IL NUOVO CIMENTO Vol. 28 C, N. 3 Maggio-Giugno 2005
DOI 10.1393/ncc/i2005-10035-3

Two years of GRB localizations with the INTEGRAL Burst Alert System(*)

S. Mereghetti and D. Götz

INAF - Istituto di Astrofisica Spaziale e Fisica Cosmica, sezione di Milano
via E. Bassini 15, 20133 Milano, Italy

(ricevuto il 23 Maggio 2005; pubblicato online il 20 Settembre 2005)

Summary. — We review the results on Gamma-ray Bursts obtained during the first two years of operations of the INTEGRAL Burst Alert System (IBAS). In many cases GRB coordinates have been distributed with an unprecedented combination of accuracy ($3'$) and speed (20–30 s). The resulting rapid follow-ups at other wavelengths, including sensitive *XMM-Newton* observations, have led to several interesting results.

PACS 98.70.Rz – γ-ray sources; γ-ray bursts.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The INTEGRAL satellite, launched on October 17, 2002, has been designed as a general purpose mission dedicated to high-resolution imaging and spectroscopy in the hard X-ray / soft γ-ray energy range. Thanks to the good imaging capabilities of its IBIS instrument [34] and the continuous data transmission to the ground, it has been possible to set up an automatic system for the rapid distribution of GRB coordinates. In the last two years, the INTEGRAL Burst Alert Systems (IBAS, [24]) has provided some of the fastest and most accurate localizations ever obtained for GRBs. In some cases the GRB coordinates were distributed while the gamma-ray emission was still ongoing. Whenever a rapid follow up at X-ray wavelengths has been carried out, mostly with *XMM-Newton*, an afterglow has been detected, often leading to very interesting results. After a brief description of the IBAS system, we summarize the global properties of the 22 GRBs localized to date and discuss a few of the most interesting cases.

2. – The INTEGRAL Burst Alert System

Thanks to its 72 hours orbit, the INTEGRAL satellite is in continuous contact with the ground stations during the observations. Therefore the data are transmitted to

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.

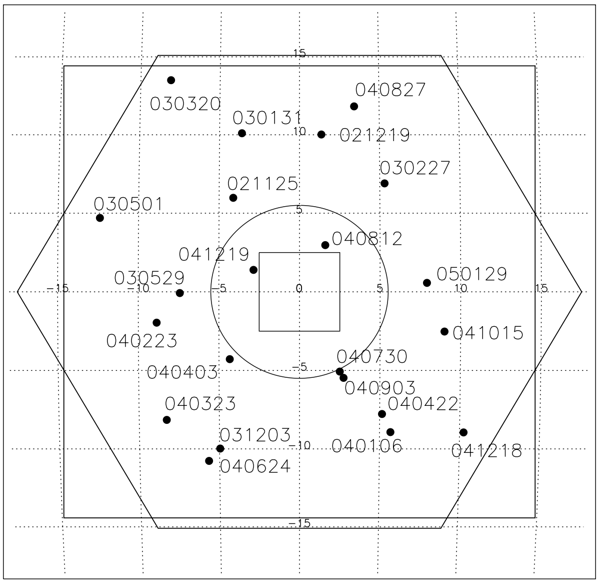

Fig. 1. – Positions of the GRBs localized with IBAS in the fields of view of the INTEGRAL instruments: IBIS (large square), SPI (hexagon), JEM-X (circle), OMC (small square).

ground without significant delays. This has allowed us to implement a software system for the automatic GRB search at the INTEGRAL Science Data Center (ISDC [5]), where the data are received after only a few seconds. The IBAS rapid localizations are based on data of the imager instrument IBIS, and in particular of its ISGRI detector [16], which offers the best performances in terms of large field of view ($29^\circ \times 29^\circ$) and angular resolution over the 20 keV–1 MeV energy range, well suited for the detection of GRBs. The search for GRBs is done in parallel by several programs using different energy ranges (between 15 and 200 keV), triggering time scales (between 8 ms and 100 s), and imaging methods (for more details see [24] and `http://ibas.mi.iasf.cnr.it`).

Typically the IBAS localizations obtained by the automatic software and distributed in real time have 90% confidence level error radii of $\sim 3'$. These errors can be reduced down to $\sim 2'$, depending on the source signal to noise ratio, in the subsequent off-line analysis. The GRB positions derived by IBAS are delivered via Internet to all the interested users. For the GRBs detected with high significance, this is done immediately by the software which sends *Alert Packets* using the UDP transport protocol. In case of events with lower statistical significance, the alerts are sent only to the members of the IBAS Localization Team, who perform further analysis and, if the GRB is confirmed, can distribute its position with an *Off-line Alert Packet*.

3. – The INTEGRAL GRB sample

Up to now (January 2005), 22 GRBs have been discovered in the field of view of IBIS. Figure 1 shows their positions in the fields of view of the INTEGRAL instruments. Only two of them were within the field of view of the X-ray monitor JEM-X [17], but none was sufficiently on axis to be also observed with the optical camera OMC [22].

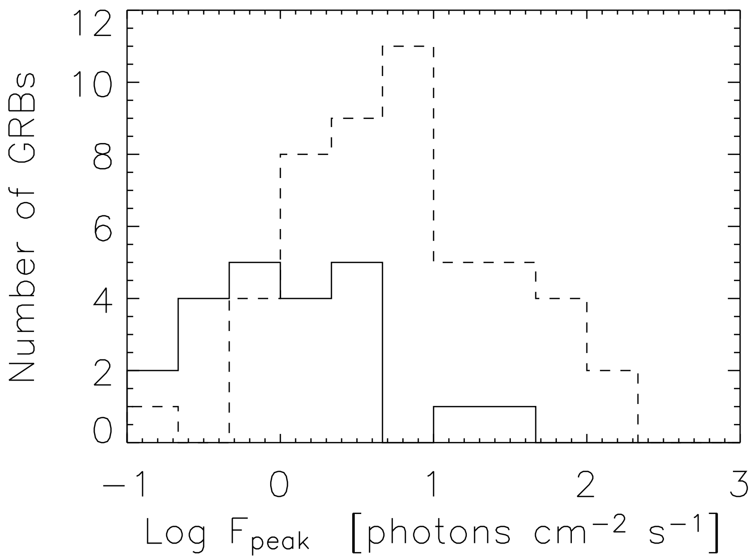

Fig. 2. – Distribution of the peak fluxes for the GRBs localized with IBAS (solid line) and with *BeppoSAX* ([8], dashed line).

The main properties of the INTEGRAL GRBs are summarized in table I. The peak fluxes in the 20–200 keV (for an integration time of 1 s) have been recomputed using the latest available calibrations and supersede previously reported values. They are typically in the range $\sim$0.3–5 photons cm^{-2} s^{-1}, except for the first GRB detected by INTEGRAL (GRB 021125, [19]), and GRB 041219 for which only a lower limit on the peak flux could be derived since it was so bright to saturate the available IBIS telemetry [14]. The sample comprises several X-ray rich bursts and one X-ray flash, XRF 040903 [15].

X-ray follow-ups have been carried out for five GRBs with *XMM-Newton* and with *Chandra* for GRB 040812, typically starting about 5–8 hours after the GRB. In all these cases an X-ray afterglow has been found within the IBAS error regions. Except for some notable exception discussed below, optical observations have been less successful. Several bursts occurred in heavily absorbed regions of the Galactic plane, which is the sky region most observed by INTEGRAL. Convincing optical and/or IR counterparts have been found for 8 GRBs, and a few other candidates have been reported. The host galaxy has been identified for GRB 031203 [28] at a remarkably small redshift of $z = 0.1$. In a few cases the optical observations were deep enough to provide interesting upper limits at early times (*e.g.*, [23]).

The overall picture indicates that the INTEGRAL sample includes many faint and X-ray–rich bursts which are also relatively dim in the optical. Indeed the bursts localized by IBAS are among the faintest ones for which good localizations have been obtained to date. This is shown in fig. 2, where we compare the peak fluxes of the GRBs localized by INTEGRAL and BeppoSAX.

TABLE I. – *Properties of GRBs detected with IBAS.*

GRB	Duration [s]	Peak Flux (20–200 keV) [photons $cm^{-2}s^{-1}$]	Power law photon index[a]	Afterglows
021125	25	22	2.2/3.7 [19]	–
021219	5.5	4.0	1.3→2.5 [25]	–
030131	124	1.9	∼ 2 [12]	opt. [7]
030227	33	1.1	1.9 [26]	opt. [4], X [26, 38]
030320	48	3.6	1.3→1.9 [37]	–
030501	40	2.7	1.75 [2]	–
030529	20	0.4	1.7 [this work]	–
031203	39	1.7	1.63 [29]	radio [30], opt. [28, 20], X [39, 35]
040106	47	1.0	1.7 [27]	opt. [21], X [11, 27]
040223	258	0.4	[b]	X [31]
040323	14	1.6	[b]	opt. [9]
040403	21	0.5	1.9 [23]	–
040422	10	3.5	[b]	–
040624	35	0.5	[b]	–
040730	43	0.4	[b]	–
040812	19	0.6	[b]	opt?, X [18]
040827	49	0.6	[b]	NIR [6], X [6]
040903	10	0.4	2.9 [15]	–
041015	30	0.2	[b]	–
041218	60	3.0	[b]	opt.
041219a	350	>12	[b]	opt. [36], NIR [3]
050129	20	0.26	[b]	–

[a] The two values for GRB 021125 are for the ranges 20–200 keV (ISGRI) and 170–500 keV (PICsIt). The arrows indicate time evolution.
[b] Results not yet published

4. – Results on individual GRBs

4·1. *GRB 030227*. – This is the first INTEGRAL GRB for which X-rays and optical afterglow searches were successful. A *XMM-Newton* Target of Opportunity Observation could start only 8 hours after the GRB, leading to the discovery of an X-ray afterglow with 0.2–10 keV flux decreasing as t^{-1} from 1.3×10^{-12} to 5×10^{-13} erg cm^{-2} s^{-1}. The afterglow spectrum was well described by a power law with photon index 1.94 ± 0.05 and absorption of a few times 10^{22} cm^{-2}, significantly larger than the Galactic value [26]. This supports the scenarios involving the occurrence of GRBs in regions of star formation. Some evidence for an emission line at 1.67 keV, which if attributed to Fe would imply a redshift $z \sim 3$, was also found in the *XMM-Newton* spectrum [26]. However, this is inconsistent with another claim for lines possibly appearing toward the end of the same *XMM-Newton* observation [38], interpreted as H- and He-like lines from Mg, Si, S, Ar and Ca at $z = 1.39$. The real statistical significance of these spectral features is debated, as in the case of similar claims in other GRBs. The much more rapid X-ray follow ups which can now be obtained with *Swift* [10] will certainly settle this important issue in the coming months.

4˙2. *GRB 030529*. – This burst has been detected during an off-line reprocessing of the first months of INTEGRAL data, which was performed in order to scan also the older data with the most recent and sensitive versions of the IBAS programs. The properties of GRB 030529, the only burst found in this off-line IBAS reprocessing, are reported here for the first time. It occurred at 19:53:15 UTC at coordinates R.A. = $09^{\rm h}\ 40^{\rm m}\ 29.3^{\rm s}$, Dec. = $-56^\circ\ 20'\ 31''$ (J2000, uncertainty $3'$). It was a faint burst, lasting about 20 s, with a power law spectrum with photon index $\Gamma = 1.71 \pm 0.20$, and fluence 4×10^{-7} erg cm^{-2} (20–200 keV). The instrumental background at the time of the burst detection was highly variable. This explains why GRB 030529 was missed by the earlier versions of the IBAS programs.

4˙3. *GRB 031203*. – Also for this GRB very interesting results could be obtained thanks to the X-ray, radio and optical follow-up observations enabled by the rapid IBAS localization. This is one of the few GRBs for which there is spectroscopical evidence of an associated Type Ic Supernova [20]. The discovery of its host galaxy led to a redshift determination of $z = 0.1$ [28], making GRB 031203 the second closest GRB, and implying a surprisingly small isotropic-equivalent energy $E_{iso} = (6 - 14) \times 10^{49}$ erg s^{-1} [29]. This value and the lower limit of the E_{peak} value ($\sim$200 keV), derived from the average spectrum, make GRB 031203 an outlier in the E_{peak}-E_{iso} relation [1].

The X-ray images obtained with *XMM-Newton* led to the discovery of an expanding ring due to the scattering of the GRB X-ray emission by dust grains in our Galaxy [35]. The modelling of this GRB "echo" gives us an indirect mean to estimate the intensity of the prompt GRB emission at X-ray energies. This gives some evidence for an X-ray flux component in excess of the low-energy extrapolation of the INTEGRAL spectrum [32,33].

4˙4. *GRB 040106*. – The afterglow of this GRB has been promptly (only 5 hours later) and deeply observed in the X-rays by *XMM-Newton*: its 1–10 keV spectrum is uniquely hard (power law photon index 1.49 ± 0.03), and its temporal decay is a power law of index 1.46 ± 0.04 [27]. Assuming that the cooling frequency ν_c is below the observed X-ray range (as suggested by the optical data), these values do not fit with any of the simple fireball models. On the other hand, if the $\nu_X < \nu_c$ regime applies, the afterglow can be described as a spherical fireball expanding into a wind environment [11].

4˙5. *GRB 040403*. – GRB 040403 is one of the faintest gamma-ray bursts for which a rapid (30 s) and accurate ($2.8'$) localization has been obtained. Its steep spectrum obtained with IBIS/ISGRI in the 20–200 keV range (power law photon index = 1.9) implies that GRB 040403 is most likely an X-ray rich burst [23].

Despite being at a Galactic latitude ($b = 30^\circ$) higher than the majority of INTEGRAL bursts and thus barely affected by interstellar extinction ($A_V \sim 0.3$), optical follow-ups were somewhat discouraged by the presence of the full Moon. Nevertheless a relatively deep limit of $R > 24.2$ at 16.5 hours after the burst could be obtained [23], indicating a rather faint afterglow, similar to those seen in other soft and faint bursts (*e.g.*, GRB 030227 [26]).

4˙6. *XRF 040903*. – This faint burst had a very soft spectrum (it was not significantly detected by IBIS above 60 keV) and it came from a direction close to the Galactic center ($l = 5.2^\circ$, $b = -1.5^\circ$). Furthermore a faint *ROSAT* X-ray source was present in its error region. For these reasons also the possibility that it was due to a Type-I X-ray burst from an unidentified low-mass X-ray binary was considered in the initial reports [13]. However, subsequent analysis indicate that a Type-I X-ray burst origin less likely [15]. In fact, its

20–100 keV spectrum is well fit by a power law with photon index $\Gamma = 2.9 \pm 0.4$, while the temperature obtained with a blackbody fit ($kT = 6.9 \pm 1.5$ keV) is much higher than those typically seen in X-ray bursts. Contrary to the X-ray bursts no spectral softening is visible in XRF 040903. Finally, no persistent emission has been seen with INTEGRAL from the putative *ROSAT* counterpart before or after the burst.

* * *

IBAS is successfully working also thanks to the continuous support of J. Borkowski, M. Beck, N. Mowlavi, S. Shaw and all the operational staff of the ISDC and MOC.

REFERENCES

[1] Amati L., Frontera F., Tavani M. *et al.*, *A&A*, **390** (2002) 81.
[2] Beckmann V., Borkowski J., Courvoisier T. J.-L. *et al.*, *A&A*, **411** (2003) L327.
[3] Blake C., Bloom J. S., Starr D. L. *et al.*, *Nature*, **435** (2005) 181.
[4] Castro-Tirado A. J., Gorosabel J., Guziy S. *et al.*, *A&A*, **411** (2003) L315.
[5] Courvoisier T. J.-L., Walter R., Beckmann V. *et al.*, *A&A*, **411** (2003) L53.
[6] De Luca A. *et al.*, submitted to *A&A* (2005).
[7] Fox D. W., Price P. A., Heter T. *et al.*, GCN Circ. n. 1857 (2003).
[8] Frontera F., in *Third Rome Workshop on Gamma-ray Bursts in the Afterglow Era*, *ASP Conf. Proc.*, **312** (2004) 3.
[9] Gal-Yam A. *et al.*,, GCN Circ. n. 2555 (2004).
[10] Gehrels N., Chincarini G., Giommi P. *et al.*, *Astrophy1. J.*, **611** (2004) 1005.
[11] Gendre B., Piro L. and De Pasquale M., *A&A*, **424** (2004) L27.
[12] Götz D., Mereghetti S., Hurley K. *et al.*, *A&A*, **409** (2003) 831.
[13] Götz D. *et al.*, GCN Circ. n. 2690, 2691, 2695 (2004).
[14] Götz D., Mereghetti S., Shaw S. *et al.*, GCN Circ. n. 2866 (2004).
[15] Kuulkers E., Götz D., Mereghetti S. *et al.*, GCN Circ. n. 2699 (2004).
[16] Lebrun F., Leray J. P., Lavocat P. *et al.*, *A&A*, **411** (2003) L141.
[17] Lund N., Budtz-Jorgensen C., Westergaard N. J. *et al.*, *A&A*, **411** (2003) L231.
[18] Lund N., *et al.*, in preparation (2005).
[19] Malaguti G., Bazzano A., Beckmann V. *et al.*, , *A&A*, **411** (2003) L307.
[20] Malesani D., Tagliaferri G., Chincarini G. *et al.*, *ApJ*, **609** (2004) L5.
[21] Masetti N. *et al.*, GCN Circ. n. 2515 (2004).
[22] Mas-Hesse J. M., Giménez A., Culhane L. *et al.*, *A&A*, **411** (2003) L261.
[23] Mereghetti S., Götz D., Andersen M. I. *et al.*, *A&A*, **433** (2005) 113.
[24] Mereghetti S., Götz D., Borkowski J. *et al.*, *A&A*, **411** (2003) L291.
[25] Mereghetti S., Götz D., Beckmann V. *et al.*, *A&A*, **411** (2003) L311.
[26] Mereghetti S., Götz D., Tiengo A. *et al.*, *ApJ*, **590** (2003) L73.
[27] Moran L., Mereghetti S., Götz D. *et al.*, *A&A*, **432** (2005) 467.
[28] Prochaska J. X., Bloom J. S., Chen H. W. *et al.*, *ApJ*, **611** (2004) 200.
[29] Sazonov S. Y., Lutovinov A. A. and Sunyaev R. A., *Nature*, **430** (2004) 646.
[30] Soderberg A. M., Kulkarni S. R., Berger E. *et al.*, *Nature*, **430** (2004) 648.
[31] Tiengo A., Mereghetti S. and De Luca A., GCN Circ. n. 2548 (2004).
[32] Tiengo A. *et al.*, 2005, in preparation.
[33] Osborne J. *et al.*, 2005, these proceedings.
[34] Ubertini P., Lebrun F., Di Cocco G. *et al.*,*A&A*, **411** (2003) L131.
[35] Vaughan S., Willingale R., O'Brien P. T. *et al.*,*ApJ*, **603** (2004) L5.
[36] Vestrand W. T., Wozniak P. R., Wren J. A. *et al.*, *Nature*, **435** (2005) 178.
[37] von Kienlin A., Beckmann V., Covino S. *et al.*, *A&A*, **411** (2003) L321.
[38] Watson D., Reeves J. N., Hjorth J. *et al.*, *ApJ*, **595** (2003) L29.
[39] Watson D. *et al.*, *ApJ*, **605** (2004) L101.