A deep search for the hosts of optically dark GRBs

A. Rossi, S. Klose, D. A. Kann, A. Nicuesa Guelbenzu

Thüringer Landessternwarte, Tautenburg, Germany; E-mail: rossi@tls-tautenburg.de

P. Ferrero

Instituto de Astrofísica de Canarias, Tenerife, Spain

J. Greiner, P. M. J. Afonso, C. Clemens, R. Filgas, M. Nardini, F. Olivares E, A. Rau, S. Savaglio, P. Schady

Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany

D. H. Hartmann

Department of Physics and Astronomy, Clemson University, Clemson, SC, USA

A. C. Updike

Department of Physics and Astronomy, Dickinson College, Carlisle, USA

T. Krühler

Dark Cosmology Centre, Niels Bohr Institute, Univ. of Copenhagen, Denmark

E. Palazzi, L. Amati, N. Masetti

INAF-IASF Bologna, Area della Ricerca CNR, Bologna, Italy

L. K. Hunt

INAF-Osservatorio Astrofisico di Arcetri, Firenze, Italy

A. J. Castro-Tirado, A. de Ugarte Postigo

Instituto de Astrofísica de Andalucía (IAA-CSIC), Granada, Spain

A. Küpcü Yoldaş, A. Yoldaş

Institute of Astronomy, University of Cambridge, Cambridge, UK

E. Pian

Scuola Normale Superiore di Pisa - Piazza dei Cavalieri, Pisa, Italy

We report on the results of a search for the host galaxies of a sample of 17 bursts with arcsec-sized XRT error circles but no detected long-wavelength afterglow, in spite of deep and rapid follow-up observations.

Gamma-Ray Bursts 2012 Conference -GRB2012,
May 07-11, 2012
Munich, Germany

1. Introduction

By the end of 2010, about 900 gamma-ray bursts (GRBs) have been localized at the arcmin scale, most of them (>80%) by the *Swift* satellite. Nearly 600 events have a detected X-ray afterglow, and nearly 400 have been detected in the optical and near infrared (NIR) bands, too. The observed brightness distribution of the optical afterglows is broad and time-dependent, spanning at least 14 magnitudes within the first hour after the burst, and at least 10 magnitudes at around 1 day (Fig. 1). In addition, there is a substantial fraction of bursts whose afterglow is not detected in the optical/NIR bands.

Here, we summarize the results of a search for the potential host galaxies of a sample of 17 *Swift* bursts with no optical afterglow but precise X-ray localization. Deep follow-up observations of 14 of these 17 X-ray error circles were performed with VLT/FORS1, FORS2, VIMOS, ISAAC, and HAWK-I in the years 2008 to 2010, months to years after the corresponding burst. Limiting 3σ AB magnitudes were typically R_C=26.5 and K_s=23.5. In some cases multi-band imaging was performed using GROND on La Silla and the near-infrared imager NEWFIRM mounted at the 4-m Mayall telescope at Kitt Peak National Observatory. All bursts in our sample have an observed duration in the *Swift*/BAT energy window of $T_{90} > 2$ seconds. All events have optical upper limits well below the average brightness of detected long-GRB afterglows (Fig. 1). Our goal was to identify and to study the host-galaxy candidates of these events in order to better understand the underlying cause of the optical dimness of these events. In order to be conservative, we searched for host-galaxy candidates in an area with a radius always twice the radius of the corresponding 90% c.l. *Swift*/XRT error circle (in the following designated as $1r_0$).

2. EROs as host-galaxy candidates

Long bursts trace the birth places of the most massive stars, which leads to the expectation that a certain percentage of all hosts of long bursts could be dust-enshrouded starburst galaxies. Among them, the most extreme cases are classified as extremely red objects (EROs; defined as having $(R-K)_{\rm AB} > 3.5$ mag).

In our sample, seven objects fall (within their 1σ magnitude error) into this category. These are: GRB 060923B, a galaxy with $(R-K)_{\rm AB} = 3.8 \pm 0.1$ mag, GRB 070429A (> 3.5 mag), GRB 080207 (4.7 ± 0.4 mag), GRB 080218B (4.1 ± 0.2 mag), GRB 080602 (> 4.3 mag), GRB 081105 (> 3.5 mag), and GRB 081204 (3.1 ± 0.5 mag). Three of them lie within their corresponding 90% c.l. XRT error circle (GRBs 080207, 080218B, and 081204), the others lie within less than $1.5r_0$. In all cases the probability to find an ERO of the given K-band magnitude within the corresponding XRT error circle is very small.

The seven EROs we have found have a magnitude between $K_{\rm AB}$ = 21.5 and 23.0, i.e. $K_{\rm Vega}$ = 19.6 to 21.1. For these K-band magnitudes the number density of EROs on the sky is in the order of 1 per 1000 arcsec^2 [1]. Our findings then imply an overdensity of EROs in the XRT error circles we have studied here. Our results indicates that an infrared-bright subpopulation of very dusty GRB host galaxies exists, which stands out from the main GRB host-galaxy population.

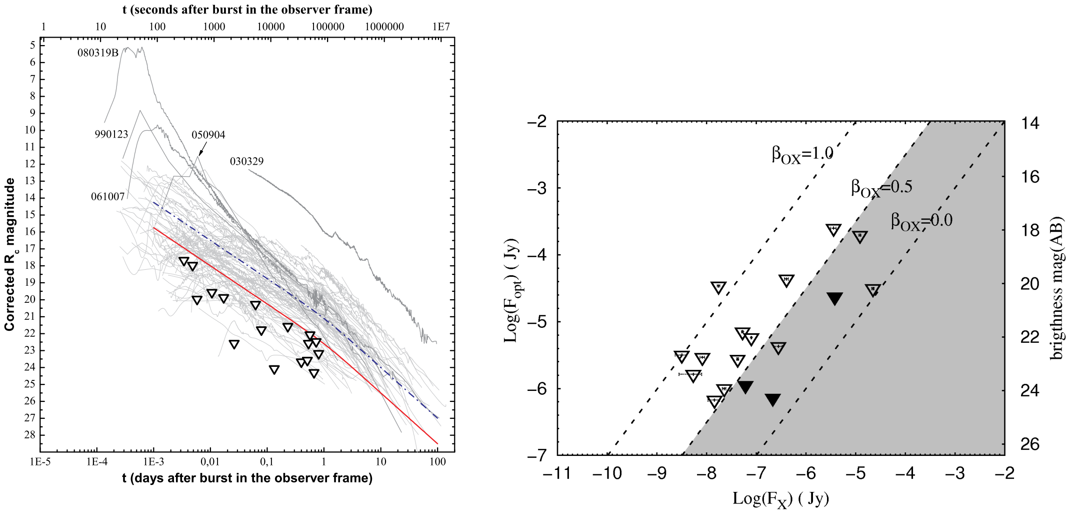

Figure 1: Left: The R_C-band light curves of all (long) afterglows in the sample of [4]. All data have been corrected for Galactic extinction. Triangles indicate equivalent R_C-band upper limits of the afterglows in our sample. The blue dashed/dotted line approximately indicates the mean of the afterglow brightness distribution. The red line indicates the borderline of all targets in our study. **Right:** Observed upper limits in the R_C band compared to the measured flux density at 1.73 keV (the logarithmic mean of the *Swift*/XRT window, $0.3-10$ keV) for the 17 bursts in our sample. In those cases where no R_C-band data were available, we used the observed spectral slope $\beta_{\rm OX}$ to shift the flux density from the native filter to the R band. The three bursts which can be considered as securely classified dark bursts according to [3] as well as [7] are marked with filled black triangles.

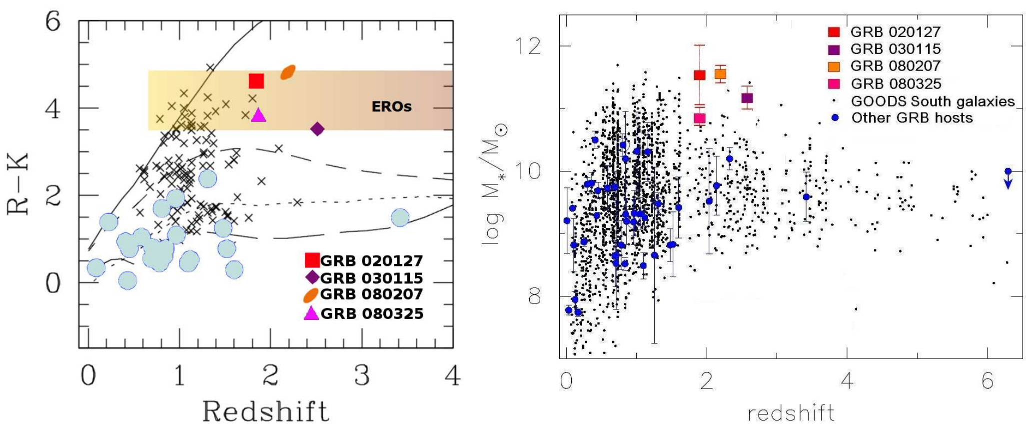

Figure 2: Left: $(R-K)_{\rm AB}$ apparent color as a function of redshift for GRB hosts (filled circles) and Gemini Deep Deep Survey field galaxies (crosses). The curves are predicted color as a function of redshift for galaxies with E (solid line), Sbc (short-dashed line), irregular (dotted), and starburst (long-dashed line) stellar populations. The ERO host of GRB 080207, discovered by us [2, 5] lies together with other EROs in a region occupied by star-forming but dust-enshrouded and massive galaxies (adapted from [6]). **Right:** Stellar mass versus redshift for GRB hosts and other galaxy populations. The ERO hosts for which mass and redshift estimations from SED fitting exist are highlighted and shown to be a distinct group, in particular more massive with respect to the known population of long-GRB host galaxies (adapted from [2]).

3. Lyman dropout candidates

For two of the 17 bursts investigated here (GRBs 050922B and 080727A) we could not find any galaxy inside $2r_0$. Therefore, we consider the optical afterglows of these events as Lyman dropout candidates. We cannot rule out very faint hosts at $z \lesssim 5$ though.

An additional but weaker Lyman dropout candidate is the optical afterglow of GRB 081012. Here we find only one galaxy between $1r_0$ and $2r_0$. Alternatively, the host could be located within $1r_0$ but is Lyman dropped out. In two further cases a galaxy is found not closer than about $1r_0$ from the center of the corresponding error circle (GRBs 060923B and 061102), but this galaxy extends with its outer parts inside the 90% c.l. XRT error circle. In other words, here the afterglow itself could have been placed well inside $1r_0$. Therefore, we do not consider the optical afterglows of these two bursts as Lyman dropout candidates.

Finally, among the seven ERO galaxies discovered in our sample, four have been detected in R, i.e. they are not Lyman dropped out. On the other hand, three ERO galaxies with no R-band detection could lie at higher redshifts (GRBs 070429A, 080602 and 081105). We conclude, in our sample we have up to six Lyman dropout candidates ($\sim$ 30%), in all other cases such an interpretation is not required (for more details see [5]).

4. Summary

The $(R-K)$ color of galaxies turned out to be a powerful criterion to find GRB host-galaxy candidates. In particular, a subsample of seven bursts shows extremely red objects inside their corresponding XRT error circle. Moreover, all three bursts in our sample that are classified as securely dark according to their observed X-ray flux belong to this group. Even though we are confronted with low-number statistics, these findings imply that a non-negligible fraction of optically dim bursts might be located in globally dust-enshrouded galaxies. In addition, we find that at most $\sim$ 1/3 of all events of our sample could be explained by Lyman dropout in the R_C band. In all other cases, high redshift is not required.

References

[1] Gonzales-Perez, V. et al., *Massive, red galaxies in a hierarchical universe - I. Counts of extremely red objects and basic properties*, *MNRAS* **398** (2009), 497.

[2] Hunt, L. et al., *The extremely red host host galaxy of GRB 080207*, *ApJ Lett.* **736** (2011), L36.

[3] Jakobsson, P. et al., *Swift Identification of Dark Gamma-Ray Bursts*, *ApJ Lett.* **617** (2004), L21.

[4] Kann, D. A. et al., *The Afterglows of Swift-era Gamma-ray Bursts. I. Comparing pre-Swift and Swift-era Long/Soft (Type II) GRB Optical Afterglows*, *ApJ* **720** (2010), 1513.

[5] Rossi, A. et al., *A deep search for the host galaxies of GRBs with no detected optical afterglow*, submitted to A&A [arXiv:1202.1434]

[6] Savaglio, S. et al., *The Galaxy Population Hosting Gamma-Ray Bursts*, *ApJ* **691** 2009, 182.

[7] van der Horst, A. J. et al., *Optical Classification of Gamma-Ray Bursts in the Swift Era*, *ApJ* **699** (2009), 1087.