The Evolution of ONe White Dwarfs towards Accretion-Induced Collapse

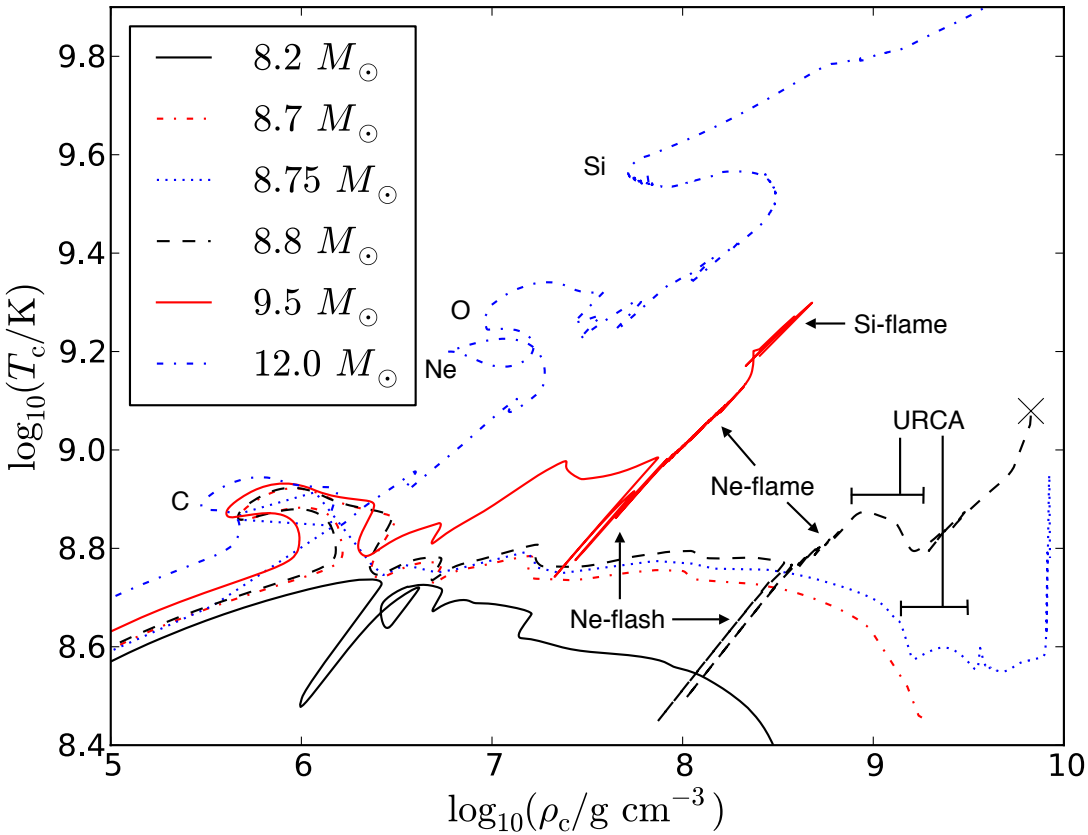
with L. Bildsten, E. Quataert, J. Brooks & others

Josiah Schwab

Hubble Fellow, UC Santa Cruz

27 March 2017

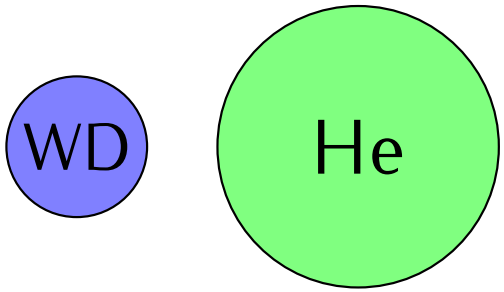
Accretion-induced collapse (AIC) is the evolution of a "bare", degenerate, growing O/Ne core.



from Jones et al. (2013)

Multiple channels are thought to lead to AIC.

Single-Degenerate



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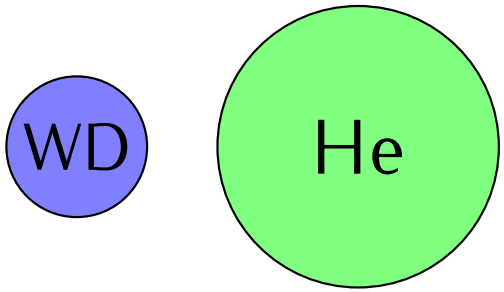
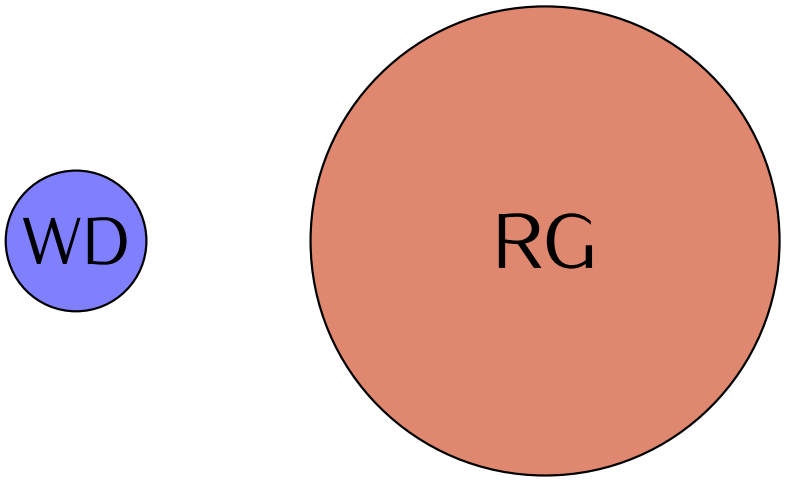


or



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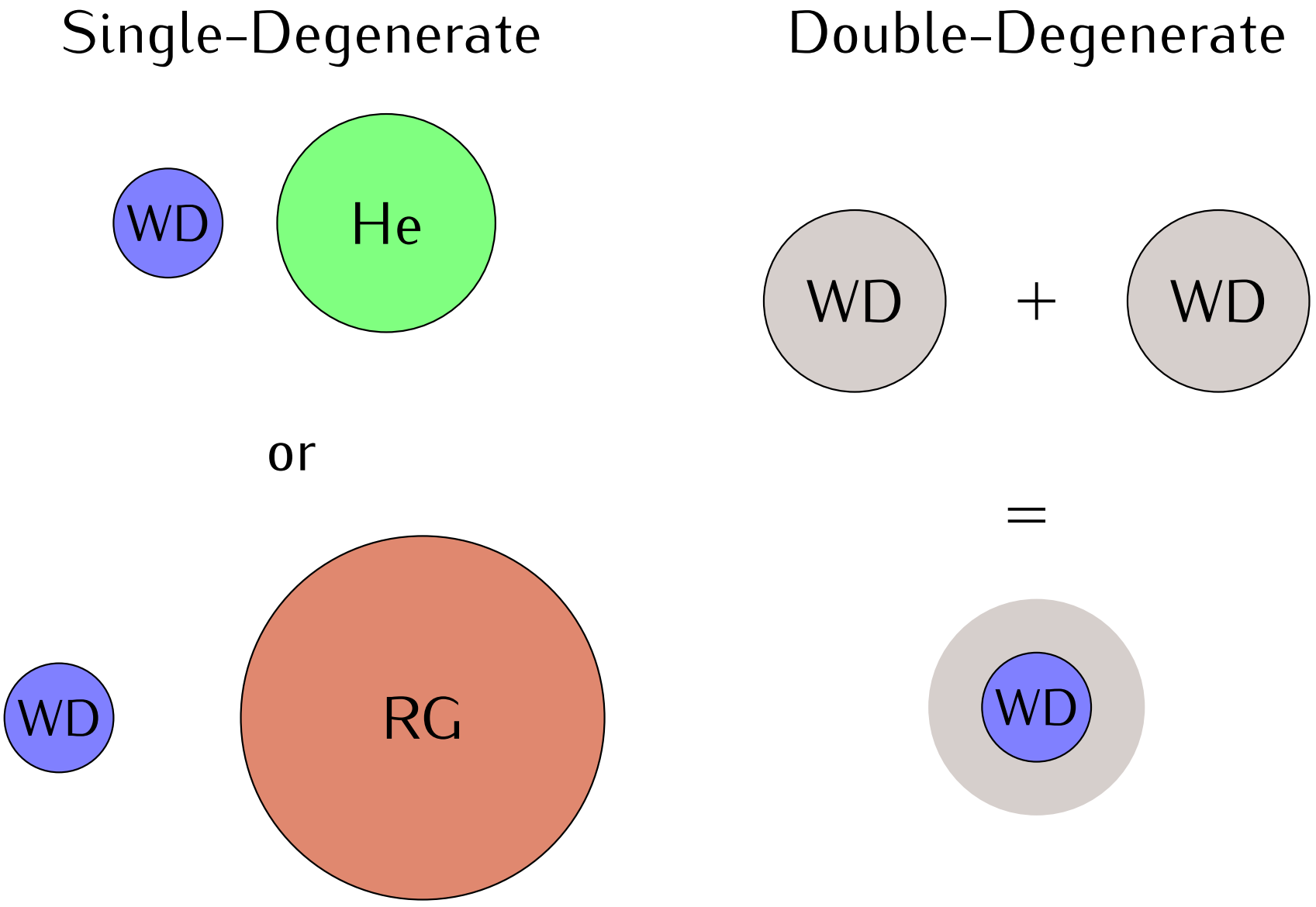
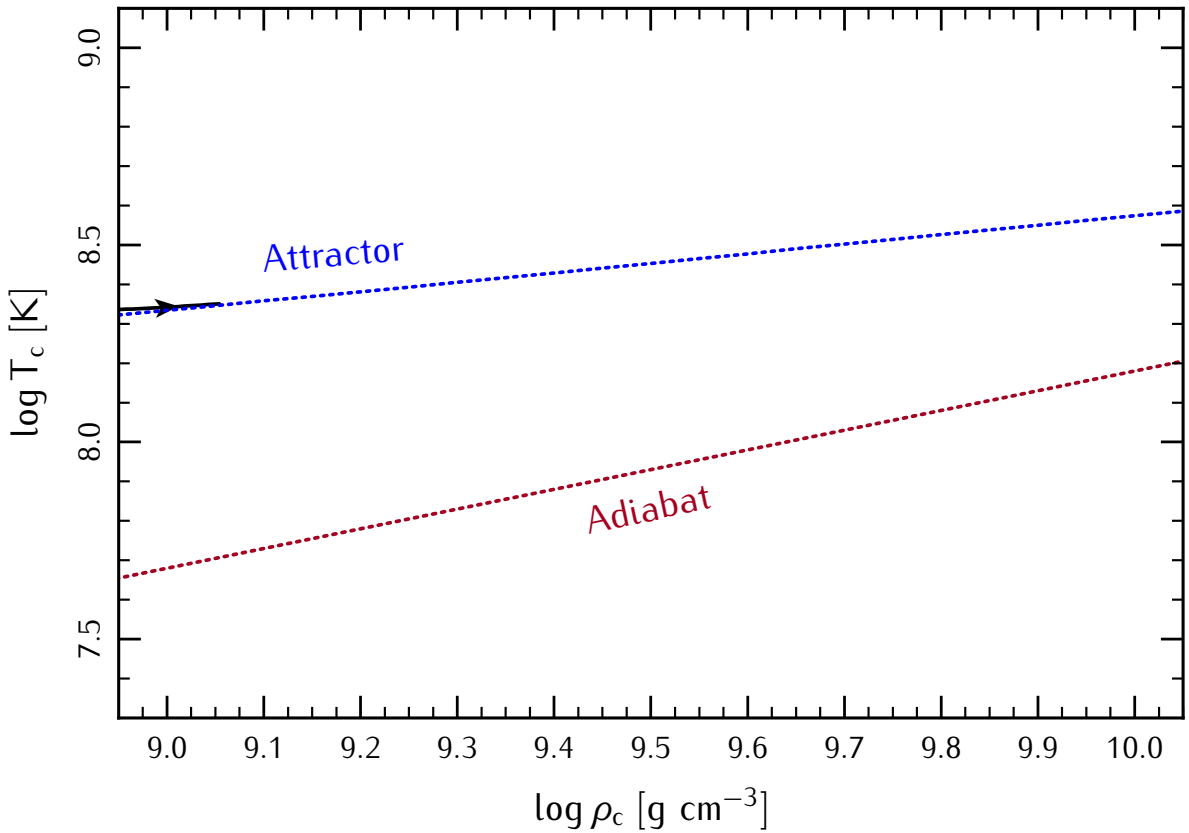


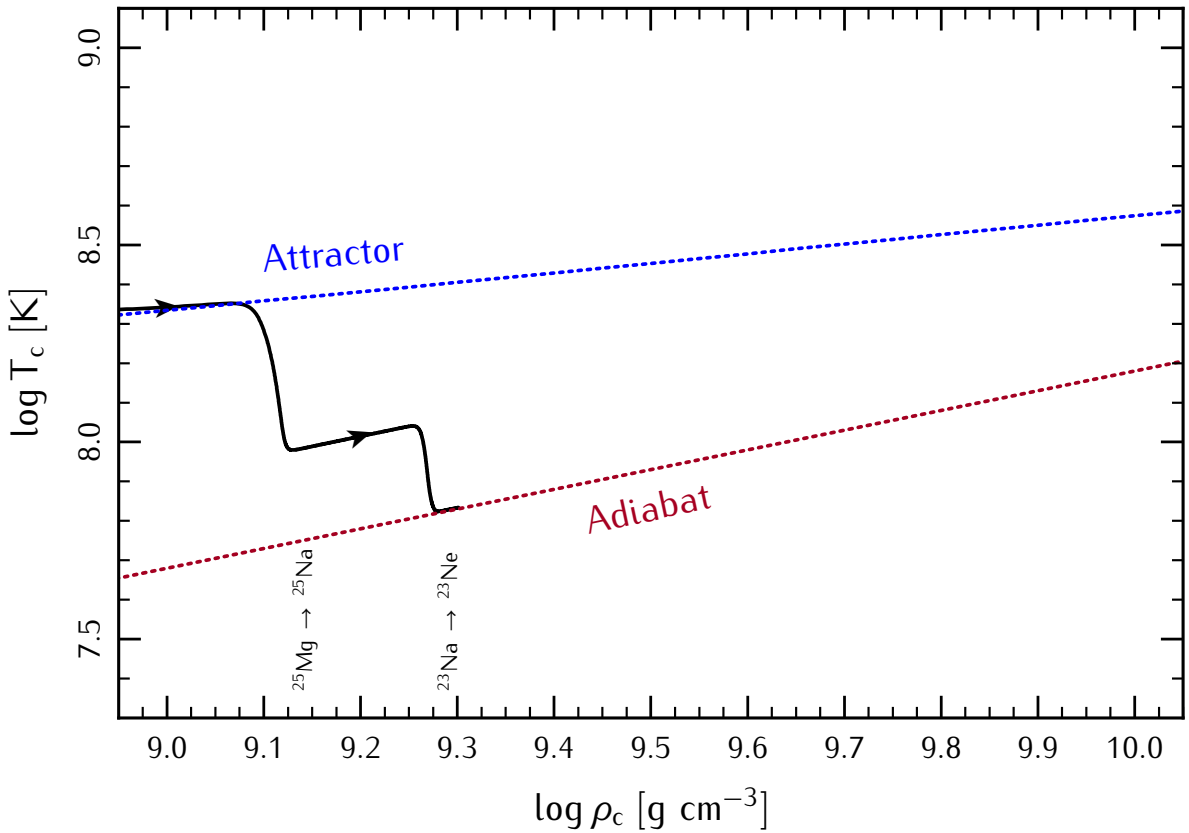
Thermal evolution of accreting ONe WDs

Initially, the temperature is set by a balance between compression and neutrino cooling.



Paczyński (1971); JS et al. (2015)

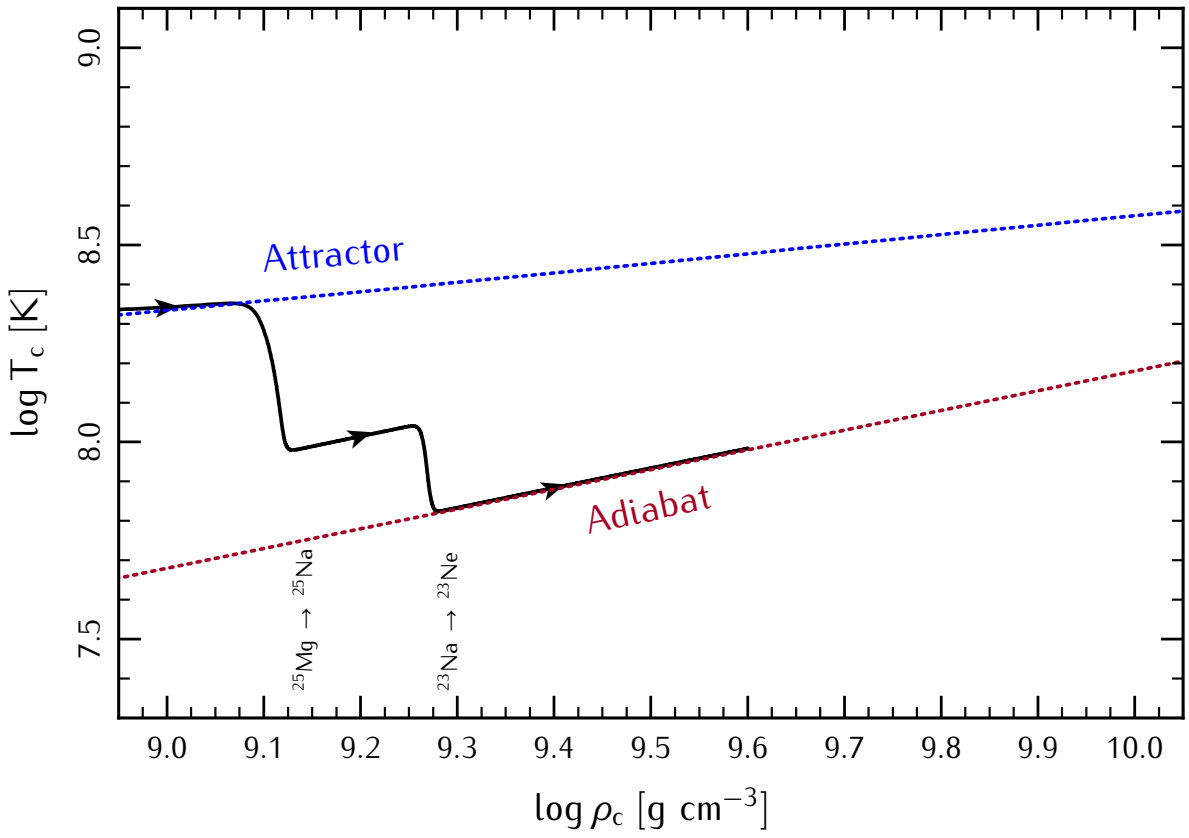
Substantial Urca-process cooling occurs associated with the $A = 23$ and $A = 25$ isotopes.



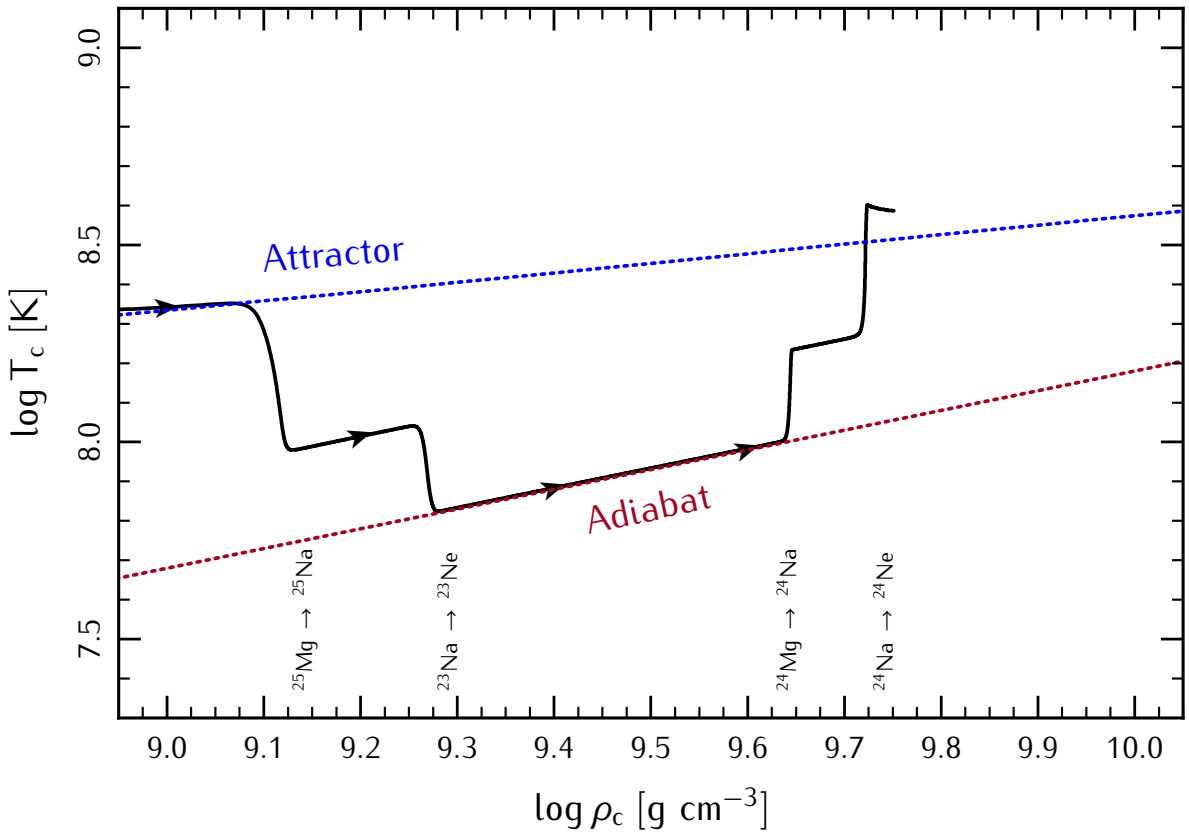
Paczyński (1973); JS et al. (2017)

This shuts off neutrino cooling

and the material evolves along an adiabat.

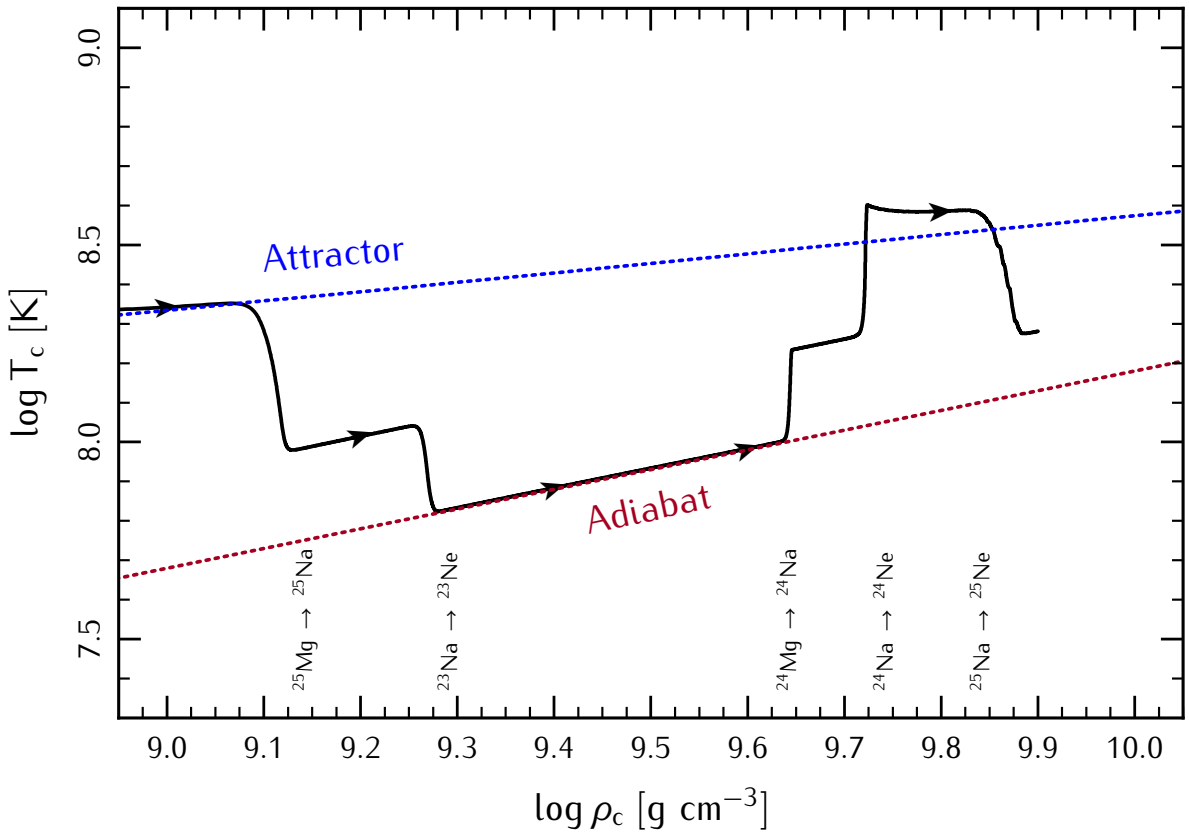


Substantial heating also occurs associated with the $A = 24$ isotopes.



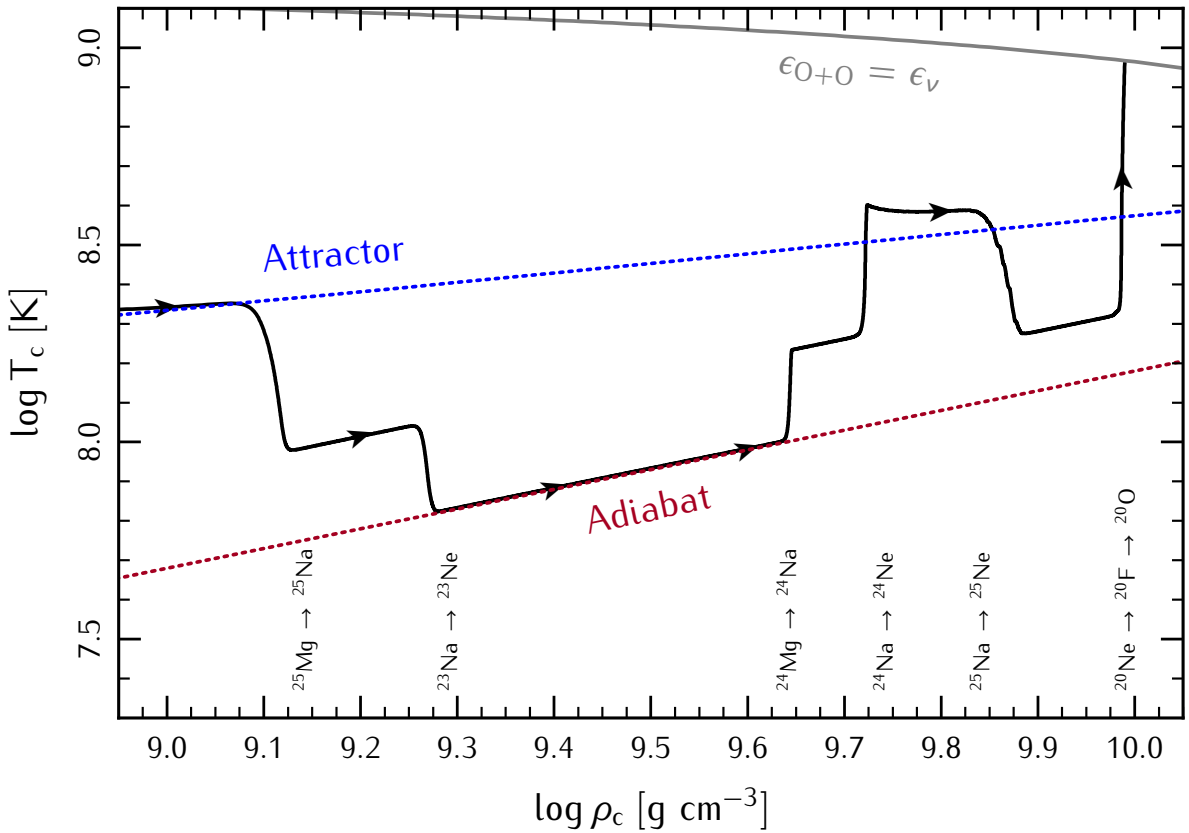
Miyaji et al. (1980, 1987); JS et al. (2015)

Urca-process cooling will set the temperature at the onset of captures on ^{20}Ne.



JS et al. (2017)

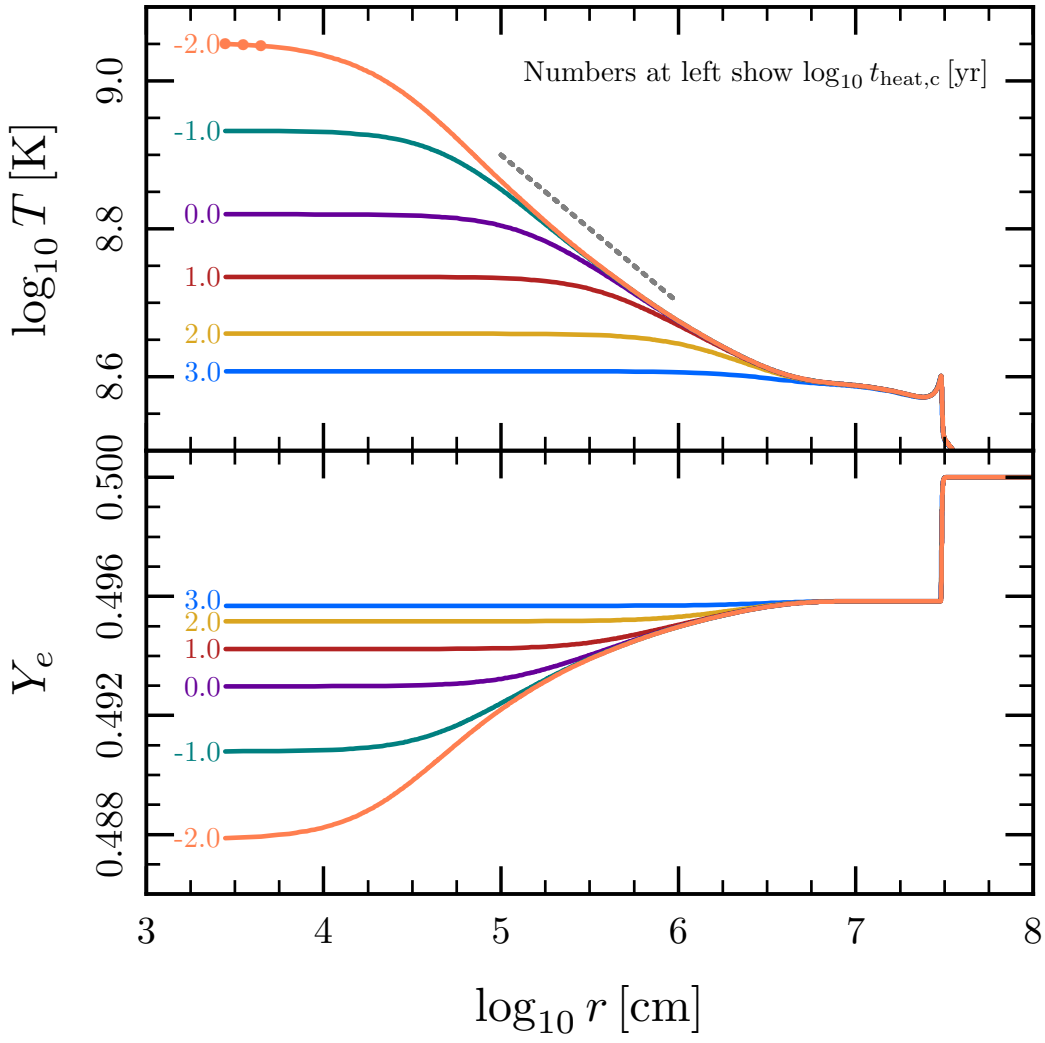
Electron captures on ^{20}Ne are exothermic; this heating will ignite oxygen fusion.



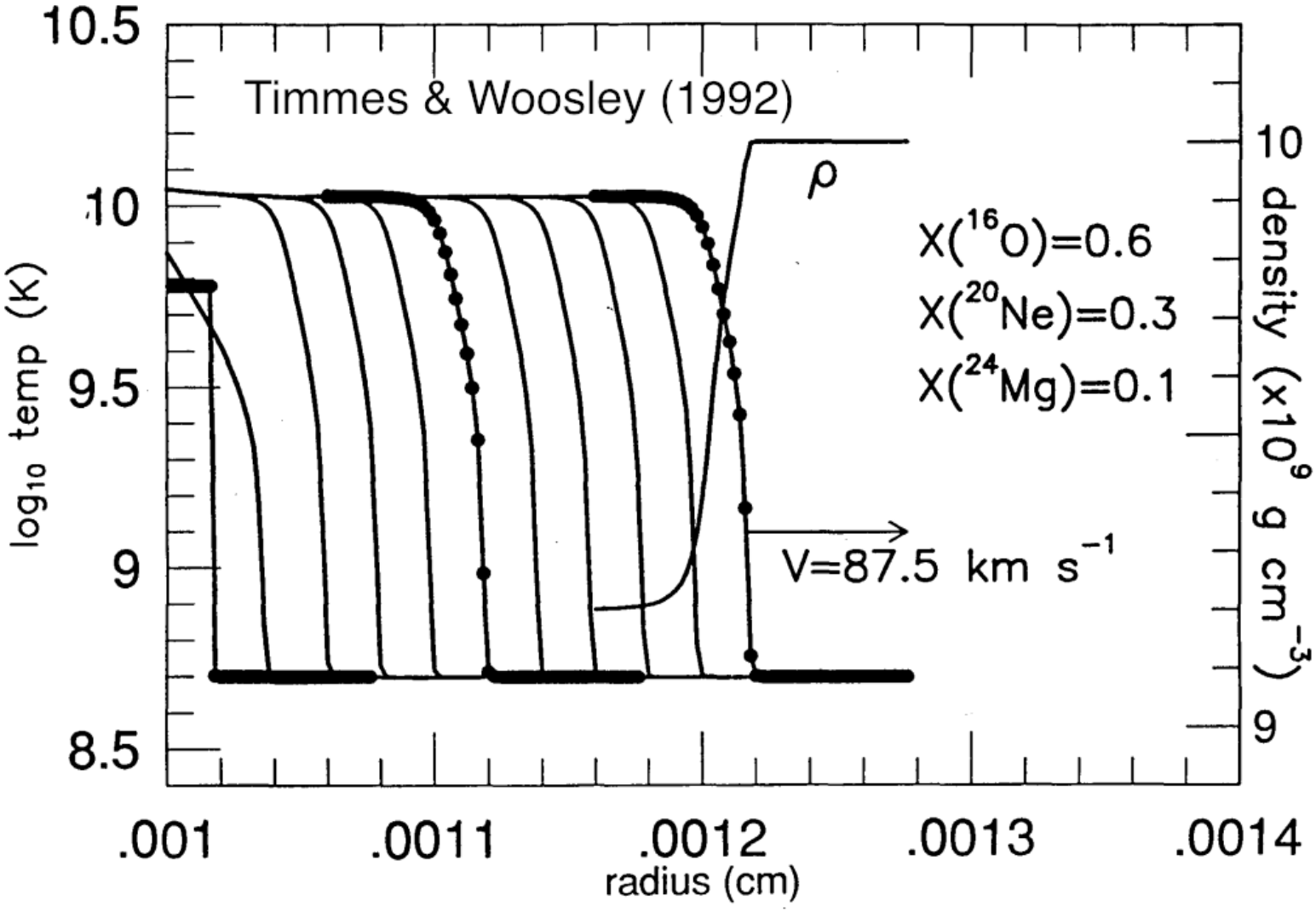
Miyaji et al. (1980, 1987); JS et al. (2015)

A thermal runaway develops in the core;

but convection is not triggered in the core.

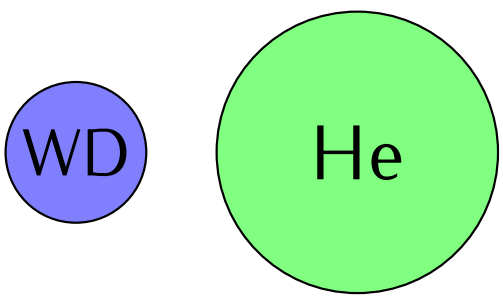


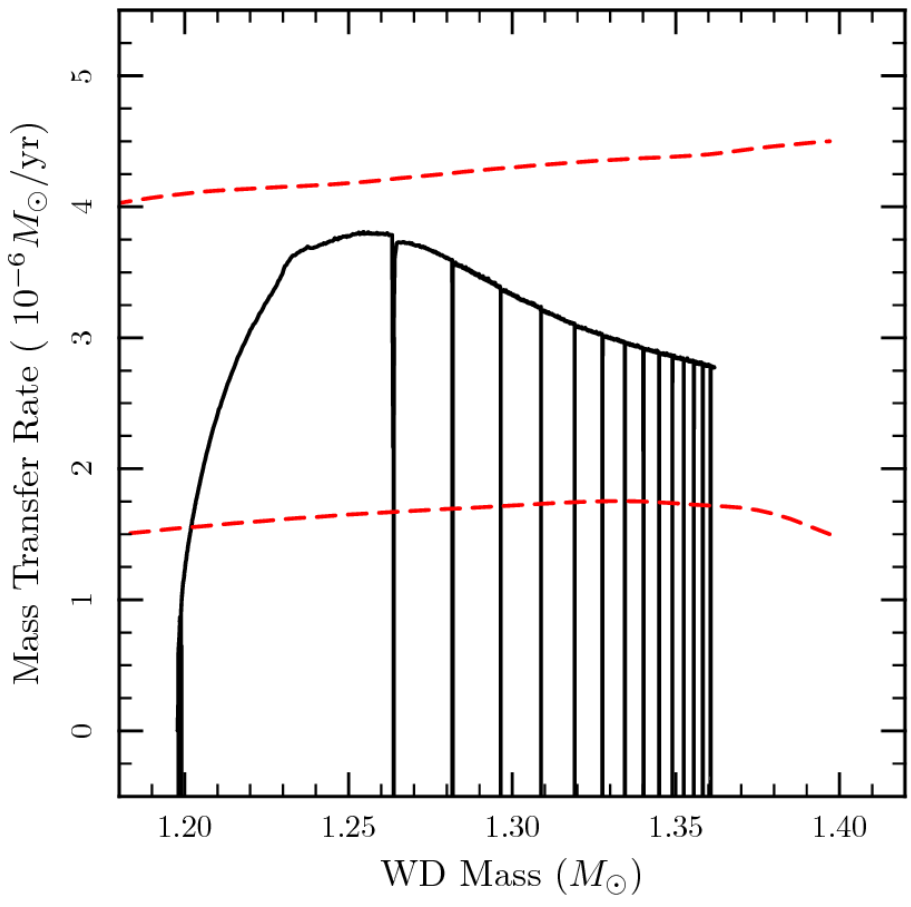
This will lead to the formation
of an outgoing oxygen deflagration wave.



He Star + WD Binaries

Mass transfer after core He-burning gives $\dot{M}$ in the regime for stable He burning on the WD.

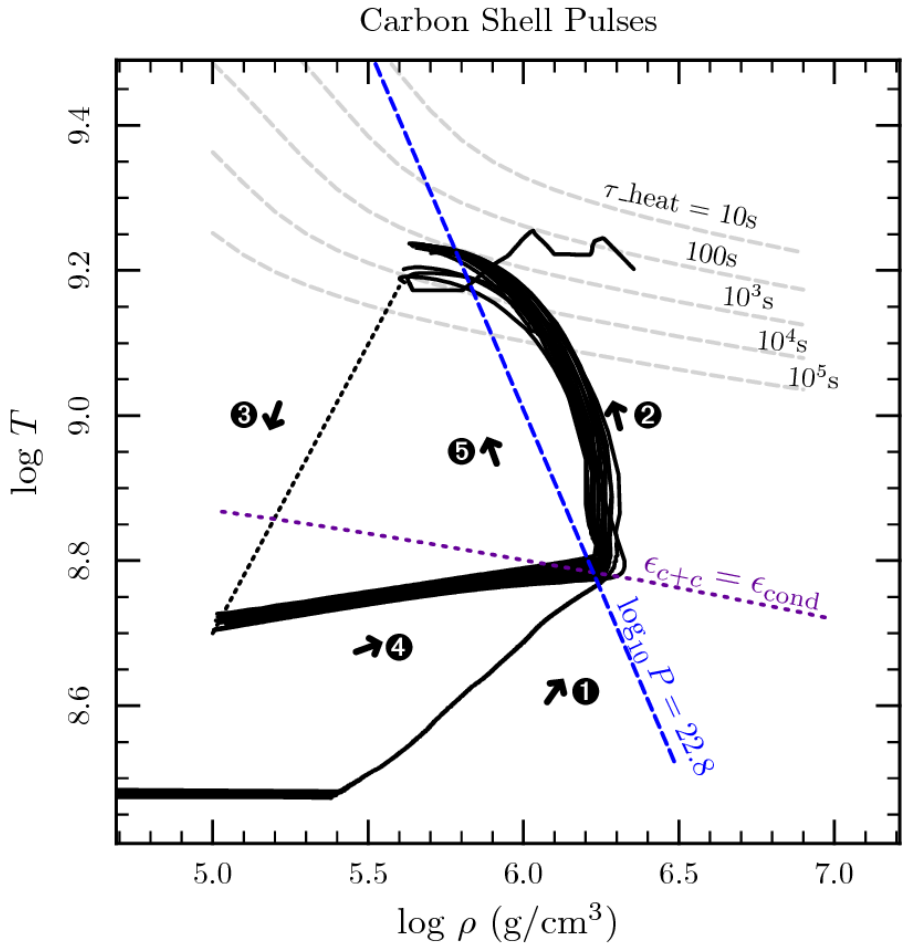




Yoon & Langer (2003); Brooks et al. (2016, 2017)

We evolve both stars plus their orbit;

there is stable He burning, plus carbon flashes.



Brooks et al. (2017)

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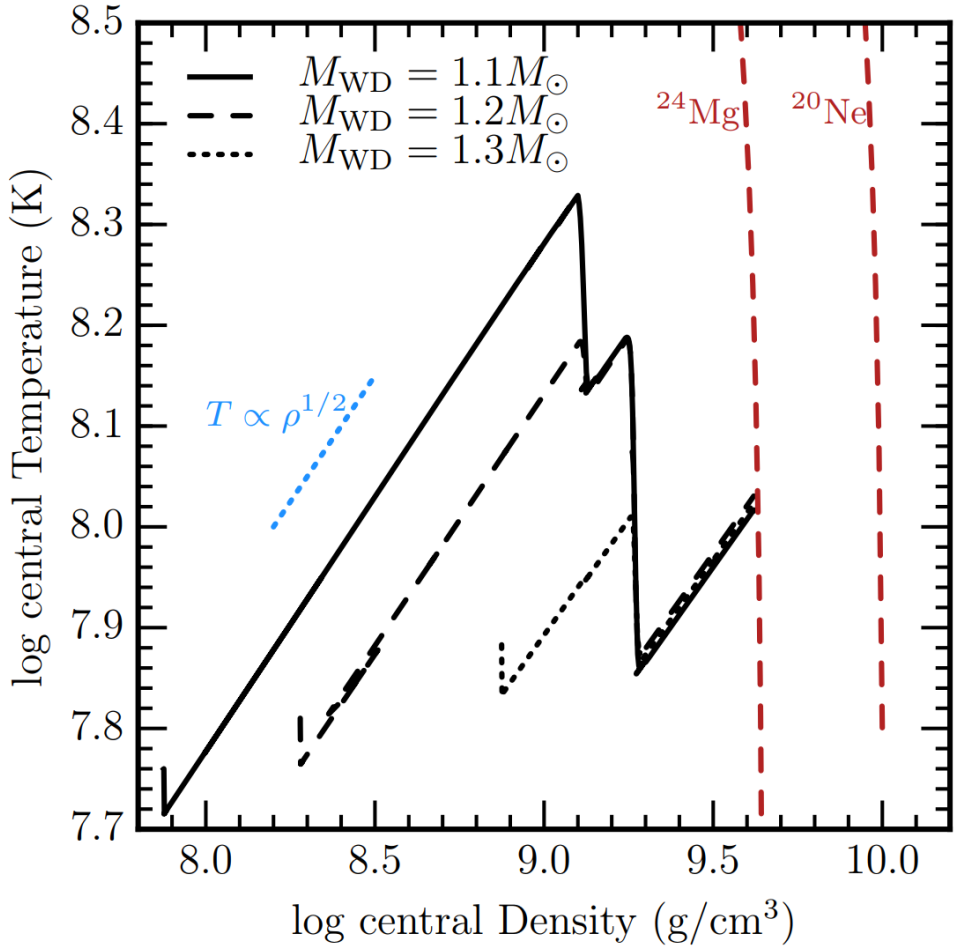
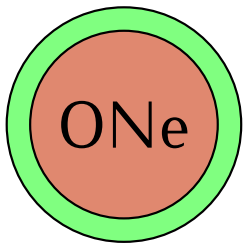


Brooks et al. (2017)

Not only do He + O/Ne WD models reach AIC, but some He + C/O WD models do too.



$\longrightarrow$ AIC

Brooks et al. (2017)

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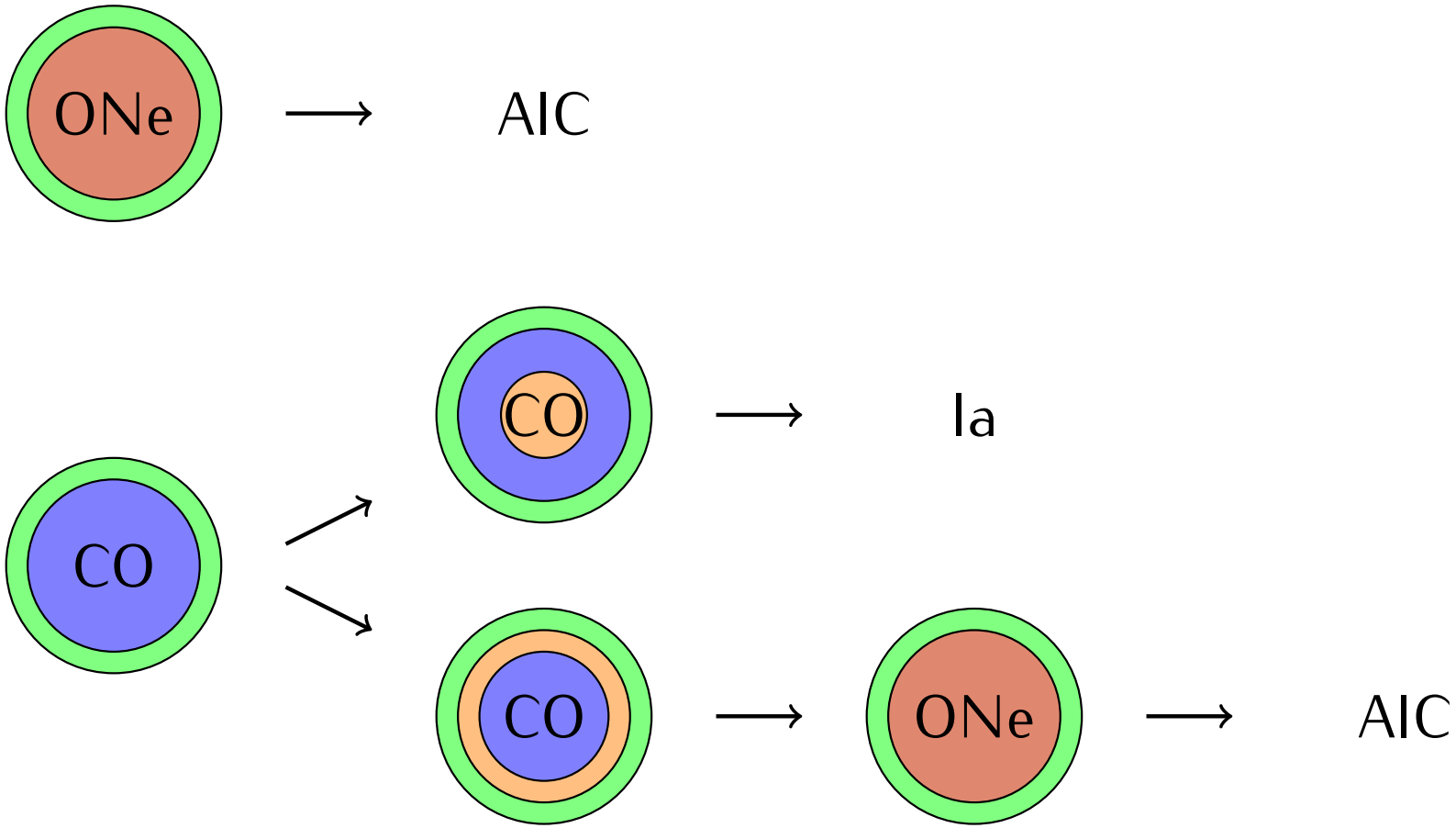

Brooks et al. (2017)

Summary and Conclusions

- This work provides an analytic understanding of the evolution of ONe WDs evolving towards accretion-induced collapse.

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- We have evolved full-star models that resolve the length-scale of the birth of the oxygen deflagration.
- We have binary evolution models of single-degenerate systems evolving to AIC.

Overview of key weak reactions

Weak reactions will drive the evolution.

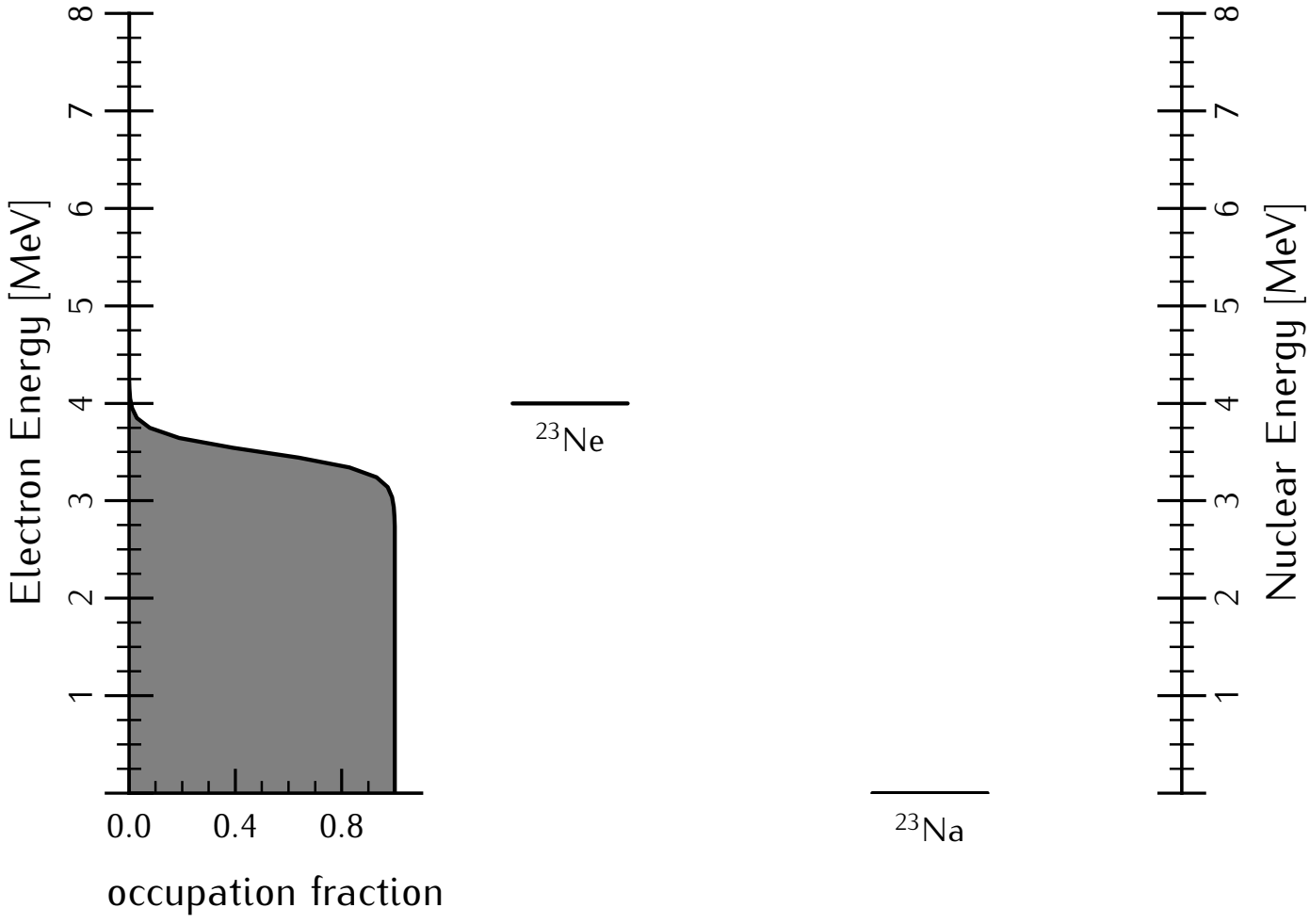
Electron capture

$$(Z, A) + e^- \rightarrow (Z - 1, A) + \nu_e$$

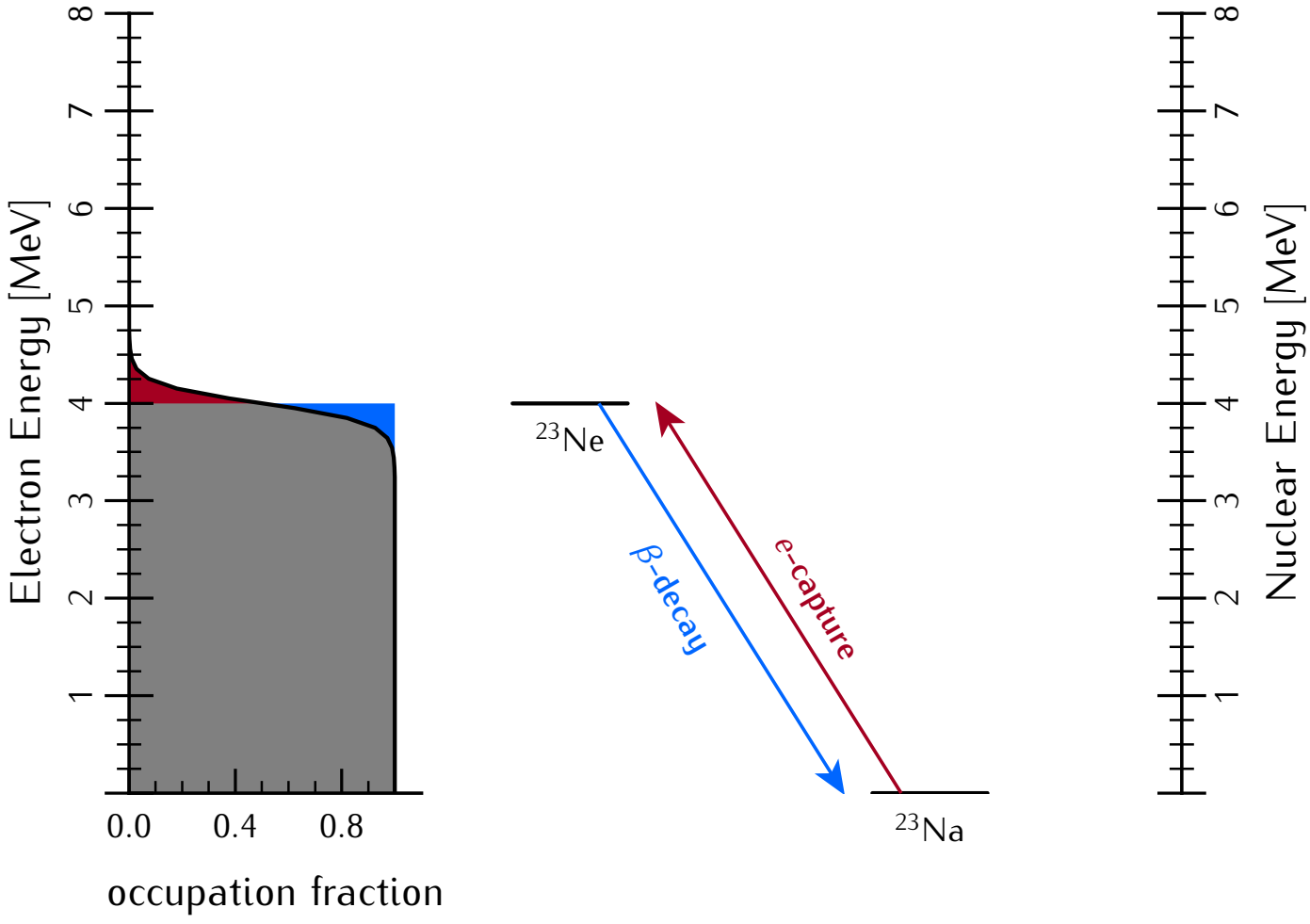
Beta decay

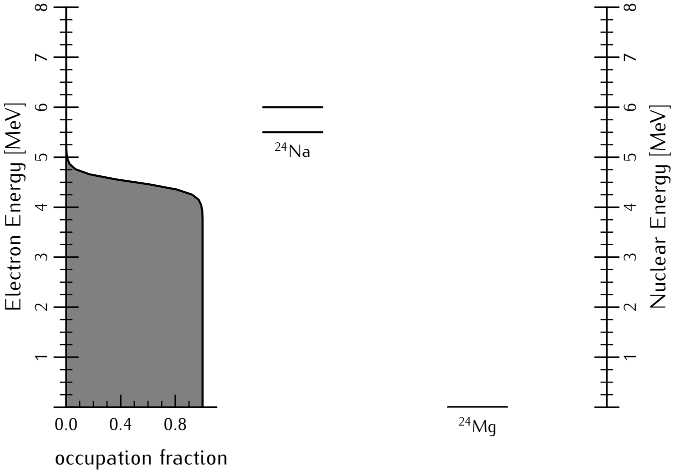
$$(Z - 1, A) \rightarrow (Z, A) + e^- + \bar{\nu}_e$$

The WD is a cold, electron-degenerate plasma; the electron Fermi energy is $\sim$ MeV and rising.



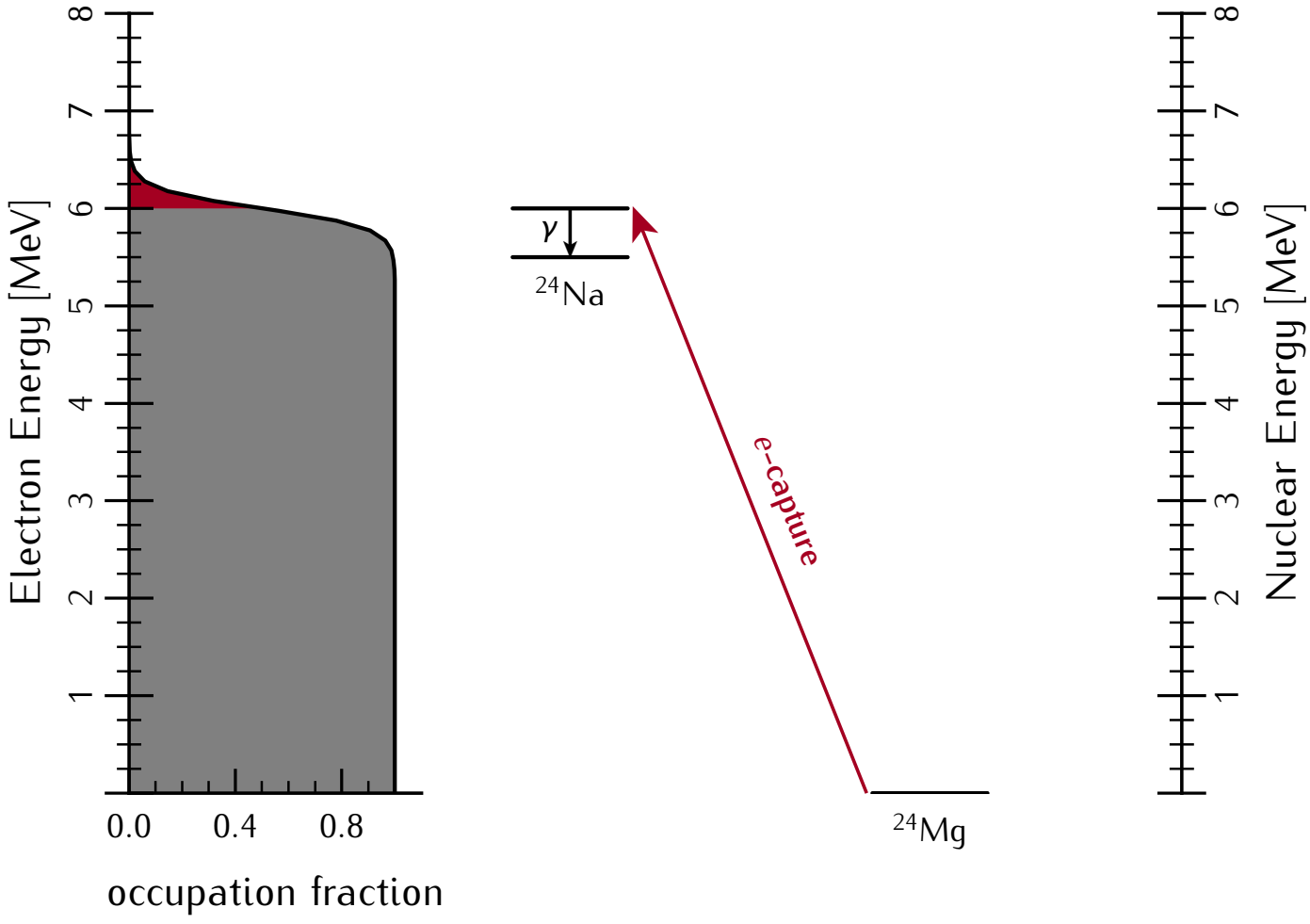
At some particular densities the plasma is cooled by emission of Urca-process neutrinos.





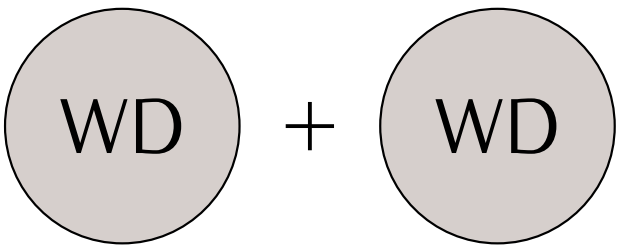
Electron Energy [MeV]
1
2
3
4
5
6
7
8
0.0
0.4
0.8
occupation fraction
^{24}Na
^{24}Mg
Nuclear Energy [MeV]

At some particular densities the plasma is heated by emission of gamma-rays.



Double White Dwarf Mergers

Double white dwarf mergers evolve towards a thermally-supported, spherical state.



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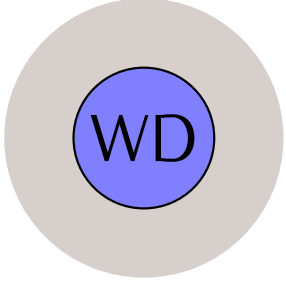
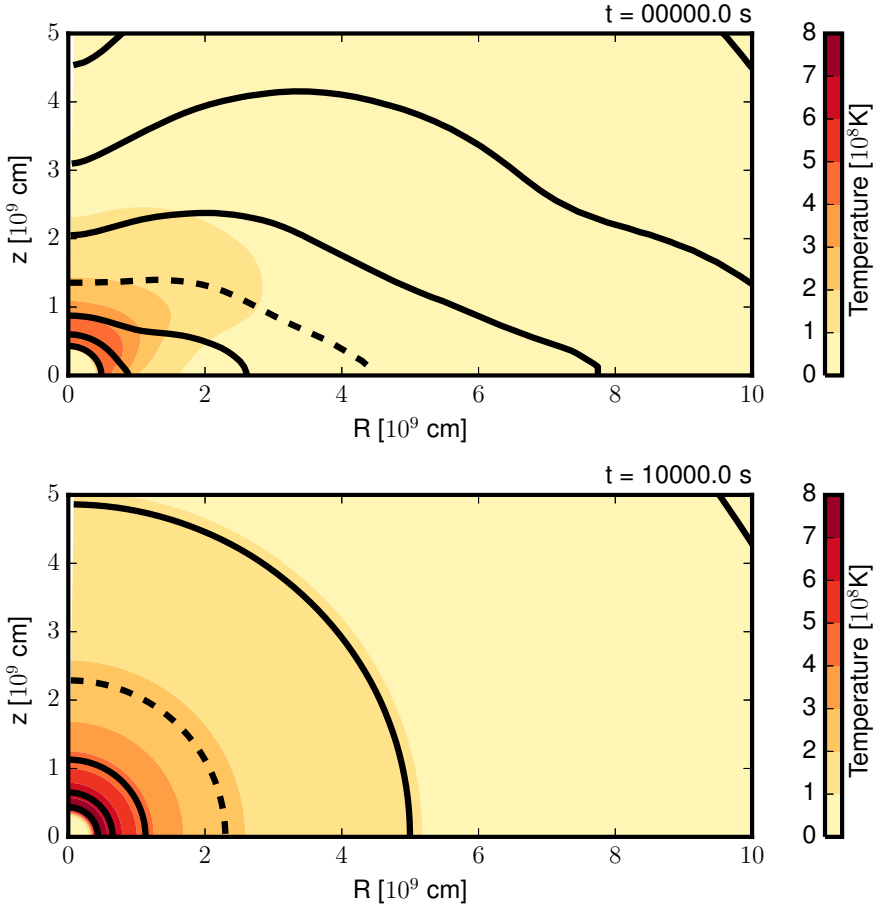
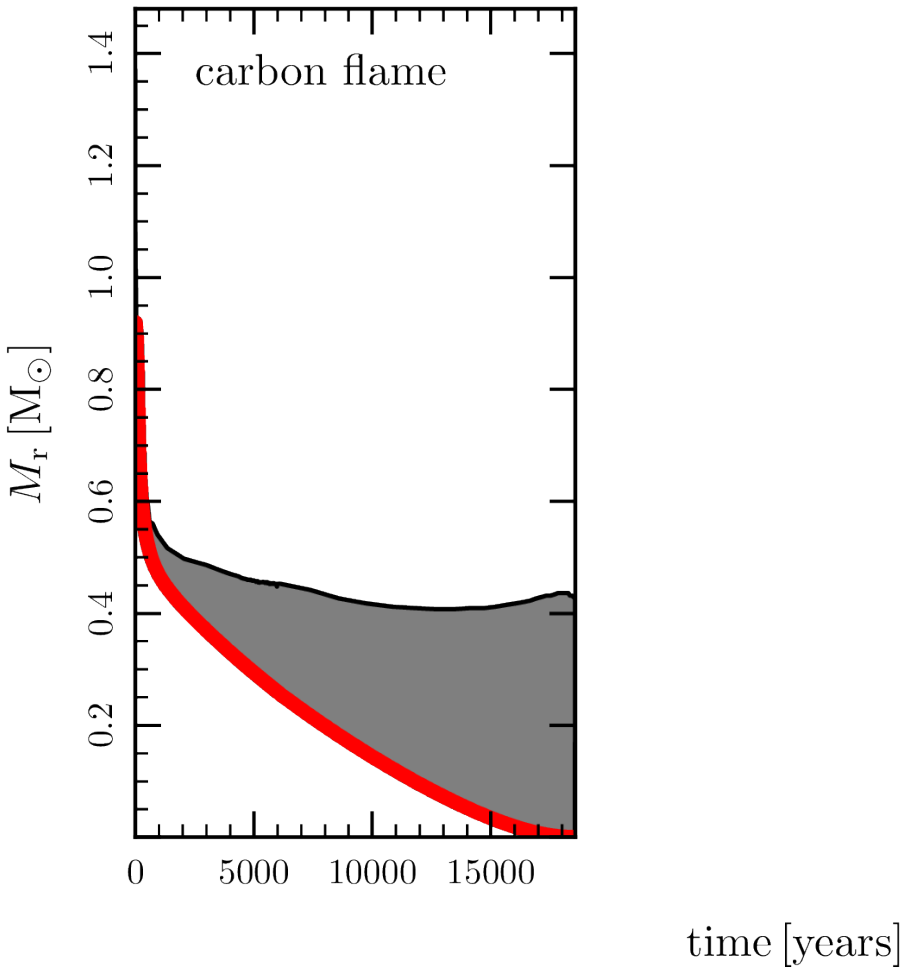




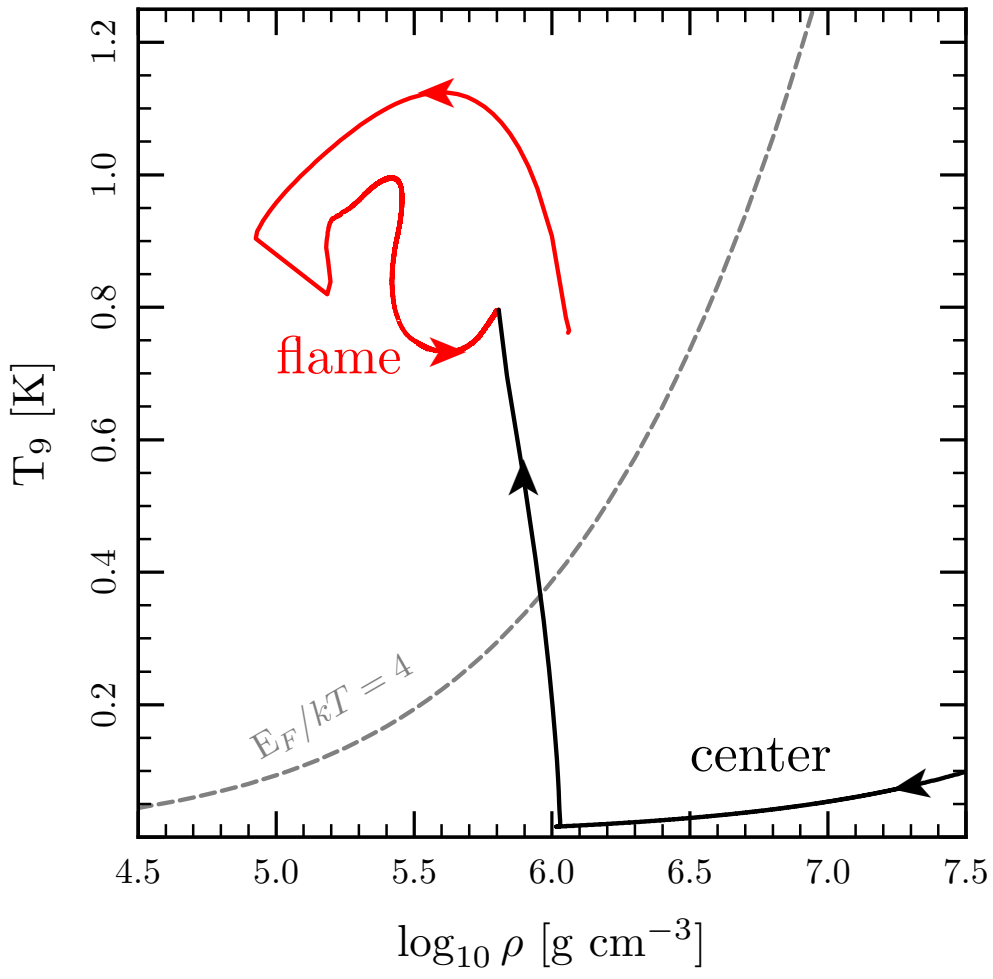
see Shen et al. (2012); Schwab et al. (2012)

A convectively-bounded carbon deflagration forms and propagates inward, reaching the center.

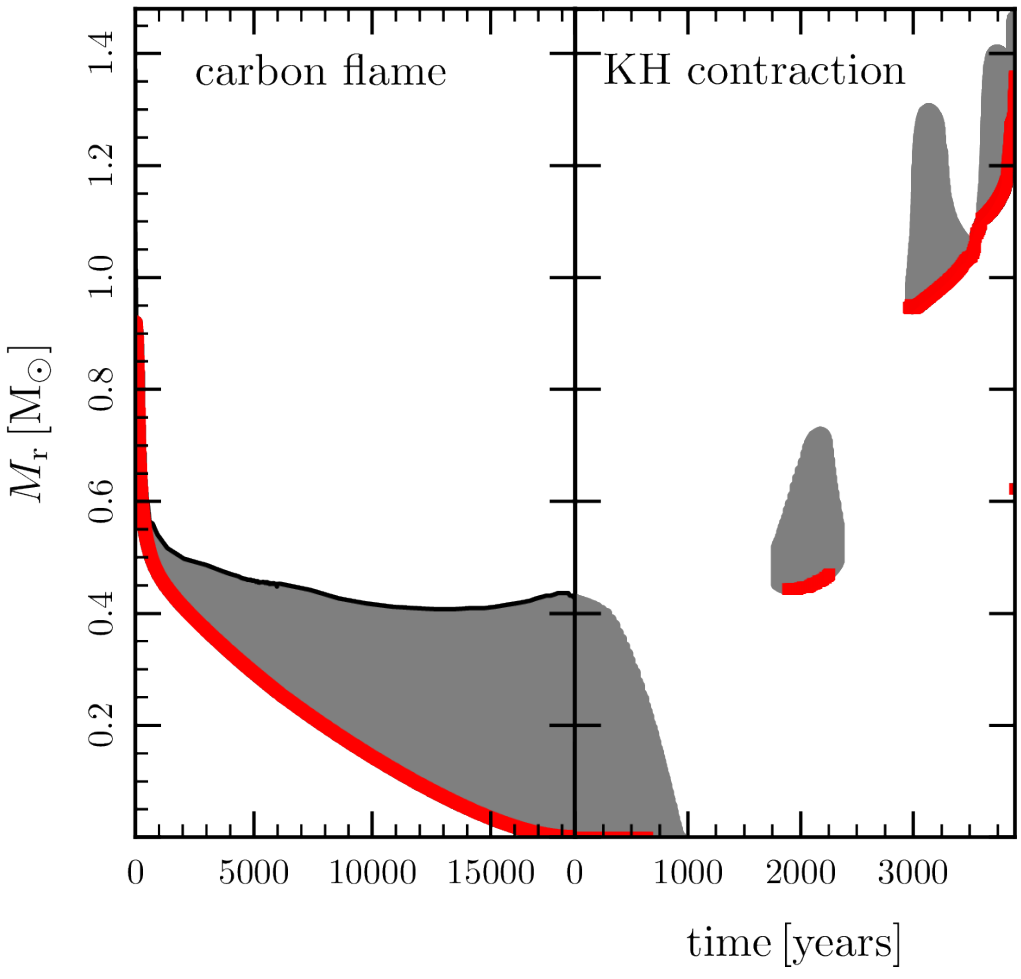


The flame reaches the center;

the material is oxygen-neon and non-degenerate.



Then the remnant undergoes a phase of Kelvin-Helmholtz contraction.



The KH contraction is neutrino-cooled and leads to off-center neon ignition.

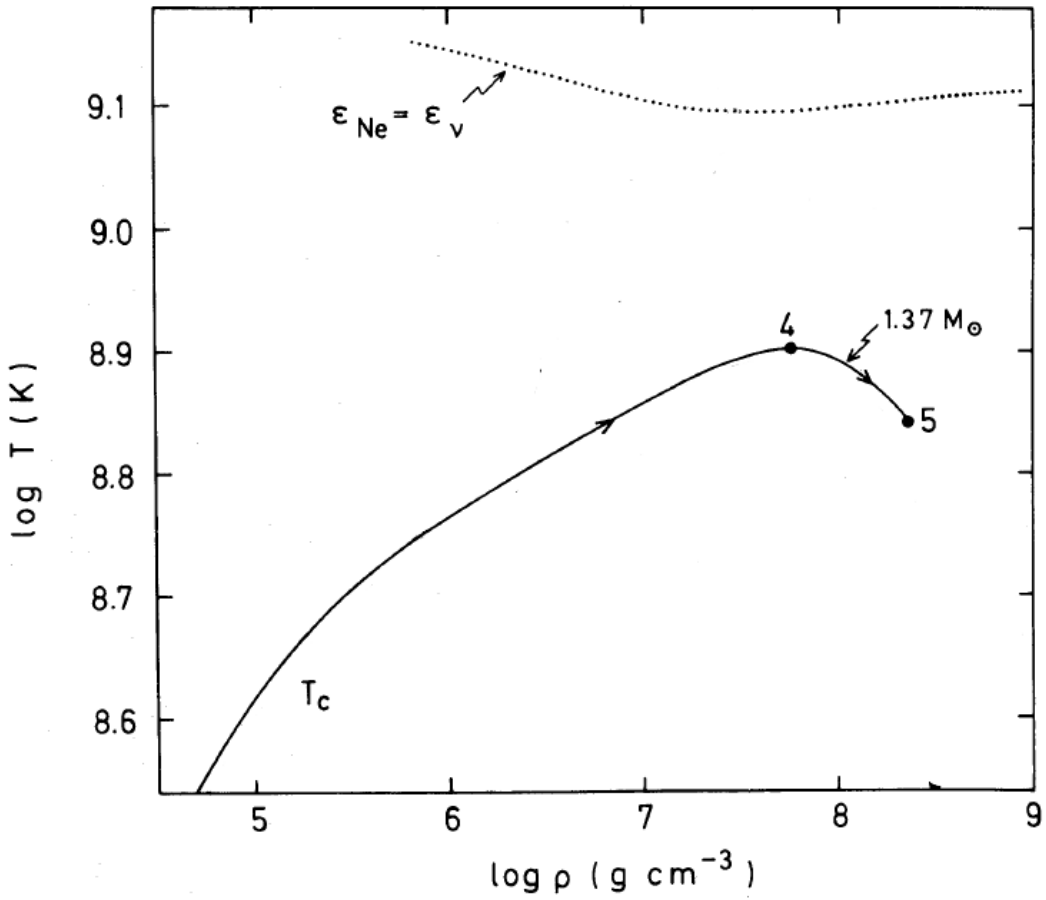


Fig. adapted from Nomoto (1984)

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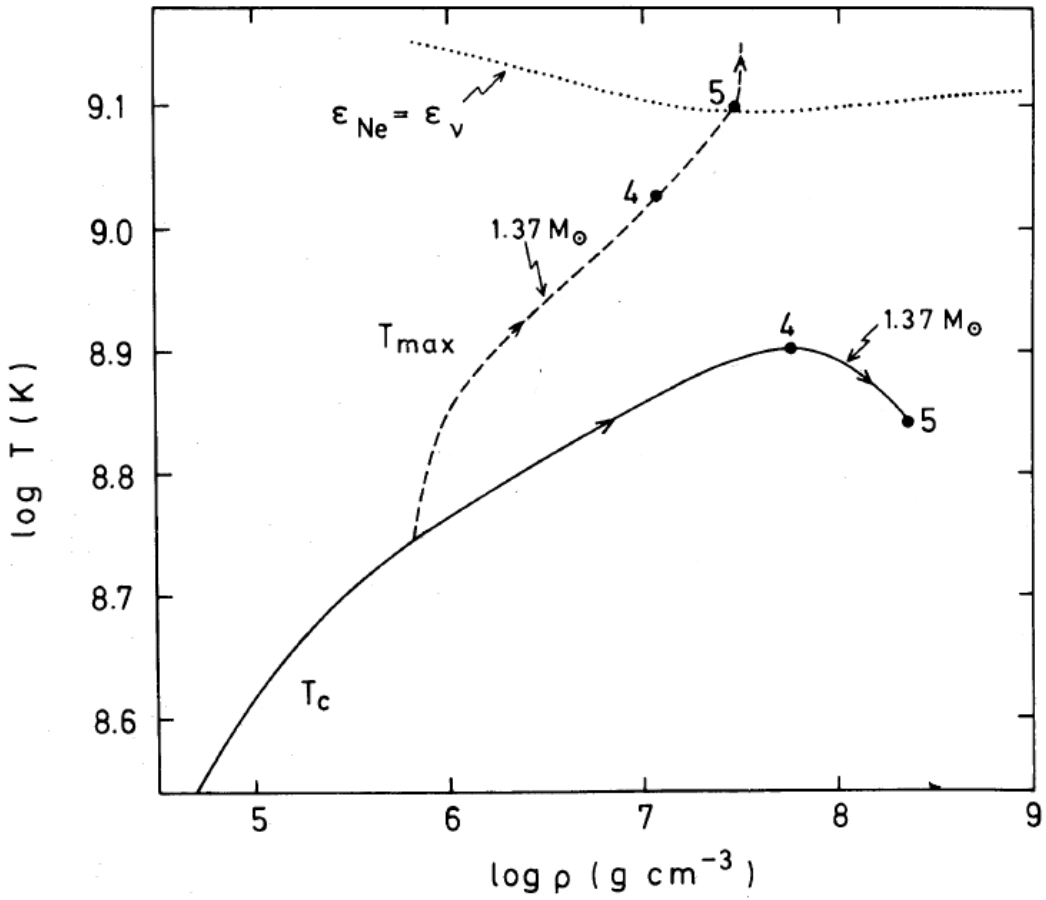
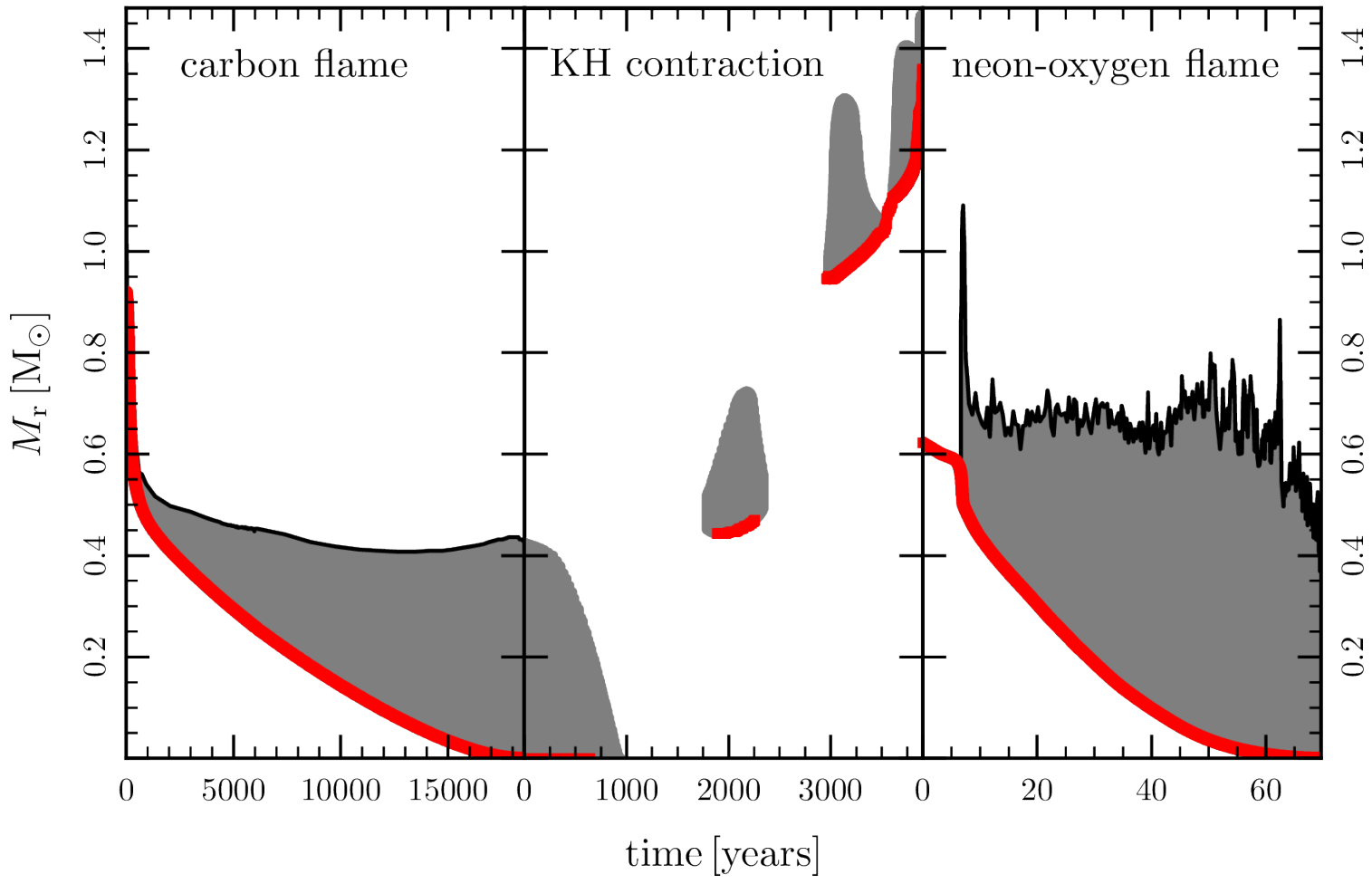


Fig. adapted from Nomoto (1984)

A convectively-bounded neon deflagration forms and propagates inward, destroying O/Ne core.



Post-merger there is a cool, giant phase,

but the carbon-burning is too deep to sustain it.