

## GRB 021219: The first Gamma-Ray Burst localized in real time with IBAS<sup>★</sup>

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**Abstract.** On December 19, 2002, during the Performance and Verification Phase of INTEGRAL, a Gamma-Ray Burst (GRB) has been detected and localized in real time with the INTEGRAL Burst Alert System (IBAS). Here we present the results obtained with the IBIS and SPI instruments. The burst had a time profile with a single peak lasting about 6 s. The peak spectrum can be described by a single power law with photon index  $\Gamma = 1.6 \pm 0.1$  and flux  $\sim 3.7$  photons  $\text{cm}^{-2} \text{s}^{-1}$  (20–200 keV). The fluence in the same energy range is  $9 \times 10^{-7}$  erg  $\text{cm}^{-2}$ . Time resolved spectroscopy performed with IBIS/ISGRI shows a clear hard to soft evolution of the spectrum.

**Key words.** gamma rays: bursts – gamma rays: observations

### 1. Introduction

Although considerable progress in the understanding of Gamma-Ray Bursts (GRBs) has been made after the discovery of their afterglows at longer wavelengths (see, e.g., van Paradijs et al. 2000) the debate on their progenitors is still open. A model involving the core collapse of a massive star (e.g. Woosley 1993) seems to be favored for long GRBs and evidence for a Supernova-GRB association has been found recently (Stanek et al. 2003; Hjorth et al. 2003). The situation is more uncertain for what concerns short (<2 s) bursts, mostly because of the lack of counterparts at other wavelengths for this class of GRBs.

A multi-wavelength approach is crucial to the understanding of the complex nature of GRBs. The short duration of the prompt  $\gamma$ -ray emission and the fading character of the

afterglow impose a rapid follow-up. This can be achieved only if the positions derived from the prompt emission are immediately distributed to the scientific community. The INTEGRAL satellite, although not built as a GRB-oriented mission, can contribute to this task thanks to the INTEGRAL Burst Alert System (IBAS; Mereghetti et al. 2003b). To date IBAS has successfully detected and located 5 GRBs, with increasing accuracy and decreasing delays (4.36' error radius after 30 s for GRB 030501; IBAS Alert 596).

GRB 021219 is the first GRB detected in real time by IBAS. This occurred only two months after the launch of INTEGRAL, while the satellite was still in its performance and verification (PV) phase. During the PV phase, the external distribution of the IBAS alerts was not enabled yet. An internal alert message, produced only 10 s after the start of the burst, reached the members of the IBAS Localization Team and a GRB Coordinates Network (GCN) circular with a preliminary position could be issued 5 hours later, after a quick analysis to confirm the GRB (Mereghetti et al. 2002). Since during the PV phase the relative alignment between IBIS and the satellite star trackers was not well measured yet, an uncertainty of 20' was attributed to the derived position. A refined position could be derived later

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(Götz et al. 2002), thanks to the presence of Cyg X-1 in the field of view.

Here we report on the results on GRB 021219 obtained with the IBIS (Ubertini et al. 2003) and SPI (Vedrenne et al. 2003) instruments. They are both coded mask imaging telescopes with a large field of view ( $29^\circ \times 29^\circ$  IBIS,  $36^\circ$  diameter SPI). IBIS is based on two detectors, ISGRI (Lebrun et al. 2003) and PICsIT (Di Cocco et al. 2003), operating in the 15 keV–1 MeV and 175 keV–10 MeV energy ranges, respectively. SPI consists of 19 Ge detectors cooled at 85 K and works in the 20 keV–8 MeV range. The GRB was located outside the field of view of the two low energy monitoring instruments JEM-X (Lund et al. 2003) and OMC (Mas-Hesse et al. 2003).

## 2. Data analysis

### 2.1. IBIS

During this observation PICsIT provided images integrated on time intervals of several minutes, which cannot be used for the study of GRBs. Owing to the telemetry limitations at satellite level this is the standard operation mode of PICsIT. Useful data for GRB studies can be obtained by PICsIT when it is operated in photon-by-photon mode (as it occurred for GRB 021125, see Malaguti et al. 2003). Our results for GRB 021219 are therefore based only on data from the ISGRI detector.

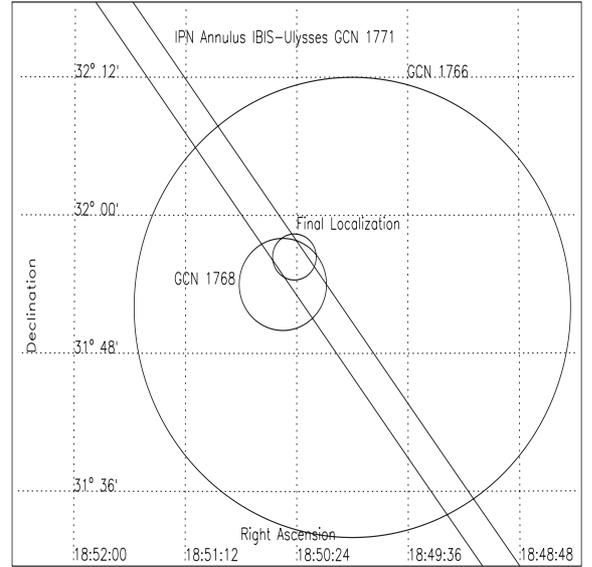
We have analyzed ISGRI single interaction events, for which the arrival time, energy deposit and interaction pixel are known.

GRB 021219 has been detected at off-axis angles  $Z = 1.38^\circ$  and  $Y = 10.02^\circ$ , in the partially coded field of view of IBIS, with a signal-to-noise ratio of 15.5 in the 15–100 keV band. The top panel of Fig. 2 shows the GRB light curve binned at 0.2 s intervals. It refers to the 15–500 keV band, and, to increase the signal to noise ratio, it has been extracted using only the pixels illuminated by the GRB for at least half of their surface. The GRB started at 07:33:55 UTC and had a  $T_{90}$  duration of 5.5 s. The time profile shows a single peak.

To derive an accurate position we selected a 15 s time interval starting at 07:33:55 UTC, obtaining  $\alpha_{J2000} = 18^{\text{h}}50^{\text{m}}25^{\text{s}}$ ,  $\delta_{J2000} = +31^\circ56'23''$ , with an uncertainty of  $2'$  radius. As shown in Fig. 1, this position is consistent with the one published earlier and with the annulus derived independently with the International Planetary Network (IPN, Hurley et al. 2002).

We have extracted the GRB peak spectrum (over a time interval of 1 s) using 128 linearly spaced bins between 19 keV and 1 MeV and then rebinned it to have at least 25 counts per channel. Since IBIS is a coded mask instrument, the background spectrum can be measured simultaneously to that of the target, by using the pixels not illuminated by the source. A fully calibrated response matrix for large off-axis angles is not available yet. Therefore, we divided the counts spectrum by the closest (in detector coordinates) spectrum of the Crab Nebula. The resulting photon spectrum (Fig. 3) is well described by a power law with photon index  $\Gamma = 1.6 \pm 0.1$  and flux in the 20–200 keV band of 3.7 photons ( $3.5 \times 10^{-7}$  erg)  $\text{cm}^{-2} \text{s}^{-1}$ .

The total (time averaged) spectrum has been obtained with the same technique and can be fitted by a power law with



**Fig. 1.** Localizations of GRB 021219: the positions published earlier are consistent with the final one derived in this work, see text.

$\Gamma = 2.0 \pm 0.1$ . The fluence in the 20–200 keV band (corrected for the telemetry gaps) is  $9 \times 10^{-7}$  erg  $\text{cm}^{-2}$ .

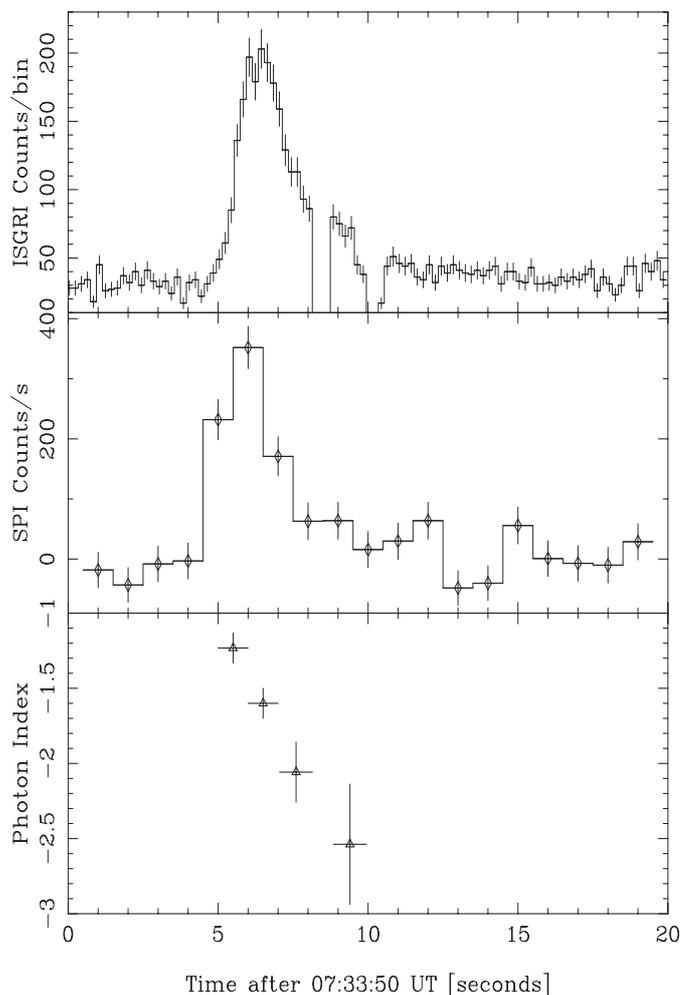
We have also investigated the spectral evolution with time. Four spectra of the duration of  $\sim 1$  s each have been extracted: one during the rising part of the GRB, one at the peak, and two during the decaying tail. All the spectra are well represented by a power law model. The corresponding photon indices, plotted in the lowest panel of Fig. 2, provide a significant evidence for a softening with time of the burst spectrum.

### 2.2. SPI

At the time of GRB 021219 the SPI instrument was in low-telemetry mode. Therefore, no single events have been transmitted to the ground in photon-by-photon mode. Only the events which occurred in several detectors (multiple events) and those analysed by the on-board pulse discriminator (PSD events) were kept. Due to this, there was no sensitivity below  $\sim 200$  keV. Still SPI transmitted to the ground the count-rates of all the events measured in each of the 19 Ge detectors in bins of 1 s (see middle panel of Fig. 2). For these events the information about the photon energy is lost and thus only a broad band count rate can be given. The background was determined using the data starting from 20 min before the burst occurrence. The peak flux and fluence have been then derived from the broad band count rate by comparison with the count rate measured for the Crab Nebula. This results in a peak flux of  $10.7 \pm 1.1$  Crab at 07:33:56 UTC, which is consistent with the value obtained with IBIS/ISGRI. The values are consistent also for what concerns the fluence.

The imaging analysis of the SPI data, using a 3 s time interval starting at 07:33:55 UTC, yields a position  $\alpha_{J2000} = 18^{\text{h}}49.3^{\text{m}}$ ,  $\delta_{J2000} = +31^\circ46.1'$ , with an uncertainty of  $30'$  ( $S/N = 8.5$ ) localizing the GRB  $17.6'$  from the IBIS/ISGRI position.

GRB 021219

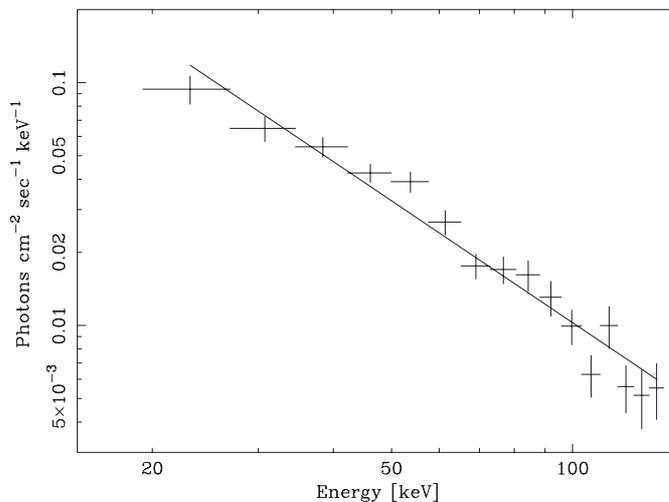


**Fig. 2.** *Upper panel:* IBIS/ISGRI light curve of GRB021219 in the 15–500 keV band binned over 0.2 s. The gaps are artifacts caused by satellite telemetry saturation. *Middle panel:* Background subtracted light curve of GRB 021219 measured with SPI. *Lower panel:* Spectral evolution of GRB 021219 with time. A clear hard-to-soft evolution is seen.

### 3. Discussion

GRB 021219 had a rather steep average spectrum, indicating that it can be considered an X-ray rich GRB. Usually GRB spectra are well described by a phenomenological model (Band et al. 1993) consisting of two power laws, one at low energies (with slope  $\alpha$ ) and one at high energies (with slope  $\beta$ ), and a smooth break typically between about 100 and 400 keV (Preece et al. 2000). The fact that no break is seen in the spectrum of GRB 021219 up to 150 keV indicates that the break, if any, is outside our detection range. The value of the photon index  $\sim 2$ , compared to the ones typically observed in the BATSE sample  $\langle \beta \rangle \sim 2.5$ , suggests that we are observing the part of the spectrum above the break. We cannot exclude, however, that the break is at higher energies: this would qualify GRB 021219 even more as an X-ray rich GRB.

GRB 021219: Peak Spectrum



**Fig. 3.** Peak spectrum of GRB 021219 as measured with IBIS/ISGRI.

The time resolved spectroscopy performed with IBIS/ISGRI indicates a clear hard-to-soft spectral evolution. This is a common feature in many GRBs observed with previous satellites (e.g. Norris et al. 1986; Ford et al. 1995; Frontera et al. 2000).

No optical counterpart for this GRB has been reported, with limiting magnitudes of  $R = 13.7$  at  $t - t_0 \sim 7.5$  hours (Lipunov et al. 2002),  $R = 18$  at  $t - t_0 \sim 11$  hours,  $I = 19.5$  at  $t - t_0 \sim 18$  hours (Henden et al. 2002) and  $R = 20.5$  at  $t - t_0 \sim 34$  hours (Castro-Tirado et al. 2002). Observations in the radio band at 4.86 GHz (at  $t - t_0 \sim 16$  hours) have not detected any new source down to a  $4\sigma$  limit of  $220 \mu\text{Jy}$  (Berger et al. 2002).

The fact no optical transient has been detected indicates a “dark” or at least dim nature of this GRB. A similar behaviour has been noticed before in other X-ray rich events. For example, the X-ray rich GRB 021211 (Crew et al. 2003) was fainter than  $R \sim 22.5$  12 hours after the burst (Klose et al. 2002). The optical time history of this GRB is compatible with the upper limits reported above for GRB 021219.

### 4. Conclusions

The successful detection and localization of GRB 021219 only one month after IBIS activation, showed that IBAS is able to derive and distribute the position of the GRBs detected in the field of view of IBIS within a few tens of seconds.

The analysis of GRB 021219 reported here shows that IBIS/ISGRI is indicated for detailed spectral studies. In fact we have been able to obtain spectra integrated over only 1 s with good statistics, thus deriving the spectral shape of the GRB and its variation with time.

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