Massive Progenitor Parade of Stripped-Envelope Supernovae

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Introduction

Stripped-envelope supernovae (SESNe) emerge from either massive single stars with strong stellar winds and eruptions or binary systems with heavy mass-transfer episodes. Since by definition all SESNe, especially type Ibc explosions come from compact progenitors several important questions raise, namely: how we can extract information on the progenitors inner structure through photometry and spectroscopy? Can we divide the two channels based on specific features of the light curves and the early spectra? Due to the different evolution of the two channels, they both can result in compact stars but their structures will be different. This may also affect the chemical composition or how each layer is built up inside the progenitor. To test this we built MESA models of progenitors from both channels in the 15-60 $M_\odot$ mass range and investigated how their features change compared to each other.

Models and Methods

We constructed our progenitor models with the 1D hydrodynamical code MESA (Modules for Experiments in Stellar Astrophysics; Paxton et al. 2011, 2013, 2015, 2018, 2019; Jermyn et al. 2023). The MESA models of the progenitors were built in the 15-60 $M_\odot$ mass range. For the single models we used solar metallicity and added different types of stellar winds. Before core collapse we simulated an eruption by cutting off the outer layers of the stars with the “mass_change” parameter.

For the binary models we considered massive close binary systems with <100 day initial periods and evolved donor stars with low metallicities that at least goes through Wolf-Rayet phase during their life time. We used the wind type „Dutch” for our models and even switched on the super Eddington wind.

For our investigation here we picked a single and a binary progenitor candidate with nearly the same final masses from our sample. In Table 1. we summarize the two models' most important data.

	Single	Binary
M_{ZAMS} ($M_\odot$)	15	60
M_{final} ($M_\odot$)	4.28	4.58
R_{final} (10^{10}cm)	8.93	4.22
$M_{He,\ final}$ ($M_\odot$)	1.81	0.26
$M_{Fe\text{-}core}$ ($M_\odot$)	1.52	1.98
Metallicity	0.02	0.007

Table 1. Parameters of the single and the binary progenitor models selected from our sample.

We exploded the candidates with the 1D Lagrangian code SNEC (SuperNova Explosion Code; Morozova et al. 2015). We varied the final energy of the model and the nickel mass to see how it affects the features of the light curves. We fixed the final energy as the explosion energy. We also took into account the Fe-core mass of the models and made the runs accordingly (Das et al. 2017). The models' core masses were usually between 1.5 and 2 $M_\odot$ which well agrees with previous findings (see for example Sukhbold & Woosley 2014).

Chemical composition

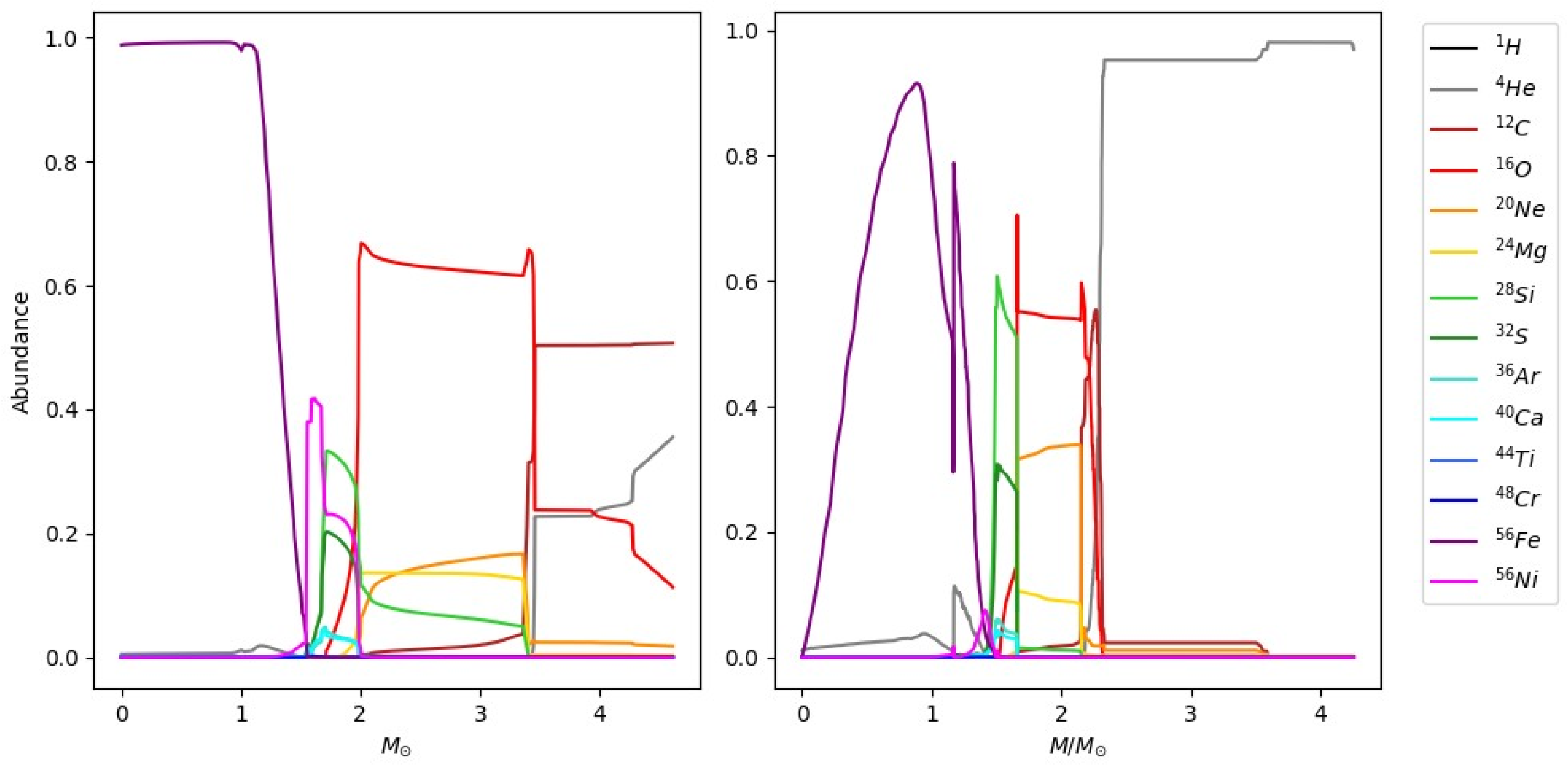

Figure 2. Chemical compositions of the two models. The left panel shows the binary model (4.58 $M_\odot$ final mass) and the right panel shows the single progenitor (4.28 $M_\odot$ final mass).

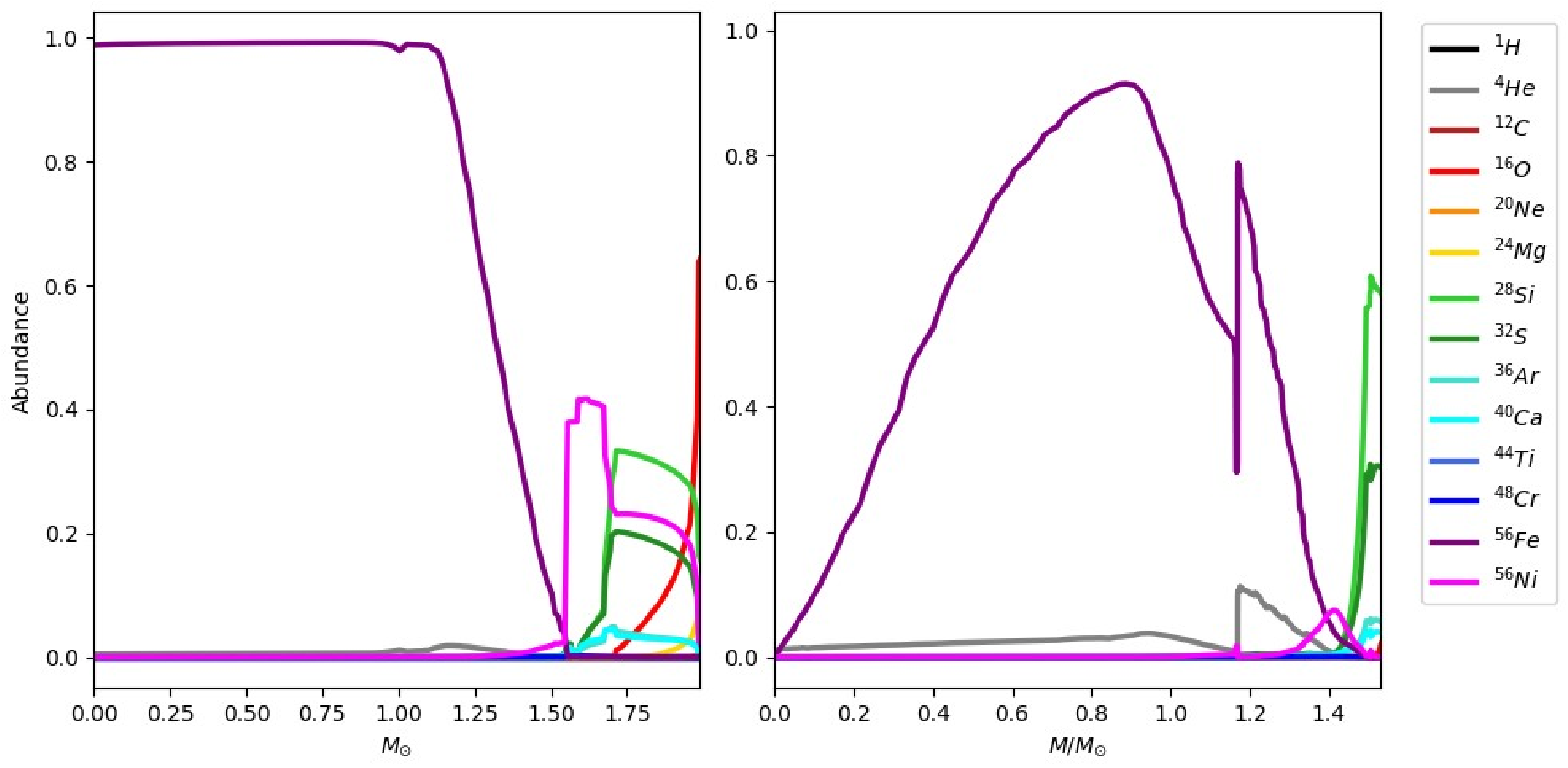

Figure 3.Same as in Figure 2. but focusing onto the core region of the models.

Density profiles

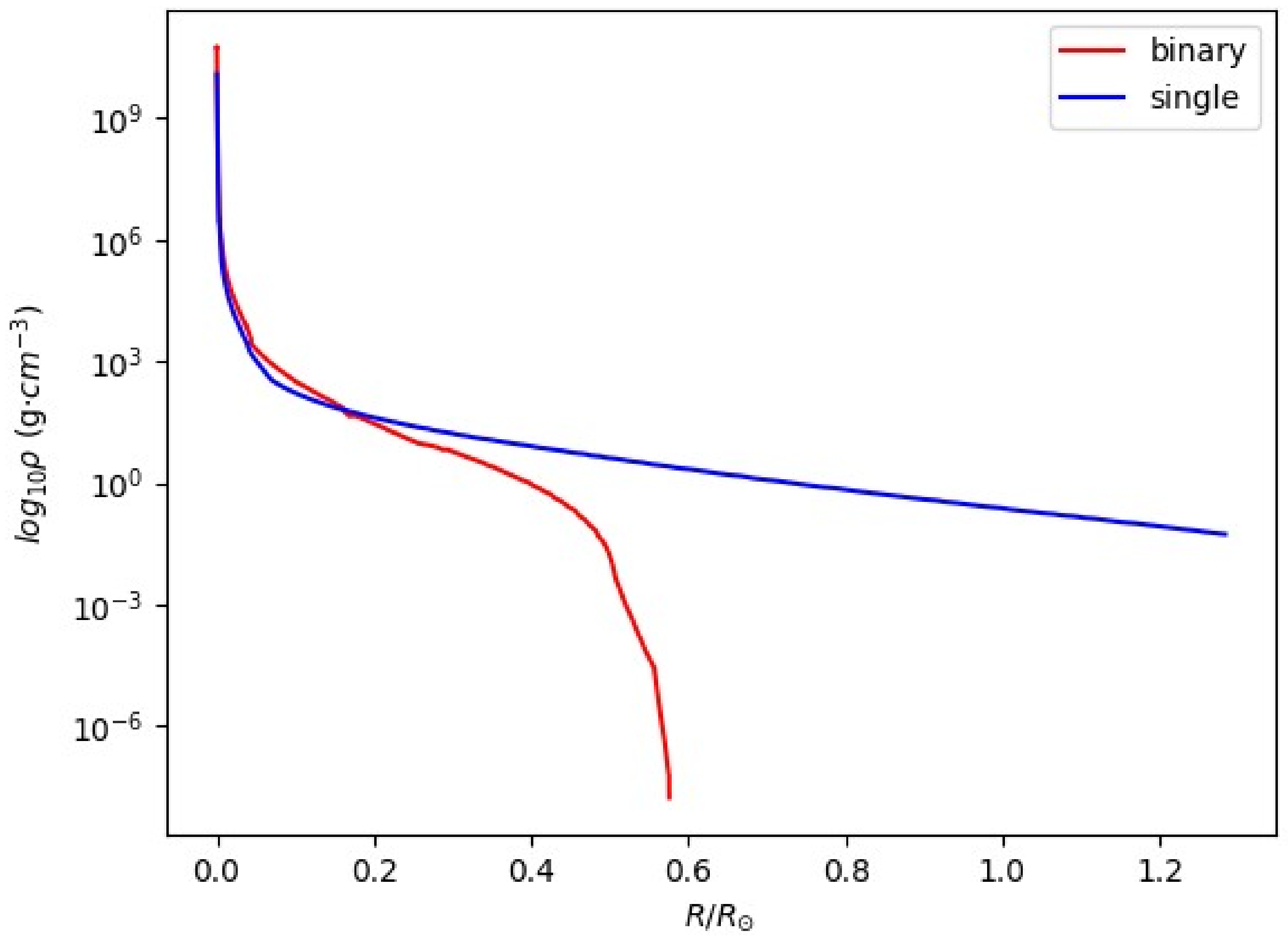

Figure 1. Comparing the single and the binary progenitors density profiles. The different profiles of the outer envelopes might be the result of the removal of the outer layers from the single progenitor.

Light curves

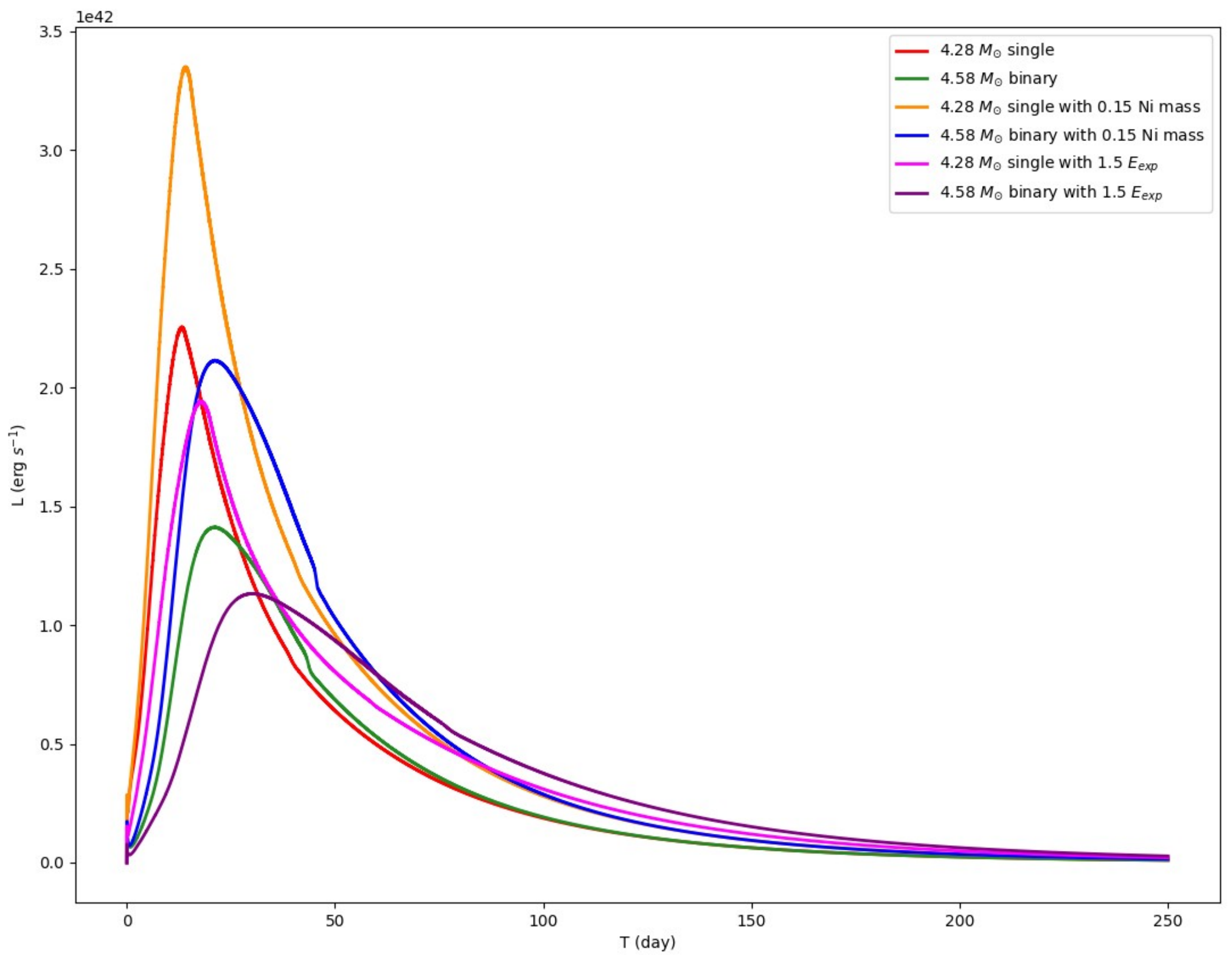

Figure 4. Different light curves of the two progenitor models. The light curve features are distinct for the two channels. The region of the peak and the maximum luminosities may result from the different compactness or even the different chemical composition.

Results

Although we evolved the binary progenitors to core collapse as single stars, notable differences in the chemical compositions are visible in Figure 1. Not only the abundance of the remaining outer He-layer, but also the mass of the O- and Si-layers have prominent differences.

Figure 2. shows the core region of the two progenitors. The rise of the nickel abundance in the binary progenitors outer core is prominent, even regarding the fact that they spent their last years as single stars.

Comparing the density profiles in Figure 3. shows a more compact core for the binary progenitor than that of the single counterpart. The higher surface density of the single progenitor is the result of the manual cutting off of the outer layers at the end of the run. Albeit the overall picture shows a more dense structure of the binary candidate.

We show the light curves of the supernova explosions of the two candidates in Figure 4. Varying the ^{56}Ni masses and the final energy affects the peak luminosity and the time of the peak also of course. The model light curves from binary progenitors tend to lower peak luminosities and have broader peaks. The main reason of this can be seen in Figure 3. Dessart et al. 2024 also found compactness in deed can alter the features of the LCs and in this case our binary progenitors have more compact structures. But not only the compactness results these light curves. Looking at Figure 2. and 3. the prominent O- and Si-layers also slow down the shock wave.

Conclusions

Models from both single and binary scenario can result in the same type of explosions, but will not generate the same progenitor stars. Due to the different evolution of donor stars in binary systems, the resulting progenitors become more compact. The light curve features caused by this compactness shows notable differences from the single progenitor's (Figure 4.). The peaks are broader and the peak luminosity is lower as the shock wave has to propagate through only a thin envelope, but the density of the medium is higher. Differences in the density profiles support the understanding of this process and even the chemical composition seems to play an important role. Our binary model has a more massive ^{16}O- and ^{28}Si-layer which are slowing down the shock wave more efficiently.

References

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