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The "Christmas burst" GRB 101225A revisited

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Abstract. Long GRBs are related to the death of massive stars and reveal themselves through synchrotron emission from highly relativistic jets. The 'Christmas Burst' GRB 101225A was an exceptionally long GRB with a thermal afterglow, very different from the standard GRB. Initially, no spectroscopic redshift could be obtained and SED modeling yielded z=0.33. A plausible model was a He-NS star merger where the He-star had ejected part of its envelope in the common envelope phase during inspiral. The interaction between the jet and the previously ejected shell can explains the thermal emission. We obtained deep spectroscopy of the host galaxy which leads to a correction of the redshift to z=0.847. Despite the higher redshift, our model is still valid and theoretically better justified than the alternative suggestion of a blue supergiant progenitor proposed by Levan *et al.* (2014) for several "ultra-long" GRBs.

1. The Christmas Burst - new emission mechanisms for a GRB

Long Gamma-ray bursts (GRBs) are thought to be the end states of rapidly rotating massive stars. Upon collapse, they produce an accretion disk around the newly formed BH and two jets emitting highly relativistic material. Those jets produce collimated γ-ray emission through internal shocks and afterglow emission from X-rays to radio in shocks with the interstellar medium. All the observed emission is synchrotron radiation. Long GRBs are accompanied by broad-line Type Ic SNe which are observed when the brighter afterglow emission has faded.

The Christmas burst, detected on Dec. 25 2010 at 18:37 UT by the *Swift* satellite was, however, very different. The X-ray afterglow had a thermal component with constant temperature and radius and dropped steeply after 0.3 days. The UV to IR afterglow was purely thermal emission and could be modeled by an expanding, cooling black-body (BB). A late, faint SN component was detected and SED modeling of the SN gave a redshift of z=0.33 (Thöne et al. 2011). Our suggested model was a He-NS merger with a common envelope phase where, during in spiral, the He-star eject part of its envelope in a thick shell with a narrow opening (Zhang & Fryer 2001; Fryer *et al.* 2013). The final merger creates a GRB and the jet interacts with the previously ejected material. The narrow opening thermalizes most of the relativistic jet creating a hot plume breaking out of the shell, the observed "afterglow" emission while the interaction at the inner border creates an X-ray emitting hotspot (Cuesta Martínez *et al.* 2015a,b). Finally, the SN shock overtakes the emission from the plume.

2. A new redshift and its implications

In June 2012 we obtained deep spectra of the host galaxy with a total exposure time of 6 h in two grisms. We detect faint emission lines of [O II], [O III] and Hβ at a common

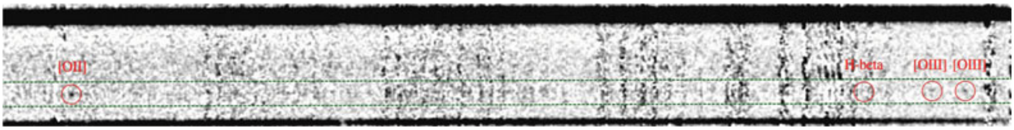

Figure 1. Spectrum of the host of GRB 101225A with faint emission lines at z=0.847.

redshift of z=0.847 (see Fig. 1), confirmed by Levan *et al.* (2014). Reinvestigating an early afterglow spectrum with the knowledge of the redshift, there might be faint Mg II absorption present in the afterglow spectrum.

The host remains to be a small galaxy (M'_g=–16.4 mag) but similar to a few other nearby GRB hosts, it is furthermore very compact (d< 600 pc) and probably not very metal poor. The intrinsic energy release of the GRB is now higher with $E_{iso} = 1.3\times10^{52}$ erg, the apparent BB radius larger and the temperature and expansion velocity higher. However, this assumes the BB emission to be spherically symmetric which is likely not the case. The new redshift makes the SN very similar in luminosity to the "standard" GRB-SN 1998bw with M_B=–19.4 mag. However, the light curve has a larger stretching factor and is considerably bluer than 1998bw. The SN might have some similarities of the SN to SNe Type II-P or super luminous SNe.

3. A new class of ultra-long GRBs?

GRB 101225A was not the only GRB with thermal components, e.g. in X-rays those are frequently detected (Starling *et al.* 2012). Most of these GRBs, however, have a synchrotron UV to IR afterglow. In Thöne et al. (2011) we found that GRB 060218 might also have had an early thermal component in the UV to IR afterglow.

Levan *et al.* (2014) suggest GRB 101225A to belong to a new class of "ultra-long" GRBs (T>1000s) and claims that GRB 1112109A is similar to GRB 101225A, which, however, does not have any thermal component. Their favorite progenitor for this GRB type is a blue supergiant to explain the very long duration. However, stellar evolution modeling reveals several problems of this progenitor: very long durations are hard to achieve, the γ-ray emission would have to drop steeply after a certain time (which is not observed) and the high angular momentum needed for producing a GRB are hard to get with such a large star.

We conclude that the originally proposed He-NS merger model is still very appealing and theoretically more sound than the suggested blue supergiant progenitor for "ultra-long" GRBs. To further investigate the progenitor we will study the blue SN component and try to search for similarities with other ISM-interaction dominated explosions such as SLSNe.

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