SN 2002lt and GRB 021211: a SN/GRB Connection at $z = 1$

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Abstract. We present spectroscopic and photometric observations of the afterglow of GRB 021211 and the discovery of its associated supernova, SN 2002lt. The spectrum shows a broad feature (FWHM = 150 Å), around 3770 Å (in the rest-frame of the GRB), which we interpret as Ca H+K blueshifted by 14 400 km/s. Potential sources of contamination due to the host galaxy and/or residuals of telluric absorption have been analyzed and ruled out. Overall, the spectrum shows a suggestive resemblance with the one of the prototypical type-Ic SN 1994I. This might indicate that GRBs are produced also by standard type-Ic supernovae.

INTRODUCTION.

After long years of study, we have now some convincing evidence that long-duration gamma-ray bursts (GRBs) are produced by the death of a massive star. The earliest hint was the spatial and temporal coincidence between SN 1998bw and GRB 980425 (at $z = 0.0085$; [1]). However, this association was hardly representative of the whole class of GRBs: GRB 980425 was indeed a very dim event, its gamma-ray energy being lower than that of classical GRBs by $\sim 4$ orders of magnitude. SN 1998bw was also a peculiar event, belonging to the class of the so-called ‘hypernovae’: it showed unusual expansion velocities and a very high luminosity, the latter being the effect of copious Nickel production (see e.g. [2]).

Very recently, however, SN 2003dh was discovered associated with GRB 030329 ([3, 4, 5]). An intensive spectral monitoring showed a strict similarity between SN 2003dh and SN 1998bw, thereby conclusively proving that hypernovae can generate classical GRBs. SN 2003dh was however somewhat fainter than SN 1998bw ([6]).
We present here photometric and spectroscopic observations highlighting the association between GRB 021211 and SN 2002lt ([7]). GRB 021211 ([8]) was a rather dim event, its total (isotropic) gamma-ray energy being $E_{\text{iso}} = (6 \pm 0.5) \times 10^{51}$ erg, at the low end of the energy distribution of GRBs ([9]). Prompt optical observations allowed an early discovery of the optical afterglow, just few minutes after the GRB onset (e.g. [10, 11]). The afterglow also turned out to be quite faint, about 3 magnitudes in the $R$ optical band. The redshift was determined to be $z = 1.006$ ([12]). Optical/NIR colors showed little or no extinction local to the host galaxy. The intrinsic faintness of the afterglow made this event a good candidate for searching a supernova component.

**DATA AND ANALYSIS**

We observed the optical afterglow of GRB 021211 with the ESO VLT–UT4 equipped with the FORS 2 instrument, during the period January – March 2003 (20 – 100 days after the GRB). Low-resolution spectroscopy was performed on Jan 8.27 UT.

Photometric data show a rebrightening of the afterglow starting $\sim$ 15 days after the burst ([13]) and reaching the maximum, $R \sim 24.5$, during the first week of January. The contribution of the host galaxy, estimated from our late-epoch images, is $R = 25.22 \pm 0.10$. Therefore, the intrinsic magnitude of the bump was $R = 25.24 \pm 0.38$. The significance of the rebrightening is at the 4-σ level. At the time of the maximum, the afterglow contribution, extrapolated from earlier epochs, is smaller than 5% under the most conservative assumptions. This suggests that the bump is powered by some different component.
To investigate the nature of the rebrightening, we obtained a spectrum with VLT+FORS 2. The reduced spectrum covered the range of wavelengths (6000–9000) Å at an acceptable S/N (> 3). The resolution was about 19 Å, and the integration time was 4 × 1 h with a seeing of 0″.6 – 1″.4. We confirm the detection of the emission line at $\lambda = 7472.9$ Å ([12]), which may be interpreted as [O II] 3727 Å in the rest frame, leading to a determination of the redshift $z = 1.006$.

Fig. 2 shows our spectrum smoothed and cleaned from the emission line [O II]. The spectrum of the afterglow is characterized by broad low-amplitude undulations blueward and redward of a broad absorption, the minimum of which is measured at $\sim 3770$ Å (in the rest frame of the GRB), whereas its blue wing extends up to $\sim 3650$ Å. The absorption feature in our spectrum is a characteristic signature of the SN ejecta (see SN 1991bg and SN 1994I in Fig. 2) and it is due to Ca II H+K absorption lines. The blueshifts corresponding to the minimum of the absorption and to the edge of the blue wing imply velocities of $v \sim 14400$ km/s and $v \sim 23000$ km/s respectively. The more convincing resemblance is found with SN 1994I, a prototypical type-Ic event, 9 days after its $B$-band maximum ([14]). It is difficult to explain such broad absorption feature in terms of other components. It was argued that the telluric absorption at $\sim 7600$ Å can
contaminate, by chance, the absorption feature. Fig. 3 shows that even in the case that the subtraction of the telluric line was not effective (which is not the case), its profile cannot reproduce the broad and double-structured deep in the spectrum. Also in Fig. 3 the position of the rest-frame Ca H+K absorption lines is marked (crosses), showing that no contamination comes from the host galaxy.

**IMPLICATIONS**

The spectroscopic features observed during the rebrightening of the afterglow of GRB 021211 and the similarity of its lightcurve with the one of SN 1994I indicate that the bump was indeed powered by a supernova. This is therefore the third GRB (second in chronological order) for which a SN association was spectroscopically confirmed. The IAU dubbed this event SN 2002lt ([15]). SN 2001ke and GRB 011121 are another possible case of SN/GRB association, although no ‘typical’ SN features have been detected in the spectrum ([17]).

**Supernova dating.** Using SN 1994I as a template, our photometric and spectroscopic data allow us to estimate the time at which the SN exploded, and to compare it with the GRB onset time. Due to the limited wavelength coverage and to the lack of multi-time spectroscopic observations, our spectrum yields only a shallow contrain, suggesting that the SN went off between $\sim 50$ and 0 days before the GRB (see Fig. 4).

Information from the photometry yields more stringent limits. After assuming SN 1994I as a template, the best match is achieved if the SN and the GRB exploded
simultaneously or separated, at most, by a few days. We stress however that also in this case the dataset is not rich enough to set firm bounds. Moreover, this result also depends upon the assumed rising time of the template SN, which was quite short (∼12 days) for SN 1994I ([18]).

**GRB progenitor.** It is also interesting to note that SN 1994I, the spectrum of which provides the best match to that observed in GRB 021211, is a typical type-Ic event rather than an exceptional 1998bw-like object, as the one proposed for association with GRB 980425 and GRB 030329 ([1, 3, 4]). If the SN associated with GRB 021211 indeed shared the properties of SN 1994I, this would open the interesting possibility that GRBs may be associated with standard type-Ic SNe, and not only with the more powerful events known as ‘hypernovae’. However, we should note that the recently studied SN 2002ap ([19]) showed significantly broader lines than our case and this difference vanished after maximum, such that it may be not easy to distinguish between the two types of SNe.
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