The broadband afterglow of GRB 030328

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Abstract. We here report on the photometric, spectroscopic and polarimetric monitoring of the optical afterglow of the Gamma-Ray Burst (GRB) 030328 detected by HETE-2. We found that a smoothly broken power-law decay provides the best fit of the optical light curves, with indices $\alpha_1 = 0.76 \pm 0.03$, $\alpha_2 = 1.50 \pm 0.07$, and a break at $t_b = 0.48 \pm 0.03$ d after the GRB. Polarization is detected in the optical $V$-band, with $P = (2.4 \pm 0.6)$% and $\theta = 170^\circ \pm 7^\circ$. Optical spectroscopy shows the presence of two absorption systems at $z = 1.5216 \pm 0.0006$ and at $z = 1.295 \pm 0.001$, the former likely associated with the GRB host galaxy. The X–ray-to-optical spectral flux distribution obtained 0.78 days after the GRB was best fitted using a broken power-law, with spectral slopes $\beta_{\text{opt}} = 0.47 \pm 0.15$ and $\beta_X = 1.0 \pm 0.2$. The discussion of these results in the context of the 'fireball model' shows that the preferred scenario is a fixed opening angle collimated expansion in a homogeneous medium.

Keywords: gamma-ray bursts; astronomical observations: visible; photometry; spectroscopy; polarimetry

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INTRODUCTION

GRB 030328 was a long, bright GRB detected on 2003 Mar 28.4729 UT, by the FREGATE, WXM, and SXC instruments onboard HETE-2, and rapidly localized with sub-arcminute accuracy (Villasenor et al. 2003). About $\sim$1 hour after the GRB, its optical afterglow has been detected by the 40-inch Siding Spring Observatory (SSO) telescope (Peterson & Price 2003). A study of the X–ray afterglow of GRB 030328 was performed by Butler et al. (2005) using Chandra data.

We report here on the study of the optical afterglow emission of GRB 030328 made, within the GRACE$^1$ collaboration, performed with 7 different optical telescopes. A more detailed presentation of these data will appear in Maiorano et al. (2005).

$^1$ GRB Afterglow Collaboration at ESO; see http://www.gammaraybursts.org/grace/
FIGURE 1. Left panel: BVRI light curves of the GRB 030328 afterglow. The solid and dashed lines represent the best-fit of the optical light curves. Right panel: broadband afterglow spectrum at 0.78 d after GRB 030328. The dashed line corresponds to a single optical-X–rays powerlaw spectral slope; the broken solid line indicates the description with $\nu_{c}$ between the optical and the X–ray ranges.

OBSERVATIONS

Optical $UBVRI$ data of the GRB 030328 Optical Transient (OT), for a total of 130 photometry points, were acquired at the 40-inch SSO (Australia), 1m ARIES (India), 2.5m NOT (Spain), 1.54m ESO Danish, 2.2m ESO/MPG, ESO VLT-Antu (Chile) and 1m USNO-FS (USA) telescopes.

A series of six 10-min optical spectra was obtained at ESO-Paranal with VLT-Antu starting 0.59 d after the GRB. The Grism 300V was used with a nominal spectral coverage of 3600–8000 Å and a spectral dispersion of 2.7 Å/pixel.

Linear polarimetry $V$-band observations were acquired between 0.66 and 0.88 d after the GRB at VLT-Antu. Five complete imaging polarimetry cycles were performed.

RESULTS

Photometry

In Fig. 1 (left) we plot our photometric measurements together with those reported in the GCN circulars\(^2\). For the cases in which no error was reported, a 0.3 mag uncertainty was assumed. The $UBVRI$ zero-point calibration was performed using the photometry by Henden (2003).

The optical data of Fig. 1 (left) were corrected for the Galactic foreground reddening assuming $E(B-V) = 0.047$ mag (Schlegel et al. 1998). The GRB 030328 host galaxy emission in the $BVRI$ bands was computed from the data of Gorosabel et al. (2005) and subtracted from our optical data set.

\(^2\)http://gcn.gsfc.nasa.gov/gcn/gcn3_archive.html
The best fit of the \( R \)-band data (in Fig. 1, left) is obtained using a smoothly broken powerlaw (Beuermann et al. 1999), with temporal indices \( \alpha_1 = 0.76 \pm 0.03 \) and \( \alpha_2 = 1.50 \pm 0.07 \) before and after a break occurring at \( t_b = 0.48 \pm 0.03 \) d from the GRB trigger, and with \( s = 4.0 \pm 1.5 \) the parameter modeling the slope change rapidity. This best-fit curve describes well the data in the other bands also (see Fig. 1, left). This means that the decay of the OT can be considered as achromatic.

From the measured jet break time we can compute the jet opening angle value for GRB 030328 which is, following Sari et al. (1999), \( \theta_{jet} \sim 3.5^{\circ} \).

**Broadband analysis**

By using the available information, we have constructed the optical-to-X–ray spectral flux distribution of the GRB 030328 afterglow at the epoch 0.78 days after the GRB, that is, the time with best broadband photometric coverage.

As Fig. 1 (right) shows, the best descriptions are a single powerlaw (dashed line) with a spectral index \( \beta_{X-opt} = 0.83 \pm 0.01 \), or a broken powerlaw with \( \beta_{opt} = 0.47 \pm 0.15 \) and assuming \( \beta_{X} = 1.0 \pm 0.2 \) from Butler et al. (2005).

However, the single powerlaw description of the broadband afterglow does not fit any of the synchrotron fireball scenarios (Sari et al. 1998, 1999). Instead, in the broken powerlaw description, which means that the synchrotron cooling frequency \( \nu_c \) lies between the optical and X–ray bands, we obtain that the GRB 030328 afterglow broadband evolution is consistent with a jet-collimated expansion in a homogeneous medium with fixed opening angle (Mészáros & Rees 1999) and with an electron distribution index \( p = 2 \).

Assuming a negligible host absorption and using the optical and X–ray spectral slopes above, we obtain for \( \nu_c \) the value \( 5.9 \times 10^{15} \) Hz, which places this frequency in the ultraviolet band.

**Spectroscopy**

Figure 2 shows the spectrum of the GRB 030328 OT. Most of the significant features can be identified with Fe II, Mg II, Al II and C IV absorption lines in a system at a redshift of \( z = 1.5216 \pm 0.0006 \). These lines are associated with the circumburst gas or interstellar medium in the GRB host galaxy. A lower redshift absorption system at \( z = 1.295 \pm 0.001 \) is also found: for it, only two lines can be identified (Fe II \( \lambda 2600 \) and the unresolved Mg II \( \lambda \lambda 2796, 2803 \) doublet). Its detection indicates the presence of a foreground absorber.

**Polarimetry**

After correcting for spurious field polarization, we found \( Q_{OT} = 0.029 \pm 0.008 \) and \( U_{OT} = -0.004 \pm 0.008 \). The fit of the data with the relation of Di Serego Alighieri (1997)
yielded for the OT a linear polarization $P = (2.4 \pm 0.6)\%$ and a polarization angle $\theta = 170^\circ \pm 7^\circ$, corrected for the polarization bias (Wardle & Kronberg 1974).

In order to check whether variations of $P$ and $\theta$ occurred during the polarimetric run, we also separately considered each of the 5 single polarimetry cycles. Although with lower $S/N$, $P$ and $\theta$ are consistent with being constant across the whole polarimetric observation run.

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