THE UNIVERSITY OF TENNESSEE KNOXVILLE
DEPARTMENT OF PHYSICS & ASTRONOMY

Sub-Chandrasekhar type Ia supernovae scenarios with large networks

Fernando Rivas [1,2] Bronson Messer [2] Austin Harris [2]
[1]University of Tennessee [2]Oak Ridge National Laboratory

Introduction

Type Ia supernovae (SNIa), though a subset, are the only type of transient in the 10^{51}erg range which attain their brightness from thermonuclear reactions, causing their lightcurves (LC) to fall within a small range of scatter after "standarization" (a calibration not unlike Cepheid variables and time-luminosity relationships; (Maoz et al. 2014; Phillips 1993).

Due to observational constraints in spectra, brightness, and angular size, they were confined to white-dwarf(WD) progenitors (Iben et al. 1984; Bloom et al. 2012; Li et al. 2011; Nugent et al. 2011), therefore fixing a physical limit to their presumed mass due to electron degeneracy, the Chandrasekhar limit: $1.4M_\odot(M_{Ch})$, and also their assumed yields: 0.6-1.0$M_\odot$ ^{56}Ni. This follows from the assumed thermonuclear energy source, which forces the explosion to reach (at least for some time) nuclear statistical equilibrium (NSE) which means their lightcurves must be powered by the so-called iron group elements (IGE; V, Cr, Mn, Fe, Co, Ni), a group formed around the least bound nucleus (Fe). Thus, the lightcurves are powered by the β-decay chain $^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co}{}^{56}\mathrm{Fe}$ (particularly the B-band).

Goal and thesis

The current outlook from simulations warrants further studies into the nature of SNIa detonations. Most urgent of which is treating neutronization throughout the hydrodynamic evolution while considering higher dimensional effects such as convection in a non-parametric way through direct numerical simulation (DNS) while starting from compositionally correct models to accurately set the starting neutronization for the event. The primary feedback for these simulations are mainly the burning shock turning asymmetric with time as it expands and varies due to coupling to the hydrodynamics, the variation of burning length scales due to dimensionality (Papathedore 2015), and the increased energy release from the nuclear network into the system via the non-alpha paths for nucleosynthesis of the same types of species (Timmes et al. 2000). It is thus the object of this work to perform three-dimensional, large network (over 100 species) simulations to further constrain the ranges for detonation in SNIa events.

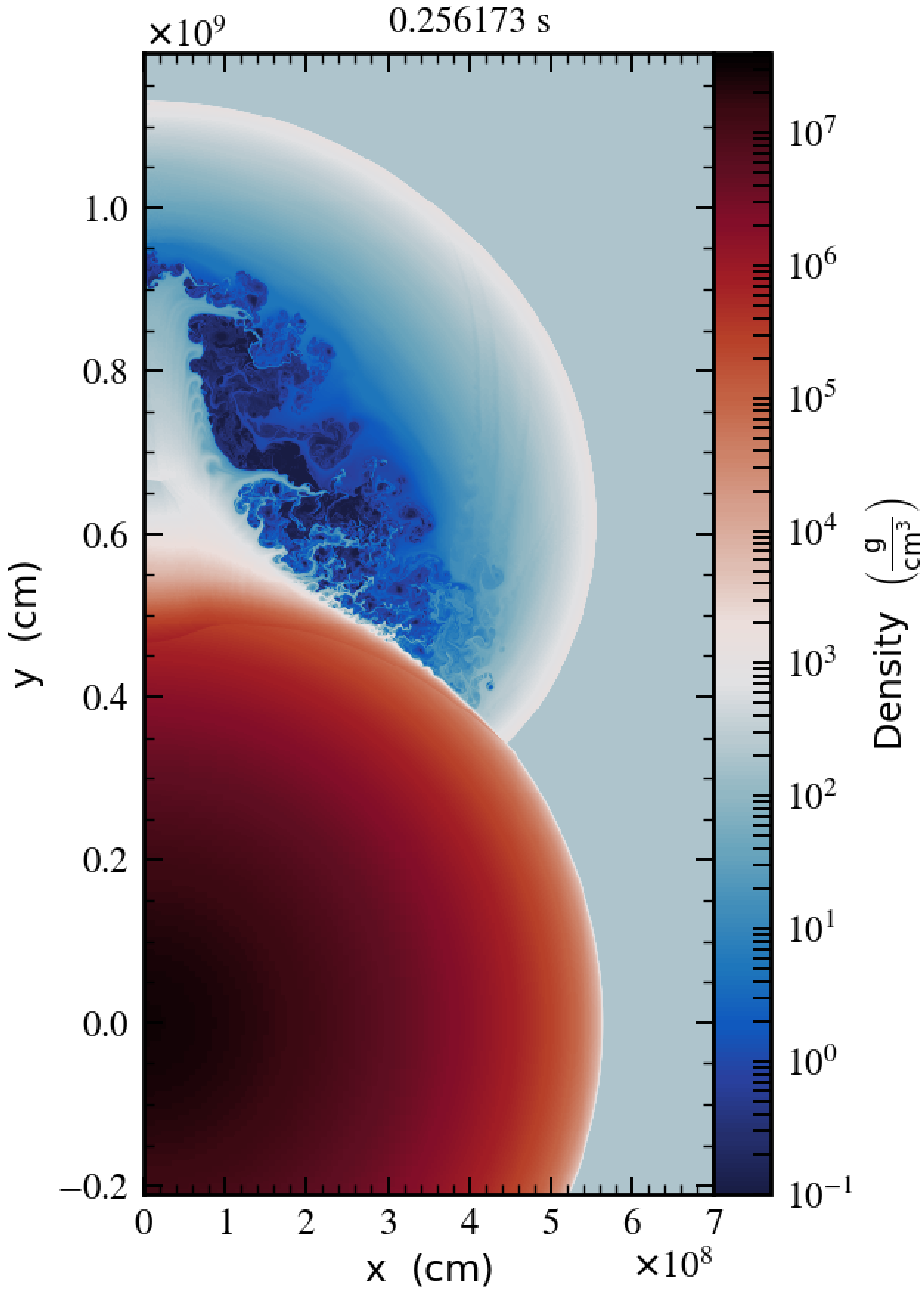


Figure 1: **Pole ignited detonation of a WD embedded in a helium shell provided by a companion star's accretion. Even though this simulation assumes azimuthal symmetry, the multi-dimensional effects of realistic detonations are already visible through Rayleigh-Taylor and Kelvin-Helmholtz instabilities causing mixing and redistribution of chemical species throughout the domain.**

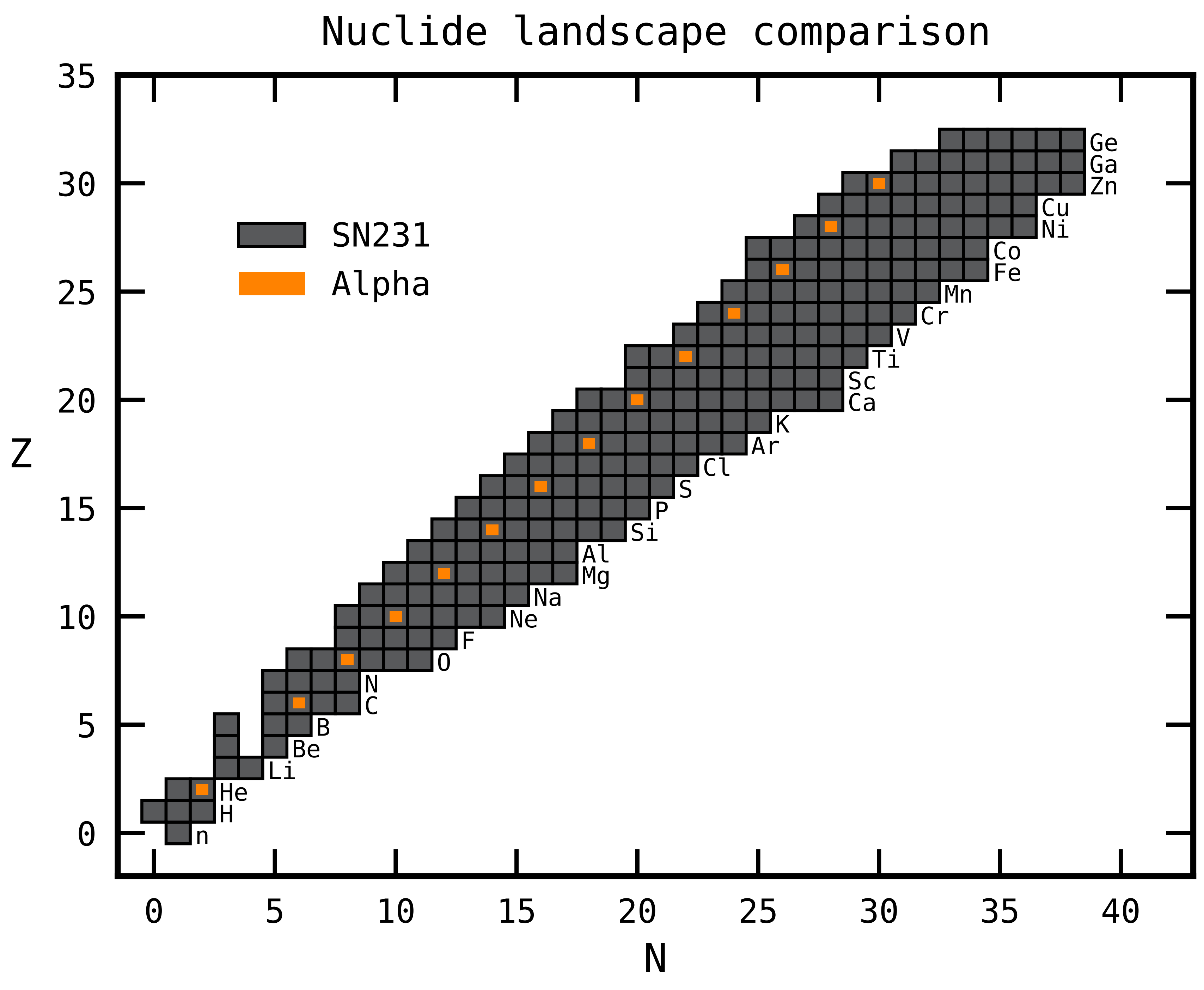
Codebase

Throughout this work, simulations will be run using the FLASH code (Fryxell et al. 2000), a modular code which can couple multiple systems of equations and perform optimizations subject to the requirements of the physics.

- `Hydro` solves the compressible Euler equations through the piece-wise parabolic method (PPM) (Colella et al. 1984), a second order Godunov finite-volume method (FVM). FVM methods are apt for unresolved shocks in the fluid due to averaging volumes before solving the equations, this in contrast with finite-difference methods which lose the shock due to it being a single point in the grid, breaking higher order solvers.
- `EoS` applies a set equation of state for the simulation, updating either hydrodynamic variables or thermodynamic ones as required by their modules `Hydro` and `Burn`, respectively.
- `Grid` uses an adaptive mesh refinement (AMR) criteria to increase the resolution of the simulation where needed (`PARAMESH`, see: Fryxell et al. 2000, , and references therein).
- `Burn` calculates burning rates for a given network of species, updating compositions and relevant fluid variables such as temperature (Timmes 1999).
- `Gravity` solves the Poisson equation for the density distribution of the simulation via a multipole expansion, yielding an external field for the `Hydro` module.

Numerical Domain

Simulations are carried out with the `FLASH` code suite on cube-shaped domain with dimensions of $\sim 7\times10^{9}$ cm per side with an extrapolated spherically symmetric WD profile in the center, plus a chemically variable envelope with a pre determined density and temperature. This envelope can vary from pure helium, to pure carbon or oxygen to include a variation of the companion accretion stream's composition or to account for pre-mixing from the WD itself into the shell envelope. The grid for the simulation is refined *ad-hoc* subject to a physical quantity (pressure unless stated otherwise) so that a scale on the order of ten kilometers is reached for the burning front.



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