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The optical and infrared afterglow of GRB031203 and the associated hypernova SN 2003lw

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Abstract

Optical and near-infrared photometric observations of the host galaxy of GRB 031203 allowed us to detect a bump in its light curves, peaking about 18 rest-frame days after the burst. We interpreted this as due to the emergence of an associated SN. Subsequent spectroscopic observations allowed us to confirm the presence of a SN, named SN 2003lw. The presence of extremely broad features in these optical spectra, very similar to the ones seen in SN 1998bw, indicate that this is a very energetic hypernova. Moreover, it was even brighter than SN 1998bw. Therefore, the three best confirmed associations between a GRB (980425, 030329, 031203) and a SN involve hypernovae. However, while GRB030329 has properties "typical" of most GRBs, the other two are quite peculiar, in particular they are very weak and nearby. Thus, it is remarkable that the three hypernovae associated to these GRBs are so similar, while the GRBs themselves are very different. Thus, a lot of open questions still remain in the associations between SNe and long-duration GRBs, questions that will soon find an answer thanks to the launch of the Swift satellite.

Keywords: GRB; SN; Spectroscopy

1. Introduction

The idea that gamma-ray bursts (GRBs) were somehow associated with supernovae (SNe) has been present in the community for a long time. However, no evidence could be found to confirm this idea. As for many other discoveries in the GRB field, things changed drastically with the advent of the BeppoSAX satellite. Thanks to discovery of the X-ray and optical afterglows associated with GRBs (Costa et al., 1997; van Paradijs et al., 1997) it has been possible to establish that GRBs are cosmological, are the most powerful explosion in the Universe after the Big-Bang, are associated with irregular star forming galaxies and, very recently, that long-duration GRBs are associated with core-collapse SN explosions. To this end people have monitored the decay of the optical and infrared light curve of afterglows looking for a re-brightening that would indicate the emergence of a SN. Various bumps have been found, peaking at ~20 days after the burst, which have been attributed to the presence of a SN (e.g., Bloom et al., 1999). However, the lack of a spectroscopic confirmation made these findings only suggestive. The real breakthrough came with the discovery of the bright SN 1998bw, spatially and temporally coincident with GRB 980425. This SN showed broad bumps in its spectra, indicating very large

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expansion velocities and was extremely bright. These SNe are now designed as hypernovae (Iwamoto et al., 1998). The spectroscopic identification of SN 2003dh, with properties similar to that of SN 1998bw, in the afterglow of GRB 030329 (Stanek et al., 2003; Hjorth et al., 2003), seems to confirm that long-duration GRBs are associated with hypernovae. However, in the case of GRB 021211, Della Valle et al. (2003) found a spectroscopic confirmation that the bump detected in the light curve was due to a typical Ic SN or to a dimmed hypernova, as 2002ap (Mazzali et al., 2002). Similar conclusions have been recently achieved by Fynbo et al. (2004) and Levan et al. (2004) after studying GRB 030723 and GRB 020410, respectively. Thus, although the association between long-duration GRBs and SNe seems to be common, there are still many open points. Here, we report the discovery of the bright hypernova SN 2003lw (Tagliaferri et al., 2004; Malesani et al., 2004) associated with the faint GRB 031203 (Götz et al., 2003; Sazonov et al., 2004).

2. Observations and results

GRB 031203 was detected by the INTEGRAL satellite with a duration of ~30 s and a peak flux of 1.3×10^{-7} erg cm^{-2} s^{-1} in the 20–200 keV band (Götz et al., 2003; Mereghetti and Götz, 2003). The X-ray and radio afterglow were soon discovered (Santos-Lleo and Calderon, 2003; Freil, 2003). Although this field is on the galactic plane and is rather crowded, the small error boxes provided for the X-ray and radio afterglow allowed to immediately identify the host galaxy of this GRB. This is an emission line galaxy at a redshift of $z = 0.105$ (Prochaska et al., 2004). We observed this host galaxy for several nights with the ESO telescopes at Paranal and La Silla, looking first for the afterglow and then for the associated SN. Indeed, we were able to detect a weak NIR afterglow, the weakest so far detected (Malesani et al., 2004). The subsequent monitoring of the galaxy allowed us to detect a brightening of its emission, that we immediately followed-up with spectroscopic observations that allowed us to detect the presence of SN 2003lw. The brightening of the galaxy light curve has been reported also by other authors (Bersier et al., 2004; Thomsen et al., 2004; Cobb et al., 2004; Gal-Yam et al., 2004). Besides the SN, in our spectra of course we also detected the strong emission lines that were already discussed by Prochaska et al. (2004). They are due to the presence of a star forming region inside this galaxy, likely the site of the GRB-SN explosion.

We observed the GRB 031203 error box about 7 h after the burst in the near-infrared (NIR) band using SofI on the ESO NTT telescope at La Silla. We then followed the source both in the NIR and in the optical bands mainly with the VLT telescopes in Paranal (for a journal of the observations see Malesani et al., 2004). Our NIR and optical light curves are reported in Fig. 1. As it can be seen from this figure, we have detected a dimming in the JHK magnitudes between the first and second night after the explosion. We interpreted this as the detection of the NIR afterglow, the weakest ever detected so far. A few days later a rebrightening is apparent in all bands. The solid lines show the evolution of SN 1998bw, that we take as a template, reddened with $E_{B-V} = 1.1$ with a time dilation factor of 1.1 due to the different redshift. To better represent our data we had to assume a SN brighter by 0.5 mag. This template, that represents our data very well, implies that the SN exploded almost simultaneously with the GRB. The rise time, in the observed R-band, is of 18 days in the rest-frame. This should be compared with the 12–20 days that type-Ic SNe usually take to reach the maximum in their light curves, the brightest events showing the slower evolution (Mazzali et al., 2002). An exact determination of the SN 2003lw luminosity is made difficult by the high absorption, whose precise value is

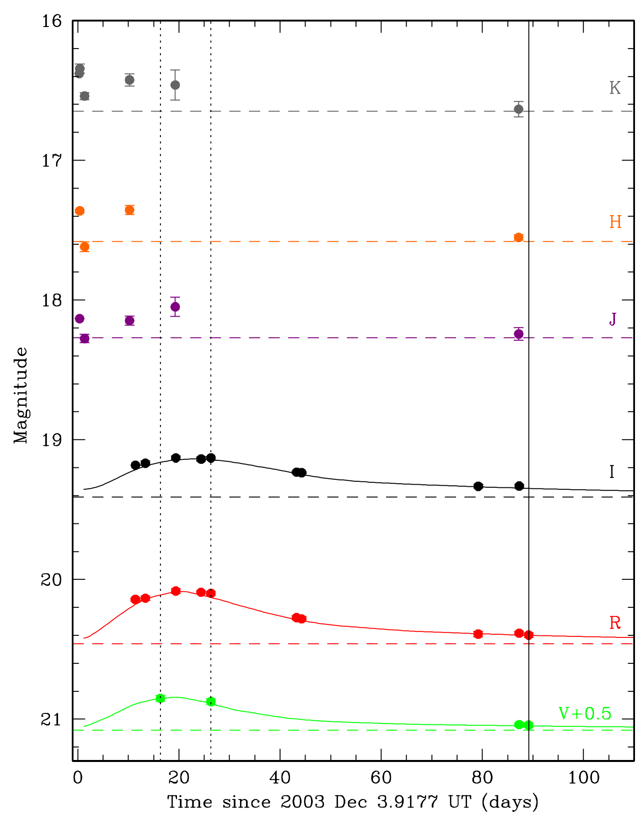

Fig. 1. GRB 031203 optical and NIR light curves. The reported error bars (often smaller than the symbol size) represent the relative errors only. The curves show the evolution of SN 1998bw rescaled at $z = 0.1055$, stretched by a factor 1.1, reddened with $E_{B-V} = 1.1$ and brightened by 0.5 mag. The vertical lines mark the epochs of our spectra (shown in Fig. 2). The dashed horizontal lines represent the host galaxy contribution (For interpretation of the references to colour in this figure legend, the reader is referred to the web of this article.)

difficult to derived. The Balmer ratios of the host galaxy imply a reddening of $E_{B-V} = 1.1$ (Prochaska et al., 2004). Assuming this reddening, SN 2003lw appears brighter than SN 1998bw by 0.5 mag in all bands, with an absolute magnitude of $M_V = -19.75 \pm 0.15$, $M_R = -19.90 \pm 0.08$, $M_I = -19.80 \pm 0.12$.

The two spectra that we obtained on 2003 December 20 and 30, i.e., 14 and 23 rest-frame days after the burst, are shown in Fig. 2. From these spectra we already eliminated the host galaxy contribution by subtracting a spectrum taken on March 1, 2004, i.e., 81 rest-frame days after the burst when the contribution from the SN should be negligible. For comparison we report also the spectra of SN 1998bw obtained at comparable epochs. The two SNe exhibit very similar spectra, with broad absorption features (the main features are identified in the figure following Iwamoto et al., 1998), indicating large expansion velocities. Thus, we classified SN 2003lw as a hypernova. A detailed modelling of the SN spectrum and its evolution is provided by Mazzali et al. (2005). Here, we briefly note that the broad peaks near 5300 and 6600 Å are the emission components due to the blending of several lines. Clearly, there is evolution between the two spectra. The shape of the redder peak is different in the two epochs, while the bluer bump is narrower and has moved at longer wavelengths in the second epoch. The latter behaviour is likely due to the change in the relative strengths of the Fe lines which concur to form the 'blue' blending.

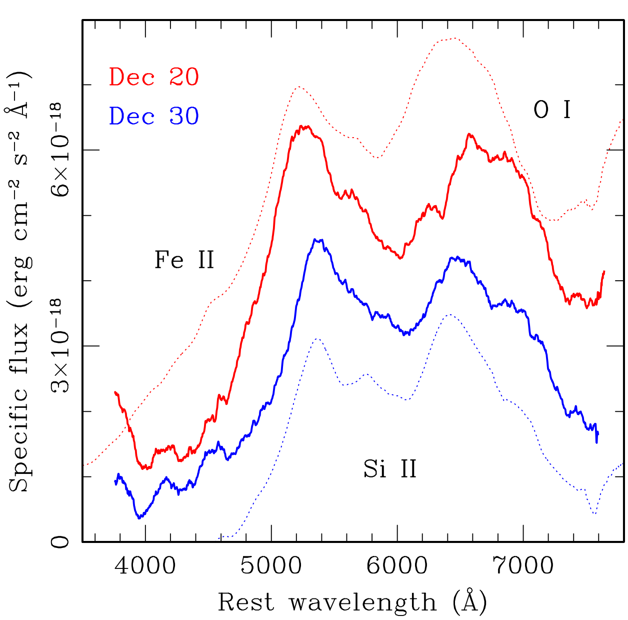

Fig. 2. The solid lines represent the spectra of SN 2003lw taken on 2003 Dec, 20 and Dec, 30, smoothed with a boxcar filter 250 Å wide. Dotted lines show the spectra of SN 1998bw (vertically displaced for presentation purpose), taken at comparable epochs and reddened with $E_{B-V} = 1.1$ (For interpretation of the references to colour in this figure legend, the reader is referred to the web of this article.).

3. Discussion

The distance of GRB031203, the second nearest GRB to date, implies that it is a very faint one, with an isotropic energy release of $\sim 1 \times 10^{50}$ erg, much fainter than most GRBs. Moreover, it does not follow the correlations that have been found for "standard" GRBs between their peak energy and energy release (Amati et al., 2002; Ghirlanda et al., 2004). The afterglow is also rather peculiar: it is the faintest NIR afterglow so far detected (Malesani et al., 2004), showing an unusually slow decay in the X-ray band (Watson et al., 2004). The optical-NIR faintness can not be due to absorption, otherwise we would not have detected the SN. For all these properties this burst is very similar to GRB 980425 (Pian et al., 2000). Thus, one would think that GRBs associated with hypernovae are different than classical GRB. However, this hypothesis is at odds with GRB 030329 which is a classical GRB associated with hypernovae SN 2003dh. These three hypernovae therefore must share a similar origin, even if the associated burst have different energetics and properties. One possibility could be that GRB 980425 and GRB 031203 are classical events, but with the relativistic jet pointing far away from the observer direction. However, radio observations seem not to confirm this hypothesis, given that much less flux is detected than what is expected.

Finally, we note that these 2 GRBs, being so faint, would have been likely missed at larger distances. Thus, it is expected that they are quite numerous, given that they are sampling a much smaller volume with respect to that sampled by classical GRBs ($z \sim 1$). If these two bursts are really isotropic weak events, than the GRB cosmic rate will increase. If, instead, they are events with the jet seen off-axis, their number will allow us to measure the beaming fraction. In any case, the detailed study of these faint and so far elusive bursts will be made possible by Swift (Gehrels et al., 2004), which will discover a large number of them.

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