

# Optical and near-infrared observations of the GRB 970616 error box<sup>\*,\*\*</sup>

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**Abstract.** We report on near-infrared and optical observations of the GRB 970616 error box and of the X-ray sources discovered by ASCA and ROSAT in the region. No optical transient was found either within the IPN band or in the X-ray error boxes, similarly to other bursts, and we suggest that either considerable intrinsic absorption was present (like GRB 970828) or that the optical transient displayed a very fast decline (like GRB 980326 and GRB 980519).

**Key words:** methods: observational — gamma-rays: bursts

## 1. Introduction

The error box of the BATSE gamma-ray burst GRB 970616 (Connaughton et al. 1997) was scanned by RXTE four hours after the event (Marshall et al. 1997). Observations revealed a previously unknown X-ray source inside the error box whose position was consistent with the one provided later on by the Interplanetary Network (IPN), yielding a combined RXTE/IPN trapezoidal error box (Hurley et al. 1997). Four days later, the ASCA satellite observed the RXTE/IPN error box and detected four X-ray sources. One of them, A#1 according to the nomenclature of Murakami et al. (1997), was suggested as the X-ray counterpart to GRB 970616. Two candidates were initially proposed by Galama et al. (1997) and Udalski (1997), but other observers (Pahre et al. 1997; Dey et al. 1997; Wheeler et al. 1997; Castro-Tirado et al. 1997) failed to confirm these.

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\*\* Based on observations carried out at the Danish 1.54-m Telescope on the European Southern Observatory, La Silla, Chile.

Observations performed by ROSAT during June 23-25 revealed eleven faint X-ray sources, lying three of them within the RXTE/IPN error box. One of the three sources, R#2, following Greiner et al. (1997), was consistent with the ASCA variable source A#1, showing a flux five times lower than the one measured by ASCA. The  $3\sigma$  upper limit to the unabsorbed ROSAT flux of the source A#4, implies a factor of seven lower than the previously measured by ASCA. The fading observed during the ASCA observation could suggest that A#1 is the X-ray counterpart to the GRB. However, the presence of another decaying X-ray source inside the RXTE/IPN error box keeps open the association with the GRB. A massive cluster of galaxies 2' away from the RXTE/IPN error box is reported by Benítez et al. (1999). Figure 1 shows the locations of the cluster and of the candidates proposed by Galama et al. (1997) and Udalski (1997).

## 2. Observations

### 2.1. Near-IR observations

Observations in the  $K'$ -band were performed with the 3.5-m telescope (+OMEGA) of the Calar Alto Observatory on 1997 June 21.18, 25.17 and 26.18 UT. Also  $J$ -band images were taken with the 2.2-m Telescope (+MAGIC) on June 25.14. The frames were centered on the candidate proposed by Galama et al. (1997). Additional  $K'$ -band observations were performed on 1998 Oct. 5.125 with the 3.5-m telescope.

### 2.2. Optical observations

Optical observations were mainly taken at La Silla with the Danish 1.54-m telescope equipped with DFOSC, whose field of view ( $13'.6 \times 13'.6$ ) enabled us to cover the four ASCA sources (see Fig. 1). Table 1 displays the observing log.

**Table 1.** Observing log of the optical observations performed with the 1.54-m Danish telescope

Date of 1997	Exposure time ( $10^3$ s)				
	<i>B</i>	<i>V</i>	<i>R</i>	<i>i</i>	free
June 25	-	-	8.9	-	-
June 26	-	-	-	7.8	-
June 27	-	-	9.6	-	-
June 28	-	-	10.2	-	-
June 29	-	-	11.2	-	-
June 30	-	2.0	9.0	-	-
July 1	-	1.2	10.5	-	-
July 2	3.6	-	7.2	-	-
July 3	1.2	-	-	-	-
July 4	1.2	-	-	-	-
July 6	-	-	3.6	-	0.9
July 7	-	-	-	-	5.6
Total 26.02 <sup>h</sup> =	6.0	+3.2	+70.2	+7.8	+6.5

Additional *R*-band imaging was obtained on 1997 July 20.199, 20.207 and 20.257 with the 0.8-m IAC80 telescope at the Observatorio del Teide. A  $1020 \times 1024$  pixels CCD provides a  $7'.4 \times 7'.4$  field of view. Limiting magnitude was  $R \sim 20$  on the 360-s exposures.

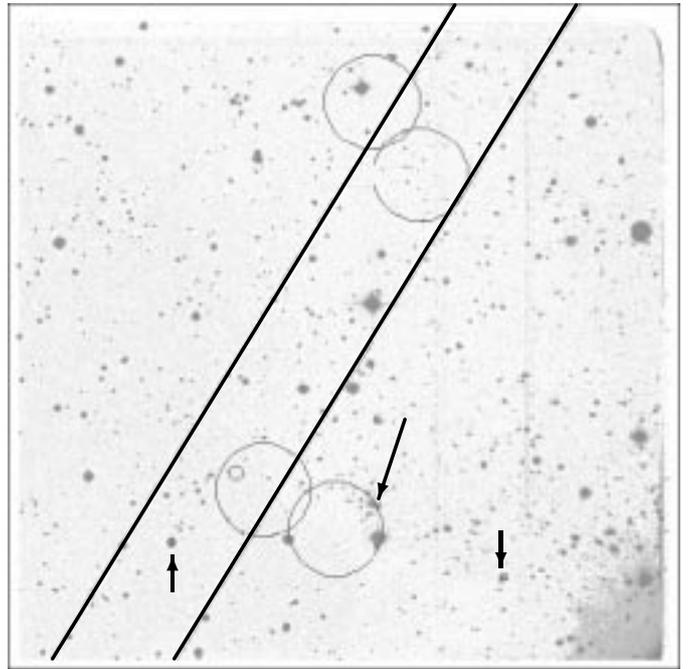
### 3. Discussion and conclusion

Optical and IR images of the RXTE error box were obtained starting 106 hours after the event. No variable optical counterpart was found within the A #1 and A #4 X-ray source error circles in the RXTE/IPN annulus, being the variation  $\Delta B \leq 0.3$ ,  $\Delta V \leq 0.2$ ,  $\Delta R \leq 0.2$  and  $\Delta i \leq 0.3$  for optical objects with  $B \leq 23$ ,  $V \leq 23$ ,  $R \leq 24$  and  $i \leq 22$ . In fact, no objects brighter than  $R = 24.2$  are seen within the error box of the ROSAT R #2 source detected at the ASCA position, consistently with the magnitudes reported by Groot et al. (1997). Therefore, either there is a considerable intrinsic absorption (as in the case of GRB 970828, Yoshida et al. 1999) or the transient optical emission displayed a fast decline, as seen in GRB 980326 (Groot et al. 1998) and GRB 980519 (Hjorth et al. 1999).

No IR variability has been found in a  $5' \times 4'$  region centered at the position of the candidate proposed by Galama et al. (1997). This object was observed at  $J = 18.3 \pm 0.2$ , and  $K' = 17.4 \pm 0.3$  and did not show any obvious IR/optical variation in the  $K'$ -band. The color is consistent with this of a late-type star, as suggested by Pahre et al. (1998) and it seems to be a non-variable star (Groot et al. 1997). Any fading or increase was  $\leq 0.5$  mag for  $K' \leq 17.0$ .

Concerning the above mentioned cluster of galaxies (the long arrow in Fig. 1), it is probably related to the X-ray source A #2, which is outside the IPN band, and consequently not related to the GRB.

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**Fig. 1.** A coadded *R*-band image of the field of GRB 970616 obtained with the Danish 1.54-m telescope. The total exposure time is 19.5 hours and the limiting magnitude  $R = 24.2$ . The straight thick lines represent the IPN arc determined by Ulysses and BATSE. The two circles fully included in the IPN band are A #4 (large, at the top) and R #2 (small at the bottom), whereas the circles partially included are A #3 (top) and A #1 (bottom). The circle totally outside the IPN band is A #2. R #1 and R #3 are outside the field of view. The two short arrows show the variable objects proposed by Galama et al. (1997) -inside the IPN band- and Udalski (1997) -outside the IPN band-. The field of view is  $13'.6 \times 13'.6$  and is totally within the RXTE/ASM error box. North is to the top and east to the left. The long arrow indicates the massive cluster of galaxies found by Benítez et al. (1999)

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### References

- Benítez N., et al., 1999 (in preparation)
- Castro-Tirado A.J., et al., 1997, IAU Circ. 6688
- Connaughton V., et al., 1997, IAU Circ. 6683
- Dey A., et al., 1997, IAU Circ. 6696
- Galama T., et al., 1997, IAU Circ. 6687
- Greiner J., et al., 1997, IAU Circ. 6722
- Groot P.J., et al., 1997, IAU Circ. 6723
- Groot P.J., et al., 1998, ApJ 502, L123
- Hjorth J., et al., 1999, A&AS (this issue)
- Hurley K., et al., IAU Circ. 6687
- Marshall F.E., et al., 1997, IAU Circ. 6683
- Murakami T., et al., IAU Circ. 6687
- Pahre M.A., et al., 1997, IAU Circ. 6691
- Udalski A., 1997, IAU Circ. 6690
- Wheeler J.C., et al., 1997, IAU Circ. 6697
- Yoshida A., et al., 1999, A&AS (this issue)