Simulations of Binary White Dwarf Mergers

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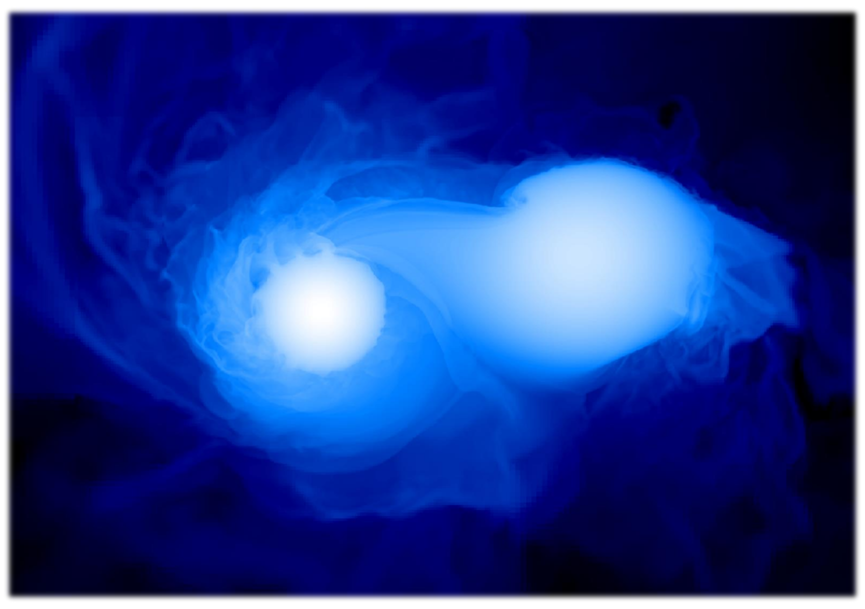
Motivation

- **Type Ia Supernovae (SNe Ia) are important astronomical events. We use them to estimate the expansion and age of the universe, and they help shape its chemical evolution.**
- **Despite extensive study, the cause of SNe Ia remains a mystery. Discovering the cause will help us better understand their properties.**
- **The merger of two white dwarf stars in a close orbit holds promise as an explanation for these events.**

Introduction

It is widely held that SNe Ia arise from exploding white dwarf stars, though the conditions that lead to the explosion are not known. A popular explanation describes a system of two white dwarfs in a close orbit, in which the stars fall toward each other and eventually merge [1]. The precise details of this merger are not known, but ultimately an explosion may occur.

The goal of this research is to further our understanding of important aspects of the merger process. A major part of this goal is the search for ignition [2]—a runaway thermonuclear fusion process that results in the explosion of the star as a supernova. Our simulations are capable of resolutions much higher than other white dwarf merger simulations conducted to date. High resolution is important [3] because localized fluctuations in temperature and density may lead to ignition, causing the star to explode. However, if the simulation is unable to resolve the scale of such fluctuations, it may fail to observe an explosion, giving qualitatively different results.



Pseudocolor image illustrating the white dwarf merger process.

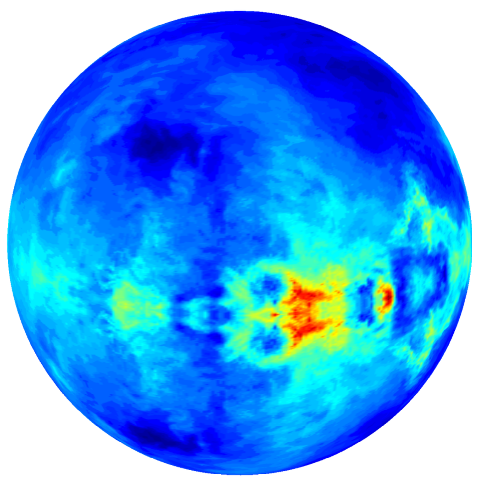
Models and Methods

We perform 3D simulations of various white dwarf merger scenarios on a cartesian mesh using FLASH, an AMR hydrocode [4].

We simulate systems of three different progenitor mass ratios: $0.6 + 0.9$ $M_\odot$, $0.8 + 1.2$ $M_\odot$, and $0.9 + 0.9$ $M_\odot$. We additionally use varying resolutions to explore the effect of mesh resolution on simulation outcomes.

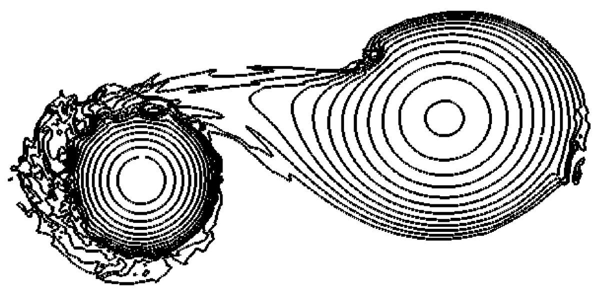
Each simulation begins just prior to mass transfer. We interpolate each star's structure onto the mesh using a self-consistent field method [5] so that tidal deformations are accurately represented. We then allow the stars to spiral inward by making their orbital velocities slightly sub-Keplerian.

Results



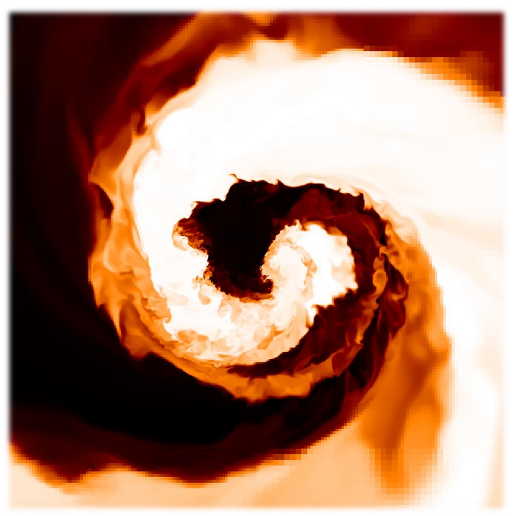
Column densities in the boundary layer of the $0.8 + 1.2$ $M_\odot$ model, computed for a spherical shell with a thickness of 512 km.

We observe that two distinct behaviors emerge. Systems with differing masses exhibit a turbulent boundary region where accreted material interacts with the surface of the accreting star.



Merger morphology at the onset of boundary-layer shock heating for the $0.6 + 0.9$ $M_\odot$ model, with 15 density contours logarithmically spanning the range from 10^4 to 10^7 g cm^{-3}. Kelvin Helmholtz instabilities are clearly visible.

Heating in this region is predominantly driven by turbulence and shear. Large-scale Kelvin-Helmholtz structures are visible.

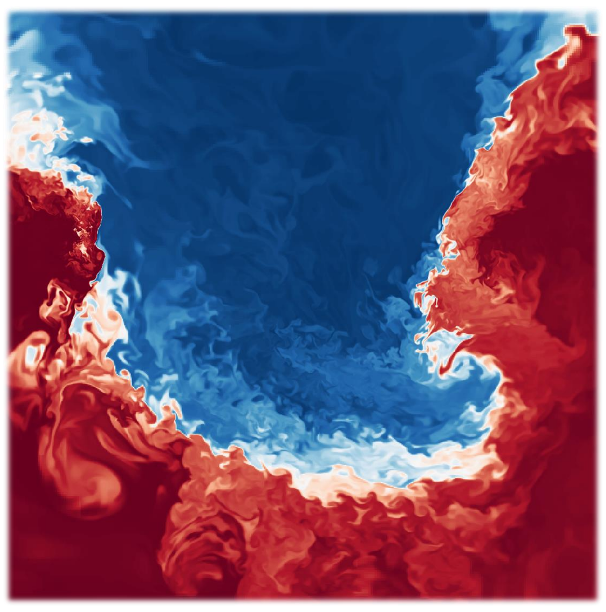


Morphology of the $0.6 + 0.9$ $M_\odot$ model at the time when ignition times are lowest. The color represents material origin, with the white representing the primary and dark, the secondary.

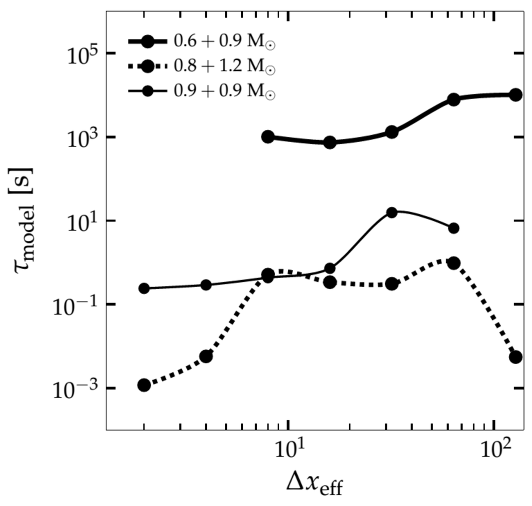
In contrast, the equal-mass progenitor model shows significant penetration of each star's core into the other. This drives the compression of the stellar material near the core at the interface between the two stars, causing it to heat up. We do not observe ignition in either case.

Discussion

We find that mesh resolution plays an important role in white dwarf merger simulations, and can qualitatively alter simulation outcomes.

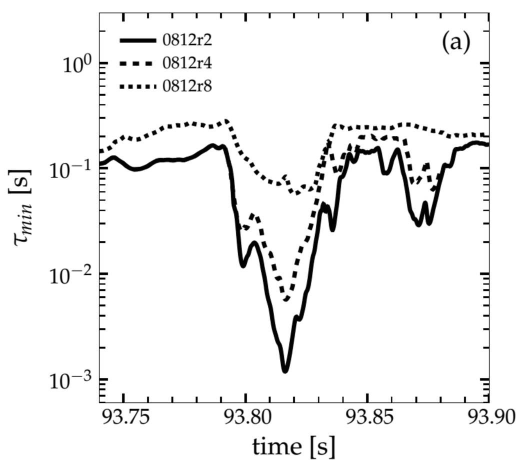


Mixing and entrainment in the $0.9 + 0.9$ $M_\odot$ model.

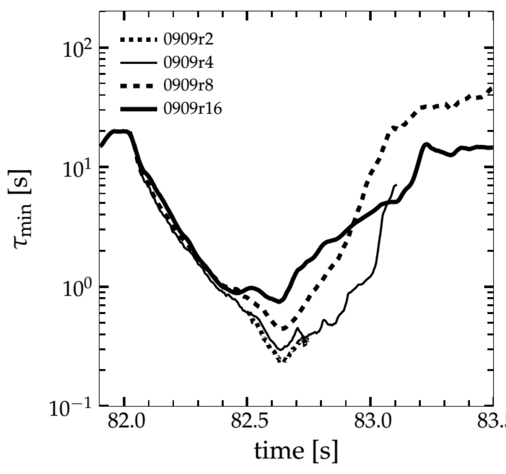


Minimum observed ignition time as a function of effective mesh resolution.

Prompt ignition in boundary layer models is driven largely by turbulence and shear, which require high resolution. The dominant factor in entrainment models is compression, which acts on a larger scale and does not need to be as well-resolved.



Ignition time evolution for various resolutions for the $0.8 + 1.2$ $M_\odot$ model.



Ignition time evolution for various resolutions for the $0.9 + 0.9$ $M_\odot$ model.

Although we do not observe ignition, the $0.8 + 1.2$ $M_\odot$ model exhibits intense burning. Higher resolution may lead to different results.

Conclusions

- **We see evidence supporting ignition in the $0.8 + 1.2$ $M_\odot$ model, but higher resolution is needed to properly represent this scenario.**
- **Ignition does not seem probable for the equal –mass merger. Higher resolution is unlikely to make a difference.**
- **We found that simulation resolution can qualitatively change outcomes, casting doubt on the many existing under-resolved simulations of this scenario.**

Acknowledgements

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