EXTREMELY HARD GAMMA-RAY SPECTRA OF THE GRBS DETECTED WITH INTEGRAL[1]

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ABSTRACT

Thanks to the IBIS Compton mode, the INTEGRAL[1] satellite is able to detect (and localize) bright and hard (E $>$ 200 keV) GRBs, which happen outside of the nominal INTEGRAL telescopes field of view. We have developed a method to analyze INTEGRAL data and to produce spectra. We present results for three bursts: 030406A, 030722A and 031111A of dozen detected by the IBIS Compton mode during the first year of the INTEGRAL mission.

Key words: GRB; gamma-ray; spectroscopy.

1. INTEGRAL/IBIS AND INTEGRAL GRBS

INTEGRAL (International Gamma Ray Astrophysics Laboratory) is an ESA mission devoted to space research in gamma-ray energy range. The IBIS instrument is a coded mask telescope on-board the INTEGRAL. IBIS contains two detection layers in the detector plane ISGRI and PICsIT. ISGRI is an array (128×128) of pixels made of semiconductive CdTe, sensitive to photons between 15 keV and ∼1 MeV. Each pixel is a cuboid: 4 mm $\times$ 4 mm (face) $\times$ 2 mm (depth). PICsIT has the same detection area as ISGRI, and is an array of 64×64 scintillators, sensitive between ∼170 keV and 15 MeV located 94 mm below ISGRI. Each scintillator is a block: of CsI 9 mm $\times$ 9 mm (face) $\times$ 30 mm (depth). ISGRI and PICsIT can act as a Compton telescope, registering photons that are scattered in one and absorbed in the other detector. The coincidence time window is a parameter programmable on-board and it was set to ~ 4 microseconds. The Compton mode is sensitive between 200 keV and ∼5 MeV. See [1] also.

The INTEGRAL satellite may detect gamma-ray bursts (GRBs) in two different ways: for about 10 bursts per year taking place in the coded area (FoV) of IBIS/ISGRI, INTEGRAL provides accurate positions (∼2 arcmin) for rapid ground- and space-based follow-up observations [3]. A significantly larger number of GRBs occurs outside of the FoV of the instruments. These bursts can be monitored by the SPI anti-coincidence system: SPIACS [2].

2. METHODS

Up to now, detailed spectral analysis was possible only for bursts that happened in the INTEGRAL field of view with the use of the standard Integral software OSA. We have developed a method to analyze spectra of bursts placed outside of the nominal field of view of INTEGRAL/IBIS.

The IBIS collimator is 3 meter long and is mounted on top of the detector unit. The walls of the collimator are made of lead and act as a shield to photons with energies up to ≈ 200 keV. The optical depth of the shield is smaller for photons arriving at large angles. Thus hard photons from off-axis sources can pass through the shield and reach the detector. In particular some off axis GRBs are detectable in IBIS.

To obtain energetic spectrum of a burst we ran Monte Carlo simulations using the mass model [5, 6] of the INTEGRAL spacecraft to generate the detector response matrices (DRM) for a source located at the position of the given burst. We have taken into account: dead-times of detectors, data gaps, VETO, detectors signal thresholds,

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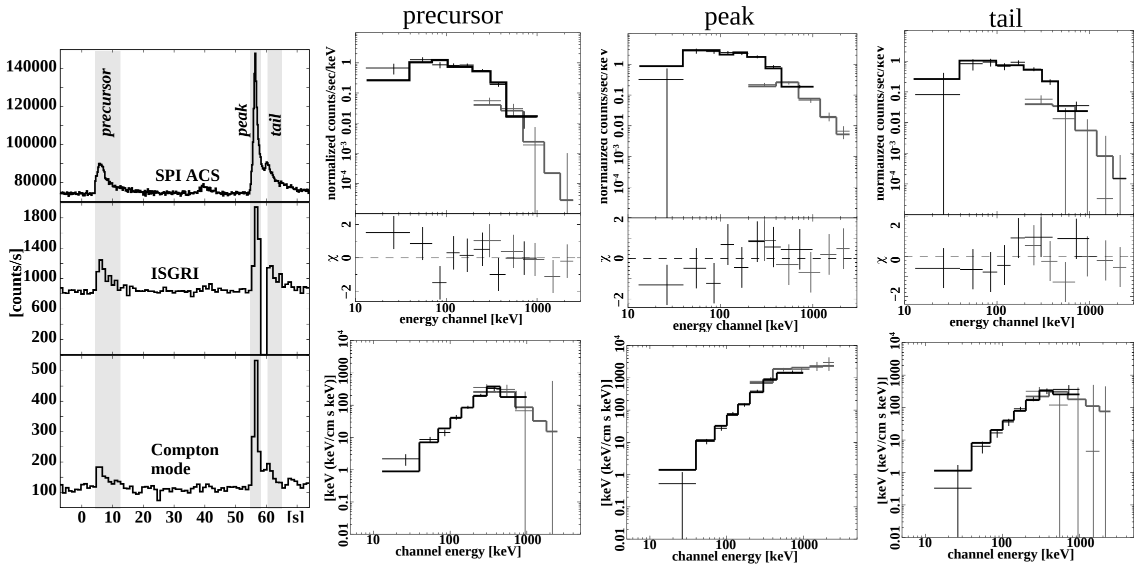

Figure 1. GRB 030406A. Photon countrates (left) in the INTEGRAL instruments: SPI-ACS, IBIS/ISGRI and IBIS Compton mode. Three right columns show spectra fitted to the combined ISGRI and Compton mode data. Upper panels show count spectra, while lower corresponding νF_ν spectra. Broken power law model was fitted in each case: to the precursor data (left of three), to the peak part data (center) and to the tail (right)

experimental background and on-board software processing settings. The ISGRI sensitivity window stretching from 24 to 450 keV was binned into seven channels. The Compton data were binned into six energy channels covering the range from 200 to 2500 keV. We used the standard XSPEC 11.2 [7] to fit the data.

3. RESULTS

We present the spectral analysis of three gamma ray bursts: 030406A, 030722A and 031111A.

3.1. GRB 030406A

This burst has been successfully triangulated by the 3[rd] IPN [9] on position with center on RA(2000) $= 19^h\,1^m\,43.0^s$, DEC(2000) $= -68^\circ\,4'\,39.4''$, using SPI-ACS/INTEGRAL, Ulysses, Konus-Wind, and Mars Odyssey data.

We have divided the data into three time intervals marked in gray in Figure 1 (left) as: *precursor*, *peak* and *tail*. The division of the main peak of the burst into the *peak* and *tail* was a consequence of the ISGRI data loss during the burst due to telemetry gap.

For each time region we tried to fit several models: single power law, broken power law, and a single black-body. The single power law model never fitted the combined ISGRI and Compton data. The broken power law fits the data very well in all analyzed regions: *precursor*, *peak* and *tail*. The best fit spectra are presented in Figure 1 (three right columns), and values of best fitted parameters are listed in Table 1.

The high energy index of $\beta = -1.7 \pm 0.3$ for *peak* may imply the absence of a peak in the source power spectrum νF_ν in the range covered by our data, i.e. up to 2.5 MeV. In order to estimate the lower limit on such a break compatible with the data we conducted advanced statistical analysis described in detail in [8]. We obtained $E_{\rm break}$ >1 110 KeV at 90% confidence level and $E_{\rm break}$ >880 keV at 99% confidence level. For details see [8].

Table 1. Results of the spectrum fits for three time ranges of GRB 030406. All the errors are at the 1σ level. chi^2/dof values for given fits amount respectively: 0.96, 1.19 and 1.19

part	[s]	α	β	$E_{\rm break}$
precursor	7.3	$0.0^{+0.3}_{-0.3}$	9.0^{+1}_{-6}	490^{+40}_{-180}
peak	2.81	$-1.5^{+0.7}_{-1.0}$	$1.7^{+0.4}_{-0.3}$	390^{+60}_{-50}
tail	4.3	$-0.8^{+0.7}_{-2.2}$	$2.8^{+1.2}_{-0.6}$	270^{+70}_{-50}

3.2. GRB 030722A

The IPN analysis of GRB 030722A yielded only an annulus, see [10]. Using the Compton mode data [8] we estimate the position of the burst on the IPN annulus to be RA(2000) $= 7^h\,6^m$ DEC(2000) $= -15^\circ 30'$ with the uncertainty of $\approx 4^\circ$. This position has been used for generation of the detector response matrix.

In case of GRB 030722A we have divided the data into two time intervals covering two peaks of the burst. Due

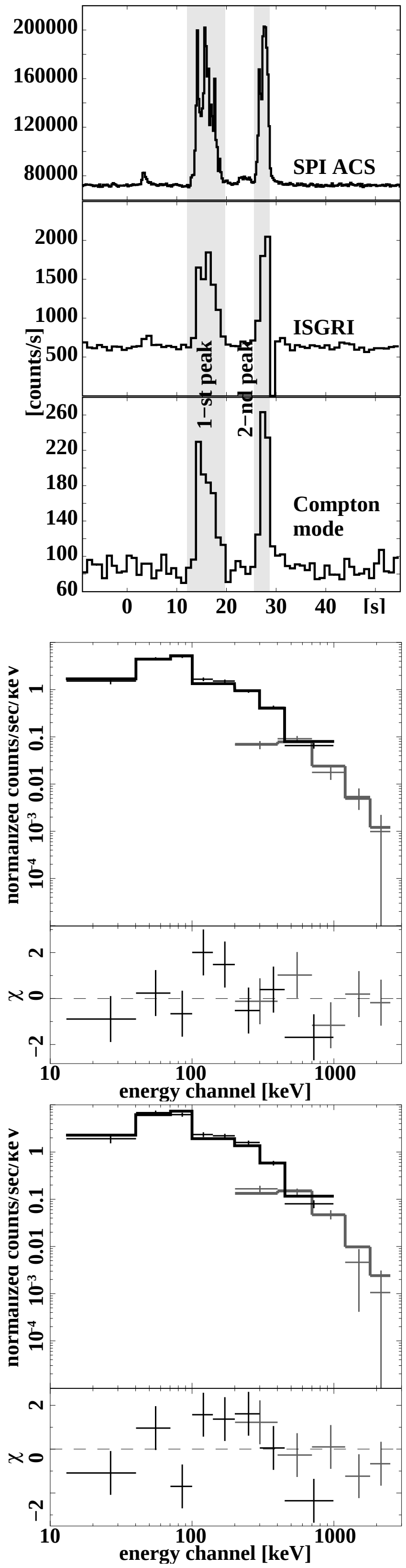

Figure 2. GRB 030722A. Photon countrates (upper panel) in the INTEGRAL instruments: SPI-ACS, IBIS/ISGRI and IBIS Compton mode. Two bottom figures show spectra fitted to the combined ISGRI and Compton mode data for two time ranges marked on the upper panel. Power law model was fitted for each peak data

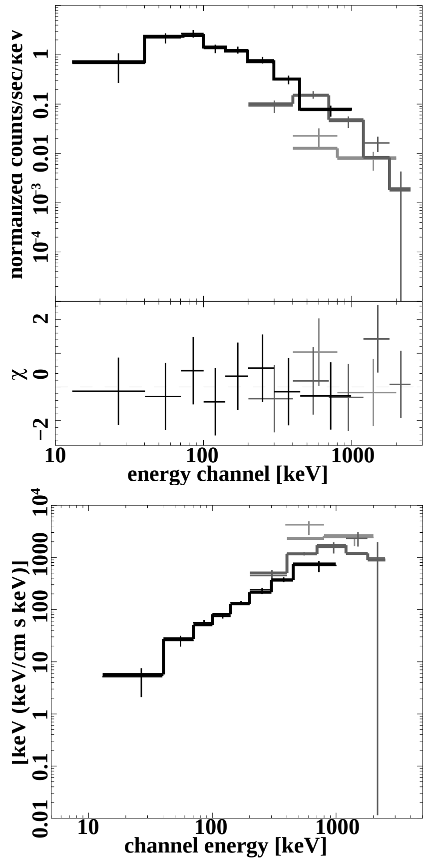

Figure 3. GRB 031111A. Upper panel shows count spectrum, while lower corresponding νF_ν spectrum. Broken power law model was fitted to the combined ISGRI and Compton mode data

to the data gaps in ISGRI during second peak we had to limit this interval, see upper panel of Figure 2.

The spectrum of the first peak has been fitted to the combined ISGRI and Compton mode data with a power law with the index $\alpha = 2.07 \pm 0.05$ with $\chi^2/\mathrm{dof} = 1.23$, for the second $\alpha = 2.05 \pm 0.06$ with $\chi^2/\mathrm{dof} = 1.9$.

3.3. GRB 031111A

GRB 031111A has been detected in the field of view of HETE-2 and additionally triangulated by IPN3 yielding an annulus [11]. Center of the region estimated as the burst position was: RA(2000) $= 4^h\,47^m$ DEC(2000) $= -18°6'$. It was 53.5° off-axis for the INTEGRAL instruments. The lightcurve of GRB 031111A consists of two overlapping Gaussian-like peaks. There is a data gap in the ISGRI data after the first peak. We decided to analyze only the rise slope of the burst covered by the simultaneous ISGRI and Compton mode data.

We have fitted a single and a broken power law models to the combined data. Broken power law fitted better with $\chi^2/\mathrm{dof} = 0.45$ for the following parameters: $\alpha =$

0.6 ± 0.2 $\beta = 2.8 \pm 0.7$ and $E_{\rm break} = 770 \pm 200$ keV. Figure 3 shows best fit as photon count spectrum and corresponding $\nu \mathrm{F}_\nu$ spectrum. The single power law yielded fit with $\chi^2/\mathrm{dof} = 1.79$ with spectral index $\alpha = 1.10 \pm 0.11$.

4. SUMMARY

We have performed a spectral analysis of several bursts that took place outside of the INTEGRAL field of view. The bursts are very hard with the spectra either flat or rising in νF_ν all the way to the MeV range. This suggests that there exists a significant class of very hard long bursts that should be detectable by GLAST.

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