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Low-luminosity Type IIP Supernovae from the Zwicky Transient Facility Census of the Local Universe. II. Lightcurve Analysis

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Abstract

The Zwicky Transient Facility Census of the Local Universe survey yielded a sample of 330 Type IIP supernovae (SNe) with well-constrained peak luminosities. In paper I, we measured their luminosity function and volumetric rate. Here (paper II), we present the largest systematic study of lightcurve properties for Type IIP SNe from a volume-limited survey, analyzing a selected subset of 129 events, including 16 low-luminosity Type IIP (LLIIP) SNe with $M_{r,\text{peak}} \geq -16$ mag. We find that plateau slope correlates with peak brightness, with many LLIIP SNe showing positive slopes—suggesting smaller progenitor radii and distinct density profiles compared to brighter Type IIP SNe. The plateau duration shows only a weak dependence on peak brightness, likely suggesting binary interaction. One SN exhibits a plateau-to-tail drop of >3.5 mag, consistent with an electron-capture or failed SN with very low or zero nickel mass. We derive explosion and progenitor parameters of the entire Type IIP SN sample using semi-analytical and radiation-hydrodynamical models. Based on radiation-hydrodynamical model fitting, LLIIP SNe are characterized by low nickel masses ($0.001\text{--}0.025 M_{\odot}$), low explosion energies ($0.1\text{--}0.28 \times 10^{51}$ erg), low ejecta masses ($8.1_{-1.7}^{+0.8} M_{\odot}$), and ZAMS masses below $11 M_{\odot}$. In comparison, the full Type IIP SN sample spans a wider range with nickel masses ($0.001\text{--}0.222 M_{\odot}$), explosion energies ($0.10\text{--}4.43 \times 10^{51}$ erg), ejecta masses ($5.4\text{--}24.8 M_{\odot}$), and ZAMS masses ($9.3\text{--}16.7 M_{\odot}$). We find strong correlations between peak brightness, explosion energy, and nickel mass that extend to the low-luminosity end. We conclude that LLIIP SNe represent the faint, low-energy end of the Type IIP population and originate from the lowest-mass core-collapse progenitors.

Unified Astronomy Thesaurus concepts: Core-collapse supernovae (304); Massive stars (732); Stellar evolution (1599); Supernovae (1668); Type II supernovae (1731); Time domain astronomy (2109)

1. Introduction

Core-collapse supernovae (CCSNe) are the explosive deaths of massive stars that play crucial roles in galactic chemical

evolution, the formation of new stars, and the creation of compact neutron stars and black holes. Moreover, their luminosities, rates, and association with massive star formation make them essential tools for probing key astrophysical parameters across vast cosmic volumes. The most common type of core-collapse SNe are Type II SNe (e.g., Li et al. 2011; Shivvers et al. 2017). They arise from the explosions of stars that retain significant portions of their hydrogen envelopes.

Low-luminosity Type IIP supernovae (LLIIP SNe), defined here as those with $M_{r,\text{peak}} \geq -16$ mag, as motivated by prior

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literature (e.g., Pastorello et al. 2004; Spiro et al. 2014; Reguitti et al. 2021), are particularly intriguing because they are thought to originate from progenitor stars with just enough mass to undergo core collapse. These events likely arise from 8 to 12 M_{\odot} progenitors, as supported by pre-SN progenitor imaging (Maund et al. 2005; Li et al. 2006; Mattila et al. 2008; O’Neill et al. 2019; Van Dyk et al. 2023), light curve simulations (Fraser et al. 2011; Pumo et al. 2017), evolutionary models of low-mass red supergiants (RSGs; Lisakov et al. 2017), and nebular spectroscopy (Jerkstrand et al. 2018). They provide valuable insight into the lower mass threshold for core collapse, which defines the boundary between stars that form white dwarfs and those that form neutron stars or black holes. LLIP SNe also serve as key candidates for probing the upper mass limit of super-asymptotic giant branch (sAGB) star formation, exploring whether they can explode as electron-capture supernovae (ECSN; Nomoto 1984; Kitaura et al. 2006; Janka et al. 2008; Jones et al. 2013; Takahashi et al. 2013; Hiramatsu et al. 2021a; Wang et al. 2025), and understanding their role in shaping elemental abundances in subsequent generations of stars (Tsujiyama & Shigeyama 1999; Siess & Pumo 2006). Furthermore, a typical initial mass function (IMF) predicts that more than 40% of CCSN progenitors fall within the 8–12 M_{\odot} range, with 25% within the 8–10 M_{\odot} subset (Sukhbold et al. 2016). It has also been suggested that LLIP SNe may instead originate from more massive RSGs with significant fallback (e.g., Woosley & Weaver 1995; Zampieri et al. 2003; Moriya et al. 2010). Thus, systematic studies of LLIP SNe are essential for improving our understanding of the progenitors, explosion properties, and the dust and chemical enrichment contributed by nearly half of all massive stars that undergo core-collapse.

However, to date, no study of the lightcurve properties of LLIP SNe has been conducted using data from a systematic SN survey. Due to their low luminosity, they are relatively difficult to detect and classify. There are only about a dozen such objects presented in the literature, focused on single-object studies or small heterogeneous samples. Early examples such as SN 1997D, SN 1999eu and SN 1999br (Turatto et al. 1998; Pastorello et al. 2004) revealed the defining characteristics of the class: very low plateau luminosities ($M_V \approx -15$ mag), unusually narrow P-Cygni profiles indicating expansion velocities of only ~ 1000 – 2500 km s $^{-1}$, extremely small ^{56}Ni masses (10^{-3} – 10^{-2} M_{\odot}), and low explosion energies. Subsequent studies of nearby events such as SN 2005cs and SN 2008bk (Mattila et al. 2008; Pastorello et al. 2009; Van Dyk et al. 2012) connected these faint light curves to low-mass red supergiant progenitors (~ 8 – 12 M_{\odot}) through direct pre-explosion imaging and hydrodynamical modeling. Spiro et al. (2014) modeled a set of underluminous Type IIP SNe and confirmed uniformly low explosion energies; Nakaoka et al. (2018) and Reguitti et al. (2021)

found similarly low ^{56}Ni yields and slow expansion velocities for SN 2016bkv and SN 2018hwm, respectively; and studies such as Jäger, Zoltán et al. (2020), Müller-Bravo et al. (2020), Yang et al. (2021), Valerin et al. (2022), Kozyreva et al. (2022), Bostroem et al. (2023), Teja et al. (2024), Dastidar et al. (2025) have recently reported additional LLIP SN candidates with low luminosities and energetics consistent with either low-mass RSG/sAGB explosions or fallback-suppressed ^{56}Ni production. In contrast to these low-luminosity events, canonical Type II SNe typically reach plateau absolute magnitudes of $M_r \simeq -16$ to -18 mag, have plateau durations of ~ 80 – 120 days, ejecta masses of ~ 8 – 18 M_{\odot} , explosion energies of order 0.3 – 1×10^{51} erg, and ^{56}Ni yields of ~ 0.01 – 0.1 M_{\odot} (e.g., Hamuy 2003; Anderson et al. 2014; Sanders et al. 2015; Valenti et al. 2016; Martinez et al. 2022b; Fang et al. 2025). These properties are generally consistent with explosions of RSG progenitors with initial masses ~ 12 – 18 M_{\odot} (e.g., see Van Dyk 2025).

In Part I of the series of three papers on LLIP SNe (Das et al. 2025), we measured the luminosity function and volumetric rate of the largest sample to date of 36 LLIP SNe (and 330 Type IIP SNe) from the Zwicky Transient Facility Census of the Local Universe (ZTF CLU; Bellm et al. 2019; Graham et al. 2019; Masci et al. 2019; De et al. 2020; Dekany et al. 2020) survey. This paper delves into their lightcurve properties. In this paper, we analyze the observed properties of the multi-band lightcurves of a selected subset of 129 Type II SNe and 16 LLIP SNe. It is well established that the morphology of Type II SN lightcurves depends on key progenitor properties (e.g., final mass, envelope mass, and radius) and on explosion parameters such as the deposited energy and the amount and distribution of synthesized ^{56}Ni (e.g., Kasen & Woosley 2009; Goldberg et al. 2019). Here, we measure observed lightcurve parameters and infer physical and explosion parameters using semi-analytical and radiation-hydrodynamical models that link SN observables to progenitor properties (e.g., Litvinova & Nadezhin 1983; Hamuy 2003; Kasen & Woosley 2009; Morozova et al. 2018; Goldberg et al. 2019; Moriya et al. 2023). Such models have been previously applied to both individual events and larger samples of Type II SNe (Hamuy 2003; Arcavi et al. 2011; Anderson et al. 2014; Spiro et al. 2014; Sanders et al. 2015; Valenti et al. 2016; Gutiérrez et al. 2017; Morozova et al. 2018; Martinez et al. 2022b, 2022a; Subrayan et al. 2023; Silva-Farfán et al. 2024; Fang et al. 2025). This paper is structured as follows: in Section 2, we define the sample selection criteria. The data and extinction correction methods are described in Sections 3 and 4, respectively. Sections 5 and 6 detail the fitting methods and results. We discuss the implications of the derived physical properties in Section 7 and conclude in Section 8.

2. Sample Selection

From the ZTF CLU experiment, we selected Type IIP SNe with well-sampled r -band light curves and a clearly defined plateau phase. The selection required (i) a GP-fit peak apparent magnitude of $m_{r,\text{peak}} < 20$ mag, (ii) sufficient temporal coverage around peak and during the plateau (more than ten total detections and at least one detection on both sides of peak, or an equivalent set of conditions ensuring a constrained rise), and (iii) a plateau lasting at least 40 days with < 1 mag decline. We refer to Paper I (Das et al. 2025) for the complete sample selection criteria to select 330 Type IIP SNe. To select the sample for lightcurve analysis, we require that the end of the plateau phase is observed in the r -band lightcurve. This is to ensure we can extract reliable progenitor and explosion parameters from the lightcurves. The epoch of the end of the plateau ($t_{\text{plateau,end}}$) is determined as the epoch where the derivative of the slope of the r -band lightcurve (Δ_{slope}) reach a local minimum, and its value is < -0.003 mag day $^{-2}$, indicating a sharp transition (see Section 5.1 and Figure 1 for details). This marks the end of the plateau phase in the lightcurve evolution. Using this criterion, we identified 129 candidates that fulfill this selection criterion. Out of these, 68 objects have ≥ 2 r -band data points in the radioactive tail phase, while 61 SNe do not have an observed radioactive tail.

3. Data

In this section, we describe the photometric and spectroscopic data used.

3.1. Optical Photometry

We perform forced photometry on the ZTF difference images using the ZTF forced-photometry service developed by Masci et al. (2019) in g , r , and i bands. For this work, we consider anything less than a 3σ detection an upper limit. In the tail phase, for a few SNe we also took photometry in the g , r , i bands with the Optical Imager (IO:O) at the 2.0 m robotic Liverpool Telescope (Steele et al. 2004) and the Alhambra Faint Object Spectrograph and Camera at the Nordic Optical Telescope (Djupvik & Andersen 2010). The P60 and LT data sets were processed with the FPipe image subtraction pipeline (Fremling et al. 2016), using Sloan Digital Sky Survey (SDSS; Ahn et al. 2012) and PanSTARRS (PS1; Chambers et al. 2016) reference frames. See Das et al. (2025) for details on photometric observations and reductions. Figure 1 shows a few representative lightcurves as examples. The photometry data and lightcurve plots for all the SNe in the sample will be made available on [Zenodo](https://zenodo.org).

3.2. Optical Spectroscopy

For each transient, at least one spectrum is usually obtained close to the peak luminosity to establish an initial spectroscopic

classification. We primarily utilize the Double Beam Spectrograph (DBSP; Oke & Gunn 1982) on the Palomar 200-inch Hale telescope and the Spectral Energy Distribution Machine (SEDM; Blagorodnova et al. 2018; Rigault et al. 2019; Kim et al. 2022) on the Palomar 60-inch telescope for this purpose. Other instruments used to obtain classification spectra include: the Alhambra Faint Object Spectrograph and Camera at the Nordic Optical Telescope (NOT; Djupvik & Andersen 2010), the Spectrograph for the Rapid Acquisition of Transients (SPRAT; Piascik et al. 2014) on the Liverpool Telescope, the Low-Resolution Imaging Spectrometer (LRIS; Oke et al. 1995) on the Keck I telescope. See Das et al. (2025) for details on spectral observations and reductions. We employ the Super-Nova Identification (SNID; Blondin & Tonry 2007) and `superfit` (Howell et al. 2005) codes for classifications.

4. Extinction Correction

We corrected for Galactic extinction using the maps provided by Schlafly & Finkbeiner (2011). For the corrections, we use the extinction law described by Cardelli et al. (1989) with a value of $R_V = 3.1$.

To estimate host-galaxy extinction, we employ the empirical $g - r$ color template constructed in Paper I (Das et al. 2025) from a subset of Type IIP SNe with negligible host reddening (identified via weak or absent host Na I D absorption). The intrinsic template has a 1σ scatter of ~ 0.35 mag. For each SN in our sample, we measure the deviation of its observed $g - r$ color from this template and attribute any excess beyond the 1σ intrinsic range to host-galaxy reddening, converting it to $A_{V,\text{host}}$ assuming the same extinction law. The template is available on [Zenodo](https://zenodo.org). See Das et al. (2025) for further details.

5. Analysis

5.1. Observed Lightcurve Properties

We employed a Gaussian Process (GP) algorithm¹⁴ (Ambikasaran et al. 2015) to fit the r -band and g -band lightcurves. The top panel of Figure 1 displays the interpolated r -band lightcurve, the middle panel shows its first derivative with respect to time (i.e., the slope, in mag day $^{-1}$), and the bottom panel shows the time derivative of the slope, denoted as Δ_{slope} (in mag day $^{-2}$).

The r -band lightcurve parameters are measured using the following criteria:

1. *Plateau onset* ($t_{\text{plateau,start}}$). Defined as the earlier of (i) the epoch when the slope becomes shallower than 0.01 mag day $^{-1}$, or (ii) the epoch when the change in slope with respect to time (Δ_{slope}) reaches its maximum value, measured within 60 days after first detection.

¹⁴ <https://george.readthedocs.io/>

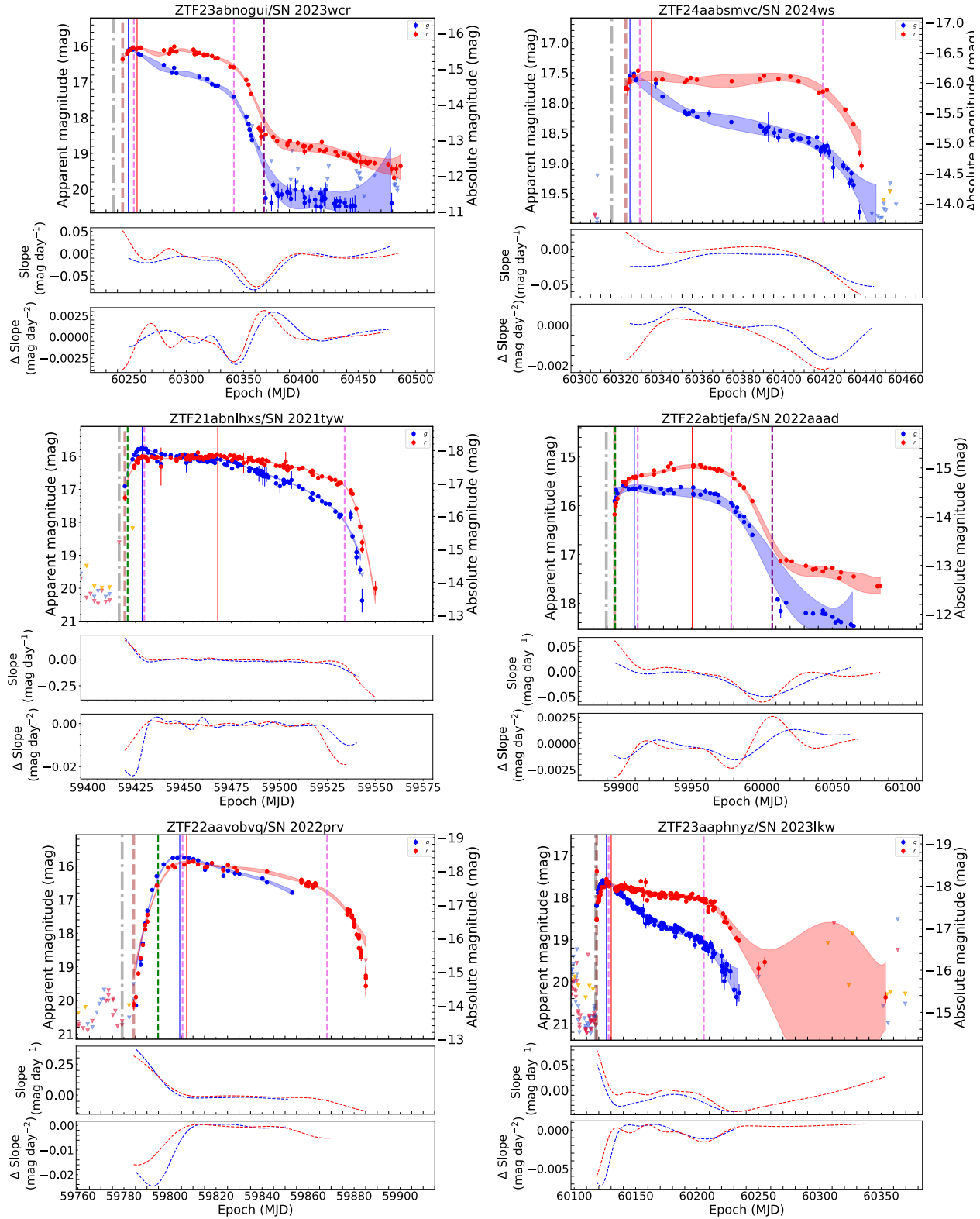


Figure 1. The upper panels show Gaussian Process fits to the lightcurves (shaded regions). Vertical dashed red lines indicate the epochs of first detection; vertical dashed grey lines mark the estimated explosion epochs. Vertical solid red and blue lines show the epochs of peak *r*- and *g*-band magnitudes, respectively. Vertical solid violet lines denote the start and end of the *r*-band plateau phase. Green dashed lines mark the epoch when the flux reaches 50% of the peak, used to compute the rise time. The lower panels show the light curve slope in units of mag day^{-1} and the change in slope (Δ slope) in units of mag day^{-2} .

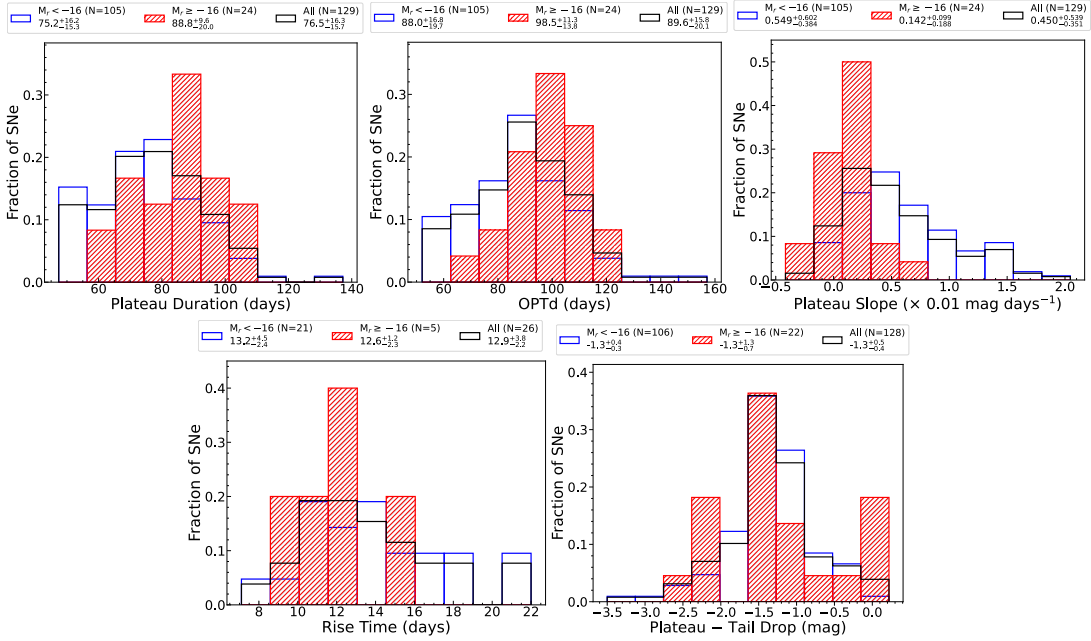


Figure 2. Distribution of observable properties of the r -band light curves for the SN sample. From left to right and top to bottom, the panels show the distributions of: (1) plateau duration, (2) optically thick phase duration (OPTd), (3) plateau slope, (4) rise time to peak, and (5) magnitude drop between the plateau and the tail phase. These observables are measured from the Gaussian Process fits described in Section 5.1. LLIIP SNe with $M_r \geq -16$ are shown in hatched red, those with $M_r < -16$ in blue, and the full sample is shown in black. The median (50th percentile) and the 16th and 84th percentiles of the distributions are indicated as median $_{-50\text{th}}^{+84\text{th}}$ in the legend.

2. *Plateau end* ($t_{\text{plateau, end}}$). The epoch of plateau end ($t_{\text{plateau, end}}$) is identified after 40 days, when the light-curve begins to steeply decline. This point is determined as the epoch where Δ_{slope} reaches a minimum below $-0.003 \text{ mag day}^{-2}$, indicating a sharp transition.
3. *Tail onset* (t_{tail}). Defined as the epoch post-plateau when Δ_{slope} reaches a maximum exceeding $0.002 \text{ mag day}^{-2}$, provided this occurs within 50 days after the plateau ends.
4. *Rise time* (t_{rise}). Defined as the time interval between the epoch when the r -band magnitude is 0.75 mag fainter than peak (half-maximum) and the epoch of maximum light.

To estimate uncertainties in these observables, we adopt a Monte Carlo approach. We simulate 50 realizations of each lightcurve based on Gaussian noise scaled to the flux errors. For each realization, we recompute the observables using the same criteria. The standard deviation of the resulting distribution of values is used as the uncertainty on the measurements of these observables. The plateau duration is measured as $t_{\text{plateau, end}} - t_{\text{plateau, start}}$. The optically thick plateau duration (OPTd) is measured as the duration between the explosion epoch and the midpoint of the plateau end and tail onset epochs. The distributions of these observed parameters are shown in Figure 2. A sharp luminosity drop between the plateau and the radioactive tail is a key prediction for both

ECSNe and failed SNe with very low or negligible ^{56}Ni production (e.g., Turatto et al. 1998; Tominaga et al. 2013). To identify such ECSN and failed-SN candidates in our sample, we measure the drop in the r -band magnitude from the end of the plateau to the first epoch on the tail, whenever the tail is detected. If a tail does not exist, this is marked as “Limit = yes” in Table A1 or indicated as a V-shaped triangle in Figure 3. These photometric definitions follow the same physical interpretation as those adopted by Anderson et al. (2014), who also identify the plateau phase through changes in the light-curve slope and characterize the transition to the radioactive tail using the steep post-plateau decline. Our implementation differs in that we use the derivatives of the lightcurve to define these transitions in a fully automated and objective way, whereas Anderson et al. (2014) relied on parametric spline fits and visually guided measurements for some phases. The data and code used for these measurements will be made publicly available on [Zenodo](#) and [GitHub](#) upon publication. The criteria are summarized in Table 1.

5.2. Measuring $H I$ Velocities

We derive expansion velocities of the $H I \lambda 6563$ line by measuring the minima of the absorption troughs in the P-Cygni profiles. A third-order polynomial is fit to the region surrounding the absorption minimum to estimate the velocity. For spectra with low resolution or strong host-galaxy

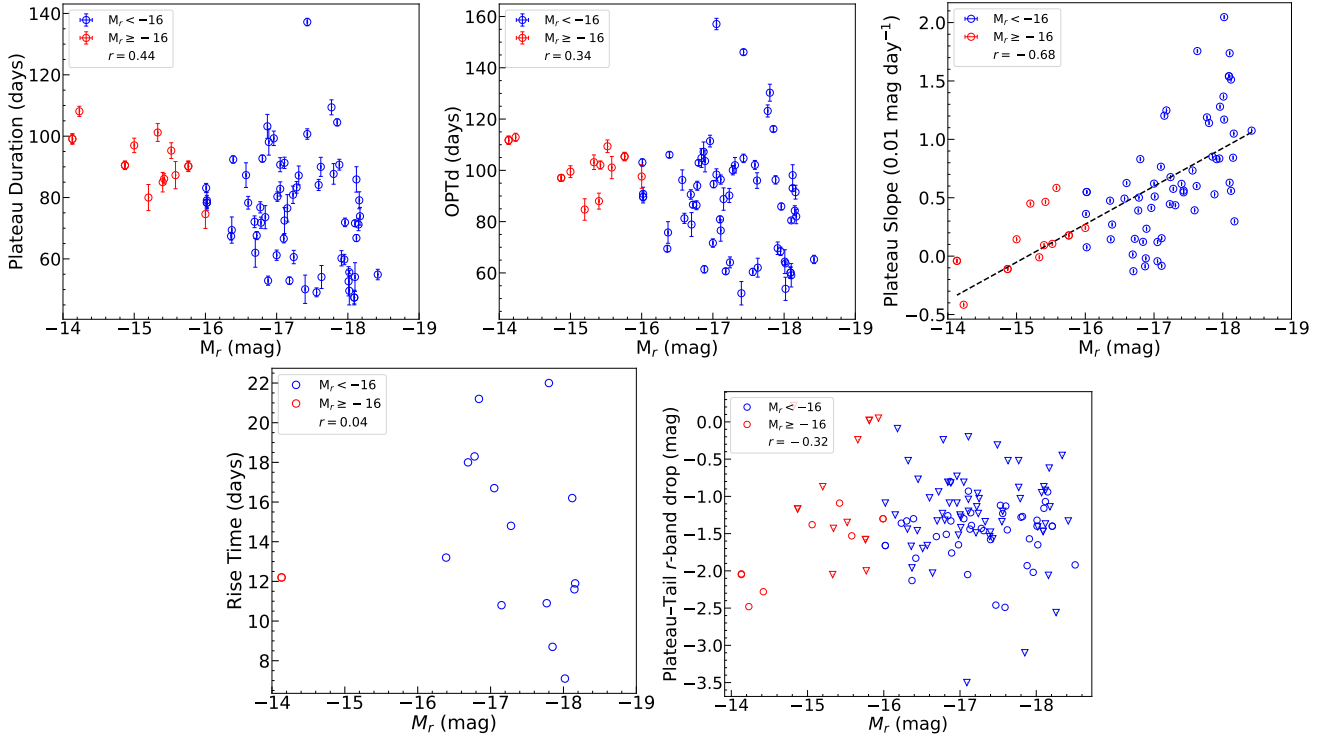


Figure 3. Observable light curve parameters as a function of r -band peak absolute magnitude (M_r). From left to right and top to bottom, the panels show: (1) plateau duration versus M_r , (2) optically thick phase duration (OPTd) versus M_r , (3) plateau slope versus M_r , (4) rise time versus M_r , and (5) the magnitude drop between the plateau and tail versus M_r . In the last panel, upper limits are indicated by V-shaped triangles for SNe without a detected tail phase. LLIIP SNe with $M_r \geq -16$ are shown in red, while SNe with $M_r < -16$ are shown in blue. See details in Section 6.1.

Table 1
Definition of Lightcurve Shape Parameters Based on Lightcurve Phase, Slope (mag day^{-1}), and Rate of Change of Slope Δ_{slope} (mag day^{-2})

Parameter	Phase / Slope Condition	Δ_{slope} Condition
$t_{\text{plateau,start}}$	Phase < 60 days; earlier of slope < 0.01 mag day^{-1} or max. Δ_{slope}	Max. Δ_{slope}
$t_{\text{plateau,end}}$	Phase > $t_{\text{plateau,start}} + 40$ days; slope < -0.03 mag day^{-1}	Min. $\Delta_{\text{slope}} < -0.003 \text{ mag day}^{-2}$
t_{tail}	Phase > $t_{\text{plateau,end}}$ and < $t_{\text{plateau,end}} + 50$ days; slope < 0	Max. $\Delta_{\text{slope}} \geq 0.002 \text{ mag day}^{-2}$
t_{rise}	Time between half-max. brightness ($(M_r + 0.75)$ mag) and peak epoch	Not applicable

contamination, we manually inspect and identify the minimum. Uncertainties are estimated via a Monte Carlo method. We first compute a noise spectrum by subtracting a heavily smoothed version of the original spectrum; the standard deviation of this residual defines the spectral noise. We then generate perturbed realizations by adding Gaussian noise of equal standard deviation to the smoothed spectrum and remeasure the velocity for each realization. The 1σ spread in the resulting velocity distribution is adopted as the measurement uncertainty. Only measurements with a standard deviation less than 50% of their velocity are considered reliable and included. The measured velocities and their errors are documented in Table A6.

We find that LLIIP SNe exhibit systematically lower H I $\lambda 6563$ velocities compared to their higher-luminosity

counterparts at all phases Figure 4. We fit a power-law of the form $V(t) = A t^{-s}$ to the binned velocity measurements. Photospheric velocities in Type II SNe are expected to follow a power-law decline during the plateau phase due to homologous expansion and the recession of the recombination front (e.g., Kasen & Woosley 2009). The best-fit relations are shown in Figure 4. For the LLIIP sample, we obtain $V(t) = (14.9 \pm 1.3) t^{-0.25 \pm 0.05}$, and for the full sample $V(t) = (26.2 \pm 2.1) t^{-0.32 \pm 0.05}$, where V is in units of 10^3 km s^{-1} and t is the phase in days since explosion.

In principle, Fe II $\lambda 5169$ is a better tracer of the photospheric velocity than H I (e.g., Dessart & Hillier 2005). However, most of our spectra were obtained with SEDM at $R \sim 100$, and we do not have sufficient resolution and SNR to robustly measure the Fe II $\lambda 5169$ absorption profile in most

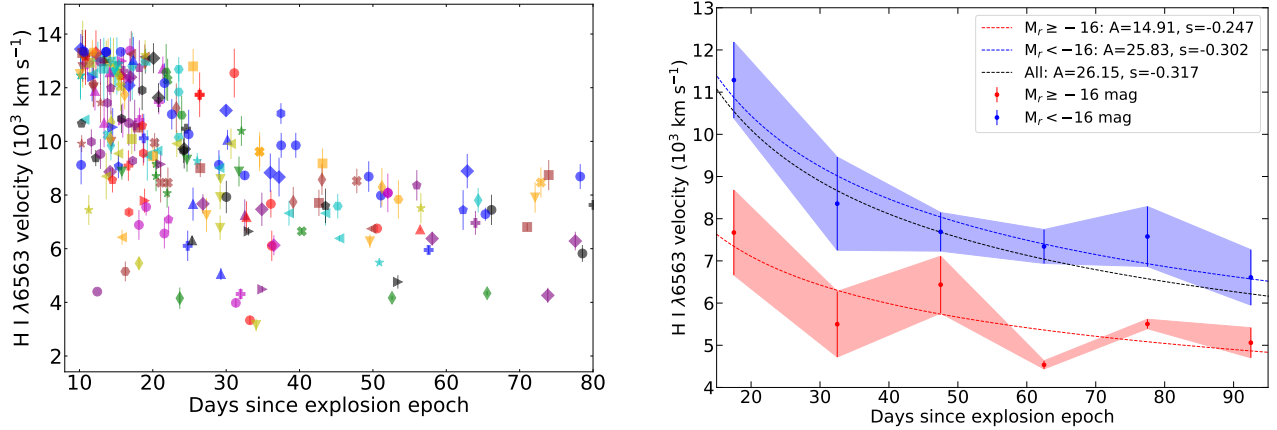


Figure 4. Left: Expansion velocities measured from the absorption minima of the H I $\lambda 6563$ P-Cygni line for all SNe in our sample. Each marker and color represents a unique SN. Right: Mean H I $\lambda 6563$ velocities with standard deviation for the full sample (black), LLIIP SNe with $M_r \geq -16$ (red), and brighter SNe with $M_r < -16$ (blue).

cases. We therefore use the $H\alpha$ velocity as a practical proxy. When needed for comparison with studies that quote Fe II velocities, we employ the empirical scaling relation between $H\alpha$ and Fe II derived by Faran et al. (2014),

$$v_{\text{Fe II}} = (0.855 \pm 0.006) v_{H\alpha} - (1499 \pm 87) \text{ km s}^{-1},$$

to estimate the corresponding Fe II velocity. These measured slopes ($s \approx 0.2\text{--}0.4$) lie within the range of shallow power-law declines inferred for Type II SN photospheric velocities in previous observational studies (e.g., Faran et al. 2014; de Jaeger et al. 2019; Lin et al. 2024). While both LLIIP SNe and brighter IIP SNe show comparable decline rates, LLIIP SNe exhibit lower velocities. At 50 days post-explosion, the average velocity inferred from these fits is approximately $5900 \pm 1200 \text{ km s}^{-1}$ for LLIIP SNe and $8440 \pm 2100 \text{ km s}^{-1}$ for SNe with $M_r \geq -16$ mag. These velocities are broadly consistent with those reported for Type II SNe in the literature (Faran et al. 2014; de Jaeger et al. 2019; Lin et al. 2024).

5.3. Bolometric Luminosity

First, we measure the bolometric luminosity of the SNe in our sample. Since we only have the g - and r -band magnitudes available for most of the SNe in our sample, we estimate the bolometric luminosities using the bolometric correction (BC) approach from Lyman et al. (2014) to estimate the bolometric magnitudes:

$$\text{BC}_g = 0.053 - 0.089 \times (g - r) - 0.736 \times (g - r)^2$$

$M_{\text{bol}} = \text{BC}_g + M_g$, where M_{bol} is the bolometric magnitude, and M_g is the absolute magnitude of the SN in g -band filter. Jäger, Zoltán et al. (2020) and Yang et al. (2021) showed that the bolometric luminosity of LLIIP SNe measured by bolometric correction approach from Lyman et al. (2014) is similar to that obtained by fitting a blackbody function to

multiband photometry, which supports the validity of the empirical correlation for the bolometric correction given by Lyman et al. (2014).

We bin the data into intervals of 2 days and use g - and r -band photometry to get the bolometric luminosity for that epoch. If only one band of photometry is available in a bin, then we use the color from the nearest epoch where photometry data for both bands is available within 10 days to calculate the bolometric luminosity.

The distribution of the plateau bolometric luminosity is shown in the left panel of Figure 5. The full sample has a median peak luminosity of $\log(L_{\text{peak}}/\text{erg s}^{-1}) = 42.33^{+0.38}_{-0.39}$. LLIIP SNe have lower peak luminosities with a median of $41.65^{+0.24}_{-0.21}$. We find a strong correlation between the mid-plateau bolometric luminosity (L_{mid}) and the nickel mass (Figure 5). The nickel mass is measured by fitting the radioactive tail (see Section 5.4.1). The best-fit relation is

$$\log L_{\text{mid}} = (0.73 \pm 0.05) \log M_{\text{Ni}} + (43.09 \pm 0.06),$$

with a Pearson correlation coefficient of $r = 0.89$ and a p -value $< 10^{-5}$. These luminosities are consistent with previous measurements for both normal and low-luminosity Type II SNe. Large-sample studies typically find mid-plateau bolometric luminosities of $\log L_{\text{mid}} \sim 42.3\text{--}42.7 \text{ erg s}^{-1}$ for ordinary SNe IIP (e.g., Bersten & Hamuy 2009; Pejcha & Prieto 2015; Valenti et al. 2016), whereas underluminous events such as SN 1997D, SN 2005cs, and SN 2008bk exhibit significantly fainter plateaus with $\log L_{\text{mid}} \sim 41.4\text{--}41.7 \text{ erg s}^{-1}$ (Spiro et al. 2014). The tight correlation we find between L_{mid} and M_{Ni} is also consistent with earlier work showing that fainter plateau luminosities correspond to smaller ^{56}Ni yields (Hamuy 2003; Pejcha & Prieto 2015; Müller et al. 2017; Martinez et al. 2022b).

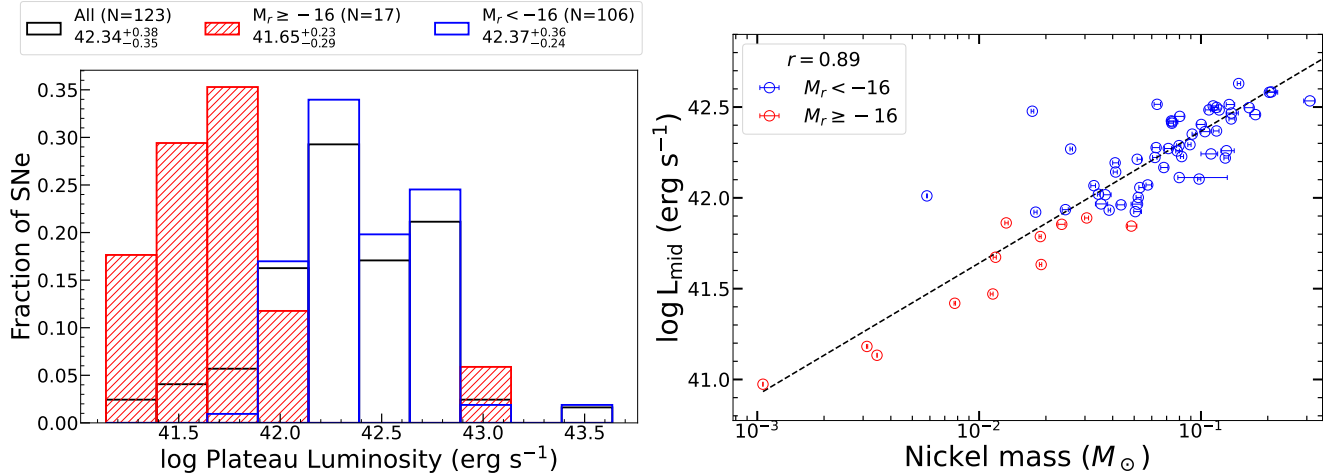


Figure 5. Left: Fractional distribution of bolometric luminosity at the mid-plateau phase. LLIP SNe with $M_r \geq -16$ are shown in hatched red, those with $M_r < -16$ in blue, and the full sample is shown in black. Right: Correlation between mid-plateau bolometric luminosity and nickel mass inferred from the bolometric lightcurve tail. LLIP SNe with $M_r \geq -16$ are shown in red, and SNe with $M_r < -16$ are shown in blue.

5.4. Estimating Physical and Explosion Parameters

In order to estimate progenitor and explosion parameters of the Type IIP sample, we use semi-analytic models Nagy & Vinkó (2016) and radiation hydrodynamical models from Moriya et al. (2023). We also use scaling relations from Goldberg et al. (2019) to constrain the explosion parameters of LLIP SNe.

5.4.1. Lightcurve Fitting to Semi-analytical Models

The model in Nagy & Vinkó (2016) is based on a two-component configuration consisting of a uniform dense stellar core and an extended low-mass envelope where the density decreases as an exponential function. Nagy & Vinkó (2016); Jäger, Zoltán et al. (2020) claim that the results from the two-component semi-analytic LC model are consistent with current state-of-the-art calculations for Type II SNe. They are useful to derive estimates or constraints of basic parameters like the explosion energy, ejected mass, and initial radius of the progenitor as well as the amount of synthesized radioactive nickel. The model assumes spherical symmetry and do not adequately model the initial transient behavior at early stages ($t < 20$ days). Thus, we only fit for lightcurve data 20 days after the explosion. We use the MCMC routine in Jäger, Zoltán et al. (2020) to fit these semi-analytical expressions. The Python code used for these fits will be made available on [GitHub](#) after publication. The best-fit lightcurves for the SNe with and without radioactive tails are shown in Figure 6. The nickel mass is measured from the lightcurve tail by fitting for both the nickel mass and the gamma-ray trapping efficiency parameter as free parameters. The priors used for the fits are shown in Table A2. We fit the semi-analytic models to Type IIP SNe. After marginalization, we have estimates with

confidence intervals (1σ) for each of these parameters. The best-fit values for each SN are listed in Table A4. The sample statistics are summarized in Table 2.

5.4.2. Lightcurve Fitting to Radiation-hydrodynamical Type II Model Grids

Moriya et al. (2023) presented a comprehensive model grid containing 228,016 synthetic Type II SN light curves, based on calculations using the radiation-hydrodynamical code STELLA. This set of model grids has previously been used in Subrayan et al. (2023) and Silva-Farfán et al. (2024) to infer explosion parameters for a sample of 45 and 186 Type II SNe, respectively. Here we also include previously unpublished models for lower-mass progenitors (9, 10 M_{\odot}) with low explosion energies (1.0, 2.0, 3.0, 4.0, $\times 10^{50}$ erg). The overall parameter space covered by the model grid is progenitor masses (9, 10, 12, 14, 16, and 18 M_{\odot} at the zero-age main sequence (ZAMS), solar metallicity), explosion energies (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 $\times 10^{51}$ erg), nickel masses (0.001, 0.01, 0.02, 0.04, 0.06, 0.08, 0.1, 0.2, and 0.3 M_{\odot}), mass-loss rates ($10^{-5.0}$, $10^{-4.5}$, $10^{-4.0}$, $10^{-3.5}$, $10^{-3.0}$, $10^{-2.5}$, $10^{-2.0}$, $10^{-1.5}$, and $10^{-1.0} M_{\odot} \text{ yr}^{-1}$ with a wind velocity of 10 km s^{-1}), circumstellar matter radii (1, 2, 4, 6, 8, and 10 $\times 10^{14}$ cm), and ten circumstellar structures ($\beta = 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5,$ and 5.0), where β is a wind structure parameter determined by the efficiency of wind acceleration (Moriya et al. 2023). The radioactive nickel is assumed to be uniformly mixed up to half the mass of the hydrogen-rich envelope.

We use this model grid to measure the explosion parameters of the CLU Type IIP SNe. Using Bayesian Inference methods requires the models to be finely sampled within the parameter

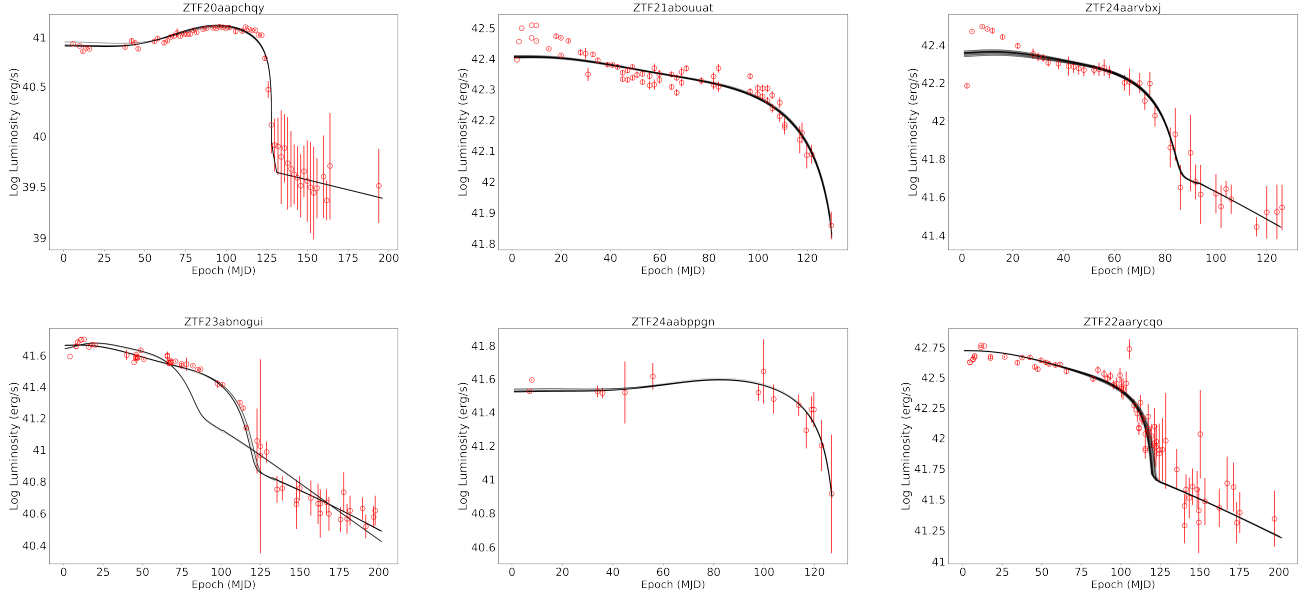


Figure 6. Bolometric light curve fits using semi-analytical models from Nagy & Vinkó (2016). Red dots show the observed bolometric luminosities, while black lines represent the best-fit model lightcurves. The panels show (left to right, top to bottom): ZTF20aapchqy (SN 2020xcd), ZTF21abouuat (SN 2021ucg), ZTF24aarvbxj (SN 2024lby), ZTF23abnogui (SN 2023wcr), ZTF24aabppgn (SN 2024wp), and ZTF22aarycqo (SN 2022ojj).

Table 2

Best-fit Physical Parameters Derived from Semi-analytical Model Fits (Nagy & Vinkó 2016) for Faint ($M_r \geq -16$), Bright ($M_r < -16$), and All Type IIP SNe

Parameter	Sample	Median	Range
$M_{\text{Ni}} (0.01M_{\odot})$	$M_r \geq -16$	$1.32^{+0.89}_{-1.00}$	0.09–4.20
	$M_r < -16$	$7.36^{+6.36}_{-4.80}$	0.56–30.98
	All	$6.52^{+6.80}_{-4.71}$	0.09–30.98
$M_{\text{ej}} (M_{\odot})$	$M_r \geq -16$	$8.06^{+0.73}_{-1.71}$	5.73–12.89
	$M_r < -16$	$13.90^{+5.45}_{-3.42}$	5.41–24.79
	All	$12.80^{+6.20}_{-5.00}$	5.41–24.79
$E_{\text{kin}} (10^{51} \text{ erg})$	$M_r \geq -16$	$0.79^{+0.49}_{-0.35}$	0.21–3.64
	$M_r < -16$	$4.74^{+3.79}_{-2.45}$	1.04–9.94
	All	$4.32^{+4.17}_{-2.91}$	0.21–9.94
$R (R_{\odot})$	$M_r \geq -16$	299^{+219}_{-142}	138–1024
	$M_r < -16$	340^{+407}_{-202}	88–1065
	All	337^{+390}_{-194}	88–1065

Note. Reported values include the median and 16th/84th percentile uncertainties, along with the full observed range. Nickel masses are scaled by a factor of $10^{-2}M_{\odot}$.

space. However, because the model grid is discrete and non-uniform, we extrapolate the model parameter by doing a weighted average of the model magnitudes weighted by the separation of the vector space of the nearest-neighbour models from the model vector to be sampled. For a given parameter vector θ , the method finds the closest models θ_{close} and weighs

them appropriately using

$$m(t, \theta) = \sum_{\theta_i \in \theta_{\text{close}}} \hat{w}^{-1}(\theta, \theta_i) m(t, \theta_i), \quad (1)$$

where $m(t, t_{\text{exp}}, \theta)$ is the magnitude for a given θ at time t , where

$$w(\theta, \theta_i) = \left(\prod_j |\theta^j - \theta_i^j| \right) \left(|\theta^j - \theta_i^j|_{\text{average}} \right)^{-1}. \quad (2)$$

The priors used for the fits are shown in Table A3. The Python code used for these fits will be made available on [GitHub](#) after publication. The best-fit values for each SN are listed in Table A5. The sample statistics are summarized in Table 3. The best-fit model lightcurves for the SNe are shown in Figures 6 and 7. The distribution of the best-fit parameters are shown in Figures 8 and 9.

5.4.3. Scaling Relations

Scaling relations have been commonly used to infer explosion parameters from lightcurve observables (Popov 1993; Kasen & Woosley 2009). Ejecta mass (M_{ej}), progenitor radius (R), and explosion energy (E) are commonly used as the primary independent variables in scaling relations. In this paper, we use scaling relations derived by Goldberg et al. (2019). We use the following relations to constrain the ejected mass ($M_{10} \equiv M_{\text{ej}}/10M_{\odot}$) and explosion energy ($E_{51} \equiv E_{\text{exp}}/10^{51} \text{ erg}$) as a function of progenitor radius

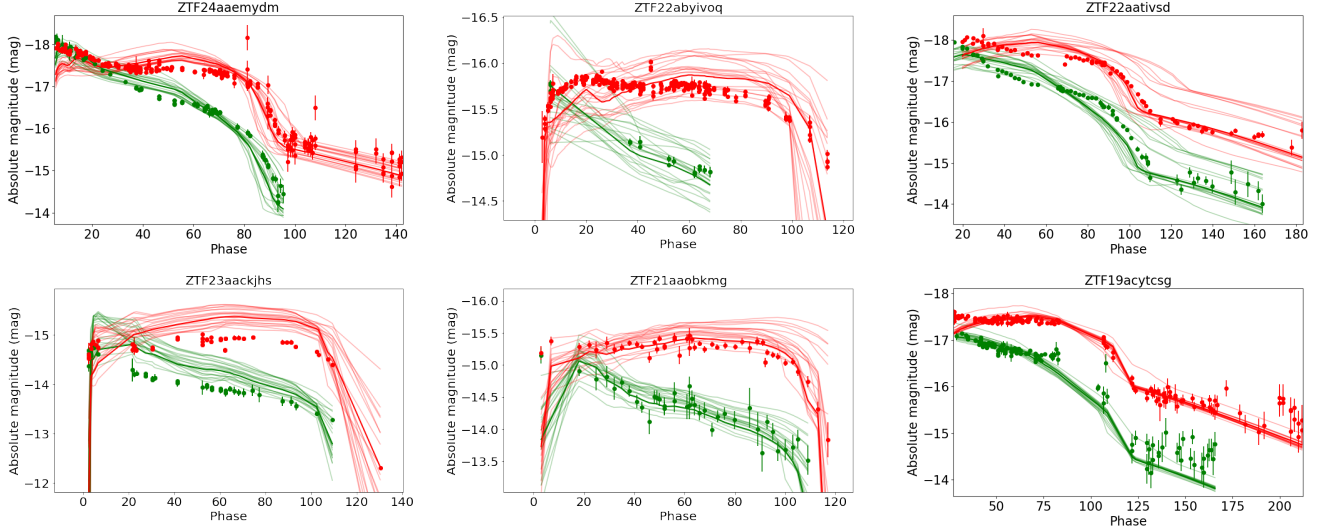


Figure 7. Radiation-hydrodynamical model fits to the r - and g -band light curves using the model grid from Moriya et al. (2023). The model grid in Moriya et al. (2023) has been extended to include $9 M_{\odot}$ and $10 M_{\odot}$ progenitors with explosion energies in the range $(1-5) \times 10^{50}$ erg. The panels show (left to right, top to bottom): ZTF24aaemydm (SN 2024chx), ZTF22abyivoq (SN 2022acko), ZTF22aativsd (SN 2022ovb), ZTF23aackjhs (SN 2023bvj), ZTF21aobkmg (SN 2021eui) and ZTF19acytcsq (SN 2019wvz).

($R_{500} \equiv R/500 R_{\odot}$), via the following relations:

$$\log(E_{51}) = -0.728 + 2.148 \log(L_{42}) - 0.280 \log(M_{\text{Ni}}) + 2.091 \log(t_{p,2}) - 1.632 \log(R_{500}), \quad (3)$$

$$\log(M_{10}) = -0.947 + 1.474 \log(L_{42}) - 0.518 \log(M_{\text{Ni}}) + 3.867 \log(t_{p,2}) - 1.120 \log(R_{500}), \quad (4)$$

where M_{Ni} is in units of M_{\odot} , $L_{42} = L_{50\text{d}}/10^{42} \text{ erg s}^{-1}$, $L_{50\text{d}}$ is the plateau luminosity 50 days after explosion and $t_{p,2} = t_p/100$ days. Here, t_p is measured from the parametric fit to the bolometric lightcurve using the following equation used in (Goldberg et al. 2019; Valenti et al. 2016):

$$\log(L_{\text{bol}}(t)) = \frac{-A_0}{1 + \exp\left(\frac{t-t_p}{w_0}\right)} + P_0 t + M_0, \quad (5)$$

where t_p represents the inflection point of the lightcurve and corresponds to the midpoint of the plateau-to-tail transition.

The constraints for LLIP SNe thus obtained are discussed in Section 6.

6. Results

In this section, we summarize the results obtained using the analysis techniques described above. The best-fit radiation-hydrodynamical values for each SN are listed in Table A5, and the sample statistics are summarized in Table 3. Similarly, the best-fit values from the semi-analytical modeling are given in Table A4, with the corresponding sample statistics summarized in Table 2.

Table 3

Best-fit Physical Parameters Derived from Radiation-hydrodynamical Model Fits (Moriya et al. 2023) for Faint ($M_r \geq -16$), Bright ($M_r < -16$), and All Type IIP SNe

Parameter	Sample	Median	Range
E_{exp} (10^{51} erg)	$M_r \geq -16$	$0.17^{+0.07}_{-0.03}$	0.10–0.28
	$M_r < -16$	$0.91^{+0.81}_{-0.54}$	0.16–4.43
	All	$0.76^{+0.89}_{-0.44}$	0.10–4.43
R_{CSM} (10^{14} cm)	$M_r \geq -16$	$4.3^{+3.0}_{-1.0}$	1.8–8.6
	$M_r < -16$	$5.8^{+1.9}_{-1.4}$	1.1–8.4
	All	$5.8^{+1.9}_{-1.6}$	1.1–8.6
M_{Ni} ($0.01 M_{\odot}$)	$M_r \geq -16$	$1.3^{+0.3}_{-1.0}$	0.1–2.5
	$M_r < -16$	$4.1^{+5.9}_{-2.1}$	0.2–22.2
	All	$3.8^{+5.9}_{-2.4}$	0.1–22.2
M_{ZAMS} (M_{\odot})	$M_r \geq -16$	$10.5^{+0.4}_{-0.7}$	9.4–11.0
	$M_r < -16$	$11.8^{+1.4}_{-1.4}$	9.3–16.7
	All	$11.5^{+1.6}_{-1.2}$	9.3–16.7
$-\log \dot{M}$ ($M_{\odot} \text{ yr}^{-1}$)	$M_r \geq -16$	$3.32^{+0.37}_{-0.26}$	2.86–4.37
	$M_r < -16$	$3.00^{+0.85}_{-0.72}$	1.29–4.48
	All	$3.01^{+0.83}_{-0.60}$	1.29–4.48

Note. Reported values include the median and 16th/84th percentile uncertainties, along with the full observed range.

6.1. Observed Parameters

The observed parameters in the r -band and their errors are shown in Table A1. The sample statistics are shown in Table 4. The lower and upper uncertainties correspond to the 16th and

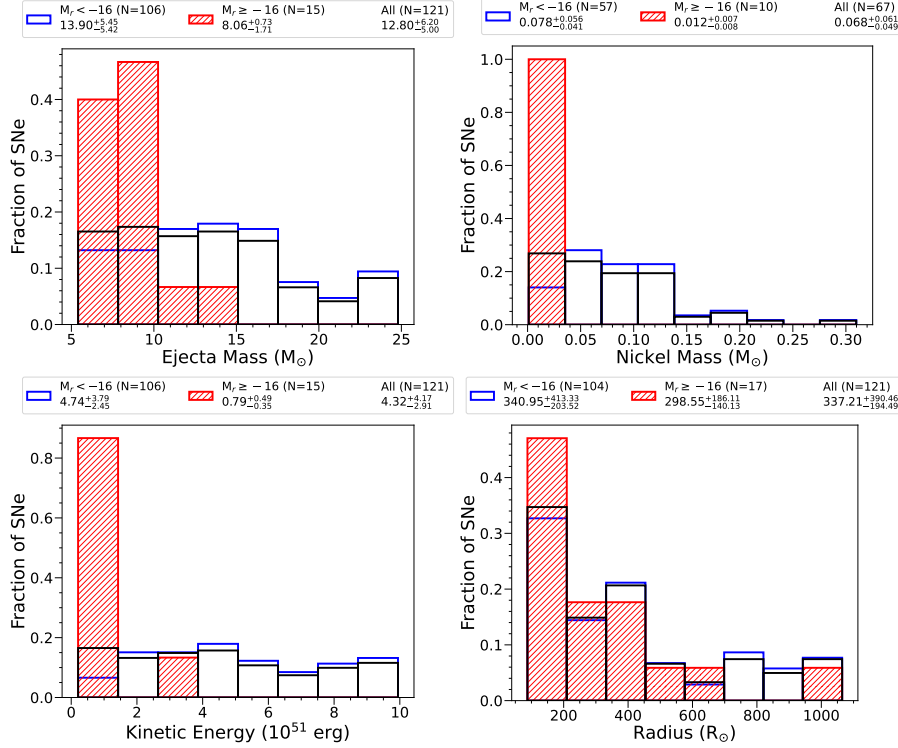


Figure 8. Distributions of ejecta mass, nickel mass, explosion energy, and radius using semi-analytical models from Nagy & Vinkó (2016). LLIIP SNe with $M_r \geq -16$ are shown in hatched red, SNe IIP with $M_r < -16$ in blue, and the full sample is shown in black.

84th percentiles, respectively. The distributions of these observed parameters are shown in Figure 2.

For LLIIP SNe ($M_r > -16$), the median plateau duration was 89^{+10}_{-20} days, with a range of 64–108 days. The median duration of the optically thick phase (OPTd) was 99^{+11}_{-14} days, spanning from 67 to 116 days. The median rise time was 13^{+1}_{-2} days, with a range from 10 to 16 days. The median plateau slope was $0.1^{+0.1}_{-0.2} \times 10^{-2}$ mag day $^{-1}$, ranging from -0.4 to 0.6×10^{-2} mag day $^{-1}$. Finally, the change in magnitude between the plateau and the radioactive tail had a median value of $-1.33^{+1.25}_{-0.72}$ mag, with observed values ranging from -2.48 to -0.22 mag. For the full Type IIP SN sample, the median values were 76^{+16}_{-16} days for the plateau duration, 90^{+16}_{-20} days for OPTd, 13^{+4}_{-2} days for the rise time, $0.4^{+0.5}_{-0.4} \times 10^{-2}$ mag day $^{-1}$ for the plateau slope, and $-1.33^{+0.46}_{-0.41}$ mag for the plateau-to-tail drop. The steepest drop of >3.50 mag was seen in SN 2022aagp, shown in Figure 10. A sharp decline from the plateau to the tail is predicted for ECSNe and failed SNe with very low or zero nickel mass (see e.g., Tominaga et al. 2013; Turatto et al. 1998). Other objects with sharp drops include SN 2021tyw (>3.10 mag), SN 2022prv (2.56 mag), SN 2023vog (2.49 mag) and SN 2020cxd (2.48 mag).

We further investigated how the lightcurve observables correlate with peak magnitude. As shown in Figure 3, the

plateau slope shows a strong correlation with peak brightness, with a Pearson correlation coefficient of $r = -0.68$ ($p < 10^{-5}$). The best-fit line is given by:

$$\text{Plateau slope (0.01 mag day}^{-1}\text{)} = (-0.33 \pm 0.04) M_r + (-4.93 \pm 0.70)$$

Brighter SNe tend to have steeper plateau slopes, indicating more rapid declines during the plateau phase. We also note that a major fraction of LLIIP SNe have positive slope. The plateau duration shows only a weak correlation with peak magnitude ($r = 0.42$). The plateau durations for faint and bright SNe span a broad range and overlap significantly. The physical implications for these results are discussed in Section 7.

6.2. Progenitor and Explosion Parameters

6.2.1. Nickel Mass

For the semi-analytical model fits, the nickel mass is measured only for SNe with a distinct radioactive tail. Within the LLIIP subsample, the median nickel mass is $0.0132^{+0.0089}_{-0.0100} M_{\odot}$, spanning 0.0009–0.0420 M_{\odot} . The lowest value in our sample is that of SN 2020cxd, with $M_{\text{Ni}} = 0.0009 M_{\odot}$. For the full Type IIP sample, the semi-analytical fits yield a median nickel mass of $0.065^{+0.068}_{-0.047} M_{\odot}$ (range 0.0009–0.3098 M_{\odot}). The radiation-hydrodynamical fits of Moriya et al. (2023) give broadly consistent values, with a

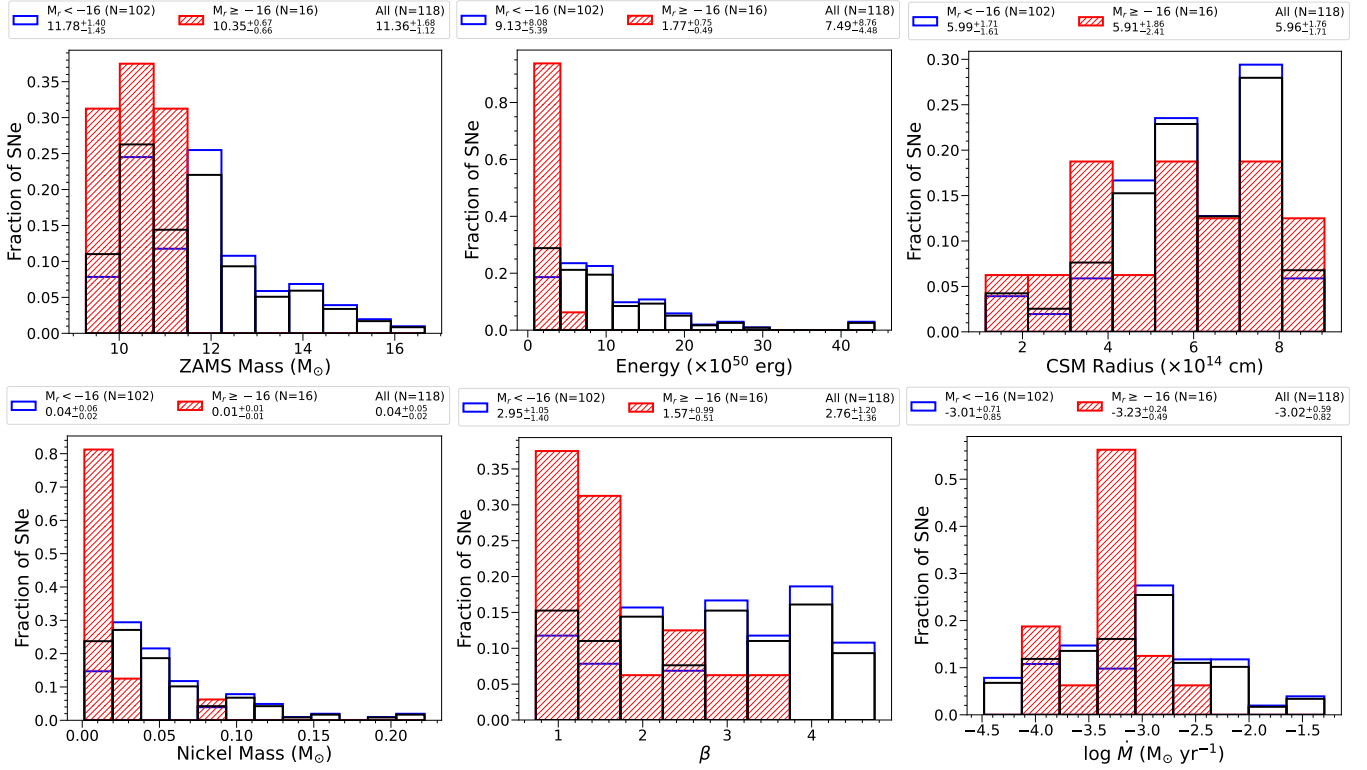


Figure 9. Distributions of the ZAMS mass, explosion energy, CSM radius, nickel mass, CSM structure parameter, and mass loss rates using radiation-hydrodynamical models from Moriya et al. (2023). LLIP SNe with $M_r \geq -16$ are shown in hatched red, those with $M_r < -16$ in blue, and the full sample is shown in black.

Table 4

Summary of r -band Lightcurve Observables, Divided into Faint ($M_r \geq -16$), Bright ($M_r < -16$), and the Full Sample

Parameter	Sample	Median	Range
Plateau Duration (days)	$M_r \geq -16$	89^{+10}_{-20}	64–108
	$M_r < -16$	75^{+16}_{-15}	47–137
	All	76^{+16}_{-16}	47–137
OPTd (days)	$M_r \geq -16$	99^{+11}_{-14}	67–116
	$M_r < -16$	88^{+17}_{-20}	52–157
	All	90^{+16}_{-20}	52–157
Rise Time (days)	$M_r \geq -16$	13^{+1}_{-2}	10–16
	$M_r < -16$	13^{+5}_{-2}	7–22
	All	13^{+4}_{-2}	7–22
Plateau Slope ($\times 0.01 \text{ mag day}^{-1}$)	$M_r \geq -16$	$0.1^{+0.1}_{-0.2}$	−0.4–0.6
	$M_r < -16$	$0.5^{+0.6}_{-0.4}$	−0.1–2.0
	All	$0.4^{+0.5}_{-0.4}$	−0.4–2.0
Plateau–Tail Drop (mag)	$M_r \geq -16$	$-1.33^{+1.25}_{-0.72}$	−2.48–0.22
	$M_r < -16$	$-1.33^{+0.42}_{-0.35}$	−3.50–0.09
	All	$-1.33^{+0.46}_{-0.41}$	−3.50–0.22

Note. Median values with uncertainties and full observed ranges are shown. Plateau slopes are scaled by a factor of $10^{-2} \text{ mag day}^{-1}$.

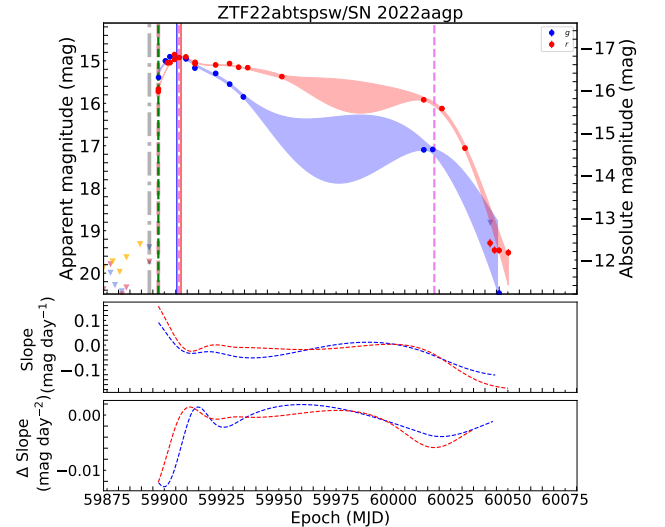


Figure 10. The r - and g -band lightcurve of ZTF22abtpsw/SN 2022aagp with GP fits (shaded regions). Vertical lines mark key epochs: first detection (dashed red), explosion epoch (dashed grey), r - and g -band peaks (solid red and blue), plateau start and end (solid violet), and 50% peak flux (dashed green). The lower panels show the light curve slope (mag day^{-1}) and its change (Δ slope, mag day^{-2}). The steepest observed drop of >3.5 mag was seen in this SN, consistent with predictions for ECSN and failed SNe with little or no nickel mass.

median of $0.038_{-0.024}^{+0.059} M_{\odot}$ for the full sample and $0.013_{-0.010}^{+0.003} M_{\odot}$ for the LLIP subsample. Rodríguez et al. (2021) studied 110 events and found ^{56}Ni masses between 0.005 and $0.177 M_{\odot}$ (average $0.037 \pm 0.005 M_{\odot}$). Martínez et al. (2022b) reported 0.006 – $0.069 M_{\odot}$ (median $\sim 0.036 M_{\odot}$) from 17 SNe, while Pejcha & Prieto (2015) and Müller et al. (2017) obtained similar medians ($\sim 0.03 M_{\odot}$) with maxima reaching $0.28 M_{\odot}$. Subrayan et al. (2023) measured Ni masses for 45 SNe, with only a single object as low as $0.01 M_{\odot}$, while most lie between 0.02 and $0.1 M_{\odot}$. Anderson (2019) found a broad distribution (0.001 – $0.360 M_{\odot}$), and Hamuy (2003) reported 0.0016 – $0.26 M_{\odot}$ from 21 SNe. In comparison with these literature samples, the LLIP SNe in our sample clearly occupy the low end of the nickel-mass distribution. Their very small ^{56}Ni yields are consistent with expectations for explosions of low-mass red supergiant progenitors or events experiencing significant fallback, as discussed in Section 7.5.

6.2.2. Explosion Energy

From the Moriya et al. (2023) radiation-hydrodynamical fits, the LLIP SNe show low explosion energies, with a median of $0.17_{-0.03}^{+0.07} \times 10^{51}$ erg and a range of 0.10 – 0.28×10^{51} erg. For the full Type IIP sample, the median energy is $0.76_{-0.44}^{+0.89} \times 10^{51}$ erg. In contrast, the semi-analytical Nagy & Vinkó (2016) models yield systematically higher values, with a median of $0.79_{-0.35}^{+0.49} \times 10^{51}$ erg for the LLIP subsample (range 0.21 – 3.64×10^{51} erg) and $4.32_{-2.91}^{+4.17} \times 10^{51}$ erg for the full sample (range 0.21 – 9.94×10^{51} erg). We note that both the ejecta masses and explosion energies from the semi-analytical fits tend to be higher, likely due to the two-component density profile assumed in these models; the caveats are discussed further in Section 7.4. In the literature, Hamuy (2003) measured 0.6 – 5.5×10^{51} erg for 21 Type II SNe, while Utrobin & Chugai (2019) and Pumo et al. (2017) obtained up to 1.4 – 2.0×10^{51} erg. Martínez et al. (2022b) report a median of 0.61×10^{51} erg (range 0.30 – 1.01×10^{51} erg). The LLIP SNe in our sample clearly occupy the low-energy end, clustering just above 10^{50} erg, and may in some cases fall below the model grid minimum of 0.1×10^{51} erg. This supports interpretations in which LLIP SNe arise from weak explosions of low-mass cores (see Section 7.5).

6.2.3. Ejecta Mass/ZAMS Mass

The semi-analytical models yield ejecta masses of 5.73 – $12.89 M_{\odot}$ for the LLIP sample, with a median of $8.06_{-1.71}^{+0.73} M_{\odot}$. For the full Type IIP sample, the corresponding median ejecta mass is $12.80_{-5.00}^{+6.20} M_{\odot}$, spanning 5.41 – $24.79 M_{\odot}$. In earlier studies, Martínez et al. (2022b) report a typical ejecta mass of $\sim 9.2 M_{\odot}$ (16–84 percentile range 8.2 – $12.7 M_{\odot}$), while Utrobin & Chugai (2019) infer somewhat higher masses up to

$\sim 14.8 M_{\odot}$. Even larger values were found by Hamuy (2003), who estimated ejecta masses in the range 14 – $56 M_{\odot}$ for some Type II SNe. LLIP SNe lie at the lower end of these distributions, consistent with expectations for low-mass RSG or sAGB progenitors, or for progenitors that have experienced significant envelope stripping prior to core collapse. ZAMS masses inferred in Subrayan et al. (2023) and Silva-Farfán et al. (2024) span 12 – $16 M_{\odot}$, with a steep IMF placing most objects near $\sim 12 M_{\odot}$. From our radiation-hydrodynamical fits, the LLIP SNe are inferred to arise from relatively low-mass progenitors, with ZAMS masses typically $< 12 M_{\odot}$ and a median of $10.5_{-0.7}^{+0.4} M_{\odot}$. For the full Type II sample, the median ZAMS mass is $11.5_{-1.2}^{+1.6} M_{\odot}$. Thus, the LLIP subsample lies toward the low-mass end of the progenitor-mass distribution, reinforcing the picture that the faintest events originate from the lowest-mass core-collapse progenitors.

6.2.4. Progenitor Radius

The progenitor radii inferred from the semi-analytical fits for the LLIP SNe span 138 – $1024 R_{\odot}$, with a median of $299_{-142}^{+219} R_{\odot}$. For the full Type IIP sample, the corresponding median is $337_{-194}^{+390} R_{\odot}$. These radii are smaller than those typically inferred for normal Type II SNe in the literature. For example, Martínez et al. (2022b) report progenitor radii of 460 – $610 R_{\odot}$, with a median of $\sim 495 R_{\odot}$, while Hamuy (2003) found a broad range of 80 – $600 R_{\odot}$ using hydrodynamical modeling. More recently, Irani et al. (2024) identified a bimodal distribution in breakout radii for 34 SNe II, with roughly half of the sample preferring compact radii ($< 10^{14}$ cm) and the other half favoring larger radii ($> 10^{14}$ cm), consistent with substantial diversity in outer-envelope structure among RSG progenitors. For additional context, the radius distribution of 74 Galactic RSGs spans 100 – $2135 R_{\odot}$ with a median of $625_{-275}^{+393} R_{\odot}$ (Levesque et al. 2005). Thus, these results suggest that LLIP progenitors are either intrinsically more compact RSGs, or that their outer hydrogen envelopes have been partially stripped through binary interaction.

6.2.5. Progenitor Mass-loss

The radiation-hydrodynamical modeling yields median pre-explosion mass-loss rates of $\log \dot{M} = -3.01_{-0.60}^{+0.83} M_{\odot} \text{ yr}^{-1}$ for the full sample, and $\log \dot{M} = -3.32_{-0.26}^{+0.37}$ for the LLIP subsample. Our results agree well with those of Subrayan et al. (2023) and Silva-Farfán et al. (2024), who report mass-loss rates in the range 10^{-4} – $10^{-2} M_{\odot} \text{ yr}^{-1}$ for samples of Type II SNe. The systematically smaller mass-loss rates of the LLIP subsample may reflect weaker winds or shorter-lived mass-loss episodes prior to explosion. The corresponding CSM radii inferred from the radiation-hydrodynamical fits span 1.1 – 8.6×10^{14} cm, with a median of $5.8_{-1.6}^{+1.9} \times 10^{14}$ cm

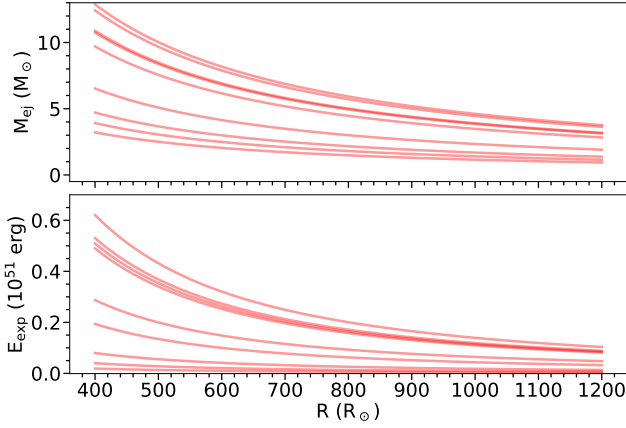


Figure 11. Ejecta mass (top) and explosion energy (bottom) versus progenitor radius, derived using the scaling relations from Goldberg et al. (2019). Red lines denote SNe with $M_r > -16$.

for the full sample and $4.3^{+3.0}_{-1.0} \times 10^{14}$ cm for the LLIP events, indicating an extended circumstellar environment that can influence early-time lightcurve and spectra (e.g., Galbany et al. 2016; Valenti et al. 2016; Förster et al. 2018; Morozova et al. 2018; Bruch et al. 2021, 2023; Jacobson-Galán et al. 2024, 2025; Hinds et al. 2025).

6.3. Scaling Relations

We investigate the physical properties of the low-luminosity Type IIP (LLIP) SNe in our sample using scaling relations between plateau luminosity, nickel mass, duration, and progenitor radius. The constraints for LLIP SNe thus obtained are shown in Figure 11. At a representative radius of $500 R_\odot$, we find that the LLIP SNe are characterized by relatively low ejecta masses ranging from ~ 2.1 to $\sim 6.5 M_\odot$ and low explosion energies between ~ 0.02 and $\sim 0.20 \times 10^{51}$ erg. These results reinforce the picture that LLIP SNe arise from low-mass progenitors undergoing weak explosions, consistent with those derived from semi-analytical and radiation-hydrodynamical analysis.

7. Discussion

7.1. LLIP SNe Exhibit Less Steep Gradients, with Most Displaying Upward Slopes

We first attempt to explain the positive slope seen in LLIP SNe through basic order-of-magnitude arguments. In standard Type IIP models such as Popov (1993), the onset of the plateau is set by hydrogen recombination, where the luminosity reaches

$$L_{\text{pl}} = 4\pi R_{\text{ej}}^2 \sigma T_I^4, \quad (6)$$

with $T_I \approx 5000$ K being the hydrogen recombination temperature. For low-luminosity plateaus, this implies a

smaller ejecta radius at the onset of the plateau phase, since

$$R_{\text{ej}} \propto L_{\text{pl}}^{1/2}. \quad (7)$$

This is consistent with the lower expansion velocities observed in LLIP SNe compared to more luminous events, resulting in smaller ejecta radius.

The photon diffusion time at this stage is given by

$$t_{\text{diff, onset}} \sim \frac{\kappa M_{\text{ej}}}{4\pi R_{\text{ej}} c} \propto M_{\text{ej}} L_{\text{pl}}^{-1/2}, \quad (8)$$

and can be estimated as

$$t_{\text{diff, onset}} \sim 200 \text{ days} \left(\frac{\kappa}{0.34 \text{ cm}^2 \text{ g}^{-1}} \right) \left(\frac{M_{\text{ej}}}{8 M_\odot} \right) \times \left(\frac{L_{\text{pl}}}{3 \times 10^{41} \text{ erg s}^{-1}} \right)^{-1/2}. \quad (9)$$

The diffusion time t_{diff} decreases with time as the ejecta expands, owing to both the dilution of density and the recombination-driven reduction in opacity.

Following the explosion, the ejecta cool both adiabatically (on the dynamical timescale t_{dyn}) and radiatively (on the diffusion timescale t_{diff}). The plateau slope is governed by the ratio of these timescales. When $t_{\text{diff}} \gg t_{\text{dyn}}$, the internal energy (dominated by radiation) evolves as

$$\frac{dE_{\text{int}}}{dt} = -\frac{E_{\text{int}}}{t} \Rightarrow E_{\text{int}} \propto t^{-1}. \quad (10)$$

As the photosphere recedes, the emergent flux remains approximately blackbody at T_I , with the luminosity given by

$$4\pi R_{\text{ph}}^2 \sigma T_I^4 = \frac{E_{\text{int}}}{t_{\text{diff}}} \approx \frac{E_{\text{int}}}{\kappa M_{\text{ej}}(r < R_{\text{ph}})/(4\pi R_{\text{ph}} c)}. \quad (11)$$

Assuming a uniform density profile in the inner ejecta, the mass enclosed within radius R_{ph} evolves as

$$M_{\text{ej}}(r < R_{\text{ph}}) \propto M_{\text{ej}} \left(\frac{R_{\text{ph}}}{t} \right)^3. \quad (12)$$

Combining the above, the photospheric radius evolves as

$$R_{\text{ph}}(t) \propto \left(\frac{E_{\text{int}}(t) t^3}{M_{\text{ej}}} \right)^{1/4}. \quad (13)$$

Using $E_{\text{int}}(t) \propto t^{-1}$, this simplifies to

$$R_{\text{ph}}(t) \propto t^{1/2} M_{\text{ej}}^{-1/4}, \quad (14)$$

and the luminosity becomes

$$L_{\text{pl}}(t) = 4\pi R_{\text{ph}}^2 \sigma T_I^4 \propto t M_{\text{ej}}^{-1/2}. \quad (15)$$

Thus, rising plateaus can naturally emerge in the low-luminosity regime.

The notably flatter or slightly rising slopes in LLIP SNe can also be explained by the contribution of ^{56}Ni decay to the

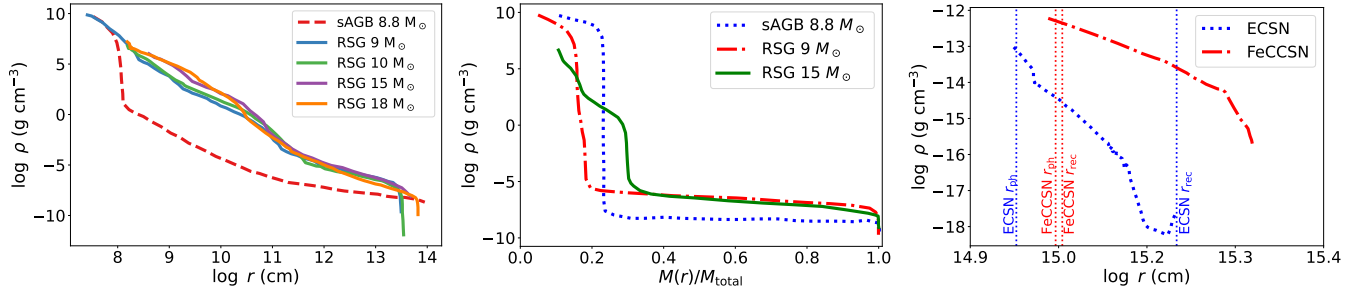


Figure 12. Left: Radial density profile of the 8–10 M_{\odot} stellar progenitor models used in Utrobin et al. (2017), Kozyreva et al. (2021), Sato et al. (2024) Center: Density profile as a function of mass coordinate of the 8–10 M_{\odot} stellar progenitor models used in Utrobin et al. (2017), Kozyreva et al. (2021) Right: Density profile of FeCCSN and ECSN models used in Sato et al. (2024). The radii of the photosphere (r_{ph}) and the recombination front (r_{rec}) at 40 days after explosion are indicated by vertical lines.

plateau luminosity. In Figure 12, we show the radial density and mass profiles of 8–10 M_{\odot} RSG and sAGB progenitors from the literature. The steeper mass density profiles of low-mass progenitors imply that the photospheric radius remains closer to the core of the star throughout the plateau phase (Sato et al. 2024). As a result, ^{56}Ni decay likely makes a stronger contribution to the overall plateau luminosity. Nakar et al. (2016) demonstrated that ^{56}Ni decay can contribute significantly ($\sim 10\%$) to the total luminosity during the photospheric phase, influencing the plateau slope. Although their models do not explicitly predict rising slopes, a combination of plateau extension and slope flattening could lead to an apparent increase in brightness over time as seen in SN 2016gfy (Singh et al. 2019). Kozyreva et al. (2019) supports this interpretation, showing that both cooling-envelope emission and nickel distribution shape the late-time behavior of the plateau. However, we note that such ^{56}Ni -driven flattening or rising would not occur unless the progenitor radii were small. For larger progenitors, the recombination-powered luminosity would dominate and naturally decline with time, overpowering the modest nickel contribution. Thus, in the low-luminosity regime, the small radii and low explosion energies of LLIP progenitors are necessary for ^{56}Ni decay to leave a visible imprint on the plateau slope. Furthermore, Kozyreva et al. (2021) find that ECSNe and low-mass CCSNe from 8 to 10 M_{\odot} progenitors exhibit rising light curves in the V and redder bands during the first 50 days, followed by a plateau and a subsequent drop to the radioactive tail. This is consistent with the steadily rising r -band light curves observed in many LLIP SNe.

Another possible contributor in the rise of the of the lightcurves could be explosion asymmetry. 3D simulations for a 9 M_{\odot} by Stockinger et al. (2020) show that large nickel-rich plumes can distort the ejecta and drive faster expansion in some directions, which lifts the light curve during the initial decline to the plateau and the early phase of the plateau. However, for a large sample, such viewing-angle-dependent effects are expected to average out.

7.2. The Plateau Duration and Peak Magnitude are Not Correlated

Single-star models predict a strong correlation between peak brightness and plateau duration in Type II SNe (e.g., Kasen & Woosley 2009). However, the observed lack of such a correlation suggests that the stars undergo substantial pre-supernova mass loss, likely requiring additional processes such as binary interaction to explain the observed diversity, especially at the low-mass end. Eldridge et al. (2018), Hiramatsu et al. (2021b), Dessart et al. (2024) also find that binary stripping can explain the duration of plateau seen in Type II SNe lightcurves. This aligns with the increasing observational consensus that a significant number of massive stars are found in binary systems, with many of them undergoing interaction (e.g., Sana et al. 2012; Duchêne & Kraus 2013; Kobulnicky et al. 2014; Sana et al. 2014; GRAVITY Collaboration et al. 2018; Bordier et al. 2022; Guo et al. 2022). Also, Zapartas et al. (2019) estimate that 33%–50% of all Type II SN progenitors undergo binary interaction, based on analytical estimates and population-synthesis simulations that track which progenitors exchange mass with a companion prior to explosion. Inferring the explosion and progenitor properties from the lightcurves using models that incorporate self-consistent progenitor evolution with binary effects will constrain the binary fraction and extent of stripping among massive stars that explode as core-collapse SNe.

7.3. Correlation of Physical Parameters

The physical parameters inferred for the sample exhibit a number of clear and physically informative correlations. Figures 13 and 14 summarize the trends between peak luminosity and the key explosion properties. For the Nagy & Vinkó (2016) semi-analytical fits, nickel mass, kinetic energy, and the energy-to-mass ratio all show strong negative correlations with peak absolute magnitude: fainter SNe systematically eject less ^{56}Ni , have lower kinetic energies, and have smaller specific energies. The trends follow the

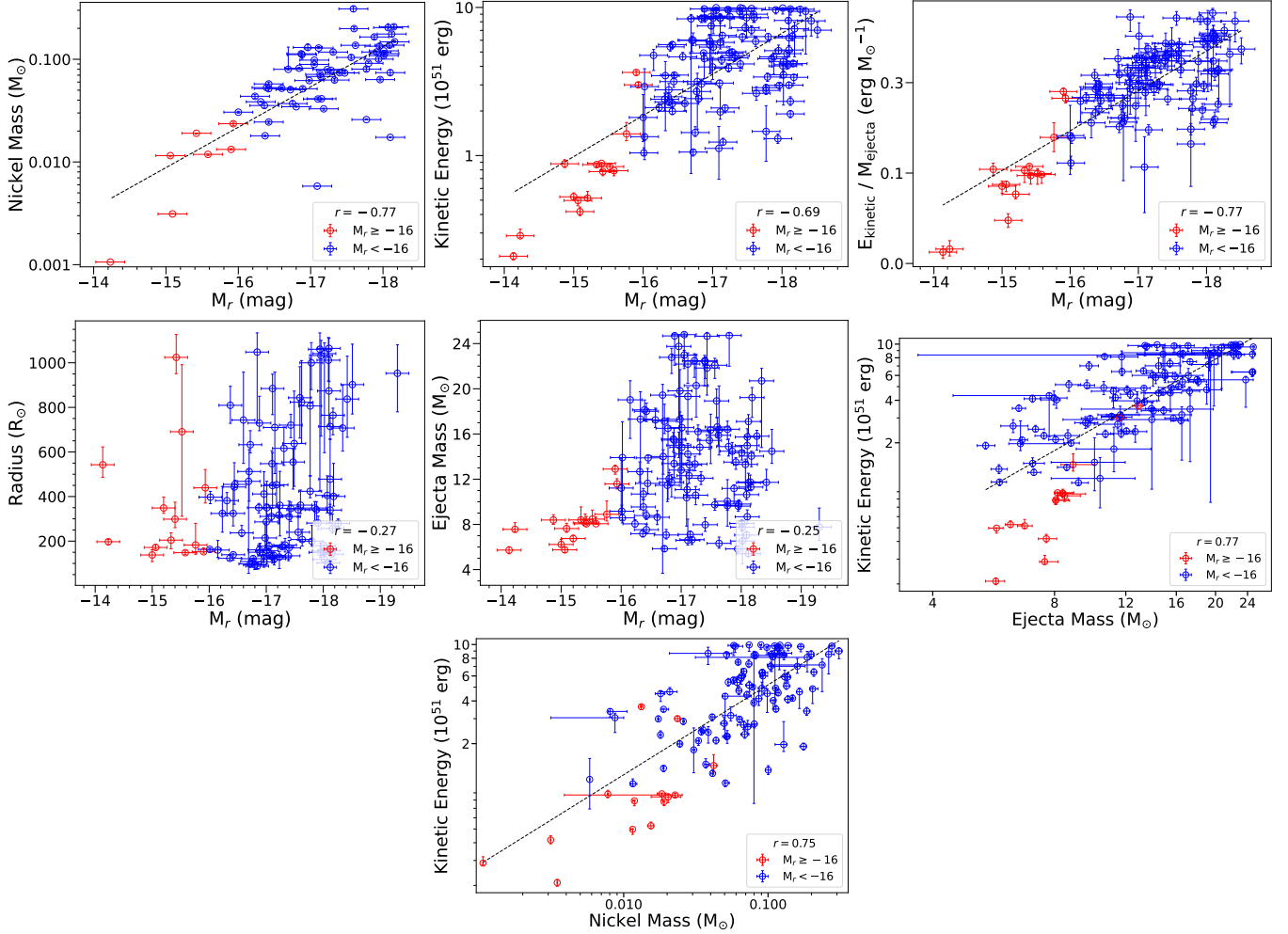


Figure 13. Correlations between peak r -band magnitude and physical parameters (nickel mass, explosion energy, energy per unit mass, radius, ejecta mass), and among the physical parameters themselves, based on semi-analytical models from Nagy & Vinkó (2016). LLIIP SNe with $M_r \geq -16$ are shown in red, SNe IIP with $M_r < -16$ in blue.

relations:

$$\log_{10}\left(\frac{M_{\text{Ni}}}{M_{\odot}}\right) = (-0.39 \pm 0.04)M_r + (-7.95 \pm 0.71),$$

$$\log_{10}\left(\frac{E_{\text{kin}}}{10^{51} \text{ erg}}\right) = (-0.28 \pm 0.03)M_r + (-4.17 \pm 0.46),$$

$$\log_{10}\left(\frac{E_{\text{kin}}}{M_{\text{ej}}}\right) = (-0.22 \pm 0.02)M_r + (-4.29 \pm 0.29),$$

with Pearson coefficients $|r| \approx 0.7\text{--}0.8$. These scalings extend the well-known luminosity- ^{56}Ni relation (Hamuy 2003; Pejcha & Prieto 2015; Müller et al. 2017; Martinez et al. 2022b) to the faint end and show that LLIIP SNe occupy the faint, low-energy end of a continuous distribution.

The semi-analytical parameters also correlate with each other. The correlations among physical parameters inferred

from the Nagy & Vinkó (2016) models are shown in Figure 15. Nickel mass and kinetic energy are tightly linked ($r = 0.75$), consistent with the idea that more energetic explosions synthesize more ^{56}Ni . The empirical relation,

$$E_{\text{kin}} [10^{51} \text{ erg}] = (22.37 \pm 3.70) \left(\frac{M_{\text{Ni}}}{M_{\odot}}\right)^{0.63 \pm 0.05},$$

is consistent with predictions in neutrino-driven explosion models (Sukhbold et al. 2016; Bruenn et al. 2016, 2023; Ebinger et al. 2019; Bollig et al. 2021; Sandoval et al. 2021; Burrows et al. 2024), as shown in Figure 16. Kinetic energy also correlates strongly with ejecta mass ($r = 0.77$), following

$$E_{\text{kin}} [10^{51} \text{ erg}] = (0.06 \pm 0.02) \left(\frac{M_{\text{ej}}}{M_{\odot}}\right)^{1.63 \pm 0.13},$$

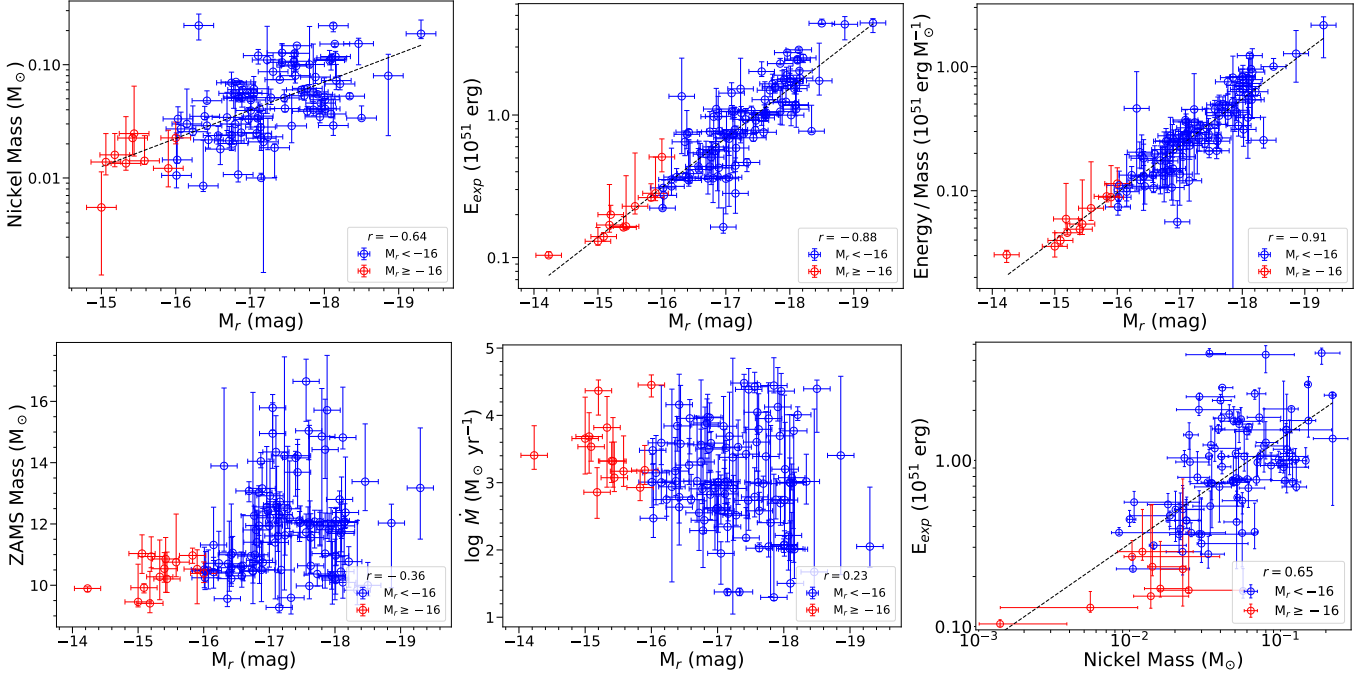


Figure 14. Correlations between peak r -band magnitude and physical parameters (nickel mass, explosion energy, energy per unit mass, radius, ejecta mass), and among the physical parameters themselves, based on radiation-hydrodynamical model fits from Moriya et al. (2023). LLIP SNe with $M_r \geq -16$ are shown in red, those with $M_r < -16$ in blue.

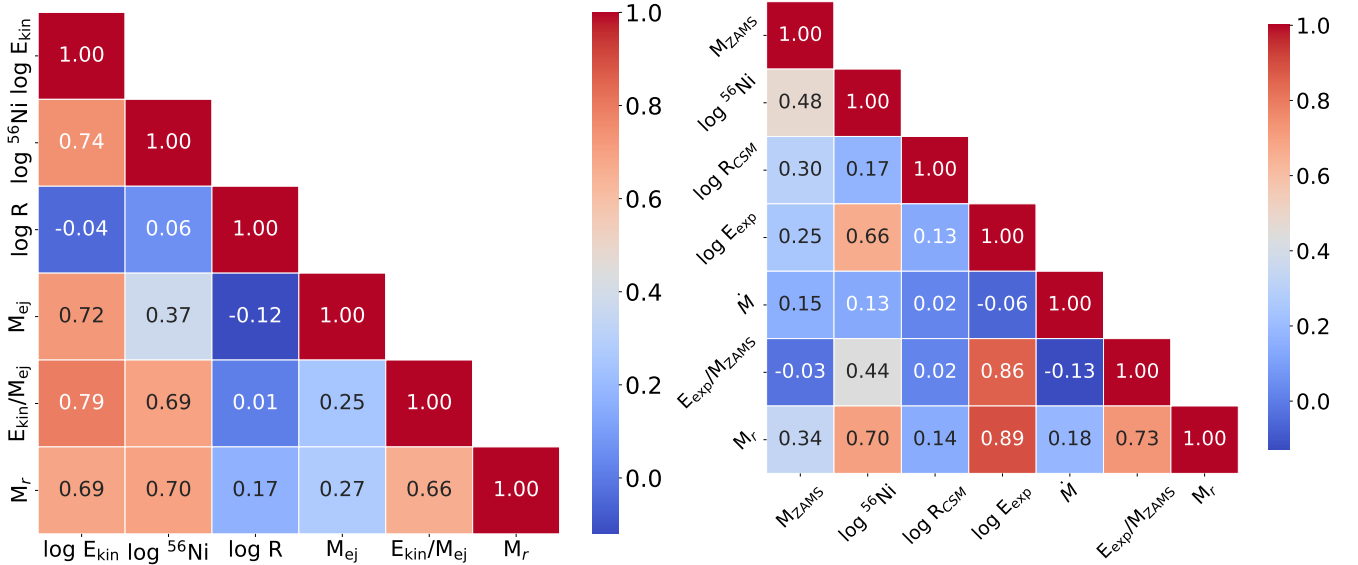


Figure 15. Correlation matrices of physical parameters derived from semi-analytical model fits (left) and radiation-hydrodynamical model fits (right).

indicating that explosions with more massive ejecta tend to be more energetic. In contrast, radius and mass-loss rate show only weak or no correlations, implying greater diversity in envelope structure and pre-SN winds.

The correlations inferred from the Moriya et al. (2023) radiation-hydrodynamical models reveal the same trends, but

with tighter relationships. Nickel mass and peak magnitude correlate with $r = -0.64$,

$$\log_{10} \left(\frac{M_{\text{Ni}}}{M_{\odot}} \right) = (-0.25 \pm 0.03) M_r - (5.64 \pm 0.51),$$

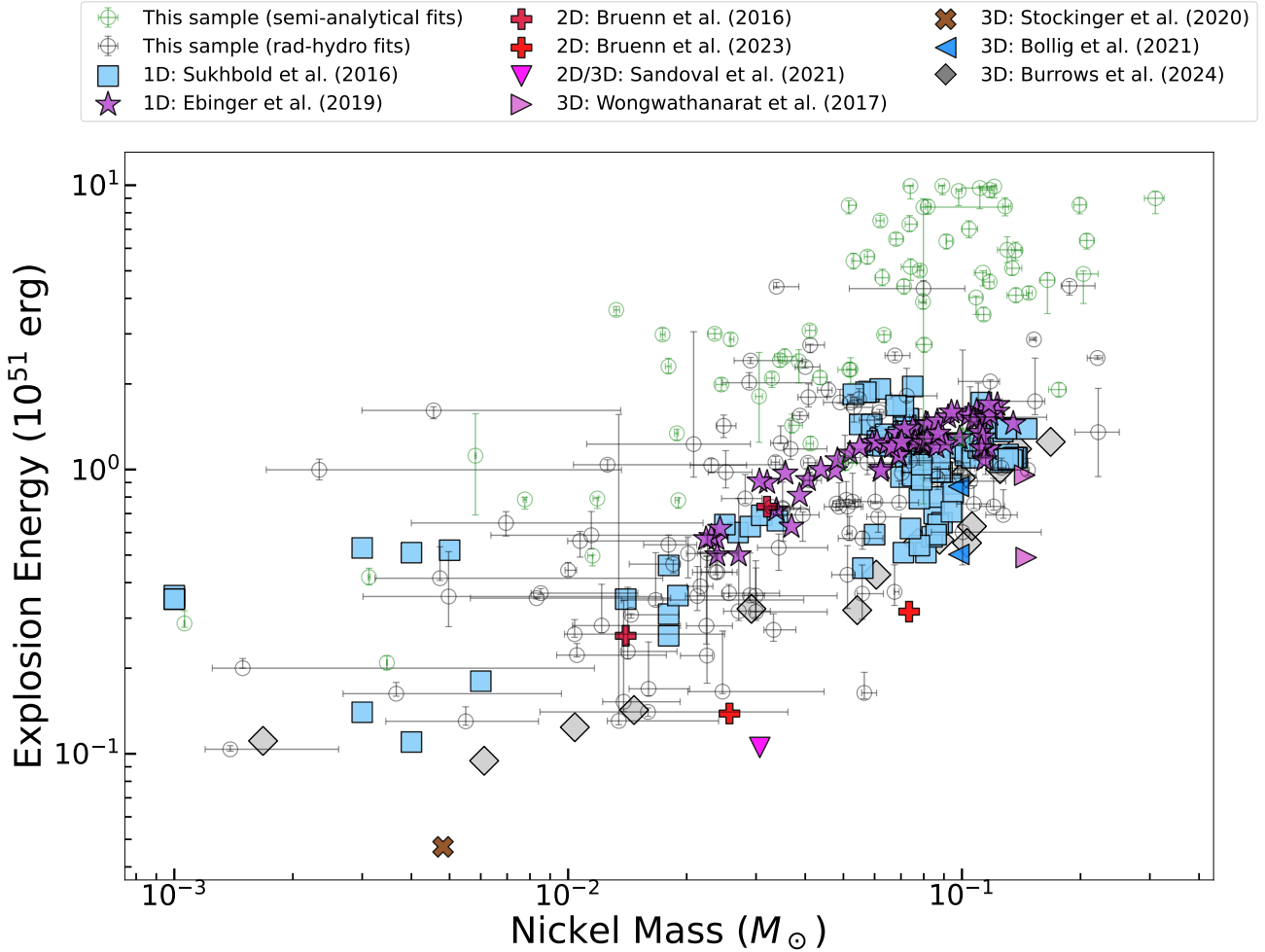


Figure 16. Nickel mass versus explosion energy for a range of core-collapse SN models, compared to our observations. Theoretical models include 1D, 2D and 3D simulations (Sukhbold et al. 2016; Bruenn et al. 2016, 2023; Ebinger et al. 2019; Bollig et al. 2021; Sandoval et al. 2021; Burrows et al. 2024). The observational sample includes semi-analytical fits (green open circles) and radiation-hydrodynamical model fits (black) from this work.

and explosion energy shows an even stronger dependence on luminosity ($r = -0.88$):

$$\log_{10}\left(\frac{E_{\text{exp}}}{\text{erg}}\right) = (-0.35 \pm 0.02) M_r - (6.08 \pm 0.31).$$

The specific energy correlates most strongly with luminosity ($r = -0.91$),

$$\log_{10}\left(\frac{E_{\text{exp}}}{M_{\text{ej}}}\right) = (-0.38 \pm 0.02) M_r - (7.05 \pm 0.29).$$

As in the semi-analytical case, explosion energy and nickel mass are tightly linked ($r = 0.65$),

$$E_{\text{exp}} = (5.7 \pm 1.4) \times \left(\frac{M_{\text{Ni}}}{M_{\odot}}\right)^{0.63 \pm 0.08},$$

consistent with neutrino-driven simulations. Mass-loss rate shows no significant correlations ($r < 0.20$), suggesting that pre-SN

winds and envelope stripping vary independently of the core properties that set the SN explosion physics. The overall distribution of the physical parameter correlations is summarized in Figures 13, 14, and the associated correlation matrices.

7.4. Caveats of the Models

We caution that while the models employed to fit the lightcurves provide useful constraints and correlations, they also introduce several assumptions and systematic effects that may influence the derived parameters. We summarize these below.

A key challenge arises from the degeneracy between key parameters such as ejecta mass, explosion energy, and progenitor radius. Fitting models to photometry in only a couple of passbands allows multiple combinations of physical parameters to produce similar light curves. This degeneracy limits our ability to extract unique solutions from lightcurve fitting alone as discussed in Singh et al. (2024), Rehemtulla et al. (2025).

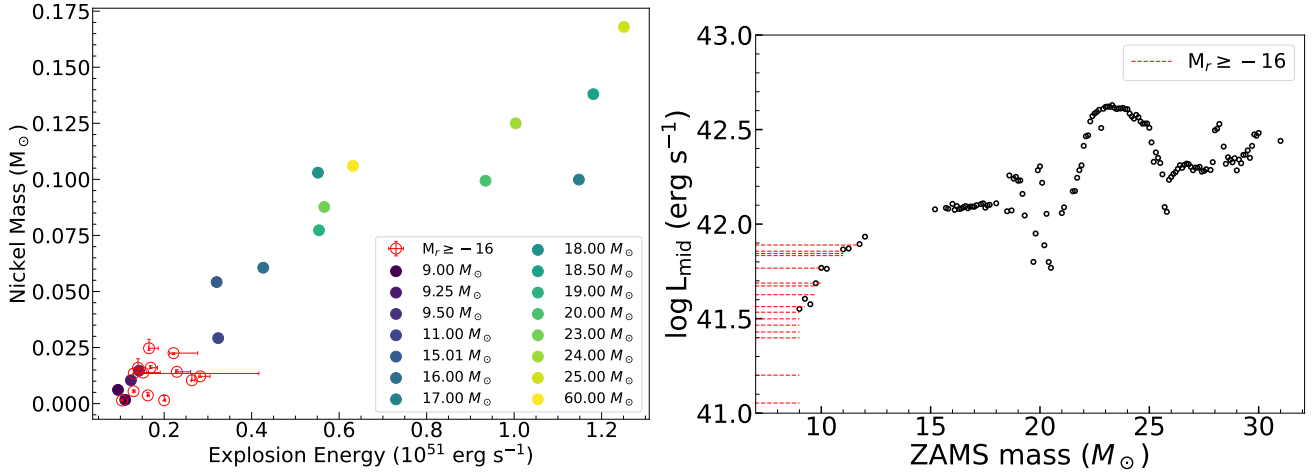


Figure 17. Left: Comparison of explosion energies from our SN sample with predictions from recent 3D core-collapse simulations by Burrows et al. (2020). Right: Comparison of mid-plateau bolometric luminosities for our SN sample (horizontal lines) with theoretical predictions from Barker et al. (2022) (black points), which relate luminosity to iron core mass.

Goldberg et al. (2019), Goldberg & Bildsten (2020) argue that breaking these degeneracies requires external constraints on at least one physical parameter.

Moriya et al. (2023) attempt to mitigate this degeneracy using the progenitor mass-radius relation embedded in the KEPLER stellar grids. Although their lightcurve model grid spans a wide range of progenitor and explosion properties, it is important to note that there are systematic limitations inherited from the underlying stellar evolution framework. For example, they employ a low mixing-length parameter, leading to progenitor radii that are systematically larger than what is inferred from observational constraints. Additionally, the assumption of continuous wind-driven mass loss throughout stellar evolution results in hydrogen-rich envelope masses that are systematically lower at the time of core collapse. These can influence the lightcurves and the physical parameters derived from fitting them (Hsu et al. 2025). While we incorporate velocity information from photospheric-phase spectroscopy to partially constrain kinetic energy, these measurements are not as constraining as those obtained during the brief shock-cooling phase immediately after explosion, which are more diagnostic (Goldberg et al. 2019). We also note that the lowest explosion energy in the model grid is 10^{50} erg; lower energies are required to better fit the lightcurves of the faintest SNe in our sample.

The semi-analytical two-component lightcurve models developed by Nagy & Vinkó (2016) assume spherical symmetry and do not accurately capture the early shock-cooling behavior at $t < 20$ days. Accordingly, we restrict our fits to data obtained after 20 days post-explosion. Despite their simplicity, Nagy & Vinkó (2016) and Jäger, Zoltán et al. (2020) find that these models yield physical parameters broadly consistent with more sophisticated hydrodynamical simulations for Type IIP SNe. To test this consistency, Yang et al. (2021) compared fitting results to those from

hydrodynamical models such as those in Martinez et al. (2020), and found that, in several cases, the inferred ejecta masses are in reasonable agreement. We find that the semi-analytical fits return higher explosion energies and ejecta mass for most SNe. This could be because of the two-component density profile and a simplified method for computing bolometric lightcurves. Prior works have also noted that lightcurve modeling can systematically overestimate ZAMS masses compared to direct progenitor imaging or nebular spectroscopy (e.g., Utrobin & Chugai 2008, 2009; Maguire et al. 2010; Sanders et al. 2015).

The correlations between physical quantities such as peak luminosity, nickel mass, explosion energy, and ejecta mass are preserved in both approaches. Nevertheless, we also observe that, for individual SN, the absolute values derived from the two methods can differ significantly (Figure 21). This highlights the presence of methodological systematics and the need for caution when interpreting parameter estimates from any single modeling framework.

7.5. What are the Progenitors of LLIP SNe?

7.5.1. 7–12 M_{\odot} Red Super Giants that Undergo Core-collapse SNe

We compare our derived explosion parameters to theoretical predictions from neutrino-driven explosion models of core-collapse SNe. Barker et al. (2022) show that the properties of a progenitor’s core can be estimated from optical photometry during the plateau phase alone. A linear correlation between iron core mass and L_{50} (luminosity 50 days post-explosion) indicates that optical photometry of Type IIP SNe can effectively probe progenitor cores. They find a robust relationship linking progenitor iron core mass to plateau luminosity (see Figure 17). The bolometric luminosities of our

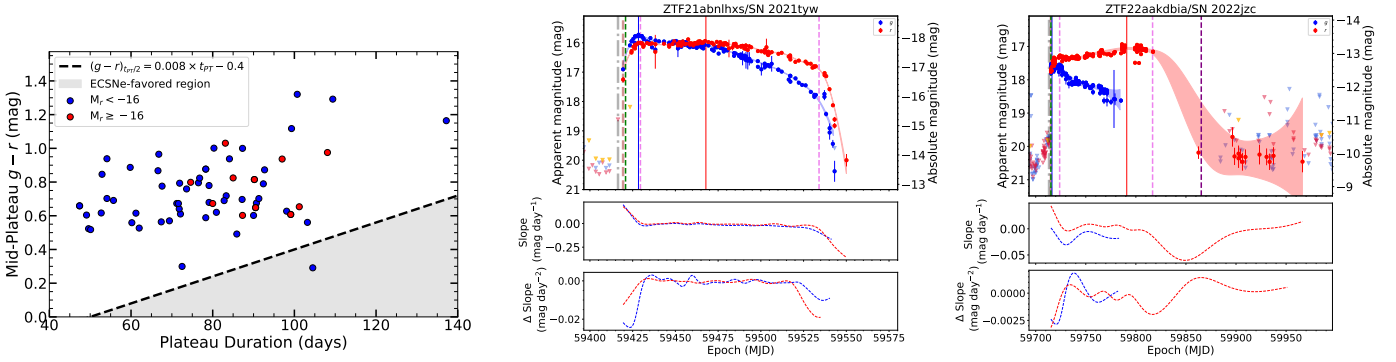


Figure 18. Left: Mid-plateau ($g-r$) colors compared to the ECSN color criterion from Sato et al. (2024), distinguishing explosions of sAGB stars from RSGs, shown in dashed black. Light curves of the SNe with the bluest (SN 2021tyw, mid-plateau ($g-r$) = 0.2 mag; center) and reddest (SN 2022jzc, mid-plateau ($g-r$) = 1.4 mag; right) mid-plateau colors.

LLIIP SN sample align with ZAMS masses below $12 M_{\odot}$. However, we note that these models assume that there is no CSM interaction. Additionally, using best-fit ZAMS mass estimates from Moriya et al. (2023) mode fits, the ZAMS mass for LLIIP SNe are lower than $11 M_{\odot}$. Furthermore, ejecta masses inferred from semi-analytical model fitting by Nagy & Vinkó (2016) suggest masses $\sim 8.2 M_{\odot}$. Assuming a neutron star mass of $1.4 M_{\odot}$, this translates to progenitor masses less than $\sim 11 M_{\odot}$.

Also, Recent 3D simulations by Burrows et al. (2020) find explosion energies of approximately 0.1 foe for their lowest ZAMS mass ($9 M_{\odot}$) progenitor model, compatible with our lowest observed explosion energies from the radiation-hydrodynamical fits (see Figure 17). Previous 1D simulations (e.g., Ugliano et al. 2012; Ertl et al. 2016; Sukhbold et al. 2016) yielded explosion energies between 0.1 and 2.0 foe.

Observations and parameterized 1D explosion models suggest typical nickel yields of $\sim 0.05 M_{\odot}$ from core-collapse SNe. However, the low nickel masses we measure imply progenitor initial masses toward the low-mass end of the CCSN spectrum. Stars with low-mass iron cores are known to produce significantly reduced nickel yields. For example, Stockinger et al. (2020) and Sandoval et al. (2021) find nickel masses of $\sim 0.002-0.005 M_{\odot}$ for a $9.6 M_{\odot}$ progenitor. Recent 3D simulations by Burrows et al. (2024) predict nickel masses in the range $0.002-0.006 M_{\odot}$ for a $9 M_{\odot}$ progenitor, rising above $0.01 M_{\odot}$ for progenitor masses exceeding $9.25 M_{\odot}$. These theoretical predictions are consistent with our measured nickel mass for LLIIP SNe.

7.5.2. sAGB Stars that Undergo Electron-capture SNe

Progenitors in the mass range $8-10 M_{\odot}$ may evolve into super-Asymptotic Giant Branch (sAGB) stars and explode as electron-capture supernovae (ECSNe). ECSN simulations consistently produce low explosion energies and nickel yields significantly lower than typical Fe CCSNe but similar to those observed for the lowest-mass Fe CCSNe. According to

Sato et al. (2024), ECSNe, without significant circumstellar material (CSM) interaction, exhibit distinctively bluer bolometric lightcurve plateaus compared to Fe CCSNe, characterized by mid-plateau ($g-r$) colors exceeding the relation $0.008 \times t_{PT} - 0.4$. This difference arises from the lower-density envelopes inherent to sAGB progenitors. We plot the mid-plateau colors for our SN sample against the Sato et al. (2024) criterion in Figure 18. While SNe 2021tyw, 2022omr, 2021cwe, and 2022prv show bluer mid-plateau colors, their peak luminosities and nickel masses favor an Fe CCSN origin. Among our LLIIP SNe sample, SNe 2023wcr, 2021gmj, 2021zgm, and 2020abcq exhibit notably bluer mid-plateau colors. However, we note that the mid-plateau colors may also be influenced by CSM interaction, as supported by the interaction signatures seen in the spectrum of SN 2021tyw. The lightcurves of the SNe with the bluest (SN 2021tyw, mid-plateau ($g-r$) = 0.2 mag) and reddest (SN 2022jzc, mid-plateau ($g-r$) = 1.4 mag) colors are shown in Figure 18.

We also compare the inferred nickel masses and explosion energies of our LLIIP sample to the ECSN models from Kozyreva et al. (2021). The nickel masses ($\sim 10^{-3}-10^{-4} M_{\odot}$) and explosion energies ($\sim 0.3-1.37 \times 10^{50}$ erg) from our sample closely match those predicted by ECSN simulations for their 8.8 and $9.6 M_{\odot}$ progenitor models. Kozyreva et al. (2021) also show that the lightcurves in the U and B bands rises during the first 50 days and then slowly declines, while the light curve in the V and redder bands rises over the same timescale and then settles into a plateau before a steep drop to the radioactive tail. The rising r -band light curves seen in some LLIIP SNe, when coupled with their low nickel masses, are consistent with theoretical expectations for explosions from sAGB stars that undergo ECSNe.

Photospheric properties alone do not reliably distinguish between ECSNe from sAGB stars and Fe-core collapse SNe from red supergiants. Nebular-phase spectroscopy, however, offers definitive diagnostic features due to distinct core compositions and nucleosynthetic pathways (Jerkstrand et al. 2018). A

comprehensive analysis of nebular spectra for the LLIP SN sample will be presented in Paper III.

8. Conclusion

We present the largest systematic study of lightcurve properties for Type IIP SNe from the volume-limited ZTF CLU survey, analyzing 129 Type IIP events, including 16 LLIP SNe. We summarize the key takeaways of the paper here:

1. Observables:

- a. The median plateau duration for LLIP SNe is 89_{-20}^{+10} days, compared to 76_{-16}^{+16} days for the full Type IIP sample. The median OPTd is 99_{-14}^{+11} days for LLIP SNe and 90_{-20}^{+16} days for the full sample. There is no strong correlation with peak magnitude, likely suggesting binary interaction.
- b. The plateau slope strongly correlates with peak brightness ($r = -0.68$), with brighter SNe having steeper declines; a significant fraction of LLIP SNe exhibit positive plateau slopes. This likely implies progenitors for most LLIP SNe have a smaller radius and different density profile from those of their more luminous counterparts.
- c. We observe a strong correlation between the mid-plateau luminosity and nickel mass ($r = -0.89$), extending to the low-luminosity end. This can be explained if a strong core explosion leads to both higher explosion energy and greater nickel yield.
- d. The steepest plateau-to-tail drop of >3.5 mag was seen in SN 2022aagp. Other objects with sharp drops include SN 2021tyw (>3.1 mag) and SN 2020cxid (2.5 mag). These are consistent with ECSNe and failed SNe with very low or zero nickel mass.

2. Explosion and Progenitor Analysis:

- a. Radiation-hydrodynamical modeling: The ZAMS masses for LLIP SNe are typically below $12 M_{\odot}$, with a median of $10.5_{-0.7}^{+0.4} M_{\odot}$, while that of the overall sample is $11.5_{-1.2}^{+1.6} M_{\odot}$. The kinetic energies are similarly lower for LLIP SNe, with a median of $0.17_{-0.03}^{+0.07} \times 10^{51}$ erg, compared to $0.76_{-0.44}^{+0.89} \times 10^{51}$ erg for the overall sample. The inferred mass-loss rates just before explosion are relatively low, with a median $\log \dot{M} = -3.32_{-0.26}^{+0.37}$ for LLIP SNe, compared to $-3.01_{-0.60}^{+0.83}$ for the overall sample.
- b. Semi-analytical modeling: LLIP SNe have low nickel masses, with a median of $0.013_{-0.001}^{+0.089} M_{\odot}$ and a range from 0.0009 to $0.0420 M_{\odot}$, while that of the overall Type IIP SNe sample is $0.0652_{-0.0471}^{+0.0680} M_{\odot}$ with a range from 0.0009 to $0.3098 M_{\odot}$. The median ejecta mass for LLIP SNe is $8.06_{-1.71}^{+0.73} M_{\odot}$ compared to $12.8_{-5.0}^{+6.2} M_{\odot}$ for the overall sample. Their kinetic

energies are also lower, with a median of $0.79_{-0.35}^{+0.49} \times 10^{51}$ erg for LLIP SNe and $4.32_{-2.91}^{+4.17} \times 10^{51}$ erg for the overall sample.

Overall, LLIP SNe occupy the faint, low-energy, low-mass end of the Type IIP population compared to more luminous events.

3. Correlation of Parameters:

- a. Nickel mass, kinetic and explosion energy, and energy-to-mass ratio strongly correlate with peak absolute magnitude, indicating that fainter SNe have systematically lower nickel mass and explosion energies. This is consistent with theoretical core-collapse SN models, which predict a strong correlation between explosion energy and nickel production.
- b. For the semi-analytical fits, nickel mass and kinetic energy correlates with peak brightness ($r = -0.77$ and $r = -0.69$ respectively). Kinetic energy-to-ejecta mass ratio shows the strongest correlation ($r = -0.77$) with peak brightness. Among physical parameters themselves, kinetic energy correlates strongly with ejecta mass ($r = 0.77$) and with nickel mass ($r = 0.75$).
- c. For the radiation-hydrodynamical fits, similar trends are observed: peak brightness correlates tightly with explosion energy ($r = -0.88$), nickel mass ($r = -0.64$) and energy-to-ejecta mass ratio ($r = -0.91$). Explosion energy also correlates with nickel mass ($r = 0.65$), while mass-loss rate shows little dependence on other explosion parameters.

The correlations between physical parameters such as peak luminosity, nickel mass, explosion energy, and ejecta mass are preserved across both semi-analytical and radiation-hydrodynamic modeling approaches. Nevertheless, we observe that for individual SNe, the absolute values derived from the two methods can differ significantly. This highlights the presence of methodological systematics and underscores the need for caution when interpreting parameter estimates from any single modeling framework. However, the low explosion energies, nickel masses and progenitor masses inferred for LLIP SNe are consistent with the explosions of low-mass RSG or sAGB stars with ZAMS masses $\lesssim 12 M_{\odot}$. Distinguishing between these progenitor scenarios will require late-time nebular spectroscopy, which will be pursued in Paper III of this series. The models in this paper assumes single-star evolution. Incorporating progenitor models that account for binary interaction and mass transfer will be crucial for constraining the binary fraction and understanding the diversity of envelope stripping among core-collapse progenitors. We also highlight the need for radiation-hydrodynamic model grids that extend to the lowest progenitor masses in the 8–10 M_{\odot} range and explore explosion energies below 10^{50} erg to adequately model the faintest Type IIP SNe. The advent of deep, multi-band,

high-cadence surveys such as the Legacy Survey of Space and Time (LSST; Ivezić et al. 2019) will enable a more complete census of the faintest slow-evolving core-collapse SNe and provide critical insights into the lowest-mass stars that explode. It will also offer deep post-plateau limits, facilitating the discovery of more Type IIP SNe with very low or even zero nickel mass, as expected for electron-capture supernovae or failed explosions.

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Data Availability

All photometric and spectroscopic data presented in this work will be made publicly available on [Zenodo](#) and [WISeREP](#) upon publication. The codes required to reproduce the lightcurve fitting will be uploaded via [GitHub](#). Machine-readable versions of all tables, lightcurve plots, and best-fit model plots will also be available on [Zenodo](#).

Software: Global Relay of Observatories Watching Transients Happen Marshal (GROWTH; Kasliwal et al. 2019) and the Fritz SkyPortal Marshal (Duev et al. 2019; van der Walt et al. 2019; Coughlin et al. 2023). Astropy (Astropy Collaboration et al. 2013), Matplotlib (Hunter 2007), george (Ambikasaran et al. 2015).

Appendix

Table A1 lists the observable lightcurve parameters such as rise time, plateau duration, and decline rate for the entire sample. Tables A2 and A3 summarize the priors used in the semi-analytical and radiation-hydrodynamical model fits, respectively. Tables A4 and A5 present the full posterior estimates of explosion and progenitor properties from the two modeling approaches. Table A6 provides the spectral observation log and $H\alpha$ velocity measurements. Figure 19 shows all the parameter correlations based on semi-analytical fits, while Figure 20 shows the same using radiation-hydrodynamical models. Figure 21 compares results between the two modeling methods.

Table A1
Light Curve Parameters for SN II, Sorted by Faintest Peak r -band Absolute Magnitude (M_r)

ZTF	IAU	M_r (mag)	Rise (days)	Plat. dur. (days)	OPTd (days)	Slope ($\times 0.01$ mag day $^{-1}$)	Δ mag (mag)	Limit?
ZTF24abtczty	SN 2024abfl	-14.1	12.2 \pm 0.4	99.1 \pm 1.5	111.7 \pm 1.5	-0.04 \pm 0.02	-2.05	no
ZTF20aapchqy	SN 2020cxd	-14.2	...	108.1 \pm 1.6	112.9 \pm 1.6	-0.42 \pm 0.02	-2.48	no
ZTF24abmkros	SN 2024xkd	-14.9	...	90.5 \pm 1.3	97.1 \pm 1.3	-0.11 \pm 0.02	-1.17	yes
ZTF23aackjhs	SN 1995al	-15.0	...	97.0 \pm 2.3	99.5 \pm 2.3	0.14 \pm 0.02	0.22	yes
ZTF22aakdbia	SN 2022jzc	-15.1	9.7 \pm 0.3	92.8 \pm 5.5	111.0 \pm 5.5	-0.18 \pm 0.02	-2.28	no
ZTF22abtjefa	SN 2022aaad	-15.1	16.0 \pm 0.3	66.5 \pm 15.0	85.8 \pm 15.0	-0.02 \pm 0.03	-1.38	no
ZTF22aazmrpx	SN 2022raj	-15.2	...	80.0 \pm 4.2	84.7 \pm 4.2	0.45 \pm 0.03	-0.87	yes
ZTF20acuhren	SN 2020abcq	-15.3	...	101.2 \pm 2.8	103.2 \pm 2.8	-0.01 \pm 0.02	-2.05	yes
ZTF21aaoakmg	SN 2021eui	-15.4	...	85.0 \pm 3.1	88.0 \pm 3.1	0.09 \pm 0.02	-1.43	yes
ZTF22aaywnyg	SN 2022pru	-15.4	...	86.1 \pm 1.6	102.1 \pm 1.6	0.46 \pm 0.02	-1.09	no
ZTF24aabppgn	SN 2024wp	-15.5	...	95.3 \pm 2.5	109.4 \pm 2.4	0.1 \pm 0.02	-1.35	yes
ZTF23abnogui	SN 2023wcr	-15.6	...	87.3 \pm 4.3	101.1 \pm 4.3	0.58 \pm 0.04	-1.53	no
ZTF24aaurua	SN 2024nez	-15.8	...	90.2 \pm 1.5	105.4 \pm 1.5	0.18 \pm 0.02	-1.58	yes
ZTF22abyivoq	SN 2022acko	-15.8	...	69.8 \pm 6.4	84.7 \pm 6.4	0.23 \pm 0.04	0.02	yes
ZTF20abeohfn	SN 2020mjm	-15.9	10.7 \pm 0.1	64.3 \pm 7.6	76.5 \pm 7.6	0.05 \pm 0.03	0.05	yes
ZTF22abssiet	SN 2022zmb	-15.9	...	66.1 \pm 11.3	76.0 \pm 11.3	0.18 \pm 0.04	-0.24	yes
ZTF19aamwhat	SN 2019bzd	-16.0	...	83.1 \pm 1.5	103.1 \pm 1.4	0.36 \pm 0.02	-2.00	yes
ZTF22abkhrkd	SN 2022wol	-16.0	...	79.1 \pm 2.6	90.8 \pm 2.6	0.08 \pm 0.03	-1.09	yes
ZTF24aaejecr	SN 2024bj	-16.0	...	78.3 \pm 2.3	89.6 \pm 2.3	0.55 \pm 0.03	-1.66	no
ZTF24aaplfd	SN 2024xm	-16.0	...	74.6 \pm 4.6	97.6 \pm 4.6	0.24 \pm 0.03	-1.30	no
ZTF19abwztsb	SN 2019pjs	-16.2	...	68.1 \pm 37.2	80.0 \pm 37.2	0.37 \pm 0.2	-1.36	no
ZTF24aabsmvc	SN 2024ws	-16.2	...	90.0 \pm 23.0	100.4 \pm 23.0	0.26 \pm 0.07	-1.25	yes
ZTF22abyohff	SN 2022acl	-16.3	...	78.7 \pm 6.5	88.7 \pm 6.4	0.33 \pm 0.04	-0.52	yes
ZTF21acgrnl	SN 2021aayf	-16.3	...	77.0 \pm 14.8	90.5 \pm 14.8	-0.14 \pm 0.04	-1.44	yes
ZTF21aaeqwov	AT 2021htp	-16.4	13.2 \pm 0.6	92.4 \pm 1.1	106.1 \pm 1.1	0.27 \pm 0.02	-1.30	no
ZTF23abaxtlq	SN 2023rix	-16.4	...	75.2 \pm 8.3	87.3 \pm 8.3	0.92 \pm 0.1	-2.13	no
ZTF21abvixel	SN 2021vww	-16.4	...	67.4 \pm 1.2	69.4 \pm 1.2	0.47 \pm 0.03	-1.67	yes
ZTF21aantsla	SN 2021ech	-16.4	...	75.3 \pm 8.0	86.5 \pm 8.0	0.25 \pm 0.04	-1.46	yes
ZTF21aafepon	SN 2021ass	-16.4	...	51.4 \pm 9.0	67.9 \pm 9.0	0.16 \pm 0.05	-0.09	yes
ZTF21acpqqgu	SN 2021aewn	-16.4	...	76.3 \pm 9.7	78.3 \pm 9.7	0.35 \pm 0.05	-0.77	yes
ZTF22abnujv	SN 2022xus	-16.4	...	53.2 \pm 20.7	62.4 \pm 20.7	0.58 \pm 0.23	-1.83	no
ZTF20acmaaan	SN 2020xyk	-16.4	...	69.4 \pm 4.2	75.8 \pm 4.2	0.14 \pm 0.03	-1.96	yes
ZTF22abfxkdm	SN 2022ubb	-16.6	...	87.3 \pm 3.9	96.2 \pm 3.9	0.49 \pm 0.03	-1.66	yes
ZTF22aavbfhz	AT 2022phi	-16.6	...	78.3 \pm 2.0	81.3 \pm 2.0	0.63 \pm 0.03	-1.02	yes
ZTF22abkbjsb	SN 2022vym	-16.7	...	60.0 \pm 9.5	66.5 \pm 9.5	0.62 \pm 0.1	-1.33	no
ZTF24aabpzuz	SN 2024vs	-16.7	...	62.0 \pm 4.7	78.9 \pm 4.7	-0.13 \pm 0.03	-1.33	yes
ZTF21aanzcuj	SN 2021enz	-16.7	18.0 \pm 0.8	72.1 \pm 1.9	90.6 \pm 1.8	0.01 \pm 0.03	-1.54	no
ZTF24aafqzur	SN 2024daa	-16.7	...	67.6 \pm 1.2	86.6 \pm 1.2	0.15 \pm 0.03	-0.94	yes
ZTF21aagtqna	SN 2021brb	-16.8	21.2 \pm 1.4	73.6 \pm 3.7	104.8 \pm 3.7	0.12 \pm 0.03	-1.26	no
ZTF18aaszvfn	SN 2021iaw	-16.8	...	76.8 \pm 1.7	86.4 \pm 1.7	0.39 \pm 0.03	-1.23	yes
ZTF19acftfav	SN 2019ssi	-16.8	14.2 \pm 0.4	61.7 \pm 8.0	76.4 \pm 8.0	0.71 \pm 0.1	-1.70	yes
ZTF23aasbvab	SN 2023ngy	-16.8	...	92.7 \pm 1.1	102.9 \pm 1.1	0.83 \pm 0.02	-1.32	yes
ZTF23aasrcyv	SN 2023nlu	-16.8	18.3 \pm 1.2	71.8 \pm 1.8	94.0 \pm 1.8	0.5 \pm 0.03	-0.24	yes
ZTF22abzqwmp	SN 2022adth	-16.8	...	61.0 \pm 11.1	73.6 \pm 11.1	0.69 \pm 0.13	-0.81	yes
ZTF22aasojye	SN 2022omr	-16.9	...	98.1 \pm 4.2	103.6 \pm 4.2	0.23 \pm 0.02	-1.76	no
ZTF19aadnxnl	SN 2019va	-16.9	...	103.2 \pm 3.8	107.2 \pm 3.8	-0.09 \pm 0.02	-0.80	no
ZTF19actnyae	SN 2019vdm	-16.9	...	52.9 \pm 1.4	61.4 \pm 1.4	-0.02 \pm 0.04	-1.33	no
ZTF23aaxadel	SN 2023pbg	-16.9	...	89.8 \pm 6.1	104.6 \pm 6.1	0.31 \pm 0.03	-0.82	yes
ZTF21abrluay	SN 2021vfh	-17.0	...	75.4 \pm 8.8	88.0 \pm 8.8	0.08 \pm 0.03	-1.28	yes
ZTF22aafsqud	SN 2022hql	-17.0	...	61.2 \pm 1.6	71.7 \pm 1.6	0.62 \pm 0.04	-1.25	yes
ZTF22abhxsph	SN 2022vyc	-17.0	...	80.3 \pm 1.4	94.6 \pm 1.4	0.51 \pm 0.03	-1.42	yes
ZTF19aazudta	SN 2019hqm	-17.0	...	73.7 \pm 16.5	90.0 \pm 16.5	0.18 \pm 0.05	-1.52	yes
ZTF22abfwxtr	SN 2022udq	-17.0	...	99.3 \pm 2.3	111.4 \pm 2.3	0.41 \pm 0.02	-0.73	yes
ZTF21aafkwtk	SN 2021apg	-17.0	...	69.3 \pm 6.0	87.0 \pm 6.0	0.33 \pm 0.04	-1.65	no
ZTF19aapafit	SN 2019cvz	-17.0	...	82.8 \pm 2.2	98.3 \pm 2.2	0.12 \pm 0.02	-1.30	no
ZTF23abbtkrv	SN 2023rvo	-17.0	16.7 \pm 1.1	90.7 \pm 2.2	157.1 \pm 2.2	-0.04 \pm 0.02	-0.81	yes

Table A1
(Continued)

ZTF	IAU	M_r (mag)	Rise (days)	Plat. dur. (days)	OPTd (days)	Slope ($\times 0.01 \text{ mag day}^{-1}$)	Δmag (mag)	Limit?
ZTF19acewuw	SN 2019ssl	-17.0	...	62.8 \pm 8.0	83.8 \pm 8.0	0.19 \pm 0.04	-1.09	yes
ZTF19aailepg	SN 2019amt	-17.1	...	100.9 \pm 10.3	109.0 \pm 10.3	0.3 \pm 0.04	-1.04	yes
ZTF19aazyvub	SN 2019hnl	-17.1	...	74.6 \pm 5.1	80.6 \pm 5.0	0.39 \pm 0.04	-1.44	no
ZTF21aakvroo	SN 2021ewe	-17.1	...	72.5 \pm 4.2	76.5 \pm 4.2	-0.08 \pm 0.03	-0.93	no
ZTF22abtspsw	SN 2022aagp	-17.1	9.0 \pm 0.0	111.5 \pm 6.3	122.5 \pm 6.3	0.99 \pm 0.06	-3.50	yes
ZTF18aaxkqgy	SN 2018ccb	-17.1	...	70.0 \pm 10.6	74.2 \pm 10.6	0.53 \pm 0.09	-1.22	no
ZTF22abfavpu	SN 2022tmb	-17.1	...	66.6 \pm 1.3	80.9 \pm 1.3	0.77 \pm 0.03	-2.05	no
ZTF21aapliyn	SN 2021foj	-17.1	...	91.3 \pm 1.8	96.4 \pm 1.8	0.15 \pm 0.02	-1.20	yes
ZTF21acafqtj	SN 2021yok	-17.1	...	59.9 \pm 10.6	69.9 \pm 10.6	0.37 \pm 0.07	-0.20	yes
ZTF21abfiuqf	SN 2021pla	-17.2	...	52.9 \pm 1.2	60.6 \pm 1.2	1.25 \pm 0.05	-1.51	no
ZTF19aanhhah	SN 2019cec	-17.2	...	80.9 \pm 2.8	90.2 \pm 2.8	0.44 \pm 0.03	-0.96	yes
ZTF22abyokkf	SN 2022acri	-17.2	...	91.7 \pm 5.2	108.2 \pm 5.2	0.08 \pm 0.02	-1.14	yes
ZTF18aatyqds	SN 2018bit	-17.2	10.8 \pm 0.2	76.5 \pm 4.4	88.8 \pm 4.4	1.2 \pm 0.07	-1.39	no
ZTF22aapargp	SN 2022niw	-17.2	...	54.0 \pm 9.6	68.7 \pm 9.6	0.46 \pm 0.09	-1.03	yes
ZTF23aanymcl	SN 2023kzz	-17.2	...	60.6 \pm 2.1	64.1 \pm 2.1	0.68 \pm 0.04	-1.23	yes
ZTF21aavhnpk	SN 2021jsf	-17.3	...	74.3 \pm 9.1	78.8 \pm 9.0	0.7 \pm 0.09	-1.34	yes
ZTF19aaniore	SN 2019ceg	-17.3	...	87.2 \pm 3.0	102.0 \pm 3.0	0.44 \pm 0.03	-1.46	no
ZTF21aabygea	SN 2021os	-17.3	14.8 \pm 0.4	83.3 \pm 1.8	100.1 \pm 1.8	0.58 \pm 0.03	-1.43	no
ZTF22absqhk	SN 2022zkc	-17.4	...	50.1 \pm 4.6	52.1 \pm 4.6	0.62 \pm 0.07	-1.48	yes
ZTF23aaqknaw	SN 2023lzn	-17.4	...	100.7 \pm 1.7	104.7 \pm 1.6	0.55 \pm 0.02	-2.03	yes
ZTF21aaagypx	SN 2021V	-17.4	...	137.2 \pm 1.1	146.1 \pm 1.1	0.56 \pm 0.02	-1.57	yes
ZTF19abbnamr	SN 2019iex	-17.4	...	94.1 \pm 10.0	100.6 \pm 10.0	0.17 \pm 0.03	-1.58	no
ZTF19aawgxdn	SN 2019gmh	-17.4	...	95.9 \pm 8.0	105.5 \pm 8.0	0.34 \pm 0.04	-1.54	yes
ZTF24aagupsf	SN 2024egd	-17.5	...	71.0 \pm 7.0	82.4 \pm 7.0	0.62 \pm 0.07	-2.46	no
ZTF18abzrgim	SN 2018gvt	-17.5	...	73.0 \pm 24.1	90.4 \pm 24.1	-0.03 \pm 0.03	-0.31	yes
ZTF19acytcs	SN 2019wvz	-17.6	...	77.4 \pm 9.2	93.1 \pm 9.2	0.25 \pm 0.04	-1.13	no
ZTF18aawpwl	SN 2020hvn	-17.6	...	54.1 \pm 3.7	62.1 \pm 3.7	1.76 \pm 0.13	-1.49	yes
ZTF23abhzfww	SN 2023twg	-17.6	...	90.0 \pm 3.0	96.0 \pm 3.0	0.6 \pm 0.03	-1.45	no
ZTF24aarvbxj	SN 2024lby	-17.6	...	49.1 \pm 1.4	60.4 \pm 1.4	0.73 \pm 0.05	-1.23	no
ZTF19aclobbu	SN 2019twk	-17.6	...	73.7 \pm 10.3	84.5 \pm 10.3	0.31 \pm 0.05	-0.52	yes
ZTF19actnwn	SN 2019vdl	-17.6	...	84.1 \pm 1.7	102.1 \pm 1.7	0.39 \pm 0.03	-1.09	yes
ZTF21abouuat	SN 2021lucg	-17.6	...	81.3 \pm 11.4	98.7 \pm 11.4	0.27 \pm 0.05	-1.20	yes
ZTF24aaabbse	SN 2023achj	-17.8	...	103.9 \pm 9.5	123.8 \pm 9.5	0.65 \pm 0.06	-1.03	yes
ZTF21acgunkr	SN 2021aaxs	-17.8	...	77.7 \pm 16.3	89.5 \pm 16.3	0.99 \pm 0.21	-0.52	yes
ZTF21abnlhxs	SN 2021tyw	-17.8	8.7 \pm 0.2	104.5 \pm 1.1	116.1 \pm 1.1	0.85 \pm 0.02	-3.10	yes
ZTF19abajxet	SN 2019hyk	-17.8	10.9 \pm 0.2	67.3 \pm 10.9	79.7 \pm 10.9	0.95 \pm 0.16	-0.88	yes
ZTF19acbwejj	SN 2019upq	-17.8	22.0 \pm 7.4	87.7 \pm 3.3	130.3 \pm 3.3	1.14 \pm 0.05	-1.28	no
ZTF23abmoxlu	SN 2023vog	-17.8	10.9 \pm 0.2	109.4 \pm 2.4	123.2 \pm 2.4	1.19 \pm 0.03	-2.49	no
ZTF21abhhrpj	SN 2021qiu	-17.9	...	90.7 \pm 1.6	96.3 \pm 1.6	0.53 \pm 0.02	-1.93	no
ZTF22aakdqg	SN 2022kad	-17.9	15.5 \pm 0.6	63.1 \pm 12.8	79.6 \pm 12.8	1.38 \pm 0.28	-1.27	no
ZTF23aailjjs	SN 2023hep	-17.9	...	60.2 \pm 2.5	69.6 \pm 2.4	0.83 \pm 0.05	-1.57	no
ZTF19aanrrqu	SN 2019clp	-18.0	...	49.6 \pm 4.5	53.8 \pm 4.5	1.17 \pm 0.11	-1.65	no
ZTF24aadkwni	SN 2024aul	-18.0	...	59.8 \pm 1.6	68.4 \pm 1.6	0.84 \pm 0.04	-1.12	no
ZTF21abjcjmc	SN 2021skn	-18.0	7.1 \pm 0.0	55.7 \pm 0.5	63.7 \pm 0.5	2.05 \pm 0.04	-1.41	yes
ZTF23abascqa	SN 2023rbk	-18.0	...	71.9 \pm 1.3	85.9 \pm 1.3	1.28 \pm 0.04	-2.02	no
ZTF24aaemydm	SN 2024chx	-18.0	...	64.3 \pm 5.6	70.9 \pm 5.6	0.92 \pm 0.09	-1.40	no
ZTF24aajxppf	SN 2024grw	-18.0	...	52.7 \pm 4.6	64.4 \pm 4.6	1.37 \pm 0.13	-1.32	no
ZTF21aaqugx	SN 2021hdt	-18.1	...	49.1 \pm 8.9	60.9 \pm 8.9	1.34 \pm 0.25	-1.07	no
ZTF21ablvzhp	SN 2021tiq	-18.1	...	85.9 \pm 4.1	98.1 \pm 4.1	0.56 \pm 0.04	-1.37	yes
ZTF21abgilzj	AT 2021qcr	-18.1	16.2 \pm 1.0	66.8 \pm 1.1	93.0 \pm 1.1	1.51 \pm 0.04	-0.92	yes
ZTF21aapkcmr	AT 2021fnj	-18.1	...	54.1 \pm 4.6	59.1 \pm 4.6	1.74 \pm 0.15	-1.34	yes
ZTF19abqrhvt	SN 2019nyk	-18.1	...	47.4 \pm 2.0	60.1 \pm 2.0	1.54 \pm 0.08	-1.47	yes
ZTF21abnudtb	SN 2021txr	-18.1	...	71.6 \pm 1.0	80.5 \pm 1.0	0.63 \pm 0.03	-1.16	no
ZTF23aaphnyz	SN 2023lkw	-18.1	...	77.5 \pm 10.7	87.7 \pm 10.7	0.46 \pm 0.07	-0.95	yes
ZTF22aaolwsd	SN 2022mxv	-18.1	12.6 \pm 0.2	104.8 \pm 20.0	122.6 \pm 20.0	1.35 \pm 0.26	-0.87	yes
ZTF19aarykkb	SN 2019dzk	-18.2	...	73.9 \pm 2.8	82.0 \pm 2.8	0.3 \pm 0.03	-0.62	yes

Table A1
(Continued)

ZTF	IAU	M_r (mag)	Rise (days)	Plat. dur. (days)	OPTd (days)	Slope ($\times 0.01$ mag day $^{-1}$)	Δ mag (mag)	Limit?
ZTF22aativsd	SN 2022ovb	-18.2	11.6 ± 0.2	71.2 ± 1.9	84.3 ± 1.9	0.84 ± 0.04	-0.94	no
ZTF19abqrhvy	SN 2019odf	-18.2	14.0 ± 0.3	93.3 ± 8.4	107.8 ± 8.4	0.71 ± 0.07	-1.14	yes
ZTF19abbwfgp	SN 2019ikb	-18.2	11.9 ± 0.3	79.1 ± 2.7	91.5 ± 2.7	1.05 ± 0.04	-2.06	yes
ZTF22aavobvq	SN 2022prv	-18.3	10.6 ± 0.2	62.8 ± 12.0	86.5 ± 12.0	1.4 ± 0.27	-2.56	yes
ZTF21aaiypya	SN 2021cgu	-18.3	13.2 ± 0.6	90.0 ± 13.1	106.5 ± 13.1	0.98 ± 0.14	-0.45	yes
ZTF19acrcxri	SN 2019ult	-18.4	...	54.9 ± 1.6	65.3 ± 1.6	1.07 ± 0.05	-1.33	yes
ZTF23aaaatjn	SN 2023cf	-18.5	...	84.6 ± 5.7	90.1 ± 5.7	0.89 ± 0.06	-1.92	no
ZTF22aarycqo	SN 2022ojo	-19.3	...	80.8 ± 11.0	96.1 ± 11.0	1.42 ± 0.2	-1.40	no

Note. ZTF and IAU names are shown in separate columns. The table includes rise time, plateau duration (Plat. dur.), optically thick duration (OPTd), decline rate during plateau (Slope, in $\times 0.01$ mag day $^{-1}$), and the plateau-to-tail drop (Δ mag). The full machine-readable table is available on [Zenodo](#).

Table A2
Priors Used in the MCMC Fitting with the Semi-analytical Models from Nagy & Vinkó (2016)

Parameter	Prior
Initial radius [R (cm)]	$\mathcal{U}[2 \times 10^{12}, 8 \times 10^{13}]$
Ejected mass [M_{ej} (M_{\odot})]	$\mathcal{U}[3, 25]$
Kinetic energy [E_{kin} (10^{51} erg)]	$\mathcal{U}[0.01, 10]$
Thermal energy [E_{th} (10^{51} erg)]	$\mathcal{U}[0.01, 10]$
Thomson scattering opacity [κ (cm 2 /g)]	$\mathcal{U}[0.1, 0.4]$
Density power-law exponent	$\mathcal{U}[0, 3]$
Ionization/recombination temperature [T_{ion} (K)]	$\mathcal{U}[0, 20000]$
Nickel mass [M_{Ni} (M_{\odot})]	$\mathcal{U}[5 \times 10^{-4}, 0.5]$
Gamma-leakage parameter [t_{γ}^2 (day 2)]	$\mathcal{U}[10^3, 10^7]$

Table A3
Priors Used in the MCMC Fitting with the Radiation-hydrodynamical Models from Moriya et al. (2023)

Parameter	Prior
M_{ZAMS} [M_{\odot}]	$\mathcal{U}(9, 18)$
Explosion Energy [10^{51} erg]	$\mathcal{U}(0.5, 5.0)$
M_{Ni} [M_{\odot}]	$\mathcal{U}(0.001, 0.3)$
Mass-Loss Rate [M_{\odot} yr $^{-1}$]	$\mathcal{U}(10^{-5.0}, 10^{-1.0})$
Wind Velocity [km s $^{-1}$]	Fixed at 10
R_{CSM} [10^{14} cm]	$\mathcal{U}(1, 10)$
Wind Structure Parameter (β)	$\mathcal{U}(0.5, 5.0)$

Table A4
Posterior Estimates of Explosion and Progenitor Properties Based on Fits to the Semi-analytical Models from Nagy & Vinkó (2016)

ZTF Name	IAU Name	M_{Ni} ($\times 10^{-2} M_{\odot}$)	M_{ej} (M_{\odot})	R_0 (R_{\odot})	E_{kin} ($\times 10^{51}$ erg)
ZTF21abrluay	SN 2021vfh	$11.96^{+1.34}_{-0.84}$	$14.8^{+1.4}_{-2.0}$	350^{+119}_{-185}	$8.49^{+1.03}_{-1.85}$
ZTF22abfxkdm	SN 2022ubb	$2.09^{+0.26}_{-0.29}$	$17.2^{+1.0}_{-0.7}$	237^{+33}_{-17}	$4.64^{+0.33}_{-0.23}$
ZTF23aasrcyv	SN 2023nlu	$0.56^{+5.65}_{-0.42}$	$16.5^{+0.9}_{-6.3}$	419^{+42}_{-189}	$3.16^{+0.44}_{-1.65}$
ZTF22abkhrkd	SN 2022wol	$3.52^{+2.66}_{-1.34}$	$13.9^{+3.2}_{-5.5}$	413^{+326}_{-276}	$2.92^{+0.94}_{-1.98}$
ZTF21aaagypx	SN 2021V	$9.12^{+0.82}_{-0.45}$	$24.7^{+0.3}_{-2.8}$	720^{+49}_{-56}	$6.33^{+0.31}_{-0.45}$
ZTF18aawpwlf	SN 2020hvn	$7.23^{+0.40}_{-0.44}$	$6.3^{+0.6}_{-0.4}$	207^{+45}_{-29}	$2.63^{+0.29}_{-0.27}$
ZTF22aafsqud	SN 2022hql	$2.39^{+1.64}_{-1.34}$	$12.8^{+1.5}_{-1.7}$	286^{+81}_{-105}	$3.97^{+0.63}_{-0.70}$
ZTF21acafqtj	SN 2021yok	$6.52^{+0.25}_{-0.64}$	$14.2^{+0.9}_{-0.6}$	885^{+65}_{-117}	$5.81^{+0.27}_{-0.57}$
ZTF21acpqqgu	SN 2021aewn	$1.89^{+0.16}_{-0.06}$	$13.9^{+0.2}_{-0.5}$	455^{+19}_{-15}	$3.49^{+0.05}_{-0.15}$
ZTF19abqrhvt	SN 2019nyk	$10.79^{+0.40}_{-0.39}$	$10.6^{+0.4}_{-0.4}$	102^{+5}_{-7}	$8.17^{+0.36}_{-0.36}$
ZTF21aaipypa	SN 2021cgu	$7.36^{+6.97}_{-2.09}$	$20.7^{+1.1}_{-5.9}$	707^{+193}_{-104}	$9.41^{+0.58}_{-4.57}$
ZTF20acuhren	SN 2020abcq	$2.27^{+0.27}_{-1.88}$	$8.4^{+1.1}_{-0.3}$	205^{+32}_{-39}	$0.87^{+0.02}_{-0.03}$
ZTF24aaurua	SN 2024nez	$4.20^{+0.24}_{-0.41}$	$8.9^{+1.2}_{-0.6}$	183^{+97}_{-42}	$1.40^{+0.27}_{-0.14}$
ZTF22aapargp	SN 2022niw	$3.84^{+1.78}_{-1.77}$	$20.3^{+2.7}_{-2.8}$	337^{+278}_{-185}	$8.66^{+0.90}_{-1.44}$
ZTF23aaqknaw	SN 2023lzn	$5.78^{+0.48}_{-0.49}$	$21.8^{+0.3}_{-2.4}$	346^{+28}_{-58}	$9.86^{+0.08}_{-1.51}$
ZTF22abhsxph	SN 2022vyc	$6.11^{+0.33}_{-0.37}$	$16.6^{+1.1}_{-1.3}$	157^{+44}_{-35}	$5.40^{+0.55}_{-0.51}$
ZTF22abzqwmp	SN 2022adth	$0.87^{+0.13}_{-0.56}$	$11.7^{+0.7}_{-1.3}$	1048^{+86}_{-319}	$3.05^{+0.23}_{-0.65}$
ZTF24aabsmvc	SN 2024ws	$1.94^{+1.68}_{-0.84}$	$19.0^{+1.7}_{-3.4}$	160^{+43}_{-33}	$4.75^{+0.45}_{-1.00}$
ZTF21aantsla	SN 2021ech	$5.52^{+0.49}_{-0.69}$	$11.6^{+1.3}_{-0.9}$	443^{+109}_{-77}	$3.16^{+0.47}_{-0.27}$
ZTF19aclobbu	SN 2019twk	$21.80^{+2.30}_{-21.34}$	$16.4^{+3.9}_{-2.2}$	89^{+90}_{-18}	$6.14^{+2.05}_{-6.01}$
ZTF21abnlhxs	SN 2021tyw	$1.80^{+0.13}_{-0.15}$	$14.5^{+0.8}_{-1.1}$	348^{+29}_{-58}	$4.50^{+0.22}_{-0.54}$
ZTF23aanymcl	SN 2023kzz	$9.06^{+0.70}_{-0.53}$	$10.6^{+0.8}_{-0.8}$	361^{+152}_{-137}	$4.91^{+0.52}_{-0.52}$
ZTF21abouuat	SN 2021ucg	$13.76^{+0.75}_{-0.72}$	$22.1^{+0.6}_{-1.2}$	341^{+24}_{-35}	$9.83^{+0.10}_{-0.79}$
ZTF19acrcxri	SN 2019ult	$18.67^{+1.05}_{-15.54}$	$11.7^{+1.1}_{-0.7}$	837^{+192}_{-171}	$8.12^{+0.83}_{-1.71}$
ZTF21aakvrv	SN 2021ewe	$12.83^{+0.71}_{-1.65}$	$6.6^{+1.9}_{-0.4}$	250^{+266}_{-114}	$1.97^{+0.89}_{-0.21}$
ZTF22absqhk	SN 2022zkc	$8.62^{+0.44}_{-0.36}$	$8.0^{+0.6}_{-0.6}$	310^{+69}_{-95}	$4.16^{+0.49}_{-0.44}$
ZTF18abzrgim	SN 2018gvt	$26.28^{+2.45}_{-1.20}$	$16.3^{+1.4}_{-3.0}$	638^{+235}_{-192}	$8.52^{+1.06}_{-2.32}$
ZTF21aapliyn	SN 2021foj	$10.57^{+1.53}_{-0.42}$	$19.3^{+0.8}_{-3.3}$	129^{+21}_{-29}	$8.53^{+0.50}_{-2.08}$
ZTF21abjcjmc	SN 2021skn	$5.04^{+2.59}_{-0.18}$	$7.8^{+0.3}_{-3.3}$	1041^{+48}_{-444}	$4.32^{+0.18}_{-2.13}$
ZTF22abyohff	SN 2022acr1	$1.08^{+3.73}_{-0.98}$	$17.3^{+2.4}_{-8.0}$	158^{+95}_{-77}	$3.46^{+0.85}_{-1.99}$
ZTF19aazudta	SN 2019hqm	$11.17^{+3.42}_{-1.16}$	$19.8^{+1.9}_{-8.1}$	531^{+274}_{-288}	$8.69^{+0.98}_{-5.05}$
ZTF22aarycgo	SN 2022ojo	$16.51^{+20.29}_{-14.52}$	$7.8^{+1.7}_{-1.2}$	953^{+128}_{-173}	$1.37^{+1.02}_{-0.58}$
ZTF19aamwhat	SN 2019bzd	$1.16^{+0.08}_{-0.04}$	$9.2^{+0.5}_{-0.3}$	163^{+6}_{-15}	$1.04^{+0.09}_{-0.04}$
ZTF22abyokkf	SN 2022acri	$16.85^{+0.86}_{-0.84}$	$22.5^{+0.6}_{-1.5}$	316^{+46}_{-39}	$9.68^{+0.24}_{-0.78}$
ZTF24aaabbse	SN 2023achj	$18.51^{+1.00}_{-0.83}$	$14.9^{+0.7}_{-0.8}$	1000^{+91}_{-120}	$3.39^{+0.21}_{-0.22}$
ZTF19abqrhvy	SN 2019odf	$23.70^{+0.68}_{-13.83}$	$19.2^{+0.9}_{-1.8}$	400^{+148}_{-43}	$7.17^{+0.77}_{-2.52}$
ZTF18aaszvfn	SN 2021iaw	$6.78^{+1.36}_{-0.67}$	$11.5^{+0.4}_{-1.4}$	121^{+14}_{-8}	$2.71^{+0.18}_{-0.19}$
ZTF23aaxadel	SN 2023pbg	$9.87^{+1.26}_{-0.60}$	$15.5^{+1.0}_{-2.4}$	161^{+25}_{-27}	$4.52^{+0.33}_{-1.21}$
ZTF22abfwxtr	SN 2022udq	$1.56^{+4.38}_{-0.23}$	$23.8^{+1.0}_{-6.5}$	412^{+100}_{-66}	$5.59^{+0.32}_{-2.01}$
ZTF21aabkmg	SN 2021eui	$1.84^{+0.13}_{-0.13}$	$8.1^{+0.8}_{-0.1}$	299^{+76}_{-38}	$0.89^{+0.01}_{-0.08}$
ZTF24aabpzuz	SN 2024vs	$9.19^{+0.73}_{-0.30}$	$14.0^{+0.6}_{-1.6}$	512^{+98}_{-133}	$6.00^{+0.37}_{-0.98}$
ZTF19aawgxdn	SN 2019gmh	$11.94^{+0.86}_{-0.61}$	$22.5^{+0.5}_{-2.2}$	134^{+18}_{-22}	$9.40^{+0.50}_{-0.90}$
ZTF19aarykkb	SN 2019dzk	$0.80^{+0.25}_{-0.02}$	$14.0^{+0.4}_{-0.9}$	765^{+32}_{-88}	$3.37^{+0.15}_{-0.29}$
ZTF22aazmrx	SN 2022raj	$0.09^{+0.24}_{-0.01}$	$6.7^{+0.3}_{-0.3}$	349^{+49}_{-24}	$0.52^{+0.06}_{-0.02}$
ZTF21abnudtb	SN 2021txr	$0.74^{+20.24}_{-0.12}$	$15.0^{+0.7}_{-1.5}$	1065^{+45}_{-149}	$6.24^{+3.53}_{-0.71}$
ZTF24aafqzur	SN 2024daa	$6.58^{+0.42}_{-0.35}$	$17.1^{+1.5}_{-1.1}$	98^{+14}_{-15}	$6.00^{+0.72}_{-0.47}$
ZTF22aavobvq	SN 2022prv	$5.91^{+0.77}_{-0.32}$	$15.8^{+0.5}_{-1.2}$	280^{+20}_{-15}	$9.71^{+0.28}_{-0.93}$
ZTF21ablvezhp	SN 2021tiq	$27.63^{+1.35}_{-1.16}$	$17.1^{+0.6}_{-1.1}$	714^{+38}_{-58}	$9.76^{+0.24}_{-0.88}$
ZTF23aaaatjn	SN 2023cf	$15.93^{+2.12}_{-5.28}$	$14.5^{+1.9}_{-1.1}$	902^{+181}_{-132}	$7.02^{+0.95}_{-0.75}$
ZTF21acgunkr	SN 2021aaxs	$2.74^{+3.30}_{-1.43}$	$10.0^{+1.9}_{-2.2}$	806^{+214}_{-312}	$1.46^{+0.72}_{-0.54}$
ZTF21abgilzj	AT 2021qcr	$6.90^{+0.47}_{-0.41}$	$11.7^{+0.8}_{-0.7}$	339^{+26}_{-20}	$2.32^{+0.17}_{-0.14}$
ZTF24aabppgn	SN 2024wp	$2.03^{+0.46}_{-0.48}$	$8.5^{+0.8}_{-0.3}$	691^{+301}_{-379}	$0.84^{+0.04}_{-0.07}$

Table A4
(Continued)

ZTF Name	IAU Name	M_{Ni} ($\times 10^{-2} M_{\odot}$)	M_{ej} (M_{\odot})	R_0 (R_{\odot})	E_{kin} ($\times 10^{51}$ erg)
ZTF20acmaaan	SN 2020xyk	$4.96^{+0.25}_{-0.28}$	$9.5^{+0.7}_{-0.6}$	264^{+225}_{-70}	$2.78^{+0.29}_{-0.25}$
ZTF23aackjhs	SN 1995al	$1.54^{+0.07}_{-0.08}$	$6.2^{+0.5}_{-0.2}$	138^{+23}_{-30}	$0.53^{+0.03}_{-0.02}$
ZTF22abtjefa	SN 2022aaad	$1.15^{+0.00}_{-0.03}$	$5.8^{+0.2}_{-0.2}$	172^{+14}_{-8}	$0.50^{+0.00}_{-0.04}$
ZTF24aaplifjd	SN 2024jxm	$3.05^{+0.06}_{-0.07}$	$11.2^{+2.6}_{-2.2}$	313^{+288}_{-236}	$1.81^{+0.77}_{-0.56}$
ZTF23aaphnyz	SN 2023lkw	$20.34^{+1.83}_{-0.73}$	$13.3^{+0.5}_{-2.2}$	405^{+88}_{-78}	$4.88^{+0.12}_{-1.04}$
ZTF23abnogui	SN 2023wcr	$1.19^{+0.01}_{-0.03}$	$8.1^{+0.6}_{-0.1}$	148^{+8}_{-8}	$0.79^{+0.01}_{-0.06}$
ZTF24aajxppf	SN 2024grw	$10.86^{+0.40}_{-0.42}$	$8.1^{+0.2}_{-0.7}$	180^{+2}_{-44}	$4.03^{+0.05}_{-0.52}$
ZTF24aaejecr	SN 2024btj	$1.89^{+0.02}_{-0.03}$	$8.6^{+0.3}_{-0.4}$	397^{+26}_{-29}	$1.34^{+0.05}_{-0.07}$
ZTF19aailepg	SN 2019amt	$12.87^{+0.45}_{-0.18}$	$22.2^{+1.0}_{-1.7}$	449^{+147}_{-102}	$8.43^{+0.61}_{-0.62}$
ZTF22aaolwsd	SN 2022mxv	$1.74^{+0.03}_{-0.02}$	$15.7^{+0.7}_{-0.7}$	158^{+18}_{-7}	$2.98^{+0.15}_{-0.13}$
ZTF19abqrhvt	SN 2019nyk	$13.71^{+1.92}_{-0.97}$	$7.1^{+0.3}_{-0.3}$	1012^{+102}_{-93}	$4.10^{+0.23}_{-0.23}$
ZTF21aapkcmr	AT 2021fnj	$7.41^{+0.46}_{-0.40}$	$8.7^{+0.6}_{-0.6}$	874^{+153}_{-155}	$5.16^{+0.35}_{-0.53}$
ZTF21aaqgxm	SN 2021hdt	$17.61^{+1.76}_{-1.01}$	$5.4^{+0.3}_{-0.3}$	478^{+180}_{-194}	$1.91^{+0.11}_{-0.11}$
ZTF23abhzfww	SN 2023twg	$13.68^{+0.53}_{-0.31}$	$15.9^{+0.8}_{-0.9}$	823^{+187}_{-184}	$5.90^{+0.41}_{-0.46}$
ZTF22abnujby	SN 2022xus	$2.45^{+0.07}_{-0.08}$	$8.8^{+0.4}_{-0.4}$	259^{+297}_{-97}	$1.99^{+0.10}_{-0.10}$
ZTF24abtczty	SN 2024abfl	$0.35^{+0.00}_{-0.00}$	$5.7^{+0.3}_{-0.3}$	543^{+80}_{-56}	$0.21^{+0.01}_{-0.01}$
ZTF22aativsd	SN 2022ovb	$20.74^{+0.92}_{-0.78}$	$11.7^{+0.6}_{-0.6}$	141^{+14}_{-8}	$6.39^{+0.35}_{-0.33}$
ZTF19acewuwv	SN 2019ssl	$13.03^{+1.09}_{-0.73}$	$15.0^{+1.2}_{-1.1}$	107^{+33}_{-25}	$5.93^{+0.66}_{-0.59}$
ZTF23aailjjs	SN 2023hcp	$11.76^{+0.22}_{-0.61}$	$13.5^{+0.4}_{-0.6}$	281^{+32}_{-29}	$9.63^{+0.26}_{-0.60}$
ZTF20aapchqy	SN 2020cxd	$0.11^{+0.00}_{-0.00}$	$7.6^{+0.6}_{-0.2}$	197^{+10}_{-14}	$0.29^{+0.03}_{-0.01}$
ZTF24aaemydm	SN 2024chx	$12.08^{+0.11}_{-1.02}$	$14.3^{+0.6}_{-0.6}$	155^{+6}_{-17}	$9.90^{+0.08}_{-0.87}$
ZTF21acgrnrl	SN 2021aayf	$3.85^{+0.06}_{-0.04}$	$12.7^{+0.9}_{-0.9}$	382^{+36}_{-68}	$2.40^{+0.24}_{-0.39}$
ZTF23abaxtlq	SN 2023rix	$1.80^{+0.03}_{-0.03}$	$10.7^{+0.5}_{-0.5}$	809^{+85}_{-81}	$2.31^{+0.16}_{-0.13}$
ZTF21aaeqwov	AT 2021htp	$5.30^{+0.25}_{-0.05}$	$18.1^{+0.9}_{-1.0}$	107^{+98}_{-15}	$5.42^{+0.35}_{-0.34}$
ZTF24aagupsf	SN 2024egd	$7.36^{+0.34}_{-0.18}$	$15.4^{+0.8}_{-0.8}$	555^{+60}_{-121}	$7.29^{+0.53}_{-0.41}$
ZTF22aavbfhz	AT 2022phi	$5.22^{+0.16}_{-0.12}$	$8.6^{+0.6}_{-0.6}$	743^{+215}_{-194}	$2.25^{+0.22}_{-0.24}$
ZTF19acytcsq	SN 2019wvz	$19.88^{+0.78}_{-0.61}$	$16.6^{+0.8}_{-0.9}$	362^{+68}_{-38}	$8.53^{+0.52}_{-0.60}$
ZTF19aazyvub	SN 2019hnl	$7.13^{+0.24}_{-0.28}$	$12.3^{+0.5}_{-0.7}$	136^{+14}_{-19}	$4.41^{+0.26}_{-0.28}$
ZTF19aaniyeg	SN 2019ceg	$11.75^{+0.31}_{-0.39}$	$14.8^{+0.7}_{-0.6}$	616^{+96}_{-76}	$4.57^{+0.30}_{-0.22}$
ZTF22abkbjsb	SN 2022vym	$5.06^{+0.33}_{-0.08}$	$5.9^{+0.2}_{-0.3}$	632^{+63}_{-37}	$1.06^{+0.04}_{-0.04}$
ZTF19actnyae	SN 2019vdm	$11.10^{+0.79}_{-1.10}$	$13.4^{+0.9}_{-1.2}$	729^{+120}_{-34}	$9.78^{+0.11}_{-1.51}$
ZTF24aadkwini	SN 2024aul	$13.40^{+0.79}_{-0.40}$	$9.6^{+0.4}_{-0.5}$	150^{+42}_{-21}	$5.10^{+0.46}_{-0.28}$
ZTF19abajxet	SN 2019hyk	$8.02^{+0.38}_{-0.38}$	$9.7^{+0.4}_{-0.4}$	392^{+366}_{-87}	$2.75^{+0.14}_{-0.17}$
ZTF21abfiuqf	SN 2021pla	$3.29^{+0.05}_{-0.10}$	$6.6^{+0.2}_{-0.4}$	453^{+96}_{-99}	$2.10^{+0.10}_{-0.15}$
ZTF24abmkros	SN 2024xkd	$0.78^{+0.01}_{-0.01}$	$8.4^{+0.5}_{-0.4}$	309^{+404}_{-166}	$0.88^{+0.06}_{-0.05}$
ZTF22aakdqgq	SN 2022kad	$10.03^{+0.41}_{-0.46}$	$5.8^{+0.3}_{-0.3}$	1061^{+73}_{-635}	$1.30^{+0.10}_{-0.09}$
ZTF21aafepo	SN 2021ass	$5.17^{+0.20}_{-0.33}$	$7.5^{+0.5}_{-0.4}$	139^{+6}_{-25}	$2.24^{+0.13}_{-0.12}$
ZTF21abvxccl	SN 2021wvw	$3.55^{+0.25}_{-0.20}$	$7.2^{+0.4}_{-0.3}$	123^{+18}_{-7}	$2.50^{+0.16}_{-0.10}$
ZTF23abbtkrv	SN 2023rvo	$9.81^{+0.18}_{-0.15}$	$24.8^{+0.1}_{-3.0}$	178^{+18}_{-12}	$9.54^{+0.14}_{-1.07}$
ZTF19abbnamr	SN 2019iex	$7.40^{+0.12}_{-0.26}$	$22.4^{+0.4}_{-1.5}$	170^{+33}_{-7}	$9.94^{+0.05}_{-1.00}$
ZTF20abeohfn	SN 2020mjm	$2.36^{+0.08}_{-0.09}$	$11.6^{+0.5}_{-0.4}$	439^{+82}_{-68}	$3.00^{+0.12}_{-0.12}$
ZTF19acbwelj	SN 2019upq	$9.13^{+0.33}_{-0.01}$	$24.7^{+0.2}_{-2.7}$	200^{+71}_{-21}	$6.36^{+0.33}_{-0.39}$
ZTF19abbwfgp	SN 2019ikb	$14.79^{+0.30}_{-0.22}$	$11.3^{+0.4}_{-0.3}$	257^{+65}_{-21}	$4.18^{+0.23}_{-0.19}$
ZTF21abhhrpj	SN 2021qiu	$16.49^{+0.70}_{-0.75}$	$11.2^{+0.3}_{-1.3}$	341^{+37}_{-47}	$4.64^{+0.29}_{-1.10}$
ZTF22abssiet	SN 2022zmb	$1.32^{+0.03}_{-0.02}$	$12.9^{+0.3}_{-0.3}$	152^{+18}_{-9}	$3.64^{+0.10}_{-0.17}$
ZTF22abtspsw	SN 2022aagp	$0.58^{+0.00}_{-0.00}$	$10.4^{+2.3}_{-2.5}$	311^{+39}_{-20}	$1.12^{+0.45}_{-0.43}$
ZTF21aavhnpk	SN 2021jsf	$6.28^{+0.24}_{-0.25}$	$12.1^{+0.6}_{-0.6}$	183^{+30}_{-31}	$4.73^{+0.34}_{-0.30}$
ZTF23abascqa	SN 2023rbk	$6.34^{+0.23}_{-0.19}$	$9.8^{+0.4}_{-0.5}$	1033^{+68}_{-362}	$2.98^{+0.10}_{-0.18}$
ZTF19abwztsb	SN 2019pjis	$4.36^{+0.17}_{-0.18}$	$8.1^{+0.4}_{-0.3}$	324^{+121}_{-84}	$2.11^{+0.11}_{-0.12}$
ZTF22aaywnyg	SN 2022pru	$1.90^{+0.01}_{-0.04}$	$8.1^{+0.7}_{-0.0}$	1024^{+102}_{-73}	$0.78^{+0.02}_{-0.05}$
ZTF19actnwn	SN 2019vdl	$30.98^{+1.62}_{-1.92}$	$18.9^{+1.0}_{-1.5}$	843^{+139}_{-181}	$9.00^{+0.50}_{-1.06}$
ZTF21aabygea	SN 2021os	$7.81^{+0.18}_{-0.12}$	$16.2^{+0.6}_{-0.7}$	175^{+22}_{-9}	$5.01^{+0.20}_{-0.23}$

Table A4
(Continued)

ZTF Name	IAU Name	M_{Ni} ($\times 10^{-2} M_{\odot}$)	M_{ej} (M_{\odot})	R_0 (R_{\odot})	E_{kin} ($\times 10^{51}$ erg)
ZTF23abmoxlu	SN 2023vog	$2.59^{+0.05}_{-0.02}$	$16.4^{+0.7}_{-0.9}$	424^{+68}_{-29}	$2.87^{+0.14}_{-0.16}$
ZTF22aakdbia	SN 2022jzc	$0.31^{+0.00}_{-0.00}$	$7.6^{+0.5}_{-0.3}$	363^{+455}_{-172}	$0.42^{+0.03}_{-0.03}$
ZTF19aadnxml	SN 2019va	$11.30^{+0.23}_{-0.55}$	$15.6^{+0.6}_{-1.1}$	350^{+19}_{-25}	$4.92^{+0.08}_{-0.49}$
ZTF21aafkwtk	SN 2021apg	$6.20^{+0.14}_{-0.15}$	$17.3^{+0.7}_{-0.7}$	214^{+67}_{-46}	$7.51^{+0.33}_{-0.35}$
ZTF19aanrrqu	SN 2019clp	$11.35^{+0.42}_{-0.36}$	$6.5^{+0.3}_{-0.2}$	118^{+52}_{-35}	$3.51^{+0.21}_{-0.17}$
ZTF23aasbvab	SN 2023ngy	$3.45^{+0.05}_{-0.04}$	$12.0^{+0.5}_{-0.6}$	93^{+32}_{-20}	$2.42^{+0.12}_{-0.13}$
ZTF18aatyqds	SN 2018btl	$4.12^{+0.07}_{-0.10}$	$7.1^{+0.3}_{-0.2}$	710^{+249}_{-207}	$1.23^{+0.08}_{-0.06}$
ZTF21aardvtn	AT 2021htp	$5.75^{+0.23}_{-0.10}$	$18.0^{+0.7}_{-0.9}$	324^{+110}_{-56}	$5.61^{+0.26}_{-0.34}$
ZTF19acftfav	SN 2019ssi	$3.70^{+0.23}_{-0.07}$	$7.1^{+0.5}_{-0.4}$	108^{+8}_{-13}	$1.43^{+0.14}_{-0.08}$
ZTF19aapafit	SN 2019cvz	$8.92^{+0.10}_{-0.20}$	$23.0^{+0.4}_{-1.0}$	135^{+6}_{-9}	$9.94^{+0.05}_{-0.69}$
ZTF24aarvbxj	SN 2024lby	$10.42^{+0.54}_{-0.42}$	$9.7^{+0.5}_{-0.5}$	240^{+73}_{-37}	$7.02^{+0.48}_{-0.49}$
ZTF21aagtqna	SN 2021brb	$8.19^{+0.16}_{-0.11}$	$22.8^{+0.8}_{-1.4}$	88^{+13}_{-10}	$8.42^{+0.47}_{-0.51}$
ZTF22aasojye	SN 2022omr	$5.16^{+0.24}_{-0.00}$	$24.7^{+0.3}_{-2.6}$	150^{+40}_{-12}	$8.50^{+0.32}_{-0.57}$
ZTF21aanzcuj	SN 2021enz	$7.98^{+5.16}_{-0.12}$	$19.4^{+1.0}_{-15.8}$	468^{+54}_{-413}	$8.37^{+0.59}_{-7.62}$
ZTF22abfavpu	SN 2022tmb	$4.10^{+0.14}_{-0.10}$	$11.1^{+0.5}_{-0.6}$	548^{+58}_{-100}	$3.08^{+0.14}_{-0.20}$
ZTF18aaxkqgy	SN 2018ccb	$6.80^{+0.29}_{-0.21}$	$13.3^{+0.7}_{-0.5}$	120^{+10}_{-27}	$6.47^{+0.32}_{-0.31}$
ZTF19aanhhhal	SN 2019cec	$7.96^{+0.15}_{-0.20}$	$13.3^{+0.7}_{-0.6}$	129^{+25}_{-52}	$3.89^{+0.26}_{-0.22}$

Note. We list the median values of ^{56}Ni mass (M_{Ni}), ejecta mass (M_{ej}), progenitor radius (R_0), and kinetic energy (E_{kin}). The 16th and 84th percentiles are used to quantify the lower and upper uncertainties around the median. A full machine-readable version of this table is available on [Zenodo](https://zenodo.org).

Table A5
Posterior Estimates of Explosion and Progenitor Properties Based on Fits to the Radiation-hydrodynamical Models from (Moriya et al. 2023)

ZTF Name	IAU Name	ZAMS Mass (M_{\odot})	M_{Ni} ($\times 10^{-2} M_{\odot}$)	R_{CSM} ($\times 10^{14}$ cm)	β	Energy ($\times 10^{51}$ erg)	$\log \dot{M}$ ($M_{\odot} \text{ yr}^{-1}$)
ZTF22abkhrkd	SN 2022wol	10.2 ± 0.4	$1.44^{+0.93}_{-0.09}$	$7.9^{+1.4}_{-1.0}$	$4.0^{+0.2}_{-0.7}$	$0.31^{+0.01}_{-0.02}$	-0.54
ZTF22abtjefa	SN 2022aaad	11.0 ± 0.6	$1.38^{+1.08}_{-0.32}$	$3.8^{+1.0}_{-0.9}$	$2.5^{+0.2}_{-0.6}$	$0.15^{+0.39}_{-0.02}$	-0.57
ZTF19abqrhvt	SN 2019nyk	11.7 ± 0.9	$3.67^{+1.74}_{-0.27}$	$7.9^{+1.7}_{-3.2}$	$3.7^{+1.1}_{-1.1}$	$1.18^{+0.62}_{-0.20}$	-0.30
ZTF19acewuwv	SN 2019ssl	12.6 ± 1.1	$5.65^{+0.84}_{-0.17}$	$6.5^{+0.7}_{-2.6}$	$0.9^{+0.1}_{-0.2}$	$0.16^{+0.06}_{-0.02}$	-0.47
ZTF21aaqugxm	SN 2021hdt	14.8 ± 1.0	$2.90^{+2.07}_{-0.53}$	$8.2^{+0.9}_{-1.6}$	$0.8^{+1.9}_{-0.1}$	$2.42^{+0.13}_{-0.11}$	-0.49
ZTF24aaasazz	SN 2024ov	10.5 ± 0.5	$3.32^{+0.93}_{-0.36}$	$5.5^{+2.2}_{-0.6}$	$1.1^{+1.6}_{-0.5}$	$0.27^{+0.08}_{-0.05}$	-0.39
ZTF20abyylgi	SN 2020svn	13.4 ± 1.4	$15.33^{+1.80}_{-5.35}$	$8.0^{+0.9}_{-1.9}$	$4.4^{+0.5}_{-0.9}$	$1.74^{+1.45}_{-0.36}$	-0.22
ZTF24aagupsf	SN 2024egd	12.0 ± 0.5	$4.10^{+0.59}_{-0.27}$	$3.4^{+1.6}_{-1.8}$	$4.3^{+0.6}_{-2.2}$	$0.92^{+0.13}_{-0.09}$	-0.64
ZTF21aanzcuj	SN 2021enz	13.1 ± 0.3	$3.43^{+2.28}_{-0.80}$	$4.6^{+1.8}_{-1.5}$	$4.0^{+0.5}_{-0.5}$	$0.53^{+0.12}_{-0.18}$	-0.48
ZTF20acveadu	SN 2020absk	10.3 ± 0.3	$0.47^{+2.53}_{-0.30}$	$5.7^{+2.3}_{-1.5}$	$3.4^{+0.6}_{-0.9}$	$0.41^{+0.24}_{-0.01}$	-0.60
ZTF19aamwhat	SN 2019bzd	10.5 ± 0.7	$1.05^{+1.45}_{-0.23}$	$4.7^{+1.3}_{-1.6}$	$2.4^{+1.0}_{-0.7}$	$0.22^{+0.04}_{-0.01}$	-0.48
ZTF19abbwfgp	SN 2019ikb	12.4 ± 1.2	$7.24^{+2.81}_{-1.22}$	$5.5^{+2.3}_{-1.8}$	$2.9^{+1.4}_{-1.6}$	$1.82^{+0.91}_{-0.16}$	-0.30
ZTF23aanymcl	SN 2023kzz	11.6 ± 0.7	$2.31^{+1.06}_{-0.53}$	$5.3^{+2.3}_{-3.1}$	$3.4^{+0.4}_{-0.8}$	$1.04^{+0.11}_{-0.12}$	-0.46
ZTF18aawpwlf	SN 2020hvn	10.6 ± 0.7	$1.26^{+4.61}_{-0.45}$	$7.8^{+1.0}_{-3.8}$	$3.8^{+0.4}_{-1.3}$	$1.04^{+0.09}_{-0.10}$	-0.41
ZTF18aatyqds	SN 2018btl	12.3 ± 0.5	$2.24^{+0.74}_{-0.50}$	$7.3^{+0.8}_{-3.3}$	$2.8^{+0.5}_{-0.6}$	$0.28^{+0.42}_{-0.08}$	-0.37
ZTF18aaxkqgy	SN 2018ccb	12.1 ± 1.1	$2.82^{+0.58}_{-0.73}$	$6.7^{+1.2}_{-1.3}$	$3.3^{+0.6}_{-0.3}$	$0.79^{+0.34}_{-0.06}$	-0.48
ZTF21acafqtj	SN 2021yok	12.6 ± 0.9	$3.52^{+1.17}_{-1.00}$	$6.0^{+1.7}_{-1.3}$	$4.3^{+0.2}_{-1.7}$	$0.72^{+0.03}_{-0.33}$	-0.45
ZTF20aaiovoy	SN 2020bad	10.5 ± 3.4	$6.93^{+1.67}_{-2.12}$	$6.2^{+1.7}_{-1.1}$	$1.0^{+1.0}_{-0.4}$	$0.76^{+0.29}_{-0.05}$	-0.55
ZTF21aafepo	SN 2021ass	11.0 ± 0.6	$2.89^{+0.52}_{-0.20}$	$7.7^{+1.1}_{-1.0}$	$2.2^{+0.9}_{-1.0}$	$0.36^{+0.30}_{-0.03}$	-0.44
ZTF23abhzfww	SN 2023twg	12.0 ± 0.6	$9.74^{+2.10}_{-0.97}$	$4.4^{+2.3}_{-2.3}$	$3.8^{+1.0}_{-0.9}$	$1.01^{+0.13}_{-0.11}$	-0.58
ZTF20abyzomt	SN 2020szs	12.1 ± 0.6	$6.00^{+0.39}_{-1.03}$	$7.0^{+0.7}_{-1.4}$	$3.8^{+0.4}_{-0.9}$	$1.49^{+0.09}_{-0.15}$	-0.48
ZTF24aaucrva	SN 2024nez	9.9 ± 0.5	$2.96^{+1.50}_{-0.39}$	$3.7^{+1.3}_{-0.8}$	$1.0^{+0.2}_{-0.3}$	$1.16^{+0.18}_{-0.46}$	-0.58
ZTF21aaobkmg	SN 2021eui	10.5 ± 0.5	$0.37^{+1.19}_{-0.20}$	$7.0^{+0.5}_{-1.3}$	$1.7^{+0.5}_{-0.7}$	$0.16^{+0.03}_{-0.01}$	-0.52
ZTF21aagtqna	SN 2021brb	13.0 ± 0.8	$5.18^{+0.16}_{-0.15}$	$6.7^{+0.7}_{-1.2}$	$3.0^{+0.4}_{-0.5}$	$0.60^{+0.17}_{-0.07}$	-0.47

Table A5
(Continued)

ZTF Name	IAU Name	ZAMS Mass (M_{\odot})	M_{Ni} ($\times 10^{-2} M_{\odot}$)	R_{CSM} ($\times 10^{14}$ cm)	β	Energy ($\times 10^{51}$ erg)	$\log \dot{M}$ ($M_{\odot} \text{ yr}^{-1}$)
ZTF19aadnrxnl	SN 2019va	14.0 ± 0.2	6.74 ^{+0.36} _{-0.02}	5.8 ^{+0.1} _{-1.4}	4.0 ^{+0.0} _{-1.2}	0.37 ^{+0.18} _{-0.08}	-0.54
ZTF19aanrrqu	SN 2019clp	12.1 ± 0.9	0.23 ^{+2.27} _{-0.12}	5.1 ^{+1.4} _{-1.8}	2.1 ^{+1.0} _{-1.0}	1.00 ^{+0.18} _{-0.16}	-0.51
ZTF20aciojzg	AT 2020wip	10.4 ± 0.5	0.83 ^{+1.98} _{-0.53}	4.4 ^{+3.4} _{-2.0}	1.5 ^{+1.7} _{-0.7}	0.35 ^{+0.01} _{-0.00}	-0.56
ZTF22abssiet	SN 2022zmb	10.5 ± 0.9	1.22 ^{+1.42} _{-0.38}	8.6 ^{+2.0} _{-1.4}	0.8 ^{+0.8} _{-0.2}	0.28 ^{+0.22} _{-0.03}	-0.50
ZTF18aaqfqa	SN 2018bek	10.0 ± 0.5	3.38 ^{+0.94} _{-0.12}	5.7 ^{+0.4} _{-1.4}	2.0 ^{+0.2} _{-0.1}	4.40 ^{+0.31} _{-0.08}	-0.64
ZTF19aailepg	SN 2019amt	12.6 ± 0.5	12.03 ^{+1.60} _{-1.90}	4.3 ^{+0.7} _{-0.9}	3.0 ^{+0.7} _{-0.6}	0.74 ^{+0.38} _{-0.04}	-0.48
ZTF23abaxtlq	SN 2023rix	10.7 ± 0.3	0.85 ^{+1.30} _{-0.09}	7.4 ^{+0.7} _{-1.9}	3.3 ^{+0.7} _{-0.3}	0.37 ^{+0.03} _{-0.01}	-0.48
ZTF21aapkcmr	AT 2021fnj	11.9 ± 1.0	0.46 ^{+1.81} _{-0.31}	8.4 ^{+0.7} _{-1.1}	4.1 ^{+0.4} _{-1.4}	1.61 ^{+0.10} _{-0.21}	-0.48
ZTF18aawgrxz	SN 2021lmp	10.8 ± 0.9	5.05 ^{+0.95} _{-0.10}	3.3 ^{+4.7} _{-2.2}	1.3 ^{+0.6} _{-0.2}	1.10 ^{+0.44} _{-0.06}	-0.60
ZTF21acgrml	SN 2021aayf	13.9 ± 2.7	22.18 ^{+5.82} _{-5.66}	5.8 ^{+2.8} _{-1.6}	3.1 ^{+1.4} _{-1.6}	1.35 ^{+1.15} _{-0.82}	-0.47
ZTF22abkbjsb	SN 2022vym	11.0 ± 0.6	2.13 ^{+0.72} _{-0.28}	5.5 ^{+2.1} _{-0.3}	1.5 ^{+0.7} _{-0.3}	0.36 ^{+0.19} _{-0.08}	-0.41
ZTF19aclobbu	SN 2019twk	11.6 ± 1.0	14.70 ^{+0.25} _{-4.70}	5.7 ^{+0.5} _{-1.1}	4.7 ^{+0.1} _{-0.9}	1.00 ^{+0.20} _{-0.08}	-0.31
ZTF22aafsqud	SN 2022hql	11.9 ± 0.9	0.50 ^{+2.46} _{-0.39}	7.7 ^{+0.9} _{-4.9}	4.0 ^{+0.8} _{-0.6}	0.36 ^{+0.31} _{-0.15}	-0.42
ZTF22abfavpu	SN 2022tmb	14.3 ± 2.1	3.36 ^{+0.16} _{-0.17}	4.9 ^{+0.9} _{-0.8}	1.1 ^{+0.5} _{-0.5}	1.06 ^{+0.10} _{-0.12}	-0.47
ZTF21abfiuqf	SN 2021pla	10.5 ± 1.5	2.08 ^{+1.64} _{-1.94}	4.5 ^{+4.0} _{-2.0}	1.7 ^{+0.6} _{-0.8}	1.23 ^{+3.65} _{-0.58}	-0.57
ZTF24aarvbxj	SN 2024lby	11.7 ± 1.0	2.88 ^{+2.55} _{-0.84}	2.0 ^{+0.5} _{-0.2}	1.6 ^{+2.1} _{-0.4}	2.02 ^{+0.34} _{-0.16}	-0.65
ZTF24aaemydm	SN 2024chx	10.2 ± 0.6	4.90 ^{+0.13} _{-0.91}	5.6 ^{+0.6} _{-0.4}	3.3 ^{+0.0} _{-0.3}	1.72 ^{+0.38} _{-0.03}	-0.32
ZTF22abtspsw	SN 2022aagp	11.4 ± 1.6	2.48 ^{+0.37} _{-0.20}	6.5 ^{+1.5} _{-0.6}	2.4 ^{+0.6} _{-0.6}	1.42 ^{+0.26} _{-0.26}	-0.58
ZTF20acfvprb	AT 2020thp	12.1 ± 0.5	5.09 ^{+0.91} _{-0.34}	7.2 ^{+1.3} _{-3.1}	1.8 ^{+0.7} _{-0.9}	0.78 ^{+0.25} _{-0.03}	-0.44
ZTF23aasbvab	SN 2023ngy	11.8 ± 0.8	2.99 ^{+3.65} _{-0.88}	7.2 ^{+1.1} _{-3.6}	2.5 ^{+1.1} _{-0.9}	0.36 ^{+0.24} _{-0.12}	-0.39
ZTF22aaevwec	SN 2022gwg	11.0 ± 1.2	4.00 ^{+0.71} _{-0.46}	3.7 ^{+3.6} _{-1.6}	1.2 ^{+1.1} _{-0.3}	2.30 ^{+0.20} _{-0.05}	-0.65
ZTF21acfajbc	SN 2021aalq	10.8 ± 0.7	6.76 ^{+1.24} _{-0.76}	4.6 ^{+1.6} _{-2.6}	4.4 ^{+0.5} _{-0.3}	2.52 ^{+0.14} _{-0.19}	-0.60
ZTF24aadkwini	SN 2024aul	10.3 ± 1.0	4.58 ^{+0.20} _{-0.57}	7.4 ^{+0.6} _{-1.9}	2.7 ^{+0.5} _{-0.4}	1.90 ^{+0.26} _{-0.19}	-0.43
ZTF21abouuat	SN 2021ucg	16.7 ± 1.0	9.94 ^{+1.88} _{-2.02}	6.4 ^{+2.6} _{-5.2}	4.7 ^{+0.2} _{-1.1}	0.96 ^{+0.08} _{-0.11}	-0.45
ZTF18aaahqbc	SN 2018aoq	12.0 ± 0.8	15.23 ^{+0.34} _{-0.79}	7.7 ^{+0.2} _{-4.3}	4.4 ^{+0.2} _{-1.3}	2.87 ^{+0.09} _{-0.04}	-0.48
ZTF21abhhrpj	SN 2021qiu	15.7 ± 3.0	7.78 ^{+3.20} _{-0.97}	7.8 ^{+1.0} _{-2.9}	2.4 ^{+1.0} _{-0.5}	1.22 ^{+0.82} _{-0.37}	-0.44
ZTF20actnuls	SN 2020aawo	12.1 ± 0.6	3.88 ^{+0.41} _{-0.34}	5.7 ^{+0.8} _{-1.0}	1.8 ^{+0.5} _{-0.4}	1.55 ^{+0.10} _{-0.09}	-0.31
ZTF22abnujvb	SN 2022xus	10.6 ± 1.3	1.67 ^{+4.59} _{-0.61}	2.4 ^{+1.8} _{-0.9}	3.8 ^{+0.5} _{-0.7}	0.35 ^{+0.32} _{-0.03}	-0.42
ZTF23abbtkrv	SN 2023rvo	15.8 ± 0.6	5.58 ^{+1.47} _{-0.32}	5.2 ^{+2.4} _{-1.2}	3.7 ^{+0.4} _{-0.7}	0.37 ^{+0.19} _{-0.14}	-0.29
ZTF19aaniore	SN 2019ceg	12.2 ± 1.2	8.67 ^{+2.49} _{-1.29}	5.8 ^{+1.7} _{-1.4}	2.8 ^{+2.0} _{-1.5}	0.93 ^{+0.18} _{-0.16}	-0.55
ZTF22aasojye	SN 2022omr	13.2 ± 0.5	5.12 ^{+0.47} _{-0.90}	4.2 ^{+3.0} _{-3.0}	4.2 ^{+0.5} _{-0.6}	0.43 ^{+0.23} _{-0.20}	-0.45
ZTF20aafckit	SN 2020uu	10.2 ± 1.0	5.21 ^{+2.44} _{-0.17}	7.9 ^{+0.9} _{-0.6}	3.4 ^{+0.3} _{-0.3}	1.72 ^{+0.24} _{-0.02}	-0.32
ZTF21aaagypx	SN 2021V	14.2 ± 1.1	12.73 ^{+2.16} _{-2.49}	7.7 ^{+0.7} _{-1.9}	3.0 ^{+0.4} _{-0.2}	0.69 ^{+0.31} _{-0.04}	-0.34
ZTF19acbwejj	SN 2019upq	14.9 ± 2.7	10.04 ^{+11.71} _{-3.36}	5.0 ^{+2.8} _{-2.9}	3.3 ^{+1.1} _{-1.2}	0.60 ^{+4.06} _{-0.28}	-0.38
ZTF23aackjhs	SN 1995al	9.5 ± 0.7	0.55 ^{+0.58} _{-0.41}	1.8 ^{+1.1} _{-0.4}	1.2 ^{+0.8} _{-0.4}	0.13 ^{+0.03} _{-0.01}	-0.56
ZTF21aaeqwov	AT 2021htp	10.4 ± 1.1	3.50 ^{+0.78} _{-0.23}	8.3 ^{+0.8} _{-0.9}	1.6 ^{+0.5} _{-0.6}	0.73 ^{+0.34} _{-0.15}	-0.58
ZTF19aanhhal	SN 2019cec	14.2 ± 3.8	11.00 ^{+10.81} _{-7.29}	7.9 ^{+1.5} _{-1.2}	1.8 ^{+2.6} _{-1.1}	1.53 ^{+0.98} _{-0.89}	-0.53
ZTF22aanrjje	SN 2022mji	9.4 ± 0.7	1.60 ^{+0.87} _{-0.34}	4.3 ^{+1.4} _{-1.0}	2.1 ^{+0.5} _{-0.9}	0.17 ^{+0.16} _{-0.02}	-0.46
ZTF21aafkwtk	SN 2021apg	12.4 ± 0.4	3.29 ^{+0.89} _{-0.31}	5.3 ^{+0.5} _{-1.6}	3.5 ^{+0.2} _{-0.4}	0.74 ^{+0.02} _{-0.04}	-0.42
ZTF24abmkros	SN 2024xkd	10.8 ± 1.0	0.39 ^{+1.84} _{-0.13}	6.3 ^{+2.1} _{-1.2}	3.0 ^{+0.6} _{-0.6}	0.11 ^{+0.01} _{-0.01}	-0.56
ZTF22aaolwsd	SN 2022mxv	11.7 ± 0.8	11.49 ^{+0.96} _{-1.46}	6.8 ^{+2.3} _{-0.8}	3.4 ^{+0.3} _{-0.5}	1.10 ^{+0.65} _{-0.28}	-0.18
ZTF24abtczty	SN 2024abfl	10.7 ± 0.4	1.97 ^{+1.49} _{-1.74}	2.6 ^{+0.4} _{-0.3}	1.1 ^{+0.2} _{-0.2}	0.10 ^{+0.04} _{-0.00}	-0.45
ZTF19abajxet	SN 2019hyk	11.9 ± 0.5	6.18 ^{+0.31} _{-0.54}	5.2 ^{+2.6} _{-2.2}	2.5 ^{+1.2} _{-0.6}	1.59 ^{+0.08} _{-0.16}	-0.60
ZTF24aaplfjd	SN 2024jxm	10.4 ± 0.3	2.26 ^{+0.86} _{-0.26}	4.3 ^{+2.2} _{-1.8}	1.6 ^{+0.3} _{-0.3}	0.51 ^{+0.17} _{-0.11}	-0.65
ZTF21aantsla	SN 2021ech	11.1 ± 0.6	2.17 ^{+0.32} _{-0.33}	5.6 ^{+1.8} _{-1.2}	2.4 ^{+0.4} _{-0.5}	0.39 ^{+0.25} _{-0.05}	-0.55
ZTF24aajxppf	SN 2024grw	11.0 ± 0.9	4.07 ^{+0.94} _{-0.49}	5.9 ^{+2.7} _{-1.8}	4.0 ^{+0.6} _{-0.7}	1.80 ^{+0.41} _{-0.27}	-0.44
ZTF19acftfav	SN 2019ssi	10.5 ± 0.4	2.39 ^{+0.59} _{-0.65}	7.0 ^{+1.8} _{-2.3}	3.8 ^{+0.7} _{-1.7}	0.43 ^{+0.17} _{-0.04}	-0.52
ZTF20actkmks	SN 2020aaun	10.0 ± 2.8	8.00 ^{+1.59} _{-1.11}	8.1 ^{+0.7} _{-2.7}	0.7 ^{+1.2} _{-0.1}	1.28 ^{+0.43} _{-0.26}	-0.48
ZTF21abnlhxs	SN 2021tyw	14.4 ± 1.3	5.75 ^{+9.46} _{-1.21}	8.1 ^{+1.0} _{-2.9}	3.1 ^{+0.7} _{-0.7}	1.06 ^{+0.52} _{-0.19}	-0.11
ZTF23aaphnyz	SN 2023lkw	12.8 ± 0.3	10.90 ^{+2.46} _{-0.93}	7.7 ^{+0.9} _{-3.7}	4.4 ^{+0.4} _{-1.4}	1.53 ^{+0.14} _{-0.12}	-0.35
ZTF19actnwn	SN 2019vdl	12.0 ± 0.5	10.72 ^{+2.17} _{-2.05}	6.2 ^{+1.3} _{-1.3}	3.2 ^{+1.1} _{-1.2}	0.76 ^{+0.24} _{-0.06}	-0.56
ZTF18aadsuxd	SN 2020yui	12.0 ± 1.4	7.99 ^{+4.37} _{-3.62}	5.3 ^{+3.1} _{-1.5}	2.8 ^{+1.7} _{-0.7}	4.33 ^{+0.58} _{-0.96}	-0.53

Table A5
(Continued)

ZTF Name	IAU Name	ZAMS Mass (M_{\odot})	M_{Ni} ($\times 10^{-2} M_{\odot}$)	R_{CSM} ($\times 10^{14}$ cm)	β	Energy ($\times 10^{51}$ erg)	$\log \dot{M}$ ($M_{\odot} \text{ yr}^{-1}$)
ZTF22aativsd	SN 2022ovb	12.1 ± 0.4	11.80 ^{+1.31} _{-4.03}	4.5 ^{+3.4} _{-0.7}	4.7 ^{+0.3} _{-1.5}	2.04 ^{+0.05} _{-0.58}	-0.58
ZTF23aaqknaw	SN 2023lzn	13.7 ± 0.7	10.49 ^{+4.86} _{-0.83}	3.8 ^{+2.5} _{-2.3}	2.8 ^{+0.6} _{-1.0}	0.91 ^{+2.09} _{-0.07}	-0.53
ZTF24aabsmvc	SN 2024ws	11.3 ± 0.9	3.00 ^{+3.10} _{-0.19}	4.3 ^{+1.2} _{-0.8}	3.4 ^{+0.4} _{-1.1}	0.32 ^{+0.27} _{-0.04}	-0.48
ZTF22abvaetz	SN 2022aang	10.2 ± 0.7	2.47 ^{+4.00} _{-0.91}	4.1 ^{+1.6} _{-0.8}	3.0 ^{+0.2} _{-0.6}	0.17 ^{+0.21} _{-0.01}	-0.49
ZTF22ablncrv	SN 2022xav	9.3 ± 0.7	1.00 ^{+0.10} _{-0.04}	1.1 ^{+0.2} _{-0.1}	0.9 ^{+0.3} _{-0.4}	0.44 ^{+0.06} _{-0.04}	-0.14
ZTF21aardvtn	AT 2021htp	10.2 ± 0.2	4.81 ^{+1.07} _{-0.21}	7.8 ^{+0.7} _{-0.9}	1.5 ^{+0.3} _{-0.4}	0.76 ^{+0.03} _{-0.05}	-0.62
ZTF22aaurbv	SN 2022pgf	10.4 ± 0.4	5.32 ^{+1.24} _{-0.47}	7.4 ^{+0.7} _{-2.1}	1.0 ^{+0.5} _{-0.4}	1.65 ^{+0.28} _{-0.37}	-0.53
ZTF19aazyvub	SN 2019hnl	11.6 ± 0.5	4.06 ^{+0.43} _{-0.21}	4.5 ^{+0.8} _{-0.6}	2.0 ^{+0.2} _{-0.1}	1.06 ^{+0.08} _{-0.10}	-0.55
ZTF24aaejecr	SN 2024btj	10.5 ± 0.8	1.26 ^{+1.82} _{-0.38}	7.4 ^{+0.6} _{-1.7}	2.5 ^{+0.7} _{-1.3}	0.43 ^{+0.16} _{-0.18}	-0.50
ZTF22aakdqgg	SN 2022kad	12.0 ± 0.8	3.46 ^{+0.29} _{-0.39}	5.8 ^{+0.7} _{-1.5}	1.7 ^{+0.7} _{-0.7}	1.24 ^{+0.37} _{-0.01}	-0.57
ZTF22aarycgo	SN 2022ojo	13.2 ± 1.8	18.75 ^{+6.94} _{-1.76}	5.3 ^{+1.5} _{-2.5}	4.6 ^{+0.3} _{-1.3}	4.43 ^{+0.32} _{-0.13}	-0.31
ZTF23abascqa	SN 2023rbk	10.3 ± 1.0	4.12 ^{+0.72} _{-0.21}	6.8 ^{+2.2} _{-2.8}	2.1 ^{+1.7} _{-0.5}	2.74 ^{+0.04} _{-0.33}	-0.64
ZTF23aasrcyv	SN 2023nlu	11.0 ± 1.2	5.59 ^{+1.43} _{-1.47}	2.6 ^{+0.9} _{-0.7}	4.6 ^{+0.3} _{-2.7}	0.57 ^{+0.07} _{-0.10}	-0.36
ZTF23aailjjs	SN 2023hcp	11.8 ± 0.5	5.48 ^{+0.16} _{-0.10}	3.9 ^{+1.4} _{-1.4}	3.3 ^{+1.1} _{-2.4}	1.77 ^{+0.31} _{-0.03}	-0.62
ZTF21aabyegea	SN 2021os	12.5 ± 1.3	5.12 ^{+0.97} _{-0.67}	7.2 ^{+0.6} _{-2.4}	4.0 ^{+0.8} _{-1.3}	0.74 ^{+0.02} _{-0.30}	-0.40
ZTF20acvjagm	SN 2020abtf	12.7 ± 0.4	1.15 ^{+2.45} _{-1.02}	7.7 ^{+1.1} _{-1.5}	3.9 ^{+0.3} _{-1.2}	0.59 ^{+0.25} _{-0.12}	-0.40
ZTF19actnyae	SN 2019vdm	10.5 ± 1.0	2.51 ^{+0.83} _{-0.49}	6.6 ^{+1.3} _{-1.0}	2.2 ^{+0.6} _{-1.1}	0.98 ^{+0.37} _{-0.23}	-0.60
ZTF21ablvzhp	SN 2021tiq	10.1 ± 0.7	22.09 ^{+1.30} _{-2.37}	2.0 ^{+0.8} _{-0.2}	3.9 ^{+0.1} _{-0.2}	2.47 ^{+0.09} _{-0.06}	-0.30
ZTF21aavhnpk	SN 2021jsf	9.6 ± 1.3	1.85 ^{+0.15} _{-0.84}	1.7 ^{+0.1} _{-0.2}	1.5 ^{+0.3} _{-0.8}	0.46 ^{+0.03} _{-0.06}	-0.14
ZTF22aaujgjc	SN 2022pfx	10.4 ± 0.7	11.09 ^{+1.04} _{-2.12}	3.8 ^{+1.8} _{-1.2}	2.1 ^{+1.5} _{-1.2}	1.17 ^{+0.32} _{-0.10}	-0.48
ZTF22abfxkdm	SN 2022ubb	10.6 ± 0.4	2.37 ^{+0.48} _{-0.38}	7.1 ^{+1.3} _{-2.3}	3.9 ^{+0.9} _{-1.0}	0.44 ^{+0.15} _{-0.02}	-0.51
ZTF22aavbfhz	AT 2022phi	10.6 ± 1.1	1.80 ^{+0.65} _{-0.48}	8.2 ^{+1.0} _{-1.0}	3.0 ^{+1.1} _{-1.3}	0.54 ^{+0.09} _{-0.12}	-0.44
ZTF22aakdbia	SN 2022jzc	9.9 ± 0.1	1.60 ^{+4.04} _{-1.49}	7.3 ^{+1.2} _{-2.4}	1.6 ^{+0.4} _{-0.1}	0.14 ^{+0.01} _{-0.01}	-0.55
ZTF22aazmrxp	SN 2022raj	10.9 ± 0.5	0.15 ^{+2.03} _{-0.05}	7.5 ^{+1.1} _{-1.7}	0.7 ^{+0.6} _{-0.2}	0.20 ^{+0.03} _{-0.00}	-0.64
ZTF20acfkzcg	AT 2021htp	11.4 ± 0.8	7.04 ^{+0.19} _{-0.05}	5.4 ^{+0.2} _{-0.7}	1.7 ^{+0.3} _{-0.7}	0.97 ^{+0.10} _{-0.17}	-0.59
ZTF21abrluay	SN 2021vfh	12.9 ± 1.4	4.88 ^{+1.34} _{-0.81}	4.6 ^{+1.5} _{-1.5}	2.1 ^{+1.6} _{-0.4}	0.74 ^{+0.32} _{-0.04}	-0.48
ZTF19acytcsg	SN 2019wvz	15.0 ± 0.6	12.60 ^{+0.67} _{-1.30}	5.1 ^{+1.0} _{-1.2}	2.5 ^{+1.0} _{-0.6}	1.01 ^{+0.16} _{-0.06}	-0.61
ZTF19abwztsb	SN 2019pjs	10.7 ± 0.8	2.56 ^{+1.76} _{-0.20}	6.3 ^{+0.7} _{-2.2}	1.9 ^{+0.4} _{-0.2}	0.37 ^{+0.05} _{-0.02}	-0.44
ZTF22aaywnyg	SN 2022pru	10.9 ± 0.9	2.25 ^{+0.15} _{-0.65}	4.6 ^{+1.4} _{-1.4}	3.4 ^{+0.5} _{-1.8}	0.22 ^{+0.55} _{-0.09}	-0.52
ZTF19abbnamr	SN 2019iex	14.2 ± 0.7	7.38 ^{+2.14} _{-0.09}	7.6 ^{+1.4} _{-1.9}	0.7 ^{+1.5} _{-0.1}	1.07 ^{+0.08} _{-0.07}	-0.65
ZTF23abbsxzs	SN 2023rtq	9.8 ± 1.4	5.27 ^{+0.34} _{-0.23}	4.8 ^{+1.7} _{-2.7}	2.9 ^{+0.5} _{-0.3}	0.77 ^{+0.40} _{-0.02}	-0.48
ZTF22abzqwmp	SN 2022adth	11.9 ± 0.6	1.07 ^{+1.84} _{-1.15}	7.2 ^{+1.5} _{-1.1}	2.1 ^{+1.1} _{-0.8}	0.56 ^{+0.09} _{-0.14}	-0.59
ZTF20acitoie	SN 2020wgp	10.7 ± 1.0	6.02 ^{+0.39} _{-1.34}	5.2 ^{+0.5} _{-1.4}	2.8 ^{+0.9} _{-0.9}	0.77 ^{+0.32} _{-0.02}	-0.55
ZTF19aapafit	SN 2019cvz	14.9 ± 1.1	6.13 ^{+1.74} _{-0.80}	7.1 ^{+0.6} _{-1.8}	3.0 ^{+0.8} _{-0.2}	0.68 ^{+0.05} _{-0.16}	-0.41
ZTF20acbigoa	SN 2020acac	10.5 ± 0.6	2.71 ^{+1.10} _{-0.46}	4.7 ^{+1.0} _{-1.2}	3.1 ^{+1.0} _{-0.7}	0.32 ^{+0.95} _{-0.05}	-0.50
ZTF21abvcxel	SN 2021vww	9.6 ± 0.6	0.70 ^{+3.01} _{-0.59}	6.2 ^{+2.2} _{-1.2}	0.9 ^{+2.1} _{-0.4}	0.65 ^{+0.12} _{-0.13}	-0.50
ZTF20aapchqy	SN 2020cxd	9.9 ± 0.1	0.14 ^{+0.25} _{-0.04}	3.3 ^{+3.4} _{-1.3}	1.8 ^{+1.1} _{-0.1}	0.10 ^{+0.01} _{-0.00}	-0.53
ZTF18aaszvfn	SN 2021iaw	12.3 ± 0.6	2.02 ^{+0.97} _{-0.04}	7.7 ^{+0.9} _{-1.7}	3.9 ^{+0.1} _{-0.8}	0.51 ^{+0.15} _{-0.18}	-0.46
ZTF20acuhren	SN 2020abcq	10.3 ± 1.0	1.34 ^{+2.13} _{-0.17}	3.9 ^{+1.6} _{-1.6}	3.6 ^{+0.8} _{-2.4}	0.13 ^{+0.86} _{-0.01}	-0.58
ZTF23abnogui	SN 2023wcr	10.8 ± 1.0	1.42 ^{+0.95} _{-0.10}	3.4 ^{+1.2} _{-0.9}	3.2 ^{+0.5} _{-0.7}	0.23 ^{+0.31} _{-0.03}	-0.50
ZTF22abyivoq	SN 2022acko	11.0 ± 0.2	1.04 ^{+2.92} _{-0.12}	5.2 ^{+2.2} _{-2.0}	2.6 ^{+0.9} _{-0.7}	0.26 ^{+0.07} _{-0.01}	-0.47
ZTF22abhsxph	SN 2022vyc	12.2 ± 0.9	3.94 ^{+0.79} _{-1.24}	7.3 ^{+1.0} _{-2.4}	4.1 ^{+0.8} _{-2.2}	0.69 ^{+0.03} _{-0.27}	-0.48

Note. A machine-readable version of this table is available on [Zenodo](https://zenodo.org).

Table A6
Spectral Log and H I $\lambda 6563$ Velocity Measurements

Source	Date	Phase (days)	Inst.	H I $\lambda 6563$ (km s ⁻¹)
SN 2019env	2019-06-25	51	P60	7980 ± 460
SN 2018bjo	2018-06-12	56	P200	6720 ± 40
SN 2018cbb	2018-05-17	45	P200	6390 ± 110
SN 2018bdv	2018-05-11	16	P60	10780 ± 640
SN 2024iwm	2024-06-01	18	SEDM	...
SN 2024iwm	2024-06-06	23	Deveny+LMI	...
SN 2024iwm	2024-06-07	24	KAST	...
SN 2021iaw	2021-05-06	33	KAST	...
SN 2018btl	2018-07-16	63	P60	8890 ± 640
SN 2021lmp	2021-05-29	24	SEDM	...
SN 2021lmp	2021-05-31	25	DBSP	...
SN 2020hvn	2020-05-07	17	P60	...
SN 2018lrq	2018-06-21	69	P200	...
SN 2018ccp	2018-07-02	18	P60	...
SN 2018cwa	2018-08-04	43	P200	7710 ± 490
SN 2018dzc	2018-07-30	20	P60	9160 ± 520
SN 2018dzc	2018-07-30	20	P60	8710 ± 570
SN 2018ecj	2018-12-01	129	Keck1	...
SN 2018dht	2018-08-04	24	P60	11840 ± 970
SN 2018dht	2018-08-04	24	P200	10150 ± 50
SN 2018dht	2018-08-04	24	P60	12690 ± 460
AT 2018lrz	2018-09-12	25	P200	10470 ± 20
SN 2018fif	2018-09-04	14	NOT	12930 ± 900
SN 2018fif	2018-09-25	35	P60	9620 ± 560
SN 2018fif	2018-09-25	35	P60	9620 ± 730
SN 2018fif	2018-11-03	73	P60	8470 ± 560
SN 2018fif	2018-11-14	84	P60	...
SN 2018fif	2018-11-19	89	P60	...
SN 2018fif	2018-11-26	96	P60	7320 ± 560
SN 2018fif	2018-12-04	103	P60	8470 ± 460
AT 2018lsa	2018-09-12	17	P200	10690 ± 850
SN 2024kan	2024-06-07	13	SEDM	...
SN 2024kan	2024-06-15	21	DBSP	...
SN 2018gvt	2018-12-05	69	P60	...
SN 2018gvt	2018-12-23	86	P60	...
SN 2018hle	2018-12-24	57	P60	7510 ± 560
AT 2018joy	2018-12-01	24	Keck1	9650 ± 460
AT 2018jwq	2018-12-01	14	Keck1	8870 ± 150
AT 2018kds	2019-01-26	58	P200	5950 ± 160
SN 2018hwm	2018-12-14	33	P200	3330 ± 150
SN 2018hwm	2018-12-17	36	P60	6110 ± 570
SN 2018kkv	2019-01-26	37	P200	...
SN 2018lev	2019-01-03	13	P60	10690 ± 910
SN 2019va	2019-03-13	56	P60	8360 ± 570
SN 2019vb	2019-01-26	10	P200	9920 ± 320
SN 2019amt	2019-03-15	37	P200	11040 ± 390
AT 2019aor	2019-03-19	83	P60	...
AT 2019aor	2019-04-06	100	P60	8420 ± 560
AT 2019txj	2019-03-15	13	P200	...
AT 2019txj	2019-04-03	32	Keck1	4310 ± 210
SN 2019dvw	2019-04-13	51	P200	5480 ± 70
SN 2019dvw	2019-04-24	62	P200	...
SN 2019dvd	2019-05-02	12	P60	...
AT 2019esn	2019-05-13	13	P200	...
SN 2019gss	2019-06-26	29	P200	9130 ± 550
SN 2019gmh	2019-07-03	32	P60	8880 ± 560
SN 2019gmh	2019-08-15	73	P60	...
SN 2019gmh	2019-09-09	98	P60	6610 ± 450

Table A6
(Continued)

Source	Date	Phase (days)	Inst.	H I $\lambda 6563$ (km s ⁻¹)
SN 2019gmh	2019-09-18	106	P60	6610 \pm 560
SN 2019gmh	2019-09-18	106	P60	6610 \pm 450
SN 2019gmh	2019-09-19	107	P60	...
SN 2019gmh	2019-09-19	107	P60	...
SN 2019gmh	2019-09-24	112	P60	...
SN 2019gmh	2019-09-30	118	P60	...
SN 2019hrb	2019-07-08	29	P60	9010 \pm 460
SN 2019hnl	2019-07-03	17	P60	10090 \pm 560
AT 2019khq	2019-06-26	14	P200	9520 \pm 400
SN 2019iex	2019-07-07	12	P60	12130 \pm 860
SN 2019iex	2019-10-21	116	P60	...
SN 2019ikb	2019-07-14	17	P60	12090 \pm 560
SN 2019ikb	2019-08-04	37	P60	8670 \pm 720
SN 2019ikb	2019-10-08	101	P60	7530 \pm 460
SN 2019ikb	2019-10-15	107	P60	10950 \pm 1020
SN 2019ikb	2019-10-15	107	P60	7530 \pm 460
AT 2019tti	2019-08-31	80	P200	...
SN 2019mkr	2019-08-10	17	P60	13380 \pm 460
SN 2019mor	2019-08-19	20	P60	...
SN 2019mor	2019-08-28	29	P60	6780 \pm 460
SN 2019mor	2019-08-28	29	P60	7930 \pm 460
SN 2019mor	2019-09-02	34	P200	3160 \pm 230
AT 2019tya	2019-08-10	11	P200	...
AT 2019ttl	2019-08-04	16	P200	6430 \pm 280
SN 2019nvm	2019-09-01	13	UH88	...
SN 2019nvm	2019-09-06	18	NOT	10510 \pm 80
SN 2019nvm	2019-11-02	74	P60	8740 \pm 560
SN 2019nvm	2019-11-13	85	P60	9890 \pm 460
SN 2019nvm	2019-11-14	86	P60	8740 \pm 460
SN 2019nvm	2020-01-29	160	NOT	6520 \pm 180
SN 2019nyk	2019-09-19	31	P60	...
SN 2019odf	2019-09-22	32	P60	10390 \pm 560
SN 2019qba	2019-09-21	11	P60	...
SN 2019qba	2019-09-21	11	P60	12920 \pm 460
AT 2019qiq	2019-09-28	18	Keck1	5460 \pm 240
SN 2019rho	2019-10-11	13	P60	13000 \pm 460
SN 2019upq	2020-01-05	97	P60	...
SN 2019ssi	2019-11-18	31	P60	...
SN 2019twk	2019-11-13	13	P60	13150 \pm 560
SN 2019twk	2019-11-24	23	P60	...
AT 2019ubr	2019-11-05	22	P200	7090 \pm 490
SN 2019ult	2019-11-24	16	P200	12430 \pm 440
SN 2019ust	2019-11-23	12	P60	...
SN 2019ust	2019-11-24	13	P200	...
SN 2019ust	2019-11-24	13	P200	...
SN 2019ust	2019-11-26	14	P60	...
SN 2019ust	2019-12-10	28	P60	...
SN 2019ust	2020-01-02	51	P60	...
SN 2019vdl	2019-12-16	29	P60	...
SN 2019vdl	2019-12-18	31	P60	...
SN 2019vdm	2019-12-19	31	P60	...
SN 2019vdm	2019-12-23	35	Keck1	7470 \pm 620
SN 2019vjl	2019-12-11	19	P60	12970 \pm 460
SN 2019vsr	2019-12-18	18	P60	...
SN 2019vsr	2019-12-19	19	P60	10110 \pm 910
SN 2019vsr	2019-12-23	23	LT	...
SN 2019vsr	2019-12-23	23	LT	...

Table A6
(Continued)

Source	Date	Phase (days)	Inst.	H I $\lambda 6563$ (km s ⁻¹)
SN 2019wbd	2019-12-13	14	P60	...
SN 2019wbd	2019-12-21	22	P200	12290 \pm 790
SN 2019wbd	2019-12-27	28	LT	...
SN 2019xbm	2020-01-07	31	P60	12540 \pm 910
SN 2019xbm	2020-01-27	51	P200	6750 \pm 130
SN 2019wvz	2019-12-28	12	LT	11880 \pm 730
SN 2019xgi	2019-12-31	14	P60	8700 \pm 860
SN 2019xgi	2019-12-31	14	P60	13290 \pm 460
SN 2019xgi	2020-01-01	15	P200	...
SN 2019xgi	2020-01-01	15	P200	12830 \pm 1020
SN 2019xvo	2020-01-12	18	P60	...
SN 2019xvo	2020-01-12	18	P60	...
SN 2019xvo	2020-01-27	33	P200	6650 \pm 160
AT 2020og	2020-01-27	26	P200	12800 \pm 650
AT 2020og	2020-02-14	43	P200	9180 \pm 560
SN 2020uu	2020-01-27	18	P200	12740 \pm 1030
SN 2020aqb	2020-02-13	24	P60	10980 \pm 720
SN 2020aqy	2020-02-02	12	P60	13280 \pm 860
SN 2020alg	2020-01-31	11	P60	...
SN 2020alg	2020-02-08	19	LT	...
SN 2020awg	2020-02-07	21	P60	11460 \pm 450
AT 2020bow	2020-02-14	79	P200	5820 \pm 310
SN 2020cxd	2020-05-22	92	P60	5770 \pm 570
SN 2020cxd	2020-06-25	126	LT	...
SN 2020cxd	2020-06-26	127	P60	...
SN 2020cxd	2020-07-01	132	NOT	...
SN 2020cxd	2020-07-28	159	Gemini	4340 \pm 180
SN 2020cxd	2020-10-19	241	Keck1	...
SN 2020edr	2020-03-06	16	P60	12450 \pm 560
SN 2020edr	2020-06-12	112	P60	...
SN 2020edr	2020-06-25	125	P200	2920 \pm 30
SN 2020edr	2020-06-25	125	P200	3120 \pm 100
SN 2020djin	2020-03-04	10	P60	12450 \pm 850
SN 2020djin	2020-03-04	10	P60	12450 \pm 910
SN 2020drl	2020-03-31	34	P60	...
SN 2020drl	2020-04-15	49	P60	...
SN 2020drl	2020-04-15	49	P60	...
AT 2020dzo	2020-03-22	21	Keck1	11630 \pm 540
SN 2020eaf	2021-01-12	311	LRIS	...
SN 2020fqv	2020-04-15	16	P60	12630 \pm 870
SN 2020gpe	2020-05-29	48	P60	8520 \pm 460
SN 2020ghv	2020-04-23	12	P60	...
SN 2020hyb	2020-05-18	27	LT	...
SN 2020jfo	2020-05-15	11	P60	10810 \pm 0
SN 2020jfo	2020-05-25	21	P60	9650 \pm 460
SN 2020jfo	2020-05-25	21	KAST	...
SN 2020jfo	2020-05-29	25	KAST	...
SN 2020jfo	2020-06-12	39	P60	7320 \pm 460
SN 2020jfo	2020-06-17	44	P60	7320 \pm 460
SN 2020jfo	2020-12-04	213	P60	...
SN 2020jfo	2020-12-07	216	ALFOSC	4350 \pm 180
SN 2020jfo	2020-12-07	216	NOT	4350 \pm 80
SN 2020jfo	2020-12-22	231	SEDM	...
SN 2020jfo	2021-01-16	255	ALFOSC	4170 \pm 240
SN 2020jfo	2021-01-16	255	NOT	4170 \pm 100
SN 2020jfo	2021-02-04	274	SEDM	...
SN 2020jfo	2021-02-09	279	NOT	4090 \pm 100

Table A6
(Continued)

Source	Date	Phase (days)	Inst.	H I $\lambda 6563$ (km s ⁻¹)
SN 2020jfo	2021-02-09	279	ALFOSC	4090 ± 120
SN 2020jfo	2021-03-09	307	ALFOSC	4100 ± 180
SN 2020jfo	2021-03-09	307	NOT	4100 ± 230
SN 2020jfo	2021-04-20	349	ALFOSC	3660 ± 260
SN 2020jfo	2021-04-20	349	NOT	...
SN 2020jjj	2020-05-23	17	P60	12360 ± 460
SN 2020kay	2020-05-26	11	P60	12930 ± 450
SN 2020lam	2020-06-04	10	P60	10660 ± 0
SN 2020lam	2020-06-06	12	NOT	9380 ± 300
SN 2020lrr	2020-06-20	17	P60	...
SN 2020lrr	2020-06-23	20	Keck1	...
SN 2020nif	2020-07-03	10	P60	13440 ± 570
SN 2020nif	2020-07-04	11	P60	...
SN 2020nif	2020-07-23	30	LT	11150 ± 200
SN 2020nny	2020-06-27	20	P60	...
SN 2020noe	2020-07-16	26	P200	11740 ± 250
SN 2020noe	2020-07-16	26	P200	11740 ± 830
SN 2020nyb	2020-07-15	15	P60	12590 ± 560
SN 2020nyb	2020-07-15	15	P60	12590 ± 560
SN 2020oco	2020-07-17	18	P60	...
SN 2020oco	2020-07-21	22	P60	6570 ± 560
SN 2020oco	2020-07-21	22	P60	...
SN 2020oco	2020-07-31	31	NOT	...
SN 2020oco	2020-07-31	31	NOT	3980 ± 160
SN 2020oco	2020-08-10	41	P60	...
SN 2020ofw	2020-08-07	29	NOT	8600 ± 160
SN 2020qmp	2020-12-12	140	DBSP	4560 ± 180
SN 2020qmp	2021-01-08	167	DBSP	4420 ± 90
SN 2020qmp	2021-02-20	210	DBSP	4590 ± 250
AT 2020rid	2020-08-15	24	NOT	...
AT 2020afdi	2020-09-13	35	NOT	4490 ± 130
SN 2020sje	2020-09-20	22	Keck1	8070 ± 540
SN 2020sje	2020-10-11	42	P60	...
SN 2020svn	2020-09-19	12	P60	...
SN 2020svn	2020-09-20	13	P60	...
SN 2020svn	2020-09-21	14	P60	...
SN 2020svn	2020-09-22	15	P60	...
SN 2020szs	2020-10-27	45	P60	7590 ± 460
SN 2020szs	2020-10-27	45	SEDM	...
SN 2020tdm	2020-09-27	15	P60	12460 ± 460
AT 2020ugt	2020-09-28	11	P60	13230 ± 920
AT 2020ugt	2020-10-21	33	P200	...
AT 2020ugt	2020-10-21	33	DBSP	...
SN 2020twk	2020-10-03	13	LT	9530 ± 560
SN 2020twk	2020-10-03	13	P60	12970 ± 850
SN 2020twk	2020-10-04	14	P60	...
SN 2020uim	2020-10-11	14	P60	9990 ± 460
SN 2020uim	2020-10-11	14	P60	...
SN 2020uim	2020-12-12	75	SEDM	...
SN 2020ult	2020-10-21	25	DBSP	...
SN 2020ult	2020-10-21	25	P200	7660 ± 620
AT 2021htp	2020-11-11	44	P60	...
AT 2020thp	2020-10-10	30	P60	...
AT 2020thp	2020-10-21	40	P200	...
AT 2020thp	2020-10-21	40	DBSP	...
SN 2020uqx	2020-10-12	12	P60	...
SN 2020uqx	2020-10-21	20	DBSP	...

Table A6
(Continued)

Source	Date	Phase (days)	Inst.	H I $\lambda 6563$ (km s ⁻¹)
SN 2020uqx	2020-10-21	20	P200	...
SN 2020uqx	2020-10-22	21	P60	...
SN 2020vef	2020-10-15	11	P60	7440 ± 560
SN 2020vef	2020-11-12	39	P60	...
AT 2020wip	2020-10-20	19	Keck1	11900 ± 740
AT 2020wip	2020-12-11	70	SEDM	...
SN 2020wgp	2020-10-23	12	P60	13330 ± 460
SN 2020wgs	2020-10-23	12	P60	...
SN 2020wgs	2020-10-28	17	P60	12390 ± 910
SN 2020wgs	2020-10-30	19	LT	...
SN 2020wgs	2020-10-30	19	LT	...
SN 2020xhs	2020-12-16	58	SEDM	...
SN 2020aasd	2020-12-07	15	LT	12810 ± 1070
SN 2020aaun	2020-12-13	21	SEDM	12710 ± 460
SN 2020abah	2020-12-12	23	LRIS	9920 ± 500
SN 2020aawo	2020-12-04	11	SEDM	...
SN 2020abbl	2020-12-12	20	LRIS	9450 ± 410
SN 2020abbi	2020-12-18	26	SEDM	...
SN 2020abcq	2020-12-10	12	SNIFS	...
SN 2020abcq	2020-12-12	14	SEDM	...
SN 2020absk	2020-12-18	14	LT	9850 ± 560
SN 2020absk	2021-02-07	64	SEDM	7810 ± 460
SN 2020absj	2020-12-12	79	SEDM	...
SN 2020abtf	2020-12-11	12	EFOSC2	...
SN 2020abtf	2020-12-16	17	SEDM	...
SN 2020abtf	8591-12-03	2366876	EFOSC2	...
SN 2020acjg	2021-11-06	140	DBSP	...
SN 2020acjg	2022-02-05	228	LRIS	...
SN 2020acjg	2022-03-04	255	LRIS	...
SN 2020adhh	2021-01-09	21	DIS	...
SN 2020aeqx	2021-01-12	15	LRIS	8560 ± 470
SN 2021V	2021-01-12	12	SEDM	...
SN 2021V	2021-02-08	39	SEDM	...
SN 2021aek	2021-01-26	14	EFOSC2	...
SN 2021aek	2021-02-04	23	EFOSC2	...
AT 2021htp	2021-02-20	143	DBSP	...
SN 2021brb	2021-02-04	10	SEDM	9120 ± 720
SN 2021brb	2021-02-19	25	SEDM	10260 ± 910
SN 2021cgu	2021-03-09	29	SEDM	...
SN 2021cwe	2021-03-07	22	SEDM	...
SN 2021cwe	2021-04-07	52	SEDM	...
SN 2021dvk	2021-04-09	42	DBSP	...
SN 2021enz	2021-03-17	14	SEDM	11430 ± 1020
SN 2021eui	2021-03-17	16	SPRAT	5150 ± 370
SN 2021eui	2021-05-31	90	SEDM	...
SN 2021gmj	2021-04-05	17	SEDM	9100 ± 570
SN 2021gvm	2021-04-03	14	SPRAT	10240 ± 310
SN 2021hac	2021-04-08	18	SEDM	6880 ± 560
SN 2021hac	2021-05-13	52	NOT	8080 ± 230
SN 2021hac	2021-05-13	52	ALFOSC	8080 ± 720
SN 2021mju	2021-05-31	71	DBSP	6810 ± 150
SN 2021jsf	2021-04-20	11	SEDM	...
SN 2021jsf	2021-04-20	11	SNIFS	...
SN 2021jsf	2021-06-09	59	SEDM	...
SN 2021jsf	2021-06-12	62	DBSP	7440 ± 740
AT 2020ghq	2021-05-24	10	SEDM	...
SN 2021nli	2021-05-31	10	SEDM	13240 ± 1240

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Source	Date	Phase (days)	Inst.	H I λ 6563 (km s ⁻¹)
SN 2021nli	2021-06-04	14	DBSP	10710 ± 430
AT 2014gz	2021-06-19	24	DIS	...
AT 2021pkh	2021-07-10	32	DBSP	...
SN 2021pqj	2021-06-12	10	DBSP	12770 ± 550
SN 2021pnh	2021-07-09	29	LRIS	5060 ± 230
SN 2021qiu	2021-06-28	12	SPRAT	...
SN 2021qiu	2021-07-05	19	SEDM	13010 ± 450
SN 2021qzi	2021-07-05	10	SEDM	...
SN 2021skm	2021-08-01	53	DBSP	7840 ± 710
SN 2021svy	2021-07-30	22	SEDM	...
SN 2021svy	2021-08-04	27	DBSP	7670 ± 360
SN 2021tyw	2021-08-03	11	EFOSC2	...
SN 2021tyw	2021-08-03	11	EFOSC2	...
SN 2021tyw	2021-08-05	13	EFOSC2	...
SN 2021tyw	2021-08-05	13	EFOSC2	...
SN 2021tyw	2021-08-06	14	EFOSC2	...
SN 2021tyw	2021-08-06	14	EFOSC2	...
SN 2021tyw	2021-08-12	20	EFOSC2	...
SN 2021tyw	2021-08-12	20	KAST	...
SN 2021tyw	2021-08-12	20	SEDM	...
SN 2021tyw	2021-08-12	20	EFOSC2	...
SN 2021tyw	2021-08-17	25	SEDM	6110 ± 570
SN 2021tyw	2021-08-21	29	SEDM	...
SN 2021tyw	2021-08-30	38	SEDM	...
SN 2021tyw	2021-09-13	51	EFOSC2	...
SN 2021tyw	2021-09-13	51	EFOSC2	...
SN 2021tyw	2021-11-09	108	SEDM	...
SN 2021ucg	2022-04-27	271	LRIS	5030 ± 380
SN 2021vfh	2021-08-21	14	SEDM	12970 ± 910
SN 2021vfh	2021-08-22	15	SPRAT	...
SN 2021wun	2021-09-06	36	SEDM	...
SN 2021wun	2022-02-02	182	DBSP	5180 ± 360
SN 2021wvw	2021-09-25	32	NIRES	...
SN 2021xat	2021-09-08	16	SEDM	...
SN 2021ywg	2021-09-25	12	NIRES	...
SN 2021ywg	2021-09-27	14	DBSP	11990 ± 990
SN 2021yyg	2021-09-27	13	DBSP	11440 ± 750
SN 2021zco	2021-09-27	11	DBSP	...
SN 2021zco	2021-09-29	13	SEDM	...
SN 2021zex	2021-12-19	89	SEDM	6620 ± 450
SN 2021zzi	2021-10-13	15	DBSP	...
SN 2021aatd	2021-10-16	10	SEDM	12510 ± 0
SN 2021aatd	2021-12-06	60	SEDM	...
SN 2021aatd	2021-12-12	66	SEDM	...
SN 2021aatd	2021-12-18	72	SEDM	7910 ± 560
SN 2021aatd	2022-01-12	97	SEDM	...
SN 2021aatd	2022-01-15	100	SEDM	...
SN 2021aatd	2022-01-25	110	SEDM	6760 ± 560
SN 2021aatd	2022-01-25	110	SEDM	7910 ± 560
SN 2021aatd	2022-01-28	112	SEDM	7910 ± 560
SN 2021aatd	2022-01-31	115	LRIS	6320 ± 100
SN 2021aatd	2022-02-08	123	SEDM	...
SN 2021aatd	2022-02-12	127	SEDM	...
SN 2021aatd	2022-08-23	316	LRIS	5290 ± 170
SN 2021aatd	2022-08-23	316	LRIS	...
SN 2021aatd	2022-10-23	376	LRIS	4770 ± 70
SN 2021aatd	2022-10-23	376	LRIS	4390 ± 310

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Source	Date	Phase (days)	Inst.	H I λ 6563 (km s ⁻¹)
SN 2021aaxs	2021-10-15	11	SEDM	...
SN 2021aaxs	2021-10-21	17	SEDM	13260 \pm 850
SN 2021abpd	2021-10-25	12	SEDM	12400 \pm 910
SN 2021abqs	2021-10-27	11	SEDM	13130 \pm 1030
SN 2021achr	2021-10-31	20	SEDM	...
SN 2021achr	2021-11-06	26	DBSP	9270 \pm 300
SN 2021adxd	2021-11-20	15	SEDM	...
SN 2021adxd	2021-11-29	24	SEDM	9710 \pm 720
SN 2021adxd	2021-12-01	26	DBSP	...
SN 2021aewn	2021-12-01	14	DBSP	10100 \pm 40
SN 2021aewn	2021-12-03	16	SEDM	11740 \pm 560
SN 2021aewn	2021-12-12	25	SEDM	...
SN 2021afud	2021-12-08	10	SEDM	...
SN 2021afud	2021-12-11	13	SEDM	...
SN 2021afud	2022-01-12	44	DBSP	...
SN 2022cru	2022-04-27	118	LRIS	4370 \pm 60
SN 2022ces	2022-03-02	25	SEDM	9320 \pm 460
SN 2022gwg	2022-04-19	12	SEDM	...
SN 2022hql	2022-04-26	12	SEDM	12530 \pm 460
SN 2022hss	2022-05-02	16	SEDM	13000 \pm 460
SN 2022iob	2022-05-23	37	DBSP	...
SN 2022iyl	2022-06-08	42	DBSP	...
SN 2022joe	2022-05-23	17	DBSP	9280 \pm 60
SN 2022jux	2022-05-23	11	SEDM	...
SN 2022jzc	2022-05-31	16	SEDM	...
SN 2022jzc	2022-06-07	23	SEDM	...
SN 2022jzc	2022-06-08	24	DBSP	4160 \pm 400
SN 2022jzc	2022-06-21	37	SEDM	...
SN 2022jzc	2022-06-27	43	SEDM	...
SN 2022jzc	2022-07-01	47	SEDM	...
SN 2022jzc	2022-07-04	50	SEDM	...
SN 2022jzc	2022-07-07	53	ALFOSC	4170 \pm 70
SN 2022jzc	2022-07-15	61	SEDM	...
SN 2022jzc	2022-07-20	66	ALFOSC	4340 \pm 80
SN 2022mxv	2022-08-21	64	SEDM	...
AT 2022ohx	2022-07-27	25	LRIS	6310 \pm 170
SN 2022oor	2022-07-29	21	DBSP	9150 \pm 490
SN 2022omr	2022-07-21	14	DBSP	...
SN 2022omr	2022-08-03	26	LRIS	9000 \pm 330
SN 2022ovb	2022-07-24	10	SEDM	13370 \pm 560
SN 2022paf	2022-07-29	14	DBSP	...
SN 2022oyp	2022-07-29	13	DBSP	...
SN 2022oyp	2022-08-23	37	SEDM	...
AT 2022phi	2022-08-26	37	DBSP	6130 \pm 370
SN 2022prv	2022-08-11	20	SEDM	...
SN 2022prv	2022-08-12	21	SPRAT	...
SN 2022prv	2022-08-19	28	SPRAT	...
SN 2022prv	2022-08-24	33	SEDM	...
SN 2022prv	2022-08-25	34	SEDM	...
SN 2022prv	2022-09-01	41	SEDM	...
SN 2022prv	2022-09-07	47	SEDM	...
SN 2022raj	2022-08-20	12	DBSP	...
SN 2022raj	2023-10-07	420	LRIS	2130 \pm 90
SN 2022rqg	2022-08-23	12	LRIS	...
SN 2022udq	2022-10-02	19	DBSP	7790 \pm 450
SN 2022udq	2022-10-06	23	SEDM	...
SN 2022vyc	2022-10-04	11	SEDM	...

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(Continued)

Source	Date	Phase (days)	Inst.	H I λ 6563 (km s ⁻¹)
SN 2022wbr	2022-10-02	16	DBSP	10840 ± 530
SN 2022wbr	2022-11-17	61	LRIS	...
SN 2022wbr	2023-01-17	121	LRIS	...
SN 2022wbr	2023-11-20	422	LRIS	...
SN 2022wol	2022-11-26	54	DBSP	...
SN 2022wol	2022-12-16	74	DBSP	4260 ± 280
SN 2022xav	2022-10-21	16	SEDM	...
SN 2022xav	2022-11-14	39	SEDM	7740 ± 560
SN 2022xav	2022-11-18	43	DBSP	8580 ± 570
SN 2022yma	2022-11-26	36	DBSP	7670 ± 510
SN 2022zkc	2022-11-17	14	SEDM	12570 ± 850
SN 2022zmb	2022-11-18	15	DBSP	9550 ± 460
SN 2022zmb	2023-03-20	136	LRIS	...
SN 2022zmb	2023-04-26	172	LRIS	3090 ± 260
SN 2022zmb	2023-05-24	200	DEIMOS	...
SN 2022zmb	2023-06-11	217	LRIS	...
SN 2022zmb	2023-12-07	394	LRIS	3040 ± 30
SN 2022aaad	2022-11-27	18	SEDM	10020 ± 870
SN 2022aaad	2022-11-29	20	ALFOSC	7490 ± 240
SN 2022aaad	2022-12-04	25	SEDM	8860 ± 570
SN 2022aaad	2022-12-15	36	SEDM	7700 ± 0
SN 2022aaad	2022-12-21	42	SEDM	7700 ± 470
SN 2022aaad	2022-12-22	43	SEDM	7700 ± 0
SN 2022aaad	2022-12-29	50	SEDM	7700 ± 570
SN 2022aaad	2023-01-07	58	SEDM	...
SN 2022aaad	2023-01-15	66	ALFOSC	4730 ± 70
SN 2022aaad	2023-01-23	74	SEDM	...
SN 2022aaad	2023-02-03	85	ALFOSC	4350 ± 60
SN 2022aaad	2023-02-16	98	SEDM	...
SN 2022aaad	2023-02-16	98	SEDM	...
SN 2022aaad	2023-03-09	119	SEDM	...
SN 2022aaad	2023-03-24	134	LRIS	3680 ± 90
SN 2022aaad	2023-03-27	137	SEDM	...
SN 2022aaad	2023-04-02	143	SEDM	...
SN 2022aaad	2023-04-09	150	SEDM	...
SN 2022aaad	2023-04-12	153	SEDM	...
SN 2022aaad	2023-04-16	157	ALFOSC	3640 ± 80
SN 2022aaad	2023-04-20	161	SEDM	...
SN 2022aaad	2023-04-27	168	DBSP	3580 ± 100
SN 2022aaad	2023-04-29	170	NIRES	...
SN 2022aaad	2023-06-11	213	LRIS	3410 ± 80
SN 2022aaad	2023-08-18	281	DBSP	3590 ± 260
SN 2022aaad	2023-09-04	298	SEDM	...
SN 2022aaad	2023-09-07	301	DBSP	...
SN 2022aaad	2023-09-16	310	DBSP	...
SN 2022aaad	2023-09-21	315	SEDM	...
SN 2022aaad	2023-10-07	331	SEDM	7700 ± 570
SN 2022aaad	2023-10-07	331	LRIS	3040 ± 40
SN 2022aaad	2023-11-10	365	DBSP	3150 ± 230
SN 2022aaad	2023-12-07	392	LRIS	2970 ± 90
SN 2022aaad	2024-02-15	461	LRIS	...
SN 2022aaad	2024-03-31	506	LRIS	...
SN 2022aang	2023-03-24	130	LRIS	...
SN 2022aang	2023-12-07	384	LRIS	...
SN 2022acbu	2022-12-16	22	DBSP	12580 ± 1050
SN 2022acko	2023-02-02	59	SEDM	...
SN 2022acko	2023-08-18	255	DBSP	3950 ± 260
SN 2022acko	2023-09-16	284	DBSP	3570 ± 140

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Source	Date	Phase (days)	Inst.	H I $\lambda 6563$ (km s ⁻¹)
SN 2022acko	2023-09-16	284	DBSP	3840 ± 80
SN 2022acko	2023-11-08	336	LRIS	3730 ± 210
SN 2022acko	2023-12-07	365	LRIS	3580 ± 240
SN 2022acko	2024-02-15	435	LRIS	3700 ± 50
SN 2022acr1	2022-12-19	18	SEDM	10800 ± 460
SN 2022acri	2022-12-18	16	SEDM	12050 ± 910
SN 2022adtt	2023-01-17	30	LRIS	7930 ± 600
SN 2022adth	2023-01-17	27	LRIS	7250 ± 640
SN 2023cf	2023-01-21	19	SEDM	13150 ± 460
SN 2023axu	2023-10-09	255	SEDM	...
SN 2023blw	2023-04-16	73	DBSP	...
SN 2023blw	2023-10-07	243	LRIS	...
SN 2023bmd	2023-03-07	27	SPRAT	...
SN 2023buy	2023-04-07	51	SEDM	8300 ± 720
SN 2023bql	2023-04-16	64	DBSP	6960 ± 440
SN 1995al	2023-03-08	21	SEDM	8460 ± 740
SN 1995al	2023-03-09	22	SEDM	8460 ± 570
SN 1995al	2023-12-07	294	LRIS	2490 ± 100
SN 2023ghl	2023-05-08	19	ALFOSC	9480 ± 940
SN 2023gss	2023-06-10	45	SEDM	...
SN 2023gxq	2023-05-24	26	DEIMOS	...
SN 2023gxq	2023-05-28	30	DBSP	...
SN 2023gxq	2023-06-11	44	LRIS	7600 ± 640
SN 2023gxq	2023-06-12	45	LRIS	...
SN 2023hcp	2023-05-15	16	SEDM	...
SN 2023hlf	2023-05-01	12	SEDM	9980 ± 460
SN 2023ijd	2023-05-28	14	SEDM	...
SN 2023ijd	2023-12-03	201	SEDM	...
SN 2023ijd	2023-12-03	201	SEDM	...
SN 2023ijd	2023-12-06	204	SEDM	...
SN 2023hzt	2023-05-28	20	DBSP	...
SN 2023hzt	2023-06-14	36	SEDM	8830 ± 720
SN 2023jid	2023-05-28	95	DBSP	...
SN 2023kne	2023-06-20	19	DBSP	7560 ± 320
SN 2023kzz	2023-08-18	65	DBSP	...
SN 2023rpu	2023-09-28	108	SEDM	...
SN 2023lzn	2023-07-10	10	SEDM	13290 ± 860
SN 2023mpj	2023-07-11	15	DBSP	9070 ± 440
SN 2023nca	2023-07-18	13	LRIS	...
SN 2023nca	2023-07-23	18	LRIS	...
SN 2023ngy	2023-07-28	13	SEDM	...
SN 2023ngy	2023-08-01	17	DBSP	7360 ± 90
SN 2023ngy	2023-08-03	19	SEDM	9560 ± 460
SN 2023nlu	2023-08-04	17	SEDM	12800 ± 1250
SN 2023vhb	2023-11-14	80	SEDM	7630 ± 0
SN 2023rix	2023-09-17	12	SEDM	12010 ± 730
SN 2023rtq	2023-09-24	17	SEDM	13030 ± 860
SN 2023rtq	2023-10-07	30	LRIS	10060 ± 370
SN 2023rvo	2023-09-19	13	SEDM	...
SN 2023rvo	2023-10-05	28	DBSP	...
SN 2023ucx	2023-10-07	13	LRIS	12710 ± 1150
SN 2023udb	2023-10-15	13	Deveny+LMI	...
SN 2023udb	2023-10-17	15	LRIS	...
SN 2023twg	2023-10-17	19	SEDM	13220 ± 560
SN 2023vcj	2023-12-09	57	SEDM	...
SN 2023vcj	2023-12-10	58	ALFOSC	6380 ± 260
SN 2023vcj	2023-12-28	76	SEDM	...

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Source	Date	Phase (days)	Inst.	H I λ 6563 (km s ⁻¹)
SN 2023vcj	2023-12-29	77	SEDM	...
SN 2023vcj	2023-12-30	78	ALFOOSC	6280 ± 350
SN 2023vcj	2024-01-06	84	SEDM	7330 ± 560
SN 2023vcj	2024-01-06	84	SEDM	7330 ± 560
SN 2023vcj	2024-01-08	86	KAST	...
SN 2023vcj	2024-01-19	97	ALFOOSC	5890 ± 160
SN 2023vcj	2024-01-26	104	SEDM	7330 ± 460
SN 2023vcj	2024-02-11	120	SEDM	...
SN 2023vcj	2024-03-09	146	ALFOOSC	4750 ± 190
SN 2023vcj	2024-03-14	151	ALFOOSC	4410 ± 120
SN 2023vcj	2024-03-30	166	ALFOOSC	4650 ± 330
SN 2023vog	2023-11-01	11	SEDM	...
SN 2023vog	2023-11-13	23	SEDM	11240 ± 920
SN 2023way	2023-11-03	10	SEDM	...
SN 2023way	2023-11-05	12	SEDM	...
SN 2023wcr	2023-12-03	40	DBSP	6650 ± 120
SN 2023wcr	2024-01-13	81	DBSP	5340 ± 210
SN 2023wcr	2024-01-13	81	DBSP	5360 ± 130
SN 2023wcr	2024-02-15	114	LRIS	4480 ± 80
SN 2023wcr	2024-03-15	143	ALFOOSC	3980 ± 240
SN 2023wcr	2024-03-19	147	SEDM	...
SN 2023wcr	2024-03-20	148	DBSP	4290 ± 290
SN 2023wcr	2024-04-03	162	SEDM	...
SN 2023wcr	2024-04-12	171	DBSP	4170 ± 150
SN 2023wcr	2024-05-01	190	DBSP	3940 ± 190
SN 2023wcr	2024-07-11	260	DBSP	3600 ± 70
SN 2023xvo	2023-11-21	34	SEDM	...
SN 2023xvo	2023-12-03	45	DBSP	...
SN 2023zcu	2024-01-10	31	SEDM	9910 ± 570
SN 2023zcu	2024-11-11	335	DBSP	4330 ± 200
SN 2023acbr	2024-02-15	53	LRIS	4760 ± 250
SN 2024V	2024-02-15	53	LRIS	...
SN 2024ov	2024-01-13	30	DBSP	...
SN 2024ov	2024-03-31	107	LRIS	4160 ± 80
SN 2024ov	2024-05-08	144	LRIS	...
SN 2024ov	2024-11-30	345	LRIS	...
SN 2024wp	2024-04-12	90	DBSP	...
SN 2024wp	2024-05-02	110	DBSP	4400 ± 80
SN 2024wp	2024-07-09	177	LRIS	4700 ± 120
SN 2024aul	2024-02-27	36	SPRAT	...
AT 2024bzq	2024-02-23	16	SEDM	...
SN 2024btx	2024-05-08	90	LRIS	4340 ± 160
SN 2024atk	2024-04-10	66	SEDM	7450 ± 560
SN 2024chx	2024-04-03	50	SPRAT	6280 ± 250
SN 2024daa	2024-03-20	33	DBSP	7250 ± 590
SN 2024dhi	2024-04-12	50	DBSP	6740 ± 100
SN 2024egd	2024-03-18	15	ALFOOSC	10530 ± 710
SN 2024ees	2024-04-02	25	SPRAT	...
SN 2024etq	2024-03-31	19	LRIS	10590 ± 450
SN 2024epy	2024-03-31	15	LRIS	12880 ± 150
SN 2024faf	2024-04-12	26	DBSP	...
SN 2024grw	2024-04-27	11	SPRAT	...
SN 2024grw	2024-05-06	20	SEDM	13100 ± 560
SN 2024hme	2024-05-07	18	DBSP	10590 ± 960
SN 2024izq	2024-05-31	20	DBSP	9950 ± 360
SN 2024jlf	2024-06-07	11	Binospec	...
SN 2024jlf	2024-06-07	11	SEDM	13340 ± 0

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Source	Date	Phase (days)	Inst.	H I λ 6563 (km s ⁻¹)
SN 2024jlf	2024-06-10	14	SEDM	13340 \pm 0
SN 2024jlf	2024-06-10	14	SEDM	13340 \pm 0
SN 2024jlf	2024-06-12	16	SEDM	13340 \pm 0
SN 2024jlf	2024-06-18	22	SEDM	12170 \pm 740
SN 2024jlf	2024-06-19	23	SEDM	11010 \pm 570
SN 2024jlf	2024-06-29	33	LRIS	8730 \pm 160
SN 2024jlf	2024-07-04	37	SEDM	9850 \pm 460
SN 2024jlf	2024-07-06	39	SEDM	9850 \pm 460
SN 2024jlf	2024-07-16	49	SEDM	8690 \pm 570
SN 2024jlf	2024-07-27	60	SEDM	...
SN 2024jlf	2024-08-01	65	ALFOSC	7290 \pm 240
SN 2024jlf	2024-08-14	78	SEDM	8690 \pm 460
SN 2024jlf	2024-08-26	90	SEDM	...
SN 2024jlf	2024-08-30	94	KCWI	...
SN 2024jxm	2024-06-15	16	DBSP	8870 \pm 300
SN 2024jxm	2024-08-28	89	DBSP	4980 \pm 180
SN 2024jxm	2024-09-04	96	SEDM	6910 \pm 560
SN 2024jxm	2024-09-05	97	SEDM	8060 \pm 560
SN 2024jxm	2024-10-09	130	LRIS	5040 \pm 200
SN 2024jxm	2024-11-30	181	LRIS	3390 \pm 140
SN 2024jxm	2025-01-26	237	LRIS	3220 \pm 320
SN 2024ldu	2024-06-18	12	SEDM	...
SN 2024ldu	2024-07-09	33	LRIS	7180 \pm 590
SN 2024mxq	2024-07-09	19	DBSP	...

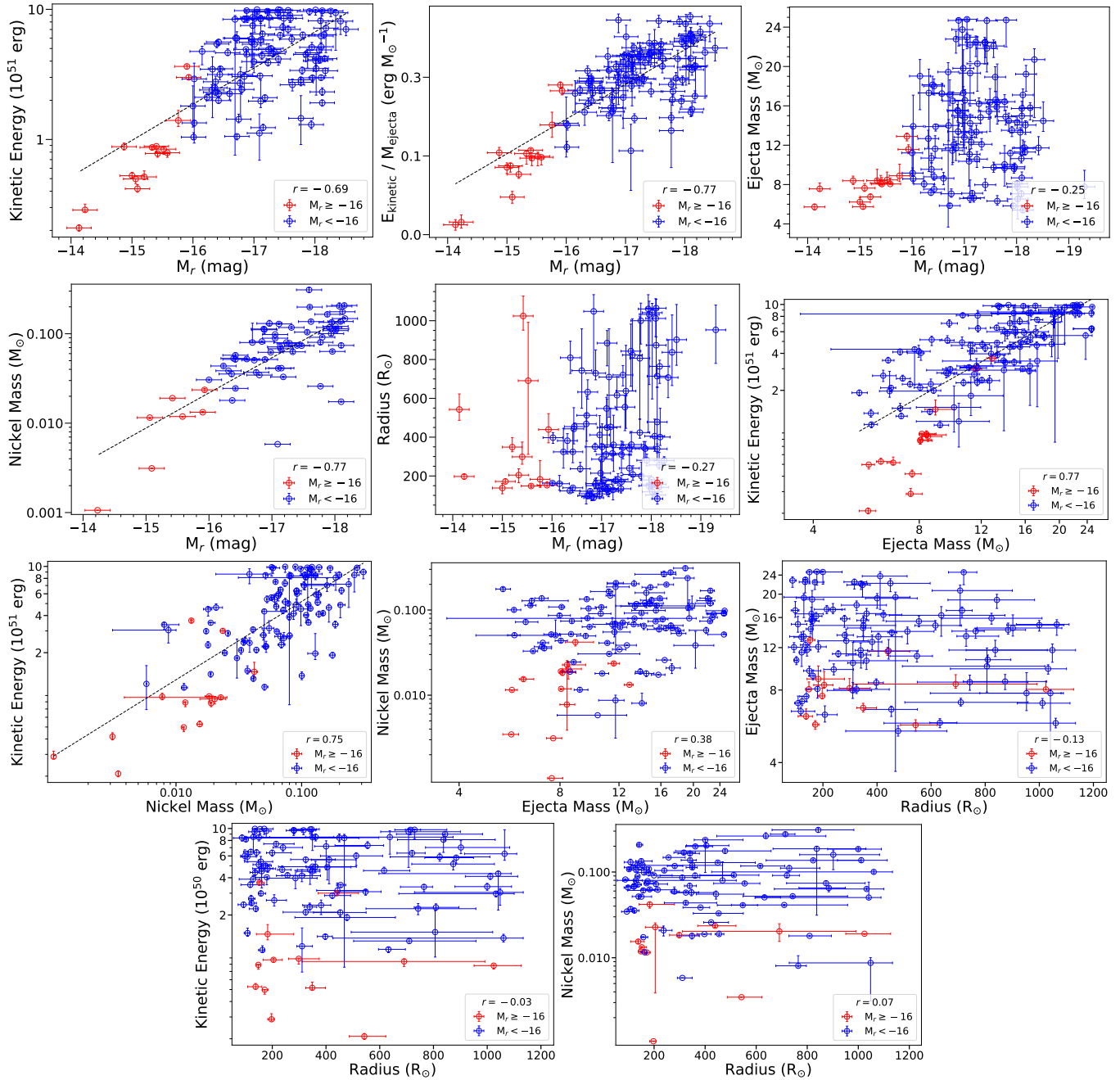


Figure 19. All correlations between peak r -band magnitude and physical parameters (nickel mass, explosion energy, energy per unit mass, radius, ejecta mass), and among the physical parameters themselves, based on semi-analytical models from Nagy & Vinkó (2016). LLIIP SNe with $M_r \geq -16$ are shown in red, SNe IIP with $M_r < -16$ in blue.

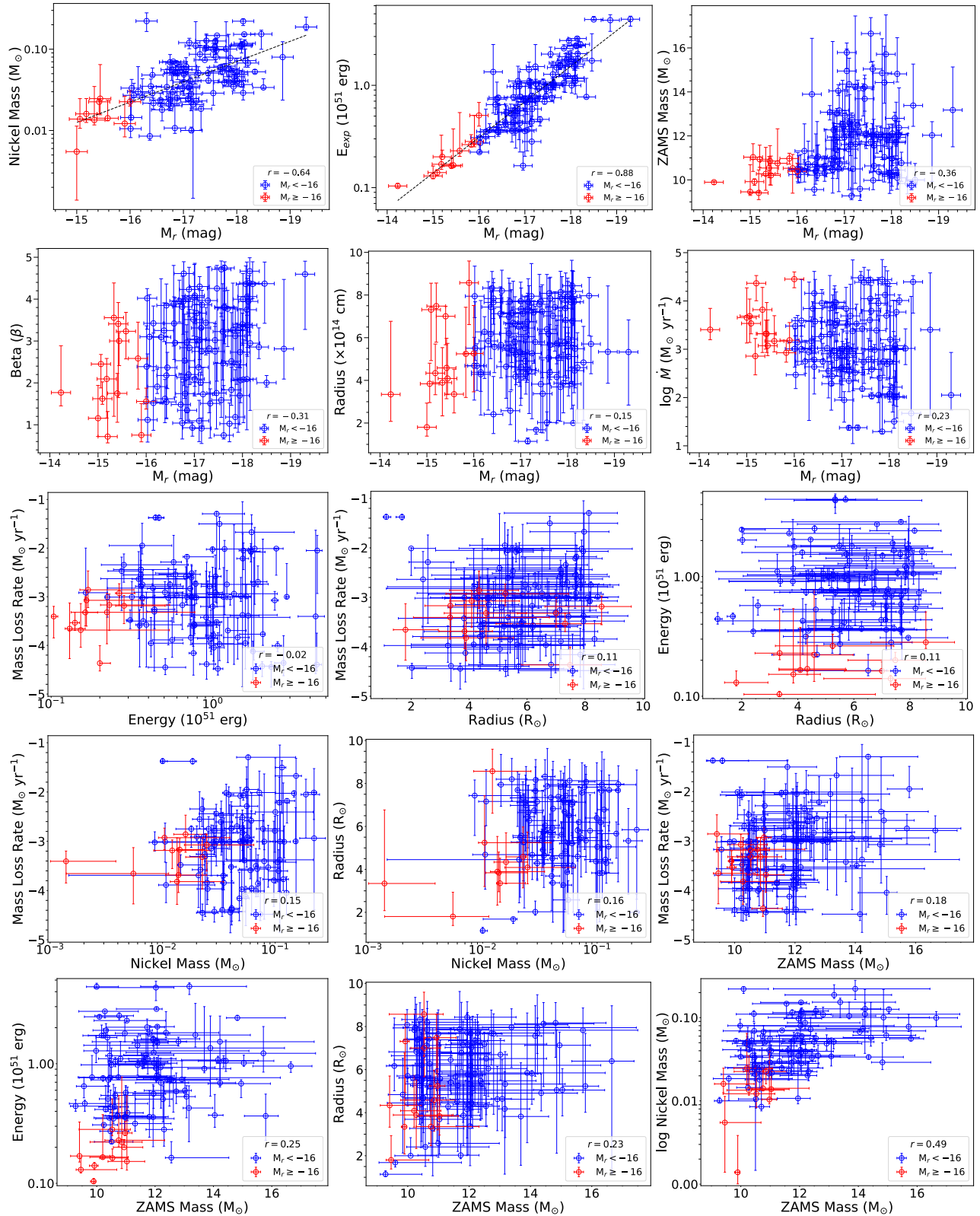


Figure 20. Correlations between peak r -band magnitude and physical parameters (nickel mass, explosion energy, energy per unit mass, radius, ejecta mass), and among the physical parameters themselves, based on radiation-hydrodynamical model fits from Moriya et al. (2023). LLIIP SNe with $M_r \geq -16$ are shown in red, those with $M_r < -16$ in blue.

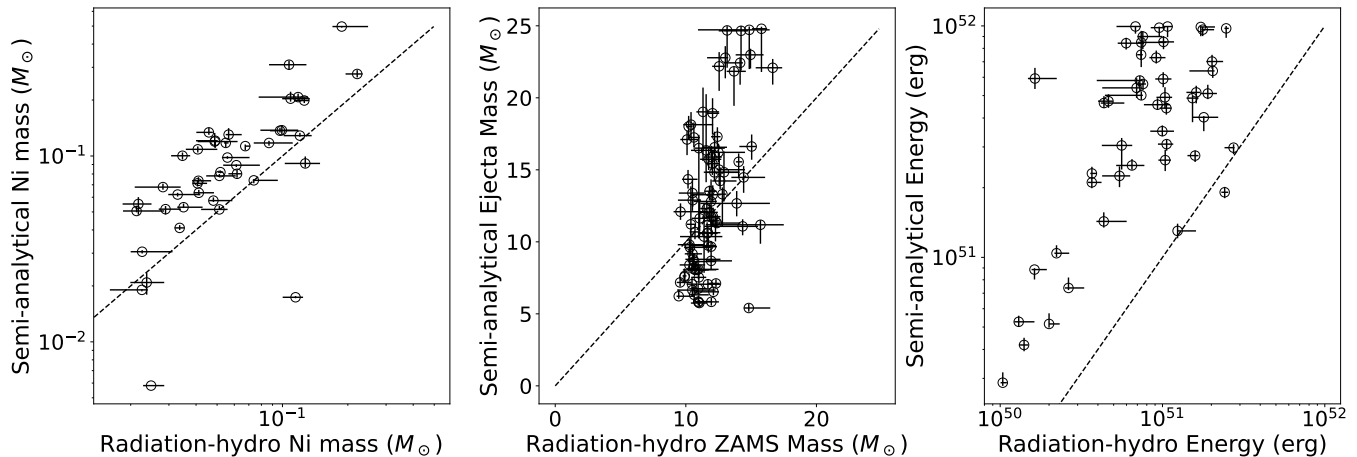


Figure 21. Comparison of physical parameters derived from semi-analytical light curve fits (y-axis) and radiation-hydrodynamical model fits (x-axis). Panels show nickel mass (left), ejecta mass versus ZAMS mass (center), and kinetic energy (right). Dashed lines indicate the one-to-one relation. Error bars reflect the 16th–84th percentile uncertainties from each method.

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