The Evolution of ONe White Dwarfs towards Accretion-Induced Collapse

with L. Bildsten, E. Quataert & others

Josiah Schwab

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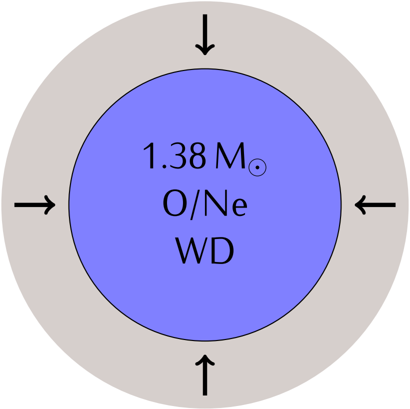
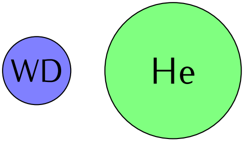
Accretion-induced collapse (AIC) occurs when an O/Ne WD reaches a critical mass.



Multiple channels are thought to lead to AIC.

Single-Degenerate



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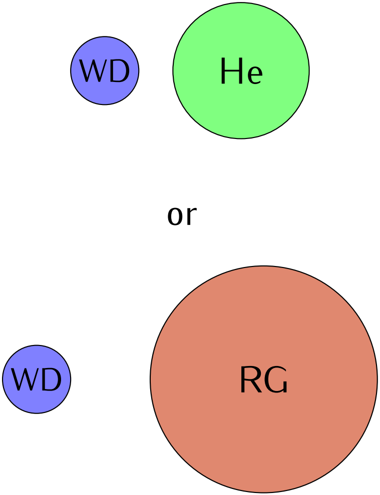

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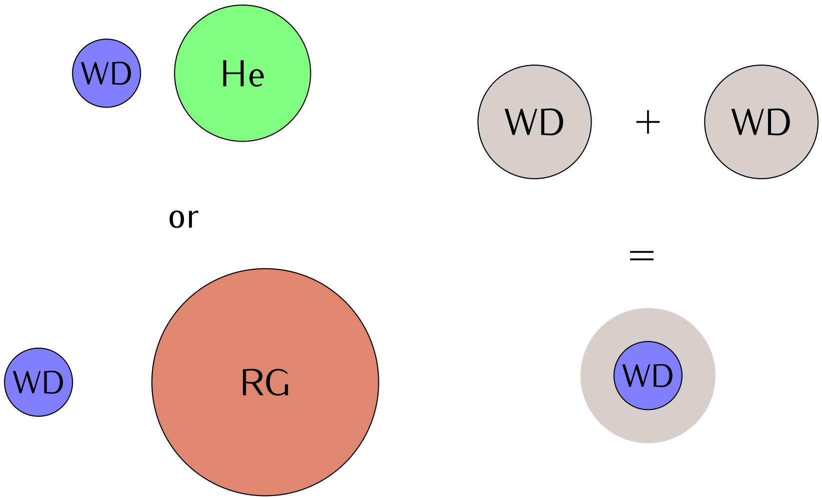

No direct observations of AIC have yet been made.

- Models of the collapse of a massive WD to form a neutron star (NS) produce a weak explosion and $\sim 10^{-3}\,M_\odot$ of Ni-rich ejecta.

  Woosley & Baron (1992); Dessart et al. (2006);

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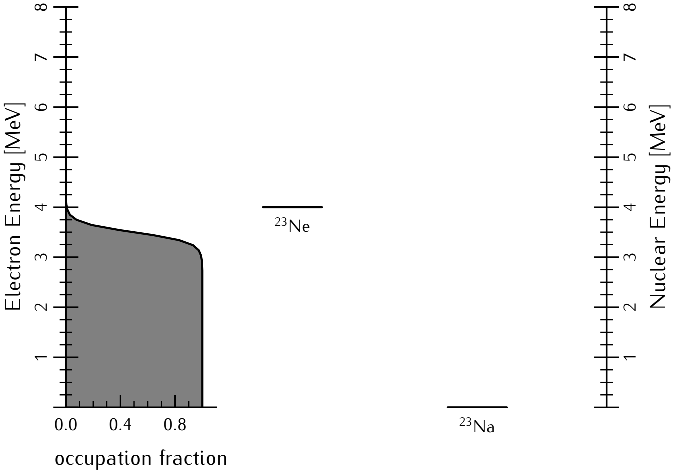
- Other radio, optical, and X-ray signatures have been predicted, but depend on whether
  - the progenitor systems have surrounding material
  - other aspects of the evolution synthesize Ni-56
  - the newly formed NS is a magnetar

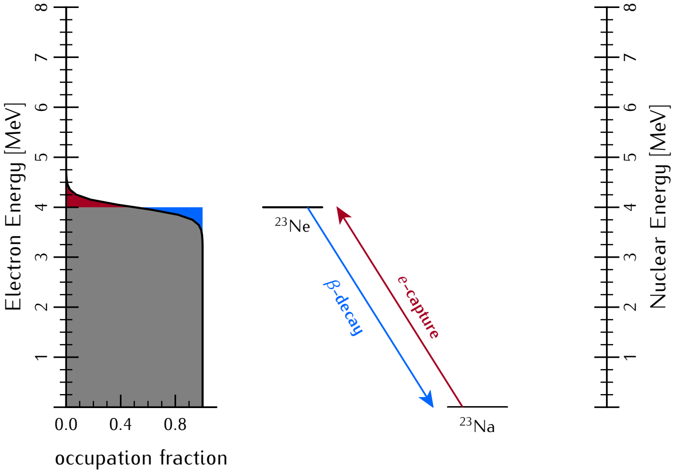
  Piro & Kulkarni (2013); Metzger & Bower (2014)

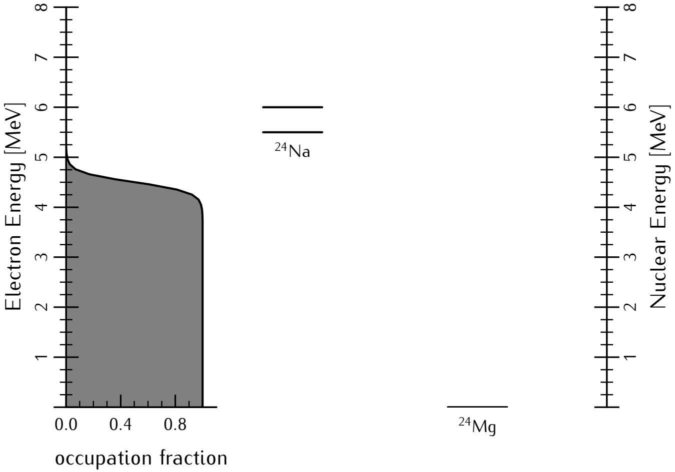
Our goal is to comprehensively re-address AIC in order to develop a modern understanding of progenitor systems, which will provide much-needed initial models for predictions of the lightcurves and spectra.

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

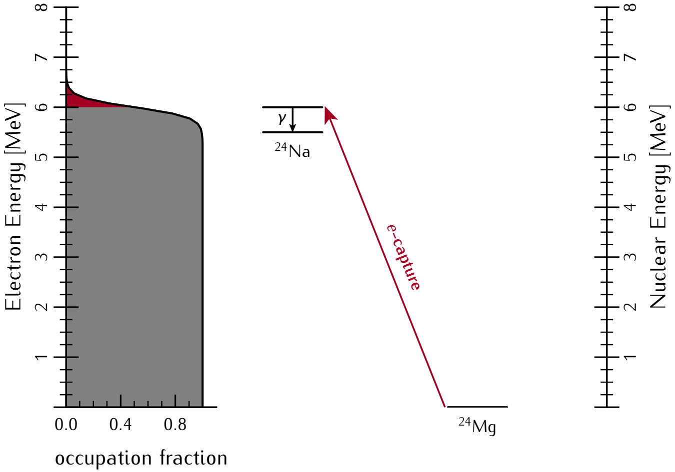


At some particular densities the plasma is cooled by emission of Urca-process neutrinos.

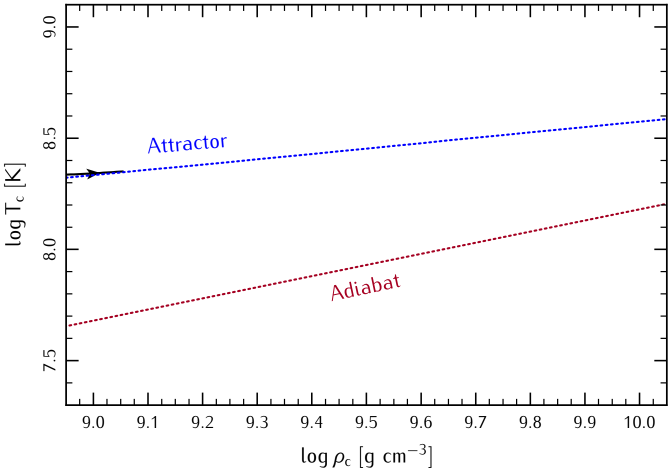



Electron Energy [MeV]
Nuclear Energy [MeV]
1
2
3
4
5
6
7
8
0.0
0.4
0.8
occupation fraction
^{24}Na
^{24}Mg

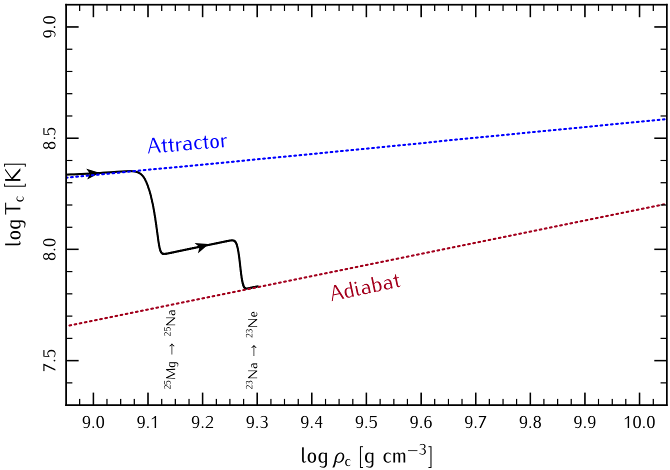
At some particular densities the plasma is heated by emission of gamma-rays.



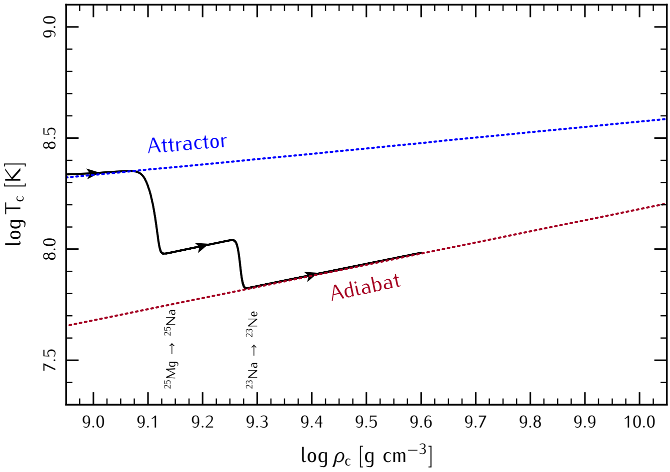
Initially, the temperature is set by a balance between compression and neutrino cooling.



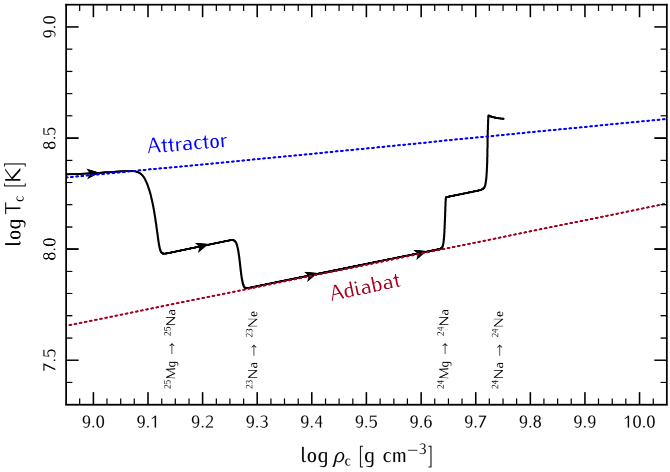
Substantial Urca-process cooling occurs associated with the $A = 23$ and $A = 25$ isotopes.



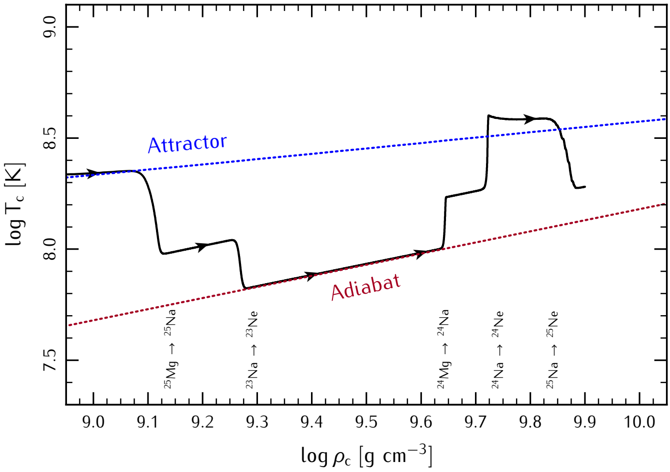
This shuts off neutrino cooling
and the material evolves along an adiabat.



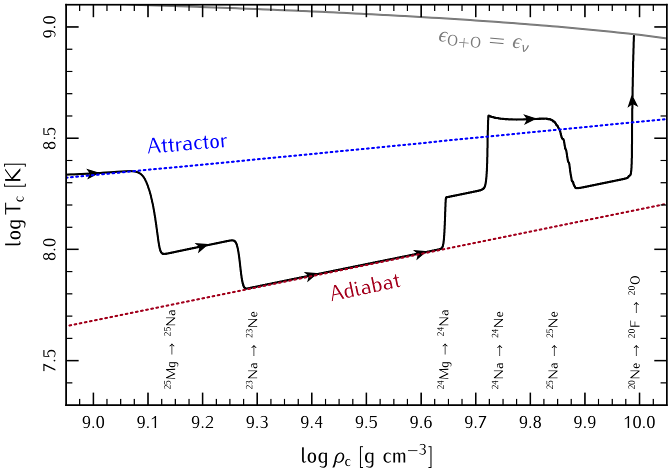
Substantial heating also occurs associated with the $A = 24$ isotopes.



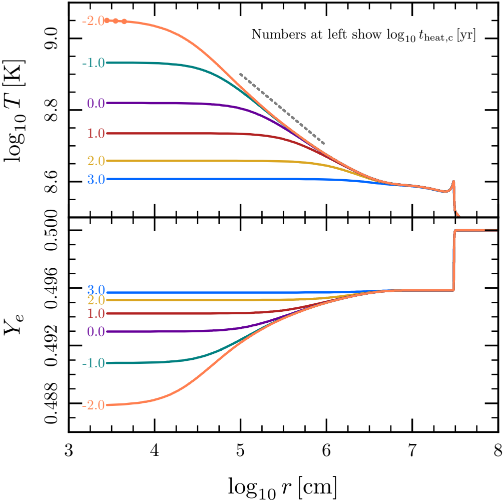
Urca-process cooling will set the temperature at the onset of captures on ^{20}Ne.



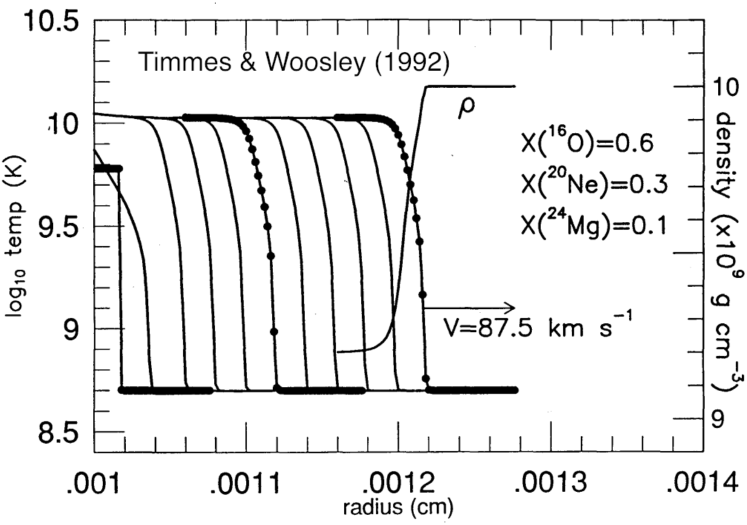
Electron captures on ^{20}Ne are exothermic; this heating will ignite oxygen fusion.



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.



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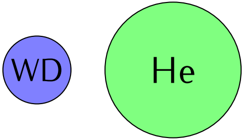
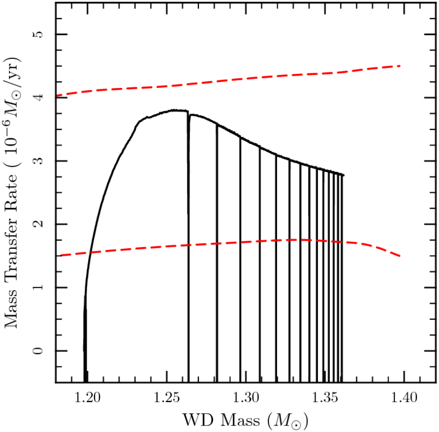
- This work provides an analytic understanding of the evolution of ONe WDs evolving towards accretion-induced collapse.
- We demonstrated the presence of a thermal runaway in the core, which will trigger an oxygen deflagration at a density such that collapse to a neutron star is likely.

Thermal timescale mass transfer gives $\dot{M}$ values in the regime for stable He burning.

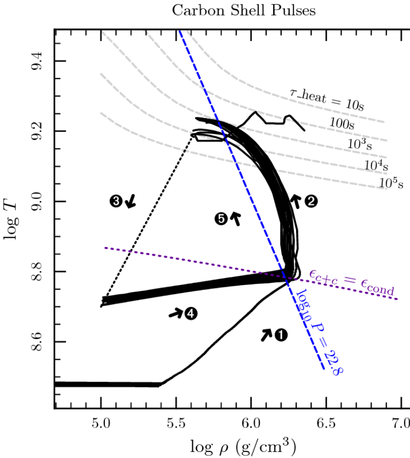




Work led by Jared Brooks; Fig. by Jared Brooks

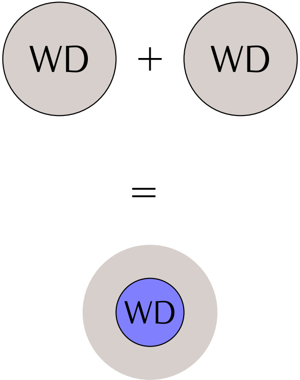
We evolve both stars plus their orbit;

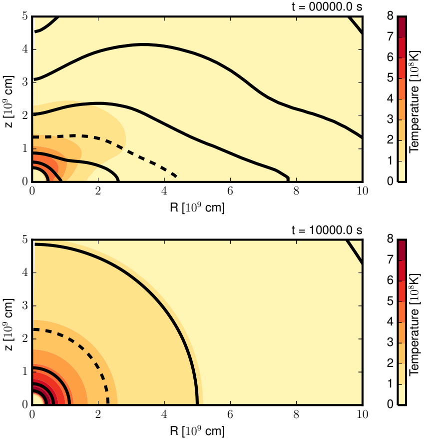
there is stable He burning, plus carbon flashes.



Work led by Jared Brooks; Fig. by Jared Brooks

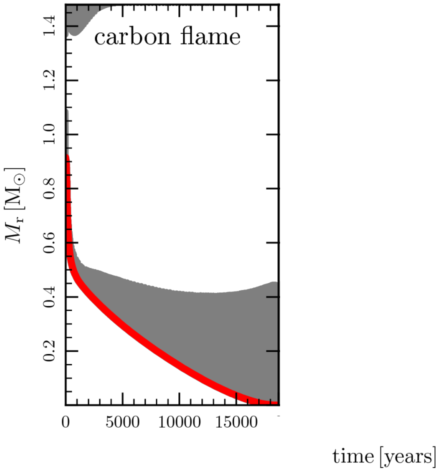
Double white dwarf mergers evolve towards a thermally-supported, spherical state.



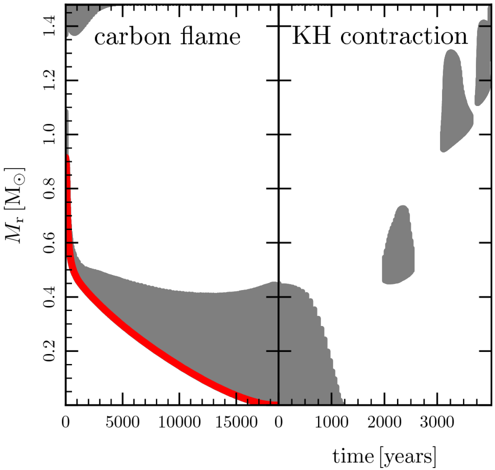


see Shen et al. (2012); Schwab et al. (2012)

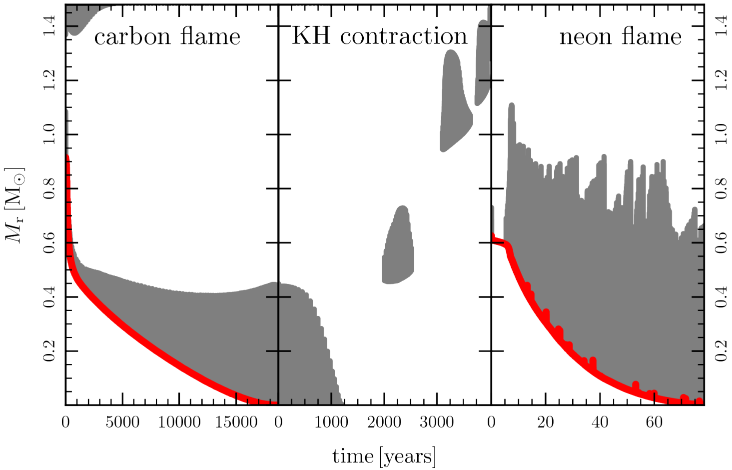
A convectively-bounded carbon deflagration forms and propagates inward, reaching the center.



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

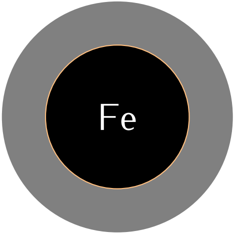


A convectively-bounded neon deflagration forms and propagates inward.



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

Core-collapse



Schwab+ (in prep)

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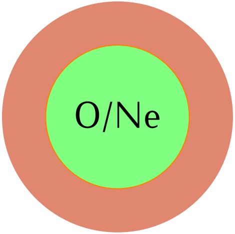
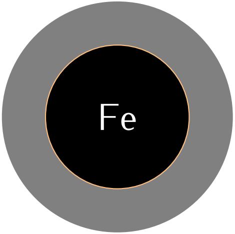
Electron-capture

Core-collapse





Schwab+ (2015)

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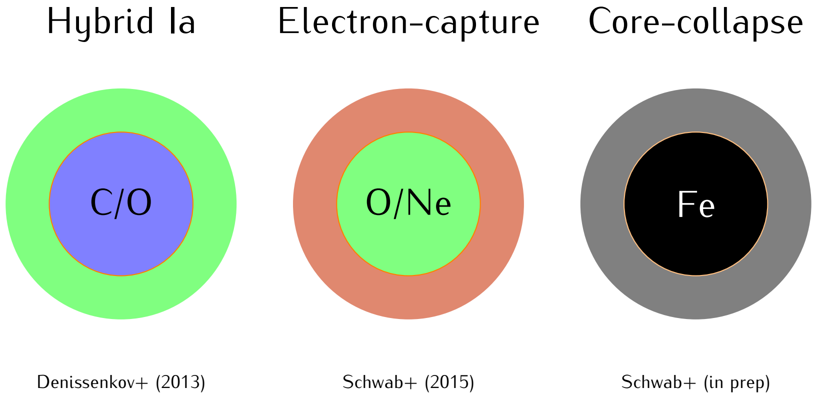

- We’ve evolved single and double degenerate progenitors beginning from "early" phases up to the beginning of collapse.

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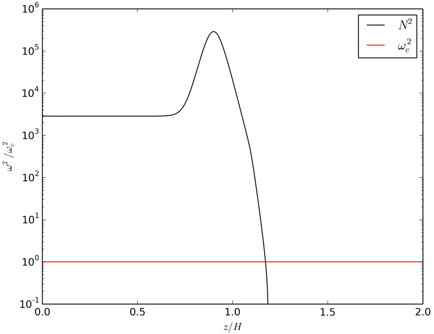
- For super-Chandrasekhar WD mergers, the likely fate is collapse to a neutron star, though the collapse may not occur via an O/Ne core.

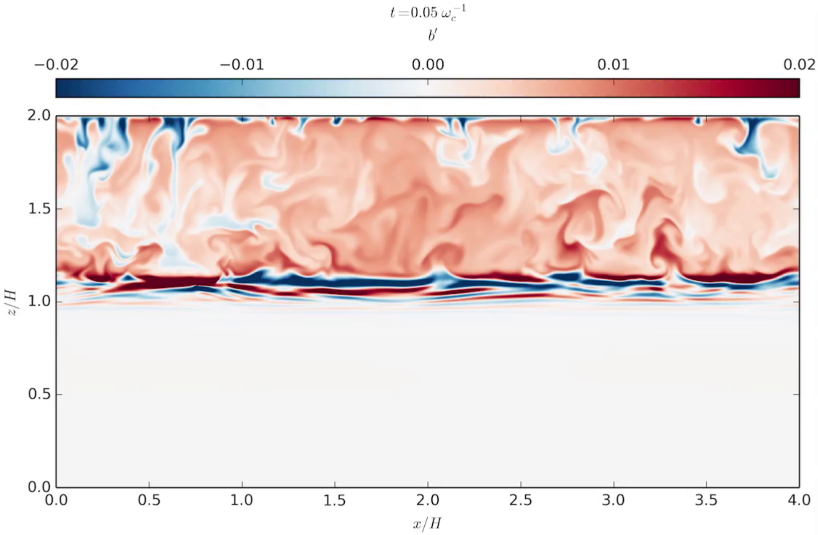
We have been performing simulations relevant to mixing in convectively-bounded deflagrations.

- Cartesian box
- Boussinesq approximation
- spectral method (Dedalus code)



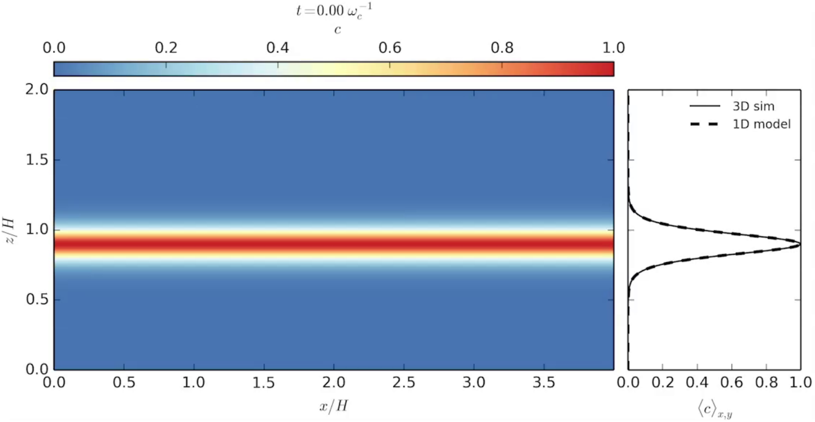
Work led by Daniel Lecoanet

Movie 1: Buoyancy Field



Simulation by Daniel Lecoanet

Movie 2: Diffusion model



Simulation by Daniel Lecoanet

Simulation Summary

- A model which treats the mixing as diffusive appears to be able to reproduce the results of the 3D calculation.
- The diffusion coefficient already begins to fall within the convection zone and has declined sharply by the location of neutral buoyancy; we see little mixing across the flame.