The Evolution of ONeMg Cores with MESA

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Abstract

We present calculations of the evolution of degenerate cores composed primarily of oxygen, neon, and magnesium which are undergoing compression. We make use of the state-of-the-art MESA stellar evolution code, along with updated weak reaction rates from Martínez-Pinedo et al. (2014). We perform a parameter study of the effects a number of quantities, including the accretion rate, $\dot{M}$, the $^{24}\mathrm{Mg}$ mass fraction, X_{Mg}, and initial core temperature, T_c.

Treatment of Weak Rates

When electrons are degenerate, the rates of electron capture and beta decay depend exponentially on density and temperature. Many existing weak reaction rate tables are too sparse to be used to study a sudden (density-driven) onset of electron capture. We developed a simple framework for calculating the necessary weak rates in the relevant regimes.

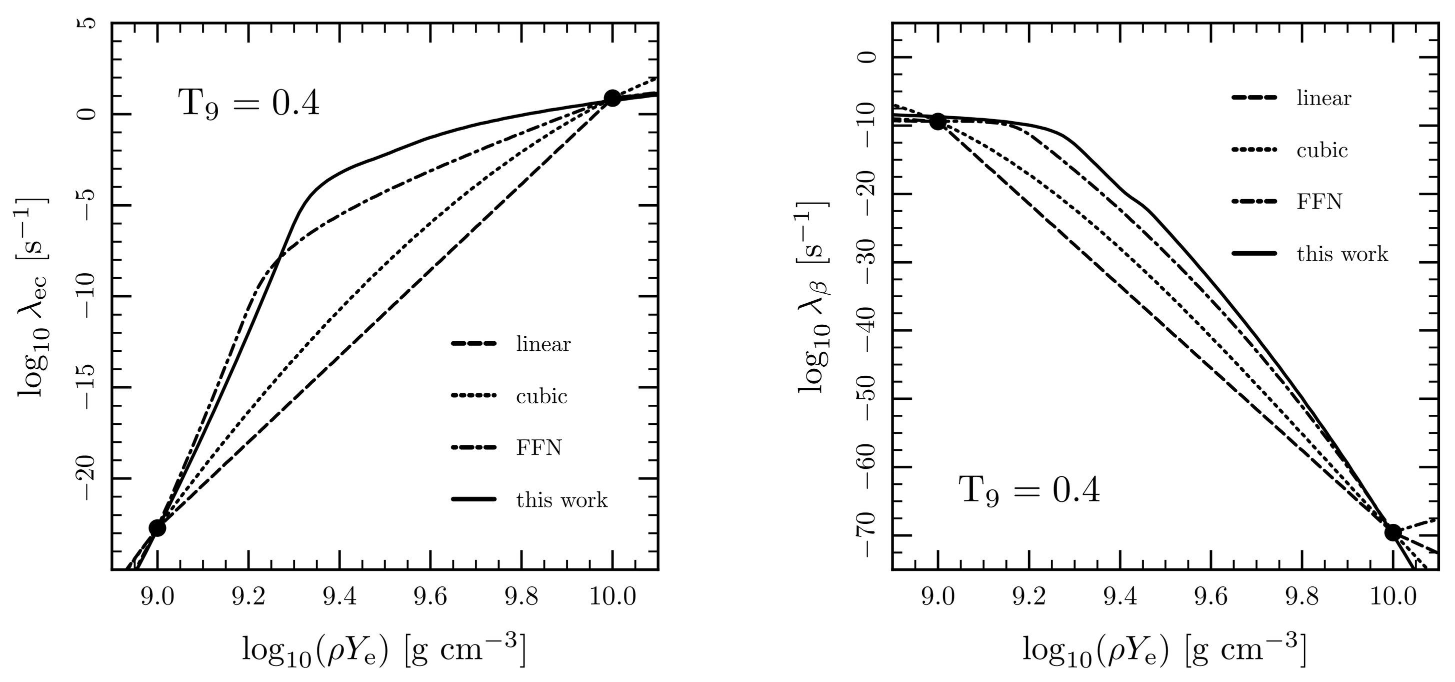

Figure: The rates of electron capture on $^{24}\mathrm{Mg}$ (left) and beta decay of $^{24}\mathrm{Na}$ (right) as a function of density at a fixed temperature of 4×10^8 K. The Oda et al. (1994) tabulated points are shown as black dots. The dashed (dotted) line shows the result of using linear (cubic) interpolation between the tabulated points. The dashed-dotted line shows the result of using the interpolation method suggested by Fuller et al. (1985). The solid line shows the rate calculated and used in this work.

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Overview of ONeMg Core Evolution

The evolution of an ONeMg core undergoing compression proceeds roughly as follows (e.g. Miyaji et al., 1980):

- Compression (accretion from a shell, companion, etc.)
- Electron captures: $^{24}\mathrm{Mg} \rightarrow {}^{24}\mathrm{Na} \rightarrow {}^{24}\mathrm{Ne}$
- Continued compression, often achieving a balance between neutrino cooling and compressional heating
- Electron captures: $^{20}\mathrm{Ne} \rightarrow {}^{20}\mathrm{F} \rightarrow {}^{20}\mathrm{O}$
- Ignition of thermonuclear oxygen burning
- Competition of outwardly propagating oxygen deflagration and electron captures on post-deflagration NSE material

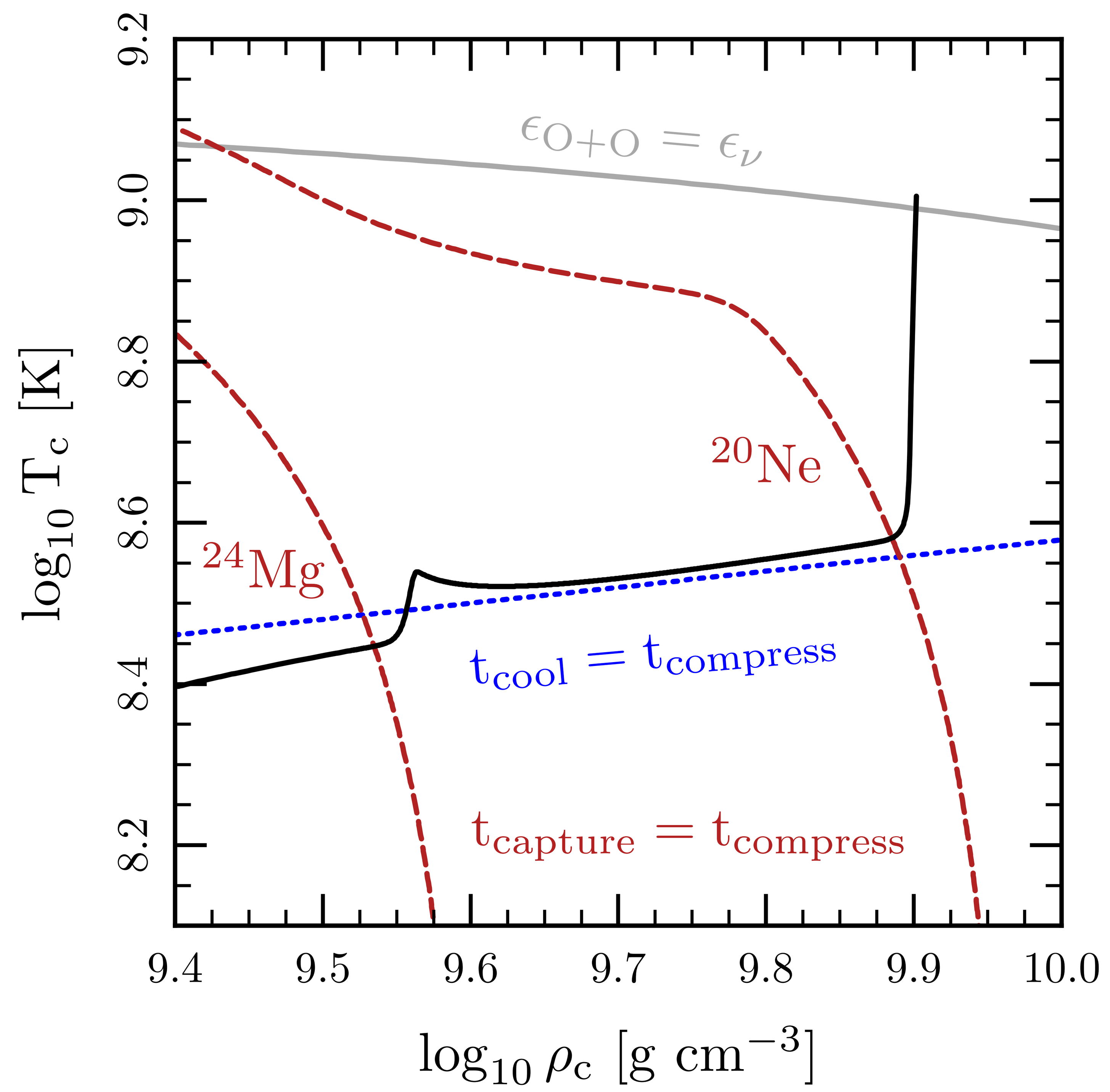

Figure: The black solid line shows the central density and temperature of the core as it is compressed by an $\dot{M} = 10^{-6}\,\mathrm{M_\odot yr^{-1}}$. The red dashed lines indicate when the capture timescales for $^{24}\mathrm{Mg}$ and $^{20}\mathrm{Ne}$ become equal to the compression time. The blue dotted line shows where the neutrino cooling time and compression time are equal. The grey solid line shows where the energy generation from thermonuclear oxygen burning exceeds the thermal neutrino losses and we stop the calculation.

Effect of the Magnesium Mass Fraction

The $^{24}\mathrm{Mg}$ mass fraction can have a strong effect on the subsequent evolution (e.g. Gutiérrez et al., 2005).

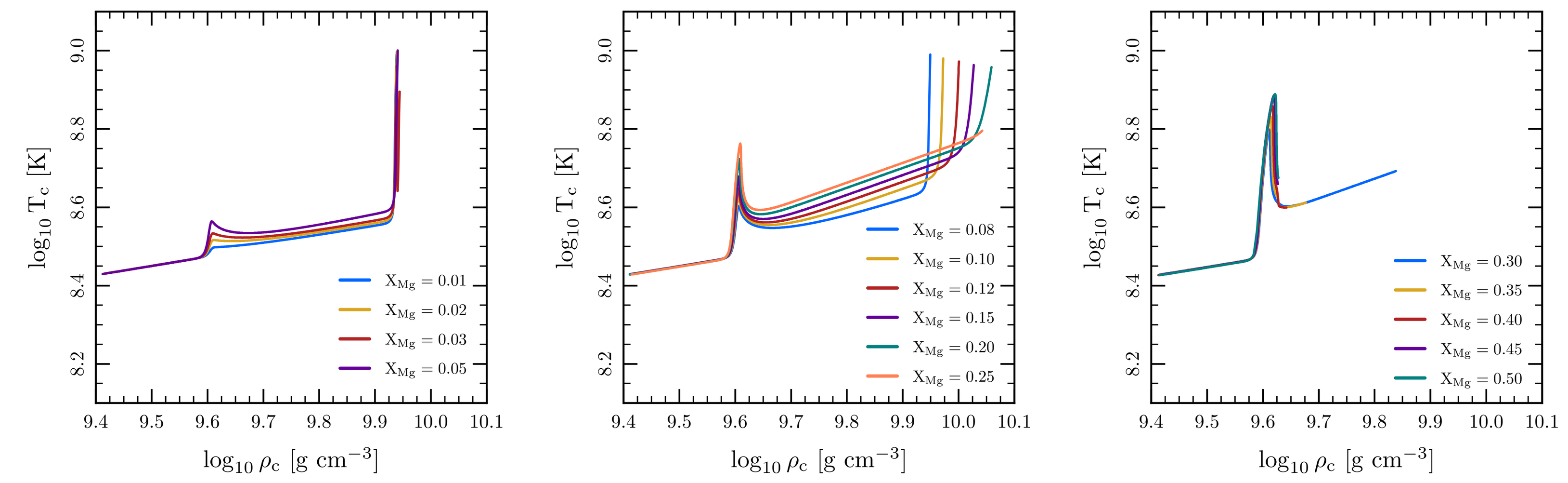

Figure: For low $^{24}\mathrm{Mg}$ mass fractions (left panel), the core has time to cool between the end of $^{24}\mathrm{Mg}$ electron captures and the onset of captures on $^{20}\mathrm{Ne}$, minimizing the effect of the $^{24}\mathrm{Mg}$ mass fraction. For intermediate $^{24}\mathrm{Mg}$ mass fractions (center panel), the core retains the entropy generated by the $^{24}\mathrm{Mg}$ captures and this changes the density at which captures on $^{20}\mathrm{Ne}$ begin. For high $^{24}\mathrm{Mg}$ mass fractions (right panel), oxygen burning is initiated at densities below the onset of electron captures on $^{20}\mathrm{Ne}$.

Ongoing & Future Work

We are exploring differences between cores formed during the late stages of evolution of super-AGB stars and those formed as the remnant of a merger of two white dwarfs (e.g. Schwab et al., 2012). We are quantifying the effects of Coulomb corrections to the weak rates. In the future, we aim to track the evolution of the oxygen deflagration as it propagates through the star. We also plan to follow the subsequent explosion/collapse using a GR hydrodynamics code.

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