



Type Ia Supernovae from non-accreting helium stars

S. Chanlaridis¹, J. Antoniadis^{1,2}, G. Gräfener¹, N. Langer^{1,2}

Fundamental Physics in Radio Astronomy

¹Argelander-Institut für Astronomie, Auf dem Hügel 71, D-53121 Bonn, Germany

²Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany



Abstract

Type Ia supernovae (SNe Ia) are luminous optical transients characterized by the absence of hydrogen and helium in their spectra. The majority of SNe Ia are thought to result from the thermonuclear disruption of white dwarfs, which is triggered by mass accretion in a binary system. However, both the details of the explosion mechanism and the exact nature of the progenitor systems remain a topic of debate.

Recent results from wide-field transient surveys, suggest that SNe Ia are far more diverse than previously thought. This diversity could be the result of varied progenitor systems. We have discovered a novel SN Ia progenitor channel, in which a thermonuclear explosion is initiated during the late evolution of stripped helium stars with masses between $\sim 1.8 - 2.7 M_{\odot}$ which are frequently produced from the mass donors in interacting massive, close binaries. This mechanism does not require accretion from the binary companion and therefore may contribute significantly to the SN Ia rate in star-forming galaxies (i.e. at early delay times).

Methods & Initial Parameters

Our numerical stellar models are constructed using the **Modules for Experiments in Stellar Astrophysics** [1].

For the first time, we follow the evolution of low-mass helium stars, from core helium burning to the onset of degenerate oxygen ignition, taking into account important aspects of input physics. More specifically, we employ:

- a reaction network of 43 isotopes, including species that may significantly affect the temperature of the core at high densities, e.g., those participating in Urca cooling, (^{25}Na , ^{25}Mg , ^{23}Na , ^{23}Ne , ^{25}Na , ^{25}Ne) or, in exothermic electron-capture reactions (^{24}Mg , ^{24}Na , ^{20}Ne , ^{20}F , ^{20}O),
- up-to-date weak reaction rates for nuclei with $A = 17 - 28$, relevant to high-density ONeMg cores [2]
- an exponentially decreasing diffusive model for convective overshooting [3]
- stellar wind and convection recipes that allow us to follow the evolution through a highly unstable super-AGB phase, during which the envelope becomes dynamically unstable, leading to super-Eddington mass-loss rates.

We explore a stellar model grid that covers the following parameters:

Table 1: Initial model parameters

Parameter	Value(s)
Initial Mass (M_i)	$0.8 - 3.5 M_{\odot}$
Overshooting (f_{ov})	0.0, 0.014, 0.016
Metallicity (Z)	10^{-4} , 10^{-3} , 0.02

References

- [1] B. Paxton, L. Bildsten, A. Dotter, F. Herwig, P. Lesaffre, and F. Timmes. Modules for Experiments in Stellar Astrophysics (MESA). *The Astrophysical Journal Supplement Series*, 192:3, January 2011.
- [2] Toshio Suzuki, Hiroshi Toki, and Ken'ichi Nomoto. Electron-capture and β -decay rates for sd-shell nuclei in stellar environments relevant to high-density ONeMg cores. *The Astrophysical Journal*, 817(2):163, jan 2016.
- [3] F. Herwig. The evolution of AGB stars with convective overshoot. *Astronomy and Astrophysics*, 360:952–968, August 2000.
- [4] S. Chanlaridis, J. Antoniadis, G. Gräfener, and N. Langer. Helium stars as progenitors of thermonuclear supernovae: Dependence on metallicity and overshooting. [in prep.].

Results

Figures 1 and 2 illustrate a) the core evolution in the $\rho_c - T_c$ plane, and b) the abundance profiles for two representative models before the onset of explosive burning.

Most models with initial masses between 1.8 and $2.7 M_{\odot}$ develop degenerate cores composed primarily of oxygen and neon, with a small amount ($\sim 0.01 M_{\odot}$) of residual carbon distributed throughout the core (blue profiles in Figure 1 and right plot in Figure 2).

Subsequent shell burning causes the core to approach the Chandrasekhar limit. When the central density reaches the threshold for electron captures on ^{24}Mg , the released energy ignites the residual carbon, which in turn leads to explosive core-oxygen burning and, most likely the disruption of the star in a thermonuclear supernova.

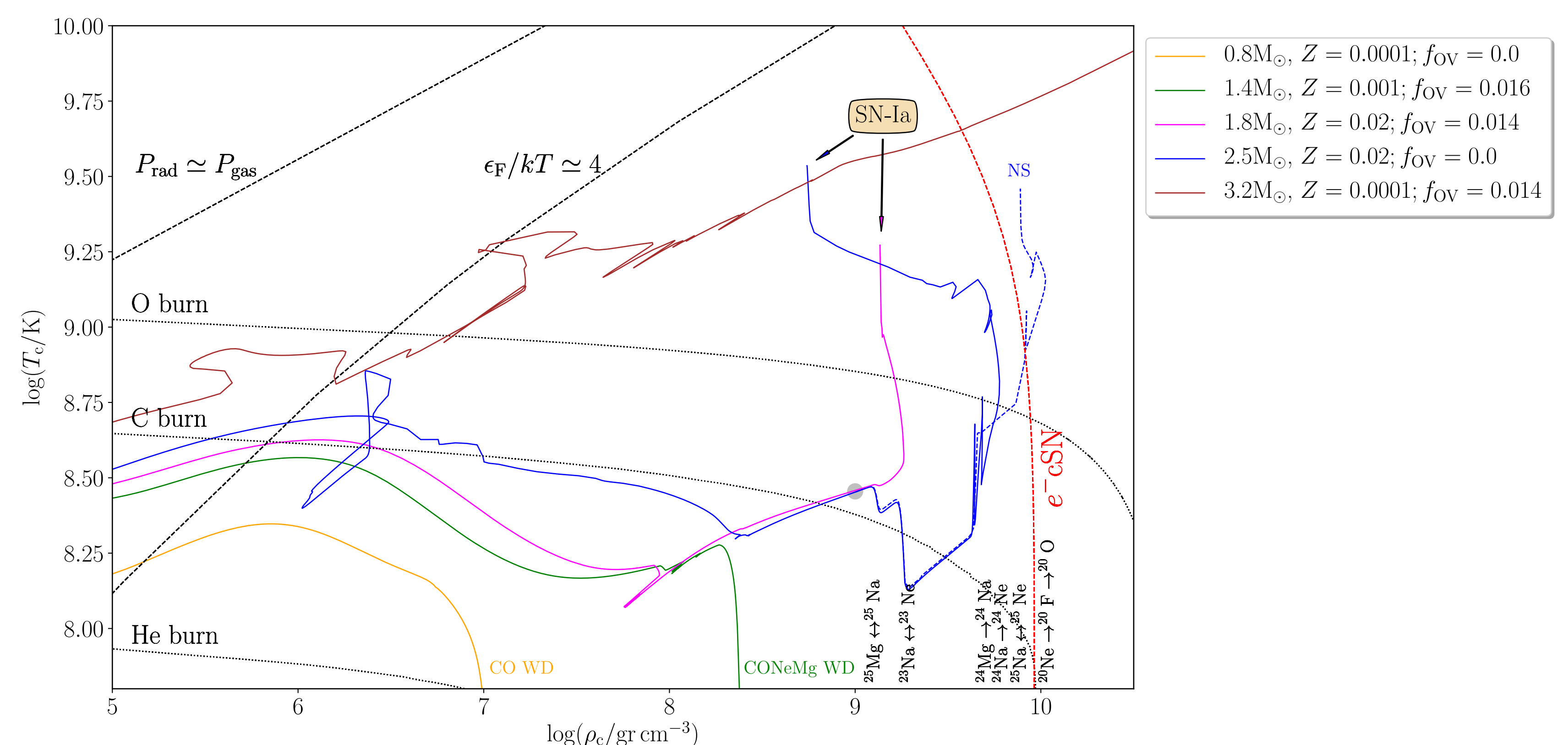


Figure 1: Examples of the evolution of different initial masses in the $\log(\rho_c) - \log(T_c)$ plane.

The importance of residual carbon in initiating the explosion is demonstrated by the blue dashed curve in Figure 1, which shows a model in which all carbon-participating thermonuclear reactions have been switched off. In this case, the core density grows beyond the threshold for e-captures on ^{20}Ne , most likely leading to an electron-capture supernova and the formation of a neutron star.

A small number of models develop a hybrid CO/ONe structure in their core, but still reach the Chandrasekhar limit. These models ignite carbon and oxygen explosively at lower densities, and could lead to more energetic explosions (magenta profile in Figure 1 and left plot in Figure 2).

In all cases, the extended He-rich stellar envelope is easily ejected, either due a strong wind (as is the case in our single-star models) or, more realistically, in a common-envelope episode with the binary companion. As a result, the star contains no helium at the time of the explosion, and hence it would be observable as a SN Ia (Figure 2).

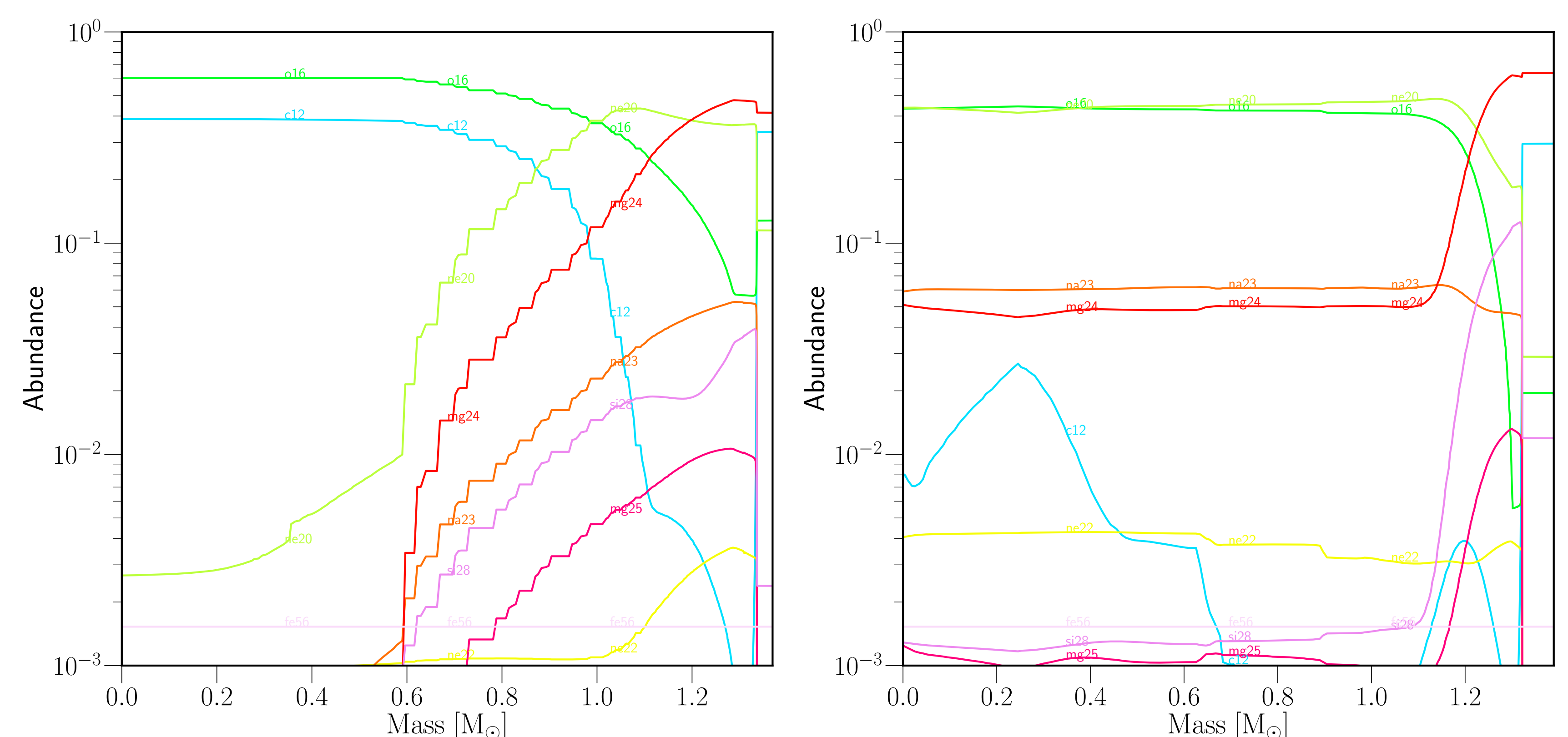


Figure 2: Structure of two stellar models when $\log(\rho_c) \approx 9.0$, shortly before Urca processes commence (gray circle in Figure 1). *Left:* Model with initial mass of $M_i = 1.8 M_{\odot}$, solar metallicity, and overshoot mixing ($f_{\text{ov}} = 0.014$). *Right:* Model with $M_i = 2.5 M_{\odot}$, solar metallicity, and no overshooting. Residual carbon from previous burning stages is visible in the core.