Viscous Evolution of WD-WD Merger Remnants

Josiah Schwab, Eliot Quataert, Ken Shen

Abstract

We present numerical hydrodynamics calculations of the evolution of a merger remnant of two unequal mass white dwarfs. We introduce an α-viscosity, motivated by the fact that the remnant is susceptible to MHD instabilities. We find that the remnant evolves to a spherical, thermally supported state, with some mass transported to large radii.

Schematic Merger Process

Recently, Shen et al. (2011) presented a model for the long-term evolution of the merger of two unequal mass white dwarfs.

- **Dynamical Merger:** $t \sim 10 P_{\rm orb}$
  Less massive WD transfers mass, and if unstable, is tidally disrupted.
- **Viscous Evolution:** $t \sim 10^4 - 10^8$ s
  Magnetic stresses redistribute angular momentum. The material transitions from being rotationally supported to thermally supported.
- **Thermal Evolution:** $t \sim 10^4$ yr
  The now-spherical, thermally supported envelope radiates at near Eddington and undergoes Kelvin-Helmholtz contraction.

Initial Conditions

We use the output of SPH simulations of WD-WD mergers, done using realistic initial conditions from Dan et al. (2011). We have mapped the results of these 3D SPH simulations onto a 2D grid. At present, we have simulated two He+He systems, 0.2 + 0.3 $M_\odot$ and 0.3 + 0.4 $M_\odot$, as well as one CO+CO system with masses 0.6 + 0.9 $M_\odot$.

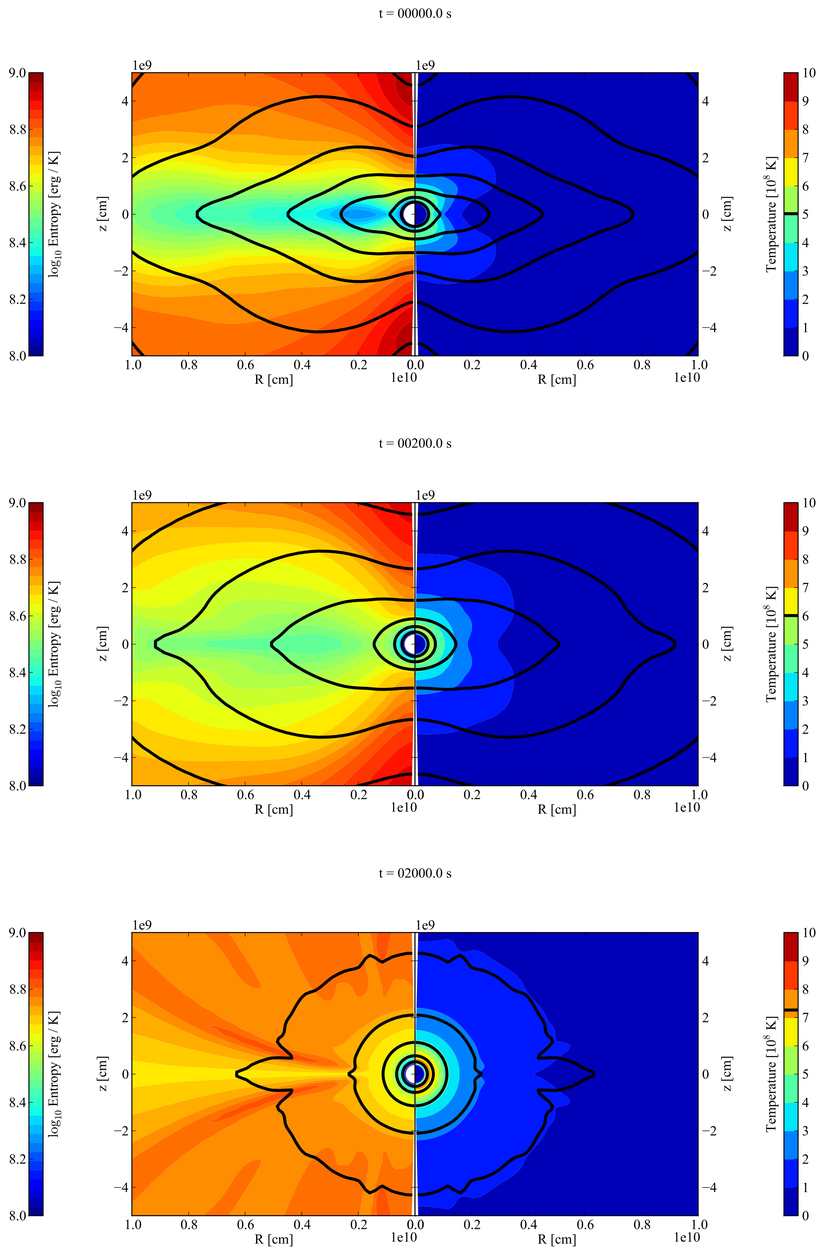
Numerical Methods

We use the ZEUS-MP/2 code (Hayes et al. 2006) modified to include an explicit shear viscosity ($\nu = \alpha c_s^2/\Omega_k$) and the Helmholtz equation of state (Timmes and Swesty 2000). The calculations are performed in 2D spherical coordinates (assuming ϕ-symmetry). We do not track any nuclear reactions as the temperature remains too low for burning to be dynamically important on the viscous timescale.

Future Work

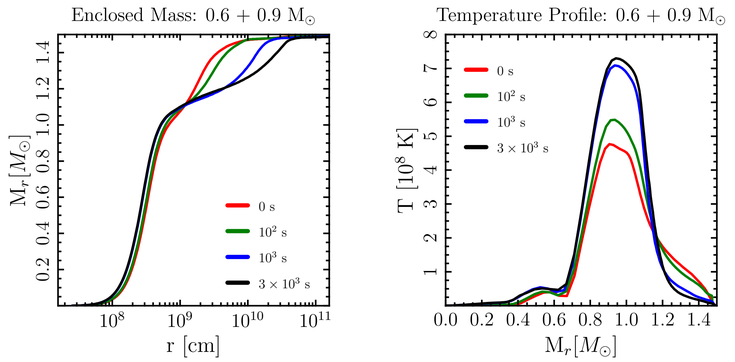
- Simulate mixed He+CO systems
- Predict the thermal evolution of the remnant
- Compare with similar 3D simulations

Snapshots of 0.6 + 0.9 $M_\odot$ remnant evolution

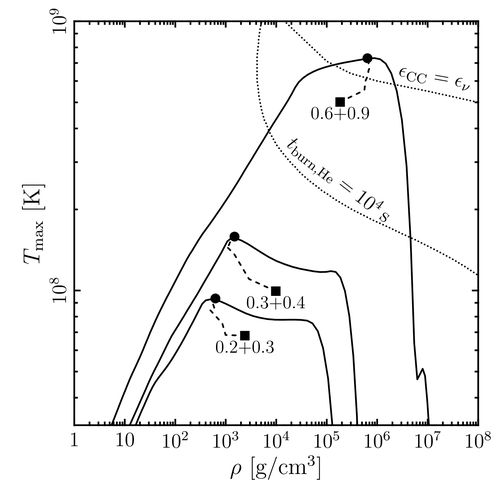


The left panel shows the entropy (log scale). The right panel is the temperature (linear scale). The solid black lines are density contours, beginning with $\rho = 10^6\,{\rm g\,cm^{-3}}$ at the innermost contour and decreasing by a factor of 10 each step outwards. The black line on the temperature color bar indicates the maximum temperature in the remnant.

Mass and Temperature Profiles



Temperature-Density Evolution



Dashed lines show the evolution of the peak temperature and that corresponding density. *Solid lines* indicate the 1D temperature-density profile reached by the remnant at the end of the simulation. The *dotted line* $t_{\rm burn,He}$ indicates where He burning would become dynamically important on the timescale of the simulation. The *dotted line* $\epsilon_{\rm CC} = \epsilon_\nu$ indicates where neutrino losses balance the energy generation from carbon fusion. (C fusion is never dynamically important within the bounds of this plot.)

Acknowledgments

JS thanks Marius Dan for providing the output of the SPH simulations performed by him and his collaborators. This work was done under support of an NSF Graduate Research Fellowship. JS thanks the AAS for travel support through its International Travel Grant Program.