Optical and near-infrared observations


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Optical-NIR monitoring of the GRB020405 afterglow Masetti et al.

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We report on photometric, spectroscopic and polarimetric monitoring of the optical and near-infrared (NIR) afterglow of GRB020405. Ground-based optical observations, performed with 8 different telescopes, started about 1 day after the high-energy prompt event and spanned a period of ~10 days; the addition of archival HST data extended the coverage up to ~150 days after the GRB. We report the first detection of the afterglow in NIR bands. The detection of Balmer and oxygen emission lines in the optical spectrum of the host galaxy indicates that the GRB is located at redshift $z = 0.691$. Fe ii and Mg ii absorption systems are detected at $z = 0.691$ and at $z = 0.472$ in the afterglow optical spectrum. The latter system is likely caused by absorbing clouds in the galaxy complex located ~2″ southwest of the GRB020405 host. Hence, for the first time, the galaxy responsible for an intervening absorption line system in the spectrum of a GRB afterglow is spectroscopically identified. Optical and NIR photometry of the afterglow indicates that, between 1 and 10 days after the GRB, the decay in all bands is consistent with a single power law of index $\alpha = 1.54 \pm 0.06$. The late-epoch VLT J-band and HST optical points lie above the extrapolation of this power law, so that a plateau (or “bump”) is apparent in the $VRJI$ light curves at 10-20 days after the GRB. The light curves at epochs later than day ~20 after the GRB are consistent with a power-law decay with index $\alpha' = 1.85 \pm 0.15$. While other authors have proposed to reproduce the bump with the template of the supernova (SN) 1998bw, considered the prototypical ‘hypernova’, we suggest that it can also be modeled with a SN having the same temporal profile as the other proposed hypernova SN2002ap, but 1.3 mag brighter at peak, and located at the GRB redshift. Alternatively, a shock re-energization may be responsible for the rebrightening. A single polarimetric R-band measurement shows that the afterglow is polarized, with $P = 1.5\pm 0.4$ % and polarization angle $\theta = 172^\circ \pm 8^\circ$. Broad-band optical-NIR spectral flux distributions show, in the first days after the GRB, a change of slope across the J band which we interpret as due to
the presence of the electron cooling frequency $\nu_c$. The analysis of the multiwavelength spectrum within the standard fireball model suggests that a population of relativistic electrons with index $p \sim 2.7$ produces the optical-NIR emission via synchrotron radiation in an adiabatically expanding blastwave, with negligible host galaxy extinction, and the X-rays via Inverse Compton scattering off lower-frequency afterglow photons.

Introduction

GRB020405 was detected by the Third InterPlanetary Network (IPN) on 2002 April 5.02877 UT with a duration of $\sim 40$ s and localized to an error box of 75 square arcmin size. In the 25–100 keV band it had a total fluence of $\sim 3 \times 10^{-5}$ erg cm$^{-2}$ and a peak flux of $\sim 10^{-6}$ erg cm$^{-2}$ s$^{-1}$ (Hurley et al. 2002). This GRB was also observed by the GRBM onboard BeppoSAX, with a duration of $\sim 60$ s in the 40–700 keV band and a 50–700 keV fluence of $\sim 4 \times 10^{-5}$ erg cm$^{-2}$ (Price et al. 2003).

Approximately 18 hours after the GRB, Price et al. (2002a, 2003) detected a relatively bright ($R \sim 18.5$) source within the IPN error box which was not present on the DSS-II red plate. This Optical Transient (OT), located at coordinates (J2000) RA = 13$^h$ 58$^m$ 0312; Dec = $-31^\circ$ 22’ 222 (with an error of 03 along both directions), was confirmed by subsequent observations and identified as the afterglow of GRB020405 (Castro-Tirado et al. 2002; Palazzi et al. 2002; Hjorth et al. 2002; Price et al. 2002b; Gal-Yam et al. 2002a; Covino et al. 2002a,b). Optical spectroscopy allowed Masetti et al. (2002a) and Price et al. (2003) to determine the redshift of the GRB, $z = 0.691$ (see also Sect. 3.3).

A counterpart to the GRB has been detected also at radio and X-ray wavelengths (Mirabal et al. 2002; Berger et al. 2003). By fitting to the optical light curves a power law $F(t) \propto t^{-\alpha}$, typical of GRB afterglows, Price et al. (2002b) and Covino et al. (2002b) found $\alpha \sim 1.26$ and $\alpha = 1.52 \pm 0.12$, respectively, from observations performed within 3 days after the GRB. By using a data set spanning $\sim 5$ days, Price et al. (2003) found instead that a better fit to the early optical afterglow light curve was obtained with a smoothly broken power law with decay indices $\alpha_1 \sim 0.9$ and $\alpha_2 \sim 1.9$ before and after a break which occurred $\sim 1.7$ days after the GRB, respectively. On the other hand, Bersier et al. (2003) found no evidence of a break between 1.24 and 4.3 days after the GRB in their $R$-band data, which followed a single power-law decay with index $\alpha \sim 1.7$.

Polarimetric measurements by Covino et al. (2003) and Bersier et al. (2003) suggest early rapid variability of the percentage of linear polarization between values of $\sim 1.5\%$ and $\sim 10\%$.

Price et al. (2003), using late-time HST observations covering the time interval between 20 and 140 days after the high-energy prompt event, found a “red bump”, or flattening, in the optical light curves of the OT and suggested that this could be due to an emerging supernova (SN) component, which they modeled with the template of SN1998bw located at the redshift of GRB020405 and further dimmed by about 0.5 mag. A similar assumption was made by Dado et al. (2002) in their modeling of the GRB020405 optical afterglow within the cannonball picture.

Optical observations also revealed the presence of a relatively large (about 2$''$)$\times$1$''$, elongated in the N-S direction) nebuloity located $\sim 2''$ southwest of the OT and interpreted as its putative host galaxy (Hjorth et al. 2002).

In this paper we report on optical imaging, spectroscopy and polarimetry, along with the first detection in the near-infrared (NIR) bands of the GRB020405 afterglow. The data were acquired, in the framework of the GRACEGRB Afterglow Collaboration at ESO: see the web page.

The paper is organized as follows: Sect. 2 describes the optical and NIR observations and the data analysis; the results are reported in Sect. 3 and discussed in Sect. 4; in Sect. 5 we report our conclusions. Throughout the paper we assume a cosmology with $H_0 = 65$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_{\Lambda} = 0.7$ and $\Omega_m = 0.3$; also, when not otherwise stated, uncertainties will be reported at 1$\sigma$ confidence level, and upper limits at 3$\sigma$ confidence level.

Observations and data reduction

Optical and NIR photometry

Optical $BVRI$ observations in the Johnson-Cousins photometric system were performed with VLT-Melipal plus FORS1, VLT-Yepun plus FORS2, NTT plus SUSI2 and EMMI, and 1.54-metre Danish telescope plus DFOSC.

FORS1 is equipped with a 2048$\times$2048 pixels Tektronix CCD which covers a 68$\times$68 field in the standard
resolution imaging mode with a scale of 02 pix\(^{-1}\). FORS2 is equipped with a mosaic of two 2048×4096 pixels MIT CCDs, usually operating in 2×2 standard binning mode, thus covering a field with size 68×68 with a spatial resolution of 025 pix\(^{-1}\) in the standard resolution imaging mode. SUSI2 incorporates a mosaic of two 2048×4096 pixels EEV CCDs which cover a field of 55×55, corresponding to 008 pix\(^{-1}\); EMMI (Red Arm) carried until 14 May 2002 a 2048×2047 pixels Tektronix CCD with a scale of 027 pix\(^{-1}\) and a field coverage of 915×86 in size. DFOSC is equipped with a 2048×2048 pixels CCD covering a 137×137 field, thus securing a spatial resolution of 039 pix\(^{-1}\).

Optical observations were also obtained on 5 and 6 April 2002 (I band) at the 1.0m Sampurnanand telescope of SO located in Nainital (India), and on 6 April 2002 at the Canary Islands (Spain) with the 4.2m WHT plus PFIP (UBVRI bands) and with the 3.58m TNG plus DOLoReS (V band). The 1.0m SO telescope carries a 2048×2048 pixels CCD, with a 13′×13′ field of view; in its standard 2×2 binning mode it has a spatial resolution of 076 pix\(^{-1}\). The imaging camera PFIP carries two 2100×4200 EEV CCDs which cover a field of view of 162×162, giving a plate scale of 024 pix\(^{-1}\); the spectrophotometer DOLoReS carries a 2048×2048 pixels Loral CCD which can image a field of 95×95 with a scale of 0275 pix\(^{-1}\).

NIR imaging was obtained at ESO NTT with SofI (J, H and K\(_s\) bands) and at VLT-Antu with ISAAC (J\(_s\) band). The SofI infrared spectrograph and imaging camera works in the 0.9–2.5 μm NIR range by using a Hawaii 1024×1024 pixel HgCdTe array. In the small-field imaging mode the plate scale is 0144 pix\(^{-1}\) and the corresponding field of view is 24×24. ISAAC is equipped, in the 0.9–2.5 μm range, with a Rockwell Hawaii 1024×1024 pixel HgCdTe array which has a scale of 0148 pix\(^{-1}\) and secures imaging with a field of view of 25×25. The J\(_s\) filter is centered at 1.24 μm and has a full width at half maximum of 0.16 μm; its overall response is 25% lower than the J filter. This is confirmed by comparing the nightly zero-point coefficients of J and J\(_s\) frames in our data set. We thus reported the ISAAC J\(_s\) magnitudes to the standard J band by increasing the observed J\(_s\)-band flux densities by 25%. In order to allow for sky subtraction, the total integration time of each NIR pointing was split into dithered images of 15 s each when using SofI, and of 30 s each during ISAAC observations. In both cases the dithering was 40′ between consecutive images.

The complete log of our optical and NIR imaging observations is reported in Table 1.

Optical images were bias-subtracted and flat-fielded with the standard cleaning procedure. In some cases (especially at late epochs), frames taken on the same night in the same band were summed together in order to increase the signal-to-noise ratio. In Fig. 1 we report the R-band image of the field of the GRB020405 counterpart obtained on 6 April 2002 with the 1.54-metre Danish telescope plus DFOSC.

Since the close environment of the afterglow is quite crowded (see Figs. 3 and 6), we chose standard Point Spread Function (PSF) fitting, rather than simple aperture, photometry. We used the DAOPHOT II image data analysis package PSF-fitting algorithm (Stetson 1987) running within MIDAS (Munich Image Data Analysis System) is developed, distributed and maintained by ESO (European Southern Observatory) and is available at [http://www.eso.org/projects/esomidas/](http://www.eso.org/projects/esomidas/) A two-dimensional Gaussian profile with two free parameters (the half width at half maxima along x and y coordinates of each frame) was modeled on at least 5 unsaturated bright stars in each image. The errors associated with the measurements reported in Table 1 represent statistical uncertainties obtained with the standard PSF-fitting procedure.

The BVRI zero-point calibration was performed by using several standard fields (Landolt 1992) taken under photometric conditions at several ESO telescopes. The single Gunn i image (6 April 2002) was calibrated using the I-band secondary standards, given that the widths, the reference wavelengths and the flux density normalizations of the two filters are very similar (Fukugita et al. 1995). However, in order to account for small differences between the filters, we added in quadrature a 3% uncertainty to the I-band magnitude error obtained from the Gunn i observation.

Concerning the single U-band measurement taken at WHT, no standard field was acquired on the same night due to non-photometric conditions of the sky. The calibration in this band was then performed on 10 May 2002 at the 1.0-metre JKT, located in the Canary Islands and equipped with a SITe2 CCD which...
has 2048×2048 pixels and an image scale of 0.33 pix⁻¹. Observations of the GRB field and of some Landolt (1992) fields were acquired in U and B to determine the CCD color term.

We then selected 6 stars of different brightness in the GRB020405 field and we used them to determine the OT optical BVRI magnitudes (see also Simoncelli et al. 2002). Two additional stars were used for the calibration in the U band. All these stars are indicated in Fig. 1 and their magnitudes are listed in Table 2. We find this magnitude calibration to be accurate to within 3%. We note that the B and R magnitudes of field stars as reported in the USNO-A2.0 catalog available at http://www.nofs.navy.mil/iffer by ∼0.6 mag with respect to our calibration, which is however consistent with that of Bersier et al. (2003) and Price et al. (2003).

Table* Optical magnitudes of selected GRB020405 field stars as indicated in Fig. 1. Values are not reported for cases in which the stars are either saturated or too faint for reliable calibration center tabularcccccc

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Figure* R-band image of the field of GRB020405 acquired with the 1.54-metre Danish telescope plus DFOSC on 2002 April 6.136 UT at ESO-La Silla. The OT is at the centre of the image, indicated with the tick marks. North is at top, East is to the left; the field size is about 3′×3′. Numbers and letters indicate the reference stars with magnitudes reported in Table 2

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