The Long-Term Outcomes of Double White Dwarf Mergers

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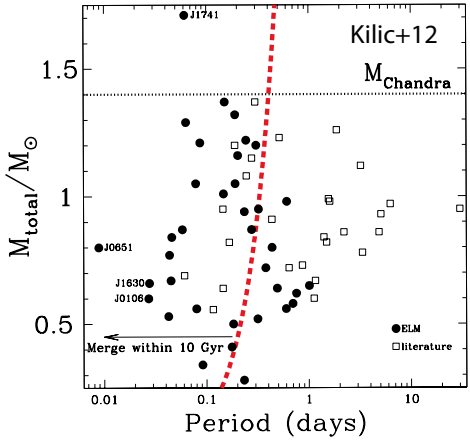
Stellar evolution produces double white dwarf (WD) binaries that will merge within a Hubble time.



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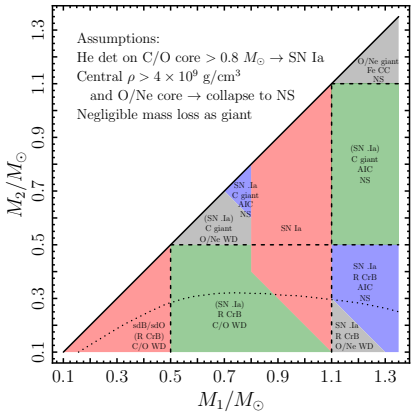
- Observe the merger events occurring in other galaxies
  - Some WD+WD mergers produce thermonuclear supernovae
    (or other explosive events) that are visible over large volumes.
- Study the remnants of WD+WD mergers
  - If the merger produces a long-lived object,
    there should be many such remnants in existence in our own galaxy.

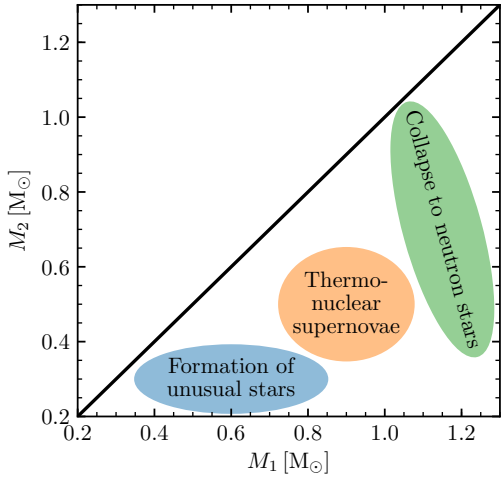
The merger of two white dwarfs

gives rise to a variety of post-merger outcomes.



e.g., Webbink (1984), ... ; Fig. from Shen (2015)

Broadly, there are two classes of outcomes: immediate destruction of the system or formation of a long-lived remnant.



The primary (more-massive) WD remains relatively undisturbed;
The secondary (less massive) WD is disrupted, forming a disk.

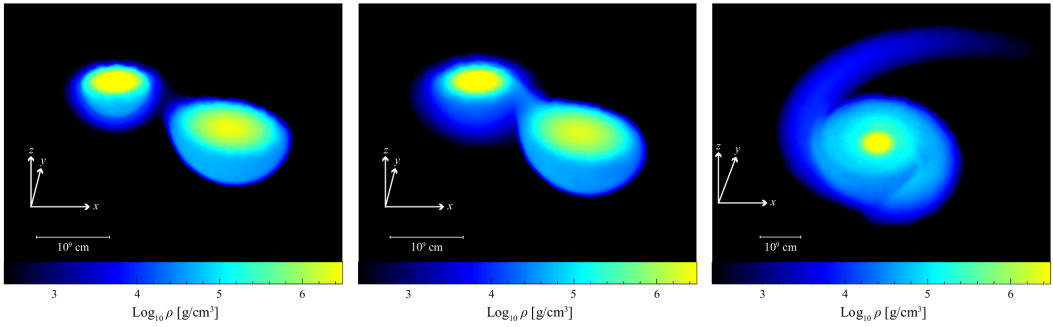
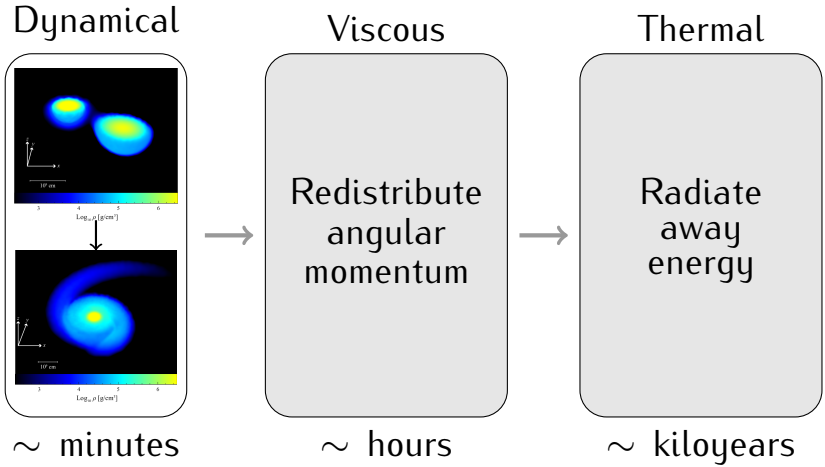


Fig. from Dan et al. (2011)

The evolution can be divided into three phases with well-separated timescales.



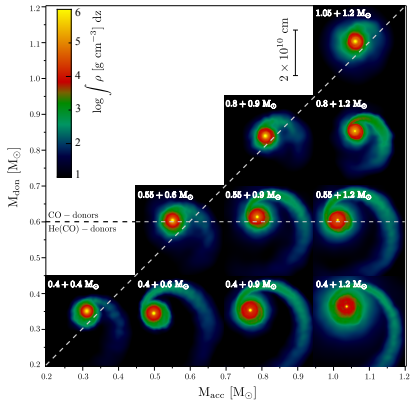
Introduction to WD+WD Mergers

The viscous evolution of WD merger remnants

The thermal evolution of WD merger remnants

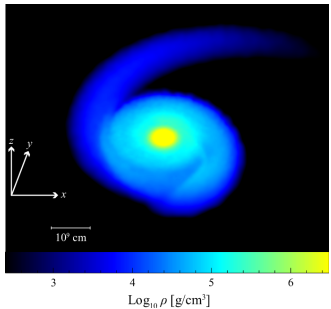
Summary and Conclusions

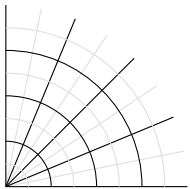
There has been extensive work performing hydrodynamics simulations of WD mergers and their immediate aftermath.



e.g., Benz et al. (1990), ..., many others since, Fig. from Dan et al. (2014)

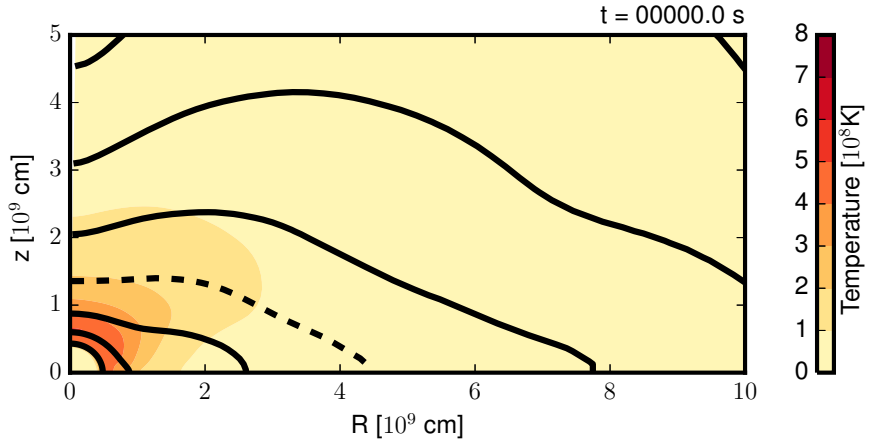
My approach maps these existing results into a hydrodynamics code that can evolve them for the viscous time.





Modified version of ZEUS-MP (Hayes et al. 2006); Schwab et al. (2012)

The remnant is unstable to the magneto-rotational instability and evolves viscously before cooling significantly.



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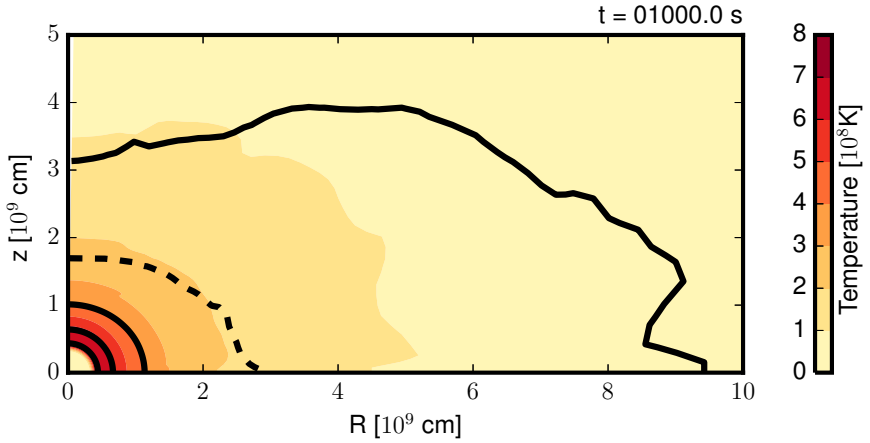

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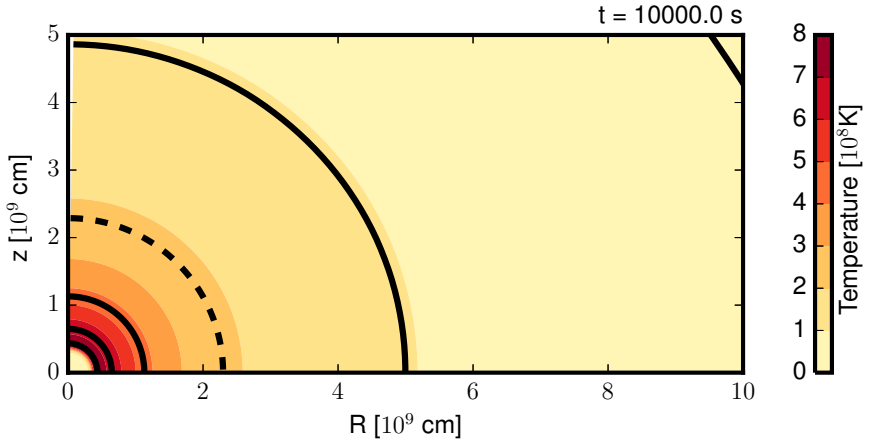
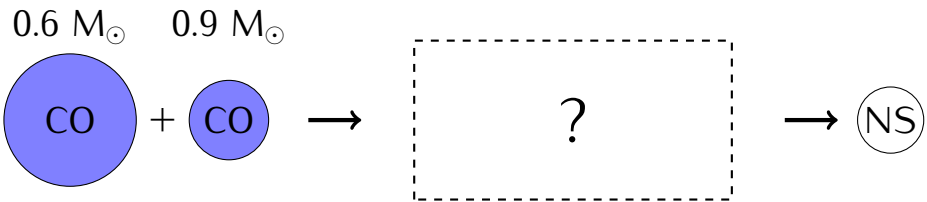
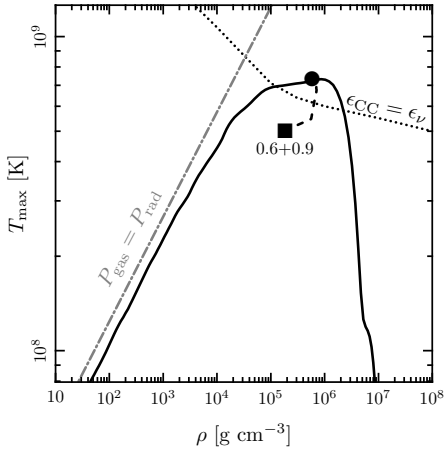


As a example system, consider the merger of carbon-oxygen WDs with a total mass in excess of the Chandrasekhar mass.



The viscous heating leads to the ignition of carbon fusion off-center in the remnant.



Schwab et al. (2012)

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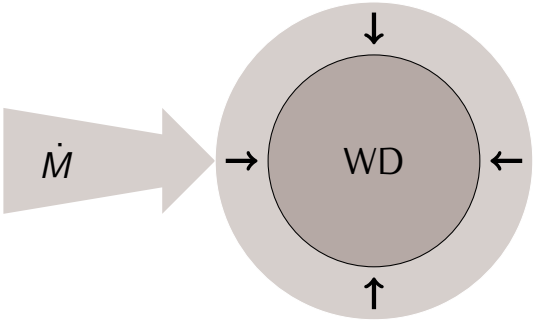
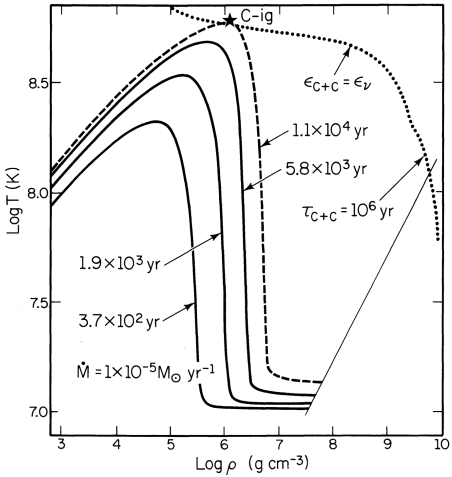
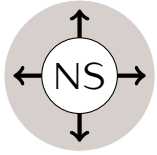
Previous work approximated the merger as an accretion event.



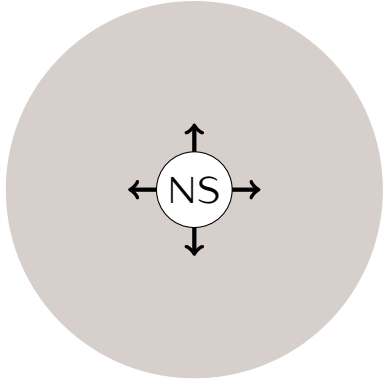


e.g., Nomoto & Iben (1985), ..., but see Yoon et al. (2007)

In the accretion picture, it can be hard to determine the radius of the remnant when it collapses to a neutron star.

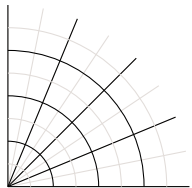


Compact Envelope:
Faint Signature



Extended Envelope:
Bright Signature

My approach maps the output of the hydrodynamics simulations of the viscous phase into the MESA stellar evolution code.



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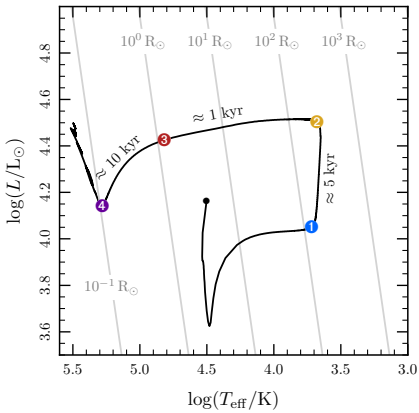
MESA

1D Stellar Evolution

MESA (Paxton et al. 2011, 2013, 2015, 2018); Schwab et al. (2016)

After the merger there is a cool, giant phase,

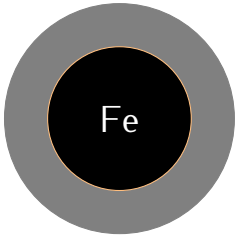
but this phase ends before the collapse to a neutron star.



Schwab et al. (2016)

The way the remnant collapses to a neutron star depends on the central composition.

Massive star core-collapse



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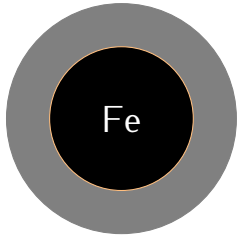
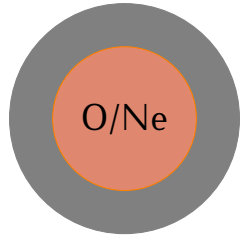
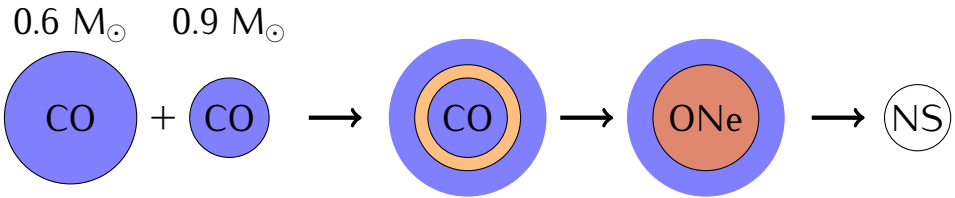


Electron-capture



Schwab et al. (2015, 2017)

The stellar evolution calculation gives the core composition.



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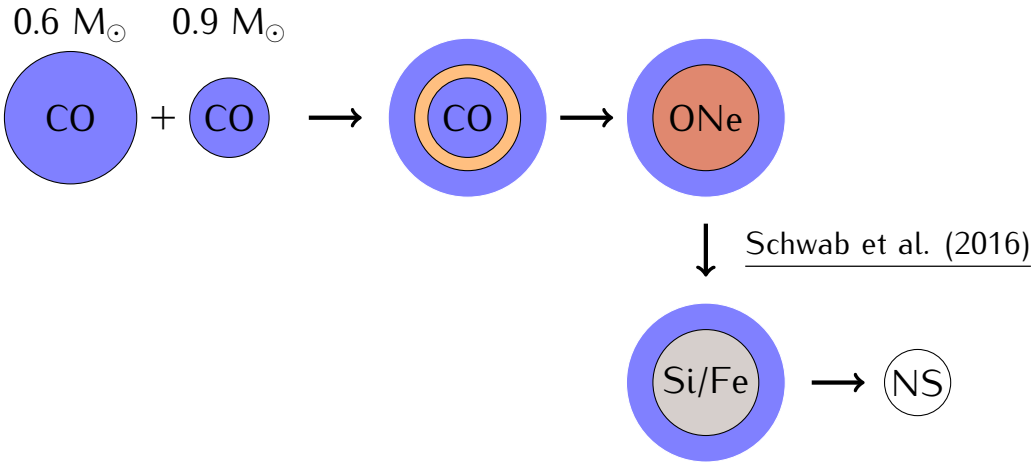

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  - **viscous** phase (rapid redistribution of angular momentum)
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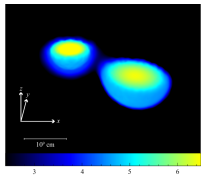
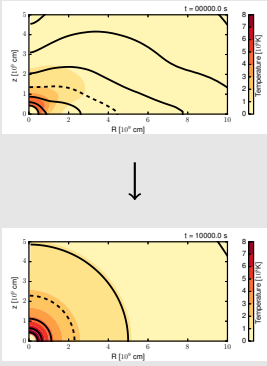
  - **dynamical** phase (merger)
  - **viscous** phase (rapid redistribution of angular momentum)
  - **thermal** phase (readjustment and stellar evolution)
- Connecting simulations of each phase enables studies of the long-term evolution of the post-merger objects.

Lagrangian Hydrodynamics



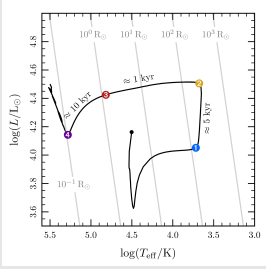
$\sim$ minutes

Eulerian Hydrodynamics



$\sim$ hours

Stellar Evolution (MESA)



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

The formalism developed here can be applied broadly.