



SN 2018bsz: Significant Dust Formation in a Nearby Superluminous Supernova

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Abstract

We investigate the thermal emission and the extinction from dust associated with the nearby ($z = 0.0267$) superluminous supernova (SLSN) 2018bsz. Our dataset combines daily cadence, simultaneous optical and near-infrared (NIR) coverage up to ~ 100 days with late-time ($+1.7$ yr) mid-infrared (MIR) observations. At 230 days after the light-curve peak, the supernova (SN) is not detected in the optical, but shows a surprisingly strong NIR excess, with $r - J > 3$ mag and $r - K_s > 5$ mag. The temporal evolution of the infrared (IR) light curve allows us to assess whether the MIR emission originates from newly formed dust, either in the SN ejecta or in a postshock

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circumstellar shell, or instead from an IR echo produced by preexisting circumstellar or interstellar dust heated by the SN radiation. Our radiative-transfer modeling shows that the circumstellar and interstellar echo scenarios cannot simultaneously reproduce the observed IR luminosity and its temporal evolution, and we therefore disfavor these interpretations. In contrast, a scenario in which new dust forms in the SN ejecta at epochs $\gtrsim 200$ days provides a self-consistent explanation for the evolution of the SN flux. We can fit the spectral energy distribution well at +230 days with $5 \times 10^{-4} M_{\odot}$ of carbon dust, increasing over the following several hundred days to $10^{-2} M_{\odot}$ by +535 days. SN 2018bsz is the first SLSN showing evidence for dust formation within the SN ejecta, and appears to form 10 times more dust than normal core-collapse supernovae (SNe) at similar epochs. Together with their preference for low-mass, low-metallicity host galaxies, we suggest that superluminous SNe may be a significant contributor to dust formation in the early Universe.

Unified Astronomy Thesaurus concepts: [Supernovae \(1668\)](#)

Materials only available in the [online version of record](#): data behind figures

1. Introduction

Core-collapse supernovae (CCSNe) are considered to be significant sites of cosmic dust production (F. Cernuschi et al. 1967; F. Hoyle & N. C. Wickramasinghe 1970; for more recent reviews see C. Gall et al. 2011b; A. Sarangi et al. 2018b). Emission from newly formed dust has been seen in both CCSNe (e.g., I. J. Danziger et al. 1989; L. B. Lucy et al. 1989; A. Elmhamdi et al. 2004; R. Kotak et al. 2009; M. Matsuura et al. 2015) and in CCSN remnants (e.g., T. Douvion et al. 2001). Additionally, CO has been detected in the near-infrared (NIR) spectra of approximately 20 Type II (hydrogen-rich) supernovae (SNe II; e.g., P. J. McGregor et al. 1987; J. H. Elias et al. 1988; J. Spyromilio et al. 1988; S. J. Petuchowski et al. 1989; S. Lepp et al. 1990; M. Matsuura 2017; J. Rho et al. 2021, 2018; S. Davis et al. 2019), and in a few Type Ic (hydrogen-poor) SNe (e.g., J. Rho et al. 2021) about 100 days after the explosion. This is considered to be an indication of chemistry triggered in the SN ejecta, and can be regarded as a precursor to dust formation (e.g., T. Nozawa et al. 2003; A. Sarangi et al. 2018b). The amount of newly formed dust in nearby CCSNe typically ranges between 10^{-5} and $10^{-3} M_{\odot}$ (see reviews by C. Gall et al. 2011b; A. Sarangi et al. 2018b), and is usually estimated from observations taken within 3 yr after explosion, or in some cases even earlier. Dust masses inferred in SN remnants are generally larger; the average mostly ranges between 10^{-1} and $1 M_{\odot}$ (e.g., H. L. Gomez et al. 2012; I. De Looze et al. 2017; A. Bevan et al. 2017; H. Chawner et al. 2019). Notably, M. Matsuura et al. (2011) used the Herschel Space Observatory to observe the far-infrared (FIR) emission of SN 1987A in 2010 and found that a large dust mass of $\sim 0.4\text{--}0.7 M_{\odot}$ had formed in this SN. Recently, the James Webb Space Telescope (JWST) found self-absorption of the ejecta dust in SN 1987A (M. Matsuura et al. 2024), confirming earlier Atacama Large Millimeter/submillimeter Array results of a large amount of ejecta dust (P. Cigan et al. 2019).

Observations of the most distant quasars ($z > 6$) show evidence for large masses of dust in galaxies in the early Universe (e.g., F. Bertoldi et al. 2003; E. Dwek et al. 2007; V. Markov et al. 2025). This is a strong argument for SNe being important dust producers in the high- z Universe (e.g., H. Hirashita & A. Ferrara 2002; H. L. Morgan & M. G. Edmunds 2003; R. Maiolino et al. 2004; S. Bianchi & R. Schneider 2007; C. Gall et al. 2011a; F. Calura et al. 2014), since other channels such as asymptotic giant branch (AGB) stars (through stellar outflows) will not have had sufficient time to produce a large quantity of dust at such early epochs

(e.g., E. Dwek 1998; A. S. Ferrarotti & H. P. Gail 2006; E. Dwek & I. Cherchneff 2011). However, it has been suggested that the AGB stars may be an important contributor to dust formation by $z \sim 6 - 7$ (R. Valiante et al. 2009, 1916). Nonetheless, it is still a challenge to account for the large amount of dust in high- z galaxies (e.g., D. D. Clayton et al. 2001; P. Todini & A. Ferrara 2001; E. Dwek & I. Cherchneff 2011), and additional dust production mechanisms are required (e.g., M. Matsuura et al. 2009), such as grain growth in the interstellar medium (ISM; B. T. Draine 2003; A. Leśniewska & M. J. Michałowski 2019).

Superluminous supernovae (SLSNe) are massive stellar explosions which are 10–100 times brighter than normal CCSNe (R. M. Quimby et al. 2011; A. Gal-Yam 2019; C. Inserra 2019). SLSNe in general have higher explosion energies and more massive ejecta than normal CCSNe (e.g., M. Nicholl et al. 2015; T. J. Moriya et al. 2018), and are potentially very different sites for molecular and dust formation (see T. Nozawa et al. 2003; I. Cherchneff & E. Dwek 2009, 2010; T. Nozawa et al. 2011). SLSNe are suspected to be related to the first generation of stars in the Universe (A. Gal-Yam et al. 2009) and have so far been found at redshifts as high as $z \approx 2$ (Y. C. Pan et al. 2017; M. Smith et al. 2018; C. R. Angus et al. 2019) or even $z \approx 4$ (J. Cooke et al. 2012; C. Curtin et al. 2019; T. J. Moriya et al. 2019).

At low redshift Universe ($z < 2$), the most common Type I (hydrogen-poor) superluminous supernovae (SLSNe I; predominantly occur in dwarf galaxies with low stellar mass and low metallicity (J. D. Neill et al. 2011; T.-W. Chen et al. 2013; G. Leloudas et al. 2015; R. Lunnan et al. 2015; C. R. Angus et al. 2016; D. A. Perley et al. 2016; T.-W. Chen et al. 2017a; S. Schulze et al. 2018). Moreover, the dwarf galaxies hosting SLSNe I are often part of interacting systems (T.-W. Chen et al. 2017b; S. V. Ørum et al. 2020). Such host galaxies are expected to be similar to galaxies at high redshift (e.g., T. M. Heckman et al. 2005; C. Cardamone et al. 2009; F. Bian et al. 2016). As SLSNe I may arise from more massive progenitors (A. Jerkstrand et al. 2017; P. A. Mazzali et al. 2019), they could potentially produce more dust than normal CCSNe at similar metallicity. However, S. Gomez et al. (2024) placed only upper limits on the dust mass in the Type I superluminous supernova (SLSN I; 2017gci, namely $0.83 M_{\odot}$ at the 3σ level and $0.44 M_{\odot}$ at the 1σ level. A larger sample of SLSNe I will therefore be required to assess their role in the early formation and evolution of cosmic dust. By comparison, L. Sun et al. (2022) found that hydrogen-rich SLSNe appear to form dust masses about 10 times larger than those observed in normal CCSNe at similar epochs.

SN 2018bsz was classified as the closest SLSN I to date, at a redshift of $z = 0.0267$ (J. P. Anderson et al. 2018). It exhibited several unusual features, including a long plateau prior to maximum light and strong optical emission lines associated with C II. Late-time spectra show hydrogen, possibly indicating late-time interaction with an H-rich shell (e.g., L. Yan et al. 2015, 2017). M. Pursiainen et al. (2022) presented detailed analyses of extensive spectroscopic datasets of the source, and more photometric datasets will be presented elsewhere (R. Roy et al. 2026, in preparation), while in this paper, we focus on the late-time behavior and mid-infrared (MIR) properties of SN 2018bsz, in order to investigate what role SLSNe play in cosmic dust formation. For consistency, we adopt the same basic parameters for SN 2018bsz as used in the early-phase study by J. P. Anderson et al. (2018). We therefore assume a Hubble constant of $H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_\Lambda = 0.73$ and $\Omega_M = 0.27$ (D. N. Spergel et al. 2007). The corresponding luminosity distance $D_L = 111 \text{ Mpc}$ and a distance modulus of $\mu = 35.23 \pm 0.02 \text{ mag}$ are used for SN 2018bsz. The rest-frame phase is with respect to the r -band peak epoch (MJD = 58267.5). Throughout this paper, all magnitudes are reported in the AB system.

2. Observations

2.1. Imaging from Ultraviolet to MIR Wavelengths

We obtained multiband light curves for SN 2018bsz from the ultraviolet (UV) to the MIR with several telescopes. We used the UV/optical telescope (UVOT; P. W. A. Roming et al. 2005) on board the Neil Gehrels Swift Observatory (N. Gehrels et al. 2004), under three target-of-opportunity programs;⁴² the Gamma-Ray Burst Optical/Near-Infrared Detector (GROND; J. Greiner et al. 2008) mounted on the 2.2 m Max Planck Gesellschaft telescope at ESO’s La Silla Observatory in Chile, as part of the GREAT survey (T. W. Chen et al. 2018); and the IR spectrograph and imaging camera Son of ISAAC (SOFI) on the 3.58 m New Technology Telescope (NTT) in the framework of the extended Public ESO Spectroscopic Survey of Transient Objects (ePESSTO; S. J. Smartt et al. 2015) program. We were also awarded Director’s Discretionary Time on the Spitzer Space Telescope (M. W. Werner et al. 2004) using the Infrared Array Camera (IRAC) instrument (G. G. Fazio et al. 2004) for late-time observations.⁴³ In addition, archival MIR observations of the field of SN 2018bsz were taken by the Near Earth Object Wide-field Infrared Survey Explorer (NEOWISE; A. Mainzer et al. 2011) project using the Wide-field Infrared Survey Explorer (WISE; E. L. Wright et al. 2010), obtained as part of the NEOWISE Reactivation survey (NEOWISE-R; A. Mainzer et al. 2014).

We discuss the data reduction, photometric calibration and template subtraction for these images in detail in Appendix A. Photometry on our optical and NIR images was obtained using the custom-built photometry pipeline AutoPhOT (S. J. Brennan & M. Fraser 2022); the version of the software used in this work is archived on Zenodo (S. Brennan 2026). All magnitudes have been measured after subtraction of the background host galaxy (Tables A1–A6). Figure 1 shows our assembled multiband light curves for SN 2018bsz from 2 days after peak (+2 days) to +535 days, combined with the prepeak ATLAS light curves from J. P. Anderson et al. (2018).

2.2. Optical and NIR Spectroscopy

We also obtained a number of optical and NIR spectra for SN 2018bsz. At +17 days, we used the Spectrograph for INtegral Field Observations in the Near Infrared (SINFONI) instrument (F. Eisenhauer et al. 2003), mounted on the ESO 8 m Very Large Telescope (VLT), to observe SN 2018bsz and the surrounding H II regions. A spectrum at +77 days was taken with the integral field unit (IFU) Wide-Field Spectrograph (WiFeS; M. Dopita et al. 2007), mounted on the Australian National University (ANU) 2.3 m telescope. A +108 day spectrum was observed with the ESO Faint Object Spectrograph and Camera (EFOSC2; B. Buzzoni et al. 1984) on the NTT through the ePESSTO Collaboration. After the SN emerged from solar conjunction, we attempted a late-time observation with X-Shooter (J. Vernet et al. 2011), mounted on the VLT, between +327 and +383 days. No SN trace was detected. Finally, we used the Multi-Unit Spectroscopic Explorer (MUSE; R. Bacon et al. 2010) to observe the host galaxy environment after the SN had faded at +417 days.

The instrumental configurations are listed in Table B1, and we describe the data reduction in detail in Appendix B. We show these optical spectra of SN 2018bsz in Figure 2, while we plot the NIR spectra in Figure B1. The complete set of spectra obtained for SN 2018bsz is presented and analyzed in M. Pursiainen et al. (2022). The spectra shown in Figures 2 and B1 are publicly available through WISEREP (O. Yaron & A. Gal-Yam 2012) and are provided as Data behind the Figure.

3. Observational Characteristics of SN 2018bsz

3.1. Extinction

Several sources can contribute to the extinction toward SN 2018bsz: a foreground (Milky Way) component; interstellar extinction within the host galaxy 2MASX J16093905-3203443; and (potentially) any circumstellar extinction surrounding the progenitor. The first of these components can be determined from Milky Way dust maps to be $E(B - V)_{\text{MW}} = 0.214 \text{ mag}$ (E. F. Schlafly & D. P. Finkbeiner 2011). The latter two components are more problematic, and we consider a number of indirect approximate methods to measure them.

We extracted the host galaxy spectrum from our MUSE data cube at the position of SN 2018bsz using a circular aperture with 0.6 radius. After correcting for Milky Way extinction, we fitted and removed the stellar continuum using STARLIGHT (R. Cid Fernandes et al. 2005), and then measured the Balmer decrement in the spectrum. Assuming that the intrinsic value of the Balmer decrement of $H\alpha/H\beta$ is 2.86 (D. E. Osterbrock 1989), we found $E(B - V)_{\text{host}}$ to be $\sim 0.32 \text{ mag}$. The host of SN 2018bsz is part of an interacting galaxy pair, where in principle one may expect relatively high amounts of dust from active star formation (e.g., L. Lanz et al. 2013).

However, if we were to apply such a high extinction correction to the SN, the spectral energy distribution (SED) fits would become poor assuming a blackbody, and the uncertainty of the derived temperature of SN 2018bsz increases by 25%. It would become $>18,800 \text{ K}$ at 3–20 days after the peak. The inferred temperature is higher (by $\sim 5000 \text{ K}$) and outside of the 3σ temperature range of other SLSNe I at the same phase (see Figure A1; C. Inserra et al. 2018b).

We tested a range of different extinctions for SN 2018bsz and found that $E(B - V)_{\text{host}}$ between 0.03 and 0.10 mag can give a reasonable agreement with the temperature evolution of

⁴² PIs: Brown, Dong, Roy, and Schulze.

⁴³ Program ID: 14273, PI: Chen.

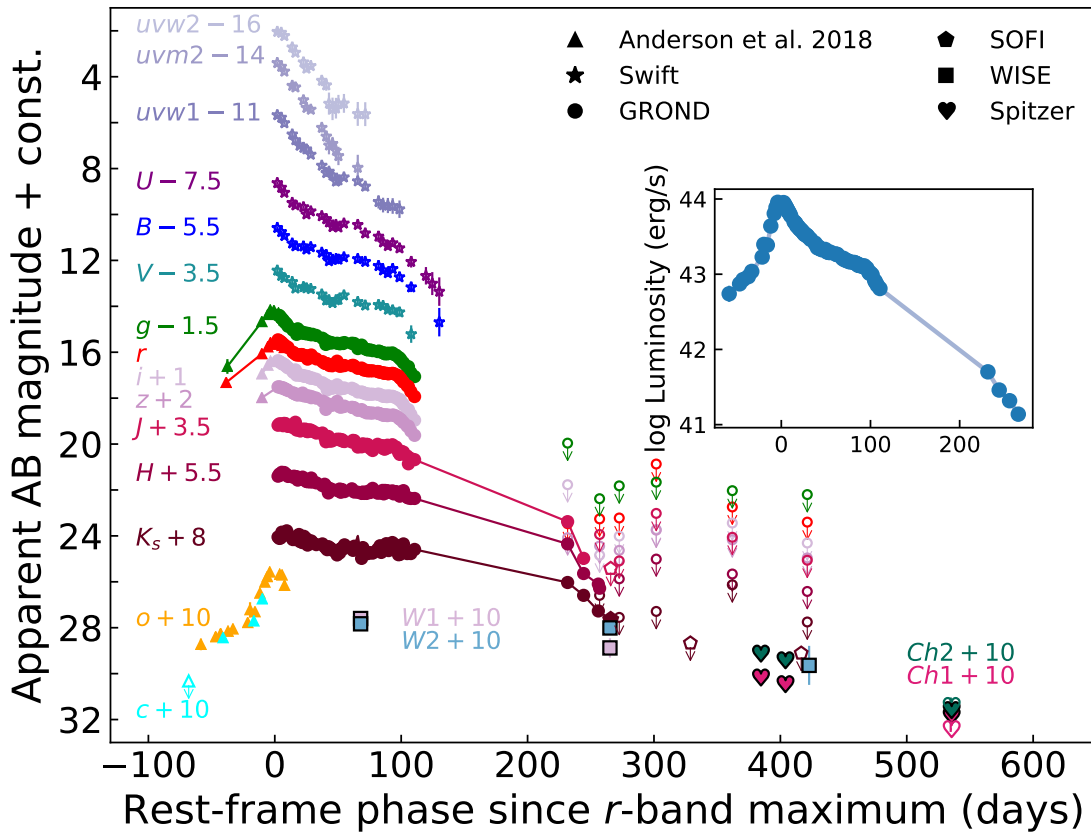


Figure 1. Multiband, host-subtracted light curves of SN 2018bsz. Photometric measurements have not been corrected for Milky Way or host galaxy extinction. The prepeak light curves are taken from J. P. Anderson et al. (2018). Marker shapes indicate data points taken using different facilities. The open symbols show 3σ detection limits. The inset panel shows the bolometric light curve of SN 2018bsz (uncertainties are smaller than the point size). Note that at late-time phases (>200 days), the SN was not detected in the optical but still detected in the NIR bands, with $r - K_s > 5$ mag.

other SLSNe at 3–20 days after the peak. J. P. Anderson et al. (2018) used $E(B - V)_{\text{host}} = 0.04$ mag derived from the equivalent width of the sodium doublet (Na I D) lines (D. Poznanski et al. 2012). For consistency, we also adopt this value here, corresponding to host $A_V = 0.13$ mag assuming the Galactic $R_V = 3.1$ (J. A. Cardelli et al. 1989). In addition, we also obtained a similar $A_V = 0.15$ mag from our STARLIGHT best fit results. Moreover, we used the spectrum of SN 2018bsz (J. P. Anderson et al. 2018) taken before our first epoch of multiband photometry to fit a blackbody. At phase -8 days, adopting host $A_V = 0.13$ mag, the inferred temperature is $\sim 13,700$ K; while assuming host $A_V = 1$ mag, it becomes $\sim 41,000$ K, which is not physically possible.

SN 2018bsz seems to lie toward the outskirts of its host and could well be positioned in the foreground, which may explain the relatively moderate reddening ($A_V = 0.13$ mag) compared to that inferred from the Balmer decrement ($A_V \sim 1$ mag). Since the Balmer decrement measurement is based on an aperture covering multiple H II regions, it does not necessarily reflect the line-of-sight extinction at the SN 2018bsz site. We therefore adopt $A_V = 0.13$ mag for the host galaxy extinction, and $A_V = 0.66$ mag for the Milky Way extinction when correcting the SN photometry and spectroscopy, unless otherwise noted.

3.2. Light Curve and Bolometric Light Curve

We have observational coverage for SN 2018bsz from UV, optical, NIR, and (for the first time for an SLSN) MIR wavelengths. Figure 1 shows our multiband light curve for

SN 2018bsz. The daily cadence over more than 100 days makes SN 2018bsz the best monitored SLSN to date, and it is also the first SLSN with daily contemporaneous seven-band coverage from optical to the NIR, thanks to GROND (Figure A2).

The early-time evolution of SN 2018bsz was presented in J. P. Anderson et al. (2018), showing an ATLAS o -band light curve with a long plateau slowly rising for ~ 43 days during the premaximum phase. The SN then displayed a steeper rise in magnitude for the next ~ 18 days in all optical bands. It reached a peak brightness at an absolute magnitude of -20.3 mag in the r band. In this paper, we focus on the evolution after the peak, where the r -band light curve displays three phases. Initially, the SN’s brightness fell steeply for 18 days, after which it entered a long, slowly diminishing plateau lasting 78 days. Finally, in the 15 days prior to solar conjunction, it dimmed by 1 mag. The evolution was similar in the other optical bands, but with a shallower decline in the NIR. After the SN emerged from behind the Sun, it was no longer detected at optical wavelengths, with $r > 23.5$ mag on $+232$ days. At the same time, surprisingly, we found the SN was still detected in the NIR bands with $J \sim 19.9$, $H \sim 18.9$, and it was brightest in K_s with ~ 18.0 mag.

We constructed a bolometric light curve of SN 2018bsz (see the inset panel in Figure 1) integrating over the full wavelength range from the UV to MIR. We have relatively sparse MIR coverage; hence, we smoothly interpolate the MIR data between the epochs $+68$ and $+265$ days. Although there is no MIR data before 68 days, the fractional MIR luminosity at

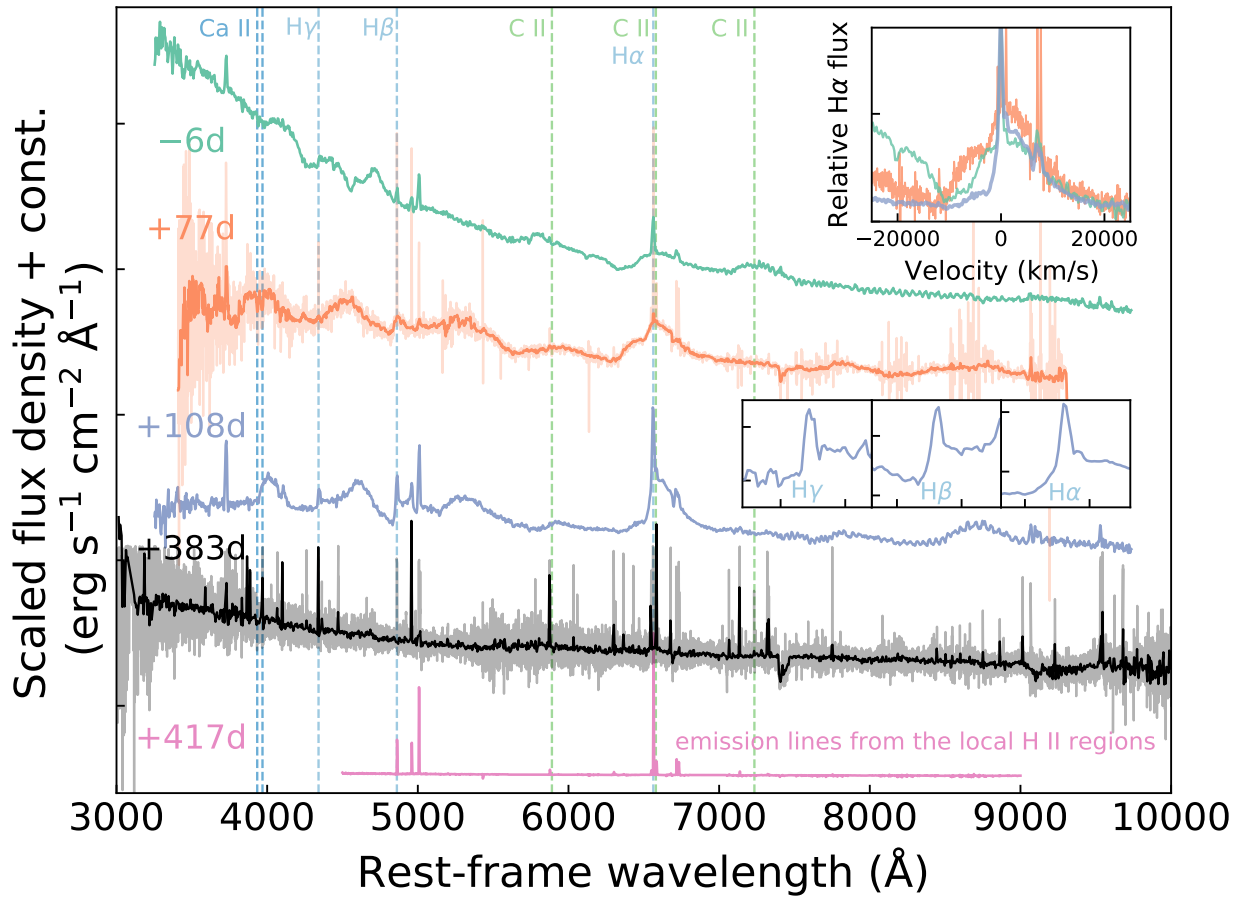


Figure 2. Spectroscopic evolution of SN 2018bsz. The -6 day spectrum is taken from J. P. Anderson et al. (2018). The Balmer lines have emerged by $+77$ days in our WiFeS spectrum (the darker line has been rebinned to $20 \text{ \AA}$). Interestingly, a strong asymmetry in the line profiles of all Balmer lines (see lower inset panels for zoom) appears in the $+108$ day EFOSC2 spectrum. This spectrum was previously presented by M. Pursiainen et al. (2022). No SN trace has been detected in the $+383$ day X-Shooter spectrum (the darker line has been binned to $5 \text{ \AA}$). The $+417$ day spectrum was extracted from the MUSE cube at the SN position. After subtracting the stellar continuum, we highlight the strong narrow emission lines from the local H II regions (pink line). The upper inset shows a zoom-in around H α , where the flux has been scaled to match the same continuum level as on the red side of the line. The spectra shown in this figure are provided as Data behind the Figure.

(The data used to create this figure are available in the [online article](#).)

$+68$ days (only 1%) suggests that the early-time contribution of the MIR is negligible. We describe in more detail the method used for constructing the bolometric light curve of SN 2018bsz and estimating the relative fractions of energy emitted in the different wavelength ranges in Appendix C.

After peak luminosity ($\sim 9 \times 10^{43} \text{ erg s}^{-1}$), the bolometric light curve declines rapidly for 16 days, by which time the luminosity has decreased by $\sim 50\%$ (to $\sim 4.7 \times 10^{43} \text{ erg s}^{-1}$). The bolometric light curve then continues to decline slowly; between $+17$ and $+40$ days, it drops another $\sim 50\%$ in luminosity. Subsequently, from $+41$ to $+96$ days, SN 2018bsz further slows its decline rate, taking around twice as long to fade by another $\sim 50\%$. At $+98$ days, the light curve shows a sudden drop in luminosity of roughly 40% in less than 13 days (to $\sim 6.5 \times 10^{42} \text{ erg s}^{-1}$). Unfortunately, our observing campaign was terminated at this epoch as SN 2018bsz went behind the Sun. When the SN became observable again at $+232$ days, it was 13 times fainter ($\sim 5 \times 10^{41} \text{ erg s}^{-1}$) than the last observation at $+111$ days. At late-time phases, there is no measurable contribution from the UV and optical to the luminosity, which is instead dominated by the NIR and MIR emission.

To construct representative SEDs for multi-epoch fitting in Figure 3, we selected a series of photometric epochs that sample the key phases of the light-curve evolution and combine data from UV to IR wavelengths (Tables A1–A6). The early photometric epochs were chosen to represent key stages of the light-curve evolution and to ensure sufficient wavelength coverage for the SED fitting. Specifically, we selected the first GROND epoch at $+2$ days to characterize the early postmaximum phase, the $+50$ and $+100$ day epochs to sample the middle and the end of the plateau phase, and another epoch around $+110$ days corresponding to the last GROND observation obtained before the solar conjunction, when the light curve was declining. The Swift/UVOT magnitudes closest in time to each of these GROND epochs were included to extend the SED coverage into the UV bands.

For the late-time evolution, we focus on the NIR and MIR observations. The $+230$ day epoch corresponds to the first GROND observation after the solar conjunction. The $+265$ day epoch combines SOFI and NEOWISE data, together with GROND photometry taken near $+257$ and $+273$ days. The $+300$ day epoch is represented by GROND upper limits, while the $+380$ day epoch includes Spitzer magnitudes and GROND limits obtained at $+362$ days. At $+420$ days, Spitzer

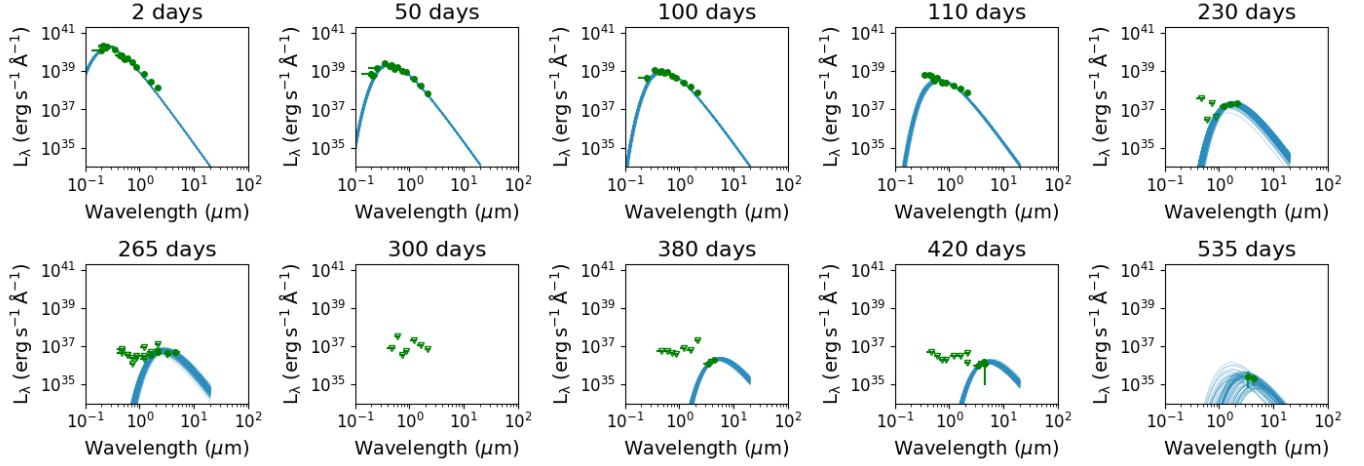


Figure 3. SED fitting for SN 2018bsz at selected epochs. The luminosities were converted from the observed magnitudes after correcting for the Milky Way extinction (green circles) while empty triangles denote 3σ upper limits. The corresponding blackbody temperatures and radii are listed in Table 1.

and NEOWISE detections are supplemented by SOFI and GROND upper limits between +417 and +423 days. Finally, the +535 days epoch includes the Spitzer photometry, providing the latest constraints on the IR emission. We also use these selected epochs for the dust modeling in Section 4.

We investigated whether there is a two-component SED by fitting the photometry at the early epochs with a blackbody function. We found that we do not require two distinct components at those epochs, and instead a single blackbody can fit the observed SED well (see Figure 3). Furthermore, we fitted the SED with a blackbody using a Monte Carlo method, and listed the inferred blackbody temperature and radius evolution in Table 1.

Table 1
Blackbody Temperature and Radius Evolution at Selected Epochs

Phase (day)	Temperature (K)	Radius (10^{15} cm)
+2.6	12,540 ($^{+660}_{-680}$)	2.01 ($^{+0.18}_{-0.17}$)
+50	6800 ($^{+540}_{-430}$)	3.07 ($^{+0.37}_{-0.39}$)
+100	5770 ($^{+350}_{-480}$)	3.08 ($^{+0.45}_{-0.34}$)
+110	4340 ($^{+350}_{-500}$)	3.77 ($^{+0.72}_{-0.55}$)
+230	1630 ($^{+290}_{-330}$)	10.99 ($^{+6.51}_{-5.28}$)
+265	1040 ($^{+220}_{-160}$)	18.16 ($^{+9.80}_{-12.92}$)
+380	530 ($^{+60}_{-60}$)	57.09 ($^{+24.71}_{-17.29}$)
+420	530 ($^{+70}_{-60}$)	48.53 ($^{+22.55}_{-16.12}$)
+535	960 ($^{+480}_{-400}$)	4.44 ($^{+4.80}_{-3.30}$)

3.3. Late-time Hydrogen from Circumstellar Material

The spectroscopic evolution of SN 2018bsz based on spectra obtained at key phases is presented in Figure 2. At early phases, J. P. Anderson et al. (2018) suggested that no hydrogen was visible in the spectra of SN 2018bsz, and that the broad, strong feature at ~ 6500 Å was not H α but rather CII λ 6580 at a velocity of $-11,000$ km s $^{-1}$. J. P. Anderson et al. (2018) suggested that the absence of H β further strengthened the claim of SN 2018bz being hydrogen-poor. The presence of other CII features at 5890, 7234 Å meant that carbon was a plausible identification for these lines. In our +17 day NIR SINFONI spectrum (Figure B1), we see no broad SN emission at the wavelength of Pa α , confirming the lack of spectral signatures of H in the ejecta around maximum light.

By +77 days, however, it is clear that hydrogen is indeed present in the spectra of SN 2018bsz. At +108 days, a peculiar line profile characterized by a sharp cutoff in flux in the blue is seen in H α , and an identical profile is also seen in H β and H γ , making this a secure identification. We interpret the late-time appearance of hydrogen as a sign of interaction between the ejecta and H-rich circumstellar material (CSM). Somewhat unusually, by +108 days the Balmer line profiles are strongly asymmetric, with the blue side of the line being suppressed. The asymmetric shape of the line profiles can be explained by the asymmetric shape of the CSM where these lines are emitted, most likely from a disk or torus (M. Pursiainen et al. 2022). Moreover, J. R. Maund et al. (2021) detect strong

polarization in SN 2018bsz during the postpeak phase, providing independent evidence for asymmetric geometry.

3.4. Color Evolution and NIR Excess

During the first 75 days after maximum light, the colors of SN 2018bsz evolve slowly toward the red in most bands. If the steep optical decline around +100 days was caused by extinction from such dust, then we might have expected substantial reddening to be observed in the $(g-r)$, $(g-i)$, and $(g-z)$ color evolution between +98 and +111 days. However, we see no strong color changes as a function of wavelength during this period, with $(g-r) \sim 0.4 \Rightarrow 0.4$, $(g-i) \sim 0.2 \Rightarrow 0.2$, and $(g-z) \sim 0.3 \Rightarrow 0.4$. Similarly, the appearance of asymmetric Balmer profiles (Section 3.3) does not coincide with any strong change in the colors of SN 2018bsz. Therefore, the suppression of the blue emission is probably not due to dust extinction.

At +108 days, the spectrum of SN 2018bsz appears to be becoming optically thin (e.g., we see the disappearance of the absorption component in Ca). We therefore consider that the contemporaneous luminosity drop in all optical bands is most likely due to the ejecta transitioning to the nebular phase. Accompanying this, we see a slight redward color evolution, similar to what is seen in other SNe as they become nebular (for example, in SN 2004et; K. Maguire et al. 2010;

M. Shahbandeh et al. 2023). As for the earlier phases, we do not require any dust component to explain this evolution.

After the SN emerged from solar conjunction, it was not detected in deep imaging in the optical bands, but was still visible in the NIR bands. At +232 days, the colors were $r - J > 3.1$, $r - H > 4.1$, and $r - K_s > 4.9$ mag (the magnitudes are corrected for the Milky Way and the host galaxy dust extinction). Moreover, the SN shows a prominent K_s -band excess (see Figure C2). We measured a color $J - K_s = 1.73 \pm 0.21$ mag at +232 days, and an even redder color $J - K_s = 2.77 \pm 0.30$ mag at +244 days. The SOFI photometry at +266 days (with a color $J - K_s > 2.15$ mag) confirms this K_s -band excess from GROND.

This rapid evolution to red colors suggests either that new dust is condensing in the SN ejecta, or newly formed dust in the circumstellar envelope, or that there is an IR light echo from preexisting circumstellar dust or ISM heated by the SN. We investigate those scenarios in detail in Section 4.

4. Dust Modeling Results

IR emission from CCSNe may arise from new dust forming in the ejecta, a thermal echo from CSM, a thermal echo from nearby ISM, or newly formed dust in the circumstellar envelope. The origin of the emission (which could be from more than one of these mechanisms) may be inferred from the temporal evolution of the emission. New dust will form at a temperature close to the dust sublimation temperature, and if it is heated by the decay of radioactive elements in the ejecta, its luminosity will fade exponentially. In the case of an SLSN powered by the spin-down of a newly formed magnetar (D. Kasen & L. Bildsten 2010), the energy deposited in the expanding remnant would similarly be expected to decline quickly. On the other hand, SN-heated circumstellar or interstellar dust will in general have a temperature lower than the sublimation temperature of the constituent dust, as it was initially colder, but could be heated to any temperature below the sublimation temperature. The temporal evolution of a light echo is determined by the geometry of the echoing material. Extensive CSM may give rise to very long-lasting echoes, such as those seen to continue many years after the explosions of SN 2002hh (M. J. Barlow et al. 2005; W. P. S. Meikle et al. 2006) and SN 1980K (B. E. K. Sugerman et al. 2012). Finally, when SN shocks propagate into a circumstellar shell, a cool dense shell (CDS) may form between the forward and reverse shocks. Dust formation in a CDS has been inferred in a number of SNe, including SN 1998S (M. Pozzo et al. 2004), SN 2005ip (N. Smith et al. 2017), and SN 2016iog (Z.-H. Peng et al. 2026). Because CDS dust formation results from interaction between supernova (SN) ejecta and nearby dense circumstellar material, it is generally expected to begin at much earlier epochs than the several hundred days typical of condensation in expanding ejecta without interaction (e.g., G. C. Anupama et al. 2009).

In the following, we expand on each of these scenarios in more detail.

4.1. Interstellar Echoes

We model the evolution of the SED of SN 2018bsz using the radiative transfer code MOCASSIN (B. Ercolano et al. 2003, 2005)⁴⁴ and present the modeling results in Figure 4. We

calculated the predicted emission from interstellar and circumstellar echoes using MOCASSIN's option to sum emission from within ellipsoidal regions defined by the light-travel time (see R. Wesson et al. 2010 for a description). We assume that the echoing medium has a low optical depth, so that photons are subject to a single scattering only (multiple scatterings would result in a more complex relationship between the epoch and the geometry of the echoing material). The echo SED consists of scattered light and thermal reemission from the echoing material of the SN light at earlier phases, to which we add the undelayed emission from the fading SN ejecta at the epoch of the observation, reddened by its passage through the assumed CSM. We represent the input SN luminosity using the integrated bolometric light curve over the 60 day period in which $L > 0.25 \times L_{\text{peak}}$. This gives a total energy of 2.6×10^{50} erg, and a luminosity of 5×10^{43} erg s⁻¹. We assume a blackbody temperature for this input luminosity of 10^4 K, consistent with the estimated temperature of the SN around the time of its peak luminosity (see Figure A1).

Figure 4 shows the temporal evolution of the emission from a volume of dust measuring $10 \times 10 \times 1$ pc, 1 pc in front of SN 2018bsz, containing $1 M_{\odot}$ of amorphous carbon dust. These parameters are arbitrarily chosen, but illustrate the general problems that any ISM echo model would have in matching the observed fluxes and temporal evolution of the SED of SN 2018bsz.

The IR emission from this dust volume is several orders of magnitude below the observed fluxes at early times, and its flux is almost constant with time, while the optical depth of this dust is not high enough to significantly reduce the undelayed optical emission from the SN. Thus, the optical limits at early epochs are severely violated, while the IR emission is insufficient. The assumed amorphous carbon dust provides greater optical extinction than silicate dust, and so changing the dust composition would only worsen this disagreement with the observations.

Placing the dust closer to the SN does not increase the echo fluxes significantly, as the echoing region then becomes smaller. One could increase the IR flux by invoking some combination of a higher flash luminosity and higher dust mass. However, the dust density required to obscure the SN completely at the observed epochs would be implausible for any interstellar dust cloud or sheet. An ISM echo is thus unlikely to be a significant contributor to the evolving IR emission, except possibly at much later epochs than considered here.

4.2. Circumstellar Echoes

Dense CSM close to the SN may give rise to a significant thermal echo. We constructed models of CSM echoes by assuming a smooth shell in which the density is proportional to r^{-2} , with the echo calculated using the same input SN luminosity parameters as the ISM models. The temporal evolution of the echo is determined by the inner and outer radii of the CSM, with the echo ending once the epoch exceeds twice the light-travel time to the outer radius. We calculated the evolution of a light echo from shells of both carbon and silicate dust, with grain radii of 0.01, 0.1 and 1.0 μm . We calculated a grid of models for each grain size, consisting of shells with inner radii between 0.001 and 0.1 pc and outer radii between $2\times$ and $500\times$ the inner radius, and we considered total dust masses in the CSM shell of 10^{-3} and $10^{-2} M_{\odot}$. If the

⁴⁴ We used version 2.02.73 of the code.

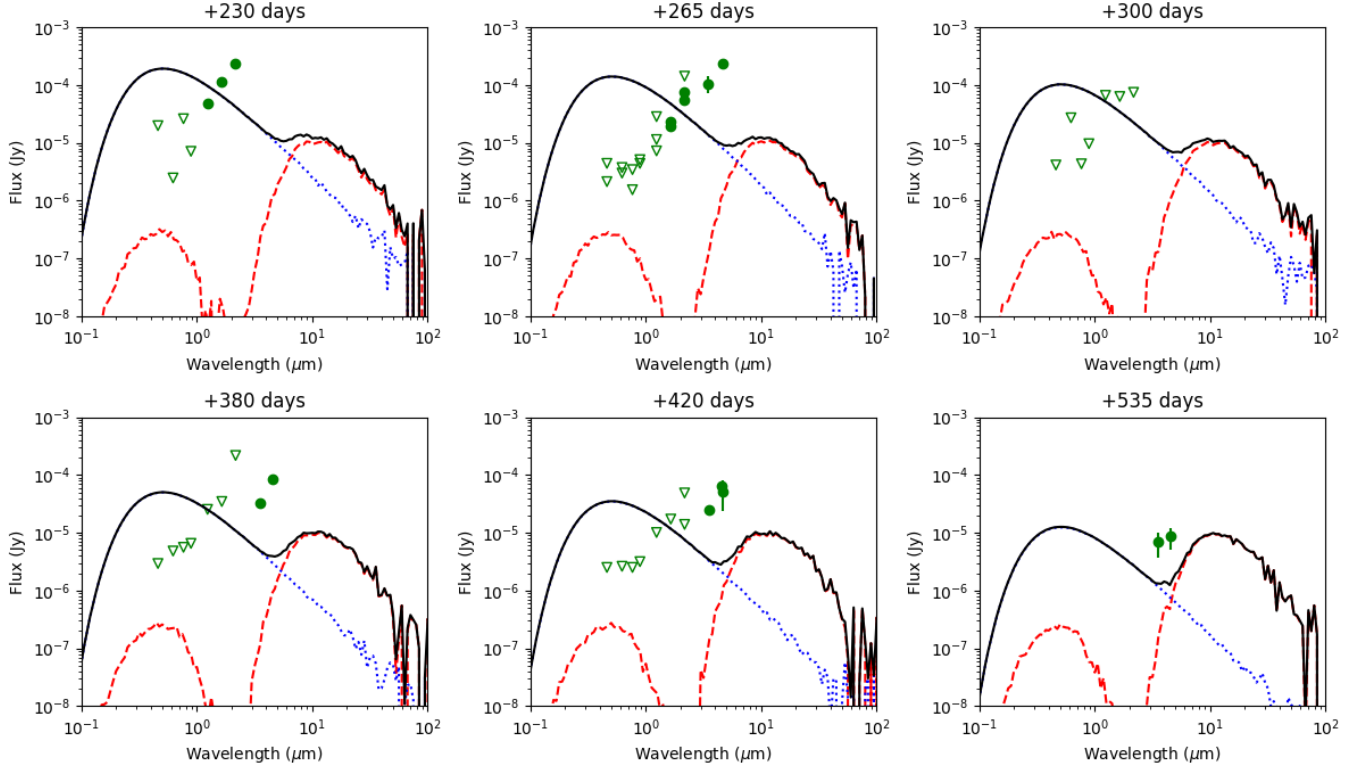


Figure 4. The temporal evolution of the emission from a sheet of ISM dust. The predicted SED consists of optical scattered light and the IR echo from dust illuminated by the SN light (red dashed line) and the undelayed emission from the SN (blue dotted line). The IR flux from this assumed ISM is orders of magnitude below the observations, and its flux is quite constant over time. The symbols are the same as those used in Figure 3. The assumed dust model is described in Section 4.1.

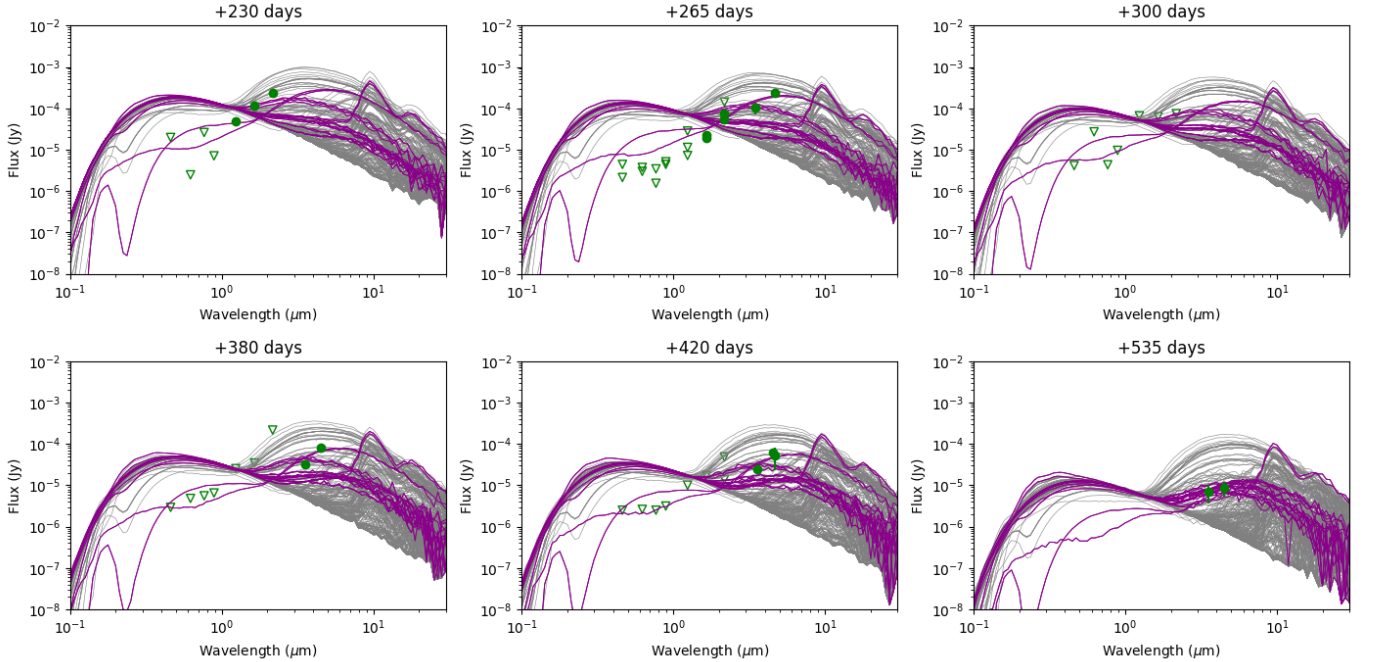


Figure 5. Echo SED calculated from a grid of circumstellar shells. 360 models are shown on each panel, covering 40 different shell geometries, three grain sizes, and two compositions (silicate and carbon dust; the difference is particularly evident in the silicate bump at $10\ \mu\text{m}$). Models which reproduce the NIR/MIR fluxes at +535 days are plotted in magenta; other models are plotted in gray. It can be seen that no model satisfies the observed optical 3σ upper limits at early epochs. The best-fitting model from this grid is shown in Figure 6, which continues this figure by presenting the predicted SED evolution. The symbols are the same as those used in Figure 3.

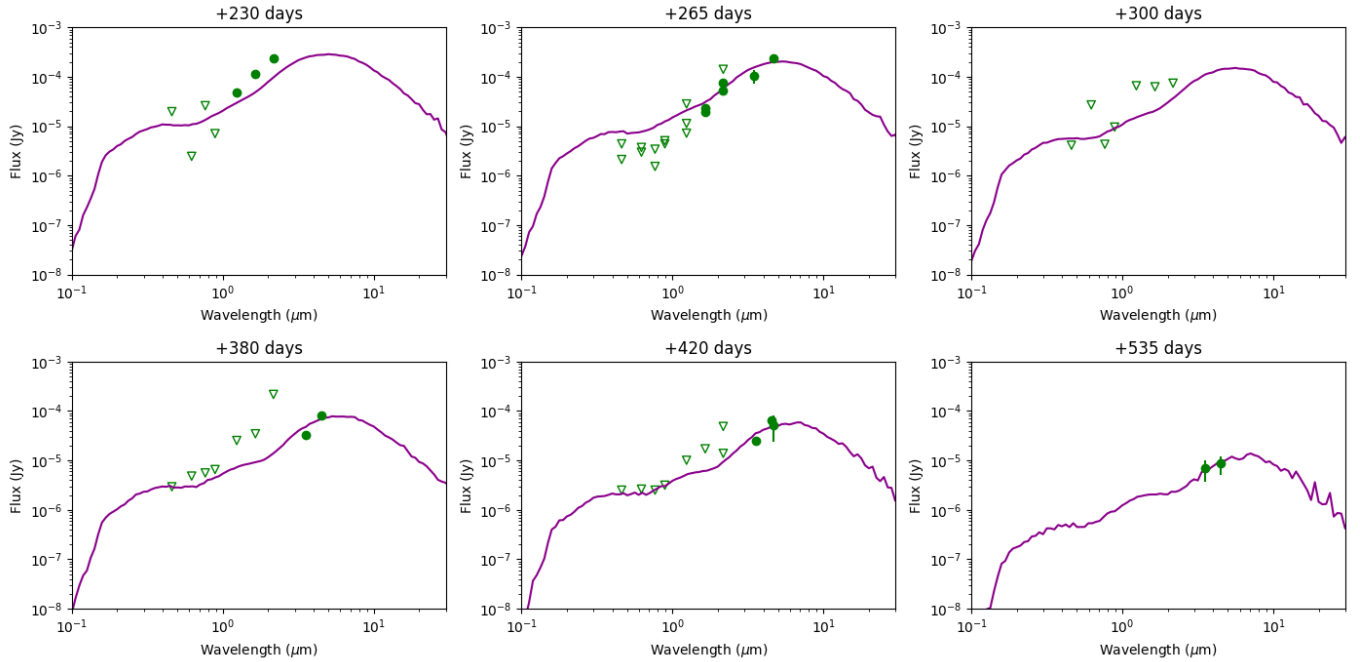


Figure 6. Continuation of Figure 5, showing only the best-fitting model from that grid. Predicted SED evolution for a smooth CSM shell (0.005–0.25 pc) composed of amorphous carbon grains with $a = 0.1 \mu\text{m}$. The symbols are the same as in Figure 3. This model yields the best overall agreement with the observed NIR/MIR fluxes among the CSM-shell geometries investigated, but it is disfavoured because it implies an optical depth that would violate the early-time optical 3σ limits and an inner radius that would lead to ejecta interaction after ~ 1 yr (Section 4.2).

gas-to-dust ratio is assumed to be 100, this corresponds to a total CSM mass of 0.1 or $1.0 M_{\odot}$ respectively. We are unable to find a shell geometry that can account for the evolution of the SED (see Figure 5) for three reasons:

First, the temporal evolution is not reproduced. For there to be a CSM echo lasting until +535 days, the shell needs to be very extensive, with at least some material ~ 270 lt-days (0.23 pc) behind the SN. This gives rise to a slowly declining echo, from which the fluxes at +230 and +265 days, for example, would not be significantly different. The observations show that over these 35 days, the IR fluxes in fact decline significantly.

Second, the temperature evolution of the dust is inconsistent with the observations: newly heated dust is too cool to reproduce the SED at the earlier epochs, and too warm at the final epoch.

And third, the optical and IR nondetections at +230 and +265 days cannot be reproduced in most of these echo scenarios; models that predict IR fluxes comparable to those observed also generally predict detectable optical signals from scattered light alone, even before including the undelayed emission from the SN ejecta at the epoch of the observation. Only models with small grains and high dust masses can reproduce the optical nondetections; none of the models which satisfy this constraint give enough IR emission to match the observed SED.

Figure 5 shows the predicted SED fluxes for the subset of echo models which can reproduce the IR observations at +535 days. The SED is the sum of the echo—both scattered optical and reprocessed IR emission—and the undelayed SN emission at the relevant epoch, reddened by the dust shell, which is echoing. It can be seen from this figure that echo geometries, which give rise to significant emission at +535 days, invariably violate the deep optical limits at +230

and +265 days, in most cases by over an order of magnitude. On the other hand, models which do not violate the optical limits at the earlier epochs do not reproduce the IR emission at the final epoch.

Figure 6 shows the predicted SED for the CSM geometry which provides the closest fit to the observations. The CSM in this model extends from 0.005 to 0.25 pc, with $10^{-2} M_{\odot}$ of $0.01 \mu\text{m}$ amorphous carbon grains. While the inner edge of the CSM is close to the SN, the maximum dust temperatures we find from this model are ~ 1000 K, too low for the dust to be destroyed. This model gives IR fluxes at +380 days and later which match the observations reasonably well, but predicts optical emission at +230 and +265 days which exceeds the observed upper limits by factors of 2–8. Furthermore, this CSM has an optical depth at $0.55 \mu\text{m}$ of 4.3, corresponding to $A_V = 4.67$ mag, where the observations support a value of ~ 0.1 mag (Section 3.1). One final consideration which rules out this model is that SN ejecta moving at 5000 km s^{-1} would reach dust at 0.005 pc after ~ 1 yr, at which point a major rebrightening at all wavelengths would be expected. This is contrary to the observed continuing decline in the bolometric luminosity out to day 535. We therefore conclude that a CSM echo alone cannot reproduce the observed optical-IR evolution of the SED.

Due to the insufficient observational constraints of geometry at late-time phases (>200 days), we have not considered modeling echoes from an asymmetrically distributed CSM. An asymmetric CSM could give rise to thermal echoes with a temporal evolution more consistent with the rapid fading of the IR emission. However, it remains difficult to see how the optical and IR nondetections at +230 and +265 days could be reproduced in this scenario, given the contradictory requirements that the amount of dust along the line of sight must be

low enough to match the early colors, yet high enough to obscure the fading SN by +230 days.

4.3. Newly Formed Dust in Circumstellar Material

While the narrow lines in the spectra of SN 2018bsz indicate the presence of CSM, we do not have a robust estimate of the CSM density or radial profile, as these quantities are generally difficult to infer even with detailed modeling. However, typical CSM densities in interacting SNe are on the order of 10^9 – 10^{10} cm $^{-3}$. Some Type II_n SNe (SNe with narrow H line emission) show NIR excesses as early as a few tens of days after explosion (e.g., M. Pozzo et al. 2004; N. Smith et al. 2008; O. D. Fox et al. 2009; C. Gall et al. 2014). This early NIR emission is often attributed to newly formed dust in a dense circumstellar shell: while SN shocks propagate into the circumstellar shell, there is a cool region between the forward and reverse shocks where dust can form (e.g., O. D. Fox et al. 2010; although see problems with this scenario raised by A. Sarangi et al. 2018a). The main argument for dust formation in these cases is that the blackbody radius estimated from the IR excess is much larger than the extent of the ejecta (C. Gall et al. 2014).

In the case of SN 2018bsz, the blackbody radius at day 265 (corresponding to the epoch with MIR observations) is 1.8×10^{16} cm (Table 8). This is already a factor of 3 further out than the maximum extent of the CSM (6.5×10^{15} cm) suggested by M. Pursiainen et al. (2022), and in fact is consistent with the radius of the ejecta, if we take it to have a velocity of 8000 km s $^{-1}$. Hence, even if dust might have formed in a “circumstellar shell,” it will have been largely engulfed by the ejecta, such that it is no longer meaningful. Alternatively, dust in the CSM could be swept up by the ejecta; however, to assess how plausible this is would require detailed hydrodynamical modeling that is beyond the scope of this work.

We caution, however, that the velocity of the ejecta in SN 2018bsz is highly uncertain—at early times the velocities we observe are associated with CSM rather than ejecta, while SNe also display stratified ejecta where different elements trace different velocity layers (C. P. Gutiérrez et al. 2017a). The blackbody radii are similarly uncertain, and as can be seen from Figure C3, the fits around 200–400 days are based on a small number of IR detections and (mostly) upper limits.

4.4. New Dust Forming in the SN Ejecta

Given that an ISM echo cannot contribute significantly to the IR fluxes (Figure 4), and an echo from a symmetric CSM is not compatible with the evolution of the SED (Figure 6), we consider models of newly forming dust in the ejecta. We adopt a configuration in which the heating source is distributed throughout an expanding dusty shell, in which the dust density is proportional to r^{-2} . The density profile may indeed be steeper than this, but it is computationally difficult to model as steeper exponents require higher grid resolution to sensibly represent. An r^{-2} distribution has also been assumed in previous works carrying out RT modeling of SN ejecta (B. Ercolano et al. 2007; A. M. Bevan et al. 2020). The temperature of the heating source is not strongly constrained by the observations, given the optical nondetections; we adopt a value of 5000 K, based on ejecta temperatures of 3000–7000 K estimated at similar epochs in SN 1987A

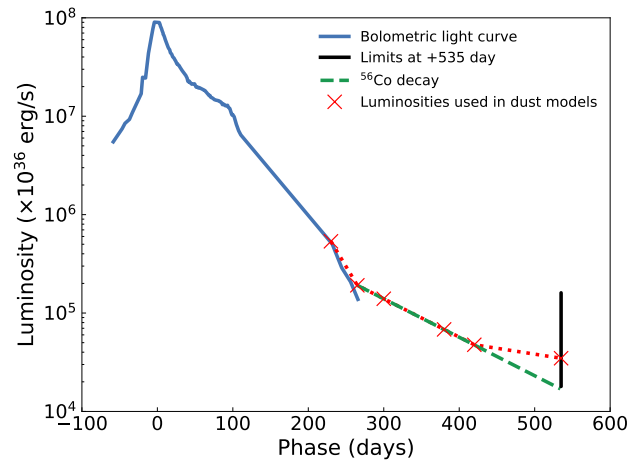


Figure 7. The observed bolometric light curve of SN 2018bsz and late-time extrapolations. Since we only detect SN 2018bsz in the MIR at +535 days, we must estimate the true bolometric luminosity that serves as input to our dust models. The lower limit on the late-time luminosity (lower edge of the black vertical line) comes from the requirement that the modeled dust mass does not decrease from previous epochs. The upper limit (upper edge of the black vertical line) comes from the most luminous 5000 K blackbody fit, which matches the MIR points. The green dashed line shows the ^{56}Co decay, while the orange points show the final luminosities that we use in our dust modeling.

(D. H. Wooden et al. 1993; B. Ercolano et al. 2007). We assumed a velocity of 1000 km s $^{-1}$ at the inner edge of the ejecta, and an outer radius 5 times the inner radius. The predicted SED is not strongly sensitive to the adopted inner radius, but outer radii much larger than the adopted value result in dust too cool to match the observed SED.

We first computed a set of models for the +230 day epoch (shown in Figure 8), spanning both silicate and carbon dust compositions with grain sizes ranging from 0.1 to 5.0 μm . At this epoch, we find that silicate dust is heated to above its assumed sublimation temperature of 1400 K and thus destroyed unless the grain radius exceeds 1 μm . Much smaller grains of amorphous carbon dust can survive due to their higher sublimation temperature of 2200 K, and their formation at this early epoch is more plausible. We therefore assume that the dust is composed only of amorphous carbon.

While Rayleigh–Taylor instabilities are expected to form during SN explosions and give rise to clumpy ejecta distributions (e.g., D. Arnett et al. 1989), the optical nondetections are difficult to reconcile with a clumpy dust distribution. In the case of SN 1987A, clumpy dust models have found that a clump volume filling factor of around 0.1 is required (B. Ercolano et al. 2007; R. Wesson et al. 2015; A. Bevan & M. J. Barlow 2016). If this is adopted for SN 2018bsz, optical emission exceeding the observed nondetections is predicted due to the high probability of photons escaping the ejecta without encountering a dense dust clump. We therefore investigated clumpy dust distributions with much higher volume filling factors, and find that a filling factor greater than about 0.7 is required to match the optical nondetections. For a given total mass, the predicted SED for smooth dust distributions is not significantly different from the predictions for clumpy distributions filling so much of the volume, and so, for simplicity, we adopt a smooth dust distribution. With this assumption, we find that the +230 day SED can be well fitted by $5 \times 10^{-4} M_{\odot}$ of amorphous carbon dust with a grain size of 0.1 μm .

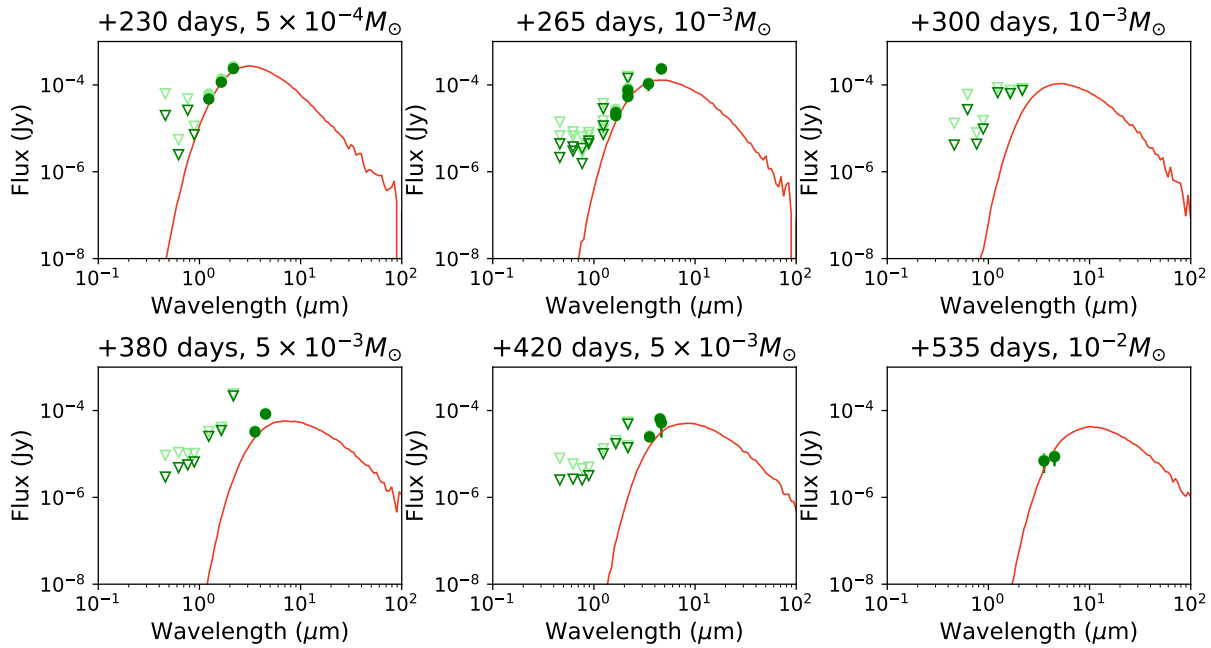


Figure 8. Predicted emission from new dust in the SN ejecta at epochs from +230 to +535 days after the peak. The symbols are the same as those used in Figure 3. Here, we also include the SN magnitudes assuming a high host galaxy extinction of $A_V = 1$ mag, shown in light green. The assumed dust model is described in Section 4.4.

At days +230 and +265, we use the luminosity from the bolometric light curve (Figure C1) in our models. To fit subsequent epochs, we investigated different rates of decline of the luminosity. From its peak until +265 days, the bolometric light curve declines with a half-life of approximately 32 days, much faster than the half-life of ^{56}Co . However, extrapolating this to +535 days, we find that the luminosity would then be much too low to reproduce the observed IR fluxes. To constrain the luminosity at this epoch, we consider two limiting cases. We first estimate an upper limit to the luminosity of $1.7 \times 10^{41} \text{ erg s}^{-1}$; above this, the emission from a 5000 K blackbody would exceed the observed IR fluxes. We then estimate a lower limit by considering models containing $10^{-3} M_\odot$ of dust, which maximizes the emission at 3.6 and $4.5 \mu\text{m}$ (higher/lower dust masses give predicted SEDs, which peak at longer/shorter wavelengths). To match the observed fluxes at these wavelengths with this dust mass requires a luminosity of about $1.7 \times 10^{40} \text{ erg s}^{-1}$.

We therefore fitted subsequent epochs by expanding the modeled dusty shell, reducing the luminosity according to ^{56}Co radioactive decay, and then varying the dust mass uniformly throughout the shell if necessary. We note that while the late-time light curve of SN 2018bsz is probably not powered by Ni (e.g., C. Inserra et al. 2013), the decline rate of SLSNe is quite similar to that of ^{56}Co until 600 days (T. J. Moriya et al. 2017), making this a reasonable choice of function for the input luminosity.

We find that until +535 days, models with a steadily increasing dust mass can fit the observations. At +535 days, calculating the luminosity by extrapolating the ^{56}Co decay, we are able to fit the observed IR fluxes but with a lower dust mass than at +420 days, which is unphysical. Enforcing a nondecreasing dust mass therefore requires a luminosity exceeding the ^{56}Co prediction to fit the MIR emission. Figure 7 shows the bolometric light curve, the extrapolated ^{56}Co decline, and the actual luminosities used in our models.

Our predicted SED at each of the six epochs considered is shown in Figure 8. We emphasize that the model fits are constrained not only by the data at each epoch, but also by the requirement that the model must evolve self-consistently between epochs. In our best-fitting set of models, the dust mass increases from about $5 \times 10^{-4} M_\odot$ at +230 days to $10^{-2} M_\odot$ at +535 days. This pattern of the dust mass increasing steadily over a few hundred days is consistent with the pattern of dust formation observationally determined in other CCSNe (e.g., R. Wesson et al. 2015; A. Bevan & M. J. Barlow 2016; A. M. Bevan et al. 2020). In Figure 9, we plot literature values of estimated dust masses at different epochs of other CCSNe (between 10^2 and 10^4 days) together with our estimated masses for the dust in SN 2018bsz. At all epochs, the largest source of uncertainty in the estimate of the dust mass is the adopted luminosity. At +230 and +265 days, the bolometric luminosity is well-constrained, and the resulting uncertainty in the dust mass is about a factor of 2. At +300 days, where only upper limits to the fluxes are available, the dust mass is unconstrained. At later epochs when the luminosity is extrapolated, the uncertainties are larger. At +535 days, as described above, a dust mass of zero is nominally compatible with the observations but would require a much higher luminosity than at earlier epochs. To estimate the uncertainty on the dust mass at this epoch, we require that the luminosity is not higher than at previous epochs, and then vary both the dust mass and luminosity to obtain fits to the SED. In this way, we estimate that the dust mass uncertainty is about a factor of five. The possible contribution of a CSM echo at this epoch may introduce an additional uncertainty, although if we assume that the mass of newly formed ejecta dust does not decrease at any point, the overestimate in the dust mass that would be caused by attributing a CSM echo to newly formed dust emission must be small.

These uncertainties notwithstanding, SN 2018bsz appears to have formed more dust at these epochs than most other

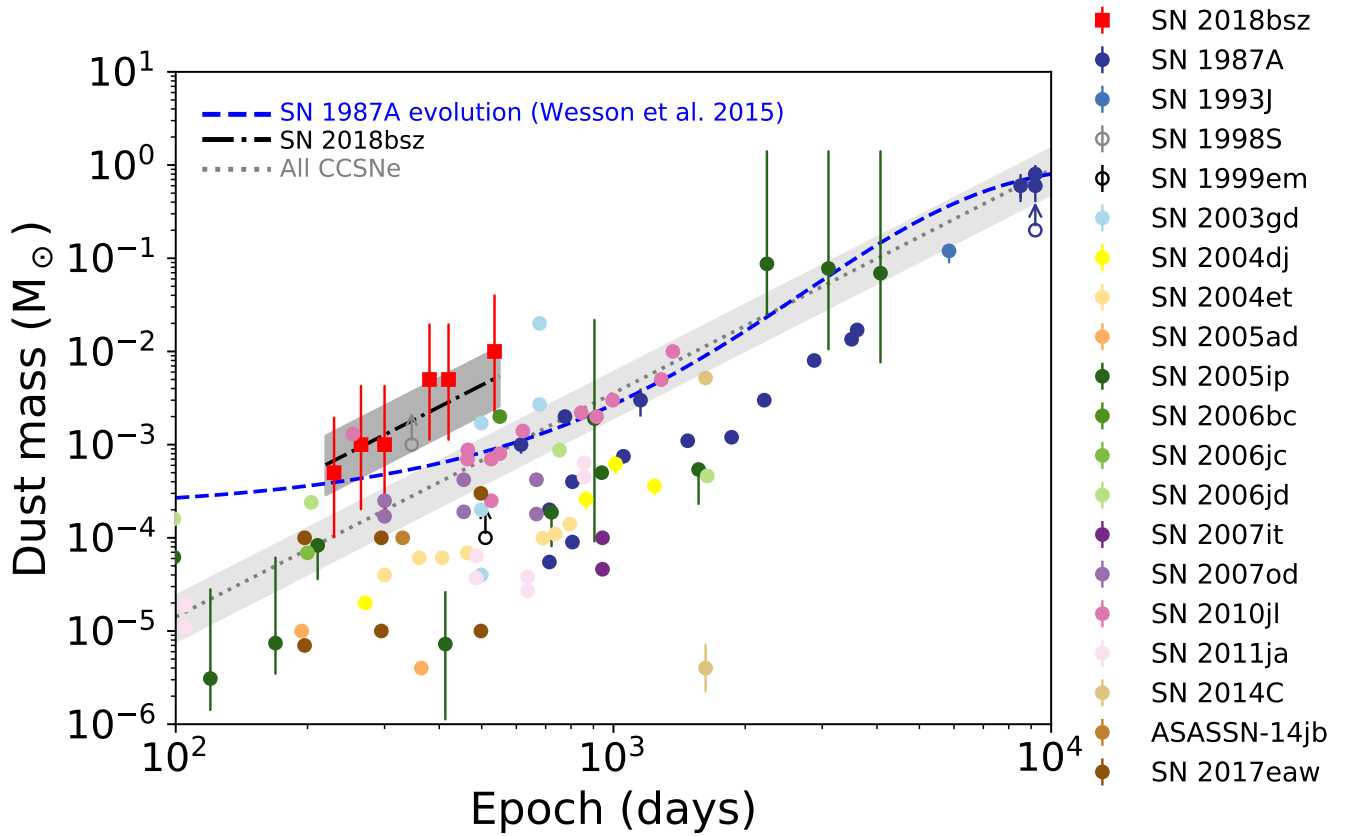


Figure 9. The dust masses inferred for SN 2018bsz, compared with literature values for other CCSNe. We find that SN 2018bsz formed 10 times more dust than normal CCSNe at similar epochs. We fit the evolution of SN 2018bsz and all other CCSNe separately, using $M_{\text{dust}} \propto t^{2.4}$ (adopting the SN 2010jl ejecta dust evolution from C. Gall et al. 2014), and show the evolution in black dashed-dotted and gray dotted lines, respectively. The gray areas indicate the 95% confidence level, incorporating dust mass uncertainties to fit the points for SN 2018bsz and other CCSNe. The blue dashed line shows the evolution of the dust mass in SN 1987A inferred by R. Wesson et al. (2015). See the webpage <https://www.nebulousresearch.org/dustmasses/> for the full collection; the SNe and references we used in this figure are for SN 1987A (We note that E. Dwek & R. G. Arendt 2015 report high dust masses at early epochs for SN 1987A. However, we do not plot these here as they are incompatible with the observed gradual evolution of the emission-line profiles (R. Wesson & A. Bevan 2021).) (M. Matsuura et al. 2011; R. Indebetouw et al. 2014; M. Matsuura et al. 2015; R. Wesson et al. 2015; A. Bevan & M. J. Barlow 2016), SN 1993J (A. Bevan et al. 2017), SN 1998S (M. Pozzo et al. 2004), SN 1999em (A. Elmhamdi et al. 2003), SN 2003gd (B. E. K. Sugerman et al. 2006; W. P. S. Meikle et al. 2007), SN 2004dj (T. Szalai et al. 2011), SN 2004et (R. Kotak et al. 2009), SN 2005ad and SN 2005af (T. Szalai & J. Vinkó 2013), SN 2005ip (O. D. Fox et al. 2010; M. Stritzinger et al. 2012; A. Bevan et al. 2019), SN 2006bc (J. S. Gallagher et al. 2012), SN 2006jc (I. Sakon et al. 2009), SN 2006jd (M. Stritzinger et al. 2012), SN 2007it (J. E. Andrews et al. 2011), SN 2007od (J. E. Andrews et al. 2010), SN 2010jl. (For SN 2010jl, we show the dust masses assuming carbon dust in A. Sarangi et al. 2018a). (K. Maeda et al. 2013; A. Sarangi et al. 2018a; A. M. Bevan et al. 2020), SN 2011ja (J. E. Andrews et al. 2016), SN 2014C (S. Tanyanont et al. 2019a), ASASSN-14jb (N. Meza et al. 2019), and SN 2017eaw (S. Tanyanont et al. 2019b).

CCSNe. The shape of the dust growth curve of SN 2018bsz is very similar to the general trend seen in Figure 9, and SN 2018bsz clearly lies at the upper edge of the spread seen in normal CCSNe. We fit the evolution of SN 2018bsz and all other CCSNe separately using $M_{\text{dust}} \propto t^{2.4}$ (adopting the SN 2010jl ejecta dust evolution from C. Gall et al. 2014), and find SN 2018bsz to have formed 10 times more dust than normal CCSNe at similar epochs. In the case of SN 1987A, R. Wesson et al. (2015) found that the majority of the dust present 23 yr after the explosion must have formed at epochs later than 1000 days. If a similar formation process is occurring in SN 2018bsz, the $10^{-2} M_{\odot}$ of dust present at +535 days will be a small fraction of the final dust mass.

Finally, even for the largest plausible value of host galaxy extinction $A_V \sim 1$ mag, the corresponding MIR extinctions in the Spitzer/IRAC bands at $3.6 \mu\text{m}$ (channel 1) and $4.5 \mu\text{m}$ (channel 2), denoted as A_{Ch1} and A_{Ch2} , are only 0.07 and 0.05 mag, respectively, and can therefore be neglected. The foreground dust screen and light echo models are still incompatible with our observations. The model for newly

formed dust in the ejecta is, however, still consistent with the data (see Figure 8).

5. Discussion and Conclusion

Several lines of evidence suggest that new dust forming in the ejecta of SN 2018bsz is responsible for the observed IR excess after ~ 200 days. CSM echoes cannot reproduce the temporal evolution of SN 2018bsz, while the CSM geometries that could explain the IR emission at much later times (>230 days) would also predict detectable optical emission from scattered light, which we do not observe. ISM echoes, on the other hand, would have to be from extremely dense dust clouds close to the SN to give rise to detectable IR emission. We find that a sheet of dust 1 pc in front of the SN and 0.1 pc deep, containing $1 M_{\odot}$ of dust, would result in an echo at 535 days with fluxes about 2 orders of magnitude below those observed. Therefore, our modeling suggests newly formed dust in the SN ejecta at epochs >200 days, with a dust composition of pure amorphous carbon. We estimate that the dust mass formed in SN 2018bsz is about 10 times larger than what is found for

other SNe at similar phases, with the dust mass increasing from about $5 \times 10^{-4} M_{\odot}$ at +230 days to $10^{-2} M_{\odot}$ at +535 days.

While our models reproduce the optical nondetections, IR excess, and overall evolution of the SED, they do not perfectly match the data. Most obviously, fluxes at $4.5 \mu\text{m}$ are under-predicted by the models at +265, +380, and +420 days. This may be due to emission from the CO fundamental band at $4.6 \mu\text{m}$, which is not included in our models; an excess at this wavelength has been observed at early times in other SNe and attributed to CO (e.g., in SN 2011dh; M. Ergon et al. 2014). In the absence of spectroscopic data at these epochs, we cannot confirm the origin of the $4.5 \mu\text{m}$ excess.

Better fits to the SED at all epochs might also be possible with a more sophisticated model invoking a distribution of grain radii instead of a single grain size. However, this would add several more free parameters to the model which the available data could not uniquely constrain. Similarly, given that silicate dust could not be present at the earlier epochs unless the grains were already extremely large, we adopt pure carbon at all epochs. Silicate dust formation at later epochs when the ejecta has cooled sufficiently is not ruled out, but is not included in our models.

However, we stress that scenarios invoking thermal echoes from ISM or CSM dust cannot be reconciled with the data, being ruled out both by their predicted temporal evolution, and by optical nondetections to several orders of magnitude fainter than the fluxes predicted by these models. We hence suggest that newly formed dust is the only credible explanation for the late-time IR emission that is seen in SN 2018bsz.

The fact that SN 2018bsz was hydrogen-poor at early times (J. P. Anderson et al. 2018), and that the Balmer lines appear after 77 days (M. Pursiainen et al. 2022), before dust formation (after 200 days), suggests that the dust formation may be enhanced by the interaction between the SN ejecta and a hydrogen-rich CSM. Mixing of metal-rich material in the ejecta with a hydrogen-rich CSM can lead to the formation of large amounts of dust, as the necessary molecular processes are thought to be more efficient in a hydrogen-rich environment (J. M. C. Rawlings & D. A. Williams 1990).

Late-time CSM interaction, together with a strongly asymmetric ejecta (as seen, for example, in luminous blue variables like Eta Carinae) may also account for the peculiar Balmer line profiles. In this scenario, around 100 days after peak brightness, we observe the Balmer lines first forming, and later, when the SN ejecta sweeps up the CSM, it causes the observed changes in their profiles. The blue side of the line profiles is absorbed by swept-up CSM, while thanks to the asymmetric geometry, we can still see the red side of the lines. We do not see such profiles in the metal lines, likely because they come from deeper layers in the ejecta. Dust will form as the shocked, swept-up CSM cools, as is observed at late times (>200 days).

Although SN 2018bsz is the first SLSN without hydrogen lines at maximum light for which dust has been detected, a late-time NIR excess was observed in one Type II superluminous supernova (SLSN II; SN 2008es ($M_V \sim -22$ mag) (S. Gezari et al. 2009; A. A. Miller et al. 2009; C. Inserra et al. 2018b). It has a broad $H\alpha$ feature during the photospheric phase and does not show any sign of strong interaction between SN ejecta and circumstellar shells in the early spectra. K. Bhirimbhakdi et al. (2019) obtained late-time photometry

of SN 2008es, which showed $r - K' > 1.5$ mag around 250–300 days after the explosion. The authors suggested that this NIR excess indicates dust condensation in a CDS that formed through circumstellar interaction (e.g., S. Mattila et al. 2008). We note, however, that SN 2018bsz has a much redder color of $r - K_s > 4.9$ mag at an epoch similar to that of SN 2008es.

C. M. B. Omand et al. (2019) investigated the effect of a pulsar wind nebula on dust formation and found that the pulsar wind can accelerate or delay dust formation. The formation timescale of carbon dust can vary from ~ 180 to ~ 590 days for SLSN I, assuming a magnetar power source. In our case for SN 2018bsz, we detect carbon dust formation within 1 yr after the explosion, which is consistent with their predicted timescale.

SLSNe I are rare events, with about one SLSN for every 3500^{+2800}_{-720} CCSNe estimated from the Palomar Transient Factory sample by C. Frohmaier et al. (2021). These authors found that the relative rate was higher in low-mass ($\log(M_*/M_{\odot}) < 9.5$) galaxies, with one SLSN for every 1700^{+1800}_{-720} CCSNe. Furthermore, subsolar metallicity appears to be required for massive stars to explode as SLSNe I (D. A. Perley et al. 2016; T.-W. Chen et al. 2017b; S. Schulze et al. 2018). Such low-mass, low-metallicity galaxies are common in the early Universe (e.g., T. M. Heckman et al. 2005; C. Cardamone et al. 2009; F. Bian et al. 2016). The dust mass deduced for SN 2018bsz is ~ 10 times larger than what is seen in most CCSNe. If the rate of SLSNe I were 10^{-2} of the CCSN rate in the high- z Universe, they could thus produce up to 10% of the dust in the early Universe if this dust is due to CCSNe only. In fact, T. J. Moriya et al. (2019) observed SLSNe at high redshifts and determined that their volumetric rate is 5 ($3.5 \lesssim z \lesssim 4.5$) to 10 ($1.5 \lesssim z \lesssim 2.5$) times higher than the local SLSN rate. One could even speculate that if SLSNe are produced by more massive stars than CCSNe, and if the initial mass function at high redshift is top-heavy, then SLSNe could be even more common.

A more self-consistent (although still approximate) estimate of the dust mass produced by SLSNe I at high redshift can be obtained from cosmological galaxy evolution simulations. For example, the cosmic dust production rate density (DD) from SLSNe can be calculated from the latest version of the L-Galaxies semi-analytic simulation (R. M. Yates et al. 2024), which contains self-consistent models for both metal production by stars and SNe and dust production and destruction. In L-Galaxies, the net dust mass ejected by CCSNe is assumed to be proportional to the ejected mass of the key chemical element from which it forms (i.e., C, Mg, Si, or Fe; see A. P. Vijayan et al. 2019, Section 3.1). The early destruction of newly condensed dust by the reverse SN shock is accounted for in the dust model via a net “condensation efficiency parameter,” which is evaluated from dust destruction models (see S. Zhukovska et al. 2008). The later destruction of dust in the ISM via SN shock wave propagation is also considered. The element mass ejection rate is calculated using a galactic chemical enrichment scheme, which tracks the birth of stellar populations and the subsequent ejection of heavy elements by a range of SN types and stellar wind mechanisms.

For the analysis here, we assume that (a) SLSNe I only form in galaxies with gas-phase metallicity $\leq 0.5 Z_{\odot}$, (b) SLSNe produce 10 times as much dust per event as CCSNe, (c) the

CCSNe/SLSNe rate ratio is 3500 at $z = 0$, and (d) the CCSN rate is proportional to the cosmic SFR density (which matches that observed by P. Madau & M. Dickinson 2014 in *L-Galaxies* at high redshift; see R. M. Yates et al. 2021, Section 4.2). Under these assumptions, *L-Galaxies* predicts an SLSN DD of $\log_{10}(M_{\text{dust,SLSN}} M_{\odot} \text{ yr}^{-1} \text{ Mpc}^{-3}) \sim -7.14$ at $z = 7$. This is around 2 orders of magnitude lower than the DD expected from CCSNe at $z = 7$ (see R. M. Yates et al. 2024, Figure 8). However, it is higher than the contribution expected from Type Ia SNe and only an order of magnitude below that expected from AGB stars, which themselves could play an important role (see R. Valiante et al. 2009; M. Mancini et al. 2015). Therefore, SLSNe could provide a nonnegligible contribution to dust production in the high-redshift Universe.

We caution that these estimates assume that all SLSNe produce as much dust as SN 2018bsz. However, SN 2018bsz is a somewhat unusual SLSN and appears quite different from the bulk of the SLSN I population (according to its unique light-curve shape and spectroscopic evolution). It is hence quite possible that only a few percent of the SLSN population produce dust.

It should nevertheless be pointed out that observational data for SLSNe I remain the limiting factor in knowing their dust masses. We may well be systematically missing the window to see evidence for dust formation in SLSNe, as the majority of them are found at $z > 0.1$ and do not have rest-frame *K*-band observations, especially at late times (>200 days). In fact, only two other SLSNe I (among ~ 200 events) have late-time rest-frame *K*-band data, namely, PTF12dam (M. Nicholl et al. 2013; T.-W. Chen et al. 2015; P. M. Vreeswijk et al. 2017), and SN 2015bn (M. Nicholl et al. 2016), although some SLSNe have displayed a rebrightening at MIR wavelengths after 200 days (L. Sun et al. 2022). A concerted effort to acquire more late-time IR data is therefore needed in order to gain a greater understanding of the contribution from SLSNe I in the early Universe.

Finally, a high luminosity combined with their preference for dwarf hosts makes SLSNe I appealing targets for high-redshift (young Universe) searches, e.g., with Euclid (C. Inserra et al. 2018a), JWST, or the Rubin Observatory Legacy Survey of Space and Time (LSST; C. Inserra et al. 2021). JWST in particular can reach down to the 27th magnitude in the IR, potentially allowing for observations of SLSNe out to $z = 20$ (L. Wang et al. 2019), and spectroscopic classification of some of these up to $z \sim 5$ (M. Nicholl et al. 2020). Further systematic observations by JWST will help to determine how much dust is formed in typical SLSNe I.

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Appendix A Imaging Observations of SN 2018bsz

Table A1 provides the host-subtracted UVOT light curve. Table A2 presents the GROND optical photometry, while Table A3 presents the GROND near-infrared photometry. Table A4 provides the SOFI near-infrared photometry. Tables A5 and A6 present the mid-infrared (MIR) photometry from Spitzer and NEOWISE, respectively. Details of these observations and the corresponding data reduction are provided below.

Table A1
Swift UVOT Aperture Photometry for SN 2018bsz with Host Subtraction

Date (UT)	MJD (day)	Phase (day)	m_{uvw2} (mag)	m_{uvm2} (mag)	m_{uvw1} (mag)	m_U (mag)	m_B (mag)	m_V (mag)
2018-05-31	58269.517	1.96	18.04 (0.09)	17.40 (0.06)	16.67 (0.06)	16.13 (0.06)	16.08 (0.06)	15.94 (0.08)
2018-06-03	58272.723	5.09	18.08 (0.08)	17.56 (0.06)	16.78 (0.06)	16.33 (0.06)	16.26 (0.06)	16.17 (0.08)
2018-06-06	58275.260	7.56	18.22 (0.09)	17.77 (0.06)	17.02 (0.06)	16.55 (0.06)	16.43 (0.06)	16.26 (0.09)
2018-06-12	58281.665	13.80	18.72 (0.10)	18.39 (0.08)	17.51 (0.07)	16.99 (0.07)	16.76 (0.07)	16.44 (0.09)
2018-06-15	58284.252	16.32	18.95 (0.11)	18.46 (0.10)	17.76 (0.08)	17.10 (0.07)	16.88 (0.07)	16.72 (0.10)
2018-06-18	58287.640	19.62	...	...	18.00 (0.09)	...	...	...
2018-06-21	58290.759	22.65	19.37 (0.14)	19.02 (0.12)	18.09 (0.09)	17.18 (0.07)	16.89 (0.07)	16.66 (0.10)
2018-06-24	58293.215	25.05	19.64 (0.17)	19.35 (0.15)	18.16 (0.10)	17.49 (0.08)	17.02 (0.08)	16.71 (0.11)
2018-06-27	58296.736	28.48	19.53 (0.15)	19.43 (0.16)	18.39 (0.10)	17.36 (0.07)	16.92 (0.07)	16.74 (0.10)
2018-07-06	58305.679	37.19	20.17 (0.24)	20.22 (0.21)	18.87 (0.13)	17.57 (0.09)	17.16 (0.09)	16.98 (0.14)
2018-07-10	58309.316	40.73	20.37 (0.24)	20.60 (0.25)	19.19 (0.14)	17.70 (0.08)	17.26 (0.09)	17.24 (0.14)
2018-07-12	58311.511	42.87	21.17 (0.48)	20.99 (0.39)	19.13 (0.16)	17.84 (0.11)	17.53 (0.12)	17.23 (0.18)
2018-07-15	58314.396	45.68	21.40 (0.49)	20.92 (0.30)	19.30 (0.15)	18.04 (0.10)	17.47 (0.10)	17.35 (0.15)
2018-07-18	58317.187	48.40	21.37 (0.45)	21.22 (0.35)	19.56 (0.17)	17.95 (0.09)	17.44 (0.09)	17.23 (0.13)
2018-07-20	58319.189	50.34	21.19 (0.40)	21.45 (0.40)	19.51 (0.16)	18.06 (0.09)	17.46 (0.09)	17.21 (0.13)
2018-07-24	58323.672	54.71	21.16 (0.41)	...	19.38 (0.16)	17.89 (0.09)	17.36 (0.09)	17.02 (0.12)
2018-08-04	58334.891	65.64	21.62 (0.52)	21.96 (0.56)	19.55 (0.16)	17.95 (0.09)	17.44 (0.09)	17.31 (0.13)
2018-08-10	58340.975	71.56	21.63 (0.52)	...	19.78 (0.18)	18.32 (0.11)	17.56 (0.09)	17.46 (0.14)
2018-08-21	58351.757	82.07	...	...	20.45 (0.29)	18.46 (0.12)	17.74 (0.10)	17.44 (0.14)
2018-08-25	58355.442	85.66	...	...	20.59 (0.32)	18.71 (0.13)	17.93 (0.11)	17.48 (0.14)
2018-08-29	58359.360	89.47	...	...	20.61 (0.33)	18.87 (0.15)	18.05 (0.13)	17.64 (0.17)
2018-09-02	58363.251	93.26	...	...	20.63 (0.34)	18.75 (0.14)	17.87 (0.12)	17.67 (0.18)
2018-09-07	58368.792	98.66	...	...	20.77 (0.38)	18.97 (0.17)	18.23 (0.15)	17.76 (0.19)
2018-09-17	58378.294	107.91	...	...	...	19.56 (0.25)	18.67 (0.21)	18.71 (0.38)
2018-09-29	58390.281	119.59	...	...	...	20.17 (0.38)	...	...
2018-10-04	58395.424	124.60	...	...	...	20.51 (0.50)	...	...
2018-10-10	58401.104	130.13	...	...	...	20.86 (0.62)	20.19 (0.62)	...

Note. Magnitudes are not corrected for Milky Way and host galaxy extinction, and all are in the AB system. The rest-frame phase is with respect to the r -band peak epoch (MJD = 58267.5). A host template was constructed from images obtained between MJD = 58562 and 59068.

Table A2
Optical Photometry for SN 2018bsz from GROND

Date UT	MJD	Phase (day)	m_g (mag)	m_r (mag)	m_i (mag)	m_z (mag)
2018-06-01	58270.139	2.57	15.89 (0.09)	15.46 (0.14)	15.37 (0.11)	15.51 (0.07)
2018-06-02	58271.229	3.63	15.90 (0.06)	15.50 (0.15)	15.41 (0.08)	15.51 (0.07)
2018-06-03	58272.284	4.66	15.97 (0.08)	15.54 (0.14)	15.46 (0.09)	15.53 (0.08)
2018-06-04	58273.202	5.55	16.04 (0.06)	15.58 (0.13)	15.47 (0.09)	15.56 (0.08)
2018-06-05	58274.229	6.55	16.09 (0.09)	15.64 (0.13)	15.52 (0.08)	15.55 (0.08)
2018-06-06	58275.202	7.50	16.17 (0.08)	15.68 (0.13)	15.53 (0.10)	15.58 (0.07)
2018-06-07	58276.181	8.46	16.22 (0.06)	15.73 (0.13)	15.58 (0.09)	15.62 (0.07)
2018-06-08	58277.188	9.44	16.27 (0.08)	15.77 (0.13)	15.63 (0.08)	15.63 (0.08)
2018-06-09	58278.258	10.48	16.37 (0.07)	15.79 (0.16)	15.68 (0.08)	15.67 (0.07)
2018-06-13	58282.168	14.29	16.53 (0.07)	16.00 (0.13)	15.85 (0.08)	15.77 (0.07)
2018-06-14	58283.088	15.18	16.55 (0.07)	16.03 (0.14)	15.89 (0.08)	15.79 (0.08)
2018-06-15	58284.241	16.31	16.59 (0.07)	16.08 (0.15)	15.77 (0.07)	15.82 (0.07)
2018-06-16	58285.246	17.28	16.72 (0.13)	16.12 (0.13)	16.00 (0.12)	15.85 (0.09)
2018-06-17	58286.132	18.15	16.48 (0.07)	16.11 (0.13)	15.96 (0.08)	15.86 (0.07)
2018-06-18	58287.160	19.15	16.64 (0.06)	16.11 (0.13)	15.98 (0.07)	15.84 (0.07)
2018-06-19	58288.211	20.17	16.66 (0.06)	16.13 (0.12)	16.00 (0.09)	15.85 (0.08)
2018-06-20	58289.219	21.15	16.61 (0.09)	16.10 (0.16)	16.01 (0.09)	15.86 (0.07)
2018-06-21	58290.070	21.98	16.65 (0.07)	16.11 (0.14)	16.02 (0.09)	15.78 (0.06)
2018-06-22	58291.208	23.09	16.68 (0.06)	16.16 (0.13)	16.04 (0.09)	15.90 (0.07)
2018-06-23	58292.275	24.13	16.66 (0.10)	16.15 (0.13)	16.05 (0.09)	15.89 (0.07)
2018-06-24	58293.135	24.97	16.70 (0.08)	16.19 (0.14)	16.05 (0.09)	15.91 (0.08)
2018-06-25	58294.144	25.95	16.68 (0.13)	16.30 (0.13)	16.07 (0.08)	15.90 (0.09)
2018-06-26	58295.071	26.85	16.70 (0.05)	16.16 (0.14)	16.08 (0.09)	15.93 (0.07)
2018-06-27	58296.161	27.92	16.72 (0.07)	16.20 (0.13)	16.12 (0.07)	15.92 (0.07)
2018-06-28	58297.106	28.84	16.74 (0.08)	16.12 (0.13)	16.13 (0.09)	15.98 (0.07)
2018-06-29	58298.192	29.89	16.72 (0.07)	16.22 (0.13)	16.13 (0.08)	15.95 (0.07)
2018-07-02	58301.203	32.83	16.77 (0.08)	16.29 (0.13)	16.18 (0.07)	16.00 (0.08)
2018-07-07	58306.184	37.68	16.89 (0.09)	16.41 (0.13)	16.33 (0.08)	16.13 (0.08)
2018-07-08	58307.961	39.41	16.96 (0.07)	16.48 (0.12)	16.41 (0.08)	16.18 (0.09)
2018-07-10	58309.005	40.43	17.16 (0.07)	16.49 (0.12)	16.42 (0.08)	16.49 (0.08)
2018-07-11	58310.051	41.44	17.11 (0.06)	16.50 (0.13)	16.64 (0.08)	16.33 (0.07)
2018-07-12	58311.036	42.40	17.04 (0.07)	16.53 (0.13)	16.49 (0.08)	16.26 (0.08)
2018-07-13	58312.019	43.36	17.09 (0.07)	16.58 (0.13)	16.54 (0.08)	16.30 (0.06)
2018-07-14	58313.109	44.42	17.09 (0.07)	16.55 (0.15)	16.51 (0.09)	16.29 (0.07)
2018-07-15	58314.130	45.42	17.09 (0.08)	16.59 (0.12)	16.57 (0.09)	16.31 (0.07)
2018-07-19	58318.105	49.29	17.11 (0.09)	16.39 (0.13)	16.42 (0.09)	16.14 (0.12)
2018-07-21	58320.200	51.33	17.13 (0.09)	16.61 (0.14)	16.60 (0.10)	16.38 (0.07)
2018-07-22	58321.082	52.19	17.12 (0.07)	16.59 (0.13)	16.58 (0.08)	16.39 (0.07)
2018-07-23	58322.127	53.21	17.11 (0.06)	16.59 (0.14)	16.58 (0.11)	16.37 (0.08)
2018-07-24	58323.024	54.08	17.12 (0.07)	16.58 (0.13)	16.57 (0.09)	16.37 (0.07)
2018-07-25	58324.115	55.14	17.08 (0.09)	16.58 (0.12)	16.56 (0.09)	16.35 (0.08)
2018-07-31	58330.098	60.97	17.11 (0.07)	16.58 (0.14)	16.57 (0.09)	16.40 (0.08)
2018-08-01	58331.043	61.89	17.12 (0.06)	16.57 (0.15)	16.61 (0.09)	16.41 (0.08)
2018-08-02	58332.079	62.90	17.12 (0.08)	16.60 (0.15)	16.62 (0.08)	16.42 (0.07)
2018-08-04	58334.962	65.71	17.34 (0.13)	16.70 (0.12)	16.73 (0.09)	16.53 (0.09)
2018-08-08	58338.020	68.69	17.19 (0.12)	16.69 (0.13)	16.73 (0.09)	16.50 (0.08)
2018-08-09	58339.043	69.68	17.29 (0.06)	16.74 (0.13)	16.76 (0.07)	16.56 (0.07)
2018-08-10	58340.096	70.71	17.33 (0.06)	16.78 (0.12)	16.78 (0.08)	16.59 (0.07)
2018-08-12	58342.057	72.62	17.38 (0.07)	16.79 (0.13)	16.82 (0.08)	16.64 (0.07)
2018-08-13	58343.057	73.59	17.40 (0.07)	16.81 (0.13)	16.82 (0.08)	16.63 (0.07)
2018-08-15	58345.043	75.53	17.40 (0.07)	16.81 (0.13)	16.83 (0.10)	16.65 (0.07)
2018-08-16	58346.978	77.41	17.43 (0.08)	16.81 (0.13)	16.83 (0.09)	16.65 (0.08)
2018-08-21	58351.040	81.37	17.47 (0.08)	16.84 (0.13)	16.83 (0.09)	16.65 (0.08)
2018-08-21	58351.990	82.29	17.45 (0.08)	16.85 (0.14)	16.83 (0.08)	16.67 (0.08)
2018-08-22	58352.995	83.27	17.47 (0.07)	16.87 (0.13)	16.85 (0.08)	16.68 (0.07)
2018-08-24	58354.008	84.26	...	...	...	...
2018-08-24	58354.997	85.22	17.52 (0.07)	16.89 (0.13)	16.91 (0.08)	16.73 (0.07)
2018-08-26	58356.005	86.20	17.53 (0.08)	16.91 (0.13)	16.92 (0.08)	16.75 (0.09)
2018-08-27	58357.006	87.18	17.57 (0.07)	16.92 (0.13)	16.91 (0.09)	16.73 (0.07)
2018-08-28	58358.054	88.20	17.55 (0.07)	16.92 (0.08)	16.93 (0.08)	16.73 (0.07)
2018-08-28	58358.972	89.09	17.57 (0.08)	16.93 (0.12)	16.93 (0.07)	16.76 (0.07)
2018-08-29	58359.973	90.07	17.54 (0.08)	16.94 (0.14)	16.90 (0.08)	16.74 (0.08)
2018-09-02	58363.006	93.02	17.53 (0.08)	16.92 (0.13)	16.92 (0.09)	16.74 (0.07)

Table A2
(Continued)

Date UT	MJD	Phase (day)	m_g (mag)	m_r (mag)	m_i (mag)	m_z (mag)
2018-09-03	58364.004	93.99	17.59 (0.07)	16.93 (0.14)	16.94 (0.07)	16.74 (0.08)
2018-09-05	58366.024	95.96	17.63 (0.07)	16.98 (0.13)	16.98 (0.08)	16.78 (0.08)
2018-09-06	58367.996	97.88	17.72 (0.06)	17.03 (0.15)	17.05 (0.08)	16.86 (0.07)
2018-09-07	58368.997	98.86	17.76 (0.08)	17.11 (0.13)	17.06 (0.08)	16.91 (0.09)
2018-09-08	58369.997	99.83	17.83 (0.07)	17.16 (0.13)	17.14 (0.08)	16.94 (0.07)
2018-09-10	58371.997	101.78	17.96 (0.07)	17.30 (0.13)	17.28 (0.08)	17.06 (0.07)
2018-09-13	58374.994	104.70	18.13 (0.09)	17.46 (0.14)	17.49 (0.10)	17.22 (0.08)
2018-09-15	58376.045	105.72	18.13 (0.15)	17.50 (0.15)	17.50 (0.09)	17.22 (0.07)
2018-09-16	58377.998	107.62	18.39 (0.07)	17.71 (0.14)	17.71 (0.10)	17.43 (0.07)
2018-09-20	58381.040	110.59	18.56 (0.10)	17.93 (0.12)	17.96 (0.09)	17.62 (0.07)
2019-01-22	58505.353	231.67	>21.46	>23.47	>20.77	>22.08
2019-02-04	58518.356	244.33	>23.25	>23.34	>21.61	>21.32
2019-02-16	58530.315	255.98	>23.09	>23.02	>22.97	>22.60
2019-02-17	58531.341	256.98	>23.88	>23.26	>23.84	>22.44
2019-03-05	58547.305	272.53	>23.32	>23.22	>23.01	>22.63
2019-04-04	58577.349	301.79	>23.16	>20.87	>22.72	>21.75
2019-04-07	58580.325	304.69	>23.38	>23.30	>23.32	>22.82
2019-04-08	58581.362	305.70	>22.68	>22.77	>22.67	>22.10
2019-04-09	58582.252	306.57	>23.28	>23.91	>22.82	>21.36
2019-04-10	58583.408	307.69	>22.87	>22.13	>22.37	>21.68
2019-04-11	58584.410	308.67	>23.08	>22.95	>21.90	>21.77
2019-04-13	58586.402	310.61	>23.40	>22.90	>22.32	>21.84
2019-06-05	58639.149	361.98	>23.53	>22.74	>22.44	>22.17
2019-08-05	58700.043	421.29	>23.70	>23.40	>23.31	>22.96
2020-02-14	58893.308	609.53	template	template	template	template

Table A3
NIR Photometry for SN 2018bsz with GROND

Date UT	MJD	Phase (day)	m_J (mag)	m_H (mag)	m_{K_s} (mag)
2018-06-01	58270.139	2.57	15.68 (0.06)	15.90 (0.06)	16.05 (0.10)
2018-06-02	58271.229	3.63	15.62 (0.04)	15.81 (0.06)	16.11 (0.08)
2018-06-03	58272.284	4.66	15.63 (0.04)	15.85 (0.06)	16.09 (0.10)
2018-06-04	58273.202	5.55	15.63 (0.06)	15.73 (0.05)	15.84 (0.09)
2018-06-05	58274.229	6.55	15.70 (0.04)	15.75 (0.08)	15.93 (0.09)
2018-06-06	58275.202	7.50	15.60 (0.07)	15.74 (0.08)	15.92 (0.09)
2018-06-07	58276.181	8.46	15.61 (0.09)	15.82 (0.08)	15.95 (0.11)
2018-06-08	58277.188	9.44	15.70 (0.08)	15.83 (0.07)	15.78 (0.11)
2018-06-09	58278.258	10.48	15.73 (0.06)	15.91 (0.10)	15.96 (0.11)
2018-06-13	58282.168	14.29	15.78 (0.08)	15.94 (0.10)	16.16 (0.08)
2018-06-14	58283.088	15.18	15.78 (0.09)	15.90 (0.10)	16.06 (0.09)
2018-06-15	58284.241	16.31	15.55 (0.09)	15.97 (0.08)	16.16 (0.09)
2018-06-16	58285.246	17.28	15.89 (0.07)	15.92 (0.07)	16.07 (0.11)
2018-06-17	58286.132	18.15	15.84 (0.11)	16.07 (0.12)	16.17 (0.09)
2018-06-18	58287.160	19.15	15.84 (0.10)	15.99 (0.11)	15.94 (0.09)
2018-06-19	58288.211	20.17	15.93 (0.07)	15.99 (0.08)	16.25 (0.09)
2018-06-20	58289.219	21.15	15.89 (0.05)	16.03 (0.06)	16.26 (0.09)
2018-06-21	58290.070	21.98	15.85 (0.10)	15.94 (0.12)	16.29 (0.08)
2018-06-22	58291.208	23.09	15.90 (0.11)	16.03 (0.11)	16.02 (0.10)
2018-06-23	58292.275	24.13	15.85 (0.08)	16.02 (0.09)	16.25 (0.10)
2018-06-24	58293.135	24.97	15.94 (0.05)	16.13 (0.06)	16.12 (0.10)
2018-06-25	58294.144	25.95	15.96 (0.04)	16.14 (0.06)	16.40 (0.10)
2018-06-26	58295.071	26.85	15.90 (0.07)	16.08 (0.08)	16.27 (0.09)
2018-06-27	58296.161	27.92	15.88 (0.12)	16.15 (0.12)	16.23 (0.09)
2018-06-28	58297.106	28.84	15.94 (0.06)	15.98 (0.08)	16.22 (0.09)
2018-06-29	58298.192	29.89	15.93 (0.08)	16.15 (0.08)	16.29 (0.10)
2018-07-02	58301.203	32.83	16.02 (0.05)	16.19 (0.06)	16.38 (0.10)
2018-07-07	58306.184	37.68	16.02 (0.05)	16.31 (0.07)	16.35 (0.10)
2018-07-08	58307.961	39.41	16.20 (0.06)	16.25 (0.07)	16.47 (0.10)
2018-07-10	58309.005	40.43	16.40 (0.10)	16.33 (0.14)	16.52 (0.09)
2018-07-11	58310.051	41.44	16.29 (0.08)	16.44 (0.12)	16.60 (0.10)

Table A3
(Continued)

Date UT	MJD	Phase (day)	m_J (mag)	m_H (mag)	m_{K_s} (mag)
2018-07-12	58311.036	42.40	16.17 (0.08)	16.63 (0.13)	16.47 (0.08)
2018-07-13	58312.019	43.36	16.37 (0.08)	16.43 (0.09)	16.52 (0.09)
2018-07-14	58313.109	44.42	16.36 (0.11)	16.49 (0.16)	16.55 (0.10)
2018-07-15	58314.130	45.42	16.36 (0.07)	16.48 (0.07)	16.62 (0.09)
2018-07-19	58318.105	49.29	16.29 (0.05)	16.52 (0.06)	16.83 (0.13)
2018-07-21	58320.200	51.33	16.29 (0.04)	16.46 (0.07)	16.74 (0.10)
2018-07-22	58321.082	52.19	16.34 (0.06)	16.60 (0.07)	16.56 (0.09)
2018-07-23	58322.127	53.21	16.31 (0.07)	16.48 (0.07)	16.53 (0.10)
2018-07-24	58323.024	54.08	16.38 (0.06)	16.56 (0.08)	16.57 (0.09)
2018-07-25	58324.115	55.14	16.39 (0.04)	16.57 (0.06)	16.39 (0.11)
2018-07-31	58330.098	60.97	16.41 (0.09)	16.45 (0.07)	16.53 (0.10)
2018-08-01	58331.043	61.89	16.34 (0.07)	16.53 (0.08)	16.63 (0.09)
2018-08-02	58332.079	62.90	16.35 (0.06)	16.59 (0.07)	16.45 (0.09)
2018-08-04	58334.962	65.71	16.63 (0.09)	16.60 (0.10)	16.00 ^a (0.29)
2018-08-08	58338.020	68.69	16.62 (0.04)	16.65 (0.05)	16.98 (0.11)
2018-08-09	58339.043	69.68	16.49 (0.08)	16.59 (0.08)	16.51 (0.09)
2018-08-10	58340.096	70.71	16.58 (0.06)	16.65 (0.07)	16.79 (0.10)
2018-08-12	58342.057	72.62	16.51 (0.08)	16.65 (0.09)	16.72 (0.09)
2018-08-13	58343.057	73.59	16.52 (0.05)	16.56 (0.07)	16.77 (0.09)
2018-08-15	58345.043	75.53	16.69 (0.10)	16.61 (0.08)	16.73 (0.10)
2018-08-16	58346.978	77.41	16.78 (0.12)	16.43 (0.11)	16.75 (0.08)
2018-08-21	58351.040	81.37	16.51 (0.08)	16.64 (0.09)	16.58 (0.08)
2018-08-21	58351.990	82.29	16.58 (0.06)	16.61 (0.07)	16.63 (0.08)
2018-08-22	58352.995	83.27	16.57 (0.06)	16.62 (0.08)	16.43 (0.09)
2018-08-24	58354.008	84.26	16.64 (0.04)	16.63 (0.04)	16.72 (0.11)
2018-08-24	58354.997	85.22	16.57 (0.06)	16.52 (0.07)	16.51 (0.09)
2018-08-26	58356.005	86.20	16.71 (0.07)	16.67 (0.08)	16.57 (0.10)
2018-08-27	58357.006	87.18	16.72 (0.07)	16.52 (0.07)	16.55 (0.09)
2018-08-28	58358.054	88.20	16.60 (0.07)	16.62 (0.07)	16.34 (0.09)
2018-08-28	58358.972	89.09	16.55 (0.06)	16.53 (0.07)	16.54 (0.08)
2018-08-29	58359.973	90.07	16.65 (0.04)	16.58 (0.07)	16.64 (0.08)
2018-09-02	58363.006	93.02	16.53 (0.09)	16.54 (0.09)	16.29 (0.09)
2018-09-03	58364.004	93.99	16.62 (0.07)	16.67 (0.08)	16.44 (0.10)
2018-09-05	58366.024	95.96	16.63 (0.06)	16.57 (0.08)	16.40 (0.10)
2018-09-06	58367.996	97.88	16.86 (0.07)	16.67 (0.11)	16.82 (0.10)
2018-09-07	58368.997	98.86	16.95 (0.08)	16.77 (0.12)	16.81 (0.10)
2018-09-08	58369.997	99.83	16.81 (0.06)	16.59 (0.07)	16.59 (0.09)
2018-09-10	58371.997	101.78	16.85 (0.05)	16.53 (0.07)	16.35 (0.10)
2018-09-13	58374.994	104.70	17.02 (0.06)	16.82 (0.06)	16.77 (0.10)
2018-09-15	58376.045	105.72	17.36 (0.05)	16.85 (0.05)	16.72 (0.10)
2018-09-16	58377.998	107.62	17.13 (0.07)	16.87 (0.09)	16.77 (0.08)
2018-09-20	58381.040	110.59	17.18 (0.06)	16.87 (0.07)	16.59 (0.09)
2019-01-22	58505.353	231.67	19.88 (0.15)	18.85 (0.14)	18.03 (0.14)
2019-02-04	58518.356	244.33	21.48 (0.28)	20.14 (0.17)	18.59 (0.11)
2019-02-16	58530.315	255.98	>21.43	20.60 (0.26)	19.27 (0.26)
2019-02-17	58531.341	256.98	>20.44	20.78 (0.24)	>18.59
2019-03-05	58547.305	272.53	>21.59	>20.37	>19.55
2019-04-04	58577.349	301.79	>19.52	>19.51	>19.29
2019-04-07	58580.325	304.69	>21.35	>20.23	>19.40
2019-04-08	58581.362	305.70	>21.12	>20.22	>19.29
2019-04-09	58582.252	306.57	>20.37	>20.67	>19.13
2019-04-10	58583.408	307.69	>21.95	>20.58	>19.50
2019-04-11	58584.410	308.67	>21.84	>20.49	>19.30
2019-04-13	58586.402	310.61	>21.22	>20.49	>19.31
2019-06-05	58639.149	361.98	>20.56	>20.16	>18.13
2019-08-05	58700.043	421.29	>21.56	>20.92	>19.75
2020-02-14	58893.308	609.53	template	template	template

Notes. The magnitudes are with host template subtraction, with 1σ errors given in parentheses. Magnitudes are given in AB mag. The rest-frame phase is with respect to the r -band peak epoch (MJD = 58267.5).

^a We do not use this magnitude in our analysis.

Table A4
SOFI Observations for SN 2018bsz

Date (UT)	MJD (day)	Phase (day)	m_J (mag)	m_{K_s} (mag)
2019-02-26	58540.344	265.75	>21.92	19.65(0.15)
2019-05-02	58605.069	328.79	...	>20.67
2019-07-31	58695.105	416.49	...	>21.11
2020-02-03	58882.373	598.88	template	...
2020-02-04	58883.338	599.82	...	template

Note. The magnitudes are after host template subtraction and given in AB mag.

Table A5
Spitzer MIR Aperture Photometry for SN 2018bsz with Host Subtraction

Date (UT)	MJD (day)	Phase (day)	m_{Ch1} (mag)	m_{Ch2} (mag)
2019-06-27	58661.648	383.90	20.17(0.24)	19.13(0.09)
2019-07-17	58681.576	403.31	20.46(0.23)	19.42(0.11)
2019-11-29	58816.551	534.77	21.84 ^a (0.70)	21.59 ^a (0.55)
2019-12-30	58847.113	564.54	template	template

Notes. We use the 2019 December 30 epoch as the host template, assuming the SN flux is negligible. The 3σ uncertainty is estimated by the standard deviation of the sky background near the SN position. The $Ch1$ and $Ch2$ channels correspond to 3.6 and 4.5 μm , respectively. The magnitudes are reported in the AB system.

^a We note that the magnitudes at +535 days could possibly be oversubtracted from the template, as there are only 30 days in between. Therefore, we assume a linear decay since +384 days and extrapolate the magnitudes at +535 days. These extrapolations yield 22.42 and 21.41 mag in m_{Ch1} and m_{Ch2} , respectively, which are consistent with the template-subtracted magnitudes within the uncertainties.

Table A6
NEOWISE MIR Light Curves for SN 2018bsz with Host Galaxy Subtraction

Date (UT)	MJD ^a (day)	Phase (day)	m_{W1} (mag)	m_{W2} (mag)
2018-08-07	58337.198	67.89	17.60(0.14)	17.83(0.16)
2019-02-25	58539.742	265.16	18.88(0.42)	18.01(0.19)
2019-08-06	58701.536	422.75	...	19.64(0.85)
Host galaxy	...	...	16.20(0.01)	16.65(0.02)

Note. The magnitudes of the host galaxy are estimated from the mean magnitude of all NEOWISE epochs up until the SN explosion. The 3σ uncertainties include statistic and systematic errors. The $W1$ and $W2$ bands correspond to 3.4 and 4.6 μm , respectively. The magnitudes are reported in the AB system.

^a average MJD of all 12–18 exposures in a single epoch.

A.1. UVOT Observations with Swift

We obtained 28 epochs of photometry for SN 2018bsz with UVOT on board the Neil Gehrels Swift Observatory. The UVOT photometry was performed using the task `uvot-source` in HEASoft⁴⁴ version 6.25, with a 3'' radius aperture. For host subtraction, a template was constructed from images obtained between MJD = 58562 and 59068. We measured the host contribution using the same source and

background apertures and numerically subtracted the host contribution from the SN light curve. While this manuscript was in preparation, a new version of the Swift CALDB was released, which affects the zero-point for our UVOT data. However, as the change in photometry is less than 0.1 mag and within the photometric uncertainties in all epochs, we have not implemented this change here, and it will not affect our results. Table A1 provides the UVOT host-subtracted light curve. For comparison, Figure A1 shows the temperature evolution of SN 2018bsz relative to the average evolution of SLSNe I and SNe II.

A.2. Optical and NIR Imaging from GROND

We used GROND to monitor the light-curve evolution of SN 2018bsz from +3 to +421 days. This seven-channel imager collects multiband photometry simultaneously in the g' , r' , i' , z' , J , H , and K_s bands. The images were reduced using the GROND pipeline (T. Krühler et al. 2008), which applies de-bias and flat-field corrections, stacks images, and provides astrometric calibration. For GROND NIR images, due to the bright host galaxy we disabled line-by-line fitting of the sky subtraction routine since this caused oversubtraction artifacts.

All photometric measurements of the imaging data were carried out using the custom-built photometry pipeline `AutoPhOT`⁴⁵ (S. J. Brennan & M. Fraser 2022); the version of the software used in this work is archived on Zenodo (S. Brennan 2026). Point spread function (PSF) photometry was performed using a PSF model built from bright, isolated sources in the image. We adopted the +610 day epoch as the host galaxy template and subtracted that before measuring the SN brightness using `AutoPhOT`. The optical magnitudes are calibrated against Pan-STARRS field stars, while NIR images are calibrated to the Two Micron All Sky Survey and converted to the AB system. The PSF model for each image is used to determine limiting magnitudes. We collect a random sample of pixels within a cutout around SN 2018bsz and build a pseudo-PSF model. We then assert a confidence that pixels at the transient are real detections, rather than a correlated noise spike.

For this work, limiting magnitudes are set to 3σ confidence. For further details, see S. J. Brennan et al. (2022). Figure A2 shows our GROND light curves of SN 2018bsz from +3 to +111 days.

In addition, we obtained several J and K_s -band images using SOFI on the NTT through the ePESSTO program. The images were reduced using the PESSTO pipeline (S. J. Smartt et al. 2015) with flat-fielding and sky background subtraction. The host templates were taken around +600 days and we measured the host-subtracted photometry of those SOFI images using `AutoPhOT`.

The optical and NIR host-subtracted photometry of SN 2018bsz is reported in Tables A2, A3, and A4.

A.3. MIR Imaging from Space

We obtained Spitzer observations at four different epochs between 2019 June 27 (at epoch +384 days) and 2019 December 30 (+564 days), just before the end of the Spitzer

⁴⁴ <https://heasarc.gsfc.nasa.gov/docs/software/heasoft/>

⁴⁵ <https://github.com/Astro-Sean/autophot>

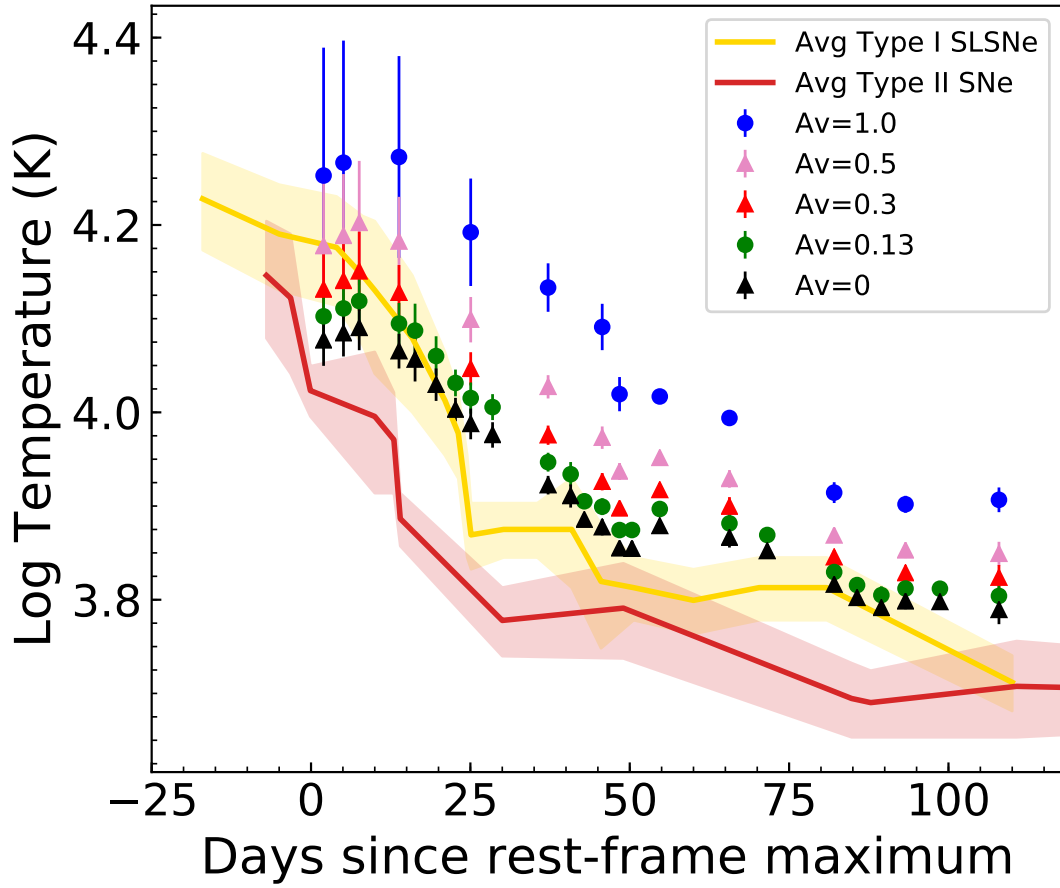


Figure A1. Temperature evolution of SN 2018bsz in comparison to the average evolution of SLSNe I and SNe II (C. Inserra et al. 2018b). The comparison samples comprise 14 SLSNe I (C. Inserra et al. 2013; M. Nicholl et al. 2015) and ~ 30 SNe II (A. Elmhamdi et al. 2003; K. Maguire et al. 2010; C. Inserra et al. 2011, 2012; M. T. Botticella et al. 2010; L. Tomasella et al. 2013; C. P. Gutiérrez et al. 2017b). The shaded regions represent the 99.73% confidence ranges for the temperature of each class of SNe. The temperature of SN 2018bsz is measured from SED fits, assuming a blackbody at selected epochs. We find that if the host extinction is between $A_V = 0.1$ and 0.3 mag, we obtain reasonable agreement with the SLSNe at 3–20 days after the peak.

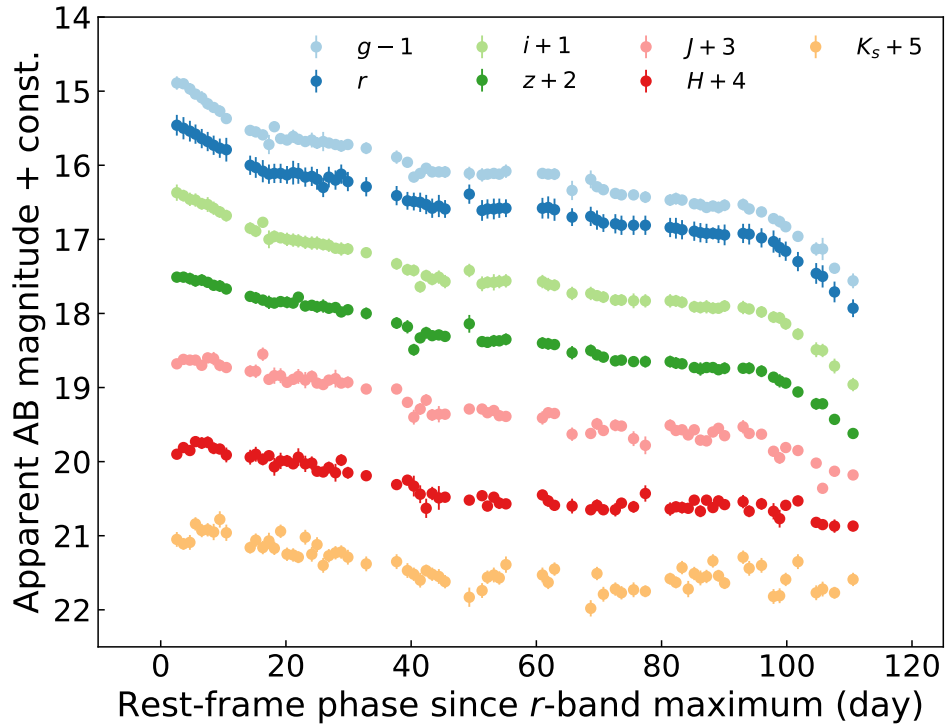


Figure A2. GROND host-subtracted light curves of SN 2018bsz. These data are the first daily cadence and simultaneous seven-band observations of an SLSN.

mission. The images were taken using IRAC in the 3.6 and 4.5 μm bands, which we here refer to as the *Ch1* and *Ch2* bands.

We aligned the images using the `geomap` and `geotran` tasks within IRAF and employed the `HOTPANTS`⁴⁶ package to carry out the host template subtraction. We used the last epoch as the host template and subtracted the other frames from it. The image subtraction results are shown in Figure C2. We measured the counts from the SN in those host-subtracted images using the `DAOPHOT` task within IRAF. With an aperture size of 6.1 pixel radius, a conversion factor of 8.461595×10^{-6} and an aperture correction of 1.112, we calculated the SN fluxes in Jansky and converted them to magnitudes. More details on the conversion factor and aperture correction can be found on the Spitzer Heritage Archive.^{47,48} The errors were dominated by the standard deviation of the sky background pixels around the SN positions.

The Spitzer m_{Ch1} measurement at +384 days is consistent with the evolution of the NEOWISE m_{W1} magnitudes. This validates our choice to use the +565 days epoch as a template, because the NEOWISE magnitudes are obtained by subtracting a template that was obtained before the SN explosion. On the other hand, assuming a linear decline from +384 to +403 days, the extrapolated magnitudes that we derived at +535 days are $m_{Ch1} \sim 22.4$ and $m_{Ch2} \sim 21.4$ mag, respectively. Those are consistent within the uncertainties of the measured Spitzer magnitudes that result from using the +565 days data as the template ($m_{Ch1} = 21.8 \pm 0.7$, $m_{Ch2} = 21.6 \pm 0.6$ mag).

The NEOWISE-R dataset consists of 12 epochs at W1 (3.4 μm) and W2 (4.6 μm) at an ~ 6 month cadence, with the final three epochs obtained after the discovery of SN 2018bsz. Each epoch consists of 12–18 individual exposures across ~ 2 days, with PSF-fitted magnitudes available in the NEOWISE-R catalog. An unresolved source was reported at the position of the host of SN 2018bsz at all epochs. We calculated the average magnitude at each epoch, where exposures flagged for poor quality were excluded, and the error was taken as the standard error of the mean combined with a flux error term to reflect the uncertainty between epochs (e.g., E. C. Kool et al. 2020). The nine NEOWISE-R epochs up until the SN discovery did not show significant evolution within the errors at the W1 and W2 bands. Based on these nine epochs, we determined mean quiescent magnitudes in the W1 and W2 bands of the host of SN 2018bsz of 13.50 ± 0.01 and 13.32 ± 0.02 mag, respectively. The mean quiescent magnitudes were then subtracted, in flux space, from the three post-SN NEOWISE-R epochs to obtain the contribution of the SN in the W1 and W2 bands at each epoch. The final SN magnitude errors include the statistical error and the systematic error of the quiescent magnitude. More details on this method are described in E. C. Kool et al. (2020).

Appendix B Optical and NIR Spectroscopic Observations of SN 2018bsz

We obtained a series of spectra of SN 2018bsz using different instruments (a log of the observations is given in Table B1).

SINFONI is a NIR IFU fed by an adaptive optics (AO) module. We used the SN itself as a natural guide star, in order to perform AO corrections. Unfortunately, as SN 2018bsz was around ~ 16 mag at the time these observations were taken, it was too faint to obtain a satisfactory AO correction. The observations hence have a seeing of $\sim 1''$, much larger than expected.

WiFeS is an IFU with 25 slitlets that are $1''$ wide and $38''$ long. The data were reduced using a custom-built pipeline `PyWiFeS` (M. J. Childress et al. 2014). The prepeak NTT +EFOSC2 spectrum was taken from J. P. Anderson et al. (2018); the postpeak spectrum at +108 days was reduced in the standard fashion using the PESSTO pipeline (S. J. Smartt et al. 2015).

The X-Shooter data were reduced using `PyPeIt`⁴⁹ package (J. Prochaska et al. 2020a; J. X. Prochaska et al. 2020b). However, no SN trace is detected, and in particular, we see no clear broad feature at the red extremity of the spectrum where we expect CO emission (~ 23000 Å). The SINFONI and X-Shooter NIR spectra of SN 2018bsz are shown in Figure B1.

At +417 days, when SN 2018bsz had disappeared in the optical, we used MUSE to observe the host environment. The data were reduced and combined into single MUSE data cubes using the standard ESO pipeline software version 1.2.11 (P. M. Weilbacher et al. 2014). We also subtracted the sky lines from our data cubes using the Zurich Atmospheric Purge v2.0 (K. T. Soto et al. 2016) software and corrected for telluric absorptions using the `molecfit` software package (A. Smette et al. 2015). Detailed data reduction procedures are described in P. Schady et al. (2019).

We measured the emission-line fluxes from the extracted MUSE spectrum at the SN position. The spectrum has been corrected for the Milky Way dust extinction and host dust extinction based on the Balmer decrement, and the stellar continuum has been subtracted. The flux and uncertainty measurement follow the method in T.-W. Chen et al. (2017b). We adopted the M. Pettini & B. E. J. Pagel (2004) calibration of the N2 and O3N2 methods, which use the $\log([\text{N II}]\lambda 6583/\text{H}\alpha)$ ratio, giving $12 + \log(\text{O}/\text{H}) = 8.27 \pm 0.06$, and the $\log([\text{O III}]\lambda 5007/\text{H}\beta)/([\text{N II}]\lambda 6583/\text{H}\alpha)$ ratio, giving $12 + \log(\text{O}/\text{H}) = 8.27 \pm 0.05$, respectively. Moreover, we also adopted a metallicity diagnostic of M. A. Dopita et al. (2016), which uses $[\text{N II}]\lambda 6583$, $\text{H}\alpha$, $[\text{S II}]\lambda\lambda 6717, 6731$ lines, giving $12 + \log(\text{O}/\text{H}) = 8.14 \pm 0.10$. Assuming a solar oxygen abundance of $12 + \log(\text{O}/\text{H})_{\odot} = 8.69$ (M. Asplund et al. 2009), we found the local metallicity at the position of SN 2018bsz to be $\approx 0.3 - 0.4 Z_{\odot}$, in line with the general properties of SLSN host galaxies (e.g., T.-W. Chen et al. 2017a).

⁴⁶ <http://www.astro.washington.edu/users/becker/v2.0/hotpants.html>

⁴⁷ <https://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/iracinstrumenthandbook/24/>

⁴⁸ https://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/iracinstrumenthandbook/27/#_Toc410728317

⁴⁹ <https://pypeit.readthedocs.io/en/latest/>

Table B1
Spectroscopic Observations

Date	MJD	Phase (day)	Telescope	Instrument	Grism or Grating	Exp. time (s)	Slit (arcsec)	Resolution (Å)	Range (Å)
2018-05-23	58261.290	−6	NTT	EFOSC2	Gr#11/Gr#16	1500/1500	1.0/1.0	13.8/13.4	3400–7400/6000–9900 ^a
2019-06-16	58285	+17	VLT	SINFONI	J	6300	IFU		11,000–14,000
2018-08-16	58346.561	+77	ANU 2.3 m	WiFeS	B3000/R3000	1800/1800	IFU	1.6/2.5	3500–5700/5400–9500
2018-09-17	58378.035	+108	NTT	EFOSC2	Gr#11/Gr#16	2700/2700	1.0/1.0	13.8/13.4	3400–7400/6000–9900 ^b
2019-04-30	58603	+327	VLT	X-Shooter	UVB/VIS/NIR	3600/3712/3600	0.9/0.9/1.0	1/1.1/3.3	3000–5560/5450–10,200/10,000–20,600
2019-05-05	58608	+332	VLT	X-Shooter	UVB/VIS/NIR	7200/7424/7200	0.9/0.9/1.0	1/1.1/3.3	3000–5560/5450–10,200/10,000–20,600
2019-05-06	58609	+333	VLT	X-Shooter	UVB/VIS/NIR	3600/3712/3600	0.9/0.9/1.0	1/1.1/3.3	3000–5560/5450–10,200/10,000–20,600
2019-06-27	58661	+383	VLT	X-Shooter	UVB/VIS/NIR	7200/7424/7200	0.9/0.9/1.0	1/1.1/3.3	3000–5560/5450–10,200/10,000–20,600
2019-08-01	58696	+417	VLT	MUSE	...	2139	IFU	...	4650–9300

Notes.

^a The −6 day spectrum is taken from J. P. Anderson et al. (2018).

^b The +108 day spectrum is presented in M. Pursiainen et al. (2022).

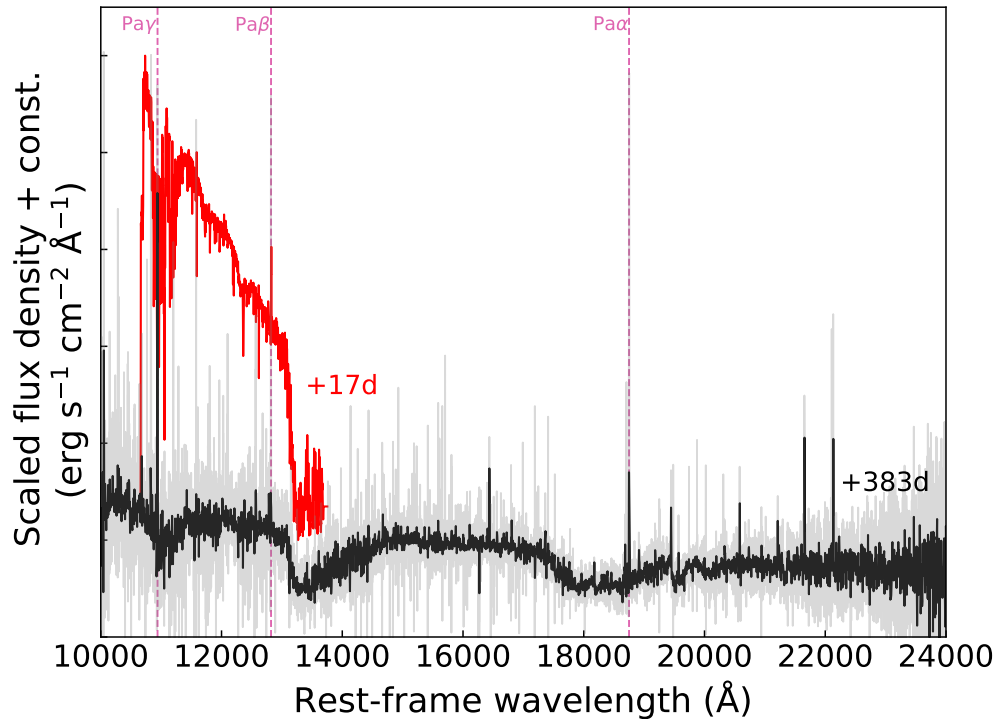


Figure B1. NIR spectra of SN 2018bsz. We extracted the SN position in the SINFONI data cube obtained at +17 days. A narrow Pa β is clearly detected, which is from the host H II region. No broad emission from the SN has been seen, confirming the hydrogen-poor ejecta at peak brightness. The X-Shooter spectrum was taken on +383 days; no trace from the SN has been detected. The spectra shown in this figure are provided as Data behind the Figure. (The data used to create this figure are available in the [online article](#).)

Appendix C Bolometric Light-curve Construction

We used the *Superbol* code⁵⁰ (M. Nicholl 2018) to construct the bolometric light curve of SN 2018bsz. We integrated the flux for SN 2018bsz over the observed bands from UV to MIR between +2 and +265 days, which gives very similar results to the bolometric light curve computed using blackbody extrapolations. We used the K_s -band epochs as our reference passband and interpolated and extrapolated the other bands by fitting a low-order polynomial to estimate the magnitude at epochs with missing data in a given filter. Unfortunately, during the prepeak rising phase, we only have the optical light curve (with two colors), and thus we used the ATLAS o band as the reference filter here. We assumed that the colors are the same as those at peak brightness to extrapolate the UV, other optical bands, and NIR. For the MIR contribution, we smoothly interpolated the MIR magnitudes between the WISE bands +68 and +265 days. For earlier phases after peak, we ran *Superbol* again with no MIR data and added a constant fraction to all epochs based on the MIR fraction at +68 days of 1%. Finally, we assumed no MIR contribution before the peak. We show the bolometric light curves with and without MIR contribution in Figure C1; those

are basically the same for the first 150 days as the MIR contribution is negligible in the early time.

The inset in Figure C1 shows the fractional luminosity in different wavelength ranges for SN 2018bsz. During the peak luminosity, the fraction of flux in the UV ($uvw2$, $uvm2$, $uvw1$; 1597–4730 Å) is 40%, optical (U , B , g , c , V , r , o , i , z ; 3018–10647 Å) is 53%, NIR (J , H , K_s ; 10707–24537 Å) is 6% and MIR ($W1$, $W2$; 2.75–5.34 μ m) is only 1% (assuming a constant fraction based on that at +68 days). After the peak, the UV fraction starts to decline, the optical fraction starts to increase and reaches 76% around +75 days, and the NIR fraction slowly increases. At +40 days, the fraction from the UV and the NIR was equal, both contributing 15% to the total luminosity. At +111 days, the fraction of UV dropped to 3%, the optical is 62%, the NIR rose to 32%, and the MIR is 3%. At the late-time phase of +232 days, there is no contribution from the UV and optical; the fraction from the NIR dominates at 74%, and the MIR is 26%. Just 34 days later, the MIR had significantly increased to 68%. The SOFI and Spitzer images and their corresponding template subtractions are shown in Figure C2. Figure C3 shows the evolution of the velocity inferred from the blackbody radius as a function of time

⁵⁰ <https://github.com/mnicholl/superbol/blob/master/superbol.py>

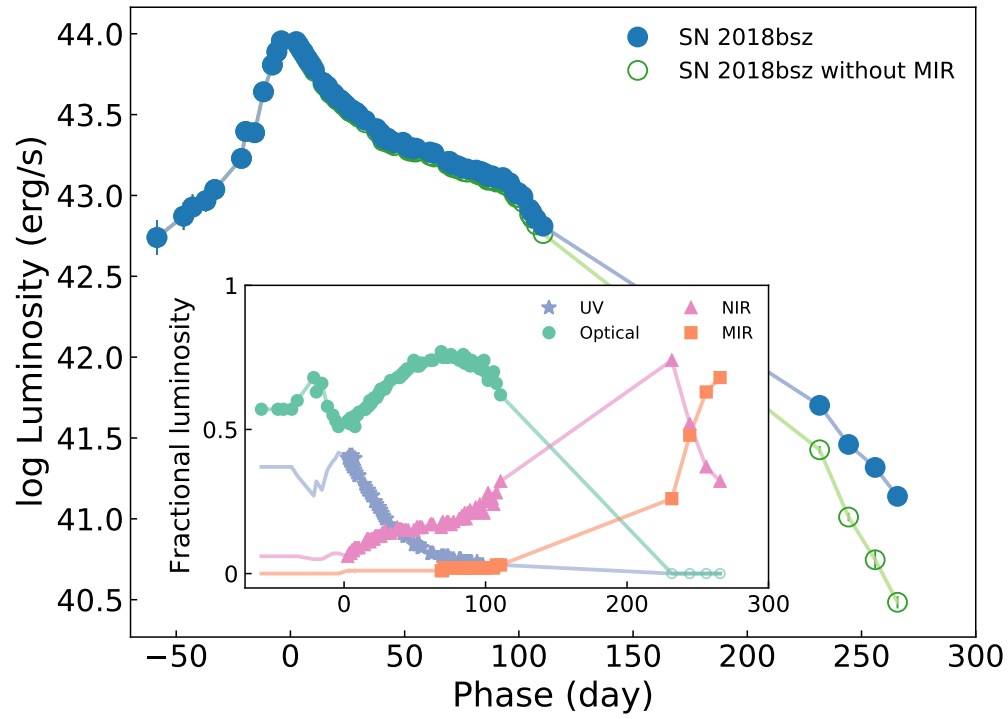


Figure C1. The bolometric light curve of SN 2018bsz. The blue solid points show the light curve integrated over all bands as discussed in the text, while the empty green points show the integration excluding the MIR contribution. The inset panel shows the relative contribution of UV ($uvw2$, $uvm2$, $uvw1$), optical (U , B , g , c , V , r , o , i , z), NIR (J , H , K_s), and MIR ($W1$, $W2$).

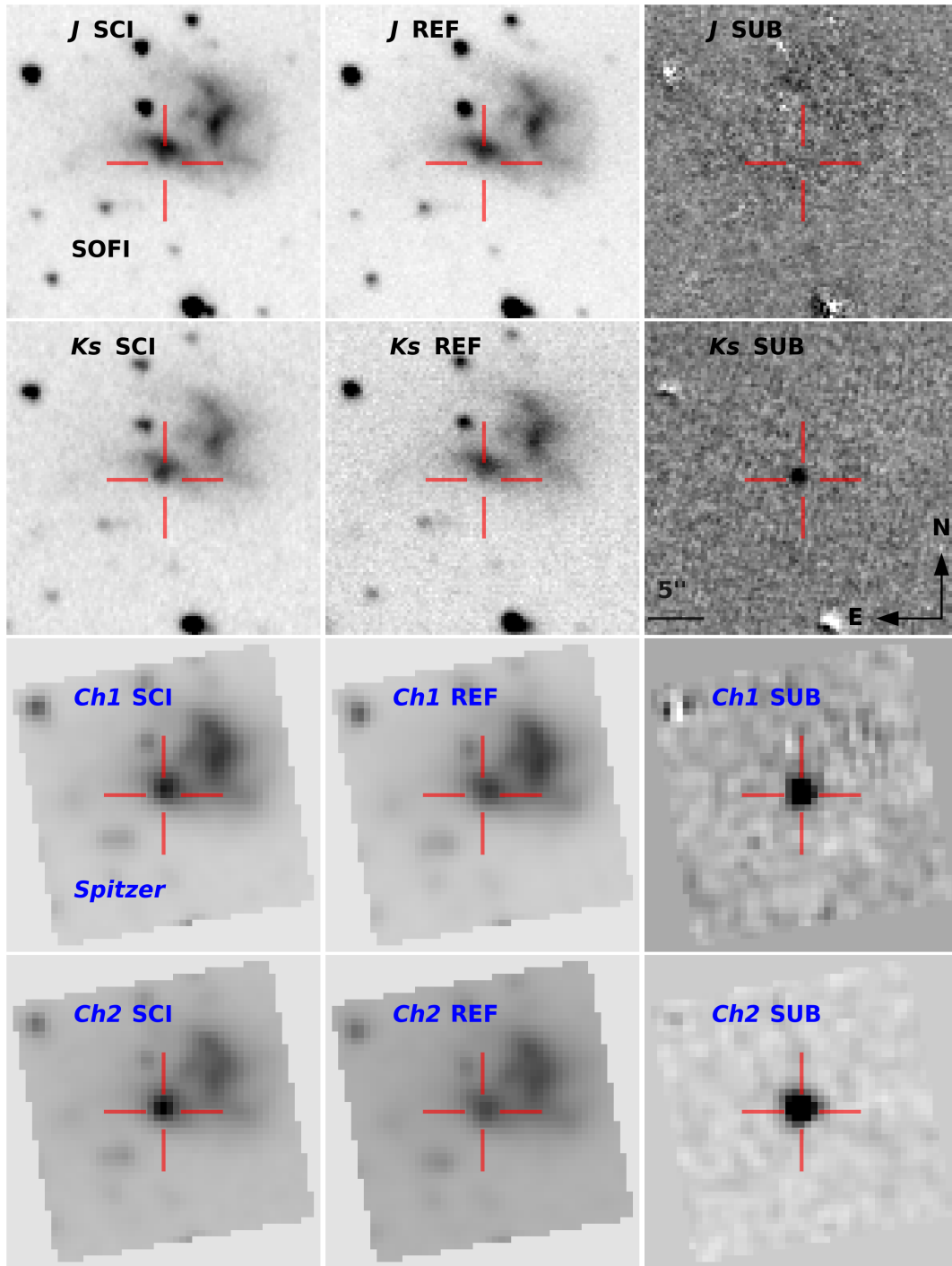


Figure C2. SOFI and Spitzer images of SN 2018bsz and template subtractions. The first row illustrates the SOFI *J*-band frame taken on +266 days, the reference image taken on +599 days, and the difference between the two (with a 3σ detection limit of >21.92 mag). The second row shows SOFI *K_s*-band images as the same epoch as in the first row. The *K_s*-band subtraction clearly detects a source at +266 days, where we detect the SN at 19.65 ± 0.15 mag. The third row displays the Spitzer *Ch1* ($3.6 \mu\text{m}$) frame taken on +384 days, the reference image taken on +565 days, and the result of their subtraction with a SN detection at 20.17 ± 0.24 mag. The fourth row presents the Spitzer *Ch2* ($4.5 \mu\text{m}$) images, at the same epoch as in the third row, where the SN was detected at 19.13 ± 0.09 mag. Each panel has the same scale and orientation as marked in the second row.

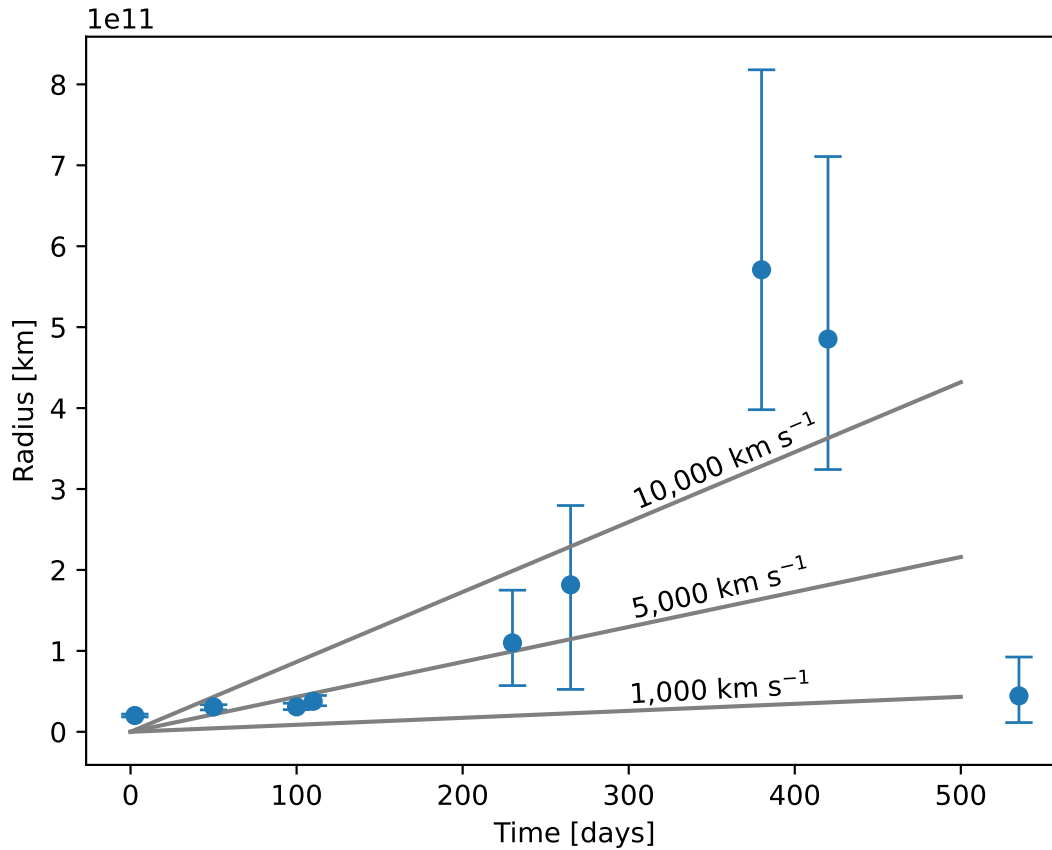


Figure C3. Evolution of the velocity as a function of blackbody radius and time for SN 2018bsz, based on the measurements listed in Table 1.

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