over 1 s. The dashed vertical line represents the end of the T_{90} at T_0+115 s.

3. Data analysis

The ESA *INTEGRAL* observatory [16] contains three high energy instruments: IBIS/ISGRI, sensitive from ∼20 keV to ∼1 MeV [17]; a high resolution spectrometer SPI, sensitive in the 20 keV–8 MeV energy range [18]; and two X-ray monitors, JEM-X, operating in the 3–35 keV energy range [19]. All 3 high-energy instruments have coded masks and operate simultaneously with the same pointing axis. However, the fields of view (FoV) are not the same for all instruments, with JEM-X having the smallest value of $\sim 5^{\circ}$. *INTEGRAL* observations normally consist of a series of pointings (science windows) of duration ∼ 3.5 ks (∼1 hour). Data from the region of GRB 120711A are available from one hour before the trigger, to 12 hours after the burst. The intensity of the burst resulted in a large number of telemetry gaps during the prompt emission phase in the IBIS/ISGRI data. Thus, only data from the SPI instrument are used for the analysis of the prompt emission. Owing to the large off-axis angle (9.5°) at which the burst occurred, JEM-X could not observe the burst until $\sim T_0$+6 ks, where T_0 is the trigger time. All *INTEGRAL* analysis is performed with the Offline Science Analysis package (OSAv9).

The *Fermi*/LAT detector [20] started to observe the field of view of the GRB at $\sim T_0$+300 s until $\sim T_0$+1.1 ks, when the position of the burst was occulted by the Earth. A second set of observations was made after the occultation phase between $\sim T_0$+2.5 ks and $\sim T_0$+7.2 ks. Due to background constraints, only photons with energies higher than 100 MeV are considered in this analysis.

All the resulting spectra are fit using the XSPECv12 package. All errors are quoted at 1σ level for one parameter of interest.

4. Results

4.1 Prompt emission

GRB 120711A was a long and bright GRB with a T_{90} of ∼115 s in the SPI 20–200 keV energy range, and a peak flux of 32 ph cm^{-2} s^{-1} in the 20 keV–8 MeV band. The burst consisted of a hard precursor followed by a soft flare at $\sim T_0$+40 s, mostly visible below 50 keV, and then ∼ 60 s of long multi-peaked and overlapping pulses with emission >1 MeV (Fig. 1).

Several spectral models are used to study the SPI time-averaged spectrum over T_{90}: single power-law, Band model, blackbody+power-law, power-law with exponential cutoff (CPL), and a multi-blackbody model (multi-bb). The CPL model marginally provides the best fit to the data with a χ^2/dof =35/30, a photon index, α, of 1.05 ± 0.02 and a break energy of 1190^{+148}_{-28} keV, making this the hardest GRB (in terms of break energy) triggered by *INTEGRAL* to date [21, 22]. The total fluence measured over T_{90} is 2.82×10^{-4} erg cm^{-2} in the 20 keV–8 MeV energy band, and 4.35×10^{-5} erg cm^{-2} in the 20–200 keV band.

The time-resolved spectral analysis during the main emission phase from T_0+63 s to T_0+113 s (Fig. 2) shows a hardness-intensity correlation. Although this is quite common behaviour in GRBs, the negligible softening from peak to peak is rather unusual. This can also be seen in the evolution of the photon index during the main pulse (Fig. 2). It is interesting to note that, although the break energy softens during the count rate dip at $\sim T_0$+90 s, there is no evolution of photon index, α, during the main emission from $\sim T_0$+70 s to $\sim T_0$+110 s.

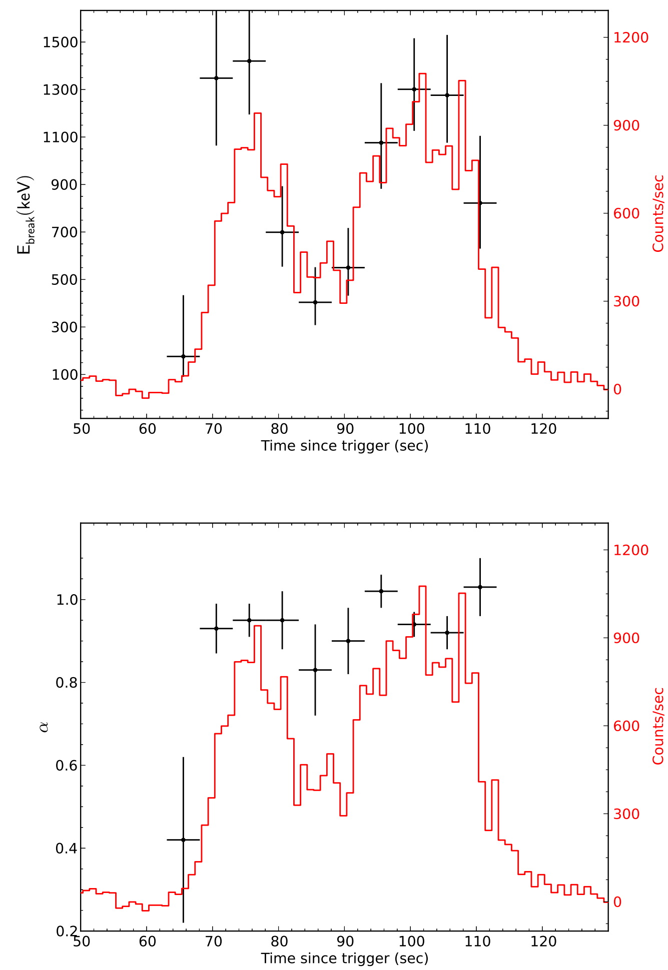

Figure 2: Time-resolved (5 s binning) spectral analysis during the main pulse of the prompt emission of GRB 120711A. On the top panel, the variation of the break energy with time obtained from the CPL model is shown. On the bottom panel, the evolution of the photon index from the CPL model is shown. The light curve in the 20 keV to 8 MeV energy band is shown as a solid line in both panels.

4.2 Long-lived hard X-ray emission

The IBIS/ISGRI data shows there is emission from this burst up to 100 keV at $\sim$6 ks post trigger and up to 50 keV at $\sim$10 ks post trigger (Fig. 3). Furthermore, emission in the 20–40 keV band is detected at the 5 σ level in the time interval T_0+17 ks to T_0+27.8 ks by combining IBIS/ISGRI data from 3 science windows (Fig. 4).

The IBIS/ISGRI light curve of the burst and long-lived hard X-ray emission in the 20–40 keV energy band up to T_0+10 ks is shown in Fig. 4. The top panel shows the light curve binned by science window ($\sim$ 3.6 ks). The lower panel shows the same light curve, starting from the decay of the main burst and with smaller time bins. It shows characteristics typical of those seen by *Swift*/XRT for GRB X-ray afterglows and is best fit ($\chi^2/\mathrm{dof} = 43/46$) by a series of three power-laws with break times at $t_{\mathrm{break},1} = 126 \pm 5$ s, $t_{\mathrm{break},2} = 267 \pm 22$ s, $t_{\mathrm{break},3} = 2.5 \pm 0.8$ ks, and $t_{\mathrm{break},4} = 7.5 \pm 2.5$ ks; plus

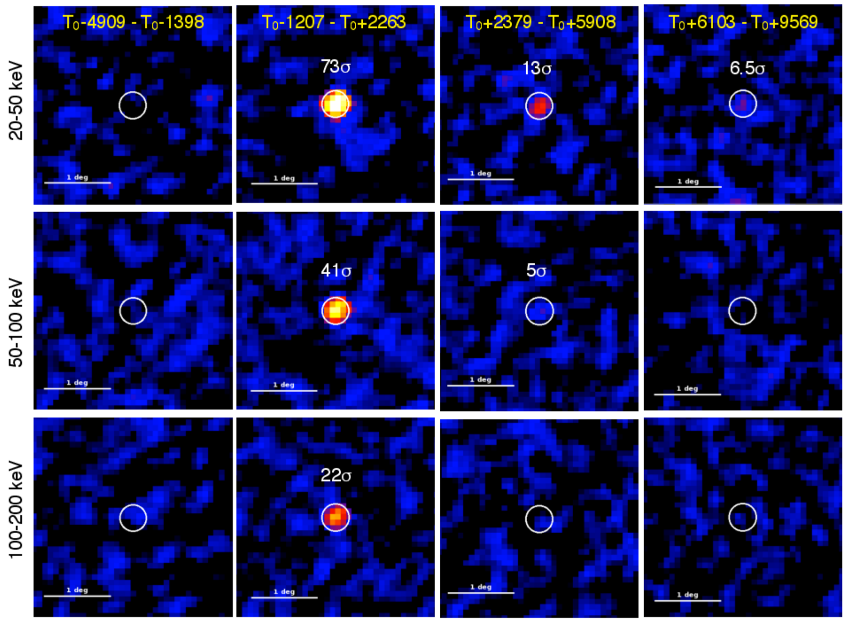

Figure 3: The partial FoV of IBIS/ISGRI ($3^\circ \times 3^\circ$), centered on GRB 120711A for four exposure times (columns) and three energy bands (rows). Each image shows one full science window (~ 1 hour). The images in the first column are before the GRB, the second column includes the GRB, and the last two columns are intervals after the GRB prompt emission. The significances of the detections are shown in the relevant images.

a constant count rate at ~ 3 counts/s, for T> T_0+8 ks. This constant count rate is consistent with the background rate in IBIS/ISGRI for this field of view for such binning.

The availability of *Fermi*/LAT data from T_0+300 s, provides an opportunity to perform spectral analysis across 6 decades in energy, when combined with the IBIS/ISGRI data (Fig. 5). Due to its lower sensitivity, SPI does not provide additional constraints to the IBIS/ISGRI data, and thus is not considered in this part of the analysis. The spectrum is best fit by a single power-law with photon index, $\alpha = 2.07 \pm 0.03$.

5. Discussion

INTEGRAL has localised more than 90 GRBs to date, and no such long-lived emission has been observed in any other case. A previous study placed upper limits from bright *INTEGRAL* GRBs of $\sim 5 \times 10^{-6}$ erg cm^{-2} in the 20–400 keV energy band, for emission 1 hour after the burst [23]. A similar upper limit of $\sim 10^{-6}$ erg cm^{-2}, in the same energy band and over 1.2 ks at < 1 hour after the burst, was obtained for GRB 041219A, which is the brightest GRB detected by *INTEGRAL* to date. In the case of GRB 120711A, the detected fluence, measured from T_0+270 s to T_0+2300 s, is $\sim 10^{-5}$ erg cm^{-2} in the 20–300 keV energy band, exceeding the upper limit for GRB 041219A by about one order of magnitude. Using the data from the prompt emission, the rest frame (k-

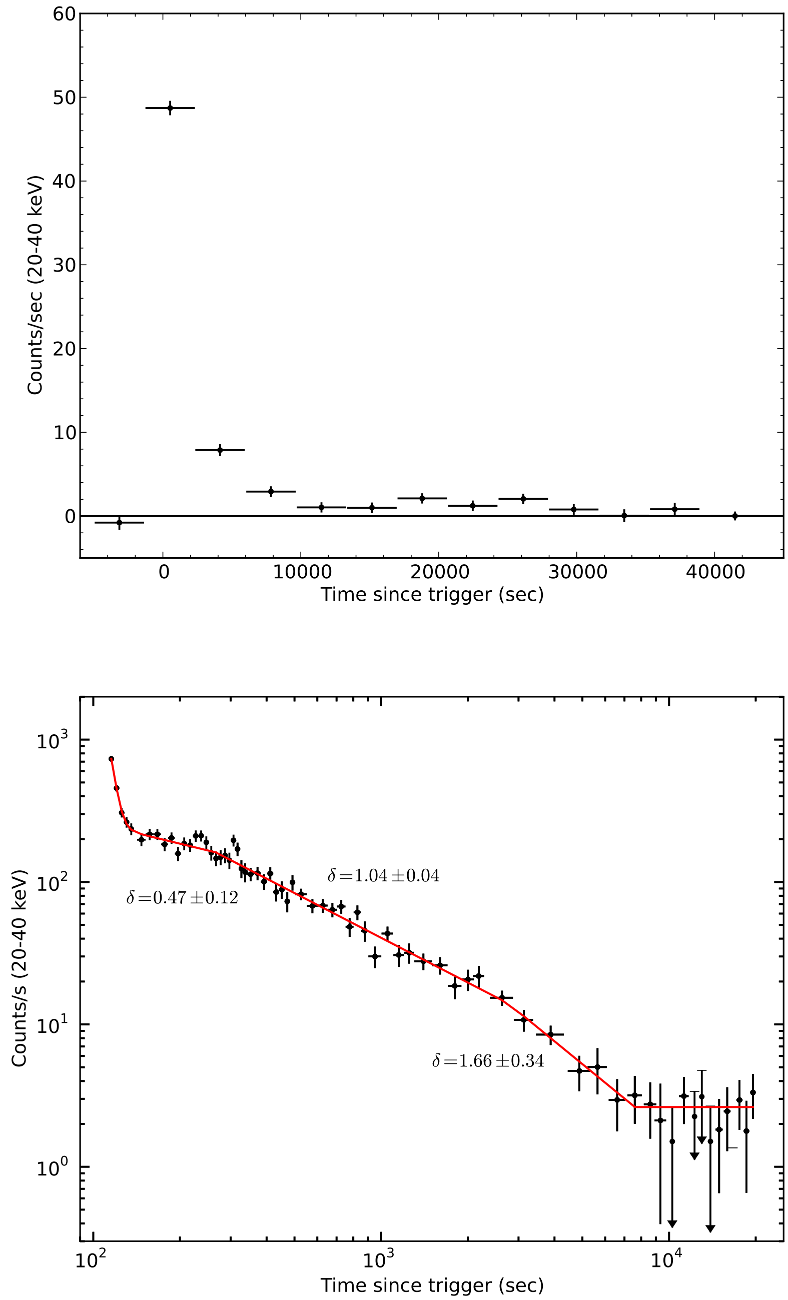

Figure 4: IBIS/ISGRI background subtracted light curve in the 20–40 keV energy range. Each point in the top panel corresponds to one science window. The solid line represents the zero count rate level. On the bottom panel, the light curve with smaller time bins up to T_0+10 ks is shown. The solid line represents the best fit to the data, consisting of four breaks ($t_{break,1} = 126 \pm 5$ s, $t_{break,2} = 267 \pm 22$ s, $t_{break,3} = 2.5 \pm 0.8$ ks, and $t_{break,4} = 7.5 \pm 2.5$ ks). The different power-law decay indices in each interval are also shown. The constant count rate level after $t_{break,4}$ is $\sim$3 counts/s, consistent with the background rate in IBIS/ISGRI for this field of view.

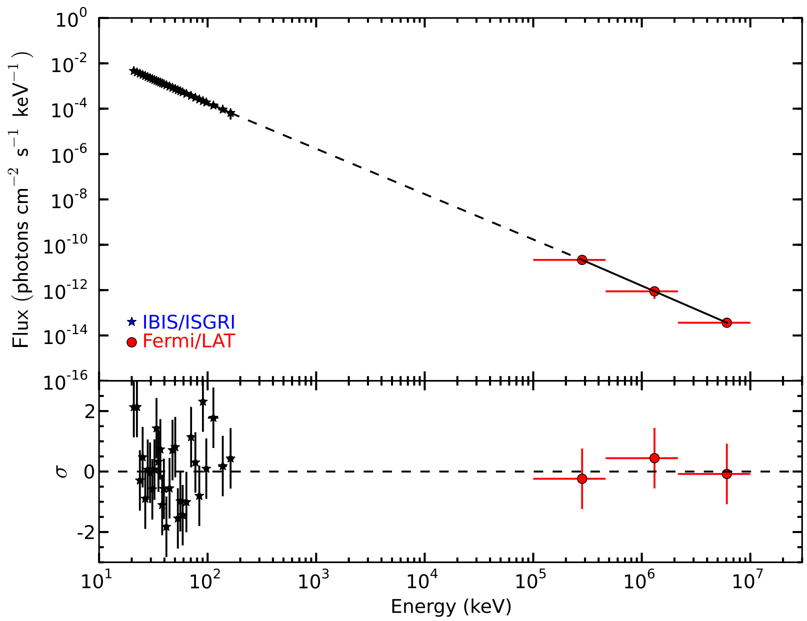

Figure 5: Broadband spectral fit (T_0+300 s to T_0+1050 s) to the simultaneous IBIS/ISGRI and *Fermi*/LAT data for GRB 120711A. The data are well fit by a single power-law model (α =2.07 $\pm$ 0.03, χ^2/dof = 37/31). The best fit model is represented by the solid and dashed (interpolation) lines.

corrected) isotropic energy radiated during the T_{90} in the 1 keV–10 MeV energy band, assuming a redshift of z=1.4(3) is $E_{\rm iso} = 1.65 \times 10^{54}$ (6.08×10^{54}) ergs.

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