Time resolved spectroscopy of GRB030501 using INTEGRAL

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The Gamma-ray instruments on-board INTEGRAL offer an unique opportunity to perform time resolved analysis on GRBs. The imager IBIS allows accurate positioning of GRBs and broad band spectral analysis, while SPI provides high resolution spectroscopy. GRB 030501 was discovered by the INTEGRAL Burst Alert System in the ISGRI field of view. Although the burst was fairly weak (fluence $F_{20-200\,\mathrm{keV}} \simeq 3.5 \times 10^{-6}\,\mathrm{erg\,cm^{-2}}$) it was possible to perform time resolved spectroscopy with a resolution of a few seconds. The GRB shows a spectrum in the 20 - 400 keV range which is consistent with a spectral index $\Gamma = -1.8$. No emission line or spectral break was detectable in the spectrum. Although the flux seems to be correlated with the hardness of the GRB spectrum, there is no clear soft to hard evolution seen over the duration of the burst.

1. Introduction

Gamma Ray Bursts (GRBs) were discovered by chance in the late 1960s by the Vela experiments (Klebesadel et al. 1973). They have been proven to be extragalactic in origin after a successful identification of an X-ray afterglow by BeppoSAX (GRB970508; Piro et al. 1998) with an optical counterpart at redshift $z = 0.835$ (Metzger et al. 1997). Even though we are now rather confident that long GRBs are related to massive explosions in distant galaxies, there are still many open questions remaining. Even though it is now commonly believed that GRBs are related to Supernova explosions (Hjorth et al. 2003), the exact mechanism by which GRBs can produce an energy output of $> 10^{52}$ergs (under the assumption that the emission is isotropic, which is probably not true) has still to be revealed. Prompt observation of GRBs in several energy ranges is essential to obtain high quality data for the study of these rapidly fading objects. Although GRBs were not one of the main targets for the scientific program of INTEGRAL, the two main Gamma-ray instruments, the imager IBIS and the spectrometer SPI, offer great capabilities for studying the prompt emission of GRBs when they occur in the field of view. Since the field of view is about 29 degrees, one Gamma-ray burst per month is expected to be observed. This rate has been confirmed so far by the six bursts in the field of view between November 2002 and September 2003 (von Kienlin et al. 2003a) In addition, the anticoincidence shield (ACS) of SPI can be used as an all-sky monitor for GRBs (von Kienlin et al. 2003a).

During the last three bursts in the field of view, both SPI and IBIS, were in full operational mode, allowing time resolved spectral analysis.

2. INTEGRAL observation

GRB030501 (Beckmann et al. 2003) was detected on 1st May 2003 at 03:10:18 UT with data from the low energy detector of the IBIS instrument, the Integral Soft Gamma Ray Imager (ISGRI; Lebrun et al. 2001), which consists of 128×128 CdTe crystals sensitive in the energy range $15 - 300\,\mathrm{keV}$. ISGRI uses the coded mask technique and offers an instrumental resolution of ~ 12 arcmin over the field of view of $29^\circ \times 29^\circ$. The source location precision depends on the brightness of the source, and is about 1 arcmin for sources with a detection significance of 10σ. The GRB was detected in the ISGRI data by the INTEGRAL Burst Alert System (IBAS; Mereghetti et al. 2001).A later analysis, performed off-line, on the ISGRI data revealed a position of (J2000.0) $19^\mathrm{h}05^\mathrm{m}30^\mathrm{s}$, $+6^\circ18^\mathrm{m}26^\mathrm{s}$ with an uncertainty of ~ 3 arcmin (Mereghetti et al. 2003). The Gamma-Ray burst had a duration of 40 seconds. Data from the spectrometer SPI were also analysed at the INTEGRAL Science Data Centre (ISDC; Courvoisier et al. 2003). SPI is designed for high spectral resolution (FWHM of 2.5 keV at 1 MeV) in the energy range $20 - 8000\,\mathrm{keV}$, which is achieved by 19 cooled Germanium detectors. A coded mask with 128 elements provides an instrumental spatial resolution of 2.8 degrees. The position accuracy for point sources can be < 5 arcmin (for a source with $S/N = 100$). The position for GRB030501 extracted from the SPI data is (J2000.0) $19^\mathrm{h}07^\mathrm{m}$, $+6^\circ25^\mathrm{m}$ (± 21 arcmin), which is 19 arcmin off the position detected by ISGRI.

The peak gamma ray flux, $f_{20-200\,\mathrm{keV}}$, in the 20 - 200 keV band measured by SPI in a 2 second bin starting at 03:10:20 UTC is $2.8 \pm 0.4\,\mathrm{photons\,cm^{-2}\,sec^{-1}}$. This is consistent with ISGRI where $f_{20-200\,\mathrm{keV}} = 2.7 \pm 1.2\,\mathrm{photons\,cm^{-2}\,sec^{-1}}$ was measured in a 1 second bin starting at 03:10:18.4 UTC, reaching the peak about 1 second before it occurs in the SPI data. The fluence, $F_{20-200\,\mathrm{keV}}$, measured for the GRB by both instruments in the same band and integrated over the full burst visibility period is also consistent:

$$\begin{aligned} \mathrm{SPI} : F_{20-200\,\mathrm{keV}} &= 39.3 \pm 2.5\ \mathrm{photons\,cm^{-2}} \\ &= 3.7 \pm 0.2 \times 10^{-6}\,\mathrm{erg\,cm^{-2}} \\ \mathrm{ISGRI} : F_{20-200\,\mathrm{keV}} &= 37.5 \pm 12.5\ \mathrm{photons\,cm^{-2}} \\ &= 3 \pm 1 \times 10^{-6}\,\mathrm{erg\,cm^{-2}} \end{aligned}$$

The GRB was also observed by the Ulysses experiment (Hurley et al. 2003). Due to the weakness of the detection the reported fluence, in the 25 - 100 keV band, is uncertain by about a factor of two, but this is still consistent with the measurements made by the INTEGRAL instruments:

$$\begin{aligned} \mathrm{SPI} : F_{25-100\,\mathrm{keV}} &\simeq 2.0 \times 10^{-6}\,\mathrm{erg\,cm^{-2}} \\ \mathrm{ISGRI} : F_{25-100\,\mathrm{keV}} &\simeq 1.5 \times 10^{-6}\,\mathrm{erg\,cm^{-2}} \\ \mathrm{ULYSSES} : F_{25-100\,\mathrm{keV}} &\simeq 1.1 \times 10^{-6}\,\mathrm{erg\,cm^{-2}} \end{aligned}$$

The $\sim 30\%$ uncertainty on ISGRI fluence is dominated by systematic errors on the response of the instrument at large off-axis angles. We note however a good agreement with the SPI value, which confirms the value obtained with ISGRI. The overall spectrum of the burst based on SPI data is shown in Figure 1. The GRB occurred in a pointed observation of 1800 sec length. The background emission was estimated from this pointing, but excluding the time when the GRB occurred. The GRB is detectable up to at least 200 keV in both the ISGRI and SPI[1] data. A single power law represents the SPI data well, resulting in a photon index of $\Gamma = -1.88 \pm 0.10$. A more complicated model (e.g. a broken power law or a Band model; Band et al. 1993) does not improve the fit, thus no spectral break is detectable. This result is consistent with the spectral slope of $\Gamma = -1.75 \pm 0.10$ derived from ISGRI data. For the ISGRI data the background can be estimated at the same time as the source flux, using the Pixel Illumination Function (PIF). Spectra are extracted computing one PIF for each energy bin (128 linearly spaced bins have been used).

There was a marginal detection of the GRB by the SPI-ACS (Hurley et al. 2003). The low countrate of this GRB is expected in the ACS data, as the effective area for events in the field of view of SPI is small for the ACS, which shields the spectrograph from the sides and from its back (von

[1] A detailed description how to perform the extraction of a GRB from SPI data can be found at http://isdc.unige.ch/Instrument/spi/pages/usermanual.html

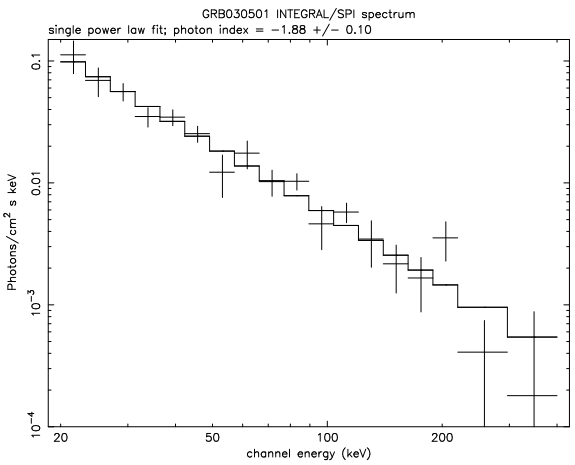

Figure 1. GRB spectrum in the range 20 - 400 keV, taken from the SPI data over 20 seconds after the burst occurance.

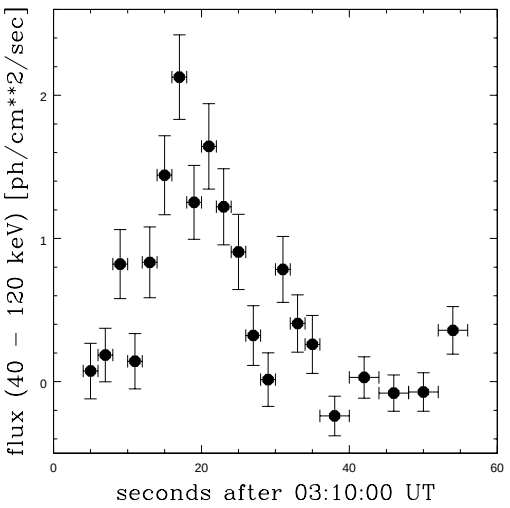

Figure 2. Lightcurve of GRB 030501 in the 40 - 120 keV energy band, taken from INTEGRAL/SPI

Kienlin et al. 2003a). The combination of Ulysses and INTEGRAL data also allowed triangulation of the GRB event by the 3rd Interplanetary Network (IPN). The result is consistent with the ISGRI position. The INTEGRAL X-ray (JEM-X) and optical (OMC) monitors were unable to provide any additional information since the GRB was located well outside of the respective fields of view of these instruments.

3. Time resolved results on GRB030501

Although the burst is comparably weak, the sensitivity of ISGRI and SPI allows the study of the lightcurve of the prompt emission. We show the SPI lightcurve in the 40−120 keV energy band in Fig. 2. The peak flux is reached ~ 10 seconds after the burst started. Spectra were extracted from the SPI data, in 5 logarithmically binned energy bands between 20 and 400 keV. For ISGRI the data have been binned in order to have at least 25 counts per bin. XSPEC 11.2 was used to fit a single power law to the data in time bins of $2-10$ seconds over a period of 30 seconds after the burst started.

The results are shown in Fig. 3. The spectrum starts apparently rather steep, but then immediately has a photon index of $\Gamma \simeq -1.5$ as the flux increases. Before the GRB is below the instrumental sensitity, it apparently softens again. In the ISGRI data there is evidence of hardness intensity correlation as seen in other GRBs before (e.g. Ford et al. 1995). This is consistent with the SPI data, though the statistic is not high enough to constrain the results. No clear spectral evolution is seen in the data.

4. Discussion

Optical follow up observation has not revealed an optical counterpart to this GRB (Boer & Klotz 2003; Fox 2003; Rumyantsev et al. 2003). Using the 1m Wise telescope in comparison with POSS-II E photographic plates, the magnitude of the optical counterpart 16.5 hours after the prompt emission can be limited to $R \geq 20.0$ mag (Ofek et al. 2003). Also analysis of optical observations carried out with the automatic 25 cm TAROT telescope shortly after the burst occurrence (i.e.

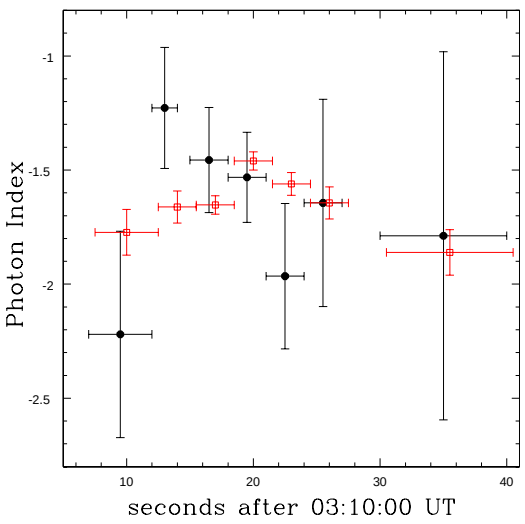

Figure 3. Evolution of the spectral slope of a single power law, fitted to the ISGRI (open squares) and SPI (filled circles) data of GRB 030501. The ISGRI data points have been shifted by +0.5 sec for better visibility. The definition of the photon index is $f_\nu \propto \nu^\Gamma$

within 15 minutes) shows no optical counter part with $R \leq 18.0$ mag (Klotz & Boer 2003).

With a Galactic latitude of only 0.2 degree and an estimated extinction of $E(B-V) \sim 15$, identification of an optical counterpart is indeed difficult, if not impossible.

As no break in the spectrum was detected in either the SPI or the ISGRI data, it can be assumed that the peak energy of this long GRB is either $E_{peak} \lessapprox 30\,\mathrm{keV}$ or $E_{peak} \gtrapprox 200\,\mathrm{keV}$. Since a very low peak energy is rather unlikely (see Preece et al. 2000), we assume a spectral break above 200 keV. GRB030501 shows a similar spectral behaviour to bursts studied before (e.g. GRB921207; Ghirlanda et al. 2002) but is about a factor ~ 10 weaker than the bursts where time resolved spectroscopy has been possible with data from previous missions.

This GRB demonstrates the great capabilities of INTEGRAL and the software package, provided by the ISDC in collaboration with the instrument teams. The time lag between GRB occurrence and providing detailed spectral and timing analysis is less than half a day.

5. Acknowledgements

RH acknowledges the support provided by the ESA Prodex Project 14527. JB was supported by the Polish grant 2P03C00619p02 from KBN and SS by PPARC grant GR/K/94867.

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