1604–2004: SUPERNOVAE AS COSMOLOGICAL LIGHTHOUSES
ASP Conference Series, Vol. 342, 2005
M. Turatto, S. Benetti, L. Zampieri, and W. Shea

SN 2003lw and GRB 031203: a Bright Supernova for a Faint Gamma-ray Burst

D. Malesani

SISSA/ISAS, via Beirut 2-4, I-34014 Trieste, Italy

G. Tagliaferri, G. Chincarini, S. Covino, D. Fugazza, and P. D'Avanzo

INAF — Brera Observatory, via Bianchi 46, I-23807 Merate (Lc), Italy

M. Della Valle

INAF — Arcetri Observatory, largo Fermi 5, I-50125 Firenze, Italy

P.A. Mazzali

INAF — Trieste Observatory, via Tiepolo 11, I-34131 Trieste, Italy

Abstract. We report photometry and spectroscopy of the bright SN 2003lw, associated with GRB 031203 at a redshift $z = 0.1055$. The spectra show a pronounced similarity with those of SN 1998bw and SN 2003dh, associated with GRB 980425 and GRB 030329 respectively. Therefore, the three best-confirmed GRB/SN associations involve a hypernova. The gamma-ray and afterglow properties of GRB 031203 are quite different from those of most GRBs, but are broadly similar to those of the nearby GRB 980425. It is therefore remarkable that the associated SNe are quite homogeneous in all these events.

1. Introduction

In recent years, extensive studies of gamma-ray burst (GRB) afterglows have revealed a physical connection between 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). 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, and were extremely bright. Thus, they are often designed as hypernovæ (Iwamoto et al. 1998). Last, bumps discovered in the light curves of several afterglows, peaking ~ 20 days after the GRB, have been interpreted as SNe at maximum outshing the afterglow (e.g. Bloom et al. 1999; Zeh, Klose, & Hartmann 2004). Spectroscopic confirmation that the bump of GRB 021211 shows SN features (SN 2002lt; Della Valle et al. 2003) supports this conclusion.

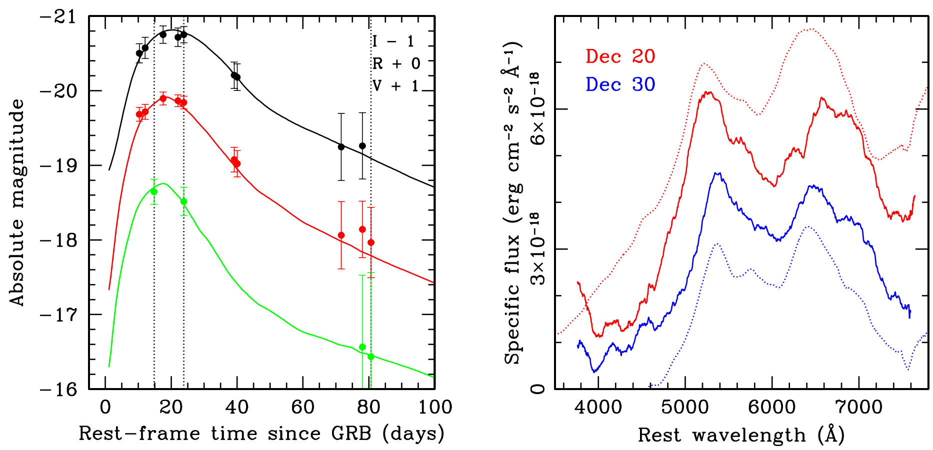

Figure 1. **Left.** VRI light curves of SN 2003lw (filled circles). The solid lines show the evolution of SN 1998bw (Galama et al. 1998; McKenzie & Schaefer 2000), rescaled at $z = 0.1055$, stretched by 10%, extinguished with $E_{B-V} = 1.1$ and brightened by 0.5 mag. Vertical lines mark the epochs of our spectra. **Right.** 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, taken on 1998 May 9 and May 19 (13.5 and 23.5 days after the GRB), extinguished with $E_{B-V} = 1.1$. The spectra of SN 1998bw were vertically displaced for presentation purpose.

2. Observations and Results

GRB 031203 was a faint GRB localized by the INTEGRAL satellite (Götz et al. 2003). At a redshift of $z = 0.1055 \pm 0.0001$ (Prochaska et al. 2004; Chincarini et al. 2004, hereafter C04), its energy release was $(1 \pm 0.4) \times 10^{50}$ erg (isotropic equivalent; Sazonov et al. 2004), much less than the usual value $\sim 10^{52} \div 10^{53}$ erg (e.g. Frail et al. 2001). We observed the host galaxy of GRB 031203 with the ESO telescopes at La Silla and Paranal, in order to search for the associated SN. Our observations allowed to detect a dim NIR afterglow (Malesani et al. 2004), the faintest ever detected for a GRB. Subsequently, long-term monitoring revealed the presence of the bright SN 2003lw (Tagliaferri et al. 2004) superimposed to the host galaxy. This finding was confirmed by other groups (Bersier et al. 2004; Thomsen et al. 2004; Cobb et al. 2004; Gal-Yam et al. 2004). A detailed discussion of the spectroscopy and the properties of the host galaxy is presented elsewhere (C04; see also Prochaska et al. 2004), while a more exhaustive discussion of SN 2003lw is reported by Malesani et al. (2004).

In Fig. 1 (left panel) we plot the VRI light curves of SN 2003lw (filled circles). Solid lines show the evolution of SN 1998bw (reddened with $E_{B-V} = 1.1$), after applying a brightening of 0.5 mag and a time dilation of 10%. Assuming this template, which reproduces our data remarkably well, the SN exploded nearly simultaneously to the GRB (up to a few days). The rise time in the (observed) R-band was 18 (rest-frame) days. Type-Ic SNe usually reach V-band maximum in $\sim 12 \div 20$ days (this band roughly corresponding to the observed R at $z = 0.1055$), the brightest events showing a slower evolution (Mazzali et al. 2002). A

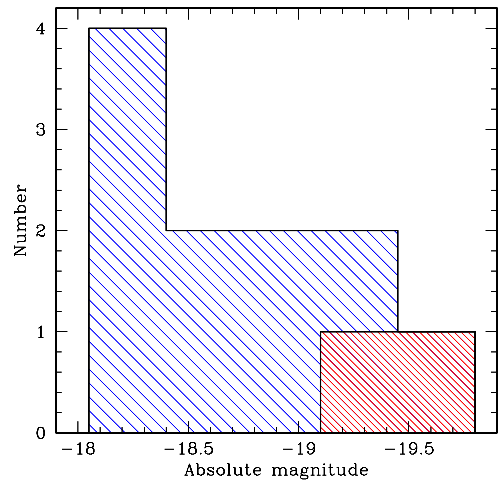

Figure 2. Distribution of GRB-associated SN peak magnitudes. SN 1998bw and SN 2003lw occupy the bright end of the distribution.

precise determination of the absolute magnitude of the SN is made difficult by the uncertain, but significant, extinction. Based on the Balmer ratios of the host galaxy, C04 and Prochaska et al. (2004) constrain the average combined Galactic and host extinction to be $E_{B-V} \approx 1.1$. Given the good spatial coincidence of the SN with the center of the host, this value should be a fair estimate for the SN extinction. With this reddening, SN 2003lw is brighter than SN 1998bw by 0.5 mag in all bands, and its absolute magnitudes are $M_V = -19.75 \pm 0.15$, $M_R = -19.9 \pm 0.08$ and $M_I = -19.80 \pm 0.12$.

The right panel in Fig. 1 shows the spectra of SN 2003lw on 2003 Dec. 20 and Dec. 30 (14 and 23 rest-frame days after the GRB). These spectra have been obtained after subtraction of the host galaxy spectrum taken on 2004 Mar. 1 (81 rest-frame days after the GRB), assuming that it contains a negligible contribution from the SN. The spectra of SN 2003lw are remarkably similar to those of SN 1998bw obtained at comparable epochs (shown as dotted lines in Fig. 1). Both SNe show very broad absorption features, indicating large expansion velocities. Thus we can classify SN 2003lw as a hypernova. The broad peaks near 5300 Å and 6600 Å are the emission components of P-Cyg 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 epoch, 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 are presented elsewhere (Mazzali et al. 2005).

3. Discussion

GRB 031203 was peculiar in many respects. Apart from being much fainter than most GRBs, its gamma-ray properties did not follow the usual correlations holding for typical GRBs (Amati et al. 2002; Ghirlanda et al. 2004). Moreover, it had a peculiar afterglow: in the NIR, it was the faintest ever detected (Malesani et al. 2004); in the X rays, it showed an unusually slow decay (Watson et al. 2004). The detection of the SN optical light implies that such faintness was not due to dust obscuration. All these properties make this burst similar to GRB 980425 (Pian et al. 2000). It is surprising that even if the burst and afterglow properties were so different from those of classical GRBs, the associated SNe were remarkably similar to SN 2003dh, the SN associated with GRB 030329. This was a rather typical GRB. These two kinds of events must therefore share a similar origin, even if the ultrarelativistic component has widely different energetics and properties. The similarity of the SNe may support the idea that GRB 980425 and GRB 031203 were classical events, but observed far from the jet axis (e.g. Maeda et al. 2002; Yamazaki, Yonetoku, & Nakamura 2003). However, radio observations argue against this hypothesis, since, in this case, much more flux would be expected at late times (Soderberg et al. 2004).

Fig. 2 shows the distribution of the peak magnitudes of the SNe associated with GRBs. Most of the data were taken by the work of Zeh et al. (2004), who fitted the late-time light curves of several afterglows. It is interesting to note that, within the limited statistics, the SNe associated with the two nearby, faint events ("the w's") are at the bright end of the distribution (see also Della Valle et al. 2003). However, it should be noted that the defining characteristic of hypernovæ is the explosion energy rather than the luminosity, which can vary significantly among the different events (see e.g. SN 2002ap; Mazzali et al. 2002).

GRB 031203 at $z = 0.1055$ and GRB 980425 at $z = 0.0085$ were very dim events. Being so faint, they would have been likely missed at larger distances. Since the volume they sample is much smaller than that probed by classical, distant GRBs ($\langle z \rangle \approx 1$), their number is quite large (Guetta et al. 2004). If these events are indeed very faint, nearly isotropic GRBs, this would immediately translate in an increase of the cosmic GRB rate. On the other hand, if they are jets observed off-axis, their number actually allows a direct measure of the (average) beaming fraction, that is the fraction of sky subtended by the jet. In any case, the discovery of these faint events is very promising for the *Swift* satellite (Gehrels et al. 2004), which will detect many of them allowing a detailed study of this largely unexplored class of events.

References

Amati, L., et al. 2002, A&A, 390, 81
Bersier, D., et al. 2004, GCN Circ 2544
Bloom, J. S., et al. 1998, Nat, 401, 453
Chincarini, G., et al. 2004, A&A, submitted (C04)
Cobb, B. E., et al. 2004, ApJ, 608, L93
Della Valle, M., et al. 2003, A&A, 406, L33
Frail, D. A., et al. 2001, ApJ, 562, L55
Galama, T. J., et al. 1998, Nat, 395, 670
Gal-Yam, A., et al. 2004, ApJ, 609, L59
Gehrels, N., et al. 2004, ApJ, 611, 1005
Ghirlanda, G., Ghisellini, G., & Lazzati, D. 2004, ApJ, 616, 331
Götz, D., Mereghetti, S., Beck, M., Borkowski, J., & Mowlavi, N. 2003, GCN Circ 2459
Guetta, D., Perna, R., Stella, L., & Vietri, M. 2004, ApJ, 615, L73
Hjorth, J., et al. 2003, Nat, 423, 847

Iwamoto, K., et al. 1998, Nat, 395, 672
Maeda, K., et al. 2002, ApJ, 565, 405
Malesani D., et al. 2004, ApJ, 609, 5
Mazzali, P. A., et al. 2002, ApJ, 572, L61
Mazzali, P. A., et al. 2005, these proceedings
McKenzie, E. H., & Schaefer, B. E. 2000, PASP, 111, 964
Patat, F., et al. 2001, ApJ, 555, 900
Pian, E., et al. 2000, ApJ, 536, 778
Prochaska, J. X., et al. 2004, ApJ, 611, 200
Sazonov, S. Y., Lutovinov, A. A., & Sunyaev, R. A. 2004, Nat, 430, 646
Soderberg, A. M., et al. 2004, Nat, 430, 648
Stanek, K. Z., et al. 2003, ApJ, 591, L17
Tagliaferri, G., et al. 2004, IAU Circ 8308
Thomsen, B., et al. 2004, A&A, 419, L21
Watson, D., et al. 2004, ApJ, 605, L97
Yamazaki, R., Yonetoku, D., & Nakamaura, T. 2003, ApJ, 594, L79
Zeh, A., Klose, S., & Hartmann, D. H. 2004, ApJ, 609, 952