MODELING TYPE IA SUPERNOVA PROGENITORS

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EXECUTIVE SUMMARY:

Type Ia supernovae (SN Ia) are thermonuclear explosions of carbon–oxygen (CO) white dwarf starss in binary systems. Observations reveal diversity in both the spectra and progenitor characteristics, suggesting multiple origins. Theoretically, three different sorts of progenitor systems have been invoked: a binary star couples with a single Chandrasekhar mass white dwarf, a similar system with a lower mass dwarf, and a merging pair of white dwarfs. All have in common the eventual fusion of roughly one solar mass of carbon-oxygen (CO) to iron-group and intermediate-mass elements. Using Blue Waters, we are modeling each of these scenarios. Our most recent work involved the merging dwarf scenario.

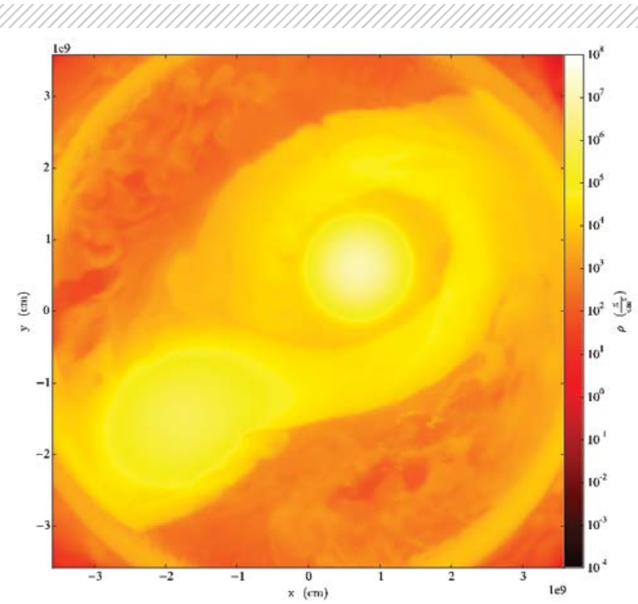

FIGURE 1: Evolution of a binary white dwarf system in the early stages of merging. This is a slice through the orbital plane of these stars. The lower-left object started as a 0.6 solar mass star, and the upper-right star started at 0.9 solar masses. The smaller star is slowly feeding its mass onto the bigger one; eventually it will be completely disrupted and the system will become completely coalesced, before possibly igniting as a Type Ia supernova.

INTRODUCTION

SN Ia are exceptionally bright explosions with an empirical relation that allows them to be used to measure cosmic distances. Both theory and observations require the progenitor to be a carbon–oxygen (CO) dwarf, but variations in how the explosion is initiated lead to different outcomes. In some cases, the explosion is highly anisotropic with significant viewing angle effects. In order to understand these fascinating explosions that are responsible for producing most of the iron on Earth as well as providing the first strong evidence for dark energy, multi-dimensional simulation is required. Subtle differences in an explosion may also affect the use of SN Ia for distance determination in an era of "precision cosmology."

METHODS & RESULTS

A suite of hydrodynamics codes has been developed and optimized specifically to study SNe Ia. Maestro [1] is a low-Mach-number hydrodynamics code that can efficiently model convection in white dwarfs during the early stages. The early stages time periods set the stage for a white dwarf's explosion and determine the outcome of the explosion. Once the explosion develops into a dynamic phase, Castro [2] solves the fully compressible equations of hydrodynamics, along with self-gravity and nuclear burning, and uses a flame model to represent the propagation of the burning front through the star. Castro can also follow the dynamics of inspiraling white dwarfs and their mutual detonation.

Last year, we used a combination of Maestro and Castro to run a Chandrasekhar mass model all the way from the early convective stage through explosion. This was one of the main goals of our Blue Waters project. This year we have focused more on the two alternate models, especially merging white dwarfs. This required substantial new coding, but we have now run the first set of test simulations for this progenitor system (fig. 1).

Both Maestro and Castro and the problem data files necessary to reproduce these simulations are available on github: https://github.com/BoxLib-Codes for other researchers.

WHY BLUE WATERS?

Blue Waters gives us the resources to study 3D systems at high resolution. All of the models considered are inherently 3D and yield outcomes that are asymmetric to varying degrees. High resolution, including several levels of mesh refinement, is required to track the nuclear burning that occurs both as a turbulent subsonic front and as detonation. In the latter case, fine resolution is needed to see the initial formation of the detonation.

PUBLICATIONS

Malone, C. M., et al., The Deflagration Stage of Chandrasekhar Mass Models For Type Ia Supernovae: I. Early Evolution. *Astrophys. J.*, 782 (2014), 11, doi:10.1088/0004-637X/782/1/11.