Double White Dwarf Mergers and the Formation of R CrB Stars

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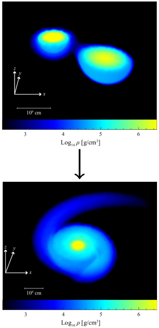
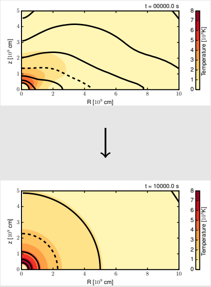
On the way to their final fates, double WD systems evolve through multiple phases.

Lagrangian Hydrodynamics



~ minutes

Eulerian Hydrodynamics



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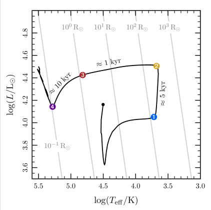
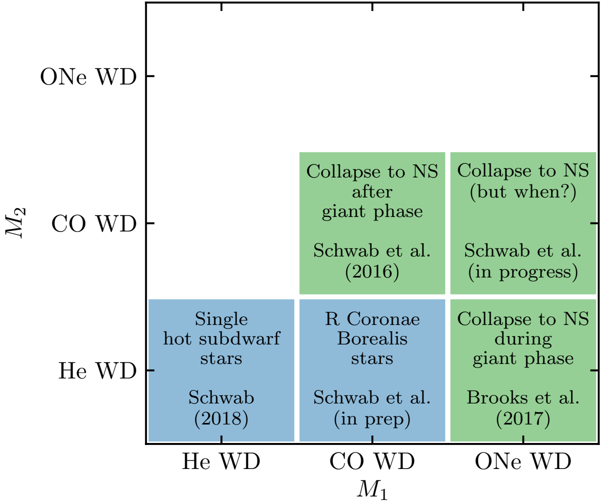
Stellar Evolution (MESA)



$\sim 10^4 - 10^8$ yr

I've applied this approach broadly over the possible range of WD+WD mergers.



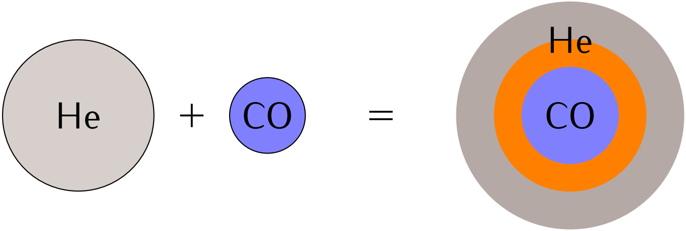
Overview

Models of RCrB Stars

Models of their more massive cousins

Summary

White dwarf mergers seem to provide a natural explanation for the formation of these objects.

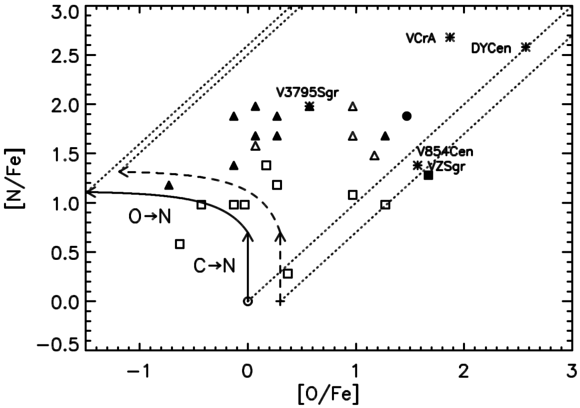


H-burning products | He-burning products

see e.g., Jeffery, Karakas, & Saio (2011)

- In addition, there can be further H and He burning during the merger.

The high nitrogen abundance requires additional CNO processing during the merger.



from Asplund et al. (2000)

Getting the detailed CNO abundances right is challenging.

- You can reach the right conditions to make ^{18}O.

  Clayton et al. (2007), Staff et al. (2012)

- ^{14}N gets destroyed in making the ^{18}O, so you need to make even more ^{14}N.

  Menon et al. (2013), Zhang & Jeffery (2014)

- The outer layers of the CO WDs are generally oxygen-rich. During the merger, it is difficult not to bring up a lot of ^{16}O. Does this require the presence of a large He-buffer layer?

  Staff et al. (2012, 2018)

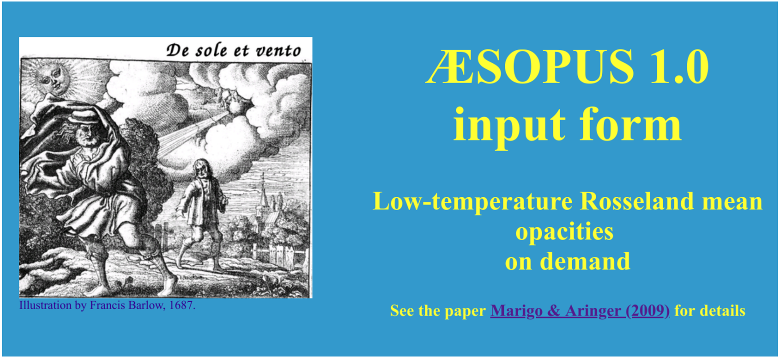
Mixing is essential but also uncertain.

- Zhang & Jeffery (2014) include convective mixing.
- Menon et al. (2013) have convection plus a parameterized mixing prescription. They characterize the required spatial and temporal properties of the mixing.
- Lauer et al. (2018) evolve rotating models and allow for rotationally-induced mixing processes.

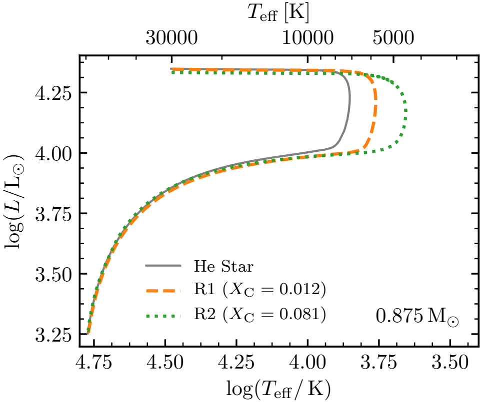
Microphysical inputs (e.g., opacities) often assume solar-scaled abundances

$$\begin{bmatrix} {}^{1}\mathrm{H} \\ {}^{2}\mathrm{H} \\ {}^{3}\mathrm{He} \\ {}^{4}\mathrm{He} \\ {}^{12}\mathrm{C} \\ {}^{14}\mathrm{N} \\ {}^{16}\mathrm{O} \\ \vdots \\ {}^{56}\mathrm{Fe} \end{bmatrix} \rightarrow \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

CNO enhancements occur on the H-rich AGB; there are convenient computational tools.



MESA can now use low-temperature, composition-dependent opacities.



Reproducing Figure 3b of Weiss (1987)

Past MESA R CrB models have shown annoying numerical issues; hopefully, these are gone.

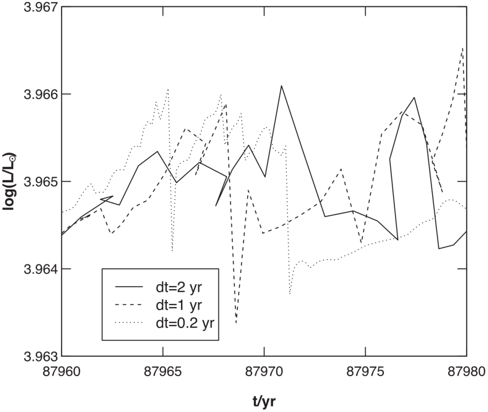


Fig. from Zhang et al. (2014), see also Menon et al. (2013)

Mass loss recipes are an important ingredient.

- Generally, recent models use Bloecker-like winds with varying efficiencies, meaning the mass loss rate is $\sim 10^{-5}\,\mathrm{M_\odot\,yr^{-1}}$.

  Menon et al. (2013), Zhang & Jeffery (2014), Lauer et al. (2018)

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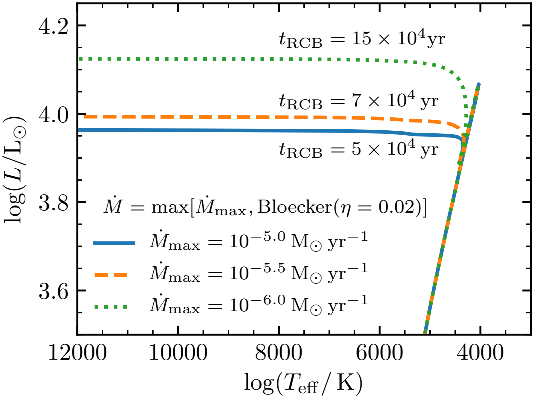
- For R CrB, $v_\infty \approx 300\,\mathrm{km\,s^{-1}}$, so the specific energy is $\sim$ 100x greater than in an AGB wind.

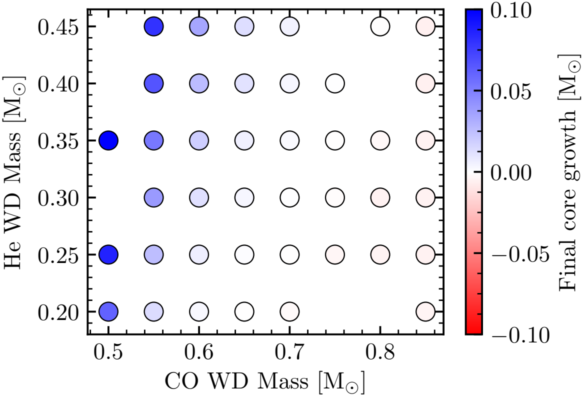
  Clayton et al. (2003, 2013)

- What about the duty cycle?

Accurate mass loss rates are required for accurate lifetime estimates.

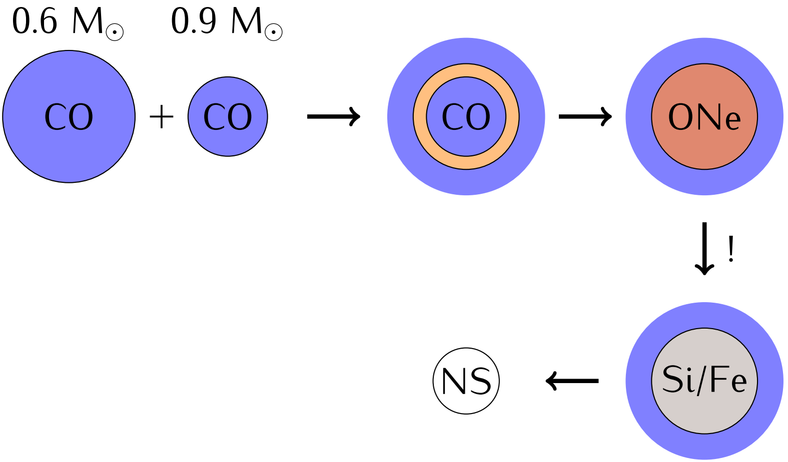


The CO WD cores don't grow significantly;
the R CrB descendants don't have high masses.



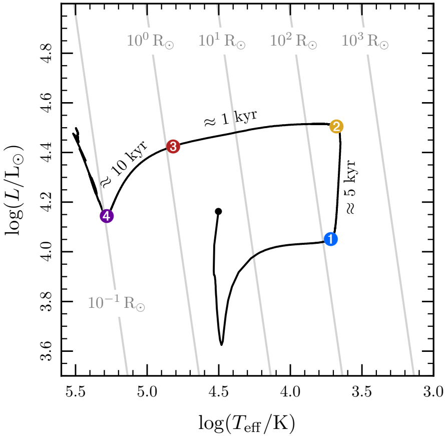
consistent with Zhang & Jeffery (2014)

The merger of two CO WDs with a super-Chandra total mass can collapse to an NS.



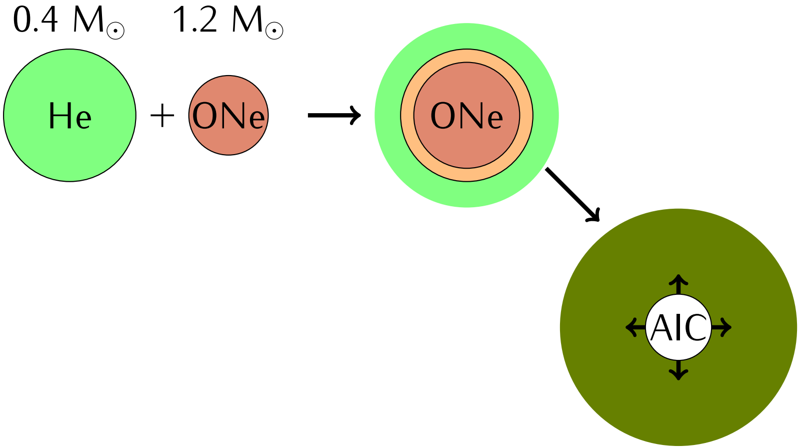
Nomoto & Iben; Saio & Nomoto (1985), JS et al. (2016)

It takes ≈ 20 kyr from merger to collapse; the models spend time in a cool giant phase.



JS et al. (2016)

The merger of He WD & ONe WD with a super-Chandra total mass can collapse to an NS.



Brooks, JS et al. (2017b)

Massive R CrB analogs may be formed.

- Are there He-shell burning R CrB-like objects, but with more massive cores and hence noticeably higher luminosities?
- At these near-Eddington luminosities, can you grow the core?

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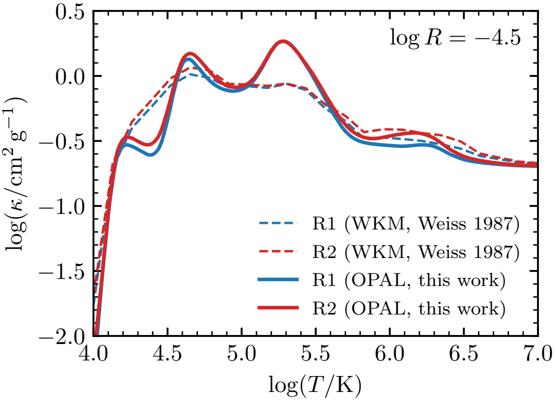
Summary

- Models of RCBs descended from double WD mergers are broadly consistent with observations, but we have to overcome
  - uncertain mass loss rates
  - uncertain mixing process
- More massive double WD mergers also make rare hydrogen-deficient objects that may sit in similar parts of the HR diagram. Even if they're 10% as common and live 10% as long, we may be able to find a few.

Opacity calculations are somewhat different than they were then...



...and low T is different too.