SN 2020ank: a bright and fast-evolving H-deficient superluminous supernova

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ABSTRACT
We investigate the observational properties of a hydrogen-deficient superluminous supernova (SLSN) SN 2020ank (at z = 0.2485), with the help of early phase observations carried out between −21 and +52 d since g-band maximum. Photometrically, SN 2020ank is one of the brightest SLSN (\( M_{\text{g, peak}} \approx -21.84 \pm 0.10 \) mag), having fast pre-peak rising and post-peak decaying rates. The bolometric light curve of SN 2020ank exhibits a higher peak luminosity \( (L_{\text{max}}) \) of \( \sim (3.9 \pm 0.7) \times 10^{44} \) erg s\(^{-1}\) and appears to be symmetric around the peak with \( L_{\text{bol}}/L_{\text{max}} \approx 1 \pm 15 \text{ d}. \) The semi-analytical light-curve modelling using the MINIM code suggests a spin down millisecond magnetar with \( P \sim 2.2 \pm 0.5 \text{ ms} \) and \( B \sim (2.9 \pm 0.1) \times 10^{14} \text{ G} \) as a possible powering source for SN 2020ank. The possible magnetar origin and excess ultraviolet flux at early epochs indicate a central-engine based powering source for SN 2020ank. Near-peak spectra of SN 2020ank are enriched with the W-shaped \( \text{O} \) features but with the weaker signatures of \( \text{C} \) and \( \text{Fe} \). Using the estimated rise time of \( \sim 27.9 \text{ d} \) and the photospheric velocity of \( \sim 12050 \text{ km s}^{-1} \), we constrain the ejecta mass to \( \sim 7.2 M_{\odot} \) and the kinetic energy of \( \sim 6.3 \times 10^{51} \) erg. The near-peak spectrum of SN 2020ank exhibits a close spectral resemblance with that of fast-evolving SN 2010gx. The absorption features of SN 2020ank are blueshifted compared to Gaia16apd, suggesting a higher expansion velocity. The spectral similarity with SN 2010gx and comparatively faster spectral evolution than PTF12dam (a slow-evolving SLSN) indicate the fast-evolving behavior of SN 2020ank.

Key words: techniques: photometric – techniques: spectroscopic – supernovae: general – supernovae: individual: SN 2020ank

1 INTRODUCTION
Superluminous supernovae (SLSNe) are nearly 2–3 magnitudes brighter than classical SNe (Angus et al. 2019; Gal-Yam 2019a; Inserra 2019) radiating total energy of the order of \( \sim 10^{51} \) erg and exhibit characteristic W-shaped \( \text{O} \) features towards blue in the near-peak spectra (Quimby et al. 2011, 2018; Gal-Yam 2019b). SLSNe are rare class of events with high-peak luminosity and were unknown before SN 2005ap (Quimby et al. 2007). They comprise \( \sim 0.01\% \) of normal core-collapse SNe (CCSNe), and nearly 150 objects have been spectroscopically confirmed so far (Quimby et al. 2013; McCrum et al. 2015; Liu et al. 2017b; Prajs et al. 2017; Gomez et al. 2020). Based on the Hydrogen abundance, these events are broadly classified into H-poor SLSNe (SLSNe I) and H-rich SLSNe (SLSNe II; Gal-Yam 2012; Branch & Wheeler 2017). Most of the SLSNe I generally occur in metal-poor faint dwarf galaxies (Lunnan et al. 2014; Chen et al. 2017a) with complex light curves having pre-peak bumps (e.g., LSQ14bdg; Nicholl et al. 2015b; see also Angus et al. 2019) and post-peak undulations (e.g., SN 2015bn; Nicholl et al. 2016). On the other hand, SLSNe II mostly present prominent and narrow hydrogen Balmer lines, also characterized as SLSNe II due to their spectral similarity with lower luminosity SNe IIn (e.g., SN 2008am; Chatzopoulos et al. 2011). However, some of these events lack the typical narrow hydrogen features, e.g., SN 2008es (Gezari et al. 2009; Miller et al. 2009), SN 2013hx and PS15br (Inserra et al. 2018a). SLSNe IIn have primarily been found in heterogeneous host environments and remain less-studied (Leloudas et al. 2015; Perley et al. 2016; Schulze et al. 2018).

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SLSNe I appear to have slow- and fast-evolving behaviour based on their different photometric and spectroscopic properties (Inserna et al. 2017; Vreeswijk et al. 2017; Pursiainen et al. 2018; Quimby et al. 2018; Inserna et al. 2018c; Inserna 2019; Könyves-Toth & Vinkó 2020). Photo- metrically slow-evolving (“PTF12damlike”; rise time \(\sim 33-100 \) d) SLSNe I also exhibit slower spectroscopic evolution in comparison to the fast-evolving (“SN 2011ke-like”; rise time \(\sim 13-35 \) d) SLSNe I (Quimby et al. 2018). In addition, the slow-evolving SLSNe I have lower SN expansion velocity \( (v_{\text{exp}}) \) of \( \lesssim 12000 \) km \( s^{-1} \) and shallower velocity gradient (between 10 and 30 d, post-peak), whereas fast-evolving ones show comparatively higher \( v_{\text{exp}} \) of \( \gtrsim 12000 \) km \( s^{-1} \) and steeper velocity gradient in the same time regime (Inserna et al. 2018a).

The physical mechanism giving rise to the high peak-luminosity feature in most of the SLSNe I remains debatable. The widely accepted physical mechanism of radioactive decay (RD) of \( ^{56}\text{Ni} \) for normal class of H-deficient CCSNe has been found to be inefficient in explaining the observed high peak-luminosity in most of the SLSNe I. Theoretically, this would require a higher nickel mass \( (M_{\text{Ni}}) \) synthesis (\( \gtrsim 5 \) \( M_{\odot} \); Gal-Yam 2012), generally not possible in the core-collapse system (Umeda & Nomoto 2002, 2008). An alternate theory based on pair-instability SNe (PISNe; Kozyreva & Blinnikov 2015) has been considered to explain features in some of the slow-evolving SLSNe I (e.g., SN 2007bi; Gal-Yam et al. 2009). However, the sharper peak rising rates and bluer colours of these objects are not favorable with this scenario (Kasen et al. 2011; Dessart et al. 2012; Jerkstrand et al. 2017). Various other plausible models are also proposed to explain the relatively wider and luminous bolometric light curves of these ultraviolet (UV) bright cosmic events, including Circumstellar Matter Interaction (CSMI; Ginzburg & Balberg 2012; Wheeler et al. 2017), spin-down Millisecond Magnetar (MAG; Kasen & Bildsten 2010; Tóth & Vinkó 2020). Photometrically slow-evolving (“PTF12damlike”; rise time \( \sim 13-35 \) d) SLSNe I (Quimby et al. 2018). In addition, the slow-evolving SLSNe I have lower SN expansion velocity \( (v_{\text{exp}}) \) of \( \lesssim 12000 \) km \( s^{-1} \) and shallower velocity gradient in the same time regime (Inserna et al. 2018a).

Detailed studies for individual SLSNe I reveal that no single model is sufficient to explain all observed phenomena in these systems. For example, a handful of SLSNe I (iPTF13ehe; Yan et al. 2015, iPTF15ebv and iPTF16bad; Yan et al. 2017b) manifest clear spectral signatures supporting the CSMI. The shock-cooling of the extended CSM usually explains the observed pre-peak bumps in the light-curves of SLSNe I (e.g., SN 2006gz; Leloudas et al. 2012, DES14X3taz; Smith et al. 2016; see also Piro 2015). Whereas ejecta interaction with the pre-expelled CSM shells is considered as the potential reason for the post-peak undulations (e.g., SN 2007bi; Gal-Yam et al. 2009, SN 2015bm; Nicholl et al. 2016), favouring the CSMI. On the other hand, there are a few observational features that favor the MAG model. For instance, the near-peak excess UV flux in the case of Gaia16apd (Nicholl et al. 2017a) is explained in terms of a central engine based power source: it may be a spin-down millisecond magnetar or a mass accreting black-hole (MacFadyen & Woosley 1999). Similarly, SLSN 2011kl, the only known case so far associated with the ultra-long Gamma-Ray Burst (U1-GRB), e.g., GRB 111209A (Greiner et al. 2015), also supports the central engine based powering mechanism (Bersten et al. 2016; Lin et al. 2020a) and hints that some of these SLSNe I may also be connected with long GRBs (Kann et al. 2019). We note that both the models (CSMI and MAG) can explain various observational aspects in the SLSNe I light curves (Inserna et al. 2013; Nicholl et al. 2014), though a few specific features favour the MAG model, including the near-peak high UV flux (Mazzali et al. 2016; Nicholl et al. 2017a), late-time flattening (Inserna et al. 2013; Liu et al. 2017a; Nicholl et al. 2017b; Blanchard et al. 2018), and spectral properties (Dessart et al. 2012; Nicholl et al. 2019). Though deeper investigations are required to explore the underlying physical mechanisms, possible progenitors and environments hosting such rare and energetic explosions.

SN 2020ank (ZTF20ahbfm) was discovered by the Zwicky Transient Facility (ZTF; Bellm et al. 2019) on 2020 January 19 at J2000 coordinates: RA = 08\(^h\)16\(^m\)14\(^s\)65 and Dec = +04\(^\circ\)19\('\)28\(''\)87 (Poidevin et al. 2020a). SN 2020ank was also detected by the Asteroid Terrestrial-impact Last Alert System (ATLAS; Torny et al. 2018) with internal name ATLAS20dzh on 2020 January 24 (Torny et al. 2020) and by the Pan-STARRS1 (PS1; Chornock et al. 2013) on 2020 March 18 as PS20eyd. SN 2020ank was classified as an SLSN I based on the spectroscopic observations from the Liverpool Telescope (LT-2.0m) and the Gran Telescopio Canarias (GTC-10.4m; Poidevin et al. 2020b). Later on, spectroscopic observations were also carried out by Dahiwal & Fremling (2020), discussing the spectrum obtained from the Palomar Observatory Hale Telescope (P200-5.1m) reporting redshift \( z = 0.2485 \). The near-peak polarimetric observations showing negligible polarization, as investigated by Lee (2020), suggests a nearly spherical explosion for SN 2020ank.

In this paper, early time photometric and spectroscopic observations of SN 2020ank have been discussed. The paper is structured as follows. The procedures describing observations, data reductions, and analysis are explained in Section 2. In Section 3, the photometric properties of SN 2020ank and its comparison with other well-studied SLSNe I are presented. The bolometric light-curve modelling using the MINIT code is presented in Section 4. Section 5 describes the spectroscopic properties of SN 2020ank, the HYBAPPSS spectral modelling, and the spectral comparison with other well-studied SLSNe I. We conclude our results in Section 6. Throughout this work, \( H_0 = 70 \) km \( s^{-1} \) Mpc\(^{-1} \) and \( \Omega_m = 0.27 \) have been adopted to estimate the distances, dates are presented in UT, and phase is given since \( g \)-band maximum.

### 2 OBSERVATIONS AND DATA ANALYSIS

Photometric observations in Bessell \( U, B, V, R, \) and \( I \) bands of SN 2020ank field were carried out with three ground-based observing facilities in India: Sampurnanand Telescope (ST-1.04m), Himalayan Chandra Telescope (HCT-2.0m), and recently commissioned Devasthal Optical Telescope (DOT-3.6m) having longitudinal advantage for time critical observations (Pandey 2016, 2018). These three telescopes are equipped with liquid nitrogen cooled CCD cameras at their Cassegrain focus. The observations were initiated using the ST-1.04m and continued with the HCT-2.0m (4 epochs) and DOT-3.6m (6 epochs). Photometric images were acquired with the 4\times 4\text{K} CCD Imagers mounted at the axial ports of both the ST-1.04m and the DOT-3.6m (Pandey et al. 2018). In addition, the Himalayan Faint Object Spectrograph and Camera (HFOSC\(^1\)) instrument at the HCT-2.0m has also been used to perform the multiband photometric data of SN 2020ank. Table 1 lists various parameters of the facilities and their back-end instruments. Standard IRAF\(^2\) tasks were executed to pre-process (e.g., bias-

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1. https://www.iiap.res.in/?q=iao_about
2. http://iraf.noao.edu

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subtraction, flat-fielding, and cosmic ray removal) the raw data. On several nights, multiple science frames in each band were stacked after the alignment of the individual images, and consequently, a better signal-to-noise ratio was obtained. To calibrate a sequence of secondary standards in the SN field, we observed Landolt photometric standard fields PG 1657 and PG 0231 (Landolt 1992). The standard and SN fields were observed on 2020 March 19 (PG 1657) and 2020 October 14 (PG 0231) with the DOT-3.6m under good photometric conditions. The Landolt field stars have a brightness range of 12.77 ≤ V ≤ 16.11 mag and colour range of −0.15 ≤ B − V ≤ 1.45 mag. Using the stand-alone version of DAOPHOT3 (Stetson 1987, 1992), the point spread function photometry on all the frames was performed. The average atmospheric extinction values in U, B, V, R, and I bands for the Devasthal site were adopted from Mohan et al. (1999). Using the Landolt standards, transformation to the standard system was derived by applying average colour terms, and photometric zero-points. In the left-hand panel of Fig. 1, the seven secondary calibrated standard stars (used to calibrate the SN magnitudes) are marked, and the respective secondary calibrated standard stars (used to calibrate the SN magnitudes) are listed in Table 2. The final SN photometry in U, B, V, R, and I bands are listed in Table 3. Here, we note that for completeness, in addition to our observations, the publicly available ZTF g and r bands data are also used (Poidevin et al. 2020a) and downloaded from the Lasair4 website (Smith et al. 2019).

The optical spectroscopic observations of SN 2020ank in low-resolution mode were performed at four epochs from HCT-2.0m using the HPOS instrument. The spectra were obtained using grism-Gr7 (3500–7800 Å), having a resolution of ∼8 Å. The journal of these observations is provided in Table 6. The arc lamp and spectrophotometric standards were also obtained during the observations, and the spectroscopic data reduction was performed using the IRAF software. The pre-processing of raw spectra, extraction of 1D spectra, and the wavelength calibration were done in a standard manner as described in Kumar et al. (2018). For flux calibration, spectrophotometric standard observations were used. The flux calibrated spectra were then scaled with respect to the calibrated photometric U, B, V, R, and I fluxes to bring them to an absolute flux scale and, finally, corrected for the host galaxy redshift. In this study, we have also used two early epoch archival spectra obtained using the OSIRIS5 at GTC-10.4m (Poidevin et al. 2020b) and DBSP6 at P200-5.1m (Dahiwale & Fremling 2020) and downloaded from the Transient Name Server (TNS)7.

### 3 LIGHT-CURVE EVOLUTION AND COMPARISON WITH OTHER EVENTS

SN 2020ank was discovered on 2020 January 19 UT 09:15:13 (MJD = 58,867.386) in the observed-frame g-band at ~20.91 ± 0.30 mag by the ZTF (Poidevin et al. 2020a). Whereas the last non-detection was on 2020 January 19 UT 08:09:24 (MJD = 58,867.340) also reported by the ZTF with a r-band upper limit of ~20.40 mag. The host galaxy of SN 2020ank is faint (g-band upper limit ~24 mag) as it was not observed up to the detection limits of Sloan Digital Sky Survey (SDSS), PS1, and Dark Energy Spectroscopic Instrument Legacy Survey (Poidevin et al. 2020b). Using this brightness limit, we constrain the explosion date (MJD_{expl} = 58857.9) by extrapolating the pre-maximum rest frame g-band light curve of SN 2020ank down to the limiting magnitude of the host galaxy by fitting a high-order spline function, as also described in Gezari et al. (2009); Kumar et al. (2020). Our observations of SN 2020ank in the Bessell U, B, V, R, and I bands span +2.8 to +51.6 d (in the rest-frame). Log of the photometric observations is tabulated in Table 3.

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3. DAOPHOT stands for Dominion Astrophysical Observatory Photometry.
4. https://lasair.roe.ac.uk/object/ZTF20aahbfmf/
5. Optical System for Imaging and low Resolution Integrated Spectroscopy.
6. Double Spectrograph.
7. https://wis-tns.weizmann.ac.il/
Table 1. Observing facilities and instruments detail used for the follow-up observations of SN 2020ank.

| Facility Location                        | Instrument       | Gain (e^-/ADU) | Readout Noise (e^-) | Binning | Plate scale (arcsec pixel^-1) | Field of view (arcmin^2) |
|------------------------------------------|------------------|----------------|--------------------|---------|------------------------------|--------------------------|
| 1.04-m Sampurnanand Telescope Manora Peak, Nainital | 4Kx4K Imager     | 3.0            | 10.0               | 4 x 4   | 0.230                        | 15 x 15                  |
| 2.0-m Himalayan Chandra Telescope Hanle, Leh        | HFOSC            | 0.28           | 5.75               | 1 x 1   | 0.296                        | 10 x 10                  |
| 3.6-m Devasthal Optical Telescope Devasthal, Nainital | 4Kx4K Imager     | 5.0            | 10.0               | 2 x 2   | 0.095                        | 6.5 x 6.5                |

*Plate scales are given for un-binned mode.

Table 2. Identification number (ID) and calibrated magnitudes of the secondary standard stars in the field of SN 2020ank as displayed in the left-hand panel of Fig. 1.

| Star ID | U (mag) | B (mag) | V (mag) | R (mag) | I (mag) |
|---------|---------|---------|---------|---------|---------|
| 1       | 17.749 ± 0.010 | 17.353 ± 0.005 | 16.615 ± 0.003 | 16.152 ± 0.005 | 15.770 ± 0.008 |
| 2       | 17.853 ± 0.017 | 17.450 ± 0.005 | 16.662 ± 0.006 | 16.229 ± 0.007 | 15.854 ± 0.008 |
| 3       | 17.747 ± 0.010 | 17.765 ± 0.007 | 16.953 ± 0.007 | 16.471 ± 0.006 | 16.008 ± 0.007 |
| 4       | 18.226 ± 0.010 | 18.069 ± 0.005 | 17.208 ± 0.006 | 16.879 ± 0.004 | 15.909 ± 0.004 |
| 5       | 17.123 ± 0.009 | –       | 18.405 ± 0.005 | 18.095 ± 0.010 | 17.969 ± 0.009 |
| 6       | 18.918 ± 0.006 | 18.958 ± 0.011 | 18.302 ± 0.004 | 17.922 ± 0.007 | 17.569 ± 0.011 |
| 7       | –       | –       | –       | –       | –       |

Figure 2. Comparison of the rest-frame $M_g$ light curve of SN 2020ank with other well-studied SLSNe I (taken from Nicholl et al. 2015a, 2016; De Cia et al. 2018; Kangas et al. 2017; Bose et al. 2018; Kumar et al. 2020, and references therein) and the long GRB connected SLSN 2011kl (Greiner et al. 2015; Kann et al. 2019). All the presented light curves are corrected for the Galactic extinction, and the $K$-corrections also have been applied. SN 2020ank appears to have comparatively brighter $M_g$, peak and faster pre-peak rising and post-peak decaying rates, apparently similar to SN 2010gx and other fast-evolving SLSNe I.

The occurrence of SN 2020ank at $z = 0.2485$ (Dahiwale & Fremling 2020) necessitated the use of applying $K$-corrections to obtain the rest-frame magnitudes. We estimated $K$-corrections using the optical spectra of SN 2020ank with help of the light version of SuperNova Algorithm for $K$-correction Evaluation code (SHAKELOOP; Inserra et al. 2018a) based on the equation given by Hogg et al. (2002). The spectra had been flux calibrated by scaling them to the photometric data before being used as an input to the SHAKELOOP code. The estimated $K$-correction terms using the near the publicly available photometric SDSS $g$ and $r$ bands data (between $\sim -21$ and $+36$ d, from rest-frame) observed by the ZTF (Poidevin et al. 2020a).

\[ M_{g, rest} = M_g + K \]
peak-spectrum (at −0.74 d, in the rest-frame) of SN 2020ank for U, B, g, V, r, R, and I bands are tabulated in Table 4. The K-correction terms for interpreting photometric epochs are obtained using the interpolation technique. However, for the photometric data points outside the spectral range, we used the same K-correction term obtained for the last available spectral epoch. Using the K-correction magnitude values, we converted $U \rightarrow UVW1_{RF}$, $B \rightarrow U_{RF}$, $g \rightarrow u_{RF}$, $V \rightarrow B_{RF}$, $r \rightarrow g_{RF}$, $R \rightarrow V_{RF}$, and $I \rightarrow R_{RF}$ bands by applying the formula,

$$M_{RF} = m_o - (5 \times \log d_L + 25) - A_o - K_{RF},$$

where $M_{RF}$ represents the absolute magnitude in the rest-frame band, $m_o$ is the apparent magnitude in the observed-frame band, $d_L$ is the luminosity distance, $A_o$ is the extinction for the observed band, and $K_{RF}$ is the K-correction term estimated from the spectra of SN 2020ank using the SHAPELOOP code. The data have been corrected for the Galactic extinction using $E(B - V) = 0.019$ mag (Schlafly & Finkbeiner 2011). The weak host emission lines (Osterbrock 1989) and insignificant Na I absorption (Poznanski et al. 2012) in near-peak spectra of SN 2020ank implied negligible host extinction.

For SN 2020ank, the multiband ($UVW1_{RF}$, $u_{RF}$, $U_{RF}$, $B_{RF}$, $g_{RF}$, $V$, and $R_{RF}$) rest-frame absolute magnitudes (after extinction and K-correction) estimated using equation 1 are plotted in the right-hand panel of Fig. 1. The phases after correcting for time dilation are plotted with respect to the $g$-band maximum. From here onward, the discussed bands and the phase will be referred to the rest frame. A low-order polynomial was fitted around the approximate rest-frame $g$-band peak brightness to estimate the date of $g$-band maximum. The date of maximum and the magnitude are estimated as $M_{JD,peak} \approx 58,894.28 \pm 0.15$ and $M_{g,peak} \approx -21.84 \pm 0.10$ mag, respectively. In the $u$-band, SN 2020ank reached a peak brightness of $M_{u,peak} \approx -21.95 \pm 0.07$ mag on $MJD_{u,peak} \approx 58,893.36 \pm 0.20$. The $UV$ bands appear to peak earlier compared to the redder bands, as found in other CCSNe (Taddia et al. 2018). For SN 2020ank, the $M_{g,peak}$ is consistent with the range of peak absolute magnitudes typically found in the case of other well-studied SLSNe I (Quimby et al. 2013; Nicholl et al. 2016; Inserra et al. 2018b). We observed the post-peak light-curve evolution of SN 2020ank in $UVW1$, $U$, $B$, $V$, and $R$ bands and calculated the decay rates. The redder bands seem to have shallower post-peak decay rates in comparison to the $UV$ bands, which is $\sim 0.05$ and $\sim 0.15$ mag d$^{-1}$ for the $R$ and $UVW1$ bands, respectively. In the case of SN 2020ank, the redder bands ($V$ and $R$; 0.06 and 0.05 mag d$^{-1}$, respectively) exhibit a steeper post-peak decay rate in comparison to the average $g$-band post-peak decay rate (for < 60 d, 0.04 mag d$^{-1}$) for the SLSNe I discussed by De Cia et al. (2018), indicating the comparatively fast-decaying behavior of SN 2020ank. Additionally, the $U$-band post-peak decay rate of SN 2020ank is well in agreement with the $^{56}Ni \rightarrow ^{56}Co$ theoretical decay curve (0.11 mag d$^{-1}$), see right-hand panel of Fig. 1.

### 3.1 The rest-frame $M_g$ light curves

We compare the rest-frame $g$-band absolute magnitudes of SN 2020ank with well-studied bright ($M_{g,peak} > -20.5$ mag) SLSNe I taken from Nicholl et al. 2015a, 2016; De Cia et al. 2018; Kangas et al. 2017; Bose et al. 2018; Kumar et al. 2020; and references therein (see Fig. 2). We also compare the $M_g$ light-curve of SN 2020ank with the only known SLSN 2011kl associated with a long-duration GRB 111209A (Greiner et al. 2015; Kann et al. 2019). For SLSNe I having Bessell $R$-band data, the transformation equations and uncertainties by Jordi et al. (2006) have been used to obtain the SDDS $g$-band magnitudes. Fig. 2 shows that SN 2020ank is a bright SLSN with $M_{g,peak} \sim -21.84 \pm 0.10$ mag, which is closer to SN 2010kd (Kumar et al. 2020) and Gaia16apd (Kangas et al. 2017; Nicholl et al. 2017a) within errors, whereas fainter than LSQ14bdq (Nicholl et al. 2015b) and SN 2015bn (Nicholl et al. 2016). SN 2020ank appears to have steeper pre-peak rising and post-peak declining rates similar to that observed for other fast-evolving SLSNe I (e.g., SN 2011ke). Further, the post-peak decay rate of SN 2020ank is also steeper in comparison to slow-evolving SLSNe I such as SN 2010kd (Kumar et al. 2020), PTF12dam (Nicholl et al. 2013), and SN2015bn (Nicholl et al. 2016).

To constrain the peak brightness, rise and decay times of a larger sample of such SLSNe I (present case and those discussed in Nicholl et al. 2015a; De Cia et al. 2018), we independently estimate the $M_{peak}$ and time taken to rise/decay by 1 mag to/from the peak absolute magnitudes ($t_{rise}^{M_{peak}}$ and $t_{fall}^{M_{peak}}$) using the rest-frame $M_g$ light curves. To estimate the values of $M_{g,peak}$, $t_{rise}^{M_{peak}}$, and $t_{fall}^{M_{peak}}$, we fitted a low-order spline function to the rest-frame $M_g$ light curves (see Fig. 3, also discussed by De Cia et al. 2018). SLSNe I having less pre- or post-peak data are omitted, but a sparse extrapolation was done wherever necessary. We plot the $t_{rise}^{M_{peak}}$ and $t_{fall}^{M_{peak}}$ and their sum with $M_{g,peak}$ in the left-hand and right-hand panels of Fig. 4, respectively. Generally, SLSNe I with higher values of $t_{rise}^{M_{peak}}$ also display the higher values of $t_{fall}^{M_{peak}}$ as also discussed by Nicholl et al. 2015a; De Cia et al. 2018, whereas no such correlation appears between $t_{rise}^{M_{peak}} + t_{fall}^{M_{peak}}$ and $M_{g,peak}$.

SN 2020ank exhibits the steepest pre-peak rising rate (lower value of $t_{rise}^{M_{peak}}$) in comparison to other SLSNe-I in the sample, except for the GRB-associated SLSN 2011kl (Kann et al. 2019). The right-hand panel of Fig. 4 also shows that SN 2020ank exhibits a

**Figure 3.** The rest-frame $M_g$ light curve of SN 2020ank fitted with the third order spline function to calculate the $M_{g,peak}$, $t_{rise}^{M_{peak}}$ and $t_{fall}^{M_{peak}}$ is shown. The black square shows the estimated $M_{g,peak}$, whereas the intersect points of green dotted line and spline fit (in blue) present magnitude values constraining $t_{rise}^{M_{peak}}$ and $t_{fall}^{M_{peak}}$ (in rest-frame $d$).
During the photospheric phase, optical-NIR colours are useful in the g-band. SN 2020ank is a fast-evolving SLSN with high peak brightness in comparison to all other plotted fast-evolving SLSNe I. In the lower panel of Fig. 6, we compare the $M_{g, peak}$ brightness of SN 2020ank decays very sharply and becomes fainter in comparison to other presented SLSNe I (except PTF12dam and SN 2011kl), see the upper panel of Fig. 6. One of the possible reasons behind this excess UV flux of SN 2020ank near the peak may be the lower production of heavier group elements during the explosion, as suggested by Yan et al. (2017a) in the case of Gaia16apd. The other possible reason could be a short-lived powering source adding extra luminosity component towards the UV or lower natal metallicity. However, these plausible reasons for explaining the excess UV flux were not found suitable in the case of Gaia16apd (Nicholl et al. 2017a). This is because of its similar metallicity and degree of spectral absorption features to the other SLSNe I having a lower UV flux. In the case of Gaia16apd, the most likely possible reason might be a central engine as a power source (it could be a spin-down millisecond magnetar with lower spin period and comparatively low mass or a magnetar with lower spin period and comparatively low mass or a higher spin period magnetar). However, the mass accreting BH; MacFadyen & Woosley 1999), which could explain both the overall luminosity and the excess UV flux (Nicholl et al. 2017a). For SN 2020ank as well, the central engine based powering source as a possible mechanism for the observed UV excess near the peak is well in agreement with semi-analytical light-curve modelling results discussed later in Section 4.1.

In the lower panel of Fig. 6, we compare the $UVW1–r$ colour evolution of SN 2020ank with the well-studied SLSNe I. The rest-frame $g–r$ colour of the fast-evolving SN 2020ank is also discussed in Section 3.3.

### 3.2 The rest-frame $g–r$ colour evolution

During the photospheric phase, optical-NIR colours are useful probes to understand the temperature evolution of SLSNe. Due to the unavailability of the rest-frame $r$-band data for SN 2020ank, the rest-frame (Galactic extinction and K-corrected) V and R bands data were transformed to the r-band magnitudes using the transformation equation and uncertainties given by Jordi et al. (2006).

So, here we compare the rest-frame $g–r$ colour evolution of SN 2020ank with that observed for the well-studied SLSNe I (see Fig. 5). The slow-evolving SLSNe I (SN 2010kd, PTF12dam, SN 2015bn, etc.) appear to have shallower rising (from blue to red) colour evolution (from $−0.4$ to $0.2$ mag in a time range of $20–100$ d). In contrast, the fast-evolving SLSNe I (e.g., SN 2010gx, SN 2011ke, 2012il, etc.) show $g–r$ colour ranging from $0.0$ to $1.2$ mag in the same temporal bin. SN 2020ank presents a bluer $g–r$ colour evolution from $+3$ to $+6$ d spanning the range from $−0.5$ to $0.1$ mag. Overall, the $g–r$ colour of the fast-evolving SN 2020ank is closer to the slow-evolving SLSNe I. The rest-frame $UVW1–r$ colour evolution of SN 2020ank is also discussed in Section 3.3.

### 3.3 Comparison of UV-brightness

In this section, we compare the rest-frame equivalent $UVW1$ brightness and evolution of the $UVW1–r$ colour of SN 2020ank with other well-studied SLSNe I (see Fig. 6). Near the peak, $UVW1$ brightness of SN 2020ank appears to be comparable to Gaia16apd, the most UV bright SLSN to date (Nicholl et al. 2017a) except the most luminous SLSN ASASSN-15lh (Dong et al. 2016). With time, the $UVW1$ flux of SN 2020ank decays very sharply and becomes fainter in comparison to other presented SLSNe I (except PTF12dam and SN 2011kl), see the upper panel of Fig. 6. One of the possible reasons behind this excess UV flux of SN 2020ank near the peak may be the lower production of heavier group elements during the explosion, as suggested by Yan et al. (2017a) in the case of Gaia16apd (see also Mazzali et al. 2016). The other possible reason could be a short-lived powering source adding extra luminosity component towards the UV or lower natal metallicity. However, these plausible reasons for explaining the excess UV flux were not found suitable in the case of Gaia16apd (Nicholl et al. 2017a). This is because of its similar metallicity and degree of spectral absorption features to the other SLSNe I having a lower UV flux. In the case of Gaia16apd, the most likely possible reason might be a central engine as a power source (it could be a spin-down millisecond magnetar with lower spin period and comparatively low mass or a mass accreting BH; MacFadyen & Woosley 1999), which could explain both the overall luminosity and the excess UV flux (Nicholl et al. 2017a). For SN 2020ank as well, the central engine based powering source as a possible mechanism for the observed UV excess near the peak is well in agreement with semi-analytical light-curve modelling results discussed later in Section 4.1.

In the lower panel of Fig. 6, we compare the $UVW1–r$ colour evolution of SN 2020ank with the well-studied SLSNe I. The rest-
frame $UVW1 - r$ colour curves of PTF12dam, SN 2015bn, and Gaia16apd are taken from Nicholl et al. (2017a), whereas calculated independently for SN 2010kd and Gaia17biu. Due to the unavailability of SDSS $r$-band data for SN 2020ank and SN 2010kd, we obtained the $r$-band data from the available $V$ and $R$ bands data using the transformation equations and uncertainties given by Jordi et al. (2006). Before estimating colours, the $UVW1$ magnitudes were converted from Vega to AB system using the zero points adopted from Breeveld et al. (2011). Near the peak, $UVW1 - r$ colour of SN 2020ank is closer to those observed in the case of Gaia16apd and Gaia17biu; however, it is $\sim 1 - 2.5$ mag bluer in comparison to other presented SLSNe I. With time, $UVW1 - r$ colours of SN 2020ank turn redder quite sharply, indicating a rapid drop in temperature, also in agreement with the estimate of temperature using the BB fitting to the photometric spectral energy distribution (SED), see Section 4.

### 4 BOLOMETRIC LIGHT CURVE

We generate the rest-frame quasi-bolometric ($UVW1, u, U, B, g, V,$ and $r$ bands) light curve of SN 2020ank using a Python-based code Superbol (Nicholl 2018). To compute the multiband fluxes, interpolation or extrapolation was done wherever necessary assuming constant colours to get the magnitudes at the individual epochs using standard methods. The uncertainties in the calculation of zero points are also taken care of by adding $3\%$ uncertainties to the bolometric luminosity error as is suggested by the software release of Superbol\(^8\). The pseudo-bolometric ($UVW1$ to $R$) light curve of SN 2020ank presents a peak luminosity ($L_{\text{max}}$) of $\sim (1.89 \pm 0.14) \times 10^{44} \text{erg s}^{-1}$. To include the expected flux contribution from $UV$ and $NIR$ regions, we extrapolated the SED (here the BB model) by integrating over the observed fluxes and obtained the full bolometric light curve. The full bolometric light-curve ($UV$ to $NIR$) of SN 2020ank (in red) between $\sim -20$ and $+50$ days, derived so, exhibited $L_{\text{max}}$ of $\sim (3.89 \pm 0.69) \times 10^{44} \text{erg s}^{-1}$ at MJD $= 58892.8$, overall consistent with other well-studied SLSNe I, see Fig. 7. In the case of SN 2020ank, the bolometric light curve is nearly symmetric around the peak with the $L_{\text{rise}}$/$L_{\text{fall}}$ e $\approx 15$ d (time taken to rise/decay by $L_{\text{max}}$ to/from the $L_{\text{max}}$).

For an extensive comparison of bolometric luminosities, the sample used in Fig. 2 was supplemented with data of PTF13ajg (Vreeswijk et al. 2014) and ASASSN-15lh (Dong et al. 2016) along with the independently generated bolometric light curves of PTF11rks, SN 2011kf and SN 2012il (Inserra et al. 2013). The comparison shows that SN 2020ank is one of the brightest SLSN with a peak bolometric luminosity higher in comparison to SN 2010kd, PTF12dam, SN 2015bn, etc., but fainter than SN 2011kf, PTF13ajg, and the most luminous SLSN ASASSN-15lh (Dong et al. 2016) in the sample. As obtained from the rest-frame $M_i$ light-curves comparison, SN 2020ank appears to have high pre-peak rising and post-peak decay rates of its bolometric light curve, similar to that of fast-evolving SLSNe I (e.g., SN 2010gx and SN 2011ke). In all, SN 2020ank is a bright SLSN having a bell-shaped light curve around the peak with a fast-evolving behaviour.

Fig. 8 shows the evolution of BB temperature ($T_{BB}$) and radius ($R_{BB}$) of SN 2020ank. The $T_{BB}$ and $R_{BB}$ values are calculated by modelling the photometric SED at individual epochs by fitting a BB function using the Superbol1 code (Nicholl 2018). From $\sim -20$ d to

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\(^8\) https://github.com/mnicholl/superbol
Table 3. Optical–photometric data of SN 2020ank in Bessell $U$, $B$, $V$, $R$ and $I$ bands observed using the ST-1.04, HCT-2.0, and DOT-3.6m. The values presented here are not corrected for Galactic extinction and $K$-corrections. It is also to be noted that the source could not be observed beyond 2020 April 19 due to the unforeseen situation of COVID-19.

| JD     | Date      | mag  | error | Filter | Telescope |
|--------|-----------|------|-------|--------|-----------|
| 2458900.117 | 2020 February 20 | 17.879 | 0.041 | $U$ | HCT-2.0m |
| 2458901.133 | 2020 February 21 | 17.886 | 0.072 | $U$ | HCT-2.0m |
| 2458912.094 | 2020 March 16 | 20.501 | 0.062 | $U$ | DOT-3.6m |
| 2458928.209 | 2020 March 19 | 20.856 | 0.071 | $U$ | DOT-3.6m |
| 2458901.133 | 2020 February 21 | 18.455 | 0.035 | $B$ | HCT-2.0m |
| 2458911.343 | 2020 March 02 | 18.930 | 0.028 | $B$ | HCT-2.0m |
| 2458912.094 | 2020 March 03 | 18.998 | 0.021 | $B$ | HCT-2.0m |
| 2458912.193 | 2020 March 03 | 19.069 | 0.030 | $B$ | DOT-3.6m |
| 2458925.109 | 2020 March 16 | 20.134 | 0.021 | $B$ | DOT-3.6m |
| 2458928.209 | 2020 March 19 | 20.402 | 0.023 | $B$ | DOT-3.6m |
| 2458956.212 | 2020 April 16 | 22.797 | 0.093 | $B$ | DOT-3.6m |

Table 4. Estimated values of $K$-corrections (in magnitudes) for different passbands are listed. The values were determined using the near-peak spectrum (at −0.74 d) of SN 2020ank using the SHAKELOOP code (Inserra et al. 2018a).

| Observed band | Rest-frame band | $K$-correction (mag) |
|---------------|-----------------|----------------------|
| $U$ (Vega)    | $UVW1$ (Vega)   | $0.57 \pm 0.02$      |
| $B$ (Vega)    | $U$ (Vega)      | $0.75 \pm 0.01$      |
| $g$ (AB)      | $a$ (AB)        | $-0.17 \pm 0.01$     |
| $V$ (Vega)    | $B$ (Vega)      | $-0.28 \pm 0.01$     |
| $r$ (AB)      | $g$ (AB)        | $-0.22 \pm 0.01$     |
| $R$ (Vega)    | $V$ (Vega)      | $-0.44 \pm 0.01$     |
| $I$ (Vega)    | $R$ (Vega)      | $-0.49 \pm 0.03$     |

Figure 6. Upper: The rest-frame $M_{UVW1}$ light curve of SN 2020ank (after applying Galactic extinctions and $K$-corrections) is presented and compared with the following well-studied SLSNe I: SN 2010kd (Kumar et al. 2020), SN 2011kl (Greiner et al. 2015; Kann et al. 2019), PTF12dam (Nicholl et al. 2013), SN 2015bn (Nicholl et al. 2016), Gaia16apd (Kangas et al. 2017; Nicholl et al. 2017a) and Gaia17biu (Bose et al. 2018). Near the peak, $UVW1$ brightness of SN 2020ank seems even higher to that observed in the case of Gaia16apd. Lower: The rest-frame $UVW1 – r$ colour evolution of SN 2020ank is compared with the same sample of SLSNe I discussed above in the AB magnitude system. Near the peak, SN 2020ank exhibits bluer colour in comparison to other SLSNe I and turns redder very sharply with time.

peak, the $T_{BB}$ of SN 2020ank seems to be constant around $\sim 16000$ K, whereas from peak to $\sim +15$ d it sharply decays with a rate of $\sim 600$ K per day. At later epochs (after $\sim +15$ d), the $T_{BB}$ appears to be constant again at $\sim 7000$ K. The near peak $T_{BB}$ of SN 2020ank is higher in comparison to well-studied slow-evolving SLSNe I PTF12dam and SN 2015bn (Chen et al. 2015; Nicholl et al. 2016), nearly consistent with intermediate decaying Gaia16apd (Kangas et al. 2017; Nicholl et al. 2017a), and lower than the most luminous SLSN ASASSN-15ih (Dong et al. 2016). On the other hand, from $\sim -20$ to $\sim +15$ d the value of $R_{BB}$ for SN 2020ank increases from $\sim 1.3 \times 10^{53}$ to $8.8 \times 10^{53}$ cm, thereafter, up to $\sim +50$ d, it decreases to $\sim 3.4 \times 10^{53}$ cm.

4.1 Light-curve modelling using MINIM

We attempt to reproduce the bolometric light curve of SN 2020ank with the RD, MAG, constant density CSMI (CSMI0), and wind-like CSMI (CSMI2) semi-analytical light-curve models (see Fig. 9) using the MINIM code (Chatzopoulos et al. 2013). MINIM is a general-purpose fitting code that finds the global solution for non-linear $\chi^2$ fitting. It uses the Price algorithm (Brachetti et al. 1997),
a controlled random-search technique, to look for the global minimum of the $\chi^2$ hyper-surface within the allowed parameter volume. After that, parameters generated by the Price algorithm for the lowest $\chi^2$ value are fine-tuned by the Levenberg-Marquardt algorithm (More 1978), which gives the final set of parameters for the best-fitted model. The uncertainties in the parameters are estimated using the standard deviation of the random vectors around the global minimum. Details about the above discussed models, MINIM code and fitting procedures are described in Chatzopoulos et al. (2012, 2013).

For all the models discussed above, we adopted the electron-scattering opacity, $\kappa = 0.1 \, \text{cm}^2 \, \text{g}^{-1}$, by considering half ionized elements for SLSNe I (Inserra et al. 2013; Nagy 2018). For RD and MAG models, the $M_{ej}$ values are estimated using equation 10 of Chatzopoulos et al. (2012), where the integration constant ($\beta$) was considered to be 13.8. In the case of RD model, $v_{\text{exp}}$ is taken equals to 12000 km s$^{-1}$ as obtained from the spectral analysis of SN 2020ank discussed in Section 5.1. However, for the MAG model, $v_{\text{exp}}$ was given by the MINIM itself as a fitting parameter. The initial period of the new-born magnetar in ms ($P_i$) is given by $P_i = 10 \times \left( 1.3 \times 10^{20} \, \text{gyr}^{-1} \, r_{\text{exp}}^{-1} \right)^{0.5}$, where $E_p$ is the magnetar rotational energy in erg. The magnetic field of the millisecond magnetar in Gauss units ($B$) is estimated by $B = 10^{14} \times \left( 1.3 \times 10^{20} \, \text{gyr}^{-1} \, r_{\text{exp}}^{-1} \right)^{0.5}$, where $t_{p,gyr}$ is the magnetar spin-down time-scale in years.

It is evident from Fig. 9 that all four models (RD, MAG, CSM10, and CSM2) fit the data adequately, i.e., with $\chi^2$/DOF ~ 1. Here, we caution that in the present case, the $\chi^2$/DOF is used as an indicator for selecting the model parameters that fit the data best and not as a statistical probe for judging the significance of the models. In this situation, the best $\chi^2$ value solely cannot be used as a criterion to declare the most probable model. Therefore, we look for the feasibility of various physical parameters retrieved from different models. The parameters obtained from the MINIM modelling using the four discussed models are tabulated in Table 5. In the RD model, the calculated $M_{ej}$ is lower than $M_{\text{Ni}}$ (see Ta-
Figure 9. Semi-analytical light-curve models (RD, MAG, CSMI0, and CSMI2) are fitted to the bolometric light curve of SN 2020ank using the MINIM code (Chatzopoulos et al. 2013). For all the model fittings, the $\kappa = 0.1 \text{ cm}^{-2} \text{g}^{-1}$ is adopted. All four discussed models well reproduced the bolometric light curve of SN 2020ank with $\chi^2/\text{DOF} \sim 1$; but, the physical reliability of the derived parameters suggested the MAG model as the most suitable one for SN 2020ank.

In summary, based on our fitting we consider the MAG model as the most probable one because (1) it fits the data well ($\chi^2/\text{DOF} \sim 1$), and (2) its parameters are realistic and closer to the ones inferred from the spectral modelling ($M_{ej}, v_{exp}$; see Section 11). So, the spin-down millisecond magnetar is found to be the most suitable powering source for SN 2020ank with $P_i \sim 2.23 \pm 0.51 \text{ ms}$ and $B \sim 2.91 \pm 0.07 \times 10^{14} \text{ G}$, giving rise to an ejected mass of $\sim 3.58 \pm 0.04 \text{ M}_\odot$. The MAG model suggests the value of progeni-
Table 5. Best-fitting parameters for the RD, MAG, CSMI0, and CSMI2 models obtained using the MINIM fitting.

| RD model | | | | | |
|----------|----------|----------|----------|----------|----------|
| $A_r^a$ | $M_{de}^b$ (M$_\odot$) | $t_d^c$ (d) | $M_{Mi}$ (M$_\odot$) | $\chi^2$/DOF |
| 9.20 ± 1.34 | 2.62 ± 0.38 | 21.66 ± 1.55 | 26.71 ± 2.55 | 0.23 |

$A_r$: optical depth for the gamma-rays measured after the 10 d of explosion. $M_{de}$: ejecta mass (in M$_\odot$). $t_d$: effective diffusion-timescale (in d). $E_p$: magnetar rotational energy (in 10$^{51}$ erg). $t_p$: magnetar spin-down timescale (in d). $R_p$: progenitor radius before the explosion (in 10$^3$ cm). $M_{cs}$: CSM mass (in M$_\odot$). $\dot{M}$: progenitor mass-loss rate (in M$_\odot$ yr$^{-1}$).

| MAG model | | | | | |
|----------|----------|----------|----------|----------|----------|
| $R_0$ (10$^{13}$ cm) | $M_{ej}$ (M$_\odot$) | $E_p^d$ (10$^{51}$ erg) | $t_d$ (d) | $t_p^e$ (d) | $v_{exp}$ (10$^3$ km s$^{-1}$) | $P_i$ (ms) | $B$ (10$^4$ G) | $\chi^2$/DOF |
| 0.28 ± 0.22 | 3.58 ± 0.04 | 4.02 ± 0.19 | 25.01 ± 0.16 | 2.79 ± 0.35 | 12.27 ± 0.91 | 2.23 ± 0.51 | 2.91 ± 0.07 | 0.38 |
| 263.20 ± 45.57 | 46.13 ± 7.78 | 9.13 ± 1.56 | 54.95 ± 11.32 | 29.69 ± 1.84 | 0.13 |
| 312.90 ± 19.87 | 45.11 ± 8.93 | 13.12 ± 0.83 | 0.58 ± 0.05 | 23.23 ± 0.59 | 0.14 |

CSMI0 model

CSMI2 model

Figure 10. Scatter plot showing the comparison of $P_i$, $B$, and $M_{ej}$ values derived for SN 2020ank using the semi-analytical light-curve MINIM modelling with the sample of the well-studied SLSNe I is presented.

4.1.1 Comparison of derived physical parameters with other SLSNe I

In this section, we compare the $P_i$, $B$, and $M_{ej}$ of SN 2020ank estimated through semi-analytical light-curve modelling using MINIM with those found in case of other well-studied SLSNe I (see Fig. 10): SN 2005ap, SCP06F6, 2007bi (Chatzopoulos et al. 2013), SN 2010gx, PTF10hgi, PTF11rks, SN 2011ke, SN 2011kf, SN 2012Ji (Inserra et al. 2013), PTF12dam (Nicholl et al. 2013), LSQ12df, SSS120810, SN 2013dg (Nicholl et al. 2014), SN 2013bn (Nicholl et al. 2016), Gaia16apd (Kangas et al. 2017), SN 2006oa, SNLS-07D2bv, SNLS-06D4eu, PTF09atu, PS1-10pm, PS1-10ahf, PS1-10ky, PS1-10awh, PS1-10bq, PTF12gy, LSQ14mo, GRB111209A/SN 2011kl, iPTF15ecn, iPTF16bad, Gaia16apd, DES sample (Angus 2019).
2017), PTF09cdw, PTF09cwj, PTF10bhp, PTF10qvy, PTF10vvg, PTF11dij, PTF12gty, PTF12mnx, PTF13aig (De Cia et al. 2018). SN 2010kd (Kumar et al. 2020), and the sample of SLSNe I from the Dark Energy Survey (DES; Angus et al. 2019). We also consider SN 2011kl for comparison, as this is the only case having confirmed association of an SLSN with a long GRB, favouring a central engine driven powering source (Bersten et al. 2016; Kann et al. 2019; Lin et al. 2020a). However, we also caution that distinct methods were used in different studies to estimate these parameters.

In the left-hand panel of Fig. 10, we present $P_i$ versus $B$ derived for SN 2020ank with other well-studied SLSNe I discussed above, whereas middle and right-hand panels show comparisons of the $M_j$ versus $B$ and $P_i$, respectively. Most of the SLSNe I presented here have $P_i$ and $B$ values varying in the range of $\sim 1-8$ ms and $\sim (1-8) \times 10^{14}$ Gauss, respectively, whereas $M_j$ values vary from $\sim 1$ to $25 M_\odot$. Overall, most of the slow-evolving SLSNe I (e.g., SN 2010kd and SN 2015bn) appear to have larger $M_j$ values in comparison to those exhibited by the fast-evolving SLSNe I (e.g., SN 2010gx and SN 2011kl), as also stated by Könyves-Tóth & Vinkó (2020). In the case of SN 2020ank, the values of $P_i$ ($\sim 2.23 \pm 0.51$ ms), $B$ ($\sim (2.91 + 0.07) \times 10^{14}$ G), and $M_j$ ($\sim 3.58 \pm 0.04 M_\odot$) are consistent with those found for other well-studied SLSNe I. However, the $P_i$ value of SN 2020ank is closer to PS1-10ahf and PS1-11bam, the $B$ is similar to DES14X3ta and DES17C3gyp (Angus et al. 2019), and the $M_j$ is consistent with that derived for PS1-11bam and LSQ12dlf. Whereas, the $M_j$ estimated for SN 2020ank ($\sim 3.58 \pm 0.04 M_\odot$) is also closer to the $M_j$ obtained for SN 2011kl ($\sim 3.22 \pm 1.47 M_\odot$; Lin et al. 2020a). The value of $P_i$ for SN 2020ank is higher whereas $B$ value is lower as compared to those obtained for SN 2011kl ($P_i \sim 0.36-0.78$ ms and $B \sim (3.1-6.8) \times 10^{14}$ G, respectively, see Bersten et al. 2016; Lin et al. 2020a). This is evident in the left-hand panel of Fig. 10 that the GRB associated SN 2011kl shows the highest value of $B$ and lowest value of $P_i$ among all the SLSNe I of the sample (except for SN 2010gx and SN 2013dg).

5 SPECTROSCOPIC ANALYSIS OF SN 2020ank

In this section, we investigate the spectral properties of SN 2020ank using spectral observations taken at six epochs (see Section 2 and Table 6). Spectra of SN 2020ank, spanning a duration of about 14 d starting from $\sim -1$ to +13 d (rest frame), are plotted in Fig. 11. The phase of each individual spectrum with respect to the g-band maximum (in d) is marked on the right-hand side of each spectrum in Table 6. Spectra of SN 2020ank, spanning a duration of about 14 d (rest frame), are plotted in Fig. 11. The near-peak spectrum (at $\sim 0.74$ d) of SN 2020ank are dominated by the W-shaped $O\,\text{II}$ features, whereas the weak $C\,\text{II}$ and $Fe\,\text{II}$ lines can also be traced. The HCT-2.0m spectra are smoothed using the Savitzky–Golay method (Quimby et al. 2018), and the smoothed spectra are overplotted with the magenta colour. The near-peak spectrum (at $\sim 0.74$ d) is regenerated using the SYNAPPS code (Thomas et al. 2011) and shown in the red. The near-peak spectra are dominated by the W-shaped $O\,\text{II}$ features, whereas the weak $C\,\text{II}$ and $Fe\,\text{II}$ lines can also be traced.

Figure 11. Galactic extinction corrected spectra of SN 2020ank in the rest-frame wavelengths are shown. The phase with respect to the g-band maximum is also mentioned on the right-hand side of each spectrum in their respective colours. The HCT-2.0m spectra are smoothed using the Savitzky–Golay smoothing method (Quimby et al. 2018), and the smoothed spectra are overplotted with the magenta colour. The near-peak spectrum (at $\sim 0.74$ d) is regenerated using the SYNAPPS code (Thomas et al. 2011) and shown in the red. The near-peak spectra are dominated by the W-shaped $O\,\text{II}$ features, whereas the weak $C\,\text{II}$ and $Fe\,\text{II}$ lines can also be traced.
The parametrized spectrum synthesis code SYNAPPS (Thomas et al. 2011) is a rewritten, automated, and improved version of the SYNOW code (written in C++ 2011) is a rewritten, automated, and improved version of the SYNAPPS spectral modelling. Consequently, we used the SYNAPPS (Thomas et al. 2011) code to attempt the spectral modelling of the near-peak spectrum (at ∼0.74 d since g-band maximum, whereas ∼28.4 d since explosion) of SN 2020ank. We were unable to perform it for the post-peak spectra taken with the HCT-2.0m, because of the poor signal-to-noise ratio. We also present the contributions from the individual ions to reproduce the near-peak spectrum of SN 2020ank using the SYN++ (Thomas et al. 2011) and the output obtained from the SYNAPPS code, see Fig. 12. All the prominent features are well reproduced by the code. The local fitting parameters (log τ, v_{min}, v_{max}, aux, and T) for individual ions obtained from the SYNAPPS spectral fitting are tabulated in Table 7. The global parameters (a_0, a_1, a_2, v_{ph}, and T_{ph}) are presented in upper-right side of Fig. 12 itself. The synthetic spectrum is obtained using the SYNAPPS code uses well-structured input known as a Y AM file consisting of different global and local parameters. The global parameters are the photospheric velocity (v_{ph}), the outer velocity of the line-forming regions (v_{out}), BB photosphere temperature (T_{ph}), and the coefficients of quadratic warping function (a_0, a_1, and a_2), which are applied to the synthetic spectrum to match the observed ones. Global parameters decide the overall shape of the spectrum. On the other hand, local parameters like the line opacity (τ), lower and upper cutoff velocities (v_{min} and v_{max}, respectively), aux parameter (aux), and the Boltzmann excitation temperature (T) depend on the individual profiles of the different elements.

In SN ejecta, matter density in shells above the photosphere could be described by two different laws. The first one is the power law with index “n” (v ∝ r^n), which is set for all compositions of ions in the model. The second one is the exponential law with the parameter e-folding velocity "v_{e-folding}" (v ∝ exp(-v/v_{e-folding})), which could be changed for each ion independently. We checked both the cases for our analysis and found that the exponential law is more reliable for fine-tuning. The SYNAPPS code can calculate two shapes of the line profile. The first case corresponds to a layer un-detached from the photosphere, giving rise to conspicuous emission and more gentle sloping to the absorption part of the profile. The second case (detached) describes a layer that has a larger v_{exp} than the photosphere. Therefore, there is a gap between the photosphere and successive layers. In our case, the lines arising due to the O_II, C_II, and Fe_II elements are considered as detached from the photosphere as they exhibit higher velocities in comparison to v_{ph}. In summary, we suppose that the real distribution of matter densities in these layers could enormously differ from the model conceptions but could be used to describe the more conspicuous and dense part of layers.

A better signal-to-noise ratio of the spectra taken using the GTC-10.4m and P200-5.1m provided an opportunity to perform the SYNAPPS spectral modelling. Consequently, we used the SYNAPPS (Thomas et al. 2011) code to attempt the spectral modelling of the near-peak spectrum (at ∼0.74 d since g-band maximum, whereas ∼28.4 d since explosion) of SN 2020ank. We were unable to perform it for the post-peak spectra taken with the HCT-2.0m, because of the poor signal-to-noise ratio. We also present the contributions from the individual ions to reproduce the near-peak spectrum of SN 2020ank using the SYN++ (Thomas et al. 2011) and the output obtained from the SYNAPPS code, see Fig. 12. All the prominent features are well reproduced by the code. The local fitting parameters (log τ, v_{min}, v_{max}, aux, and T) for individual ions obtained from the SYNAPPS spectral fitting are tabulated in Table 7. The global parameters (a_0, a_1, a_2, v_{ph}, and T_{ph}) are presented in upper-right side of Fig. 12 itself. The synthetic spectrum is obtained using the C_II, O_II, and Fe_II ions, however, the bluer region (from ∼ 3400 to 4500 Å) is mainly dominated by the W-shaped O_II features.

### Table 6. Log of the spectroscopic observations of SN 2020ank.

| Date (UT) | MJD | Phase * | Instrument   | Wavelength (Å) | Resolution (Å) | Exposure time (s) | Telescope |
|-----------|-----|---------|--------------|----------------|---------------|------------------|-----------|
| 2020 Feb 13 | 58,892.926 | −1.084 | OSIRIS | 3660–7800 | 2.1 | 900 | GTC-10.4m |
| 2020 Feb 14 | 58,893.360 | −0.737 | DBSP | 3400–10,500 | 1.5 | 500 | P200-5.1m |
| 2020 Feb 19 | 58,898.000 | +2.980 | HFOSC | 3500–7800 | 8 | 2700 | HCT-2.0m |
| 2020 Feb 20 | 58,899.000 | +3.781 | HFOSC | 3500–7800 | 8 | 3600 | HCT-2.0m |
| 2020 Mar 02 | 58,910.000 | +12.591 | HFOSC | 3500–7800 | 8 | 2700 | HCT-2.0m |
| 2020 Mar 03 | 58,911.000 | +13.392 | HFOSC | 3500–7800 | 8 | 3600 | HCT-2.0m |

*Phase is given in the rest-frame d since g-band maximum. b Downloaded from the TNS; [https://wis-tns.weizmann.ac.il/object/2020ank](https://wis-tns.weizmann.ac.il/object/2020ank)

![Figure 12. The near-peak spectrum of SN 2020ank and the synthetic spectrum (in red) obtained by the SYNAPPS (Thomas et al. 2011) spectral fitting are shown in the bottom. Individual ion contributions for all the elements that were used to regenerate the best-fitting spectrum are also shown. All the prominent spectral features are well generated by the code using C_II, O_II, and Fe_II elements. The bluer region (from ∼3400 to 4500 Å) of the spectrum is dominated by the W-shaped O_II features. The C_II and O_II features are at higher velocities (∼16500 and 17730 km s⁻¹, respectively) in comparison to Fe_II line velocity (∼13100 km s⁻¹).](image-url)
~14810 K and the $v_{\text{ph}}$ of ~12050 km s$^{-1}$ are obtained. It is noteworthy that the estimated $v_{\text{ph}}$ is consistent within the error bars with the $v_{\text{exp}}$ ~12270 ± 900 km s$^{-1}$ obtained from the bolometric light-curve modelling using the MINIM code (see Section 4.1). Also, $T_{\text{ph}}$ obtained through the SYNAPPS spectral fitting (~14810 K) closely matched to those independently derived using BB fitting to the spectrum (~14800 ± 300 K) and BB fitting to the photometric SED (~15400 ± 800 K) at similar epoch. The absorption minima of lines interpreted as C ii and O ii were fitted by larger velocities (~16500 and 17750 km s$^{-1}$, respectively) than for Fe iii (~13100 km s$^{-1}$), see Table 7. However, this spectrum of SN 2020ank could also be modelled using O ii and C iii in place of O ii and C ii (Hatanano et al. 1999) as suggested by Könyves-Tóth et al. (2020) for the fast-evolving SLSN 2019neq. Using the equations 4 and 6 of Könyves-Tóth et al. (2020), we also estimated the number density of ions at the lower level of the transition ($n_i$), full number density of the ion (N), and the mass density (ρ, in eV) for the C ii and Fe iii ions (see Table 7). To calculate the same, we obtained the statistical weight of the lower level (g) and the partition function (ζ(T)) from the National Institute of Standards and Technology9, and also tabulated these values in Table 7. The oscillator strength (f) and the excitation potential of the lower level (g) are adopted from Hatanano et al. (1999), whereas values of τ and T are taken from the SYNAPPS spectral fitting. We are unable to calculate the values of n$_i$, N, and ρ for O ii ion because the reference line for O ii ion is considered as a forbidden transition by Hatanano et al. (1999), as also stated by Könyves-Tóth et al. (2020).

Using the estimated $v_{\text{ph}}$ from the SYNAPPS spectral fitting and a rise time ($t_r$, time since date of explosion to the peak bolometric luminosity) of ~27.9 ± 1.0 d (rest-frame), we computed photospheric radius ($r_{\text{ph}}$) of ~2.4 × 10$^{15}$ cm and total optical depth ($\tau_{\text{tot}}$) of ~74.6 for SN 2020ank. The details about methods of calculation of the above-discussed parameters are well described in Könyves-Tóth et al. (2020). In the case of SN 2020ank, the value of $r_{\text{ph}}$ is lower and $\tau_{\text{tot}}$ is higher in comparison to those estimated for slow-evolving SN 2010kl ($r_{\text{ph}}$ ~6.2 × 10$^{15}$ cm and $\tau_{\text{tot}}$ ~60) and fast-evolving SN 2019neq ($r_{\text{ph}}$ ~5.1 × 10$^{15}$ cm and $\tau_{\text{tot}}$ ~43) by Könyves-Tóth et al. (2020). Using the above discussed values of $v_{\text{ph}}$ and $t_r$, we also estimated the $M_{\text{ej}}$ (~7.2 ± 0.5 M$_{\odot}$) and kinetic energy ($E_k$ ~6.3 ± 0.1) × 10$^{51}$ erg for SN 2020ank applying equations 1 and 3 of Wheeler et al. (2015). The estimated value of $E_k$ for SN 2020ank is nearly 2 to 3 times higher than what neutrino driven explosion can give at maximum and favours a jet feedback mechanism (Soker 2016; Soker & Gilkis 2017). The calculated $M_{\text{ej}}$ ~7.2 ± 0.5 M$_{\odot}$ of SN 2020ank (using the spectral analysis) is higher than the $M_{\text{ej}}$ obtained from the semi-analytical light-curve modelling (~3.58 ± 0.04 M$_{\odot}$) using the MINIM code (see Section 4.1). Comparatively lower value of $M_{\text{ej}}$ obtained using the light-curve modelling might attribute to the underestimation of the peak luminosity by the MAG model. The estimated $M_{\text{ej}}$ value of SN 2020ank is lower in comparison to the well-studied slow-evolving PTF12dam (~10 - 16 M$_{\odot}$; Nicholl et al. 2013), whereas closer to the fast-evolving SN 2010gx (~ 7.1 M$_{\odot}$; Inserra et al. 2013).

### 5.2 Spectral comparison

In the section, we compare the near-peak spectrum of SN 2020ank (in red) with the spectra of SN 2010gx (fast-evolving; Pastorello et al. 2010), PTF12dam (slow-evolving; Nicholl et al. 2013), and Gaia16apd (intermediate-decaying; Kangas et al. 2017; Nicholl et al. 2017a), see Fig. 13. Overall, the spectral features of SN 2020ank are similar to the three other SLSNe I. The near-peak spectrum of SN 2020ank appears to closely match with the spectrum of SN 2010gx at ~3 d. The closely matched absorption features of SN 2020ank with those of SN 2010gx indicate nearly equal ejecta velocities. The spectral features of SN 2020ank also match well with the ~3 d spectrum of Gaia16apd, however, the minima of the absorption features fall at bluer wavelengths, indicating higher ejecta velocity as compared to Gaia16apd. The close spectral resemblance of SN 2020ank with SN 2010gx puts it in the category of “SN 2011ke-like” (fast-evolving) SLSN, as suggested by Quimby et al. (2018). To confirm this fast-spectral evolution, we compare the near-peak spectrum of SN 2020ank with the near- and post-peak spectra (at +22 d) of PTF12dam (slow-evolving). The near-peak spectral features of SN 2020ank appear similar to that observed in the spectrum of PTF12dam at +22 d, confirming the comparatively faster spectral evolution of SN 2020ank.

### 6 RESULTS AND CONCLUSION

We have presented the early optical photometric and spectroscopic observations of the fast-evolving and bright SLSN 2020ank. The photometric data were obtained in the Bessell U, B, V, R, and I bands (from ~4 to +52.2, rest frame) using the ST-1.04m, HCT-2.0m, and the DOT-3.6m along with the publicly available SDSS g and r bands data (from ~36 d, rest frame) from the ZTF. The spectral analysis were performed on the post-peak spectra observed with the HCT-2.0m (from ~3 to +13 d, rest frame) at four epochs. These spectral data were also supplemented by two publicly available spectra obtained from the GTC-10.4m and the P200-5.1m (at ~1.08 and ~0.74 d, rest frame). Apart from providing well-calibrated photometric data of this newly discovered bright and fast-evolving SLSN, the main findings of the present analysis are the following:

1) The post-peak decay rate of SN 2020ank in the rest-frame $U$-band is consistent with the theoretical decay rate of $^{56}\text{Ni} \rightarrow ^{56}\text{Co}$ (0.11 mag d$^{-1}$) and turns shallower as we go towards redder bands (~0.05 mag d$^{-1}$ for $R$-band). Also, the light-curve decay of

Table 7. Best-fitting local parameters obtained using the SYNAPPS spectral fitting on the near-peak spectrum of SN 2020ank along with the inferred values of g, ζ(T), n$_i$, N, and ρ are listed.

| Element | log τ | $v_{\text{max}}$ (10$^3$ km s$^{-1}$) | $v_{\text{max}}$ (10$^3$ km s$^{-1}$) | aux | $T$ (10$^3$ K) | g | ζ(T) | log(n$_i$) cm$^{-3}$ | log(N) cm$^{-3}$ | log(ρ) g cm$^{-3}$ |
|---------|-------|-----------------------------------|-----------------------------------|-----|----------------|---|------|-----------------|----------------|----------------|
| C ii    | ~0.773| 16.500                            | 47.511                            | 4.068| 16.000         | 6 | 6.24 | 3.413           | 5.902           | ~16.798        |
| O ii    | 4.554 | 17.740                            | 31.934                            | 0.651| 12.522         | — | —    | —               | —               | —              |
| Fe iii  | 2.841 | 13.110                            | 36.871                            | 0.435| 13.234         | 7 | 34.48| 10.002          | 12.057          | ~9.795         |

9 https://www.nist.gov/pml/atomic-spectra-database
SN 2020ank seems steeper than other well-studied slow-decaying SLSNe I.

2) The well-sampled rest-frame $g$-band light curve exhibits a peak-absolute magnitude of $\sim -21.84 \pm 0.10$ mag, indicating SN 2020ank as one of the bright SLSNe I. The pre-peak rising and post-peak decaying rates of the light curve are similar to other well-studied fast-evolving SLSNe I (e.g., SN 2010gx, PTF11rks, and SN 2011ke) but comparatively steeper in comparison to the slow-evolving SLSNe I (e.g., SN 2010kd, PTF12dam, and SN 2015bn). However, the rest-frame $g-r$ colour evolution of SN 2020ank is not consistent with the fast-evolving SLSNe I and is closer to the slow-evolving ones.

3) The bolometric light curve of SN 2020ank is symmetric around the peak with $L_{\text{max}}/c \approx L_{\text{max}}/c \approx 15$ d and takes nearly 27 d to reach the $L_{\text{max}}$ of $\sim 4 \times 10^{44}$ erg s$^{-1}$. The estimated value of the $L_{\text{max}}$ for SN 2020ank is higher than SN 2010gx, SN 2010kd, PTF12dam, SN 2015bn, Gaia16apd, etc., whereas lower in comparison to that were observed for SN 2011ke, PTF13ajg, and ASASSN-15lh. Overall, the light-curve comparison of SN 2020ank with other well-studied slow- and fast-evolving SLSNe I suggests that it is a fast-evolving SLSN having a high peak brightness.

4) Semi-analytical light-curve modelling using MINIM rules out RD and the CSMI as possible powering mechanisms for SN 2020ank. Our findings suggest a spin-down millisecond magnetar having $P_0 \sim 2.23 \pm 0.51$ ms and $B \sim (2.91 \pm 0.07) \times 10^{14}$ G as possibly powering source with total ejected mass of $\sim 3.58 \pm 0.04 M_\odot$. The observed excess $UV$ flux near the peak in the case of SN 2020ank also supports the central engine based power source.

5) Spectroscopic analysis helped to probe chemical composition of the ejecta and constrain crucial physical parameters of SN 2020ank. The SYNAPPS spectral modelling reveals that the near-peak spectrum of SN 2020ank is dominated by the W-shaped O II features along with comparatively fewer contributions from the C II and Fe III species. The $T_{\text{ff}}$ ($\sim 14800$ K) and $v_{\text{ph}}$ ($\sim 12050$ km s$^{-1}$) estimated by the SYNAPPS code are consistent within error bars to the $T_{\text{ff}}$ calculated from SED fitting to the photometric data ($\sim 15400 \pm 800$ K) and $v_{\text{exp}}$ ($\sim 12270 \pm 900$ km s$^{-1}$) computed by the best fitted MAG model.

6) Using the value of $v_{\text{ph}}$ obtained from the SYNAPPS spectral fitting and assuming diffusion time-scale $\approx t_\text{d} (\sim 27.9 \pm 1.0$ d) with $\kappa = 0.1$ cm$^2$ g$^{-1}$, we constrain the $r_{\text{ph}}$ ($\sim 2.4 \times 10^{15}$ cm), $\tau_{\text{ext}}$ ($\sim 74.6$), $M_{\text{ej}}$ ($\sim 7.2 M_\odot$), and $E_\text{f}$ ($\sim 6.3 \times 10^{51}$ erg) for SN 2020ank.

7) The near-peak spectral comparison of SN 2020ank shows that the spectral features are similar to those observed in SN 2010gx and Gaia16apd. However, higher blueshifted absorption features in SN 2020ank than Gaia16apd indicate higher ejecta velocity in the former. The near-peak spectral similarity with SN 2010gx and apparent similarity with the spectrum of the PTF12dam (slow-evolving) at $+22$ d confirms comparatively faster spectral evolution of SN 2020ank.

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DATA AVAILABILITY

The photometric and spectroscopic data used in this work can be made available on request to the corresponding authors.

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