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GRB 011121: Jet, wind and supernova – all in one

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Abstract. We report optical and near-infrared follow-up observations of GRB 011121. We discover a break in the afterglow light curve after 1.3 days, which implies an initial jet opening angle of $\sim 9°$. The jet origin of this break is supported by the achromatic spectral energy distribution. During later phases, GRB 011121 shows significant excess emission above the flux predicted by a power law decline, interpreted as light from an underlying supernova. The deduced parameters for the decay slope as well as the spectral index favor a wind scenario, i.e. an outflow into a circum-burst environment shaped by the stellar wind of a massive GRB progenitor. Due to its low redshift of z=0.36, GRB 011121 is the so far best example for the GRB-supernova connection, and provides compelling evidence for a circum-burster wind region expected to exist if the progenitor was a massive star.

1. Introduction

GRB 011121 was detected by the GRBM/WFC onboard BeppoSAX on 2001 November 21, 18:47:21 UT and localized to initially 5 arcmin accuracy (Piro 2001). Subsequent analysis refined this position to 2 arcmin accuracy (Piro 2001), and the triangulation of the GRB arrival timings as measured by Ulysses, BeppoSAX (Hurley et al. 2001) and HEND further refined the coordinates. A follow-up X-ray observation with the BeppoSAX narrow-field instruments revealed the fading X-ray afterglow (Piro et al. 2001).

Follow-up optical/NIR observations of GRB 011121 were quickly started by several groups, leading to independent discoveries of the afterglow (e.g., Wyrzykowski et al. 2001; Greiner et al. 2001). Further observations revealed a rather small distance, $z \approx 0.36$ (Infante et al. 2001), and excess emission above the early power-law decay (Garnavich et al. 2001). The interpretation of this excess light as a possible supernova bump attracted much attention and resulted in the so far best sampling of GRB afterglow emission at late times. Here we report results of observations obtained by the GRACE[1] (GRB Afterglow Collaboration at ESO) consortium (for more details see Greiner et al. 2003).

2. Observations and Results

We used the Schlegel, Finkbeiner, & Davis (1998) extinction of $E(B-V) = 0.46$ mag along this line of sight through the Galaxy, corresponding to $A_V \approx 1.4$ mag. Accurate photometry of the afterglow requires a careful removal of contaminating light from the underlying GRB host galaxy which has an angular extent of two arcseconds. This was accomplished with simple intensity profile models which were derived from an image taken on 9 February 2002 with no sign of the afterglow anymore. The host subtracted light curves are shown in the accompanying paper of Zeh et al. (these proceedings). Two spectra taken at day two after the GRB and near the supernova maximum, respectively, are shown in Fig. 1.

The main results are

- a break in the light curve at ~ 1.3 days
- a related change of the decay slope of $\Delta\alpha = 0.82 \pm 0.73$
- no significant change of the SED (Fig. 2)
- an agreement of the measured α and β values with the jet-wind scenario
- a late-time bump, interpreted as a supernova feature
- a decline which is faster than the supernova template 1998bw
- a spectrum near the supernova peak which is shallower than the 1998bw template, and reminiscent of a 6300 K blackbody (Fig. 2)
- a host galaxy which is more than 3 mag brighter than the SN at maximum, and among the brightest 5% Sbc galaxies
- a practically extinction-free GRB environment along the line of sight
- a star formation rate of 1.2 $M_\odot$/yr (based on OII) and 0.66 $M_\odot$/yr (Hα), respectively

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[1] http://zon.wins.uva.nl/~grb/grace/

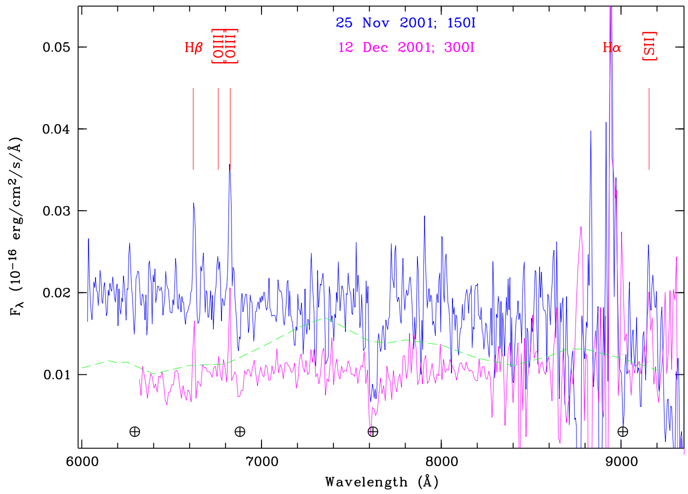

Figure 1. Spectrum of GRB 011121 taken with VLT/FORS2 equipped with the 150I (25 Nov. 2001, top) and 300I (12 December 2001, bottom; shifted by 0.01 units downwards) grisms, respectively. Both spectra represent basically the host spectrum, since the afterglow has faded far below the brightness of the host. The dashed line shows the spectrum of SN 1998bw at 24 days after the maximum (Patat et al. 2001), redshifted to z=0.36 and diminished in brightness to 85%.

3. Conclusions

While our α and β values are consistent with those reported by Garnavich et al. (2002) and Price et al. (2002), the change in our values due to the discovery of the break and the evolution during the four days after the GRB leads to a preference of the wind model.

Our observations reveal a light curve break at early times and the appearance of extra light at late times. The former is believed to be evidence for a collimated outflow (a fireball jet), whereas the latter could be due to supernova light. Indeed, if we check various afterglow models with respect to their predicted $\alpha - \beta-$relations we find the jet–high-mass progenitor model as the scenario most consistent with the data. The afterglow of GRB 011121 thus provides another case in support of the current standard paradigm of long-duration gamma-ray bursts: the collapsar model (Woosley 1993, Hartmann & Woosley 1995) in which the birth of a black hole inside a rapidly rotating massive star is announced via jet formation, breakout, and propagation into a stellar environment that was shaped by the strong winds of the pre-collapse star. In fact, GRB 011121 is the first case, where all three signatures (jet break, wind density profile and supernova bump) have been found, while in earlier cases only two of these three ingredients could be found (e.g., Jaunsen et al. 2001). However, even with GRB 011121 this line of reasoning remains circumstantial, and many more afterglows have to be observed, and better sampled than is presently the case, to seriously establish the GRB-collapsar picture.

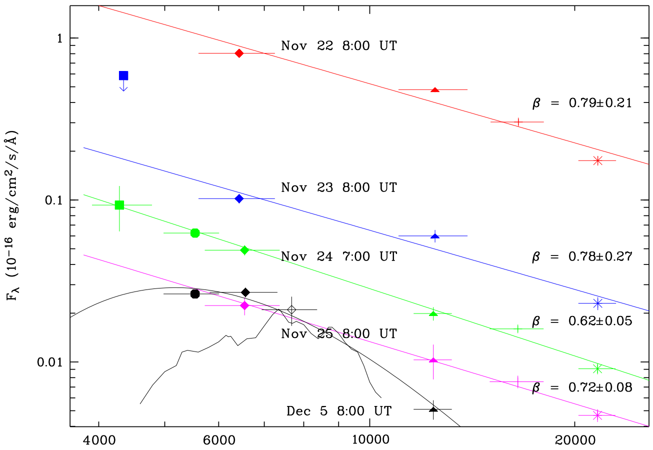

Figure 2. Extinction-corrected SED of GRB 011121 on four consecutive days, starting about 14 hrs after the GRB, and on 5 December 2001 near the maximum of the supernova-bump. The best-fit power law slopes β are given at the right side except for December 5. The December 5 spectrum is clearly not of power law type. The smooth solid curve is a blackbody with a temperature of 6300 K, while the thin solid line is the spectrum of SN 1998bw, redshifted to z=0.36.

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