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# The supernova detection of the shortest collapsar event GRB 200826A

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Observational and theoretical evidence have identified two different origin for the gamma-ray bursts (GRBs): the death of very massive stars or the merger of compact objects. The evidence for massive star explosions is indicated by the observed association with type Ic broad line supernovae, while the association with kilonovae indicates a merger origin. GRBs are also classified as long and short events and long GRBs (LGRBs) are often observed in association with collapsar GRBs. This happens so frequently that the classification as long or short GRBs is commonly interpreted as synonym of a massive star or merger origin. In this context the peculiar short GRB 200826A at redshift $z = 0.7486$, with a rest-frame duration of $\sim 0.5$ s, goes against this common interpretation. The relatively low redshift motivated multi-wavelength follow-up campaign to search for a possible associated supernova (SN), and thus understand the origin of this burst. To this aim we obtained a combination of deep near-infrared (NIR) and optical imaging. Our analysis reveals an optical and NIR bump in the light curve whose luminosity and evolution are in agreement with those of several LGRB-SNe. We conclude that GRB 200826A is a typical collapsar event in the low tail of the duration distribution of LGRBs. These findings support theoretical predictions that events produced by massive star explosions can be as short as 0.5 s in the host frame and further confirm that duration alone is not an efficient discriminator for the progenitor class of a GRB.

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## 1. Introduction

Traditionally, gamma-ray bursts (GRBs) are divided in two classes based on their duration and their spectral hardness in the gamma energy range. The majority of observed GRBs have durations longer than 2 s, a soft high-energy spectrum and are termed "long GRBs" (LGRBs), as opposed to "short GRBs" (SGRBs) [1, 2].

Except for less than a handful of cases (GRBs 060505, 060614, 111005A [e.g., 3–5]), all long GRBs have succesfully been associated with highly energetic broad-lined type Ic supernovae (SNe), unless they are too far away to detect this component. Therefore, they have been associated with the deaths of very massive stars [the collapsar model; e.g., 6, 7]. On the other hand, the association of SGRB 170817A with the gravitational-wave source GW170817 by the LIGO and Virgo interferometers, as well as the kilonova (KN) AT2017gfo, showed that SGRBs are connected with the merger of compact objects. [e.g., 8–11]. [12] showed that the 2 s duration commonly used to separate collapsars and non-collapsars is inconsistent with the duration distributions of *Swift* and *Fermi* GRBs and only holds for old *CGRO*/BATSE GRBs. These authors find also that, in the context of the collapsar model, the duration overlap of the two populations is very large [13] and bursts shorter than 1 s in the different catalogs and especially the *Swift* and *Fermi* sample have a non-negligible probability to be collapsars. In this direction is the case of GRB 040924, classified as short for its rest-frame duration ($\sim$ 1 s), an associated SN was detected [14, 15] thus identifying its origin as being the collapse of a massive star. Indeed, the most secure way is to determine whether the event is associated with a supernova (SN) and is a LGRB, or with a KN and is a SGRB.

We here present follow-up observations and the search for a SN associated to GRB 200826A, a short-duration burst detected by several space-based GRB detectors [see 16] Due to its observed short duration (GBM $T_{90}$ = 1.14 s, [17]; Konus-*Wind* $T_{90}$ = 0.772 s, [18]), this burst is classified as SGRB. The optical counterpart ZTF20abwysqy was found by the ZTF survey project within the large error circle of *Fermi*/GBM [19–21]. The GRB spectroscopic redshift ($z$ = 0.748) was obtained thanks to LBT/MODS observations [22, 23] and the corresponding luminosity distance was used to calculate the rest-frame energetics. This showed that GRB 200826A was consistent with classical LGRBs [23, 24]. A SN bump in the afterglow light curve was finally reported by [25], with additional observations reported in [24, 26].

Throughout this work, the flux density of the afterglow is described as $F_\nu(t) \propto t^{-\alpha}\nu^{-\beta}$, and a $\Lambda$CDM world model with $\Omega_M = 0.308$, $\Omega_\Lambda = 0.692$, and $H_0 = 67.8$ km s$^{-1}$ Mpc$^{-1}$ [27] has been assumed. All data are in observer frame, unless differently specified.

## 2. Observations, image subtraction and analysis

The optical follow-up was performed with LBT in the Sloan filters $g'$ and $r'$ bands using the two twin MODS instruments, and in the Sloan $r'$ filter with the Device Optimized for the Low Resolution (DOLoRes) optical imager and spectrograph mounted on the Telescopio Nazionale Galileo (TNG) on La Palma (Canary Islands, Spain). We have also observed GRB 200826A twice with AZT-22 1.5m telescope equipped with the SNUCAM CCD camera [28] at the Maidanak Astronomical Observatory (MAO, Uzbekistan). Additional data was obtained from the literature, in particular we have re-analyzed the $r'$ $i'$-band Gemini/GMOS data from [26] and the $r'$-band data of Gran

Telescopio Canarias (GTC) at 3.99 d reported in [24][1]. Further details of the analysis are reported in [23].

The transients lies within its host galaxy, which is $\gtrsim 1$ mag brighter than the typical GRB-SN. Therefore, to unveil the late transient, the constant contribution from the host galaxy needs to be removed via image subtraction. Before this, input and reference images were aligned using the WCSREMAP package[2]. Image subtraction was then performed using a routine based on `HOTPANTS`[3] [29]. This algorithm matches the PSF and count flux of both input images. The PSF is modeled via Gaussian functions in sub-regions of the original image. The software outputs a noise map of the resulting difference image, which is used to derive the uncertainties in the measured fluxes. The routine creates a grid of input Gaussian widths and sub-region sizes and searches for the solution with the lowest noise. In contrast to the optical images, only two stars (the AO reference star and another star close to it) were useful to map the PSF and flux. Unfortunately, this impacts the optimal use of HOTPANTS to scale the template image to the flux of the science image. Instead, a better result was obtained using the `PSF-MATCH` task under IRAF and scaling the images to have the same flux for the two stars. All image-subtracted data have been analyzed using aperture photometry as detailed in [23]. Table 1 provides a summary of all the photometry of the transient and the host galaxy including values collected from the literature. Apparent magnitudes were corrected for Galactic extinction using the [30] interstellar extinction curve, a total-to-selective extinction of $R_{\rm V}$ = 3.1, and a reddening along the line of sight of $E(B-V) = 0.058$ mag [31].

## 3. The late bump as supernova emission

Although the sparse data precludes determining the evolution of the late bump seen in the transient light curve, a comparison can be made with other GRB-SNe to look for similarities. In Fig. 1 we show those GRB-SNe with comparable peak luminosities and colors, including GRB 980425/SN 1998bw [33], GRB 060218/SN2006aj [34], GRB 130702A/SN 2013dx [35, 36]. Due to the non-negligible redshift of GRB 200826A, the observed $r'$-, $i'$- and $H$-band data sets correspond approximately to the rest-frame $U$, $B$, and $z'$-bands, respectively. In the following comparison, we will refer to these rest-frame bands.

The SN associated with GRB 200826A appears fainter than SN 1998bw in the rest-frame $B$-band than SN 1998bw, but is of comparable luminosity or slightly brighter ($\lesssim 0.5$ mag) than SN 1998bw in rest-frame $z$-band. The most striking feature is the suppression in the rest-frame $U$-band, at least 1 mag compared to SN 1998bw at 28 d. This prompted a further investigation into GRB-SNe with redder colors, and produced a possible agreement with GRB 130702A/SN 2013dx.

## 4. Summary and conclusions

GRB 200826A is a temporally short GRB at $z = 0.748577 \pm 0.000065$ with a rest-frame duration of $\sim 0.5$ s, below the threshold of 2 s commonly used to separate SGRBs and LGRBs. To better understand the nature of this event, we initiated a follow-up campaign spanning a period of 1

[1]PI A. J. Castro-Tirado, program GTCMULTIPLE4B-20A
[2]http://tdc-www.harvard.edu/wcstools
[3]https://github.com/acbecker/hotpants

**Table 1:** Photometry of the Transient.

| $\Delta$t[a] (d) | Magnitude AB[b] | Filter | Telescope | Ref.[c] |
|---|---|---|---|---|
| 7.21 | > 23.5 | $r'$ | LBT/MODS | [3] |
| 7.21 | > 23.6 | $g'$ | LBT/MODS | ” |
| 15.7 | > 24.3 | $R_C$ | MAO | ” |
| 28.3 | 24.53 ± 0.21 | $i'$ | Gemini | [1,3] |
| 28.3 | > 25.6 | $r'$ | Gemini | [1,3] |
| 31.9 | > 25.3 | $r'$ | TNG | [3] |
| 33.3 | > 25.7 | $r'$ | LBT/MODS | ” |
| 33.3 | > 25.8 | $g'$ | LBT/MODS | ” |
| 37.1 | 24.06 ± 0.20 | $H$ | LBT/LUCI | ” |
| 46.1 | 25.36 ± 0.26 | $i'$ | Gemini | [1,3] |
| 46.1 | > 25.5 | $r'$ | Gemini | [1,3] |
| 50.88 | > 25.6 | $r'$ | LBT/MODS | [3] |
| 50.88 | > 26.2 | $g'$ | LBT/MODS | ” |
| 97.0 | > 24.7 | $H$ | LBT/LUCI | ” |
| 158.5 | 22.84 ± 0.20 | $H$ | LBT/LUCI | ” |
| 287 | 22.92 ± 0.08 | $r'$ | LBT/LBC | ” |
| 287 | 22.58 ± 0.05 | $i'$ | LBT/LBC | ” |

a Mid-time after the *Fermi*/GBM trigger in the observer frame.

b The photometry is not corrected for Galactic extinction. The first part (above the double line) is the result of image subtraction and represents the pure transient. The second part has been used to study the host and as references for the subtraction.

c [1] [26]; [2] GCN 28306 [32]; [3] [23]; [4] [24]. the full $\sim 6' \times 6'$. MODS1 was equipped with the $g'$ filter and MODS2 with the $r'$ filter.

year which involved the LBT telescope in Arizona (USA), the TNG telescope on La Palma (Canary Islands, Spain) and the Maidanak Astronomical Observatory (Uzbekistan). We were able to obtain deep $H$-band observations between 21 to 91 d after the burst trigger in the rest-frame $z'$-band. Image subtraction shows a faint transient within its host galaxy. Finally, we were able to put strong upper limits on the UV rest-frame luminosity thanks to our LBT and TNG $r'$-band observations. Our results show that the evolution and color of the late bump is in good agreement with other GRB-SNe, and especially with the fast rising GRB 130702A/SN 2013dx. Thus we firmly classify this burst as a collapsar event. This evidence weakens the effectiveness of simple duration as an indicator of the source of a GRB and gives strong support to theoretical predictions that collapsar events may have an observable duration shorter of the classical short/long divide (about 2 s), and down to 0.5 s or less [e.g., 13].

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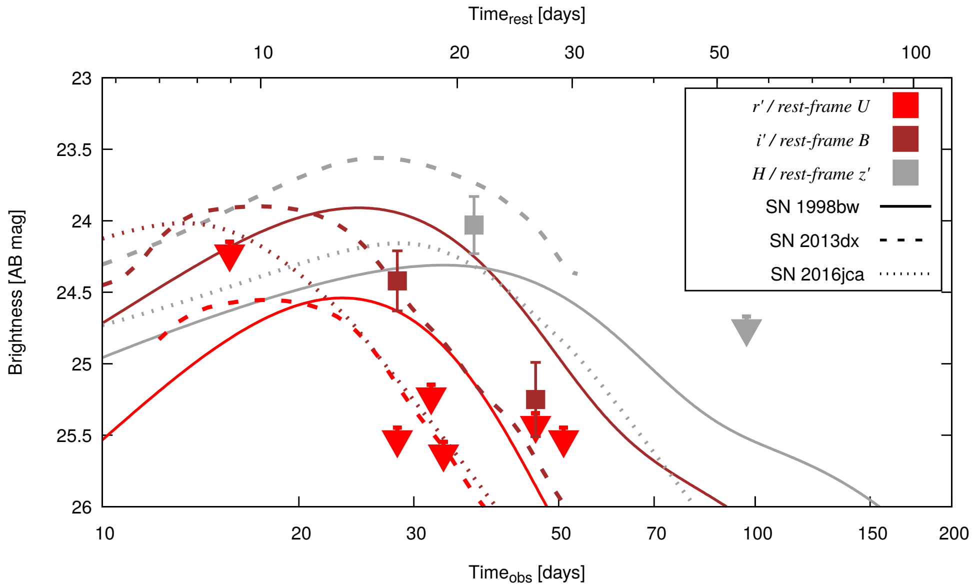


**Figure 1:** Light curve in $i'$ and $H$ bands after removing the host component via image subtraction (see Table 1). Only data after 10 d (observer frame) are shown. The data are corrected for Galactic extinction (see § 2). The SN light curve templates obtained from SN 1998bw, 2013dx, and SN 2016jca are shown for comparison and to stress the large range of variability and color of GRB-SNe (See §3). Downward-pointing triangles are upper limits. Figure from [23].

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