The evolution and fate of super-Chandrasekhar mass white dwarf merger remnants

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

Dynamical Time (min)

Completion of merger

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

Viscous Time (hr)

Redistribute ang. mom.

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

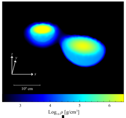
Thermal Time (kyr)

Radiate away energy

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

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

3D
Lagrangian
Hydrodynamics



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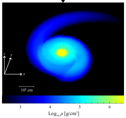
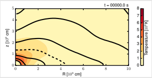


∼ minutes

Dan et al. (2011)

→

2D
Eulerian
Hydrodynamics



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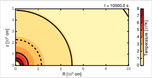
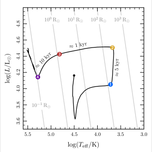


∼ hours

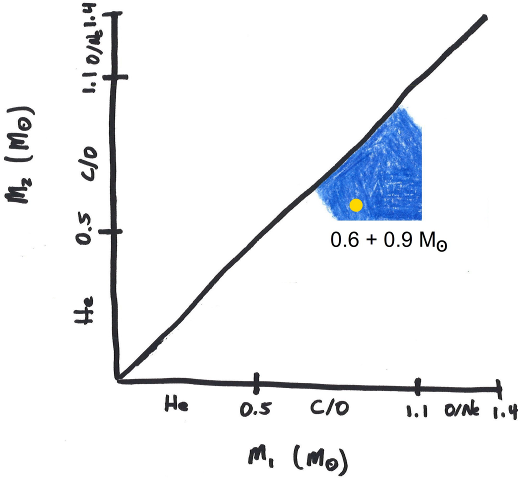
→

1D
Stellar
Evolution

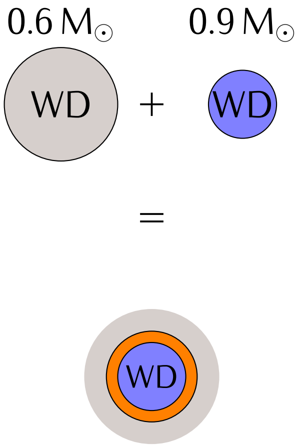


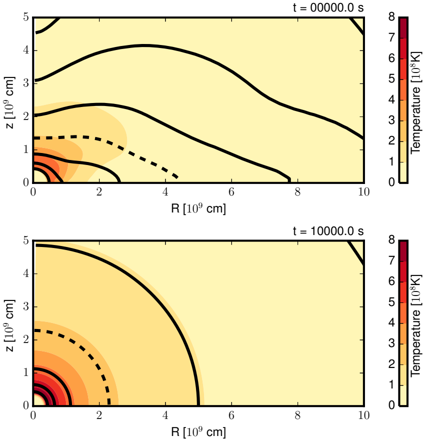
$\sim 10^4$ yr

There are a wide variety of possible outcomes depending on the masses of the WDs.



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





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

Previous work has taken several approaches.

Model merger as accretion on cold WD

Nomoto & Iben (1985); Saio & Nomoto (1985)
Finds off-center carbon ignition before core ignition (so no Ia; instead massive ONe core $\rightarrow$ NS).

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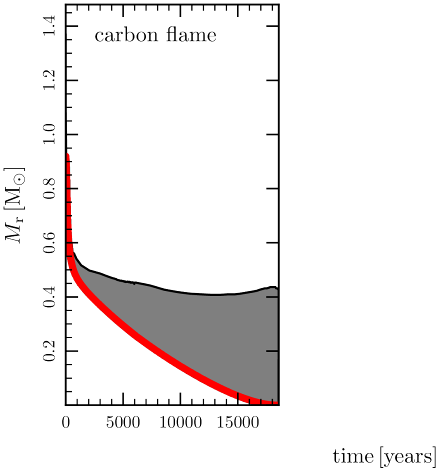
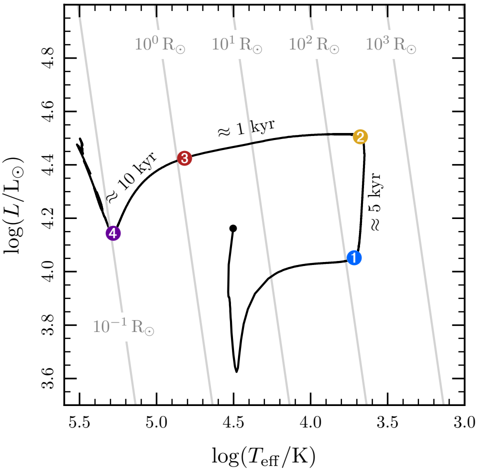
Use initial conditions from SPH merger sims

Yoon et al. (2007)
Can avoid off-center carbon ignition if angular momentum transport slow compared to neutrino cooling. (This seems unlikely to me, given MRI.)

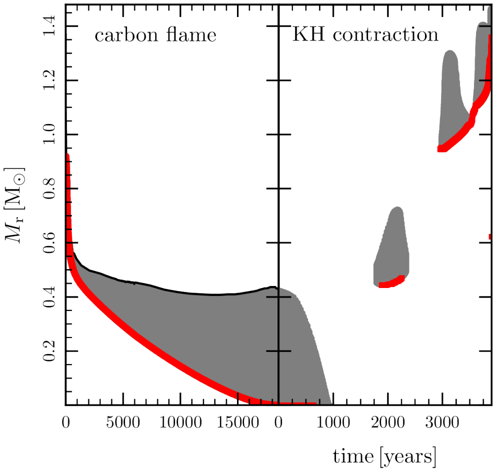
A convectively-bounded carbon deflagration forms and propagates inward, reaching the center.



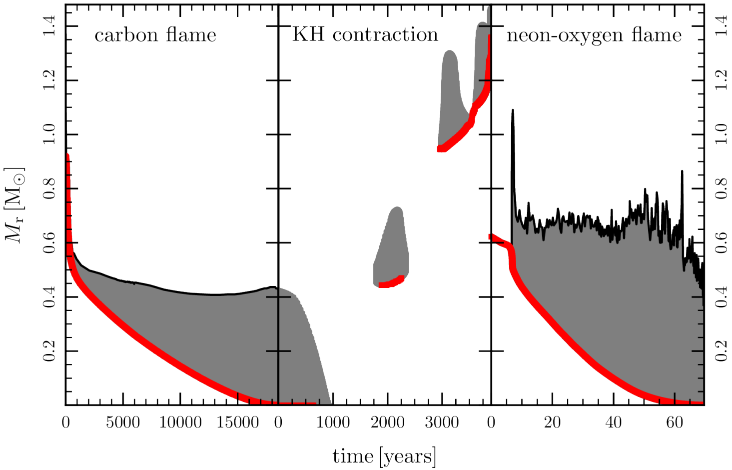
Post-merger there is a cool, giant phase,
but the carbon-burning is too deep to sustain it.



Then the remnant undergoes a phase of Kelvin-Helmholtz contraction.



A neon-oxygen deflagration forms and propagates inward, burning to Si-group.



A key uncertainty in our calculations is the amount of mass loss during the evolution.

Effect on final fate

- If mass loss causes the remnant to become sub-Chandrasekhar, then the end product may be a massive WD (and not a NS).

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Effects on observational manifestation

- The material shed would be primarily carbon/oxygen and which could cause the remnant to be obscured by a dusty wind.

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- We've outlined the observational signatures of the merger remnants during the pre-collapse phase. ($L \sim 3 \times 10^4 \mathrm{L}_\odot$, lifetime $\sim 10^4$yr, dusty?)
- At the time of collapse there won't be an extended envelope to capture the energy of the explosion (so the signature of the NS formation is likely faint and fast).

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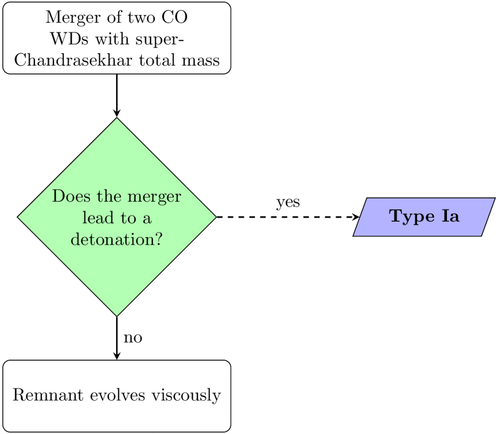
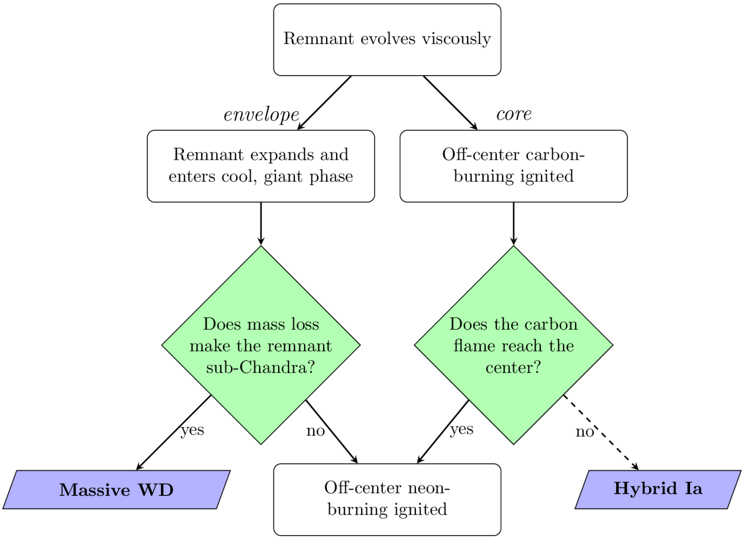
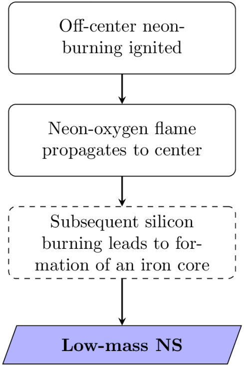
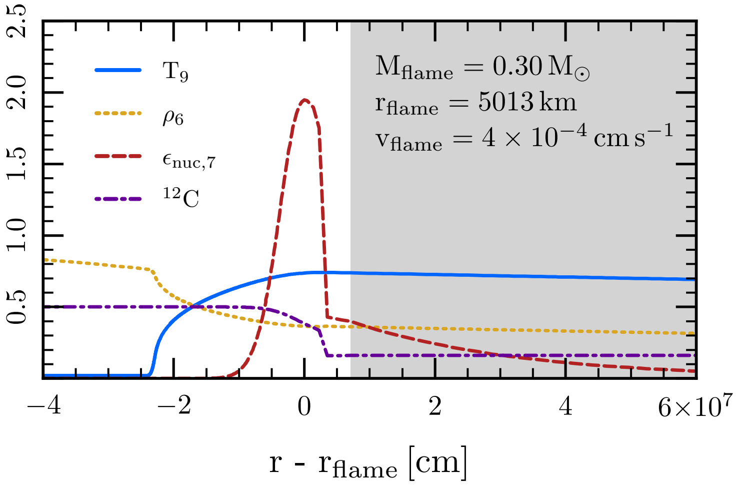
- Most broadly, I've been working to develop the tools and formalism necessary to take output from WD merger simulations and follow the remnants to their final fates.


Merger of two CO WDs with super-Chandrasekhar total mass
Does the merger lead to a detonation?
yes
Type Ia
no
Remnant evolves viscously

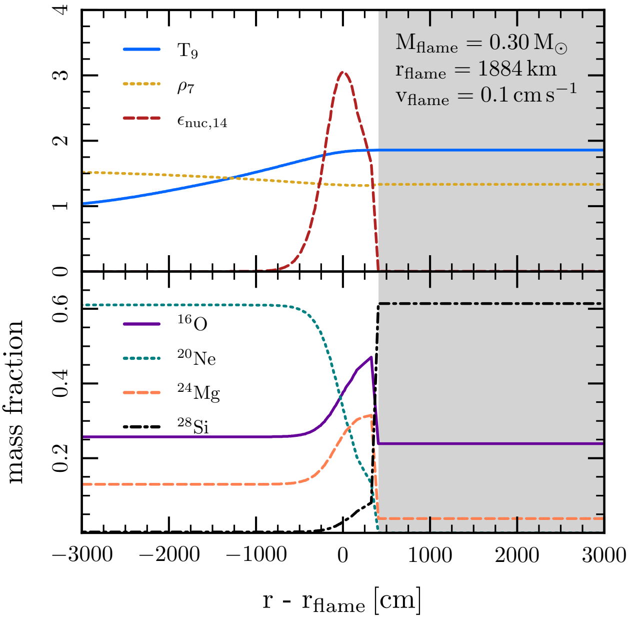


Remnant evolves viscously
envelope
core
Remnant expands and enters cool, giant phase
Off-center carbon-burning ignited
Does mass loss make the remnant sub-Chandra?
Does the carbon flame reach the center?
yes
no
yes
no
Massive WD
Off-center neon-burning ignited
Hybrid Ia


Off-center neon-burning ignited
Neon-oxygen flame propagates to center
Subsequent silicon burning leads to formation of an iron core
Low-mass NS



2.5
2.0
1.5
1.0
0.5
T_9
ρ_6
$\epsilon_{nuc,7}$
^{12}C
$M_{flame} = 0.30\,M_\odot$
$r_{flame} = 5013\,km$
$v_{flame} = 4 \times 10^{-4}\,cm\,s^{-1}$
−4
−2
0
2
4
$6{\times}10^7$
r - r_{flame} [cm]



T_9
ρ_7
$\epsilon_{nuc,14}$
$M_{flame} = 0.30\,M_{\odot}$
$r_{flame} = 1884\,km$
$v_{flame} = 0.1\,cm\,s^{-1}$
^{16}O
^{20}Ne
^{24}Mg
^{28}Si
mass fraction
r - r_{flame} [cm]