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ISO observations of the GRB 970402 error box*

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Abstract. Following the detection by BeppoSAX of GRB 970402, a Target-of-Opportunity Observation by ISO was sheduled for 5 April, about 55-hours after the event, i.e. simultaneous with a second BeppoSAX pointing. The CAM instrument was used in the 6″/pixel mode, in the 8-15 μm band (IRAS) for covering the entire BeppoSAX GRB error box. A further observation was carried out on 13 April, with a similar set-up. Imaging was performed with the 6″/pixel mode in the GRB error box, and with the 1.5″/pixel field of view, in the smaller X-ray source error box. A PHT observation was also performed on 5 April. About 50 sources were detected with ISOCAM in a field centred in the GRB error box. 7 of them lie within the smaller X-ray error circle. With the exception of the variable star BL Cir, no other variable object was found in the entire GRB error box. 5-σ upper limits for any new object are $F_{(12\mu m)} \leq 0.14$ mJy and $F_{(174\mu m)} \leq 350$ mJy.

Key words: gamma rays: bursts – stars: BL Cir – infrared: general

1. Introduction

Gamma-ray bursts (hereafter GRBs) are brief flashes of cosmic high energy photons, and they remain one of the major mysteries for high-energy astrophysicists, the main problem being the lack of knowledge about their distance scale. With the advent of the Italian/Dutch X-ray satellite *BeppoSAX*, it has been possible for the first time, to find counterparts at other wavelengths for both GRB 970228 (Costa et al. 1997, van Paradijs et al. 1997) and GRB 970508 (Piro et al. 1997a, Bond 1997). This development can be considered as one major step towards the solution of the GRB enigma.

GRB 970402 was detected as a rather weak, highly-structured Gamma-Ray Burst on April 2.93 UT by the PDS and Wide Field Camera instruments aboard *BeppoSAX* (Feroci et al. 1997, Heise & in't Zand 1997). The coordinates of the burst were: $\alpha = 14^h 50^m 16^s$, $\delta = -69° 19'.9$ (equinox 2000.0) with an error circle of radius 3′. Eight hours after the burst (April 3.28-3.57 UT), BeppoSAX detected a previously unknown X-ray source, labelled SAX J1450.1-6920, within the field of GRB 970402 (Piro et al. 1997b). The 2-10 keV flux from the source showed a decreasing trend. Only an upper limit was derived from the second X-ray observation (April 4.63-5.21 UT), indicating that the source decreased by at least a factor of three from one observation to the other. The decline in the X-ray emission was attributed to the X-ray afterglow of GRB 970402.

Searches for *quiescent* counterparts have been conducted in the past in all wavelengths, including the IR. Schaefer et al. (1987) used the IRAS data base at wavelenghts of 12, 25, 60 and 100 μm and looked for candidates within 23 well localized GRB error boxes, but without finding any convincing counterparts. Aiming to detect *transient* IR-emission from this burst, we requested a target-of-opportunity observation with ISO, the European Space Agency's *Infrared Space Observatory* (Kessler et al. 1996), that started only 55 h after the gamma-ray event. Soon after, we learned that a fading near-IR counterpart was indeed observed for GRB 970228 (Soifer et al. 1997) and another would subsequently be detected for GRB 970508 (Morris et al. 1997).

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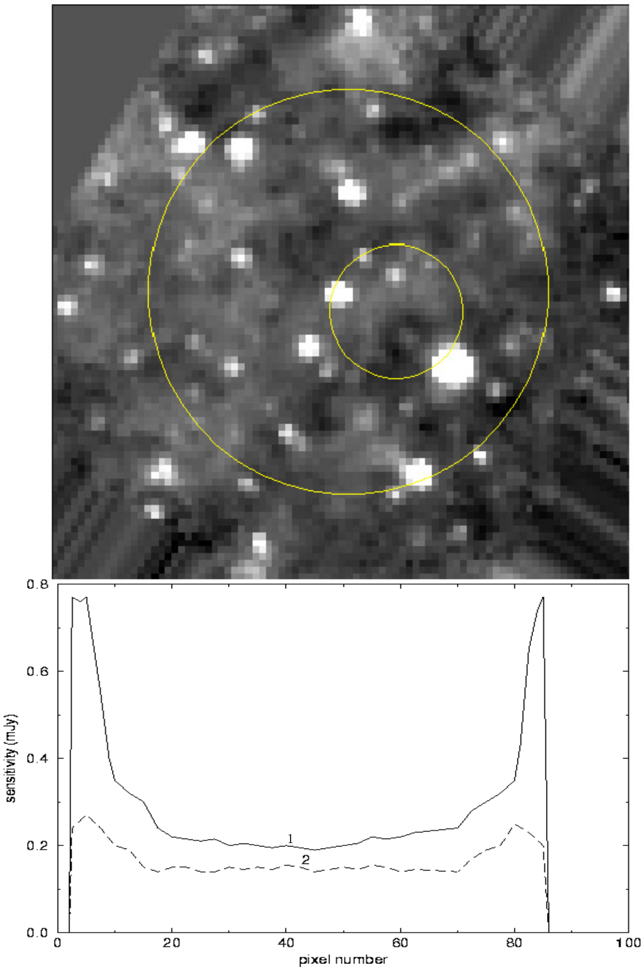

Fig. 1. ISOCAM co-added image for the GRB 970402 gamma-ray error box, based on the images obtained on 5 and 13 April 1997. The field of view is 9′ × 9′, centered at α = 14^{h}50^{m}16^s, δ = −69°19′.9 (equinox 2000.0). The large and small error circles are the GRB and 1SAX J1450.1-6920 error boxes respectively (Heise and in't Zand 1997, Piro et al. 1997). North is up and east to the left. The 5-σ detection limit as a function of the position is indicated in the lower panel for rows 77 (# 1) and 33 (# 2) of this 88 × 88 pixel image.

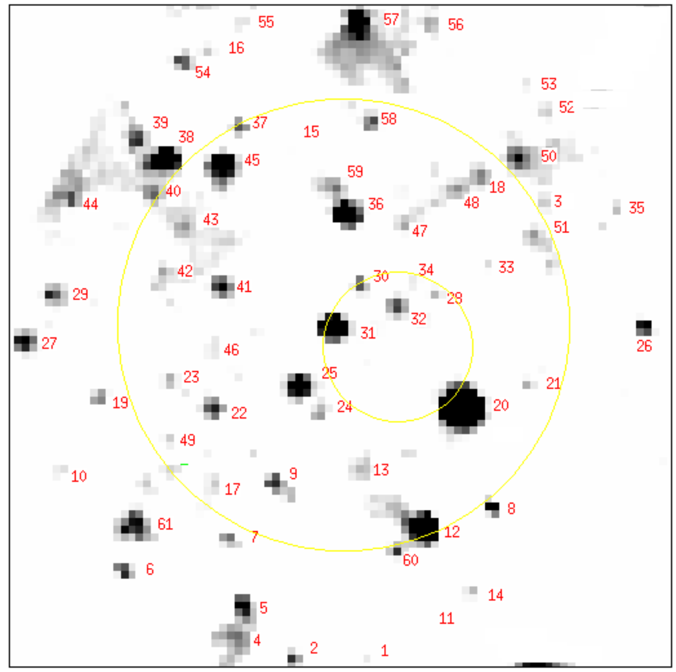

Fig. 2. Identification-chart for all the sources in Fig. 1 and listed in Table 2.

2. Instrumentation and observations

The first ISO observations were scheduled on 5 April, with the CAM (Cesarsky et al. 1996) and PHT (Lemke et al. 1996) instruments. Filters CAM LW10 (8-15 μm) and PHT C_160 (134-218 μm) were used respectively. The second set of observations was performed on 13 April. In order to cover the full 3′ radius GRB error box and the 50″ radius BeppoSAX error box of the GRB970402, the observing strategies listed in Table 1 were adopted.

The dominant sources of noise for the CAM long-wavelength (LW) detector for faint source work are cosmic ray glitches and flat-fielding imperfections. Both problems are alleviated by ensuring that each point on the sky is visited by as many array pixels as possible within the available time, while still ensuring adequate dwell time per position for minimal detector stabilisation to occur, and to support deglitching. Splitting the observation into two separate rasters improves glitch rejection.

Once the images were sky-substracted, flat-fielded and the glitches were removed, photometry was acquired. A 3 pixel diameter aperture (18″) was used.

In regions of high diffuse illumination or high source density, CAM's sensitivity may be degraded from the expectations due to source confusion "noise". Note that the diameter of the central spot of the ISO PSF is, in arcseconds, 0.84 times the wavelength in μm, or 8″.4 at 10 μm. Such confusion effects limited the achieved sensitivity for these measurements on the crowded field of GRB 970402, relative to what could be achieved on a relatively empty field (5-σ ∼ 100 μJy for the strategy used).

The data was reduced using ISOCAM Interactive Analysis Software (CIA) (Ott et al. 1997) and post-processed to remove residual glitches and unstable background using a wavelet transform-based program developed at CEA, Saclay (Starck et al. 1995). Processing steps involve deglitching, dark field subtraction, flat-fielding and responsive transient correction. Increased confidence in the photometry and glitch rejection was achieved by comparing in detail the different rasters recorded on each of the two days used for ISO observations.

Careful inspection of the noise statistics at different parts of the raster images reveals a 5-σ detection limit of about 140 μJy for point sources inside the GRB error circle, with the sensitivity falling to about 300 μJy at 5-σ towards the edges of the raster coverage, outside the GRB error box. In Fig. 1 a profile of the

Table 1. Journal of the ISO observations presented in this paper.

Date (1997)	Instrument	Wavelength	Number of raster steps	Readouts per positions	Step size (pixels)	Exp. time (seconds)	Target	Pixel size	Beam size
Apr. 05	CAM	12 μm	8 × 8	12	8	2 x 4,820	GRB error box	6″	6″
Apr. 05	PHT	170 μm	9 × 9		0.5	1,219	GRB error box	92″	80″
Apr. 13	CAM	12 μm	9 × 9	11	7	2 x 5,560	GRB error box	6″	6″
Apr. 13	CAM	12 μm	8 × 8	10	7.3	2 x 3,800	X-ray error box	1.5″	6″

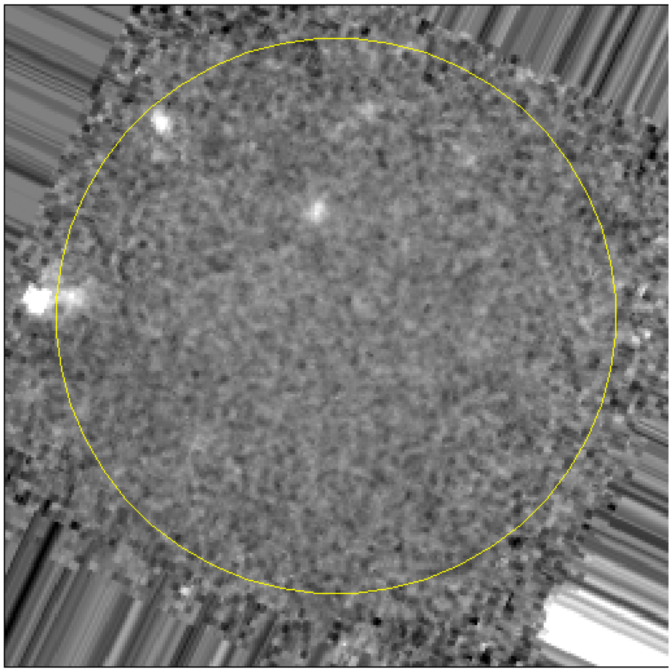

Fig. 3. The ISOCAM image obtained on 13 April 1997 for the GRB 970402 X-ray error box. The plate scale is 1.5″/pixel. The field of view is about 2′ x 2′ square, centered at α = 14^{h}50^{m}06^{s}, δ = −69°20′.0 (equinox 2000.0). North is up and east to the left.

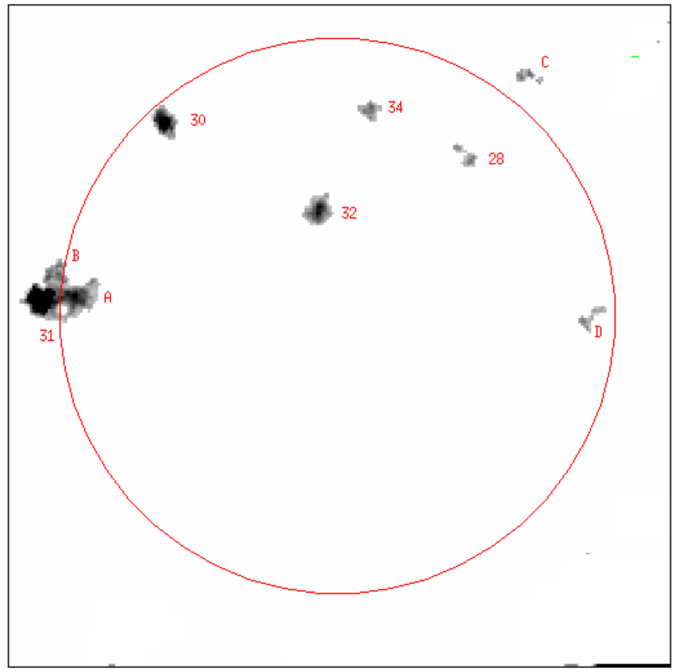

Fig. 4. Identification chart for the sources listed in Table 3.

5-σ sensitivity limit as a function of position across the raster is presented for a coaddition of the two 5 April 6″/pixel field of view (pfov) rasters. This is the relevant measure of precision for this paper which compares results from the raster pairs taken on different days. A somewhat better sensitivity limit will be achieved when these ISO observations are all coadded for comparison with future follow-up observations on this field. Also, more sophisticated photometry routines could be applied to reduce scatter in the measurements and eventually further constrain the upper limit from CAM.

The PHT observations were taken in the C_160 filter which is centred at 174 μm with δ_λ/λ = 0.51. This filter is used in combination with a 2x2 detector array with 92″ square pixels (Lemke et al. 1996). At 175 μm the point-spread function has a FWHM of ∼ 80″. An area of 8′x8′ was mapped using a 9 x 9 grid raster with 46″ steps in both directions. The resulting noise level in the central 6′x6′ is about 70 mJy/pixel. However, at 174 μm the sensitivity is limited by the cirrus confusion noise which has an amplitude of more than 70 mJy for spatial frequencies of order 90″ at the galactic latitude (b = -9°) of our target. The resulting 5-σ point source PHT sensitivity is 350 mJy.

3. Results and discussion

The CAM 6″ pfov co-added image is shown in Figs. 1 and 2. Most (95 % of) IR sources in the 12 μm images and listed in Table 2 seem to be identified with stars in the Galaxy.

The 1.5″ pfov image (Figs. 3 and 4), with much better resolution than the 6″ pfov image, shows that there is at least one source close to object # 31, labelled A. This source is a bright galaxy, the brightest extragalactic object within the X-ray error box (Pedersen et al. 1997b). Another nearby source (labelled B) could be scattered stray light (Table 3) and a further ISO measurement would be needed to confirm or refute that possibility.

The PHT 174 μm map (Fig. 5) shows no indication for the presence of a point source at the expected GRB position. A strong extended structure can be seen with an amplitude of about 3 MJy/sr which is probably due to infrared galactic cirrus. From

Table 2. IR sources detected in the GRB field (CAM 6″ pfov).

Source number	$F_{12-\mu m}$ 5 Apr (mJy)	$F_{12-\mu m}$ 13 Apr (mJy)	comments[1]
1	0.70	0.90	star
2	0.65	0.82	star
3	1.27	1.35	star
4	1.08	0.93	galaxy
5	0.31	0.18	star
6	0.81	0.79	star
7	0.62	0.60	star
8	1.71	1.73	star
9	12.23	12.26	star
10	0.50	0.49	galaxy ?
11	0.38	0.49	star ?
12	0.67	0.57	star
13	0.25	0.30	star
14	0.56	0.64	star
15	1.04	1.56	galaxy
16	0.66	1.32	star
17	0.25	0.32	star
18	0.96	0.71	star
19	0.18	0.17	star ?
20	54.88	50.80	star
21	0.46	0.67	star
22	1.69	1.24	star
23	0.37	0.41	star
24	0.38	0.39	star
25	1.83	1.82	star
26	3.10	2.96	star
27	0.50	0.53	galaxy
28	0.28	0.25	star
29	0.51	0.48	star
30	0.54	0.40	star
31	3.28	3.28	star
32	0.64	0.63	star
33	0.55	0.50	galaxy
34	0.25	0.16	star
35	0.85	0.65	star
36	0.20	0.24	star
37	0.56	0.59	star
38	0.63	0.74	star
39	5.54	5.32	star
40	0.34	0.40	star
41	0.89	0.88	star
42	0.66	0.70	star
43	0.24	0.36	star
44	2.90	2.85	star
45	0.46	0.30	star
46	2.68	2.67	star
47	0.72	0.53	star

[1] based on CCD images obtained at La Silla (Pedersen et al. 1997b)

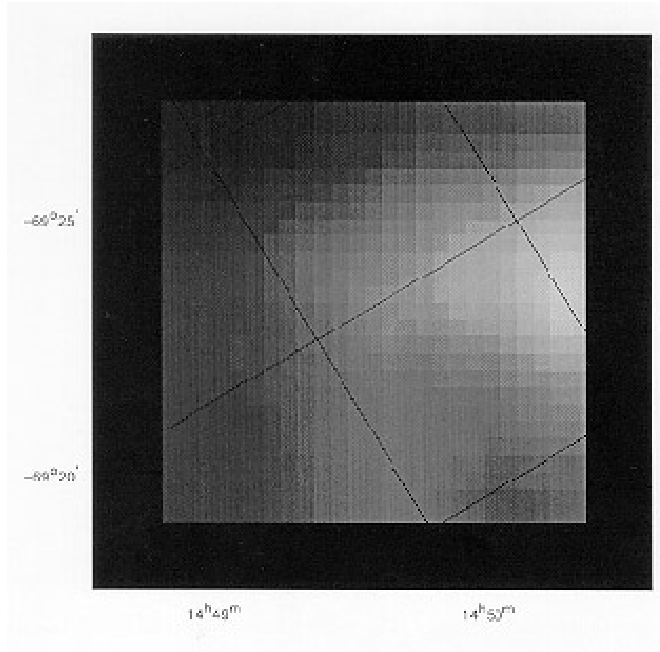

Fig. 5. ISOPHOT image of the GRB 970402 gamma-ray error box at 174 μm, obtained on 5 April 1997. The field of view is $8'.1 \times 8'.1$.

Table 3. IR sources detected by ISO in the 1SAX J1450.1-6920 error box (CAM 1.5″ pfov).

Source number	$F_{12-\mu m}$ 13 Apr (mJy)	comments
28	0.38	star
30	0.89	star
31	2.57	star
32	0.66	star
34	0.33	star
A	0.96	galaxy
B	0.45	
C	0.33	star
D	0.20	star

the measured noise per pixel we derive an 5-σ upper limit of 350 mJy at 174 μm.

The first ISO observation was carried out during the second *BeppoSAX* pointing (4.63-5.21 April), when no X-ray source was detected, implying a decrease by a factor of three or more in the X-ray flux, with respect to the first pointing (Piro et al. 1997).

With the exception of one object, none of the $\sim$ 40 sources *inside* the GRB error box displays significant variability in the 8-days interval between the two succesive ISO pointings, above a 5-σ level which is $\sim$ 140 μJy in the inner parts of the raster and $\sim$ 300 μJy in the outer parts (Table 2). The above-mentioned IR source (# 20), the brightest one in the field of view, is the variable star BL Cir (Hoffmeister 1965), which lies just outside the error box of SAX J1450.1-6920. On the basis of its optical spectrum (a late G - early K type, Pedersen et al. 1997a) and its faintness, the object has been suggested to be a previously unknown R CrB star (Harrison et al. 1997). The strong IR excess observed in the ISO data would rather indicate that the object might have undergone a strong episode of dust formation, resembling a Mira-type star. It is very unlikely that this single object is responsible of the high-energy event, as no theoretical GRB model would account for the phenomenon, but it could be worthwhile to monitor this object from now on.

Among the variety of GRB models, a considerable fraction deals with accretion of matter onto a compact object through an accretion disk, which might emit significantly in the IR. The emission at IR wavelengths could be enhanced in the case that the source heats up the surrounding dust, producing large amounts of IR radiation after the event (McBreen, Plunkett and Metcalfe 1995). One of the few dozens of theoretical models involving GRBs at cosmological distance is the fireball model (Meszaros and Rees 1993a,b), in which the release of 10^{51} erg within a small region and in a very short time leads to the formation of a forward blast wave moving ahead of a fireball, sweeping up the interstellar matter, and producing an afterglow at frequencies gradually declining from X-rays to visible and radio wavelengths (Paczynski and Rhoads 1993, Meszaros and Rees 1997). This type of behaviour has recently been observed in several bursts. As the fireball continues to radiate at longer wavelengths which increase with time (Katz 1994), IR emission should eventually be detected, but we have failed to detect transient IR emission from GRB 970402 with ISO.

4. Conclusions

We observed with ISO the region of the sky containing the entire BeppoSAX GBR error box for GRB 970402. Two target-of-opportunity observations were carried out as a result of the rapid *BeppoSAX* detection of the event. The main result is that with the exception of the variable star BL Cir, none of the 40 objects within the GRB error box displayed significant variability Therefore no strong additional and variable emission appeared following the X-ray afterglow, allowing strict upper limits to be placed on the variable IR emission at 12 μm and 174 μm. There is a possibility of detecting a fading (or faded) source in a future ISO observation. There are plans for further observations of GRB error boxes.

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