Analyses of Hydrogen–stripped core–collapse supernovae using MOSFiT and MESA based tools

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1. Introduction

Core-collapse Supernovae (CCSNe) are extremely powerful explosions that mark the death of massive stars, further sub-divided into various classes subjected to the presence/absence of H in their photospheric phase spectra (Filippenko, 1988; Filippenko et al., 1993; Smartt, 2009; Maoz, 2014; VanRossum, 2016; Könyves-Tóth et al., 2020). Among H-deficient ones, near peak the Type Ib SNe exhibit prominent Helium (He)–features in their spectra, whereas Type Ic SNe show neither H nor He obvious features. Prominent features of intermediate-mass elements such as O, Mg, and Ca are also seen in Type Ib and Type Ic SNe spectra. Another very interesting class, known as Type IIb SNe form a transition class of objects that are supposed to link SNe II and SNe Ib (Filippenko, 1988; Filippenko et al., 1993; Smartt, 2009). The early-phase spectra of SNe IIb display prominent H–features, while unambiguous He–features appear after a few weeks (Filippenko, 1997). The CCSNe are the final destinations of massive stars (≥ 8–10 M☉; e.g., Garry 2004; Woosley & Janka 2005; Groh 2017), resulting from the core-collapse due to the exhaustion of the nuclear fuel in their cores.

Underlying physical mechanisms behind above-mentioned classes of CCSNe are still not understood well. One popular mechanism is the neutrino–driven outflow (Müller, 2017, and references therein) but other mechanisms have also been proposed (e.g., magnetorotational mechanism of the explosion of CCSNe as discussed in Bisnovatyi-Kogan, Moiseenko, & Ardelyan (2018)). In many cases, the CCSNe explosions are not spherically symmetrical. As a particular case, studies by Cough, Wheeler & Milosavljevic (2009) indicate that the asymmetrical CCSNe from red supergiants are powered by non-relativistic Jets. Further, Piran et al. (2019, and references therein) mention that gamma-ray bursts (GRBs) that accompany rare and powerful CCSNe (popularly known as ‘hypernovae’) involve the association of relativistic jets emerging due to the explosion of a certain class of massive stars exploding under specific physical conditions.

During the last stages of their lives, the stars are fully evolved and contain mostly intermediate (e.g. Si, Mg etc.) to high mass elements (e.g. Fe, Ni, Co etc.)
through various nuclear processes. So, stellar deaths through these catastrophic events are also responsible for the chemical enrichment of our universe apart from the birth of compact objects like neutron stars and black holes only. Nuclear–astrophysics aims at understanding the nuclear processes that take place in the universe. These nuclear processes generate energy in stars and contribute to the nucleosynthesis of the elements and the evolution of the galaxy through many possible channels including SN explosions. The collapses of the stellar cores produce elements through various possible ways (e.g. s/r/p processes) enriching interstellar medium. This research field has now evolved as a developed one (e.g. Liccardo et al., 2018; Meyer, Petru-shevska, & Fermi-LAT Collaboration, 2020, and references therein) demanding a multi-wavelength study to better understand not only the nuclear processes but also the nature of the possible progenitors behind such cosmic explosions. It is now known that a good fraction of well-studied H-stripped CCSNe happen in diverse types of host galaxies (see figure 1) having a range of physical properties like mass, luminosity, age, star formation rates, etc. Late time observations of these host galaxies are of crucial importance to decipher the nature of possible progenitors exploding in a diverse range of environments. Apart from multi-band observations of these events, detailed studies about ambient media of such host galaxies and their pre-explosion images are very useful to constrain the nature of possible progenitors.

In the light of above and the published work earlier, as part of the present analysis we chose a sample of 4 H-stripped CCSNe (i.e. SN 2009jf (Sabu et al., 2011; Valenti et al., 2011), iPTF13bvn (Cao et al., 2013; Bersten et al., 2014; Eldridge et al., 2015), SN 2015ap (Aryan et al., 2021a), and SN 2016bau (Aryan et al., 2021a)) to fit their multi-band optical light curves using MOSFiT (Guillochon et al., 2018). Further, the fitting parameters obtained using MOSFiT are used to characterize the nature of possible progenitors using 1-dimensional stellar evolution code MESA (Paxton et al., 2011, 2013, 2015, 2018, 2019). All the analyses performed in this work make use of publicly available tools. More details about the usefulness of analysis tools like MESA/MOSFiT (and others) are described in Aryan et al. (2021b, 2022, among many other) depicting how these tools can be boon to the transient community.

This paper has been divided into five sections. A brief introduction and methods to fit the light curves of various SNe have been presented in section 2.. In section 3., the basic assumptions and various physical and chemical properties of the possible progenitors of different SNe have been presented. We discuss the major outcomes of our studies in section 4. and provide our concluding remarks in section 5..
Table 1: The adopted total-extinction values (E(B-V)$_{tot}$), adopted luminosity distances (D$_L$), and redshift (z) of SNe considered in the present analysis.

| SN name      | E(B-V)$_{tot}$ (mag) | (D$_L$) (Mpc) | redshift                  |
|--------------|----------------------|---------------|---------------------------|
| SN 2009jf    | 0.112 (Sahu et al., 2011) | 34.66 Mpc (Sahu et al., 2011) | 0.007942 (Sahu et al., 2011) |
| iPTF13bvn    | 0.21 (Bersten et al., 2014) | 25.8 Mpc (Bersten et al., 2014) | 0.00449 (Cao et al., 2013) |
| SN 2015ap    | 0.037 (Prentice et al., 2019; Aryan et al., 2021a) | 46.6 Mpc (Aryan et al., 2021a) | 0.01138 (Aryan et al., 2021a) |
| SN 2016bau   | 0.579 (Aryan et al., 2021a) | 21.77 Mpc (Aryan et al., 2021a) | 0.003856 (Aryan et al., 2021a) |

Figure 2: The results of MOSFiT fittings to the multi band light curves of SN 2009jf, iPTF13bvn, SN 2015ap, and SN 2016bau, respectively. For type Ib SNe, the radioactive decay of $^{56}$Ni and $^{56}$Co is considered to be the prominent powering mechanism for their light curves. Thus, the default model from MOSFiT has been employed to fit the light curves of these SNe.
2. Fitting the light curves using MOSFiT

MOSFiT is a Python-based package that downloads data from openly available online catalogs, generates the Monte Carlo ensembles of semi-analytical light-curve fits to downloaded data sets along with their associated Bayesian parameter posteriors and provides the fitting results back. Besides fitting data downloaded from openly available online catalogs, one can also perform a similar analysis to the private data sets. MOSFiT employs various powering mechanisms for the light curves of different types of SNe. Some of them are: a) default model incorporating the Nickel-Cobalt decay (Nadyozhin, 1994), b) magnetar model that takes a magnetar engine with simple spectral energy distribution (Nicholl, Guillochon, & Berger, 2017), and c) csm model which are interacting CSM–SNe (Chatzopoulos et al., 2013; Villar et al., 2017). A detailed description of all the models available through MOSFiT is provided in Guillochon et al. (2018).

In this work, we tried to fit the multi-band light curves of four Type Ib SNe. These four SNe are SN 2009jf, iPTF13bvn, SN 2009jf, and SN 2016bau. We employ the default model to fit the multi-band light curves of these SNe. The multi-band light curves of SN 2009jf and iPTF13bvn have been taken from Sahu et al. (2011) and Bersten et al. (2014), respectively, while the source of multi-band light curves of Sahu et al. (2011) and Bersten et al. (2014), respectively. The multi-band light curves of SN 2009jf, iPTF13bvn, SN 2015ap, and SN 2016bau have been taken from Aryan et al. (2021), Meyer, Petrushevska, & Fermi-LAT Collaboration (2020), and Sahu et al. (2011), iPTF13bvn, Meyer, Petrushevska, & Fermi-LAT Collaboration (2020), once again under-predicts the $M_{ej}$. Similarly, for SN 2015ap and SN 2016bau, we obtain ejecta masses of $\sim 1.54 M_{\odot}$ and $1.54 M_{\odot}$, respectively. The $M_{ej}$ from our MOSFiT fittings for SN 2015ap is close to Prentice et al. (2019) but lower than what is obtained from (Aryan et al., 2021a). For SN 2015ap, Meyer, Petrushevska, & Fermi-LAT Collaboration (2020) also produced similar value of $M_{ej}$. The $M_{ej}$ from our MOSFiT fittings for SN 2016bau are very close to (Aryan et al., 2021a) while Meyer, Petrushevska, & Fermi-LAT Collaboration (2020) predicts much lower value.

Figure 2 shows the results of fitting default model using MOSFiT to the multi band light curves of SN 2009jf, iPTF13bvn, SN 2015ap, and SN 2016bau. The corner plot of the fitting parameters of the default model for SN 2015ap has been shown in figure 3 as an example. Similar corner plots are generated for other SNe also. The fitting parameters of the default model to other four SNe are listed in Table 2.

3. Understanding the possible progenitors of the sub-sample of CCSNe using MESA

MESA (version r11701) is a one dimensional stellar evolution code. It is open source, rich, efficient having thread-safe libraries for a wide range of applications in computational stellar astrophysics. The capacity of MESA is enormous. It can be used to study various phases of stellar evolution resulting in various types of SNe, pulsations in stars, accretion onto a Neutron star, black hole formations and many other astrophysical phenomena. Following Cao et al. (2013), Aryan et al. (2021a), and Sahu et al. (2011), iPTF13bvn, SN 2015ap, SN 2016bau, and SN 2009jf have progenitors with ZAMS masses in the range of 11 to 20 $M_{\odot}$. In this work, following Aryan et al. (2021a) and Pandey et al. (2021), we attempt to understand the physical and chemical properties of 12 $M_{\odot}$ and 20 $M_{\odot}$ ZAMS stars which could be the possible ZAMS mass range for the progenitors of these SNe. We briefly mention the MESA settings and assumptions for our calculations below.

For the 12 $M_{\odot}$ ZAMS progenitor model that could be the progenitor of iPTF13bvn, SN 2015ap or SN 2016bau (from Cao et al. (2013), Aryan et al. (2021a)), our calculations closely follow Aryan et al. (2021a). A brief description of the 12 $M_{\odot}$ ZAMS pro-
genitor model has been provided. Starting from the pre–main sequence (PMS), the 12\( M_\odot \) ZAMS star is evolved through various stages on the HR diagram until the onset of core-collapse. We consider rotation–less progenitor having an initial metallicity of \( Z = 0.02 \) because these three SNe prove to be arising in the regions having metallicities close to solar metallicity. The convection is modelled using the mixing theory of Henyey et al. (1965) by adopting the Ledoux criterion. The mixing-length parameter is set to \( \alpha = 3.0 \) in the re-
Table 2: Best-fit parameters and 68% uncertainties for the default model. The parameters for the source with * are the results from Meyer, Petrushkova, & Fermi-LAT Collaboration (2020) presented here for comparison with our studies. In this table, $M_{ej}$ is the ejecta mass, $f_{NI}$ is the Nickel mass fraction, $\kappa$ is the Thomson electron scattering opacity, $\kappa_r$ is gamma-ray opacity of the SN ejecta, $v_{ej}$ represents the ejecta velocity, $T_{min}$ is an additional parameter for temperature floor [ please see Nicholl, Guillochon, & Berger (2017), for further details ], $\sigma$ is an additional variance parameter which is added to each uncertainty of the measured magnitude so that the reduced $\chi^2$ approaches 1, and $t_{exp}$ is the epoch of explosion since first detection.

| Source name | $\log M_{ej}$ ($M_\odot$) | $\log f_{NI}$ | $\kappa$ (cm$^2$ g$^{-1}$) | $\log \kappa_r$ (cm$^2$ g$^{-1}$) | $\log v_{ej}$ (km s$^{-1}$) | $\log T_{min}$ (K) | $\log \sigma$ | $t_{exp}$ (days) |
|-------------|-----------------|-------------|----------------|-----------------|----------------|----------------|-------------|---------------|
| SN2009jf    | 4.50$^{+0.18}_{-0.13}$ | 4.75$^{+0.13}_{-0.18}$ | 0.03$^{+0.01}_{-0.01}$ | 5.00$^{+0.14}_{-0.18}$ | 3.93$^{+0.03}_{-0.03}$ | 3.69$^{+0.01}_{-0.01}$ | 3.69$^{+0.01}_{-0.01}$ | 3.69$^{+0.01}_{-0.01}$ |
| SN2009jf*   | 4.50$^{+0.19}_{-0.12}$ | 4.75$^{+0.11}_{-0.20}$ | 0.13$^{+0.04}_{-0.08}$ | 5.00$^{+1.52}_{-1.64}$ | 3.95$^{+0.02}_{-0.02}$ | 3.61$^{+0.01}_{-0.01}$ | 3.61$^{+0.01}_{-0.01}$ | 3.61$^{+0.01}_{-0.01}$ |
| iPTF13bvn   | 4.50$^{+0.15}_{-0.09}$ | 4.75$^{+0.14}_{-0.13}$ | 0.04$^{+0.01}_{-0.01}$ | 5.00$^{+0.14}_{-0.13}$ | 3.81$^{+0.02}_{-0.02}$ | 3.65$^{+0.01}_{-0.01}$ | 3.65$^{+0.01}_{-0.01}$ | 3.65$^{+0.01}_{-0.01}$ |
| iPTF13bvn*  | 4.50$^{+0.21}_{-0.12}$ | 4.75$^{+0.14}_{-0.13}$ | 0.12$^{+0.05}_{-0.04}$ | 5.00$^{+1.54}_{-1.62}$ | 3.82$^{+0.01}_{-0.01}$ | 3.56$^{+0.00}_{-0.01}$ | 3.56$^{+0.00}_{-0.01}$ | 3.56$^{+0.00}_{-0.01}$ |
| SN2015ap    | 4.50$^{+0.10}_{-0.03}$ | 4.75$^{+0.14}_{-0.13}$ | 0.04$^{+0.01}_{-0.01}$ | 5.00$^{+0.14}_{-0.13}$ | 4.01$^{+0.02}_{-0.02}$ | 3.69$^{+0.01}_{-0.01}$ | 3.69$^{+0.01}_{-0.01}$ | 3.69$^{+0.01}_{-0.01}$ |
| SN2015ap*   | 4.50$^{+0.16}_{-0.12}$ | 4.75$^{+0.13}_{-0.22}$ | 0.10$^{+0.05}_{-0.03}$ | 5.00$^{+1.58}_{-1.68}$ | 4.15$^{+0.03}_{-0.03}$ | 3.41$^{+0.24}_{-0.25}$ | 3.41$^{+0.24}_{-0.25}$ | 3.41$^{+0.24}_{-0.25}$ |
| SN2016bau   | 4.50$^{+0.01}_{-0.02}$ | 4.75$^{+0.02}_{-0.02}$ | 0.05$^{+0.00}_{-0.00}$ | 5.00$^{+0.03}_{-0.03}$ | 3.95$^{+0.02}_{-0.02}$ | 3.82$^{+0.01}_{-0.01}$ | 3.82$^{+0.01}_{-0.01}$ | 3.82$^{+0.01}_{-0.01}$ |
| SN2016bau*  | 4.50$^{+0.18}_{-0.23}$ | 4.75$^{+0.21}_{-0.25}$ | 0.10$^{+0.04}_{-0.03}$ | 5.00$^{+1.41}_{-1.44}$ | 3.58$^{+0.14}_{-0.14}$ | 3.55$^{+0.31}_{-0.38}$ | 3.55$^{+0.31}_{-0.38}$ | 3.55$^{+0.31}_{-0.38}$ |

Figure 4: The evolutions of 12 M$_{\odot}$ and 20 M$_{\odot}$ models (both having Z = 0.02) on HR diagram from PMS till the exhaustion of He-burning in their core. The blue solid circles mark the beginning of PMS evolution of the two models.

gion where the mass fraction of hydrogen is greater than 0.5, and $\alpha = 1.5$ for the other regions. Further, the semi-convection is modelled following Langer et al. (1985) having an efficiency parameter of $\alpha_{sc} = 0.01$. For the thermohaline mixing, following Kippenhahn et al. (1980), the efficiency parameter is set as $\alpha_{th} = 2.0$. The convective overshooting is modelled using the diffusive approach of Herwig (2000), with $f = 0.01$ and $f_0 = 0.004$ for all the convective core and shells. For the stellar wind, Dutch scheme is used with a scaling factor of 1.0. We employed satisfactory spatial and temporal resolution in our models by choosing mesh_delta_coeff = 1.0 and varcontrol_target = 5d-4.

For the 20 M$_{\odot}$ ZAMS progenitor model, similar settings have been used including an initial metallicity of Z = 0.02. SN 2009jf occurred in a region having metallicity close to the solar metallicity thus Z = 0.02 is used for the 20 M$_{\odot}$ model too, serving as the possible progenitor of SN 2009jf. A slightly better spatial resolution is employed by taking mesh_delta_coeff = 0.8.

Figure 4 shows the evolutions of the 12 M$_{\odot}$ and 20 M$_{\odot}$ ZAMS progenitors on the HR diagram starting from pre-main-sequence (PMS) to the exhaustion of He-burning in the core. At the end of the core He-burning phase, both models are living in the redgiant/supergiant phase. Figure 5 and figure 6 show the snapshots of the chemical compositions of the progenitor stars at two phases each. The left panels of figure 5 and figure 6 show the stellar compositions when
Figure 5: The abundances of various elements in the stellar interior of the 12 $M_\odot$ progenitor with $Z = 0.02$, at two stages. Left: The abundances of various elements when the model has just arrived on the main-sequence. Right: The abundances of various elements as the model has finished core-He burning. The compositions of heavier elements in the stellar interior have increased now.

Figure 6: The abundances of various elements in the stellar interior of the 20 $M_\odot$ progenitor with $Z = 0.02$, at two stages. Left: The abundances of various elements when the model has just arrived on the main-sequence. Right: The abundances of various elements as the model has finished core-He burning. Similar to 12 $M_\odot$ model, the compositions of heavier elements have increased now.
the models have just landed on the ZAMS while their right panels show the chemical compositions of models until the end of the core He-burning. The grey circles in each subplot indicate the location of the mass coordinates at 0.25, 0.5, 0.75 and 1.00 times the total stellar mass. It can be noticed that initially (depending on the metallicity), the fraction of H and He are much higher than other heavy metals but as the models evolve and reach the end of the He-burning in the core, the composition of heavier elements increases in the core. Other important noticeable properties include the significant stripping of envelope due to the presence of stellar wind as the models evolve. The 12 M\(_{\odot}\) progenitor model has lost around 1 M\(_{\odot}\) as it reaches the termination stage of core-He burning while at the similar stage, the 20 M\(_{\odot}\) progenitor model has lost a significant amount of envelope retaining 15.1 M\(_{\odot}\) of total ZAMS mass. The high mass loss in the case of 20 M\(_{\odot}\) progenitor model could be attributed to the presence of comparatively stronger stellar winds than the case of 12 M\(_{\odot}\) model.

The SNe considered in this study are all type Ib. SNe Ib have been considered to originate from massive stars which lose almost all of their hydrogen envelope, most probably due to binary interaction (e.g., Yoon et al., 2010; Dessart et al., 2012; Eldridge & Maund, 2016) or due to strong stellar winds (e.g., Gaskell et al., 1986; Eldridge et al., 2011; Groh et al., 2013). Here, to produce such a stripped model, the hydrogen envelopes are artificially stripped. Specifically, after evolving the model until the exhaustion of helium, an artificial mass-loss rate of \(\dot{M} \gtrsim 10^{-4} M_{\odot} \text{ yr}^{-1}\) has been imposed until the total hydrogen masses of the models go down to 0.01 M\(_{\odot}\). After the hydrogen masses in the models reach the specified limit, the artificial mass loss is switched off and the models are further evolved on the HR diagram until the onset of the core-collapse. Starting from 12 M\(_{\odot}\) at ZAMS, our model has a total mass of 3.42 M\(_{\odot}\) at an stage just before the core-collapse. For the 20 M\(_{\odot}\) ZAMS progenitor, the model has a total mass of around 6.50 M\(_{\odot}\) just before the core-collapse. Thus, after approaching the ZAMS sequence, our models evolve to become giants-supergiants. Further, they suffer stripping and evolve ahead to start Si-burning in their respective cores. As a result, our models develop inert Fe-cores that result in the core-collapse due to the absence of any further fusion processes in the core. Figure 7 shows the variation of core temperature (\(T_{\text{core}}\)) with the core density (\(\rho_{\text{core}}\)) as the models evolve from PMS until the onset of their core-collapses. In the last evolutionary phases, the \(T_{\text{core}}\) and \(\rho_{\text{core}}\) reach in excess of \(10^{10}\) K and \(10^{13}\) g cm\(^{-3}\), respectively. Such high central temperatures and densities are considered to be the suitable physical conditions for the stellar core to collapse.

Further, figure 8 shows the mass fractions of various elements present inside the model stars when their cores are about to collapse. Near the surface of the stellar models, the fraction of He is much higher compared to other elements. Such high mass fractions of He near the surface of progenitors just before the core collapse is responsible for the type Ib SNe displaying strong He-features in their spectra. As we move inwards towards the centre of the stellar models, the cores consist mainly inert \(^{56}\)Fe, responsible for the cores to collapse.

4. Results and Discussion

This work demonstrated the usefulness of publicly available analysis tools to understand the physical and chemical properties of a sub-set of CCSNe and their possible progenitors. We used publicly available data as inputs to MOSFiT. Utilizing these data, MOSFiT provided various physical and chemical properties of CCSNe for assumed progenitor stars along with explosion epochs and range of required temperatures, velocities, ejecta mass, opacity, etc. Further, based on these observed properties, a certain ZAMS mass progenitor could be chosen as the possible progenitors of these CCSNe and the stellar evolutions depicting various stages of evolutions could be performed to shed light on the physical structure and required chemical engineering. The findings of the present studies can be summarized as mentioned below:
Figure 8: The mass fraction of various elements in the stellar interiors near the onset of core-collapse. Both the models show very high mass fraction of $^{56}$Fe in the core, which is indicative of the arrival of the core-collapse phase. Left: The mass fraction of various elements near the arrival of the core-collapse phase of a 12 M$_{\odot}$ ZAMS progenitor with metallicity Z=0.02. Right: The mass fraction of various elements near the arrival of the core-collapse phase of a 20 M$_{\odot}$ ZAMS progenitor with metallicity Z = 0.02.

1) With the help of MOSFiT, we fit the multi-band light curves of four H-stripped CCSNe namely, SN2009jf, iPTF13bvn, SN2015ap, and SN2016bau. The parameters obtained through MOSFiT fittings were compared to those available in the literature. We demonstrated the usefulness of MOSFiT and how it could be used with an extensive data set to constrain various physical parameters more realistically.

2) In the later part of this study, we demonstrated the importance of MESA to understand the physical and chemical properties of possible progenitors. MESA proved to be an excellent tool to study stellar evolution. In this work, we performed 1-dimensional stellar evolutions of two progenitor models having ZAMS masses of 12 M$_{\odot}$ and 20 M$_{\odot}$, which could serve as the possible progenitors of the four H-stripped CCSNe considered for the present study. We studied the evolutions of these models on HR diagram as they evolved through various phases throughout their lifetime. Further, we studied the variation of the chemical composition inside the stellar interior as the models evolved on the main–sequence and reached the stage of He-burning termination in the core. It was noticed that as the model evolved on the main–sequence and reached the stage of termination of He-burning in the core, the stellar interior composed more and more of heavier metals.

3) Further, we studied the variation of $\rho_{\text{core}}$ and $T_{\text{core}}$ as the models evolved from PMS up to the stages where their cores undergo core–collapse. The $\rho_{\text{core}}$ and $T_{\text{core}}$ reached in excess of $10^{10}$ gm cm$^{-3}$ and $10^{10}$ K in the late evolutionary stages marking the onset of core–collapse.

4) As another piece of evidence, we also studied the mass fractions of various elements in the stellar interiors. We found out that during the last evolutionary stages, the central regions of the stellar models are mainly composed of inert $^{56}$Fe, marking the arrival of core–collapse stage.

5) As a next step, the output of MESA models on the verge of the onset of core–collapse could be provided as input to other explosion codes capable of simulating synthetic stellar explosions. The outputs obtained through such simulations could be compared to actual SNe properties and to understand new types of transients in near future.

5. Conclusion

In this work, we demonstrated the significance of MOSFiT and MESA to understand the physical and chemical properties of H-stripped CCSNe, particularly Type Ib. MOSFiT is used the fit the multi-band light curves of SNe by taking into account default powering mechanisms. The fitting results provide various physical properties including the SN temperature, velocity, opacity, ejecta mass, explosion epochs, etc. Depending on the high or low ejecta mass, ZAMS pro-
genitors of different initial masses could be modeled. Also, the variations in opacity, explosion epochs and photospheric velocities are highly sensitive to SN light curves. Thus, parameters obtained using MOSFiT could serve as initial guesses for the progenitor models using MESA that later explode synthetically to give SNe light curves and photospheric velocities. Thus, parameters obtained using MOSFiT could serve as initial guesses for the progenitor models using MESA that later explode synthetically to give SNe light curves and photospheric velocities. So, based on these properties, stars of certain ZAMS mass range can be modeled to depict as possible progenitors of CCSNe. The snapshots of various physical and chemical properties can be obtained from MESA outputs which are extremely essential to understand the stellar properties of possible progenitors of CCSNe. Thus, our studies display how publicly available analysis tools can be used to remove the shear dependency on unpublished data to extract useful scientific information about a variety of transients and to understand related aspects of nuclear astrophysics, a broader and interdisciplinary emerging research area.

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Additional Software

NumPy (Harris et al., 2020), Matplotlib (Caswell et al., 2021), mesaPlot (Wise, M., 2019), Mesa_Reader (Bill Wolf, 2017), TULIP (Laplace, 2021)

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