Double White Dwarf Mergers and the Formation of R CrB Stars

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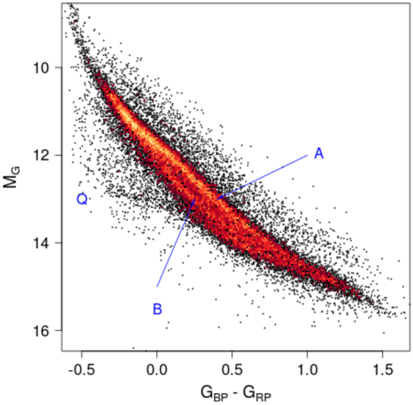
Current and future surveys are expanding our knowledge of the Galactic WD population.



Gaia Collaboration (2018)

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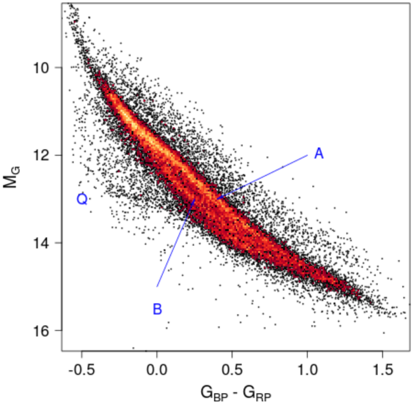


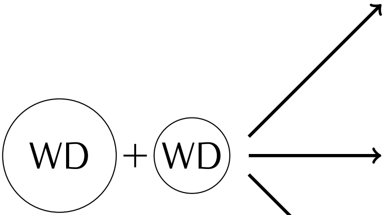
Gaia Collaboration (2018)

Find compact binaries (periods minutes – hours) in time-domain surveys.

ZTF

BlackGEM

The merger of two white dwarfs has a wide range of possible outcomes.

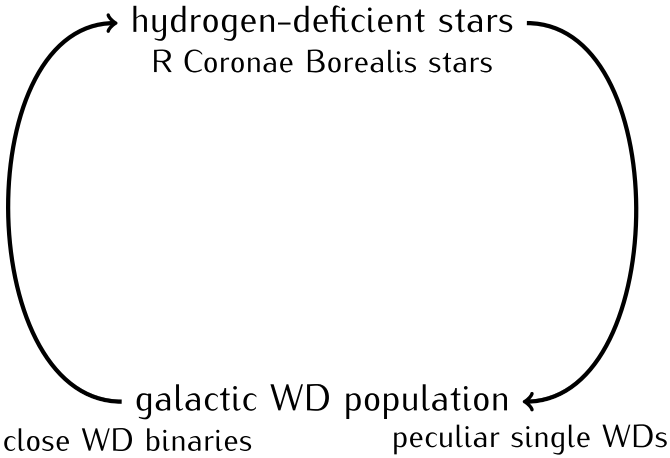


hydrogen-deficient stars

this talk

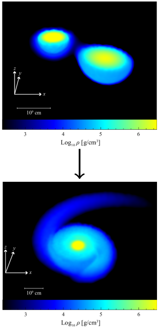
thermonuclear supernovae

accretion-induced collapse
(formation of a neutron star)


hydrogen-deficient stars
R Coronae Borealis stars
galactic WD population
close WD binaries
peculiar single WDs

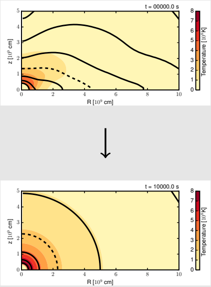
On the way to their final fates, double WD systems evolve through multiple phases.

Lagrangian Hydrodynamics



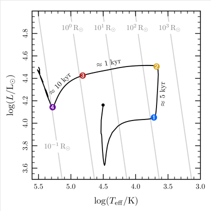
$\sim$ minutes

Eulerian Hydrodynamics



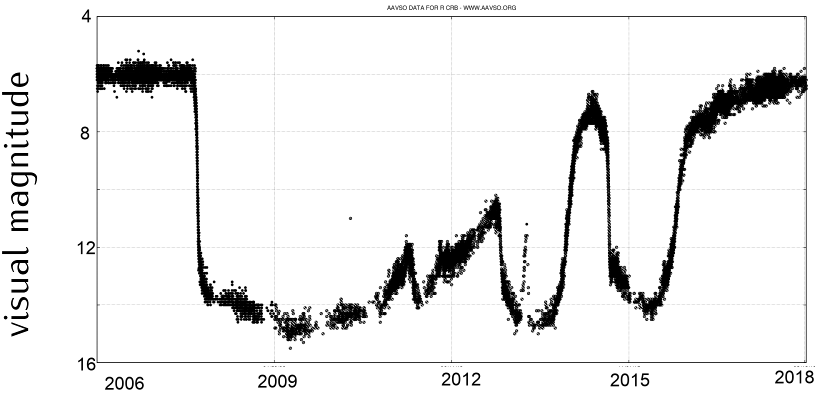
$\sim$ hours

Stellar Evolution (MESA)



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

Recent light curve of R CrB (discovered 1795)

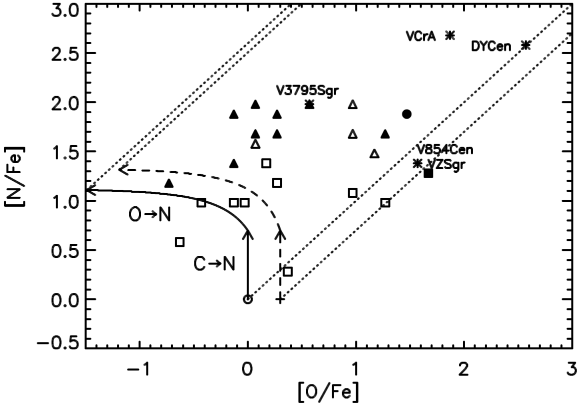


via AAVSO LC generator

These are cool, hydrogen-deficient giant stars.

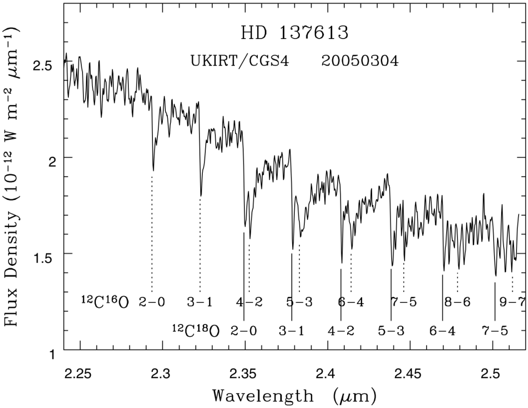
- ~150 known (MW, MCs, M31)
- carbon-rich (variability is dust-formation)
- $T_{\rm eff} \approx 7000\,{\rm K}$
- $L \sim 10^4\,{\rm L}_\odot$
- from pulsations (none are in binaries), inferred to be low mass stars $\approx 0.8 - 0.9\,{\rm M}_\odot$

Their overall CNO abundances imply additional CNO-cycle processing has occurred.



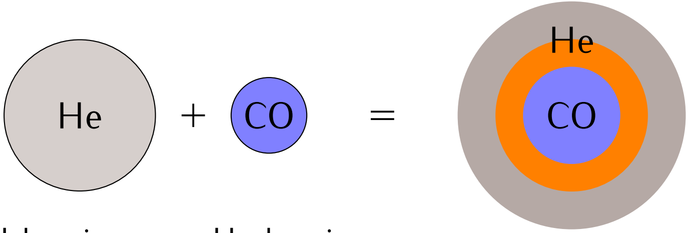
from Asplund et al. (2000)

The R CrBs also have unusual CNO isotopic ratios (e.g., lots of oxygen-18, little carbon-13).



from Clayton et al. (2007)

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 (and must) be further H and He burning during the merger.

Reproducing the detailed CNO abundances challenges models, but is therefore constraining.

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

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

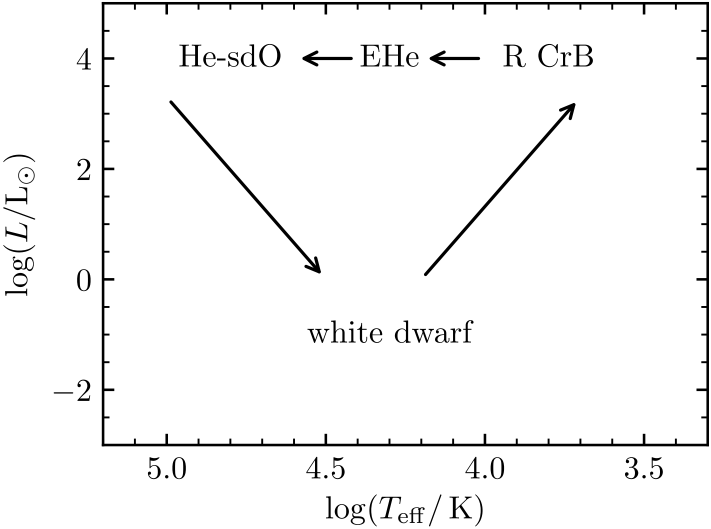
- ^{14}N gets destroyed in making the ^{18}O, so you need to make even more ^{14}N. (H on He WD?)

  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. (He on CO WD?)

  Staff et al. (2012, 2018)

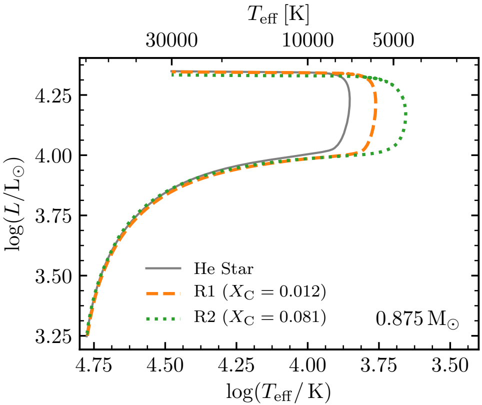
I'll mostly show models on the HR diagram.



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

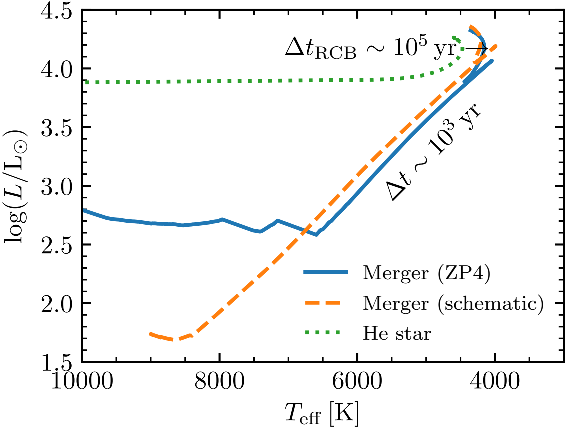
$$\begin{bmatrix} ^{1}\mathrm{H} \\ ^{2}\mathrm{H} \\ ^{3}\mathrm{He} \\ ^{4}\mathrm{He} \\ ^{12}\mathrm{C} \\ ^{14}\mathrm{N} \\ ^{16}\mathrm{O} \\ \vdots \\ ^{56}\mathrm{Fe} \end{bmatrix} \rightarrow \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

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



Reproducing Figure 3b of Weiss (1987)

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



Mass loss recipes are an important ingredient.

- There are dusty shells around the R CrB stars that have likely been formed during this phase.

  Montiel et al. (2015, 2018)

- 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)

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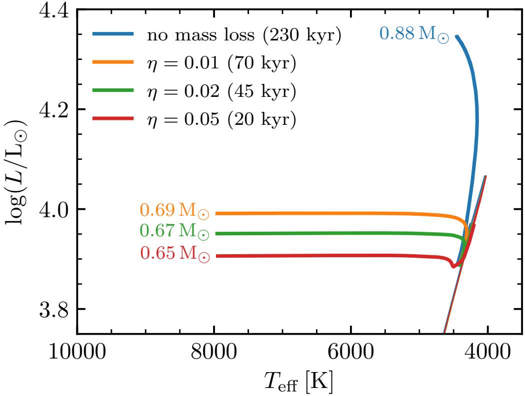
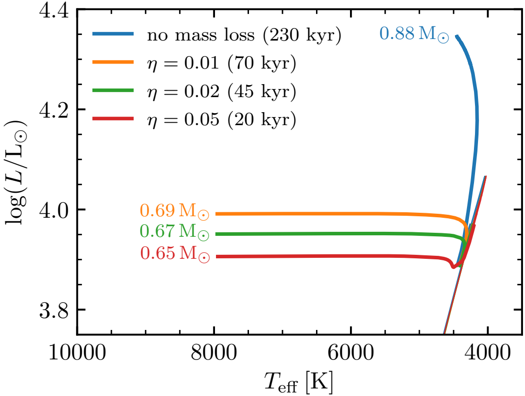
- Generally, recent models use AGB winds (Bloecker-like) with varying efficiencies, meaning the mass loss rate is $\sim 10^{-5}\,\mathrm{M_\odot\,yr^{-1}}$.

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

Accurate mass loss rates are required for accurate lifetime estimates...



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



- The R CrB stars are well explained as the product of He WD + CO WD mergers.
- There should be ~ 10 "recent" mergers (that have lower luminosities) in the Milky Way.
- R CrB stars eventually leave behind $\approx 0.7\,M_{\odot}$ CO WDs (H-free), but lifetimes are sensitive to uncertain mass loss rates.

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- R CrB stars eventually leave behind $\approx 0.7\,M_\odot$ CO WDs (H-free), but lifetimes are sensitive to uncertain mass loss rates.
- These stars (and related objects) are exciting because the provide opportunity to "watch" and understand double white dwarf mergers.