Mem. S.A.It. Suppl. Vol. 5, 160

Memorie della
Supplementi

SN 2003lw and GRB 031203: a bright supernova for a faint gamma-ray burst

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Abstract. Optical and near-infrared observations of the gamma-ray burst GRB 031203, at $z = 0.1055$, are reported. A very faint afterglow is detected superimposed to the host galaxy in our first infrared JHK observations, carried out ~ 9 hours after the burst. Subsequently, a rebrightening is detected in all bands, peaking in the R band about 18 rest-frame days after the burst. The rebrightening closely resembles the light curve of a supernova like SN 1998bw, assuming that the GRB and the SN went off almost simultaneously, but with a somewhat slower evolution.

Key words. gamma rays: bursts — supernovae: individual (SN 2003lw)

1. Introduction

In recent years, extensive optical and near-infrared (NIR) follow-up of gamma-ray bursts (GRBs) has revealed a physical connection between a significant fraction of long-duration GRBs and core-collapse supernovæ (SNe). First, the bright SN 1998bw was discovered spatially and temporally coincident with GRB 980425 (Galama et al., 1998; Kulkarni et al., 1998). Then, SN 2003dh was detected in the afterglow of GRB 030329 (Stanek et al., 2003; Hjorth et al., 2003). Both SNe showed broad bumps in their spectra, indicating very large expansion velocities (up to 30 000 km/s), and were extremely bright.

These highly-energetic SNe are designed as hypernovæ (e.g. Iwamoto et al., 1998). Last, bumps discovered in the light curves of several afterglows, peaking ~ 20 days after the GRB, have been interpreted as due to the emerging of SNe out of the afterglow light, based on their brightness, temporal evolution and col-

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ors (e.g. Bloom et al., 1999; Garnavich et al., 2003). The bumps resemble the light curve of SN 1998bw, with a certain scatter in the brightness and rise time (e.g. Zeh, Klose & Hartmann, 2004). Spectroscopic confirmation that the bump of GRB 021211 has a SN spectrum (SN 2002lt; Della Valle et al., 2003) supports this conclusion. These observations indicate that the GRB/SN association is common.

GRB 031203 was discovered by the INTEGRAL satellite on 2003 Dec 3.91769 UT (Götz et al., 2003), with a duration of $\sim$ 30 s and a peak flux of 1.3×10^{-7} erg cm^{-2} s^{-1} (20 − 200 keV; Mereghetti & Götz, 2003a). The X-ray and radio afterglows were soon discovered (Santos-Lleo & Calderon, 2003; Frail, 2003). A compact galaxy, located at a consistent position, was proposed to be the GRB host galaxy by Prochaska et al. (2003). The redshift was $z = 0.1055 \pm 0.0001$ (Prochaska et al., 2003, 2004), making GRB 031203 the second closest burst after GRB 980425 at $z = 0.0085$ (Galama et al., 1998).

Given the low redshift of this event, the isotropic-equivalent burst energy is extremely low, $E_{\rm iso} \sim 3 \times 10^{49}$ erg (20-2000 keV; Watson et al., 2004; Prochaska et al., 2004), well below the standard reservoir $\sim 2 \times 10^{51}$ erg of normal GRBs (Frail et al., 2001; Bloom, Frail & Kulkarni, 2003). Only GRB 980425 (Galama et al., 1998) and XRF 020903 (Sakamoto et al., 2004) were less energetic.

After the ultimate confirmation, coming from spectroscopic observations and reported by our group (Tagliaferri et al., 2004), the IAU named this event SN 2003lw.

2. Observations and data reduction

We observed the field of GRB 031203 starting $\approx$ 7 h after the trigger, to search for the near-infrared (NIR) afterglow, using SofI on the ESO-NTT at La Silla (Chile). Subsequent imaging with ISAAC on the ESO-VLT showed the presence of a varying source coincident with the putative host galaxy of GRB 031203: the total flux had dimmed in the J, H and K filters by a few tenths of a magnitude (see Fig. 1). We therefore started a campaign to monitor the optical/NIR light curve of the event, searching for a SN rebrightening. Moderate-resolution spectra (FWHM ≈ 10 Å) were also taken with the VLT.

A detailed discussion of the spectroscopy and of the host galaxy will be presented elsewhere (Chincarini et al., 2004, hereafter C04), while a more ehaustive discussion of the present work is reported in (Malesani et al., 2004).

3. Results and discussion

In Fig. 1 we show the light curves of GRB 031203. Early-time NIR photometry shows a dimming in all bands between the first and second night after the GRB. This is confirmed by PSF-matched image subtraction. We believe that we have seen the NIR afterglow of GRB 031203. The magnitudes are $J = 20.60 \pm 0.09$, $H = 19.05 \pm 0.07$, $K = 17.56 \pm 0.05$ (9 hours after the GRB), obtained by subtracting the host contribution. There is no variation between the two K-band observations of the first night (separated by 2.6 h), suggesting a break in the light curve or a bumpy behaviour.

A few days after the GRB, a rebrightening is apparent in all optical/NIR bands. The rebrightening amounts to $\approx 30\%$ of the total flux, and is coincident with the center of the host galaxy to within $0.1''$ ($\approx$ 200 pc at $z = 0.1055$). For comparison, we show in Fig. 1 the VRI light curves of SN 1998bw (Galama et al., 1998; McKenzie & Schaefer, 2000), placed at $z = 0.1055$ and dereddened with $E_{B-V} = 1.1$ (see below). Even after correcting for cosmological time dilation, the light curve of SN 2003lw is broader than that of SN 1998bw, and requires an additional stretching factor of ≈ 0.9 to match the R and I bands. Near the peak, the light curve is rather flat, resembling the hypernova SN 1997ef (Iwamoto et al., 2000) more than SN 1998bw. The R-band maximum is reached on approximately 2003 Dec. 24 ($\sim$ 18 comoving days after the GRB). Assuming a light curve shape similar to SN 1998bw, which had a rise time of 16 days in the V band, our data suggest an explosion time nearly simultaneous with the GRB. However, given that SN 2003lw was not strictly identical to SN 1998bw, and as we lack optical data

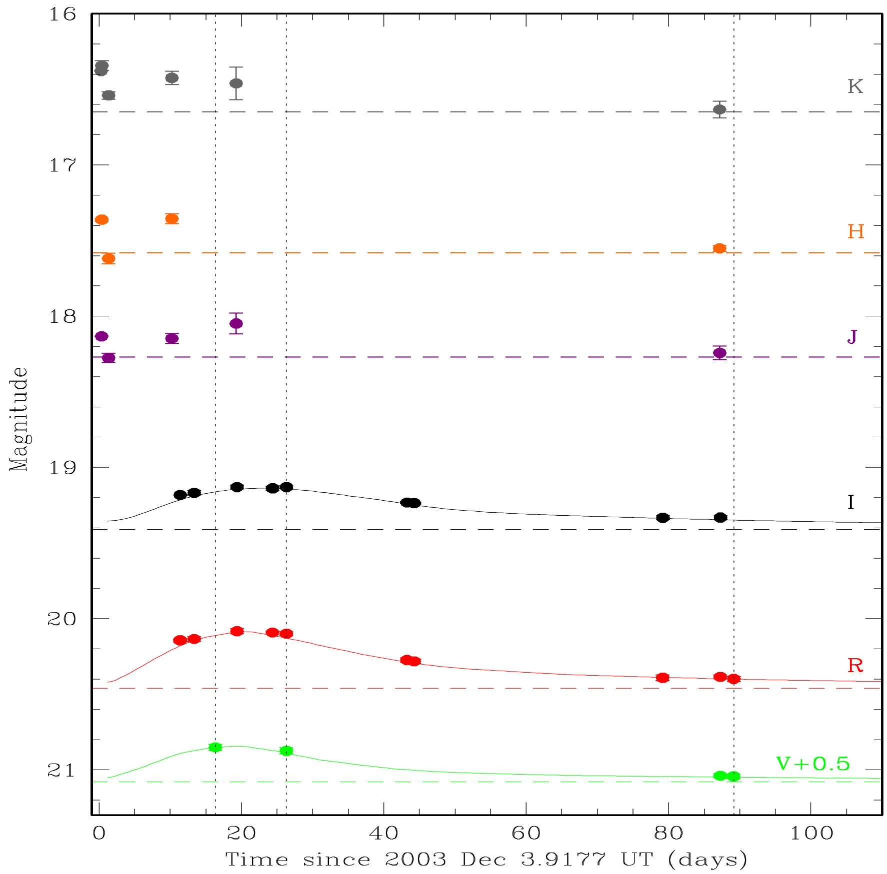

Fig. 1. Optical and NIR light curves of GRB 031203 (dots). Error bars indicate the amount of relative errors only. The solid curves show the evolution of SN 1998bw (Galama et al., 1998; McKenzie & Schaefer, 2000), rescaled at $z = 0.1055$, stretched by a factor 1.1, extinguished with $E_{B-V} = 1.1$ and brightened by 0.5 mag. Dashed lines indicate the host galaxy contribution. Vertical lines mark the epochs of our spectra.

in the days immediately following the GRB, a lag of a few days cannot be ruled out. Type-Ic SNe usually reach V-band maximum in $\sim$ 12-20 days, the brightest events showing a slower evolution (see e.g. Fig. 2 of Mazzali et al., 2002).

A precise determination of the absolute magnitude of the SN is made difficult by the uncertain, and significant, extinction. C04 and Prochaska et al. (2004) constrain the average combined Galactic and host extinction to be $E_{B-V} \approx 1.1$ based on the Balmer ratios of the host galaxy. Given the good spatial coincidence of the SN with the center of the host, such value is likely a good estimate for the SN extinction. We also adopt a Galactic extinction law (Cardelli, Clayton & Mathis, 1989) with $R_V = 3.1$.

With the assumed reddening, SN 2003lw appears brighter than SN 1998bw by 0.5 mag in the V, R, and I bands. The absolute magnitudes of SN 2003lw are hence $M_V = -19.75 \pm 0.15$, $M_R = -19.9 \pm 0.08$, and $M_I = -19.80 \pm 0.12$.

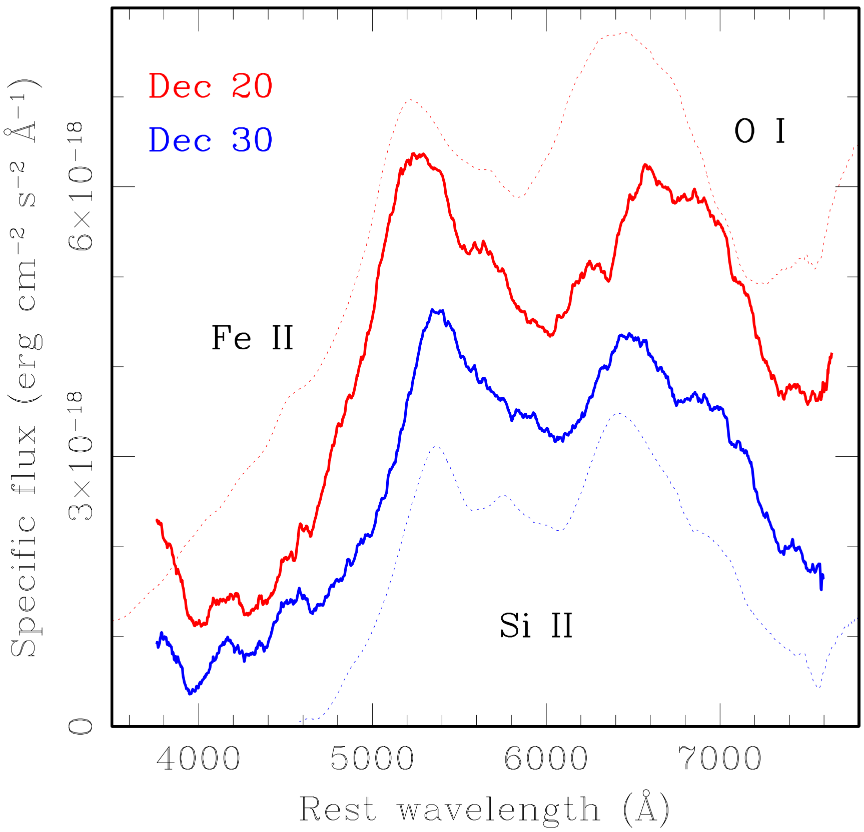

Fig. 2. Spectra of SN 2003lw, taken on 2003 Dec. 20 and Dec. 30 (solid lines), smoothed with a boxcar filter 250 Å wide. Dotted lines show the spectra of SN 1998bw (from Patat et al., 2001), taken on 1998 May 9 and May 19 (13.5 and 23.5 days after the GRB, or 2 days before and 7 days after the V-band maximum), extinguished with E_{B-V} = 1.1 and a Galactic exinction law (Cardelli, Clayton & Mathis, 1989). The spectra of SN 1998bw were vertically displaced for presentation purpose.

Fig. 2 shows the spectra of the rebrightening on 2003 Dec. 20 and Dec. 30 (14 and 23 rest-frame days after the GRB), after subtracting the spectrum taken on 2004 Mar. 1 (81 rest-frame days after the GRB). This assumes that the latter spectrum contains only a negligible contribution from the SN, which is confirmed by the photometry (Fig. 1). The spectra of SN 2003lw are remarkably similar to those of SN 1998bw obtained at comparable epochs (shown as dotted lines in Fig. 2; from Patat et al., 2001). Both SNe show very broad absorption features, indicating large expansion velocities. Thus we tentatively classify SN 2003lw as a hypernova. The main absorptions are identified in Fig. 2 as in SN 1998bw, following Iwamoto et al. (1998). The velocity of the Si II line in SN 2003lw is apparently smaller than in SN 1998bw. The broad peaks near 5300 Å and 6600 Å are probably the emission components of P-Cygni profiles due to the blending of several lines. There is evolution between the two epochs: the bluer bump is observed at longer wavelengths in the second spectrum, and is slighty narrower. Moreover, the shape of the redder peak is different in the two epochs. Both peaks appear at redder wavelengths than in SN 1998bw. Detailed modeling of the spectra will be presented elsewhere (Mazzali et al., 2004).

The afterglow of GRB 031203 was very weak, the faintest ever detected in the optical/NIR. Extrapolation in the R band yields a luminosity $\sim$ 200 times fainter than the dimmest afterglow discovered so far (GRB 021211: Fox et al., 2003; Pandey et al., 2003). The detection of the SN optical light implies that the reason of such faintness was not an extreme dust obscuration. Also given the low redshift of the event, this example shows that some optical afterglows may escape detection just because they are faint (e.g. Fynbo et al., 2001; Lazzati et al., 2002; De Pasquale et al., 2003). GRB 031203, together with GRB 980425 at $z = 0.085$, was a very dim event, perhaps a jet observed far from its axis (e.g. Maeda et al., 2002; Yamazaki, Yonetoku & Nakamura, 2003). Being so faint, they would have been likely missed at cosmological distances. Since the volume they sample is much smaller than that probed by classical, distant GRBs with $\langle z \rangle \approx 1$, the rate of these events could be much larger. As noted by Thomsen et al. (2004), this would increase the detection rate for the *Swift* satellite (Gehrels et al., 2004). More rapid and efficient observations, also soon feasible thanks to *Swift*, will allow a detailed study of this largely unexplored class of events.

GRB 031203 was quite similar to GRB 980425, even if overall more powerful. Both events consisted in a single, underenergetic pulse. Their afterglows were very faint or absent in the optical, and showed a very slow decline in the X-ray (Pian et al., 2000; Watson et al., 2004). Last, they were both accompained by a powerful hypernova.

Acknowledgements. This work was supported by contract ASI/I/R/390/02 of the Italian Space Agency for the Italian *Swift* Project, by the Italian Ministry for University and Research and by the Italian National Institute for Astrophysics (INAF).

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