Journal Club: The peculiar short-duration GRB 200826A and its supernova

A. Rossi, et. all

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Abstract

Gamma-ray bursts (GRBs) are classified as long and short events. Long GRBs (LGRBs) are associated with the end states of very massive stars, while short GRBs (SGRBs) are linked to the merger of compact objects. GRB 200826A was a peculiar event, because by definition it was a SGRB, with a rest-frame duration of ~ 0.5 s. However, this event was energetic and soft, which is consistent with LGRBs. The relatively low redshift (z = 0.7486) motivated a comprehensive, multi-wavelength follow-up campaign to characterize its host, 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 together with spectroscopy. Our analysis reveals an optical and NIR bump in the light curve whose luminosity and evolution is in agreement with several LGRB-SNe. Analysis of the prompt GRB shows that this event follows the $E_{\rm p,i} - E_{\rm iso}$ relation found for LGRBs. The host galaxy is a low-mass star-forming galaxy, typical for LGRBs, but with one of the highest star-formation rates (SFR), especially with respect to its mass ($\log M_*/M_\odot$ = 8.6, SFR ~ 4.0 $M_\odot$/yr). 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 collapsars 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.

WHAT ARE YOU 200826A?

https://www.youtube.com/watch?v=EmIOQ4Lzcy4

- The first observations made it all seem to be a Short Gamma ray burst with a T_90=1.14s by GBM and T_90=0.772s by Konus-Wind, in a z=0.748.
- ZTF survey project launched and it observed an isotropic energy releades and peak energy of a typical long gamma ray burst
- Bump in the SN afterglow light curve

CONCLUSIONS

consistent with the $E_{p,i} - E_{iso}$ "Amati" relation followed by LGRBs. The spectral lag is also more typical of LGRBs.

It was followed by an optical and X-ray afterglow with a luminosity between those LGRB and SGRB afterglows.

The evolution and colour of the late bump is in accordance with GRB-SNe, for example GRB 130702A/SN 2013dx.

The possible alternative scenario of a genuine SGRB followed by a KN like AT2017gfo is not likely due to the different evolution and luminosity of the light curve.

The host galaxy of GRB 200826A is typical of an LGRB host galaxy, but with highest SFR and sSFR rates than expected.

Distance of 0.75 kpc from the centre of its host galaxy, which is consistent with the majority of LGRBs.

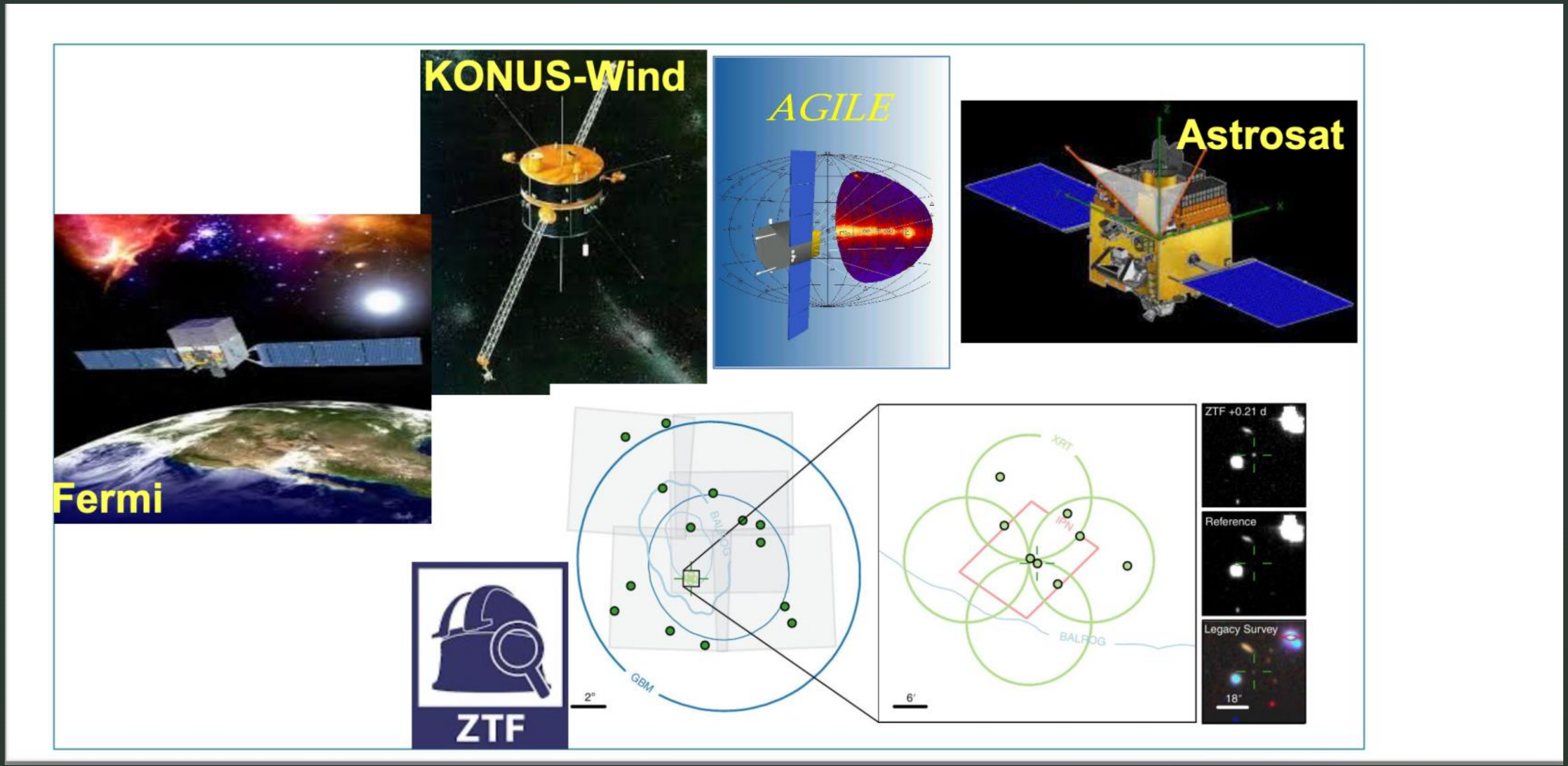
Observations and data analysis

CHANGE DUE TO REDSHFIT FROM
THE BANDS

FROM	TO
r’ (650 to 670 nm)	U (300 to 365nm)
i’ (700 to 900 nm)	B (450 to 495 nm)
H-Band (1500 to 1800nm)	Z (850 to 1000 nm)

TELESCOPES USED FOR THE DATA

- SEE THE POWER POINT PRESENTATION FROM ROSSI


KONUS-Wind
AGILE
Astrosat
Fermi
ZTF
GBM
BALROG
2°
XRT
IPN
BALROG
6′
ZTF +0.21 d
Reference
Legacy Survey
18″

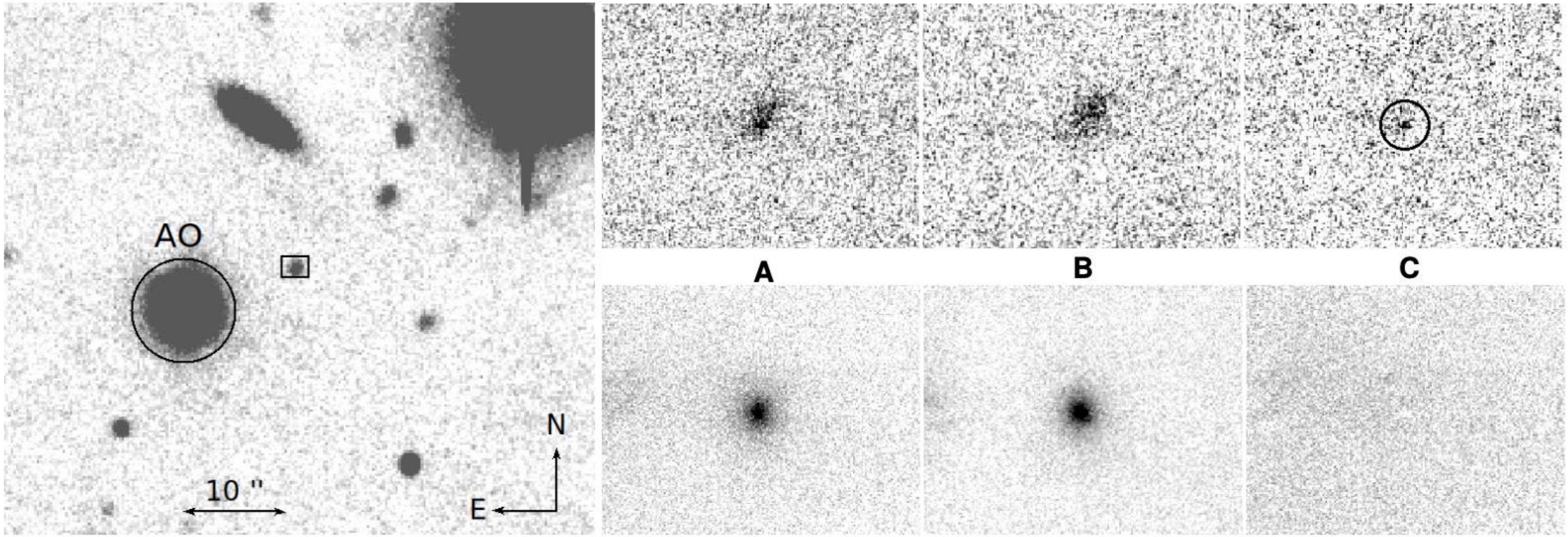


Figure 1. Left: $1' \times 1'$ field-of-view (FoV) finding chart derived from the TNG r'-band imaging obtained on 2020-09-27 UT. The star used for AO observations with SOUL and the LBT/LUCI camera is highlighted. The rectangular region is centered on the location of the afterglow, and its angular size is the same as the panels on the right. **Right:** Results of the H-band follow-up using the second generation SOUL Adaptive Optics with LUCI-1 at the Large Binocular Telescope. The top row shows the location of the host and the GRB (see the region in the left panel). For comparison, the bottom row shows the location of a star in the field. From left to right: A) the LUCI-1 AO H-band imaging obtained on UT 02-10-2020 (i.e., close to the peak of the SN); B) LUCI-1 AO H-band image obtained four months later when only the host is visible; and C) the subtraction between these two epochs, where the transient is highlighted with a circle (top) and the field star is cleanly subtracted (bottom). The FoV of each panel is $2''.6 \times 2''.0$. The LUCI-1 AO FoV is $30'' \times 30''$. In each panel North is up, East is to the left. The transient lies at a projected distance of 0.75 kpc from the center of its host galaxy as discussed in §3.5.

Light curve

- SN 1998bw as a SN template
- Smoothly broken power law, since late afterglow is brighter than the deep *r′* upper limits obtained at ~ 30 d after subtraction of the host-galaxy contribution.
- The last detections in the *g′* and *r′* bands are at ≈ 2.2 and ≈ 4 d
- any late emission detected via subtraction is not from the afterglow
- “long” GRB with a duration in the short tail of the distribution

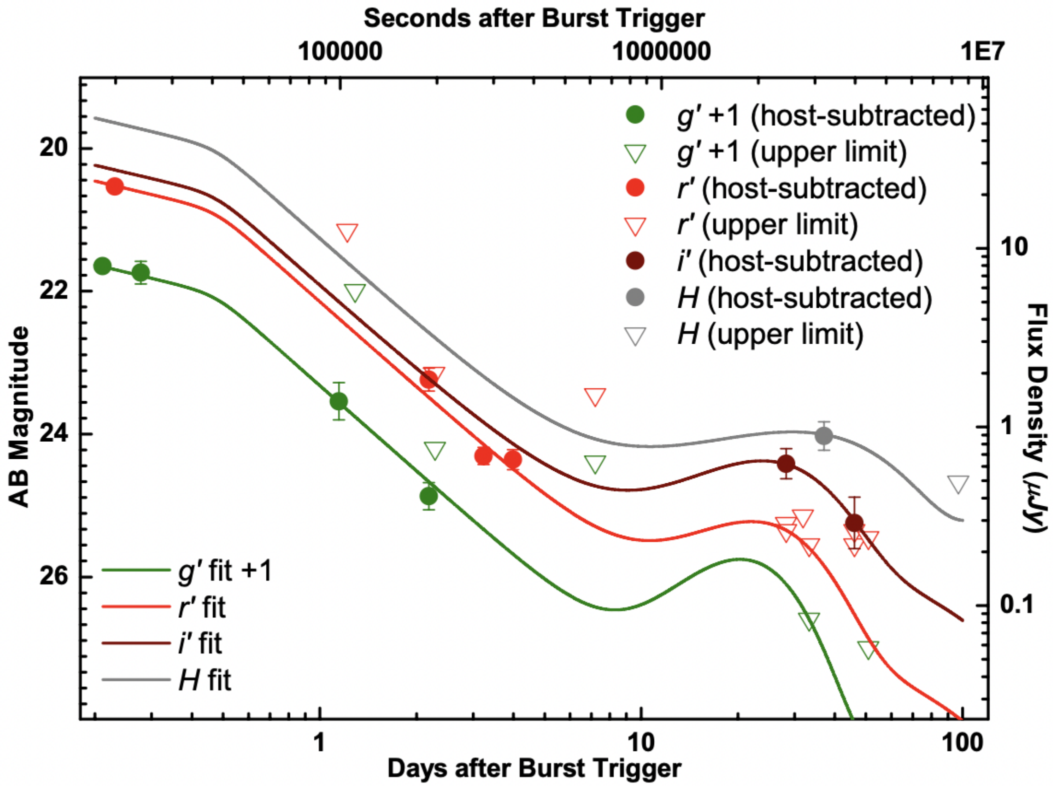


Figure 2. Light curves of the afterglow and SN component of GRB 200826A in the $g'r'i'H$ bands, after subtraction of the host-galaxy contribution. The data have been modeled with a smoothly broken power-law for the afterglow, and with a SN 1998bw template red-shifted to $z = 0.7486$ for the SN phase. In the g' and r' bands, we forced the individual SN light curve components to go through the most significant deep upper limit in each band to obtain upper limits on the potential SN luminosity. Note the g' band is offset by 1 mag for reasons of clarity. See Tab. 1, §2.4 and §3.3 for more information.

RESULTS

- LGRBs follow a strong cor- relation known as the “Amati Relation”
- Parameters reported by the Konus-*Wind* and *Fermi*/GBM teams were used
- the position in the Ep,i – Eiso plane may not be sufficient for classification

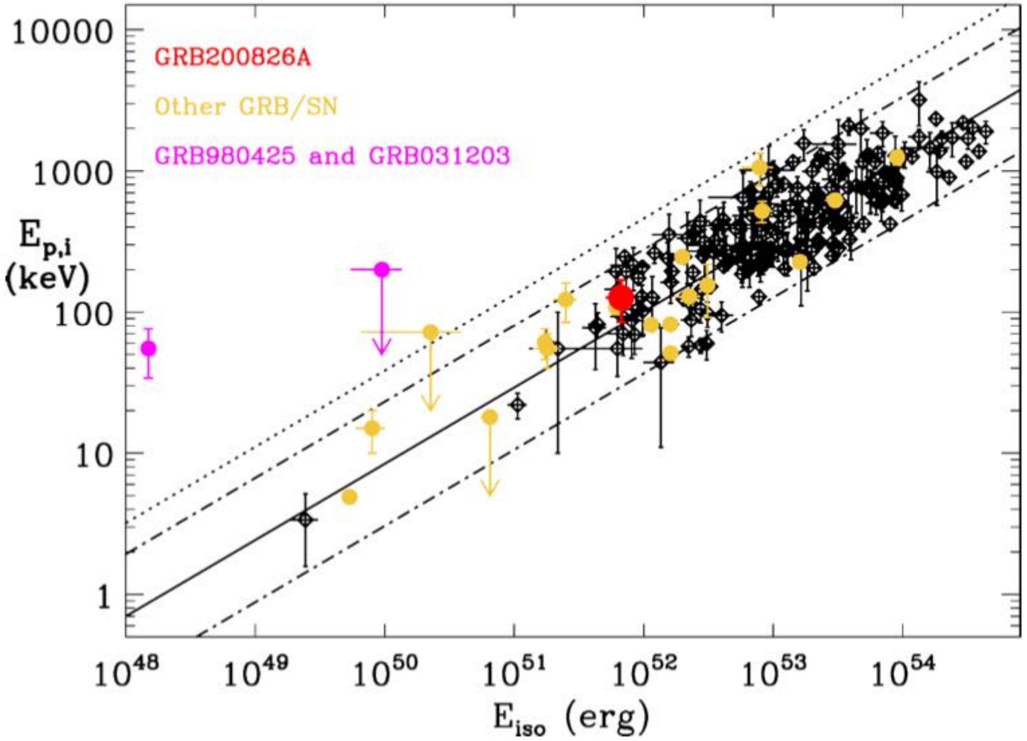


Figure 3. GRB 200826A (red) in the $E_{p,i} - E_{iso}$ plane. GRBs with an associated SN are highlighted in green, outliers in blue (see §3.1). GRB data is from Amati et al. (2019).

- energy-hardness (*EH*) parameter
- 95% cluster region of long bursts $T90,i$ – *EH* diagram
- Ambiguous
- GRB 201221D follow the Ep,i – $Eiso$ relation for LGRBs but are in the SGRB region in the $T90,i$ – *EH* diagram.

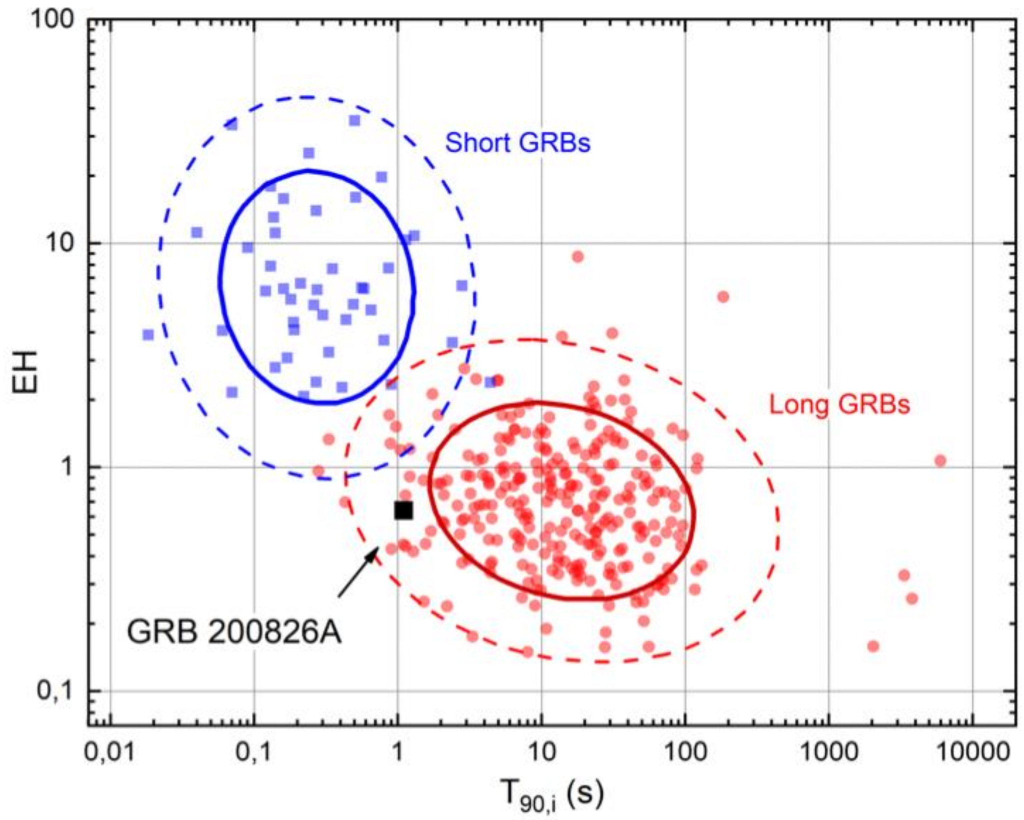


Figure 4. The $T_{90,i}$ – EH diagram for SGRBs (blue squares) and LGRBs (red circles) with corresponding cluster analysis results. 68% and 95% confidence regions are shown by bold solid and thin dashed curves. Data from Minaev & Pozanenko (2020a,b).

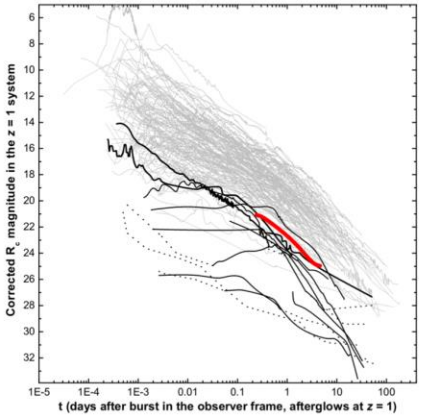


Figure 5. The optical afterglow of GRB 200826A (red line) compared with the sample of extinction-corrected afterglows shifted to $z = 1$ from Kann et al. (2010, 2011, 2022, in prep.). Hereby, time and magnitudes are given in the observer frame, but assuming all GRBs are at $z = 1$ in a perfectly transparent universe. Light gray are LGRBs, thicker black lines SGRBs with secure redshifts (solid lines connect detections, dashed lines connect upper limits). All magnitudes are Vega magnitudes. The afterglow of GRB 200826A lies intermediately between those of secure LGRBs and secure SGRBs.

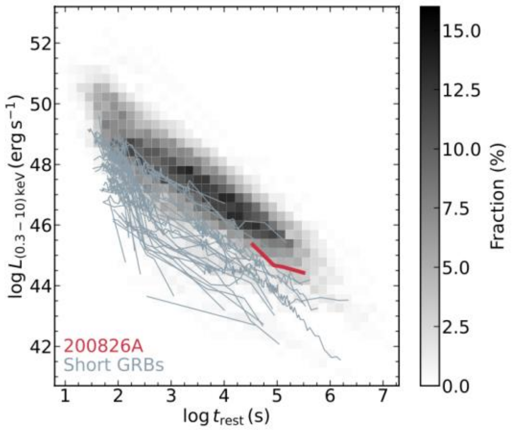


Figure 6. The X-ray afterglow of GRB 200826A (red line) in the context of the X-ray afterglows of 449 *Swift* GRBs with known redshifts. This event could be followed-up by Swift/XRT only after 10ks, but the few data points obtained show that the luminosity of GRB 200826A is in between the long and short populations. The grayscale on the right is used to convert a given luminosity and time into a fraction of bursts.

Afterglow

- Optical and in XRAY
- Faintest for LGRBs and brightest for SGBS
- afterglow luminosity is not a good method for discriminating between, nor understanding the nature of this burst.

The late bump as supernova emission

- sparse data precludes determining the evolution of the late bump seen in the transient light curve
- comparison can be made with other GRB-SNe to look for similarities
- GRB 980425/SN 1998bw, GRB 060218/SN2006aj , GRB 100316D/SN1010bh, GRB 130702A/SN 2013dx and GRB 161219B/SN 2016jca

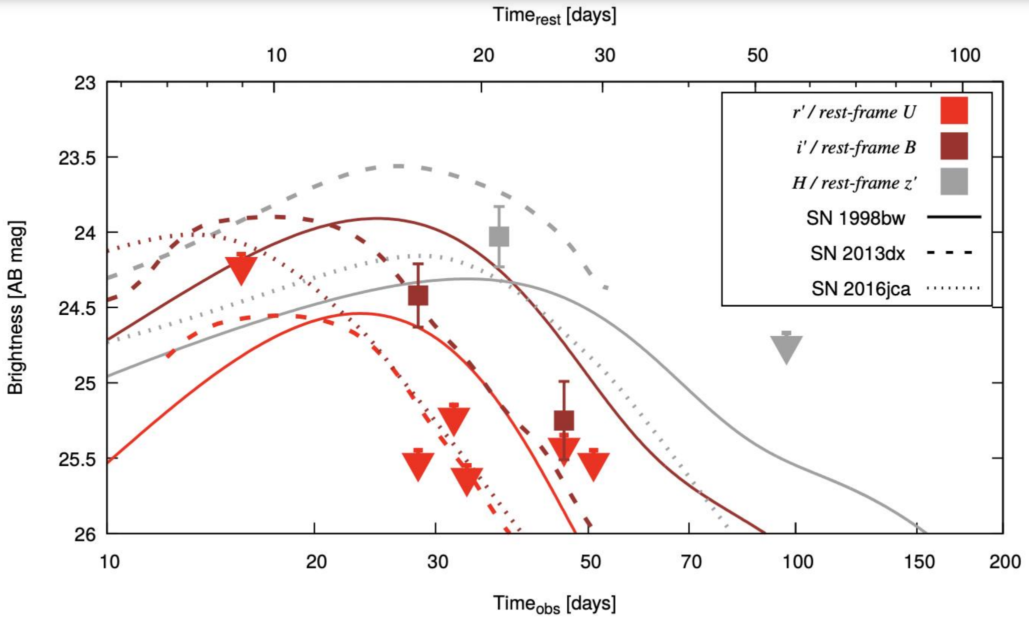
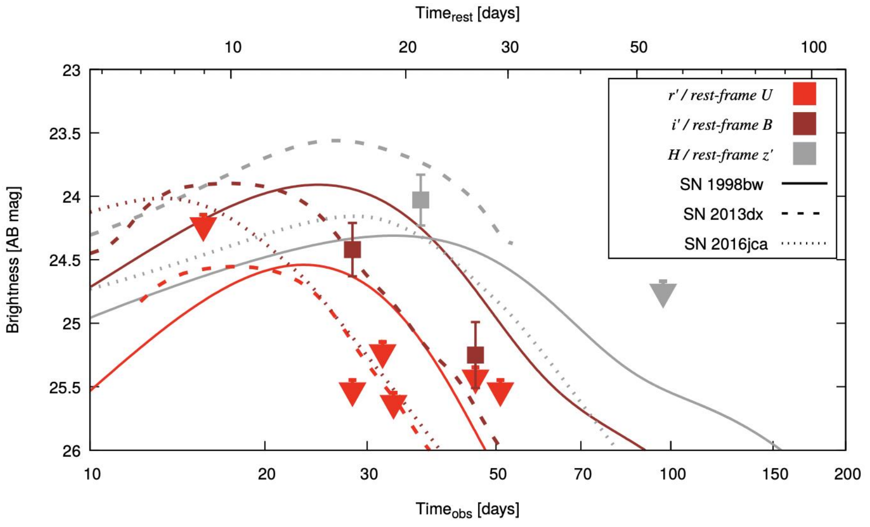


Figure 7. Light curve in *i'* and *H* bands after removing the host component via image subtraction (see Table 1). Only data after 10 d (observer frame) are shown. The data are corrected for Galactic extinction (see § 2.3). The SN light curve templates obtained from SN 1998bw, 2013dx, and SN 2016jca are shown for comparison and to stress the large range of variability and color of GRB-SNe (See §3.3). Downward-pointing triangles are upper limits.



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- SN associated with GRB 200826A is less than half as luminous as SN 1998bw in the same rest-frame band.
- In the rest frame B-band the suppression is also strong com-pared to SN 1998bw with ki′ = 0.56 ± 0.10. The rest-frame z′-band detection (observed H band) is, however, marginally brighter than SN 1998bw (kH = 1.18 ± 0.22).
- There is more common with the GRB 130702A/SN 2013dx
- When compared with the list of k values of Klose the k factor ranges between 0.5 and 2. This supports for a SN.

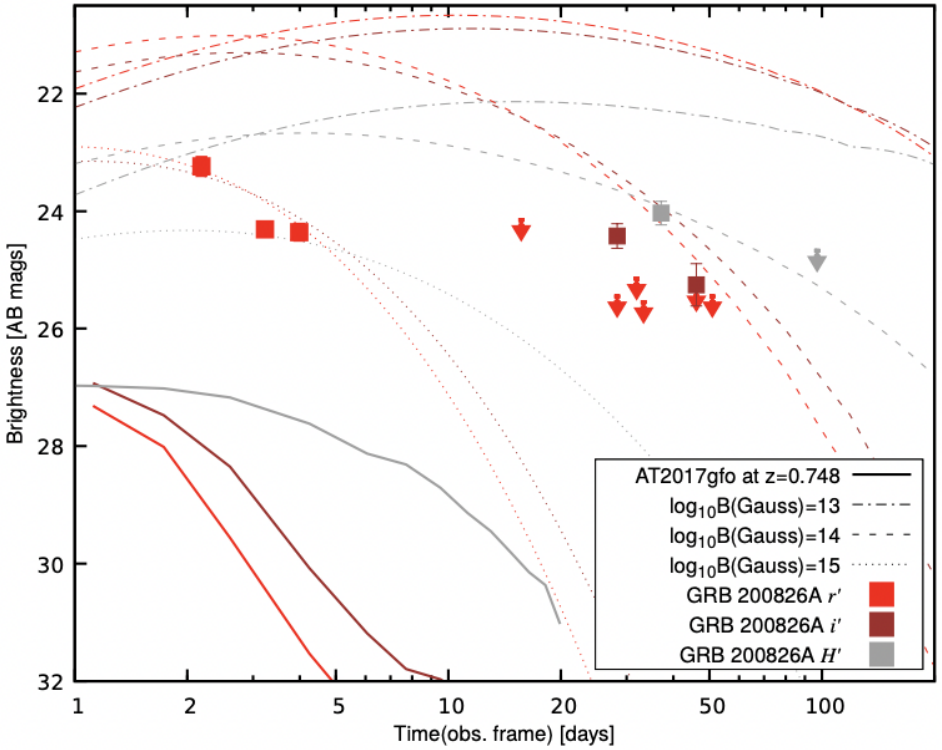
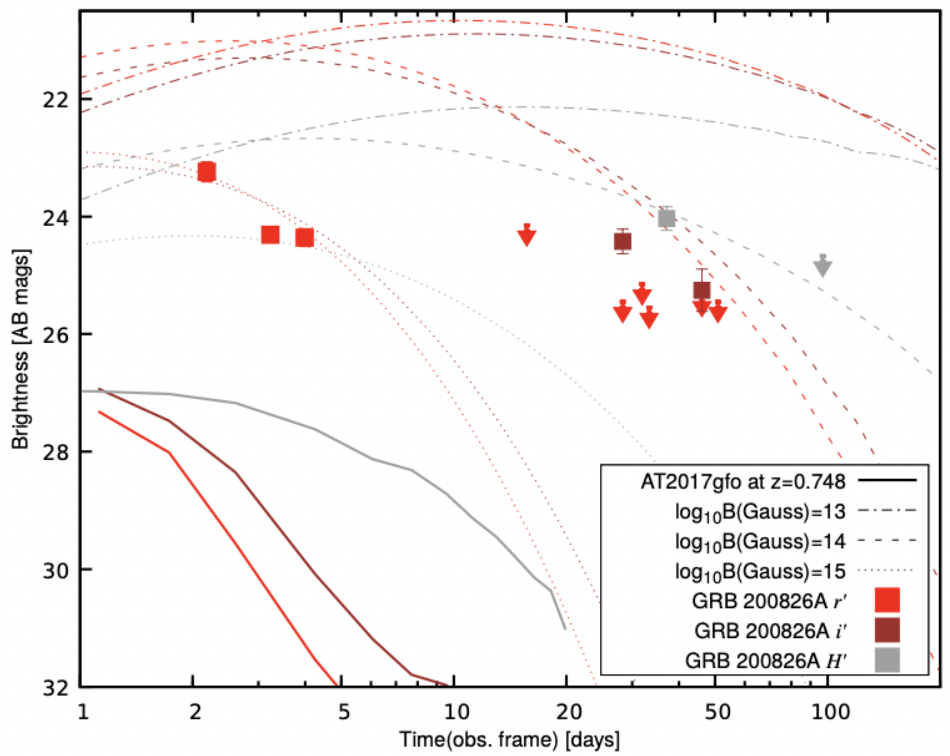


Figure 8. Light curves of GRB 200826A after host subtraction compared with the light curves of AT2017gfo (solid lines) from Rossi et al. (2020b) and with theoretical KN light curves boosted by a magnetar from Perego et al. (2017) with three different magnetic field strengths (dotted, dashed, dot-dashed lines; §3.4). Downward-pointing triangles are upper limits.

Kilonova

- late-time photometry of the transient is com- pared with the light curve of AT2017gfo, the KN associated with the binary NS merger GW 170817 and the SGRB 170817A
- The comparison shows that the luminosity of the transient was at all times at least 3 mag brighter than the peak luminosity of AT2017gfo
- Not so much the magnitude difference but the slower temporal evolution
- This was seen examining when the *B*-band detection (*i′* band) detection is close to maximum light.
  - It is more than 15 days from the peak in the KN

Magnetar



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- KN model presented in Perego was used and extended to consider spin-down energy injection
- spherically symmetric ejecta model
- $B \sim 10^{14}$G and $\varepsilon_{th} = 0.03$
- GOOD: The calculations suggest that the observed transient could be compatible with the late emission of a spin-down powered KN
- BAD:
  - No explanation for the red colour and *r*′ band suppression in UV
  - 10 d the KN is brighter than the observed data

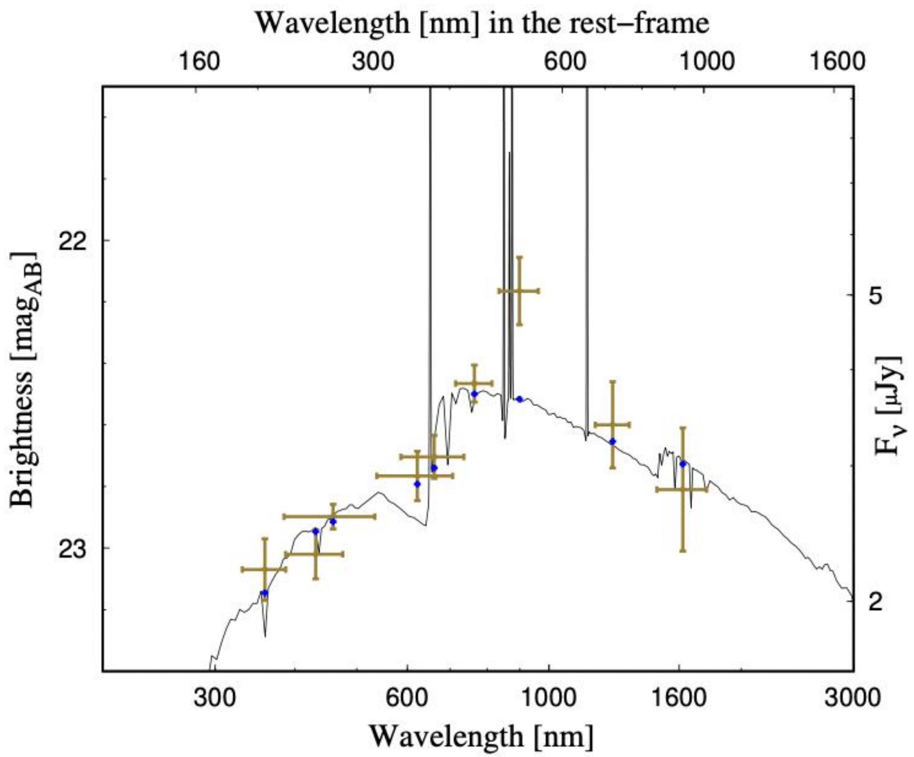

Figure 9. Le PHARE modeling discussed in §3.5 of the SED obtained from the final LBT/LBC $UR_C i'z'$, MAO B, LBT/MODS $g'r'$, LBT/LUCI J, and LBT/LUCI+SOUL H band imaging (see Table 1). The blue points indicate where the photometry would be placed according to the best-fit model and without contribution from emission lines.

HOST GALAXY

- Using the derived redshift as a fixed input, the optical/NIR SED of the host galaxy was modeled
- galaxy dominated by a young population with global dust reddening E(B-V) ~ 0.2 maG
- Low stellar mass log $M_*/M_\odot$ = 8.6 ± 0.2
- The B-band dust-corrected absolute magnitude is MB = −20.01 mag
- star-formation rate is SFR = 13.0+10.9 $M_\odot$/yr.

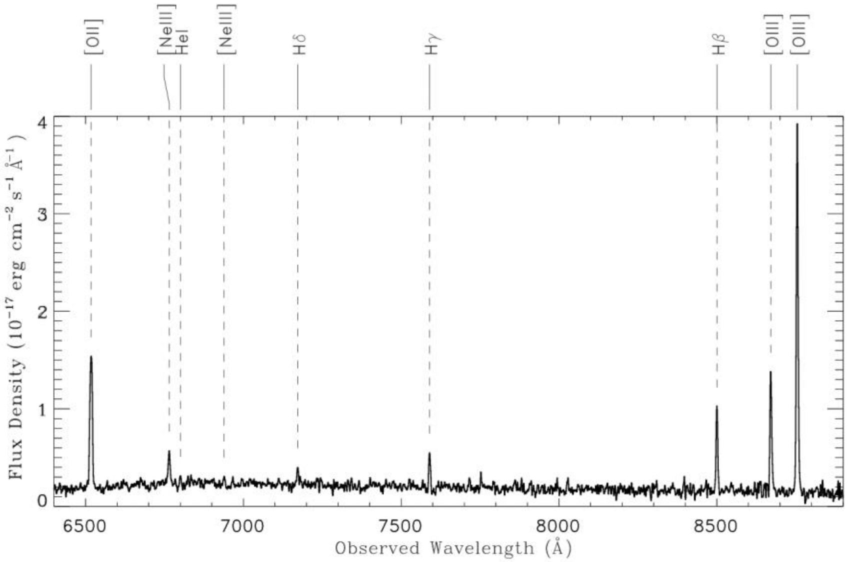

Figure 10. LBT/MODS observed spectrum of the host galaxy of GRB 200826A binned by 2.5 Å for presentation purposes. The detected emission lines are marked.

- A redshift of $z = 0.75$ simultaneous detection of the following emission lines: [O II], [O III] and [Ne III] doublets, He I λ3889, and Balmer Hδ λ4101, Hγ λ4340, and Hβ λ4861

- dust extinction is in agreement with the broad range of values found for LGRB hosts, also in comparison with the SFR
- It is different from the afterglow-derived negligible extinction, indicating that the GRB sight-line might be crossing a relatively dust-free region
- high SFR the highest measured so far in the LGRB host population
- The resulting sub-solar metallicity ($Z/Z_\odot \simeq 0.4$) is consistent with the value derived for the LGRB hosts at similar redshift
- GRB 200826A is characterized by a typical metallicity but larger than usual SFR and sSFR for a LGRB host.

THE END

- With the results we are faced with a GRB of short duration which exploded in a star-forming galaxy, with a moderately faint afterglow, emitted by a jet most likely propagating into a wind environment, and followed by a bump in the light curve whose colour and luminosity are typical for a GRB-SN. Thus we firmly classify this burst as a collapsar event.
- duration as an indicator of the source of a GRB, not so good
- the first detection of a SN with AO observations
- these future facilities will assess whether peculiar events like GRB 200826A are actually the result of the rich variety of the collapsar phenomenon