The Formation and Evolution of R Coronae Borealis Stars

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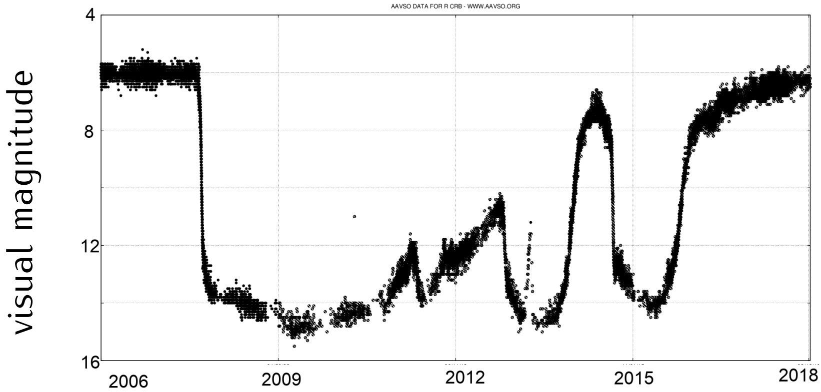
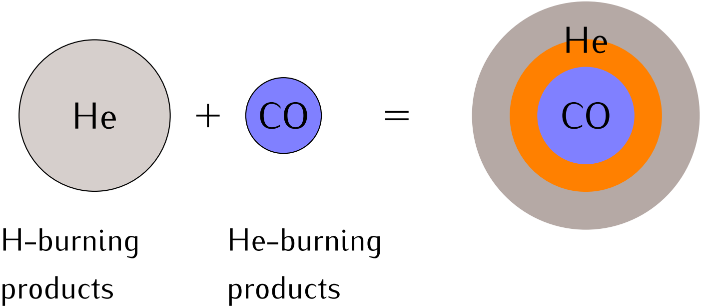
Recent light curve of R CrB (discovered 1795);
H-deficient giant, $T_{\rm eff} \approx 7000\,\mathrm{K}$, $L \sim 10^4\,\mathrm{L}_\odot$



via AAVSO LC generator

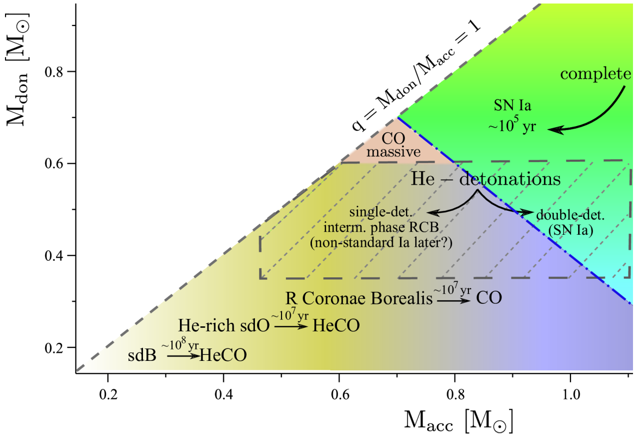
White dwarf mergers seem to provide a natural explanation for the formation of these objects.



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

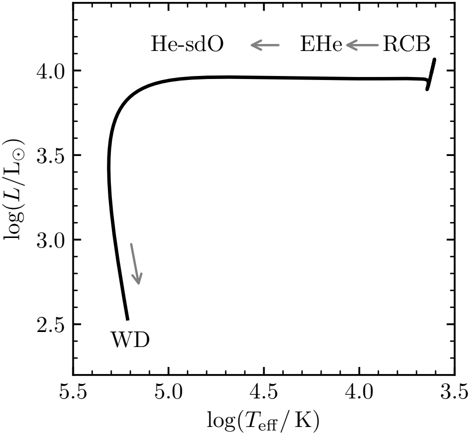
- In addition, there can (and must) be further H and He burning during the merger.

The RCBs and single sdOBs are the products of low mass WD mergers



Webbink (1984); Iben & Tutukov (1985); Fig. from Dan et al. (2014)

After their He-giant phase,
the RCBs will evolve back to the blue.



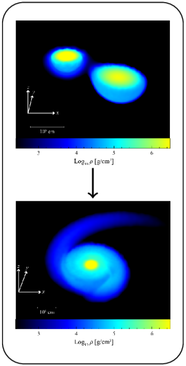
e.g., Jeffery (2008)

What are RCBs and why are they related objects?

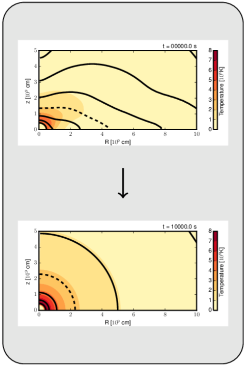
Models of RCB stars and their descendants

Summary

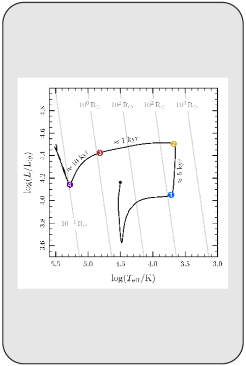
On the way to their final fates, double WD systems evolve through multiple phases.



$\sim$ minutes



$\sim$ hours



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

Merger models prefer lower mass CO WDs in order to reproduce RCB surface abundances.

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

  Clayton et al. (2007), Menon et al. (2013)
- The presence of outer He layers (which are larger on lower mass CO WDs) can prevent the merger from dredging up too much ^{16}O.

  Staff et al. (2012, 2018)

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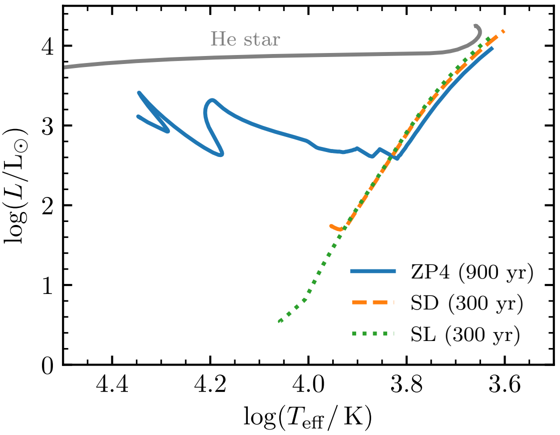
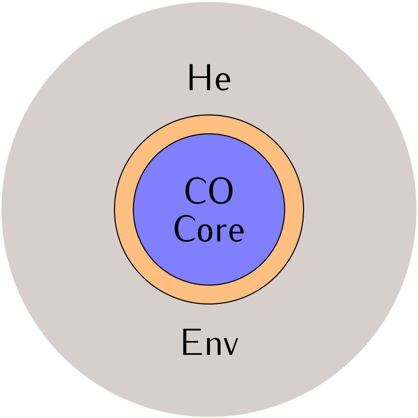
- He layers become small around $0.7\,M_\odot$, which is also around where systems may start to be able to be destroyed by double detonations.

Initial conditions motivated by mergers suggest a short, lower-luminosity post-merger phase.

Models of $0.3\ M_\odot + 0.6\ M_\odot$ He + CO WD merger



The RCB phase is depletion of the He envelope via core growth and mass loss.



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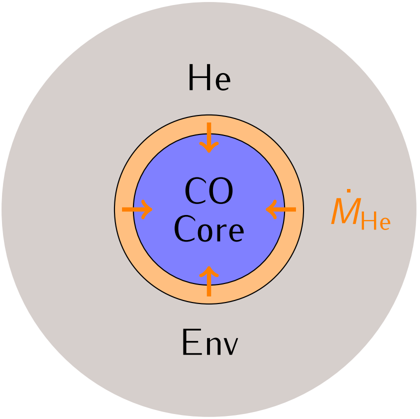
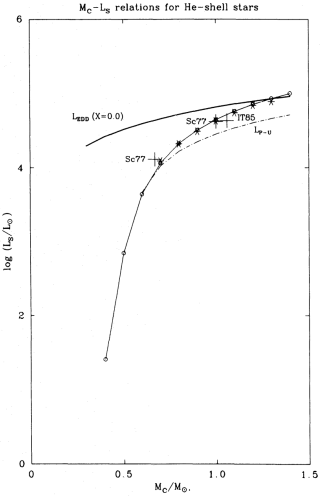


The core growth rate scales with the core mass.

$$\dot{M}_{\mathrm{He}} = L/Q_{\mathrm{He}}$$

$$L \propto M_{\mathrm{core}}^{\alpha}$$

$\alpha \approx 5$ at $M_{\mathrm{core}} \approx 0.6\ \mathrm{M}_{\odot}$



Jeffery (1988)

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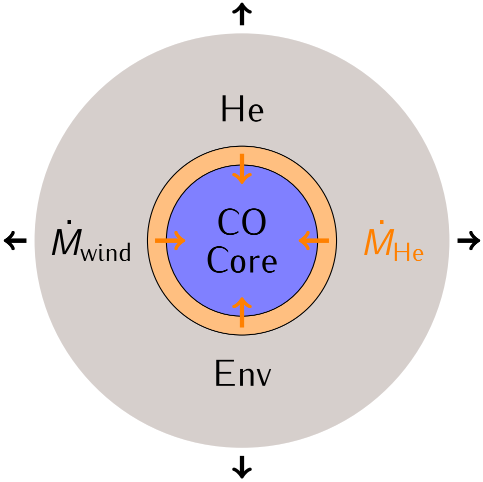

Mass loss recipes are an essential ingredient.

- The RCB phenomenon itself is indicative of mass loss and there are dusty shells around the RCB stars that likely formed during this phase.

  Montiel et al. (2015, 2018)

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- The RCB phenomenon itself is indicative of mass loss and there are dusty shells around the RCB stars that likely formed during this phase.

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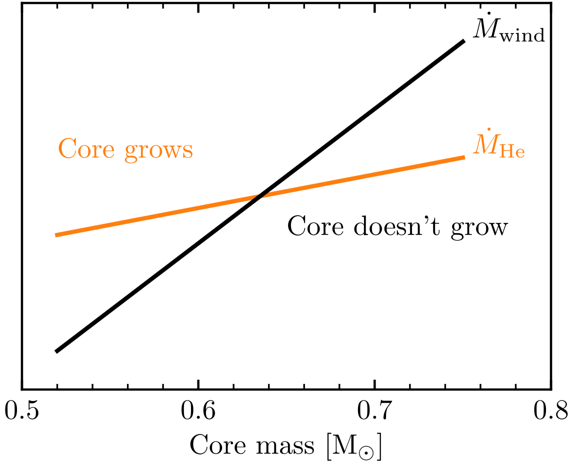
- Recent models use AGB winds, meaning the mass loss rate is $\sim 10^{-6} - 10^{-5}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$.

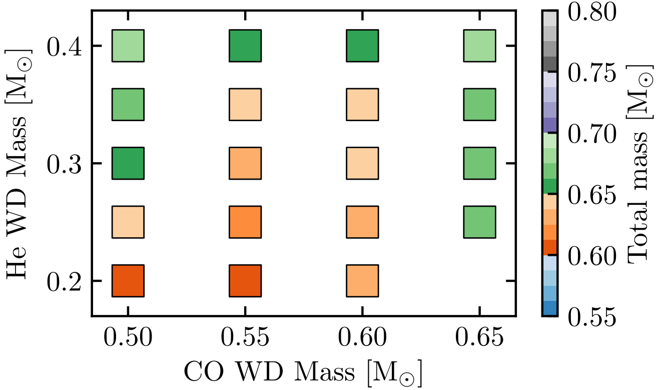
  Menon et al. (2013), Zhang & Jeffery (2014), Lauer et al. (2018)

- Mass loss presumably increases with L; for Blöcker (1995) prescription, $\dot{M}_{\mathrm{wind}} \propto L^{3.7}$.

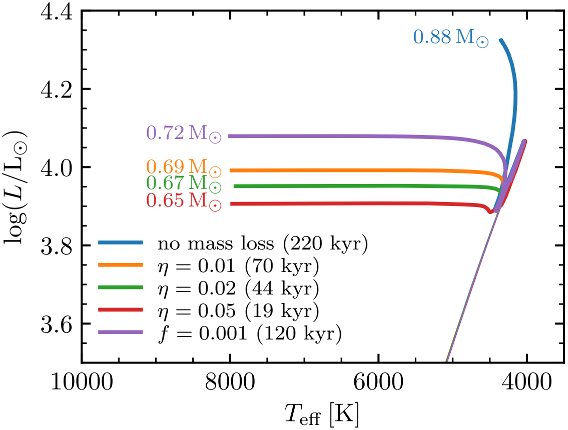
Low mass cores can grow; high mass ones can't.



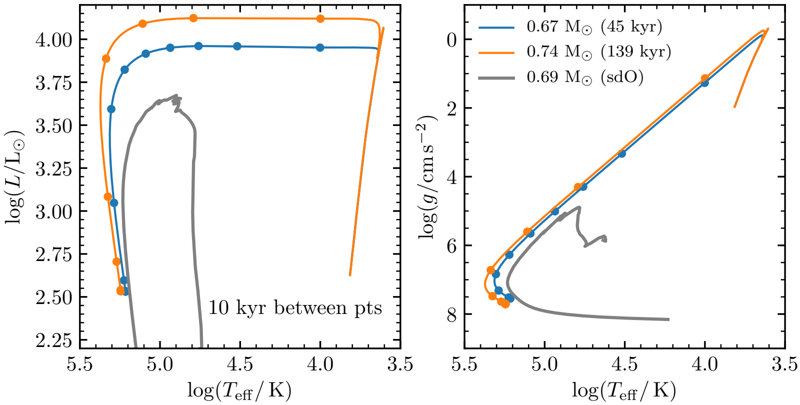
If the CO WD cores don't grow significantly; the RCB descendants don't have high masses.



Accurate mass loss rates are required for accurate lifetime estimates.



The ratio of RCBs to their blue descendants is doubly sensitive to the core mass they reach.



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Summary

- The RCB stars are the product of He WD + CO WD mergers; these are "between" those that make hot subdwarfs and supernovae.
- There should be ~ 10 "recent" mergers (that have lower luminosities) in the Milky Way.
- RCB stars eventually leave behind $\approx 0.7\,\mathrm{M}_{\odot}$ CO WDs (H-free), but lifetimes are sensitive to uncertain mass loss rates.

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- RCB stars eventually leave behind $\approx 0.7\,M_{\odot}$ CO WDs (H-free), but lifetimes are sensitive to uncertain mass loss rates.
- Potential to refine models by exploiting the connections between RCB populations and their blue descendants (EHes, He-sdOs).