Double white dwarf mergers as the origin of single sdB stars

with K. J. Shen

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A WD+WD merger can be broken to stages, each with well-separated timescales.

Dynamical Time (min)

Completion of merger

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

Viscous Time (hr)

Redistribute ang. mom.

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

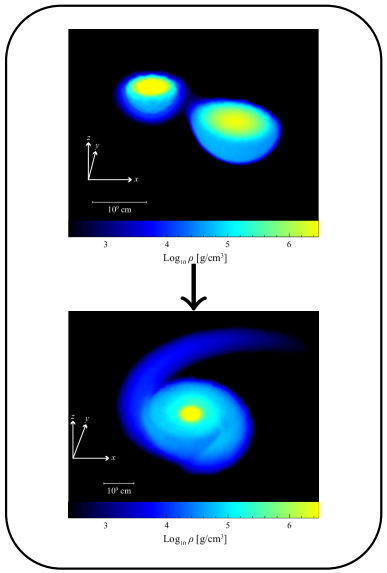
Thermal Time (kyr)

Radiate away energy

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

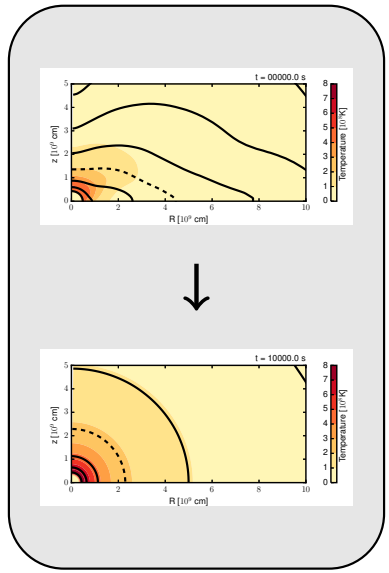
Studying each stage requires different approaches, but we can chain them together.

3D Lagrangian Hydrodynamics

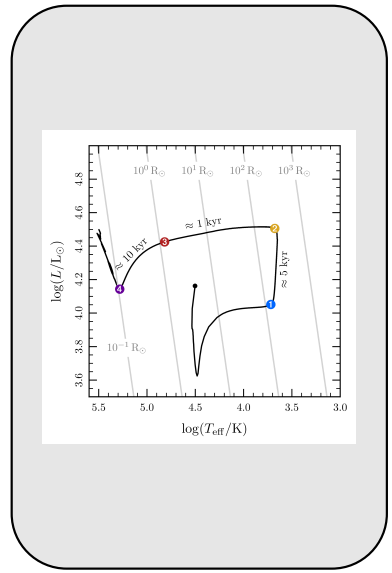


Dan et al. (2011)

2D Eulerian Hydrodynamics



1D Stellar Evolution



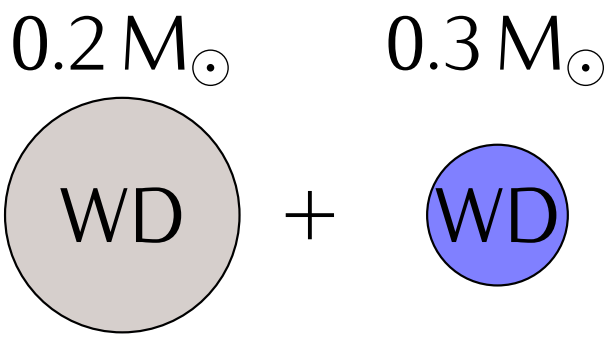
$\sim$ minutes

$\sim$ hours

$\sim 10^4$ yr +

e.g., Yoon et al. (2007); Schwab et al. (2016)

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



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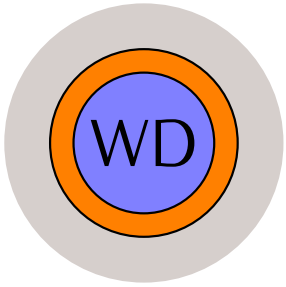
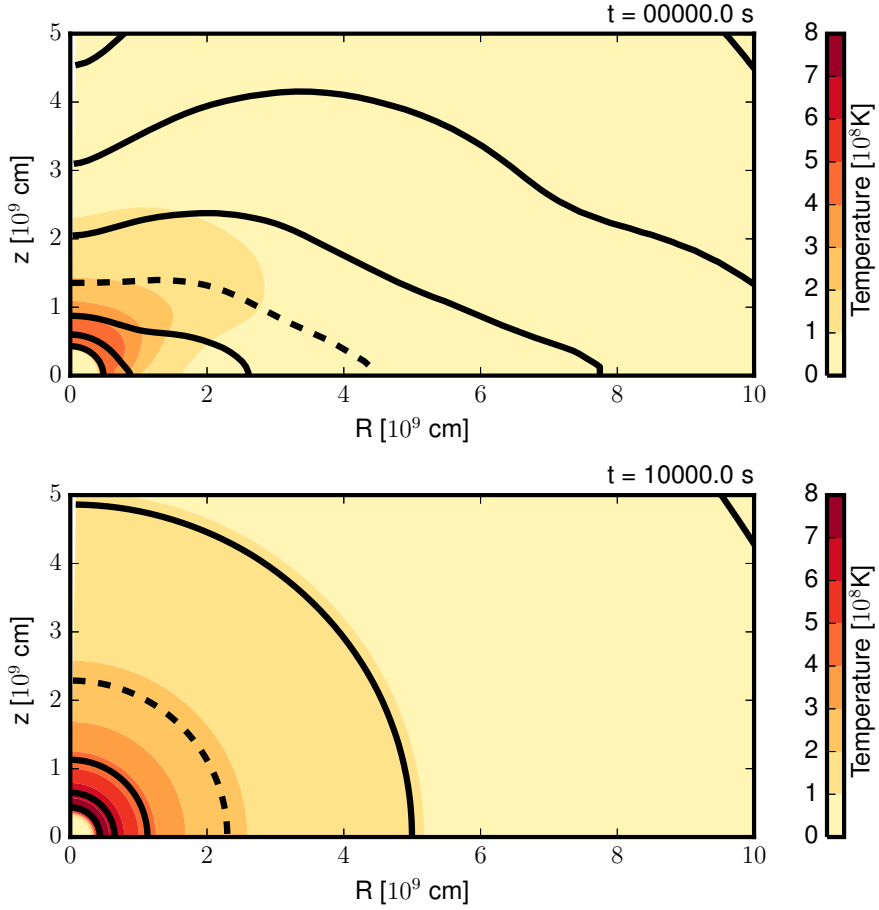
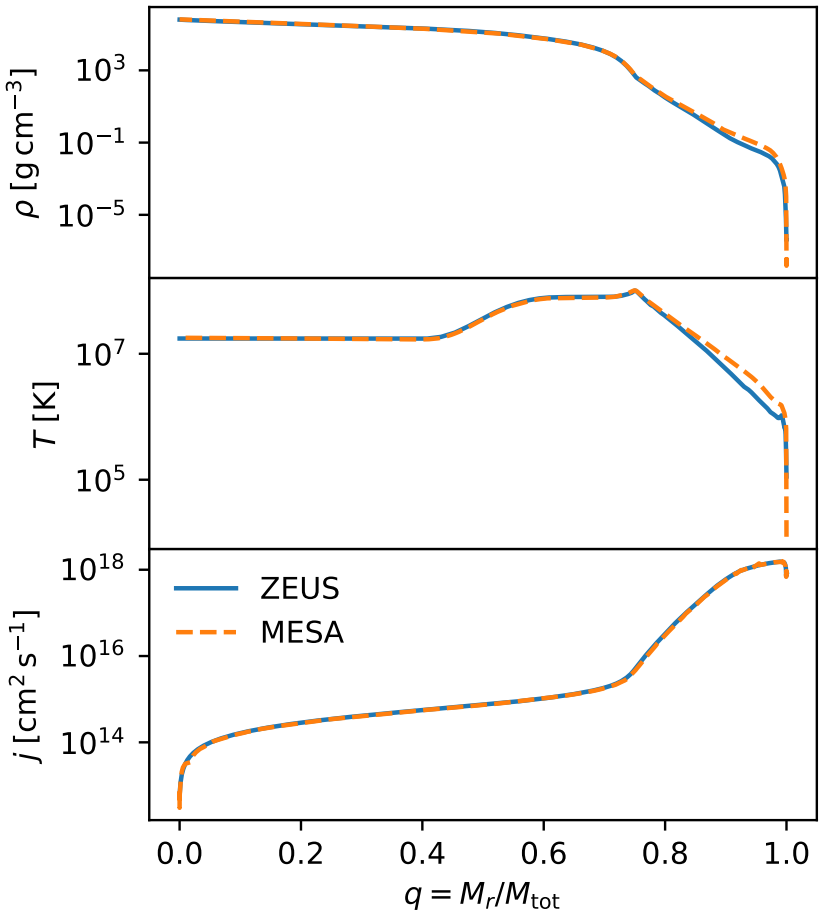




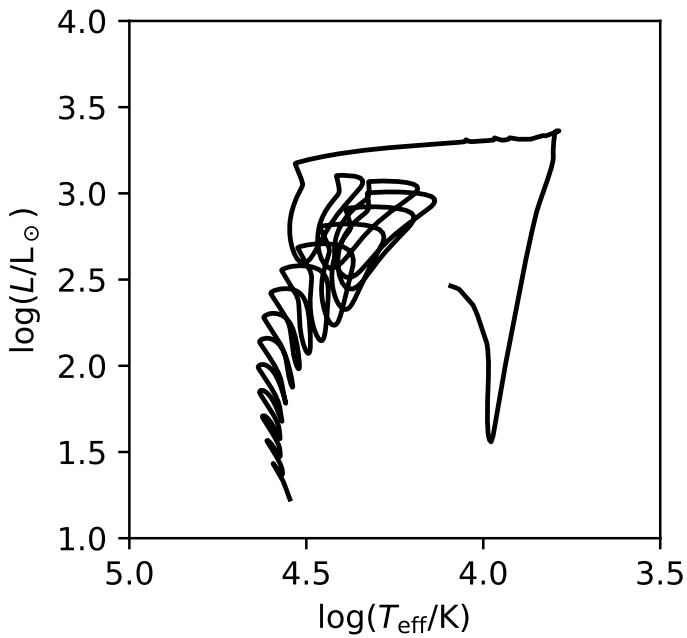
see Shen et al. (2012); Schwab et al. (2012)

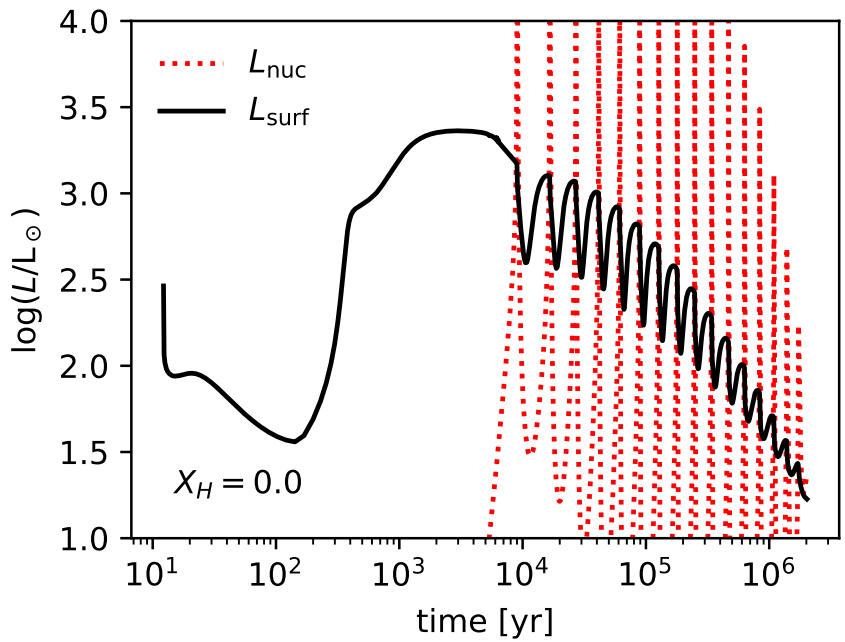
I map the output of my previous work into the MESA stellar evolution code.



Evolve the models forward to core helium-burning.

radiate thermal energy from the merger ($\sim 10^4$ yr)

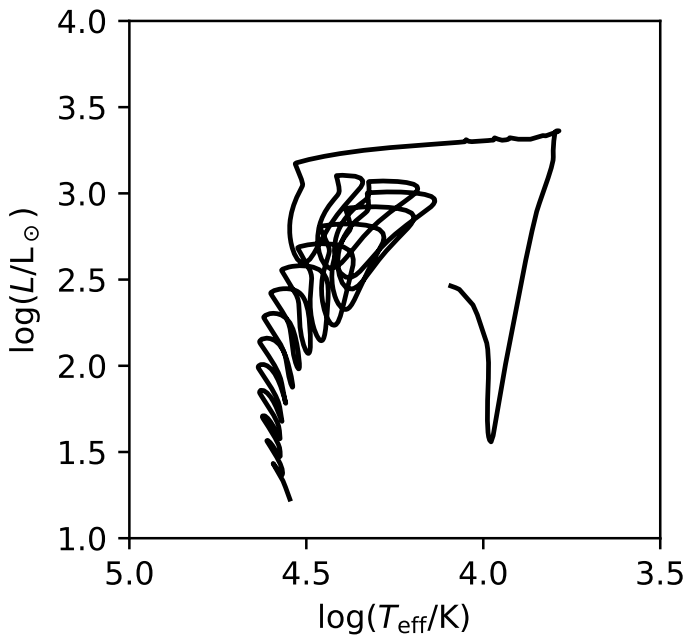


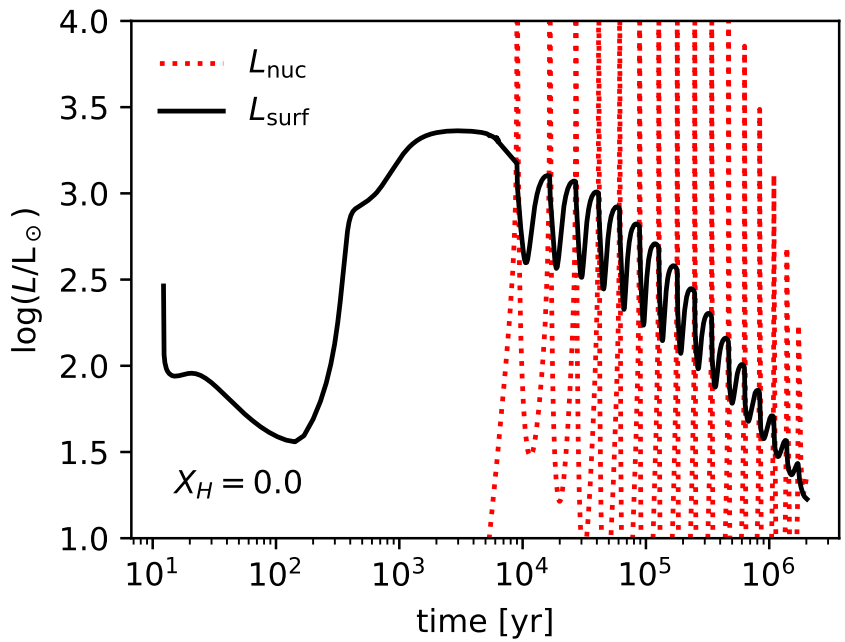


Evolve the models forward to core helium-burning.

off-center He flashes propagate inwards ($\sim 10^6$ yr)

see Saio & Nomoto (1998); Saio & Jeffery (2000)





Hydrogen is not self-consistently included in hydro simulations of the WD+WD merger.

The pre-merger WDs have H envelopes

- expect $M_H \sim 10^{-3}\,\mathrm{M}_\odot$

  e.g. Istrate et al. (2016); Hall & Jeffery (2016)

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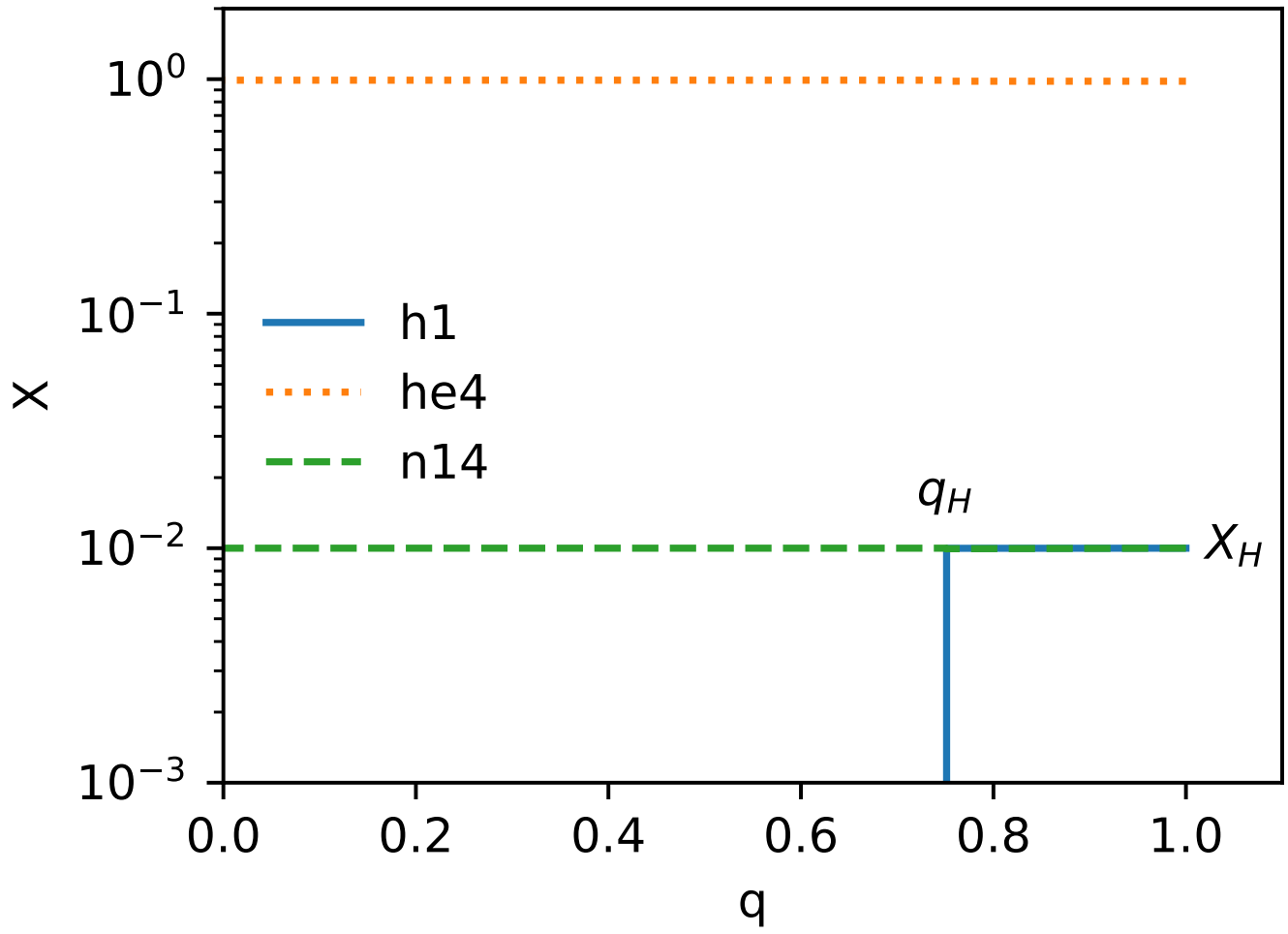
First mass transferred is the H envelope

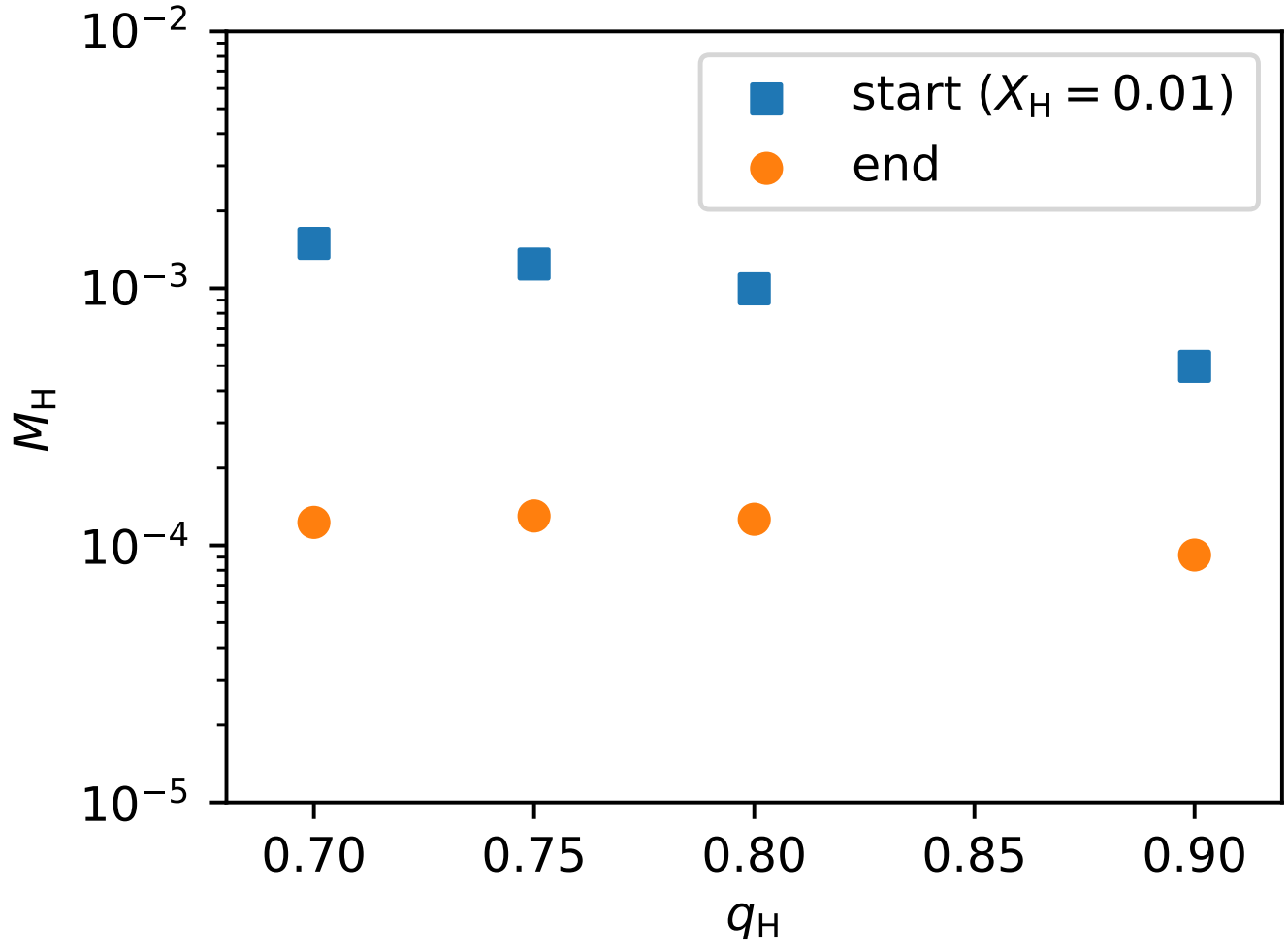
- can have important effects on orbital evolution

D'Antona et al. (2006); Kaplan et al. (2012); Shen (2015)

In my models, the hydrogen is evenly distributed in the outer part of the model.



When core helium-burning begins,
only $\sim 10^{-4}\,\mathrm{M}_\odot$ of hydrogen remains.



Element diffusion doesn't help H survive.

- Rotational mixing overwhelms diffusion
- Only have $\sim 10^6$ years

rotation	diffusion	$M_H[10^{-4}M_\odot]$	$X_{H,\text{surface}}$
yes	no	1.32	0.01
yes	yes	1.30	0.01
no	no	2.02	0.01
no	yes	2.00	0.52

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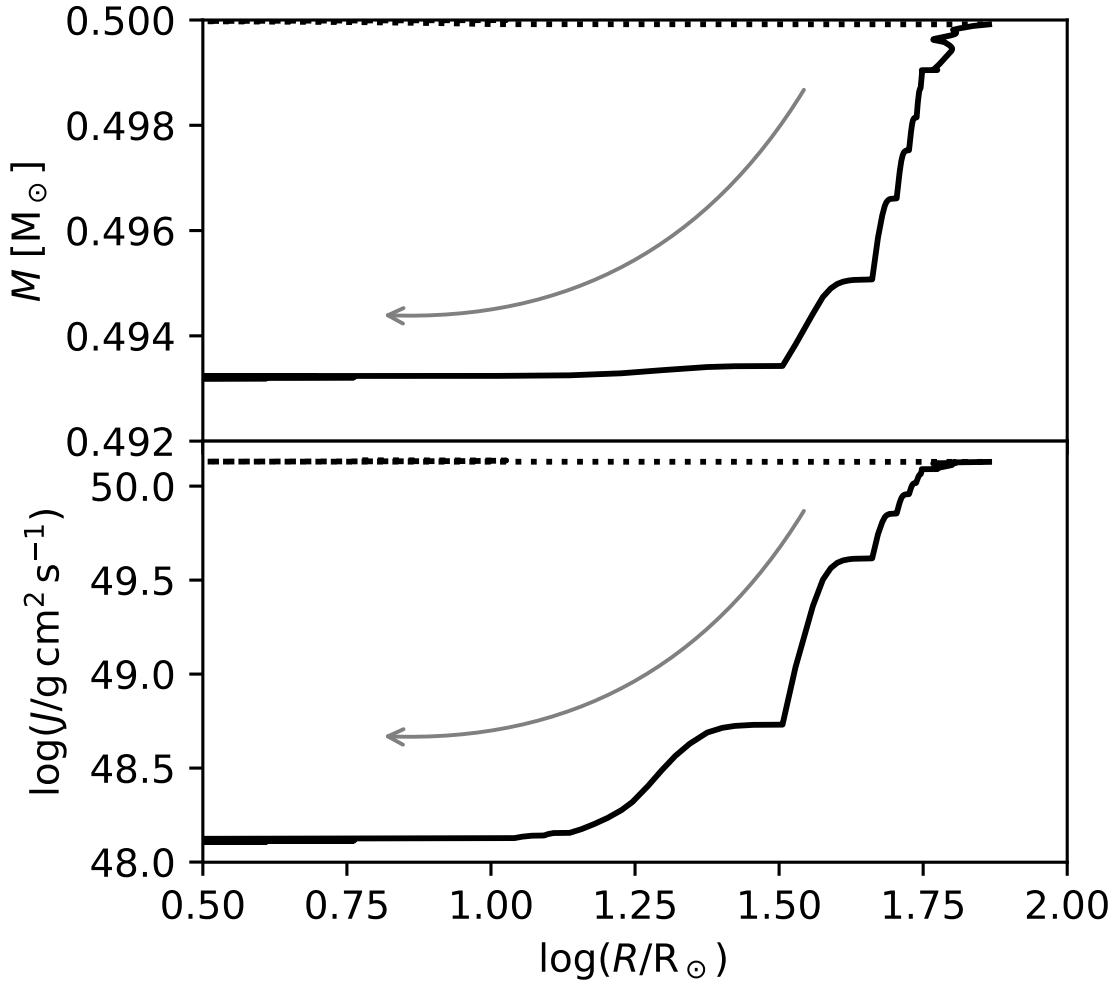
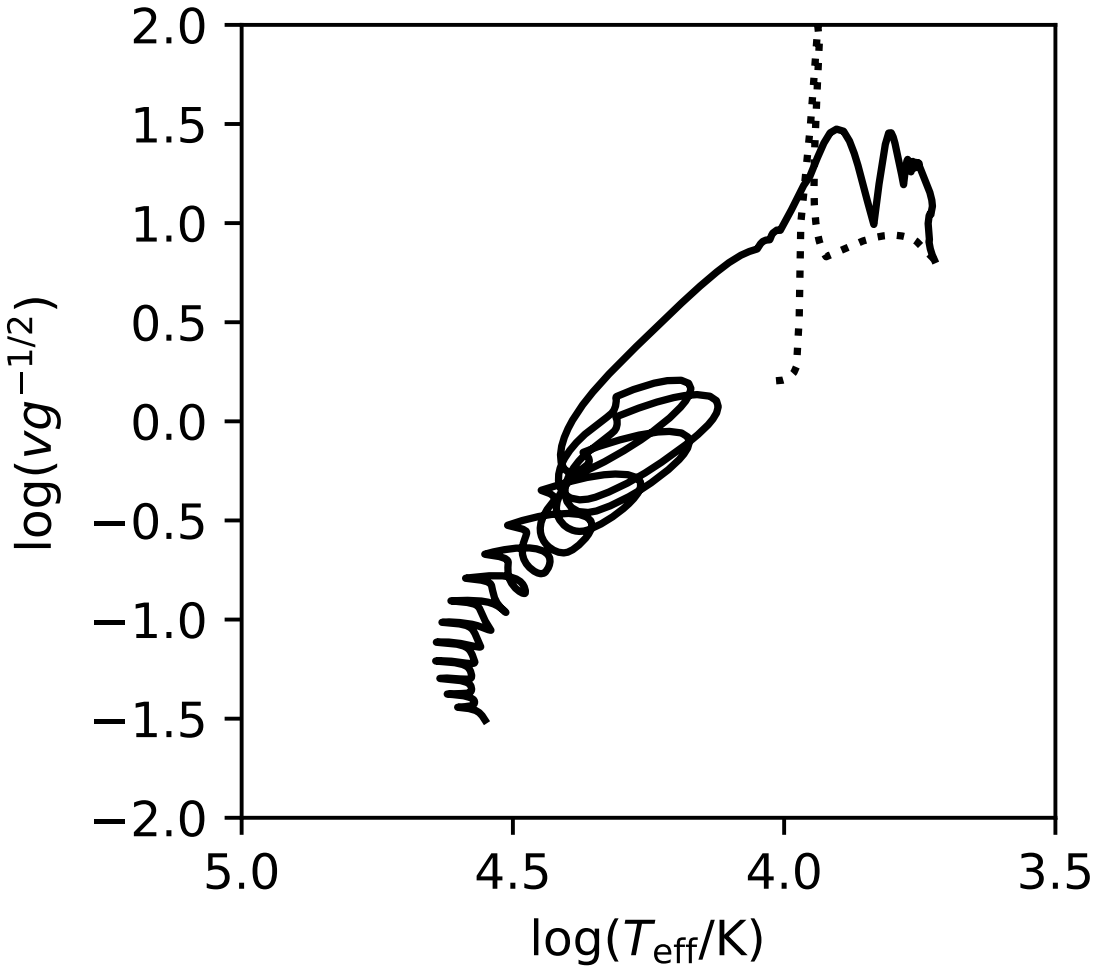
- Single hot subdwarfs seem not to be fast rotators ($v \sin i < 10\,\mathrm{km\,s^{-1}}$).

Geier & Heber (2012)

As the remnant contracts, the outer layers reach critical rotation and are shed.



When core helium-burning begins,
the models are no longer rapidly rotating.



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- In this model of the remnant of a $0.2 + 0.3\ M_\odot$ He WD merger, at the time when core helium-burning begins
  - only $\sim 10^{-4} \mathrm{M}_\odot$ of hydrogen remains
  - the model is no longer rapidly rotating

The hydrogen mass fraction doesn't affect the total fraction of H that burns.