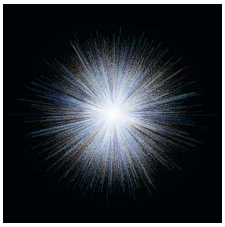
OPTICAL AND NEAR-INFRARED MONITORING OF THE GRB020405 AFTERGLOW



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ABSTRACT: We report on the photometric, spectroscopic and polarimetric monitoring of the optical and near-infrared (NIR) afterglow of GRB020405. Observations started about 1 day after the high-energy prompt event and spanned a period of ~140 days. Optical and NIR photometry of the afterglow indicates that during the first 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 inclusion of HST and late-time VLT points in our data set produces a bump in the *RIJ* light curves around 20-40 days after the GRB; this bump can be modeled with a SN2002ap underlying the afterglow. However, *V*-band data cannot be fit with this model. Alternatively, HST and late-time *J*-band data can also be fit using a power law with decay index steeper ($\alpha' = 1.85 \pm 0.15$) than that of the early decay phase. Spectroscopy indicates that the GRB is at $z = 0.691$ and that the host galaxy complex is prospectically close to another one at $z = 0.472$. A single polarimetric *R*-band measurement shows that the afterglow is polarized, with $P = 1.5 \pm 0.4$ % and polarization angle $\theta = 172° \pm 8°$.

INTRODUCTION: GRB020405 was detected by the IPN network on 2002 April 5.02877 UT as a burst with duration ~40 s. In the 25-100 keV band it had a total fluence of ~3×10^{-5} erg cm^{-2} and a peak flux ~10^{-6} erg cm^{-2} s^{-1} (Hurley et al. 2002). Approximately 18 hours after the GRB, Price et al. (2002) detected a relatively bright (R ~ 18.5) source which was not present on the DSS-II red survey. This Optical Transient (OT) was located well within the IPN error box and close (~1'.8) to its centre, at coordinates (J2000) RA = 13^h 58^m 03^s.12; Dec = -31° 22' 22".2 (error: 0".3 along both directions).

Following observations (e.g., Covino et al. 2003) showed that this object was indeed fading. Assuming a power law decay in the shape $F(t) \propto t^{-\alpha}$, typical of GRB afterglows, Covino et al. (2002a) found $\alpha = 1.52 \pm 0.12$. However, Price et al. (2003) found that a smoothly broken power law with indices $\alpha_1 \sim 0.9$ and $\alpha_2 \sim 1.9$ (and a break time $t_b \sim 1.7$ days after the GRB) better fitted the early afterglow data. Price et al. (2003) also found, with late-time HST observation, a red 'bump' in the optical light curve, which they interpreted as due to an emerging supernova component, modeled with a SN1998bw dimmed by about 0.5 mag. Deep optical imaging also showed a number of other extended objects around the OT, possibly in interaction among them (Masetti et al. 2002b; Price et al. 2003).

Preliminary reduction of a low-resolution spectrum allowed Masetti et al. (2002a) to determine the redshift of the OT as $z = 0.695 \pm 0.005$ from the detection of emission and absorption lines. This value was subsequently refined to $z = 0.6898 \pm 0.0004$ by Price et al. (2003). The broadband optical spectral shape was modeled as a power law ($F_\nu \propto \nu^{-\beta}$) with index $\beta = 1.23 \pm 0.12$ by Price et al. (2003) and $\beta = 1.43 \pm 0.08$ by Bersier et al. (2003).

Polarimetric measurements by Covino et al. (2003) and Bersier et al. (2003) suggest early rapid variability of the percentage of linear polarization in the *V* band between values of 1.5% and 10%.

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. Data were acquired as part of our ongoing GRB optical follow-up programs. We also reanalyzed public HST data on this GRB. A complete analysis of these data is reported in Masetti et al. (2003)

OBSERVATIONS. The optical and NIR photometry were collected starting on 2002 April 6 at several telescopes at ESO: in particular, we used the VLT units *Antu*, *Melipal* and *Yepun*, the NTT, and the Danish 1.54-m telescope. Further early optical imaging was acquired at TNG and WHT (Canary Islands, Spain) on April 6 in the *UBVRI* filters and at the 1.04-m Sampurnanand SO telescope (Naini Tal, India) in the *I* band on April 5 and 6. This ground-based data set spanned a period of roughly 10 days; in order to extend it in time we also retrieved and analyzed the already public archival HST data on this GRB (see Price et al. 2003).

Optical mid-resolution spectra were taken at VLT-*Melipal* on April 6 and 7; spectral dispersion was 5.5 and 2.6 Å/pix, respectively. In the second spectroscopic observation the slit was rotated of about 40° with respect to the Parallactic Angle in order to include in it both the OT and a galaxy located ~2" southwest of it.

A single polarimetric *R*-band measurement was acquired at VLT-*Melipal* on April 6.

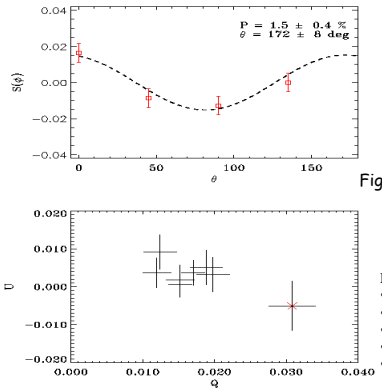


Fig. 7

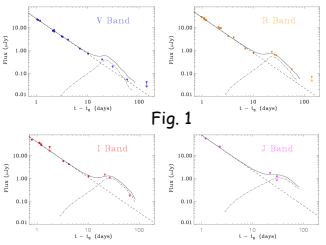


Fig. 1

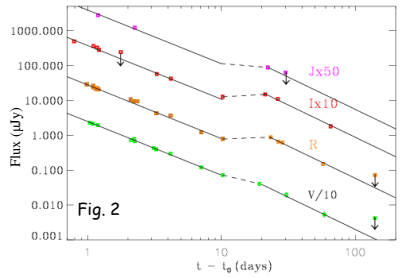
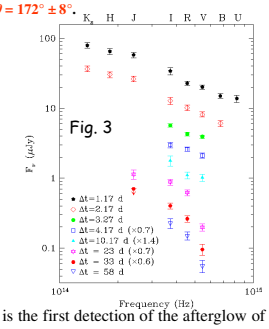


Fig. 2



PHOTOMETRY. We clearly detected the OT in all optical and NIR bands: concerning the latter ones, this is the first detection of the afterglow of this GRB. In order to take into account any possibly host galaxy complex contribution in the ground-based observations, we followed two ways (when applicable): (i) we fit the light curves with a simple power law plus constant ($F \propto t^{-\alpha} + const$); (ii) we measured, on the last (23 August 2002) HST images, the contribution of the host galaxy complex within an aperture radius matching the ground-based telescopes PSFs. The two methods gave consistent results, and showed that the host contribution to the OT luminosity is of the order of few percent (and thus negligible within the uncertainties) in the first days of observation. This procedure was however applied to *VRIJ* data only, because no late-time HST or ground-based data are available for other optical or NIR filters.

The host-subtracted ground-based data show that *V*, *R* and *I* fluxes decay with a simple power law decay, with index $\alpha = 1.54 \pm 0.06$. Actually, when fitting the data from each single band we get slightly different values for α, but all these are consistent with the number quoted above.

When we add the HST data (in which the host contribution was subtracted by applying a PSF-based method for the OT removal) to the *VRI* light curves, the presence of a red bump is indeed apparent (Fig. 1). This bump, however, is also well fit with an emerging SN2002ap, brightened by ~1.3 mag, at the OT redshift ($z = 0.69$; see below), and not only with a SN1998bw (which has to be dimmed by 0.6 mag). This is anyway true for *R*, *I* and *J* light curves only; *V*-band data are not acceptably fit by either SN. We note that this rebrightening can also be modeled in all bands with a power law, offset from the early-time one and slightly steeper, with index $\alpha' = 1.85 \pm 0.15$ (Fig. 2). This behaviour resembles that of the refreshed shock illustrated e.g. in Kumar & Piran (2000) or in Beloborodov (2003).

OPTICAL-NIR SPECTRAL FLUX DISTRIBUTION. We have then constructed a series of optical-NIR broadband spectra at 8 different epochs. The data points were corrected for the Galactic absorption ($E(B-V) = 0.055$; Schlegel et al. 1998) and converted into fluxes using the tables by Fukugita et al. (1995) for the optical and by Bersanelli et al. (1991) for the NIR. The spectra of the first two epochs were not corrected for the host contribution as it can be determined for the *VRIJ* bands only; however, given this was quite modest at those epochs (see above), we simply added a 5% error in quadrature to the uncertainties in the optical-NIR fluxes.

The spectra of 1.2 and 2.2 days after the GRB (Fig. 3) clearly show a break at 2.5×10^{14} Hz, i.e. in the *J* band, and slopes $\beta_{NIR} = -0.65 \pm 0.2$ and $\beta_{opt} = -1.3 \pm 0.2$. This break can be interpreted as due to the synchrotron cooling frequency ν_c in the simplest case of a spherical fireball expanding in a homogeneous medium (Sari et al. 1998) and with $p \sim 2.6$. Multiwavelength spectra of the three following epochs, made with *VRI* points, were instead plotted after having subtracted the host galaxy contribution. The spectral slopes on these three epochs are still consistent with the optical one of the first two epochs.

Broadband spectra of the OT emission during the bump (~20, ~30 and ~60 days after the GRB) follow instead a power law shape with $\beta = -3.5 \pm 0.5$, in agreement with the findings of Price et al. (2003). A remarkable NIR-to-optical spectral curvature is also observed.

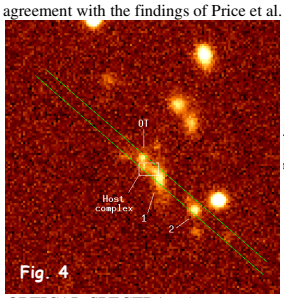
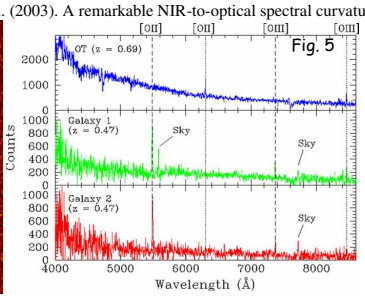
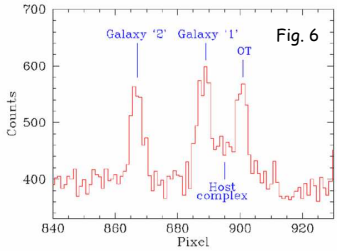


Fig. 4





OPTICAL SPECTRA. The spectra acquired on April 6 and 7 at VLT show the variety of emission and absorption lines typically seen in GRB afterglows. From these, we determine a redshift $z = 0.691 \pm 0.001$ for the GRB. This value refines the preliminary redshift given in Masetti et al. (2002a) and is closer to that reported by Price et al. (2003). Both absorption and emission features in the OT spectrum are consistent with this value.

Fig. 4 reports a sketch of the setup with which the VLT spectrum of April 7 was obtained: the 1"-wide slit was rotated by 40° towards East with respect to the N-S direction in order to acquire also the spectrum of a galaxy 2" southwest of the OT. This galaxy is marked as '1' in Fig. 4. This setup choice allowed us to include yet another galaxy (indicated as '2' in Fig. 3 and located ~6" southwest of the OT) inside the slit.

From the detection of [OII] and [OIII] emission lines in their spectra, both Galaxies '1' and '2' appear to be at a substantially lower redshift, $z = 0.472 \pm 0.001$ (Fig. 5). Thus, although prospectically close to the host galaxy complex of GRB020405 (Price et al. 2003), Galaxy '1' appears to be not part of that interacting system.

This result overrides the one reported in Masetti et al. (2002b): the preliminary analysis of the Galaxy '1' spectrum was biased by the fact that the host complex contribution was not completely removed (see the brightness profile along the slit reported in Fig. 6).

OPTICAL POLARIMETRY. In our *R*-band measurement we find, after having corrected for field spurious polarization, $Q_{OT} = 0.016 \pm 0.006$ and $U_{OT} = -0.009 \pm 0.006$. The cosine fit of the polarization data (Fig. 7, upper panel) with the relation described in Di Serego Alighieri (1997) gives for the OT a linear polarization $P_{OT} = 1.5 \pm 0.4$ % (corrected for the polarization bias; see Di Serego Alighieri 1997) and a polarization angle $\theta_{OT} = 172° \pm 8°$. These values are corrected for possible instrumental and interstellar polarization by using field stars; the result was checked with the use of observations of polarized and unpolarized standard stars. The intrinsic polarization of the OT is also indicated by its position with respect to those of some field stars in the U vs. Q plot (Fig. 7, lower panel). This value for the polarization is consistent with those measured by Covino et al. (2003), but is at variance with that (9.9 ± 1.3 % or 6 ± 3 %) obtained by Bersier et al. (2003) from *V*-band observations acquired nearly simultaneusly with ours. We independently analyzed the polarimetric data of Bersier et al. (2003) and, by applying our PSF-fitting photometric procedure, we obtain a 3σ upper limit on the *V*-band polarization of 36%. This value is higher than, but still consistent with the measurement and upper limit obtained by the above authors.

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