Discovery of the Faint Near-IR Afterglow of GRB 030528[1]

Rau A.*, Greiner J.*, Klose S.†, Castro Cerón J. M.**, Fruchter A.**, Küpcü Yoldaş A.*, Gorosabel J.**, Levan A. J.**, Rhoads J. E.** and Tanvir N. R.‡

*Max-Planck Institute for extraterrestrial Physics, Garching , Germany
†Thüringer Landessternwarte, Tautenburg, Germany
**Space Telescope Science Institute, Baltimore, USA
‡Department of Physical Science, Univ. of Hertfordshire, Hatfield Herts, UK

Abstract. We report on the discovery of the near-IR transient of the long-duration gamma-ray burst GRB 030528 and its underlying host galaxy. The near-IR transient was first observed in *JHKs* with SofI at the 3.6 m ESO-NTT 16 hrs after the burst and later observations revealed a fading *Ks*-band afterglow. The afterglow nature was confirmed by *Chandra* observations which found the source to be a fading X-ray emitter. The lack of an optical afterglow and the early faintness in the near-IR (Ks>18.5 mag) place GRB 030528 in a parameter space usually populated by dark bursts. We find the host to be an elongated blue galaxy.

OBSERVATIONS

On May 28 2003 *HETE-2* localized a moderately bright (peak flux of 4.8×10^{-8} erg/cm^2/s at 30-400 keV) long-duration Gamma-ray burst (GRB) [1] 107 min after the observed prompt emission (13:03 UT). Shortly after, ToO observations of the circulated $2'$ radius error circle were initiated with the the 3.6 m ESO-New Technology Telescope (NTT) equipped with the Son of ISAAC (SofI) infrared spectrograph and imaging camera at La Silla/Chile. Here we report on *JHKs* imaging data of the first three nights supplemented by later *I*-, *Js*- and *K*-band imaging with the Mosaic2 imager at the 4 m Blanco Telescope at the Cerro Tololo Inter-American Observatory (CTIO), the Infrared Spectrometer And Array Camera (ISAAC) at the 8.2 m Very Large Telescope (VLT) in Paranal and the 3.8 m United Kingdom Infra-Red Telescope Fast-Track Imager (UKIRT UFTI) on Mauna Kea, respectively (see Tab.1 for an observing log).

NTT-SofI observations were accomplished 16, 41 and 87 hrs after the GRB. Unfortunately, the *HETE-2* localization was revised to a $2\overset{\prime}{.}5$ radius error circle displaced by $1\overset{\prime}{.}3$ from the earlier position [2] after these images were taken. Given the $5\overset{\prime}{.}5$ field of view of NTT-SofI, our data were not covering the entire revised error circle. This, and the non-detection of a transient in optical (R>18.7 mag 2.3 hrs after the burst [3]) and radio[4] observations of the crowded field would have made the discovery of the counterpart nearly impossible without *Chandra* observations. Following the detection of four

[1] for the GRACE collaboration

TABLE 1. Observation log.

Instrument	Date (Start UT)	Filter	Exp. [min]	Seeing	Magnitude
NTT-SofI	29.5. 04:58	J	15	$0.8''$	20.9 ± 0.9
NTT-SofI	29.5. 05:16	H	15	$0.8''$	19.9 ± 0.9
NTT-SofI	29.5. 05:32	Ks	15	$0.8''$	18.5 ± 0.4
NTT-SofI	30.5. 04:54	J	20	$1.6''$	$>20.1\pm0.7$
NTT-SofI	30.5. 05:16	H	20	$1.1''$	$>18.9\pm1.6$
NTT-SofI	30.5. 05:40	Ks	20	$1.1''$	18.8 ± 0.3
NTT-SofI	1.6. 04:07	Ks	60	$0.8''$	19.5 ± 0.6
Blanco-Mosaic2	4.6. 02:10	I	40	$1.2''$	21.4 ± 0.5
UKIRT-UFTI	12.6. 08:55	K	116	$0.6''$	19.3 ± 0.2
Blanco-Mosaic2	30.6. 03:00	I	40	$1.1''$	21.4 ± 0.5
VLT-ISAAC	17.9. 00:12	Js	50	$0.6''$	21.3 ± 0.4
VLT-ISAAC	27.9. 00:27	Js	60	$0.9''$	21.4 ± 0.4
VLT-ISAAC	29.9. 23:38	Js	94	$0.7''$	20.9 ± 0.4
VLT-ISAAC	1.10. 00:04	Js	60	$0.6''$	21.0 ± 0.6

X-ray sources inside the revised error circle on June 3 [5] one of these sources (CXOU J170400.3–223710) was found to be fading in our SofI-*Ks*-band images [6]. A second *Chandra* observation on June 9 showed a significant fading of the counterpart candidate while the other sources inside the error circle did not reveal any brightness decline [7].

The NTT-SofI and VLT-ISAAC data were reduced using the *Eclipse* package[8]. The reduction of the Blanco-Mosaic2 data was performed with *bbpipe*, a script based on the *IRAF/MSCRED*, and the UKIRT-UFTI observations were reduced using *ORACdr*. The photometry was performed with *IRAF/DAOPHOT*. We calibrated the *JJsHK* and *Ks* images against several stars contained in the 2MASS All-Sky Point Source Catalog[2] from the neighbourhood of the GRB. The Mosaic2 I-band images were calibrated using USNOFS field photometry[9]. The magnitudes are corrected for foreground extinction[10] (A_K=0.22, A_H=0.35, A_J=0.54 and A_I=1.17) for the given galactic coordinates.

THE NEAR-IR AFTERGLOW

Observations from the first night ($\sim$16 hrs after the burst) showed the afterglow to be near the detection limit of the *JH*-band SofI images. The source is well visible in *Ks* at an extinction corrected magnitude of 18.5 ± 0.4. It was thus $\sim$1.5 mag brighter than the faintest *K*-band[3] afterglow observed at that time after the burst, that of GRB 971214.

The afterglow shows a probable fading in *Ks* from 16 to 80 hrs after the burst by $\sim$1 mag (Fig. 1). This corresponds to a decay with a slope of $\alpha\sim0.6 Ks/K$-band data from June 1 (NTT) and June 12 (UKIRT) shows constant magnitudes. Therefore, the host galaxy seems to dominate the *K*-band emission already after $\sim$3 days. Unfortunately, the observing conditions from the second night (41 hrs after the burst) make the

[2] http://irsa.ipac.caltech.edu/applications/Gator/

[3] We assume here $K\sim Ks$, which is justified within the error of the estimated magnitudes.

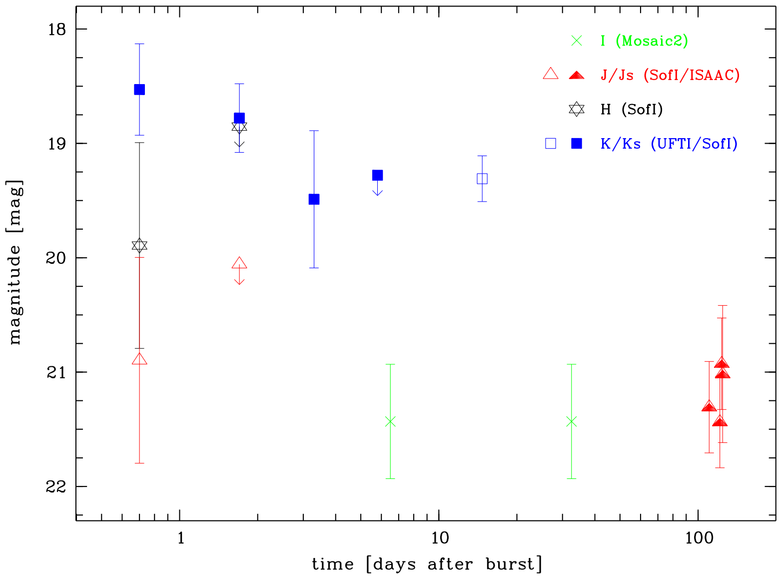

FIGURE 1. Light curves in I (marked by a cross), J/Js (triangle/filled triangle), H (star) and K/Ks (square/filled square). For J and H only upper limits exist for t=1.7 days. The Ks-band upper limit at t=5.8 days is from [11]. All magnitudes are corrected for foreground extinction in the Galaxy.

estimation of an early fading in J and H not feasible. No decay is seen in the J/Js-band[4] when comparing the SofI observations and the ISAAC observations from >100 days. This suggests, that the afterglow emission was strongly extinguished in the J-band (in addition to the galactic extinction) and the emission dominated by the host galaxy already at the time of our first SofI observation.

It is unlikely that we would have found this IR counterpart without *Chandra*, and the non-detection in the optical would have led to the classification of GRB as a dark burst. While $\sim$60% of all well localized GRBs have no detected optical/NIR afterglow, the fast reaction time and deep detection limit of $\sim$19.5 in Ks were important for the discovery of the near-IR transient of GRB 030528.

THE HOST GALAXY

Late time K-band imaging with UKIRT revealed the potential underlying host galaxy (see Fig. 2). The data show an East-West elongated object at the position of the transient with a size of $\sim 1.5'' \times 0.8''$. This shape suggests the host to be either an elliptical or edge-on disk galaxy. The apparent brightness of $K\sim$19.5 mag and I-$K\sim$2 mag places the host of GRB 030528 well in the mean of the sample of GRB host galaxies detected in the K-band [12] and is more typical for a star-forming rather than for an elliptical galaxy.

---

[4] The J and Js filters differ slightly in width and efficiency. For a flat spectrum a first order assumption of $J\sim Js$+0.4 mag can be used.

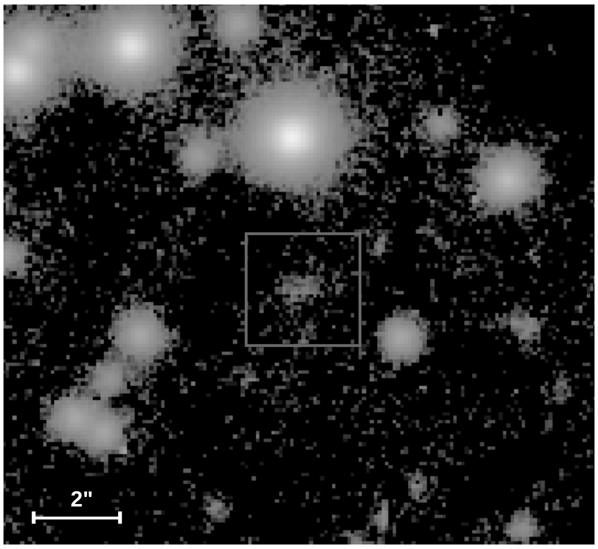

FIGURE 2. *K*-band image taken with the 3.8m UKIRT equipped with the UFTI on June 12, 15 days after the prompt emission. North is up and East to the right. The potential host galaxy of GRB 030528 (square) shows an elongation in East-West direction.

ACKNOWLEDGMENTS

This work is primarily based on observations collected at the European Southern Observatory, Chile, under the proposal 71.D-0355 (PI: E.v.d.Heuvel) with aditional data obtained at the Cerro Tololo Inter-American Observatory and the United Kingdom Infra-Red Telescope. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

REFERENCES

1. Atteia, J-L., Kawai, N., Lamb, D., Ricker, G., Woosley, S., et al., GCN, **2256**, (2003)
2. Villasenor, J., Butler, N., Crew, G., Doty, J., Prigozhin, G., et al., GCN, **2261**, (2003)
3. Ayani, K., and Yamaoka, H., GCN, **2257**, (2003)
4. Frail, D.A. and Berger, E., GCN, **2270**, (2003)
5. Butler, N., Dullighan, A., Ford, P., Ricker, G., Vanderspek, R., et al., GCN, **2269**, (2003)
6. Greiner, J., Rau, A. and Klose, S., GCN, **2271**, (2003)
7. Butler, N., Dullighan, A., Ford, P., Ricker, G., Vanderspek, et al., GCN, **2279**, (2003)
8. Devillard, N., The Messenger, **87**, 19, (1997)
9. Henden, A., GCN, **2267**, (2003)
10. Schlegel, D.J., Finkbeiner, D.P., Davis, M., ApJ **500** 525, (1998)
11. Bogosavljevic, M., Mahabal, A. and Djorgovski, S.G., GCN, **2275**, (2003)
12. le Floc'h, E., Duc, P-A., Mirabel, I.F., Sanders, D.B., Bosch, G., et al., A&A, **400**, 499, (2003)