GRB 000911: Evidence for an Associated Supernova?

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Abstract. We present photometric and spectroscopic observations of the late afterglow of GRB 000911. We detect a moderately significant re–brightening in the R, I and J lightcurves, associated with a sizable reddening of the spectrum. This can be explained through the presence of an underlying supernova, outshining the afterglow ~ 30 days after the burst event.

INTRODUCTION

An anomalous re–brightening was detected in the optical lightcurves of at least two gamma–ray bursts ~ 30 days after the burst event (GRB 980326: [1]; GRB 970228: [9], [5]). These have been tentatively interpreted as due to the simultaneous explosion of a supernova (SN) with a lightcurve similar to that of SN1998bw [4] which outshines the afterglow emission at the time of the SN peak.

Here we present the results of a simultaneous multi–filter observational campaign designed at detecting and studying the spectrum of the re–brightening component in the burst of September 11$^{\text{th}}$, 2000. We observed the optical transient (OT) in five filters at three epochs. A low resolution spectrum was taken ~ 36 days after the burst explosion. A detailed analysis of these data is provided in [6].

OBSERVATIONS AND DATA MODELING

We observed the OT associated with GRB 000911 with the ESO/VLT-Antu telescope (instruments, FORS1 and ISAAC), the Keck I telescope (instrument, LRIS) and the MSO 50-inch telescope. Furthermore, we obtained low resolution spectra with the FORS1 instrument (grism 150I, blocking filter OG590) on day 36, around the time of the expected peak SN emission. The resulting spectrum is shown by the filled circles in Fig. 2. The spectrum, despite its very low resolution, was determined to be considerably redder than any afterglow spectrum observed so far. A power–law fit yielded $F(\nu) \propto \nu^{-5.3\pm0.8}$ (1σ error, $\chi^2 = 22$ for 21 degrees of freedom, hereafter d.o.f.).

We have modeled the data with a composite spectrum given by combining an external shock synchrotron component [7] plus a host galaxy. In addition, we examined the possible role of a supernova component.

The photometric data were dereddened for Galactic extinction and converted to flux densities. Extinction in the host galaxy was not modeled since no additional extinction was required by the data.

The lightcurve modelling was obtained as the sum of the above three contributions. First we considered an external shock afterglow component (hereafter ES) of the form:

$$F(\nu,t) = A_{\mathrm{ES}}\, \nu^{-\alpha} t^{-2\alpha}. \quad (1)$$

This equation holds for a jet geometry after the break time [10]. Such a configuration is obtained by a broadband fitting of the GRB 000911 afterglow [8]. The constant flux from a host galaxy was added in the five bands as a free parameter (G_B, G_V, G_R, G_I and G_J).

First, an ES plus galaxy model was fitted to the data. The best fit gave a decay slope $\alpha = 0.724 \pm 0.006$ (temporal slope $\delta = 1.45 \pm 0.012$) with $\chi^2 = 24.4$ for 18

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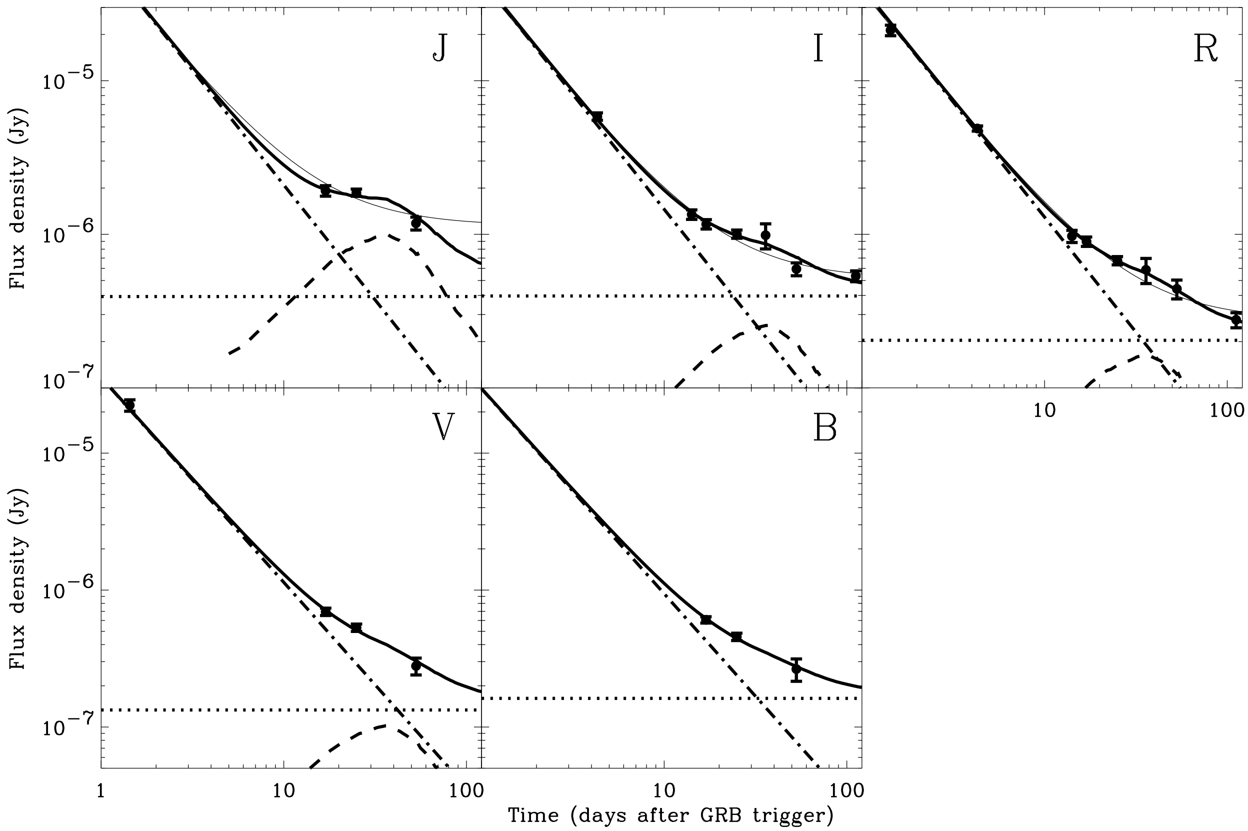

FIGURE 1. Lightcurves of the afterglow of GRB 000911. From top left to bottom right, the *J*, *I*, *R*, *V* and *B* lightcurves are plotted. The thick solid curves show the best fits obtained with our three component model. The dashed, dotted and dot–dashed lines show the SN, galaxy and ES components, respectively. The thin solid lines in the *J*, *I* and *R* panels indicate the best fit for a model comprising only the galaxy and ES (without SN). The thin line is indistinguishable from the thick solid line for the *V* and *B* filters.

d.o.f.. This is an acceptable fit, with chance probability of $P \sim 10\%$ to obtain a higher χ^2 value. However, the fit can be improved by adding the SN component at the redshift $z = 1.06$ of the host galaxy [8]. The lightcurve of the supernova component was obtained by spline interpolation of the data of SN1998bw (z=0.0085; [4]). Cosmological parameters $H_0 = 65$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$ were adopted to compute the flux as a function of redshift, and the time profile was stretched by a factor $1+z$. Following [1], the spectrum of the supernova was analytically extended in the rest frame ultraviolet assuming a power–law $F(\nu) \propto \nu^{-2.8}$ for $\lambda < 3600$ Å.

The addition of the supernova component changes slightly the spectral slope of the ES component ($\alpha = 0.748 \pm 0.006$) with $\chi^2 = 13.9$ ($P \sim 67\%$). An F test applied gives a statistical confidence of 99.8% (2.9σ) for the fit improvement. Alternatively, we allowed the redshift to vary. Interestingly, we obtain $Z_{\rm SN} = 1.1$, in good agreement with the $z = 1.06$ measured spectroscopically by [8] for the host galaxy of GRB 000911.

The re–brightening component in the lightcurve is hence remarkably similar in luminosity, shape and color to the lightcurve of SN1998bw. As a final test, we allowed for a temporal shift Δt between the SN and GRB explosions. Keeping all the other SN parameter fixed to the values of SN1998bw and the redshift $z = 1.06$, we obtain $\Delta t = 0^{+1.5}_{-7}$ days (1σ), showing that the SN explosion may anticipate the GRB but only by ~ 1 week (see, e.g., the Supranova model by [11]).

The best fit three component model (ES plus galaxy plus SN) is shown by the thick solid line in Fig. 1. The figure also shows the three individual components (ES, galaxy and SN).

To better constrain the models, we added photometric information to the spectrum. In the upper panel of Fig. 2, the spectrum (filled dots) is plotted together with the *J* band measurement at day 25 (diamond). Note that the change in the *J* magnitude from day 25 to day 36 is expected to be small (see the first panel of Fig. 1). In the lower panel, the best fit galaxy components obtained with the lightcurve fitting procedure (from left to right G_B, G_V, G_R, G_I and G_J) are shown for the five photometric filters used (triangles). We modeled the ensemble of these data with a galaxy spectrum (templates from [2]) plus a power–law ES spectrum (parameters fixed to the best–fit values from the lightcurve) and a type Ic supernova spectrum a few days after the peak (SN 1987M, [3])

The two models were fitted as follows: the total template spectrum was fitted to the spectral data together with the *J* band measurement; galaxy magnitudes derived from the template galaxy were fitted to the data in the lower panel. For the galaxy plus ES model, a formal best fit was obtained with a dust–enshrouded starburst galaxy template. The fit gave $\chi^2 = 58$ for 27 d.o.f. ($P \sim 0.05\%$). A better fit ($\chi^2 = 37$ for 27 d.o.f., $P \sim 9\%$) was obtained by adding a SN component, with a moderately dust–enshrouded starburst galaxy ($0.11 < E_{B-V} < 0.21$) as a template. The fit is shown in Fig. 2 overlaid on the data.

In order to obtain a single statistical indicator combining the photometric and spectral information, we finally fitted simultaneously all the available data with the appropriate galaxy template. This yielded $\chi^2 = 44$ (39 d.o.f.) and $\chi^2 = 69$ (40 d.o.f.) for the models with and without SN component, respectively. The χ^2 decrease has a statistical significance of 4σ, according to the F–test.

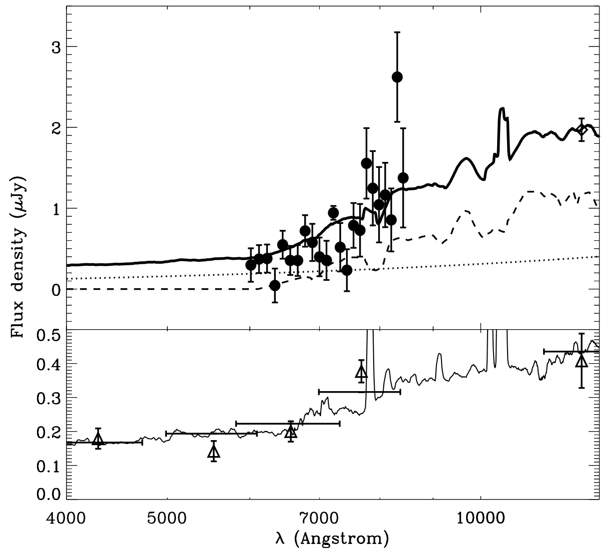

FIGURE 2. Spectrum of the OT of GRB 000911 observed 36 days after the burst explosion (upper panel, filled dots). The spectrum is modelled with a SN type Ic spectrum plus a background starburst galaxy and an ES component (see text). The solid line shows the total spectrum smoothed with a 110 Å boxcar filter, while the dashed line represents the supernova component (SN1987M, see text). The lower panel shows the template spectrum of the best fit galaxy model (thin solid line). Triangles are the galaxy photometric measurements as derived from the multiband fitting. The vertical position of the horizontal bars indicate the *BVRIJ* filter fluxes derived from the galaxy template; their width is equal to the full width at half maximum of the filters.

CONCLUSIONS

We presented late time multifilter observations of the optical transient associated to GRB 000911. This set of observations was designed to detect and analyze the re–brightening associated with (some) GRB afterglows approximately one month after their explosion ([1]; [9]; [5]). In addition to photometric data, a low resolution spectrum was taken $\sim$ 36 days after the burst explosion.

The lightcurve and spectrum were fitted with an external shock plus galaxy model, with the possible addition of a supernova, similar to SN1998bw. The addition of the SN component gives a better fit, with a statistical significance of 4σ.

With the present data, a word of caution should be spent, since is not possible to unambiguously assess the presence of the SN. However, if future observations will allow us to better constraint the magnitude of the host galaxy and will confirm the presence of the rebrightening, we will be able to disentangle the SN component and to provide simultaneous multiband SEDs at the time of our 3 VLT observations. Such time resolved broad band SEDs will allow to better understand the spectral evolution of the bump in the lightcurve and hence to understand its physical origin.

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