The latest two GRB detected by *Hete-2*: GRB 051022 and GRB 051028

A. J. Castro-Tirado[*], S. McBreen[†], M. Jelínek[*], S. B. Pandey[*], M. Bremer[**], A. de Ugarte Postigo[*], J. Gorosabel[*], S. Guziy[*,‡], G. Bihain[§], J. A. Caballero[§], P. Ferrero[¶], J. de Jong[‖], K. Misra[††] and D. K. Sahu[‡‡]

[*]*Instituto de Astrofísica de Andalucía (IAA-CSIC), P.O. Box 3.004, E-18.080 Granada, Spain*
[†]*Astrophysics Missions Division, RSSD, ESA-ESTEC, Noordwijk, The Netherlands*
[**]*Institute de Radioastronomie Milimetrique (IRAM), 38406 Saint Martin d´Héres, France*
[‡] *Nikolaev State University, Nikolskaya 24, 54030 Nikolaev, Ukraine*
[§]*Instituto de Astrofísica de Canarias (IAC), 38205 La Laguna, Tenerife, Spain*
[¶]*Thüringer Landessternwarte Tautenburg, Sternwarte 5, D-07778 Tautenburg, Germany.*
[‖]*Max-Planck Institut für Astronomie, Koennigstuhl 17, D-69117 Heidelberg, Germany*
[††]*ARIES, Manora Peak, Nainital 263 129, India*
[‡‡]*Indian Institute of Astrophysics, 560034 Bangalore, India*

Abstract. We present multiwavelength observations of the latest two GRB detected by *Hete-2* in 2005. For GRB 051022, no optical/nIR afterglow has been detected, in spite of the strong gamma-ray emission and the reported X–ray afterglow discovered by *Swift*. A mm afterglow was discovered at PdB confirming the association of this event with a luminous ($M_V = -21.5$) galaxy within the X-ray error box. Spectroscopy of this galaxy shows strong a strong [O II] emission line at z = 0.807, besides weaker [O III] emission. The X-ray spectrum showed evidence of considerable absorption by neutral gas with $N_{H,X-ray} = 4.5 \times 10^{22}$ cm^2 (at rest frame). ISM absorption by dust in the host galaxy at $z = 0.807$ cannot certainly account for the non-detection of the optical afterglow, unless the dust-to-gas ratio is quite different than that seen in our Galaxy. It is possible then that GRB 051022 was produced in an obscured, stellar forming region in its parent host galaxy.

For GRB 051028, the data can be interpreted by collimated emission (a jet model with $p = 2.4$) moving in an homogeneous ISM and with a cooling frequency ν_c still above the X-rays at 0.5 days after the burst onset. GRB 051028 can be classified as a "gray" or "potentially dark" GRB. The Swift/XRT data are consistent with the interpretation that the reason for the optical dimness is not extra absorption in the host galaxy, but rather the GRB taking place at high-redshift.

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INTRODUCTION

Nowadays, dark GRBs seem to constitute a significant fraction of the GRB population. Although no optical/nIR afterglows have been detected for this class, transient X-ray and radio emission has allowed to pinpoint the parent galaxies where the bursts have occurred. About 48% (34/71) of well-localized GRBs by the *Swift*/XRT so far in the 1st yr of the *Swift* Era do not show an optical (or near-IR) afterglow, in spite of deep searches (down to 21-22 mag) being performed for nearly all in $<$ 24 hr.

The main possible scenarios that have been proposed are the obscuration scenario, the low-density scenario and the high-redshift scenario (also discussed in [1,2]). The first one could be due to: i) a high column density of gas around the progenitor like a

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dusty, clumpy medium in giant molecular clouds (GMCs [3]) or ii) to dust in the host galaxy at larger distances. In the latter case, this will only account for no more than 10% of events (discussed in [4]). The occurrence of a burst in a low-density ambient medium [5] will result in a very dimmed afterglow as well. But this seems unlikely too due to the fact that it is now well accepted the relationship of long-duration GRBs with core-collapse supernova whose progenitors would have not been able to travel too far away from their parent star-forming regions where they were born. The high-z case, in which the Ly-α forest emission will affect the optical band, will not be expected for more than 10% of the events [6].

It is therefore, most essential to chase new potential dark GRBs and to study whether the reason for its *darkness* could due to the obscuration scenario (the a-priori most plausible scenario for the reasons given above).

GRB 051022

The bright GRB 051022 constituted a perfect study case. It was discovered by *Hete-2* on 22 Oct 2005 [7]. The burst started at 13:07: UT and lasted for $\approx$ 200 s, putting it in the “long-duration” class of GRBs [8]. It was also observed by *Mars Odyssey* and *Konus*/WIND [9], making of it the highest fluence event detected by *Hete-2* in its 5-yr lifetime, with the exception of the nearby GRB 030329. By the time when *Swift* slewed and started data acquisition (about 3.5 hr after the event onset), fading X-ray emission was detected by the *Swift*/XRT, what can be considered as the first clear detection of the GRB 051022 afterglow [10]. This triggered a multiwavelength campaign at many observatories aimed at detecting the afterglow at other wavelengths.

Multiwavelength observations

We triggered optical, near-IR and mm observations at different observatories. We also made use of the public X-ray data from *Swift*/XRT which were taken starting at 3.5 hr after the event. Further details are given in [11].

Following the reported discovery of the X-ray afterglow, the main observational result is the detection of the mm afterglow superimposed to a bright optical/nIR potential host galaxy, in spite of the afterglow remaining undetected at optical/nIR wavelengths.

The obscuring medium

According to its observed properties, this event is located undoubtely in the dark GRB locus of the $F_{opt} - F_{X-ray}$ diagramme of Jakobsson et al. [1]. It is obvious that the afterglow was not detected neither at optical nor at near-IR wavelengths due to obscuration in the line of sight. In order to estimate the amount of extinction by dust at optical wavelengths, the SED predicts a magnitude $R \sim 18.3$ at $T_0 + 33$ hr, from which we infer a considerable extinction toward GRB 051022, with a lower limit A_R = 3.2 mag in the observer frame, i.e. equivalent to A_V = 1.7 mag in the rest frame at z =

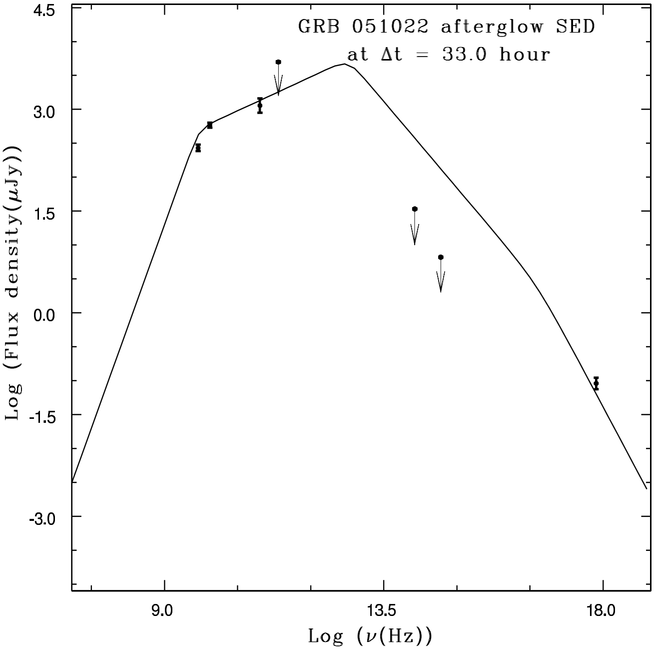

FIGURE 1. The SED of the GRB 051022 afterglow at T_0 + 33 hr (prior to the 2.9 day break time). We consider $p = 2.6$, assuming the slow-cooling regime. We have also included the radio detections at the WSRT [12] and VLA [13], as well as the 220 GHz and optical and near-IR upper limits reported in this paper. The initial parameters given at T_0 + 0.06 days are $\nu_a = 5.1 \times 10^9$ Hz, $\nu_m = 6.5 \times 10^{14}$ Hz, $\nu_c = 2.1 \times 10^{17}$ Hz and $F_{\nu,max} = 5.5$ mJy.

0.807 (see next subsection) from which a H equivalent column density at rest frame of $N_{H,opt} \geq 0.4 \times 10^{22}$ cm^2 is derived, assuming the relationship $A_V = 0.56 \times N_H$ (10^{21} cm^{-2}) + 0.23 [14].

From the X-ray spectral data, we have derived $N_{H,X-ray} = (0.9 \pm 0.2) \times 10^{22}$ cm^2 (observer frame) assuming the absorbing material being in a neutral cold state. This is equivalent to a $N_{H,X-ray}$ value at rest frame higher by a factor of $(1 + z)^{2.6}$ (= 5) at z = 0.807, i.e. $N_{H,X-ray} = (4.5 \pm 1.0) \times 10^{22}$ cm^2 (rest frame). Therefore, the $N_{H,X-ray}/N_{H,opt}$ ratio is ~ 9, as found in other GRBs [15,16] but not in two dark GRB host galaxies where $N_{H,X-ray}/N_{H,opt}$ was consistent with unity, or less: GRB 970828 [17] and GRB 000210 [4], where in both the dust-to-gas ratio is compatible with the Galactic one.

But could the absorption not take place in the circumburst environment of the GRB by in the ISM of the host galaxy itself ? The value of $A_V = 1.0$ derived from the host galaxy SED (see next subsection) cannot account for the properties of this event considering a dust-to-gas ratio similar to the Galactic one.

Therefore we are left with the possibility of the burst arose from a giant Molecular cloud (GMC) were the $N_{H,X-ray}$ values are typical to the one found here and that the early gamma-ray radiation can destroy dust in the environment paving the way for the afterglow light going out through the molecular cloud.

The host galaxy

The GRB 051022 host galaxy is, unlike, most of the GRB hosts, brighter than L^* ($M_V \geq -21.5$). We have also derived a SFR (UV) $\geq$ 20 $M_{\odot}$/yr and we foresee that this galaxy will be detected as sub-mm wavelengths as it was the case for the host galaxies of GRB 000210 and GRB 000418 [18].

GRB 051028

GRB 051028 was discovered by *Hete-2* on 28 Oct 2005 [19]. The burst started at T_0 = 13:36:01.47 UT and lasted for $\approx$ 16 s, putting it in the "long-duration" class of GRBs. *Swift* started to observe the field $\sim$ 7.1 hr after the event and detected the X-ray afterglow $5.2'$ away from the center of the initial $33' \times 18'$ error box [20].

Optical and X-ray observations

Target of opportunity observations were triggered at several optical facilities in Asia and Europe. We also made use of the public X-ray data from *Swift*/XRT which consists of four observations starting $\sim$ 7.1, 120, 160 and 230 hr after the event respectively.

The X-ray data confirm the presence of a decaying X-ray source in the fraction (70 %) of the *Hete-2* error box covered by the *Swift*/XRT, as already pointed out by Racusin et al. [20]. The optical counterpart was discovered on our *R*-band images taken at the 4.2m WHT telescope starting 7.5 hr after the onset of the gamma-ray event. A faint R = 21.9 object was detected inside the *Swift*/XRT error circle. Further details are given in [21].

The optical data prior to 4 hr (i.e. in the range T_0 + 2.7 hr and T_0 + 4 hr) show a bumpy behaviour very similar to the one seen in other events like GRB 021004 [22], GRB 030329 (see [23] and references therein) and GRB 050730 [24]. In fact, the similarity with GRB 050730 is remarkable, if GRB 051028 is shifted up by 3 magnitudes (Fig. 5), and thus there is evidence for at least two of such bumps taken place, superimposed to the power-law decline. This could be explained in the context of the energy injection model [25]. Unfortunately there is no X-ray data available at this epoch.

High redshift and/or dust in the surrounding ISM ?

We have extrapolated the optical and X-ray fluxes of GRB 051028 afterglow to T_0 + 11 hr and derived a value of $\beta_{opt-X} = 0.55 \pm 0.05$. Thus GRB 051028 is located in the "gray" or "potentially dark" GRB locus on the dark GRB diagram by Jakobsson et al. [1]. How can the optical faintness of GRB051028 be explained ?

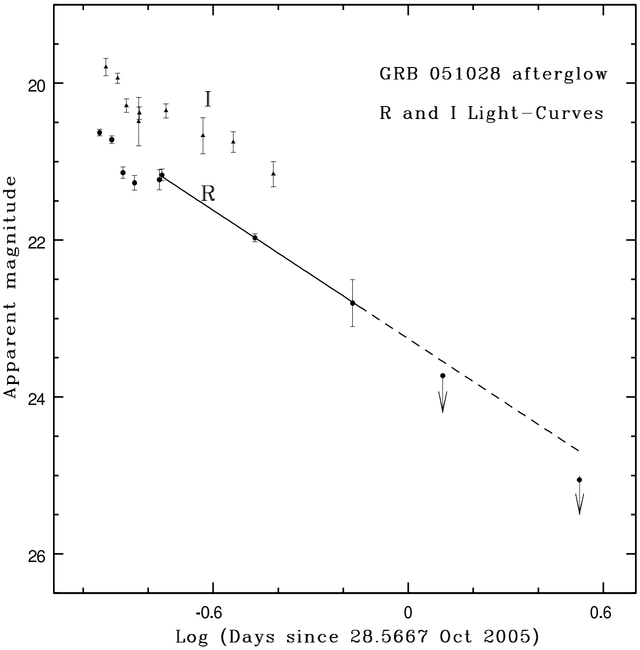

FIGURE 2. The GRB 051028 *R* and *I*-band lightcurves obtained at Hanle, Tautenburg and La Palma (WHT) starting 2.5 hr after the event onset and continuing up to 3.5 days later. The data after 4.0 hr are fit by a power-law decline exponent α_{opt} = 0.9 ± 0.1.

Although the redshift of this event could not be properly measured due to its faintness at the time of the discovery, we are able to constrain it on the basis of the *VRI*-band data presented in this paper. Using the magnitudes derived here and correcting them for the Galactic extinction in the line of sight, we determine a spectral optical index β_{opt} = 2.1 ± 0.4 . In the simplest fireball models [26], $F_\nu \propto \nu^{-\beta}$ with $\beta = p/2$ for $\nu > \nu_c$ and $\beta = (p\text{-}1)/2$ for $\nu < \nu_c$. Thus, for a typical range of p values in the range $1.5 < p < 3$ [27], β_{opt} should be in the range $0.25 < \beta_{opt} < 1.5$. In fact, the GRB 051028 data before T_0 + 0.5 day, are well fitted by a jet model with $p = 2.4$ in the slow cooling case, moving through the ISM (with ρ = constant) and with a cooling frequency ν_c still above the X-rays, so β_{opt} should be ~ 0.7 . What is the reason for the discrepancy in the β values?

This is naturally explained by the fact that at $z \sim 3.2$ and $\sim$4.0, the Lyman-α break begins affecting the *V* and *R* passbands respectively. Therefore, one obvious explanation for the β_{opt} value found for GRB 051028 is that it also arose at a $z \approx 3.6 \pm 0.4$. This value is in fact in agreement with the pseudo-z derived for this burst [28] and with the fact that no host galaxy is detected down to $R = 25.1$. This high-redshift is also supported by the late break time, as typical afterglows undergo a jet break episode before T_0 + 1 day in the rest frame [27].

The X-ray afterglow of GRB 051028 can be compared to other GRB afterglows in the sense that its flux at 11 hr is typical, i.e., one can assume that the burst has occurred on a classical n $\sim$ 1 cm^{-3} environment. The optical afterglow, on the other hand, is dim. This indicates that the faintness of the optical emission is not due to a low-density environment as in the case of some short GRBs, such as GRB 050509b [29]. Instead, we propose that GRB 051028 occurred in a galaxy at $z \approx 3.6 \pm 0.4$.

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