10.4 m GTC observations of the nearby VHE-detected GRB 190829A/SN 2019oyw

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ABSTRACT

Aims. Gamma-ray burst (GRB) 190829A (z = 0.0785) was detected by Fermi and Swift and also at very high energy (VHE) by the High-Energy Stereoscopic System (HESS) telescopes. The prompt emission displayed two emission episodes separated by a quiescent gap of ~40 s. We present the 10.4 m Gran Telescopio Canarias (GTC) observations of the afterglow of GRB 190829A and its underlying supernova. We also compare GRB 190829A to GRB 180728A, a GRB with similar behaviour, and discuss the implications on underlying physical mechanisms producing these two GRBs.

Methods. We present multi-band photometric data along with spectroscopic follow-up observations taken with the 10.4 m GTC telescope. Together with the data from the prompt emission, the 10.4 m GTC data are used to understand the emission mechanisms and possible progenitor.

Results. A detailed analysis of the multi-band observations of the afterglow requires the cooling frequency to pass between the optical and X-ray bands at early epochs. The afterglow then transitions to the underlying supernova (SN) 2019oyw, which dominates later on.

Conclusions. Although the prompt emission temporal properties of GRB 190829A and GRB 180728A are similar, the two pulses are different in the spectral domain. We find that SN 2019oyw associated with GRB 190829A is powered by Ni decay and is a Type Ic-BL SN. The spectroscopic and photometric properties of this SN are consistent with those observed for SN 1998bw, but evolved earlier.

Key words. gamma-ray burst: general – gamma-ray burst: individual: GRB 190829A – supernovae: individual: SN 2019oyw

1. Introduction

Multiwavelength observations of nearby (redshift z ≤ 0.2) long-duration gamma-ray bursts (GRBs) and their association with Type Ic supernovae with broad lines (Type Ic-BL SNe) have revolutionised our understanding of the explosion mechanisms and environments of massive stars across the electromagnetic spectrum (Woosley 1993; Hjorth & Bloom 2012). Some of these nearby GRBs also belong to the classes of low/intermediate-luminosity GRBs and ultra long-duration GRBs, which are outliers that have revealed crucial observational evidence that is used to distinguish between potential powering mechanisms and progenitors (Georgy et al. 2009; Dessart et al. 2017). As...
underlying SN features are faint and diluted by their host galaxies, 8–10 m class optical–near-infrared (NIR) facilities play a vital role in extracting information (Pandey 2013; Cano et al. 2014). So far, only a handful of nearby GRBs have been found to have associated Ic-BL SNe: GRB 980425/SN 1998bw (z = 0.00867; Galama et al. 1999), GRB 030329/SN 2003dh (z = 0.16867; Stanek et al. 2003), GRB 031203/SN 2003lw (z = 0.10536; Malesani et al. 2004), GRB 060218/SN 2006aj (z = 0.03342; Mirabal et al. 2006; Modjaz et al. 2006), GRB 100316D/SN 2010bh (z = 0.0592; Chornock et al. 2010), GRB 130702A/SN 2013dx (z = 0.145; D’Elia et al. 2015), GRB 171205A/SN 2017iuk (z = 0.0368; Izzo et al. 2019), and GRB 180728A/SN 2018fp (z = 0.117; Izzo et al. 2018).

GRB 190829A belongs to a subclass of long bursts whose prompt emission light curves show double episodes: the first being a fainter, harder pulse (a precursor), and the second, following a quiescent phase, being a significantly brighter and softer main pulse (Chand et al. 2020; Coppi et al. 2020). These events provide a unique opportunity to probe deeper into the nature of the central engine of GRBs (Hu et al. 2014; Chand et al. 2020; Fraija et al. 2020) emitting even at very high energy (VHE; de Naurois & H. E. S. Collaboration 2019; Sahu & Fortín 2020). The proximity of GRB 190829A also provided the opportunity to discover the underlying SN (Bolmer et al. 2019; Lipunov et al. 2019; Perley & Cockeram 2019; Terreran et al. 2019; Dichiara et al., in prep.), posing the natural question of whether such double-episodic prompt emission GRBs have a particular connection with progenitor models invoking SN features (Woosley & Bloom 2006; Davies et al. 2007). In the Fermi era, Lan et al. (2018) studied a large sample (101) of such GRBs. Among these, there are only 11 bursts with known redshifts. In this sample, GRB 180728A is the nearest burst (z = 0.117) also found to be associated with SN 2018fp (Izzo et al. 2018; Selsing et al. 2018; Wang et al. 2019) and exhibiting remarkable similarity with the properties of GRB 190829A. Therefore, observed prompt emission properties with a significant quiescent temporal gap at Swift/BAT and Fermi/GBM frequencies for these two nearby and SN-connected GRBs prompted us to perform a joint prompt emission analysis using a sophisticated tool, the Multi-Mission Maximum Likelihood framework (3ML)1 to explore their prompt spectral properties systematically.

Very high energy photons from GRB 190829A were detected by the High Energy Stereoscopic System (H.E.S.S.; de Naurois & H. E. S. Collaboration 2019) making this burst the nearest to be seen at these high frequencies. Many ground-based telescopes searched for counterparts soon after the Swift and Fermi gamma-ray detection and follow-up observations at other wavelengths were reported. Using the 10.4 m Gran Telescopio Canarias (GTC, Canary Islands, Spain) optical-NIR observations and a redshift of z = 0.0785 ± 0.005 were reported (Valeev et al. 2019), thus triggering larger facilities to follow up the event. This follow-up later led to the discovery of the re-brightening of the underlying transient AT 2019oyw/SN 2019oyw (de Ugarte Postigo et al. 2019; Lipunov et al. 2019b; Terreran et al. 2019; Volnova et al. 2019). Afterglow observations at radio frequencies were also reported by Chandra (2019), Laskar et al. (2019), and Rhodes et al. (2020).

In this paper, we present the analysis of the prompt emission properties of GRB 190829A and GRB 180728A. We also discuss our late-time photometric and spectroscopic observations of GRB 190829A/SN 2019oyw using the 10.4 m GTC telescope and their comparison with other well-studied similar events. This paper is organised as follows. In Sect. 2, we present the prompt observations and data analysis of GRB 190829A and GRB 180728A. We then focus on the optical spectroscopic observations of GRB 190829A and their analysis in Sect. 3. In Sect. 4, we present the optical photometric observations of GRB 190829A. Finally, we discuss and conclude in Sect. 5. All the uncertainties are quoted at the 1σ level throughout this paper, unless otherwise mentioned. We assume the Hubble constant H0 = 70 km s⁻¹ Mpc⁻¹ and density parameters Ωm = 0.27 (Jarosik et al. 2011).

2. Prompt emission properties: GRB 190829A and GRB 180728A

The Fermi satellite first triggered on GRB 190829A on 29 August 2019 at 19:55:53 UT (T0, Fermi GBM Team 2019). After 51 s, the Burst Alert Telescope (BAT) onboard Swift also triggered and located this event at 19:56:44 UT with a duration of T090 = 58.2 ± 8.9 s (Dichiara et al. 2019; Lien et al. 2019). Both Fermi/GBM and Swift/BAT reported the temporal behaviour of this GRB as having a double-peaked structure. Konus-Wind also detected two emission episodes in the waiting mode with a total duration of ~61.8 s. The time-integrated spectrum of the first episode using Konus-Wind data in the 20 keV to 2 MeV range was best described using a power law with an exponential cut-off model with $E_c = 759^{+282}_{-281}$ keV and a spectral slope index of $\alpha = -1.33^{+0.30}_{-0.23}$ (Tsvetkova et al. 2019). The X-ray telescope (XRT) onboard Swift began observing the field 97.3 s after the BAT trigger and found a bright, fading uncatalogued X-ray source and continued to monitor it until four months after the trigger. The astrometrically corrected X-ray position is RA(J2000) = 02h58m10s,57s, Dec(J2000) = -08◦57′30′′,1 with an uncertainty of 1′8 (90% confidence radius; Evans et al. 2019).

Observations by the Gamma-ray Burst Monitor (GBM, Meegan et al. 2009) onboard the Fermi satellite were obtained from the GBM archive2 and analysed using the 3ML software. We used data from three of the twelve sodium iodide (NaI) detectors with the strongest detections and one of the two bismuth germanate (BGO) detectors with the best detection (if available). We used the data from Fermi along with Swift/BAT data to examine the temporal and spectral prompt emission properties of GRB 190829A and GRB 180728A. These two nearby GRBs show similar temporal behaviour consisting of two episodes: a weak precursor and a main burst, separated by a quiescent gap. This rarely observed temporal behaviour prompted us to compare the two. To perform the time-averaged and time-resolved spectral analysis, we reduced the time-tagged event (TTE) mode data of GBM using the gtburst4 software as they have high time precision in all 128 energy channels. We retrieved the Swift/BAT light curve and spectrum following the standard procedure3, and fitted spectrum with the Band function (Band et al. 1993) and various other models (Blackbody, Cut-off Power law, Power law or their combinations) based upon the model fit, residuals of the data, and their parameters. The results based on

1 https://github.com/threeML/threeML
2 $T_{90}$ is the burst duration defined as the time interval over which 5% to 95% of the counts are accumulated.
3 https://beasarc.gsfc.nasa.gov/W3Browse/fermi/fermigbrst.html
4 https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/gtburst.html
5 https://www.swift.academynet/analysis/bat/index.php
the analysis described above are presented in Figs. 1 and 2, and the values are provided in Table 1. The episodes are identified with the Bayesian Blocks method (Scargle 1998).

For GRB 190829A, the time-averaged spectrum of the precursor (first episode) is best described as a power law with an exponential high-energy cut-off function with a photon index of $-1.56^{+0.17}_{-0.08}$ and a cut-off energy corresponding to the peak energy, $E_p = 123.51^{+56.14}_{-31.61}$ keV. On the contrary, the main episode is best fit by a Band function with $E_p = 11.23^{+0.30}_{-0.20}$ keV, low-energy spectral index ($\alpha$) = $-0.23^{+0.26}_{-0.24}$ and high-energy spectral index ($\beta$) = $-2.53^{+0.01}_{-0.01}$, consistent with Lesage et al. (2019). However, in the case of GRB 180728A, the precursor episode is best described by a power law with photon index equal to $-2.45^{+0.04}_{-0.03}$ whereas the main episode is best described with a band+ b1 ackbody component with $E_p = 102.70^{+12.32}_{-12.00}$ keV, $\alpha = -1.50^{+0.01}_{-0.01}$, $\beta = -2.91^{+0.12}_{-0.12}$ and the temperature (kT) = $5.61^{+0.09}_{-0.10}$ keV.

3. 10.4 m GTC spectroscopic observations of GRB 190829A/SN 2019oyw

Spectroscopic observations of GRB 190829A were triggered at the 10.4 m GTC (+OSIRIS) soon after the burst and a set of spectroscopic observations were acquired (see Table 2). We obtained optical spectroscopy covering the range 3700–10 000 Å from 0.32 to 4.09 d post-burst (in the rest-frame), in order to monitor the optical evolution of GRB 190829A/SN 2019oyw; see Table 2. To improve the signal-to-noise ratio (S/N), the spectra at nearby epochs and their respective phases were averaged. In the following sections, the redshift determination and spectral analysis of the underlying supernova along with the comparison to other similar nearby events are described.

3.1. Redshift determination

The Ca H and K absorption line doublet (3933.664 and 3968.470 Å) was identified in the observed spectrum (see Fig. 3) which allowed us to determine a redshift of $z = 0.0785 \pm 0.0005$ (Valeev et al. 2019). Emission lines (O III, Hα, Hβ) of the underlying galaxy are also visible at the same redshift, thus supporting the physical association between GRB 190829A and the SDSS galaxy J025810.28-085719.2, as first proposed by Dichiara et al. (2019). In order to achieve the maximum spectral resolution at bluer wavelengths we used the R1000B (and especially the R2500U) grisms on 30 August 2019 in order to constrain the redshift.

3.2. Spectroscopic evolution of GRB 190829A/SN 2019oyw

The upper panel of Fig. 4 shows the spectral evolution. Multiple spectra observed at similar epochs were co-added to improve the S/N. All the spectra were de-reddened for the Galactic and host extinction values (Schlafly & Finkbeiner 2011; Chand et al. 2020) and also shifted to the rest-frame wavelength. Because of poor S/N, the smoothing of spectra was done using the Savitzky–Golay method by fitting the second-order polynomial function for each $\lambda$ in the range $\lambda = \lambda_0/5 < \lambda < \lambda_0 + \lambda_0/5$, as described by Quimby et al. (2018). All the spectra were flux calibrated by scaling them to the observed photometric flux density values (shown with black circles in Fig. 4) wherever possible.

As shown in Fig. 4, the first two spectra (at 0.32 and 1.29 d post-burst) are featureless and typical of those expected from GRB afterglows, but a transition from the afterglow (AG) to the underlying SN is clearly illustrated with broad lines as emerging features in the later (after $\sim2.23$ d) optical spectra of GRB 190829A/SN 2019oyw, indicating high velocities already at this stage. The spectrum at 0.32 d shows a power-law behaviour, whereas the spectra at 1.29, 2.23, and 4.09 d appear to deviate from the power law and can be constrained with the blackbody function implying blackbody temperatures ($T_{BB}$) of $\sim5100$, $\sim4660$, and $\sim4575$ K, respectively (shown with cyan colour in the upper panel of Fig. 4). The associated SN 2019oyw spectrum at 4.09 d appears to have Si II (\lambda6355 Å) and Ca II NIR [(8498 Å, 8542 Å, and 8662 Å) spectral features (blue arrows) at higher velocities, which are typical of those seen in Type Ic-BL SNe.

In the bottom panel of Fig. 4, the spectrum of SN 2019oyw taken at $\sim4.09$ d is compared with other GRB/SNe spectra: SN 1998bw (Patat et al. 2001), SN 2006aj (Pian et al. 2006), and SN 2010bh (Bufano et al. 2012). For comparison, all the spectra were normalised, de-reddened (Galactic + host) and shifted to the rest-frame wavelength. It is apparent that the observed broad spectral features for GRB 190829A/SN 2019oyw are similar to those observed in the other SNe. The spectrum of SN 2019oyw taken at $\sim4.09$ d bears a close resemblance to the spectrum of SN 1998bw taken at 7 d. This time difference between the spectra of
the two SNe indicates that SN 2019oyw evolved faster than SN 1998bw.

4. 10.4 m GTC photometric observations of GRB 190829A/SN 2019oyw

Photometric observations of GRB 190829A/SN 2019oyw obtained by the 10.4 m GTC telescope show that this GRB lies in the outskirts of the host; see Fig. 5. Multi-band optical photometry observations obtained for GRB 190829A/SN 2019oyw were measured using aperture photometry through standard procedures after image subtraction. A model for the light profile of the galaxy was determined in order to estimate the contribution from the host assuming a symmetric light distribution, and we subtracted this model from the images containing the GRB/SN in order to obtain accurate photometric measurements. The photometry was calibrated against a number of stars from the SDSS catalogue (Alam et al. 2015) in the field of view. These calibration stars were specifically chosen because they are isolated, not saturated, and are in a constant background. The derived AB magnitudes in SDSS (ugriz) filters for the afterglow/SN 2019oyw are provided in Table 3.

The optical photometric observations of GRB 190829A/SN 2019oyw spanning from 0.29 to 40.33 d after the trigger are shown in Fig. 6 along with the XRT light curves (at 10 keV) in the observer frame. The magnitudes have been corrected for Galactic as well as the host galaxy extinction using $E(B-V) = 0.049$ mag and 1.04 mag, respectively. The host-galaxy extinction is adopted from the best-fit model of Chand et al. (2020) obtained for the Small Magellanic Cloud (SMC) extinction law. The plotted ugriz light curves of GRB 190829A/SN 2019oyw are contributions of the AG and the associated SN, whereas the constant flux contribution from the host galaxy has already been removed using the template subtraction technique. Late-time $i$-band (in black) data (up to ~40 d after the burst) for GRB 190829A/SN 2019oyw clearly show the expected SN signature with a late-time bump peaking at ~20 d. The light curves in the $g, r, i, z$-filters up to ~2.3 d post burst were individually fitted with a single power-law model. The temporal flux decay indices in each of the four filters were determined to be $\alpha_g = 1.77 \pm 0.08$, $\alpha_r = 1.45 \pm 0.01$, $\alpha_i = 1.53 \pm 0.13$, and $\alpha_z = 1.25 \pm 0.01$. To extract the afterglow contribution from the entire $i$-band GTC dataset, we used the flux temporal decay index determined in the $i$ filter measured up to ~2.3 d post burst. We also use the value of $\alpha_i$ for subsequent analysis as this value is close to the average value of the decay indices obtained using all four individual filters.

4.1. Light-curve evolution

Using the temporal decay indices determined in Sect. 4, we extrapolated the AG contribution up to ~41 d (see Fig. 6, cyan dashed line) and subtracted it from the $i$-band light curve to obtain the light curve of the associated SN (in lime green). SN
2019oyw appears to emerge at very early phases (from ~3 d) and reaches peak magnitude at ~20 d. The X-ray light curve (at 10 keV) shows a late-time bump at ~20 d, contemporaneous with the SN bump (see Fig. 6 in red); however, we do not see any blackbody evolution at the four epochs of the joint spectral energy distributions (SEDs; see Fig. 7). Interestingly, such late time XRT bumps at 10 keV were also observed in the cases of GRB 171205A (Izzo et al. 2019) and GRB 180728A (Wang et al. 2019; Rueda et al. 2020). Based on observations, the progenitors and powering mechanisms for these nearby rare events are constrained to the plausible models such as ‘Colllapsar’ (Woosley 1993) and the binary-driven hypernova model (Ruffini et al. 2001, 2016). A separate detailed investigation is underway to obtain a detailed understanding of this subclass of nearby bursts, namely GRB 171205A/SN 2017iuk, GRB 180728A/SN 2018fip, and GRB 190829A/SN 2019oyw, with noticeable late-time X-ray bumps (at 10 keV) along with evolution of the XRT photon indices ($\Gamma_{\text{XRT}}$).

### 4.2. SED evolution of GRB 190829A

Near-simultaneous optical and X-ray SEDs were constructed at four different epochs covering the afterglow decay phase and the peak of SN 2019oyw; see times indicated by cyan shaded bands in Fig. 6. The SEDs at XRT frequencies were collected from the Swift/XRT page\(^6\) and modelled using XSPEC to determine the spectral indices. The 10.4 m GTC extinction corrected SEDs were fitted using a single power-law model as discussed above. The X-ray temporal decay index using data taken at 10 keV was found to be $\alpha_{\text{X-ray}} \sim 1.34^{+0.06}_{-0.06}$ between $\sim3 \times 10^8$ and $\sim4 \times 10^8$ s. This temporal index was used along with those estimated at optical frequencies $\alpha_{\text{opt}}$ to study the evolution of the SEDs. The details of the four epochs of SEDs and their corresponding indices for the different segments of optical and X-ray data (SED 1 - SED 4) are listed in Table 4. We used the closure relations $\alpha_{\text{opt}} = \beta_{\text{opt}}$, $\alpha_{\text{X-ray}} = \beta_{\text{X-ray}}$ (Sari et al. 1998; Gompertz et al. 2018) to constrain the model and location of the cooling-break

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\(^6\) https://www.swift.ac.uk/xrt_spectra/

### Table 1. Comparison between different models used for the episode-wise time-averaged joint spectral analysis of Fermi/GBM and Swift/BAT data of GRB 180728A and GRB 190829A.

| GRB 180728A | Episode | Time (s) | Model | Log(Likelihood) | AIC $^{(a)}$ | BIC $^{(b)}$ |
|-------------|---------|----------|-------|----------------|-------------|-------------|
| 1           | $-1.70 \sim 1.31$ | PL* | 1475.81 | 2961.76 | 2981.78 |
|             |         | CPL | 1475.81 | 2963.82 | 2987.81 |
|             |         | Band | 1471.44 | 2957.15 | 2985.11 |
|             |         | PL+BB | 1475.81 | 2965.89 | 2993.85 |
|             |         | CPL+BB | 1487.62 | 2985.39 | 3005.41 |
|             |         | Band+BB | 1471.24 | 2960.92 | 2996.77 |

| GRB 190829A | Episode | Time (s) | Model | Log(Likelihood) | AIC $^{(a)}$ | BIC $^{(b)}$ |
|-------------|---------|----------|-------|----------------|-------------|-------------|
| 1           | $-0.64 \sim 8.06$ | PL | 2268.45 | 4549.07 | 4574.61 |
|             |         | CPL | 2261.82 | 4537.84 | 4567.62 |
|             |         | Band | 2262.13 | 4540.54 | 4574.54 |
|             |         | PL+BB | 2264.48 | 4545.24 | 4579.24 |
|             |         | CPL+BB | 2261.43 | 4541.21 | 4579.43 |
|             |         | Band+BB* | Unconstrained | Unconstrained | Unconstrained |

| 2           | $47.04 \sim 62.46$ | PL | 2182.14 | 4374.42 | 4394.47 |
|             |         | CPL | 2175.54 | 4363.29 | 4387.31 |
|             |         | Band* | 2147.17 | 4308.61 | 4336.60 |
|             |         | PL+BB | 2150.16 | 4314.60 | 4342.59 |
|             |         | CPL+BB | 2148.33 | 4313.02 | 4344.97 |
|             |         | Band+BB | 2142.71 | 4303.85 | 4339.75 |

Notes. In the model column, the best-fit model is marked with a star. The PL, CPL, and BB correspond to the power law, cut-off power law and blackbody models, respectively. $^{(a)}$Akaike information criterion, $^{(b)}$Bayesian information criterion.

### Table 2. GRB 190829A/SN 2019oyw spectroscopic observation log taken with the 10.4 m GTC.

| MJD | Phase (d) | Range (Å) | Detector | Exp time (s) |
|-----|----------|-----------|----------|--------------|
| 58725.120411 | 0.293 | 5100–10000 | OSIRIS+R1000R | 600 |
| 58725.127789 | 0.301 | 3630–7500 | OSIRIS+R1000B | 600 |
| 58725.180198 | 0.375 | 3440–4610 | OSIRIS+R2500U | 1200 × 2 |
| 58725.216805 | 0.393 | 3630–7500 | OSIRIS+R1000B | 1200 |
| 58726.202041 | 1.387 | 3630–7500 | OSIRIS+R1000B | 900 × 2 |
| 58726.223595 | 1.397 | 5100–10000 | OSIRIS+R1000R | 600 |
| 58727.230284 | 2.405 | 3630–7500 | OSIRIS+R1000R | 600 |
| 58727.241158 | 2.414 | 5100–10000 | OSIRIS+R1000R | 600 |
| 58729.228917 | 4.407 | 3630–7500 | OSIRIS+R1000R | 750 × 2 |
| 58729.246993 | 4.420 | 5100–10000 | OSIRIS+R1000R | 600 |
4.3. SN 2019oyw properties and comparisons

The extracted light curve of SN 2019oyw in absolute magnitude (in black) is plotted in the rest-frame; see Fig. 8. The absolute magnitudes are calculated from de-reddened apparent magnitudes and are corrected for cosmological expansion (Hogg et al. 2002) to get the rest-frame magnitudes, as described in Kumar et al. (2020). The $i$-band light-curve evolution of SN 2019oyw (see Fig. 8, black solid line) is compared with other well-studied low-redshift GRB-SNe such as SN 1998bw (red; Galama et al. 1998), SN 2006aj (blue; Bianco et al. 2014), and SN 2010bh (green; Cano et al. 2011). The light curves of these comparison SNe have been corrected for Galactic as well as host galaxy extinction using values taken from Cano (2013) and references therein.

Light curves of the four SNe connected to GRBs (see Fig. 8) are fitted with low-order polynomials to estimate the peak absolute magnitudes ($M_i$) and the times taken by the SNe to rise and fall by 1 mag from the peak ($t_{\text{rise}}^{\text{1mag}}$ and $t_{\text{fall}}^{\text{1mag}}$, respectively). The peak magnitude of SN 2019oyw is $M_i = -19.04 \pm 0.01$ mag, which is brighter than SN 2006aj ($M_i = -18.36 \pm 0.13$ mag) and SN 2010bh ($M_i = -18.58 \pm 0.08$ mag), and more similar to the peak absolute magnitude of SN 1998bw ($M_i \sim -18.95$ mag).
The calculated value of $\rho_{1,\text{mag}}$ for SN 2019oyw is found to be $13.32 \pm 0.04$ d, which is lower in comparison to those estimated for other GRB-SNe, namely SN 1998bw ($\sim 24.8$ d), SN 2006aj ($\sim 20.3$ d), and SN 2010bh ($\sim 17.1$ d). This indicates a steeper post-peak decay rate for SN 2019oyw as can also be inferred from the faster spectral evolution in Sect. 3.2. Examining the value of $\rho_{1,\text{mag}}$ for SN 2019oyw ($9.67 \pm 0.02$ d), we find it to be most similar to SN 2006aj ($\sim 8.80$ d) and SN 2010bh ($\sim 9.0$ d), whereas it is lower in comparison to that observed in the case of SN 1998bw ($\sim 13.3$ d). We also estimate the value of the ejected nickel mass ($M_{\text{Ni}}$) as $0.5 \pm 0.1 M_\odot$ for GRB 190829A/SN 2019oyw using the relation between $M_{\text{peak}}$ and $M_{\text{Ni}}$ given by Lyman et al. (2016). The discussed light curves of the four GRB-SNe have also been compared with the $56\text{Ni} \rightarrow 56\text{Co}$ theoretical decay curve. SN 2019oyw appears to be consistent with this decay curve (shown with a black dotted line) soon after the peak.

As studied by Wheeler et al. (2015) (see also Cano 2013), we can estimate the ejecta mass ($M_{\text{ej}}$) and kinetic energy ($E_{\text{k}}$) of the SN using the photospheric velocity near to the peak and rise time (see Eqs. (1) and (3) of Wheeler et al. 2015). SN 2019oyw exhibits a rise time ($t_i$, i.e. the time taken from the GRB detection to the SN peak time in the i-band) of $19.19 \pm 0.25$ d. We are unable to estimate the photospheric velocity ($v_{\text{ph}}$) for SN 2019oyw due to the absence of late time spectral coverage. Therefore, we use the average value of photospheric velocity ($\sim 20000 \pm 2500$ km s$^{-1}$) of GRB/XRF-SNe estimated by Cano (2013). For SN 2019oyw, using $t_i$ and $v_{\text{ph}}$ we obtain $M_{\text{ej}} = 5.67 \pm 0.72 M_\odot$ and $E_{\text{k}} = (13.55 \pm 5.08) \times 10^{51}$ erg. For this analysis, the fiducial optical opacity $\kappa = 0.1 \text{cm}^2 \text{g}^{-1}$ and the fiducial gamma-ray opacity $\kappa_{\gamma} = 0.03 \text{cm}^2 \text{g}^{-1}$ are adopted as suggested by Wheeler et al. (2015). The estimated values of $M_{\text{ej}}$, $M_{\text{Ni}}$, $E_{\text{k}}$ and $E_{\text{ph}}$ for SN 2019oyw are in close agreement with those estimated for SN 1998bw by Nakamura et al. (2001). For SN 2019oyw, the $E_{\text{ph}}/M_{\text{ej}}$ is also highly consistent with the values estimated by Lyman et al. (2016), Cano et al. (2017), and Pandey et al. (in prep.).

5. Results and discussion

The prompt emission light curve of GRB 190829A, consisting of two emission episodes separated by a quiescent gap, is found to be similar to that exhibited by another nearby GRB 180728A. A time-averaged and time-resolved spectral analysis of the double-episode prompt emission using Swift/BAT and Fermi/GBM data for GRB 190829A and GRB 180728A reveals diverse $E_{\gamma}$ and $\alpha$ evolution posing a challenge to the proposed progenitor models. For GRB 190829A, the low-energy spectral index ($\alpha$) overshoots the synchrotron limits in later time bins, which poses a problem for synchrotron models, whereas for GRB 180728A the evolution of $\alpha$ remains within the synchrotron limit.

We also present 10.4 m GTC spectroscopy (0.32 to 4.09 d post burst, in the rest-frame) and the redshift determination for GRB 190829A, a VHE-detected GRB. Our spectrum taken as early as 0.32 d shows a featureless power-law behaviour as expected for GRB afterglows, whereas the spectrum taken at a later epoch (4.09 d post burst) shows the type Ic-BL broad absorption features (Si II and Ca II NIR lines) indicative of higher velocity outflows as reported by de Ugarte Postigo et al. (2019). Thermal evolution of the spectra at three later epochs shows decreasing photospheric temperatures from $\sim 5100–4575$ K, typical of those observed in other similar SNe (Cano et al. 2017). Spectroscopically, around 4.09 d post burst, the underlying SN closely resembles GRB 980425/SN 1998bw.

The host-subtracted 10.4 m GTC $ugriz$ band photometry was used to construct the light curves from 0.27 to 37.99 rest-frame days after burst. These clearly show a power-law decay nature typical of that observed in GRB afterglows until $\sim 2.3$ d post burst.

### Table 3. Optical and photometric data of GRB 190829A/SN 2019oyw in SDSS $u$, $g$, $r$, $i$, and $z$-bands obtained with the 10.4 m GTC.

| MJD     | Phase (d) | Exp time (s) | Filter | mag (AB) | error (mag) |
|---------|-----------|--------------|--------|----------|-------------|
| 58725.195050 | 0.365 | 120 | u | 21.77 | 0.05 |
| 58726.186209 | 1.381 | 120 x 4 | u | $>22.83$ | – |
| 58727.204482 | 2.377 | 120 x 5 | u | $>23.28$ | – |
| 58728.229954 | 3.400 | 120 | u | $>23.65$ | – |
| 58729.203136 | 4.376 | 120 x 5 | u | $>23.64$ | – |
| 58725.196004 | 0.367 | 60 | g | 21.08 | 0.05 |
| 58726.184473 | 1.382 | 120 x 2 | g | 25.36 | 0.05 |
| 58727.212898 | 2.385 | 120 x 3 | g | 25.04 | 0.04 |
| 58728.231701 | 3.403 | 120 x 3 | g | 23.95 | 0.06 |
| 58729.211539 | 4.383 | 120 x 3 | g | 24.64 | 0.09 |
| 58725.190825 | 0.368 | 30 | r | 19.68 | 0.01 |
| 58726.191965 | 1.364 | 60 x 2 | r | 21.75 | 0.06 |
| 58727.224253 | 2.396 | 180 | r | 22.60 | 0.03 |
| 58728.236767 | 3.407 | 120 | r | 22.94 | 0.03 |
| 58729.222909 | 4.394 | 60 x 2 | r | 22.59 | 0.06 |
| 58725.115196 | 0.287 | 10 x 3 | i | 18.40 | 0.02 |
| 58726.176400 | 0.354 | 50 | i | 18.79 | 0.01 |
| 58726.183430 | 1.382 | 60 x 2 | i | 20.73 | 0.05 |
| 58727.217984 | 2.388 | 120 | i | 22.34 | 0.06 |
| 58728.238499 | 3.409 | 120 | i | 22.30 | 0.02 |
| 58729.216606 | 4.387 | 120 | i | 22.15 | 0.08 |
| 58732.158872 | 7.331 | 30 x 3 | i | 22.00 | 0.04 |
| 58736.180631 | 11.35 | 30 x 2 | i | 21.08 | 0.03 |
| 58739.131398 | 14.30 | 30 x 2 | i | 20.76 | 0.09 |
| 58754.138870 | 29.31 | 60 x 2 | i | 21.23 | 0.02 |
| 58765.162492 | 40.33 | 60 | i | 22.48 | 0.01 |

Notes. a)Time after the burst, b)Galactic extinction corrected.
(between 0.32 to 4.09 d post-burst) and determine the electron energy index $p$, assuming the afterglow follows the model predictions in the case of an ISM-like ambient medium. However, photometrically, apart from showing a typical afterglow decay at early epochs, a deviation from the power law decay is clearly seen in all filters with a clear signature of a re-brightening peaking around $\sim$20 d post burst in the $i$-band. The peak brightness ($M_i \sim -19.04\text{ mag}$) of SN 2019oyw confirms the SN as being one of the brightest GRBs/SNe and similar to SN 1998bw in terms of other estimated parameters such as $M_{Ni}$, $M_{ej}$, and $E_k$. While the values of $M_{ej}$ and $E_k$ are higher than usual, their ratio is closer to those seen in other type Ibc-BL and GRB/SNe (Lyman et al. 2016; Cano et al. 2017). The low value of $^{56}\text{Ni}$, and the post-peak decay rate are indicative of $^{56}\text{Ni}$ as a possible powering source for SN 2019oyw.

It is also notable that Wang et al. (2019) attempted to explain the nature of the prompt emission of GRB 180728A in terms of the type II binary-driven hypernova (BdHN II) model (Rueda et al. 2020) for the observed underlying SN as an alternative to the ‘Collapsar’ model (Woosley 1993; Hjorth & Bloom 2012). In the near future, with more observations of events of this kind, it would be very interesting to decipher whether or not...
such nearby GRBs, with two emission episodes in their prompt emission phase, have underlying SN features.

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