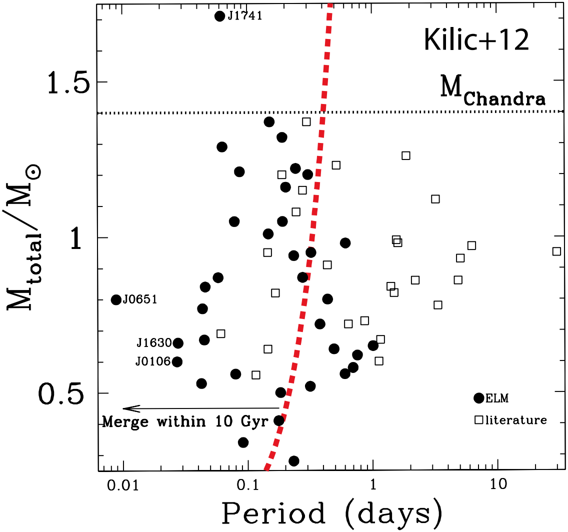
The Long-Term Evolution of White Dwarf Merger Remnants

with L. Bildsten, E. Quataert, K. Shen, & others

Josiah Schwab

18 May 2015

There are WD+WD binaries that will merge.

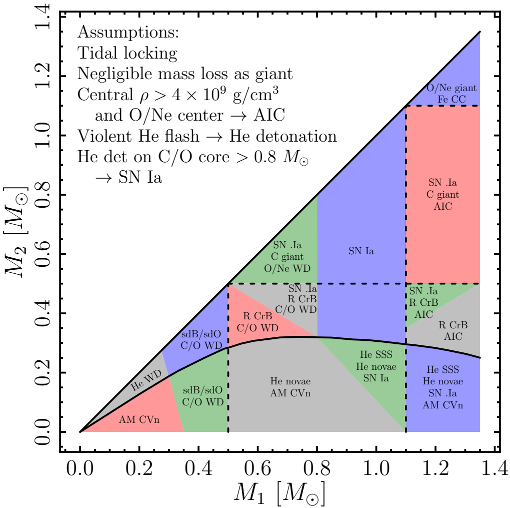


In the Milky Way, the rate is measured to be approximately one WD+WD merger per century.

- The white dwarf merger rate per unit stellar mass is $\boxed{1.4^{+3.4}_{-1.0} \times 10^{-13}\ \mathrm{yr}^{-1}\ \mathrm{M}_{\odot}^{-1}}$.
- The rate of super-Chandrasekhar mergers is only $\boxed{1.0^{+1.6}_{-0.6} \times 10^{-14}\ \mathrm{yr}^{-1}\ \mathrm{M}_{\odot}^{-1}}$.

Badenes and Maoz (2012)

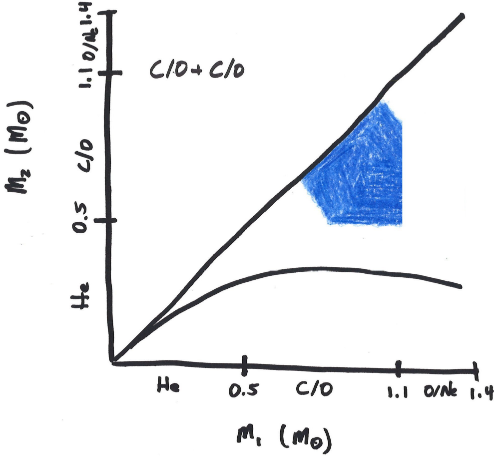
There are a wide variety of post-merger outcomes.



e.g., Webbink (1984), ...

Fig. from K. Shen

I will primarily discuss the merger of two carbon-oxygen (CO) white dwarfs.



If the total mass exceeds the Chandrasekhar mass the remnant may collapse to form a neutron star.

$$1.4\ M_\odot \text{ (neutron star)} + \sim 0.1\ M_\odot \text{ (envelope)}$$

- The small envelope makes these good candidates for generating faint and fast transient events.
- These systems are likely to undergo prompt explosions; prompt explosions are thought to imply low neutron star kick velocities.

The evolution has well-separated timescales.

Dynamical Time (min)

Completion of merger

$t_{\mathrm{dyn}} \sim P_{\mathrm{orb}}$

Viscous Time (hr)

Redistribute ang. mom.

$t_{\mathrm{visc}} \sim \alpha^{-1} P_{\mathrm{orb}}$

Thermal Time (kyr)

Radiate away energy

$t_{\mathrm{therm}} \sim E/L$

The primary WD remains relatively undisturbed;
The secondary WD is disrupted, forming a disk.

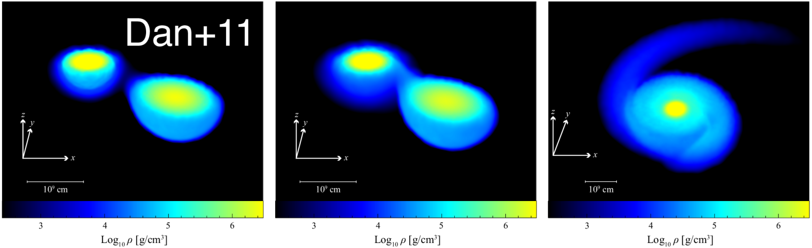


Fig. from Dan et al. (2011)

A new model for the long-term evolution of double WD mergers was proposed by Shen et al. (2012).

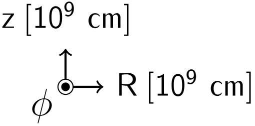
Previous work (e.g., Nomoto & Iben 1985)

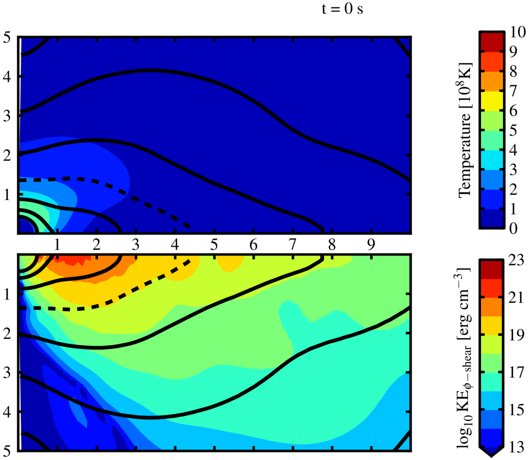
- Material from this disk will accrete onto the primary WD at the Eddington limit.

Shen et al. (2012) model

- The disk will evolve viscously, converting the kinetic energy in the Keplerian shear into heat, long before cooling significantly.

I've done multi-D hydro calculations of the viscous evolution (Schwab et al. 2012)





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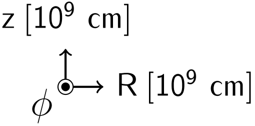

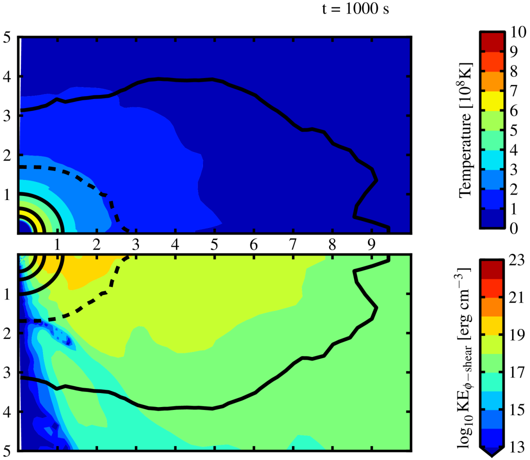

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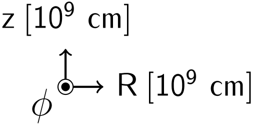
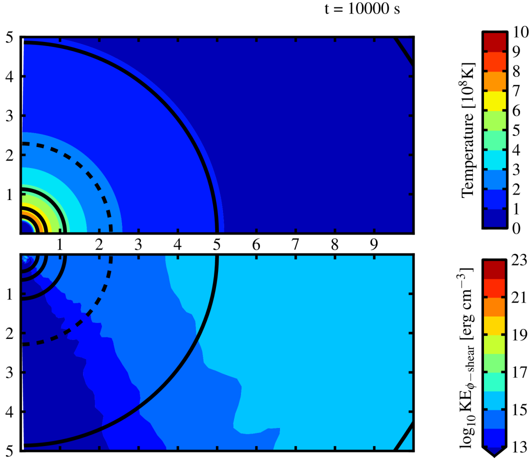
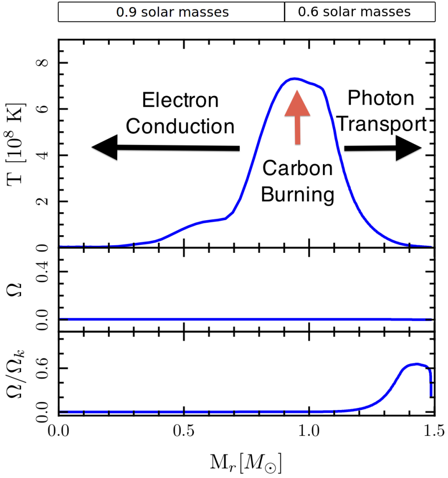




Energy generation and heat transport will drive the next phase of evolution.



Introduction to WD+WD Mergers

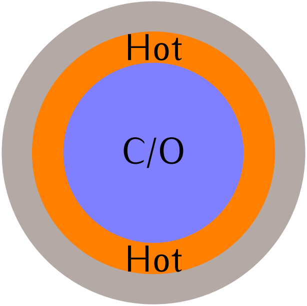
The Viscous Evolution of WD Merger Remnants

The Thermal Evolution of WD Merger Remnants

Evolution towards Accretion-Induced Collapse

Conclusions

This doesn't make a Type Ia Supernova.



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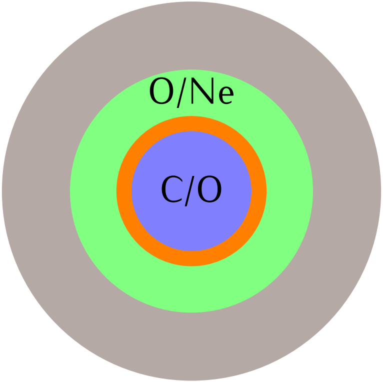

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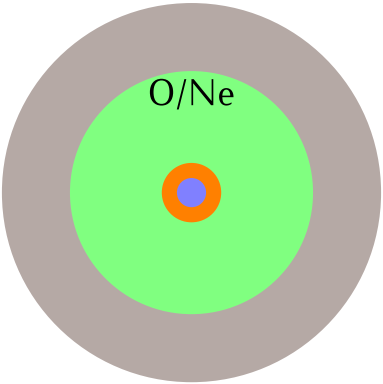

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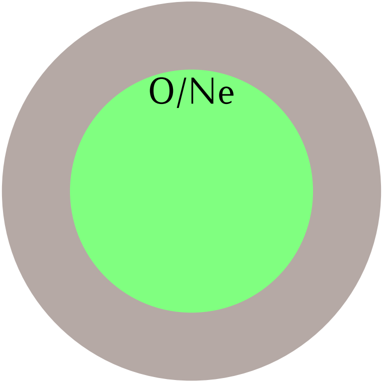
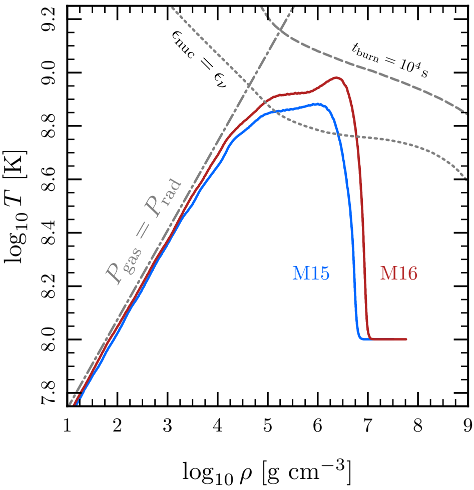
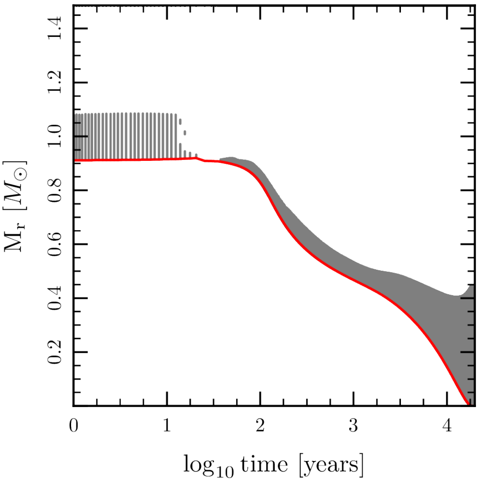


The WD+WD merger ignites carbon off-center.

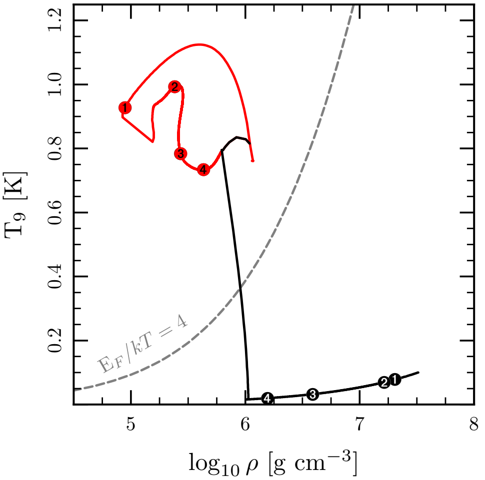


Carbon flame propagates inward...



e.g., Timmes et al. (1994)

…which converts the WD to oxygen-neon and lifts the degeneracy.



The oxygen-neon core will contract;
this will cause off-center Ne ignition.

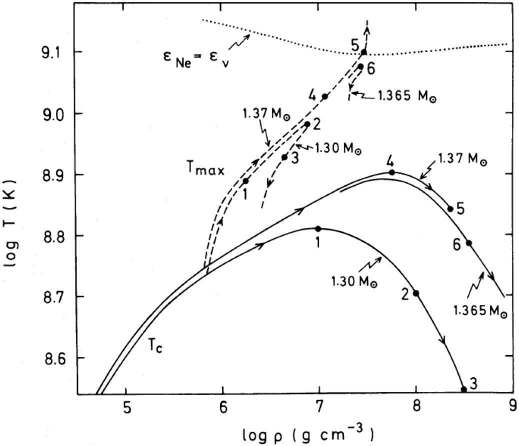
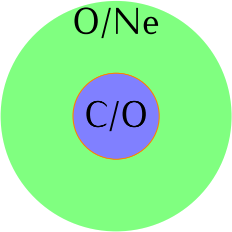


Fig. from Nomoto (1984)

The outcome depends on the central composition; does the off-center burning reach the center?

Hybrid Ia



Denissenkov+ (2013)

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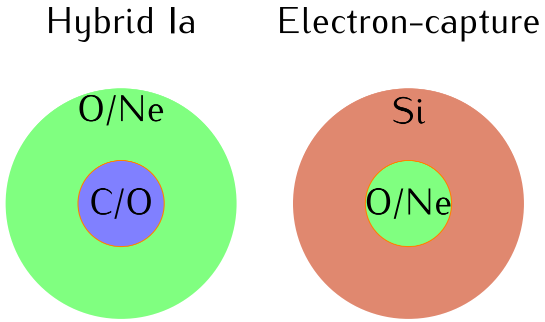

Denissenkov+ (2013)

Schwab+ (2015)

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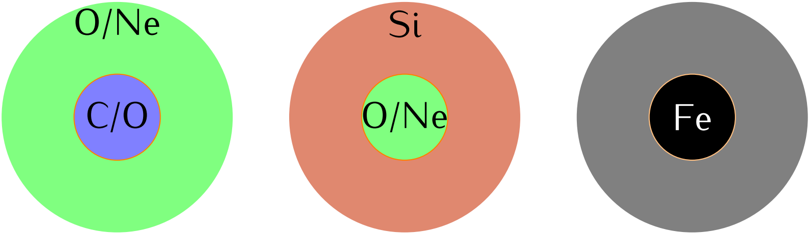
Hybrid Ia | Electron-capture | Core-collapse



Denissenkov+ (2013) | Schwab+ (2015) | Schwab+ (in prep)

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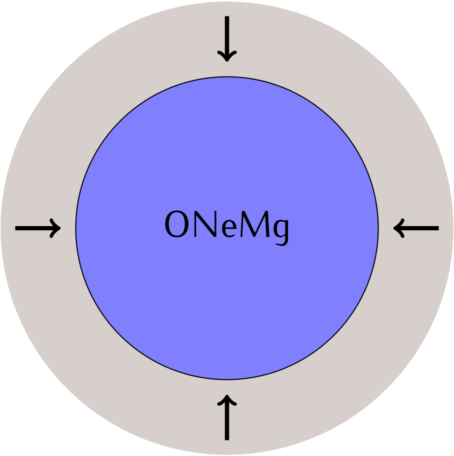
What happens as an ONeMg white dwarf approaches the Chandrasekhar mass?



Near the Chandrasekhar mass, the central density of the white dwarf increases dramatically.

When the central density (ρ_c) has increased by an order of magnitude...

- $M \approx 1.37 M_\odot \rightarrow \rho_c \approx 10^9 \text{ g cm}^{-3}$
- $M \approx 1.43 M_\odot \rightarrow \rho_c \approx 10^{10} \text{ g cm}^{-3}$

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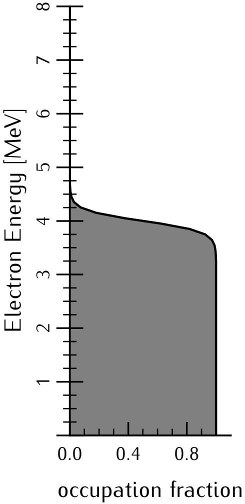
...the electron chemical potential (μ_e) will have doubled.

- $\rho_c \approx 10^9 \text{ g cm}^{-3} \rightarrow \mu_e \approx 4 \text{ MeV}$
- $\rho_c \approx 10^{10} \text{ g cm}^{-3} \rightarrow \mu_e \approx 9 \text{ MeV}$

Electron capture reactions become important!



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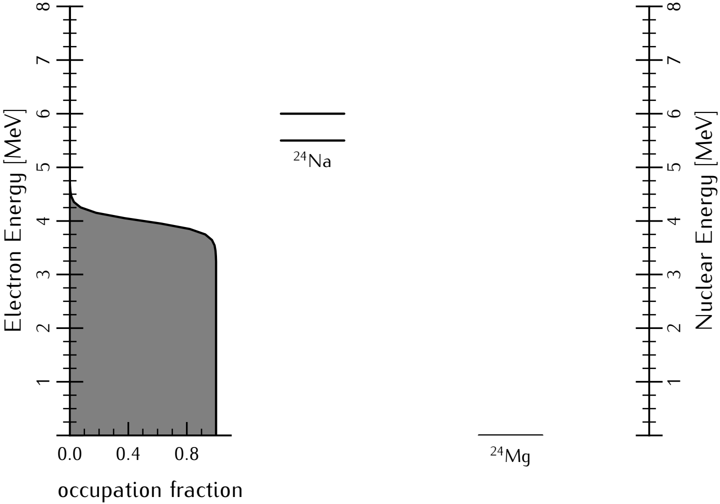

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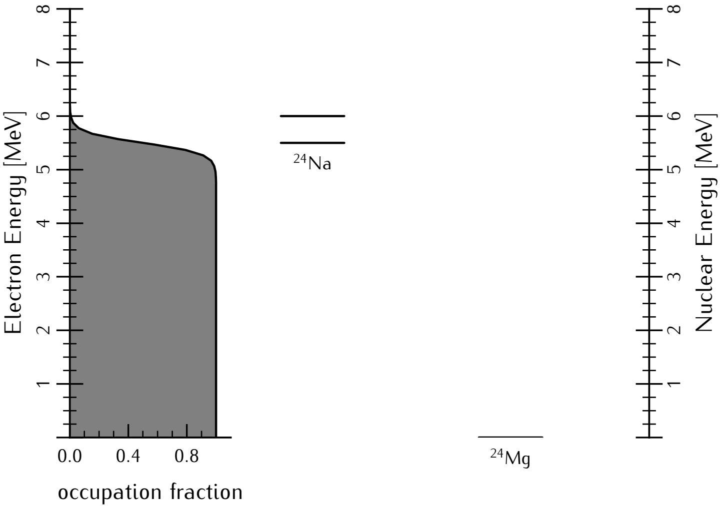

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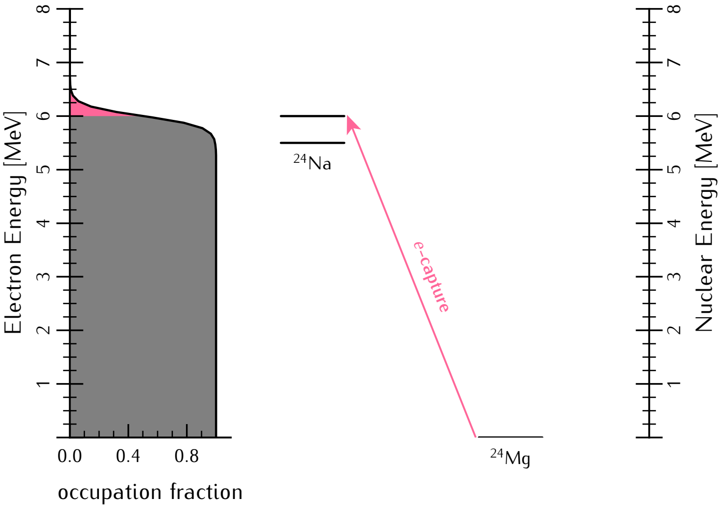

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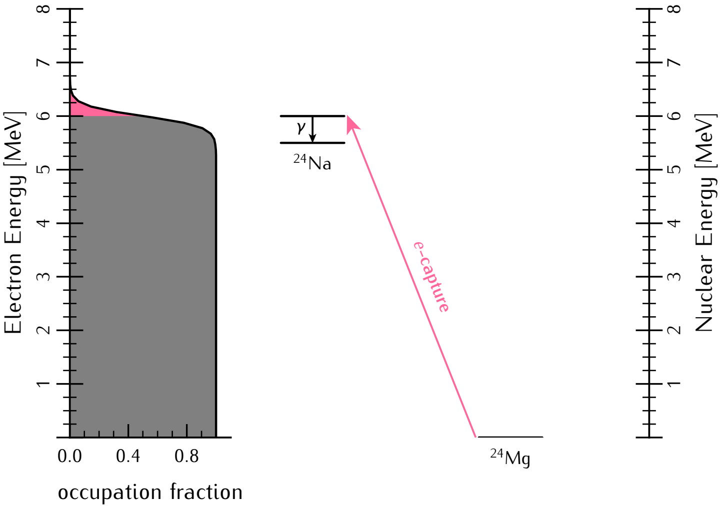
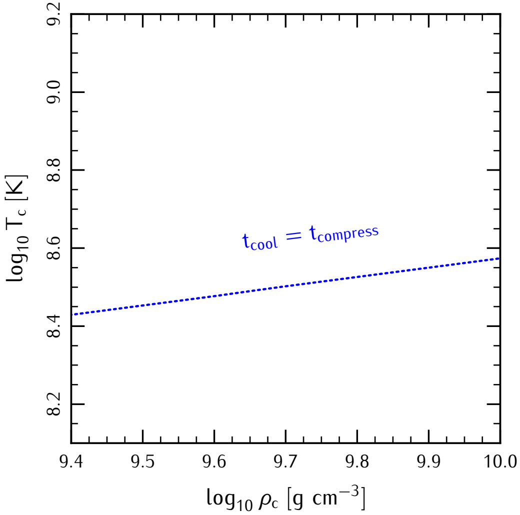


The temperature is set by a balance between compression and neutrino cooling.



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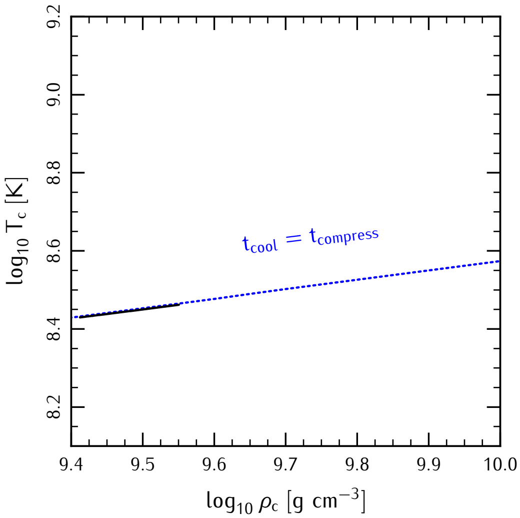
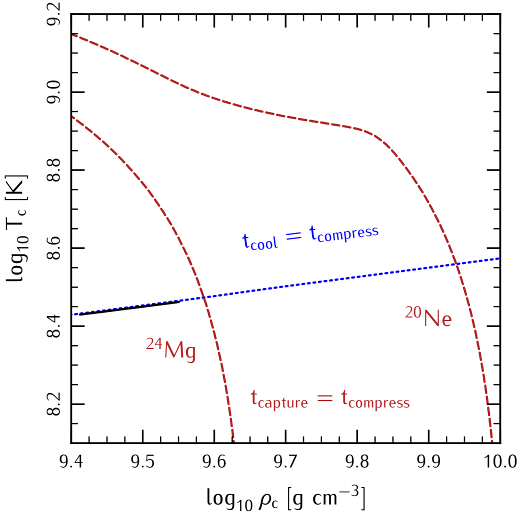


Electron-captures are important when their rate is approximately the compression rate.



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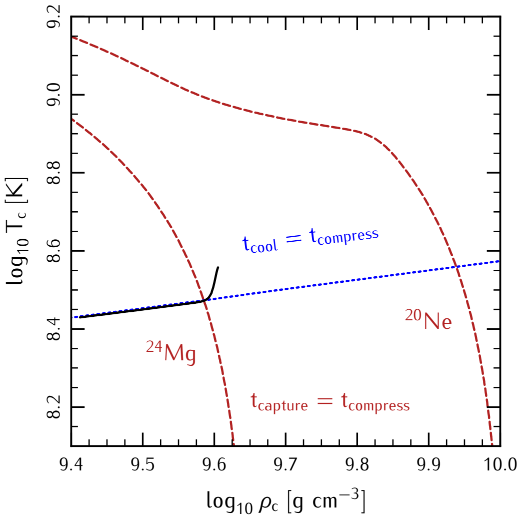
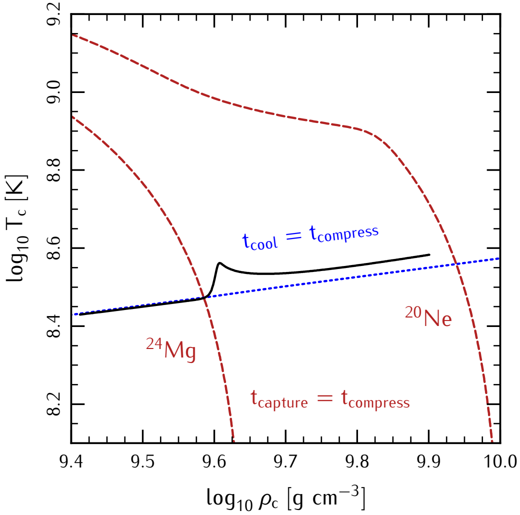
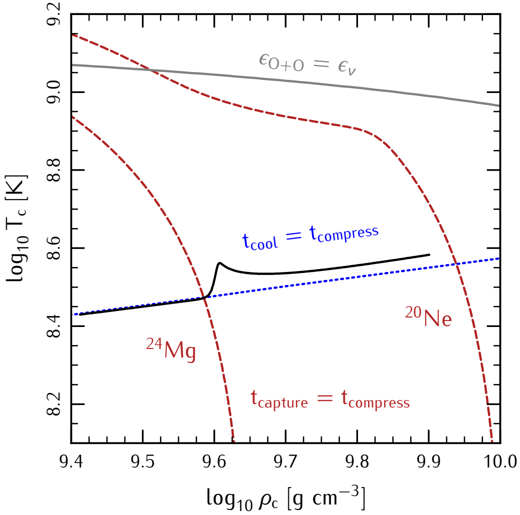


Magnesium captures remove electrons, leading to more rapid compression.



Neon captures cause a large temperature change; this will ignite oxygen fusion.



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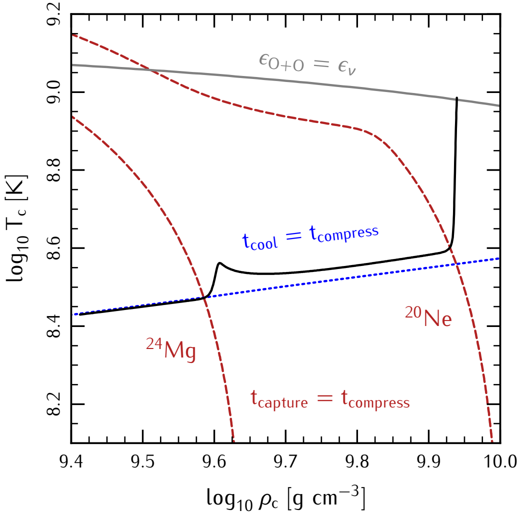
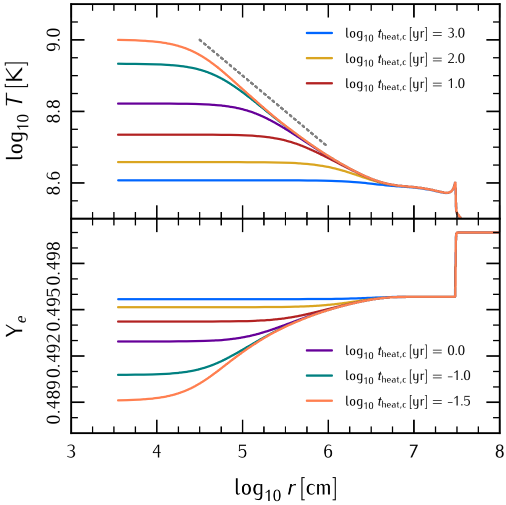
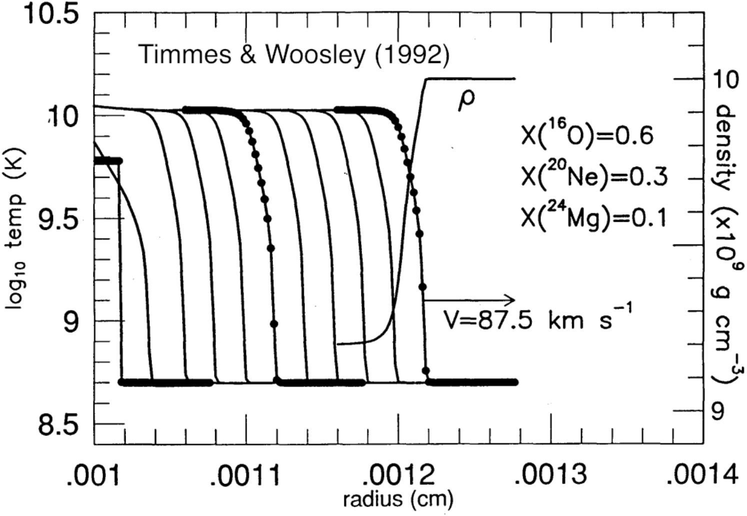


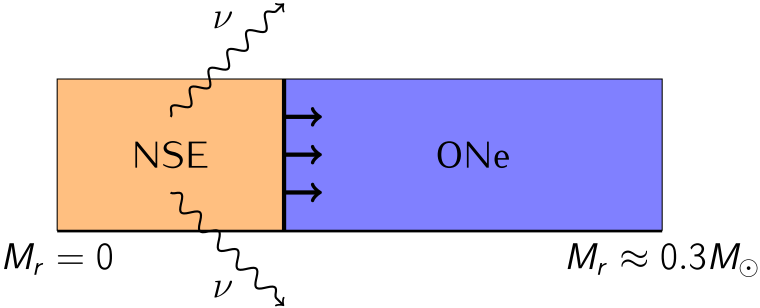
A thermal runaway develops in the core;
but convection is not triggered in the core.



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



There is a competition between the deflagration and the weak reactions occurring in its ashes.



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We have:

- provided an analytic understanding of the evolution of ONeMg cores towards AIC.
- demonstrated the presence of a thermal runaway in the core, which will trigger an oxygen deflagration at a density such that collapse to a neutron star is likely.
- enabled the generation of realistic progenitor models for studies of the observational signatures of accretion-induced collapse.

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- For super-Chandrasekhar WD mergers, the likely fate is collapse to a neutron star; the evolution towards collapse appears to be more complicated than previously understood.

- This work is important make the realistic progenitor models necessary to predict the observational signatures of these events.