Shock Dynamics of Sub-Chandrasekhar Mass Double Detonations in Type Ia Supernovae

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It is widely thought that type Ia supernovae (SNe Ia) are thermonuclear explosions of white dwarf (WD) binary systems, although their exact progenitor systems and explosion mechanisms are still debated. Despite this, a particular mechanism and its accompanying progenitor scenarios have garnered significant attention in the last few decades; the sub-Chandrasekhar-mass double detonation, which has shown promise in recovering the proper SNe Ia observables (Shen et al., 2024). The sub-Chandrasekhar-mass double detonation involves a primary carbon and oxygen (CO) WD that is accreting helium (He) from a degenerate or non-degenerate companion. When the He shell becomes sufficiently massive, a detonation is triggered in the shell which eventually propagates into the CO and triggers a detonation in the core. The CO can ignite soon after the shock transitions into the core in what is called the *edge-lit* scenario, deeper into the core at a more central point where the shock collides with itself in the *shock convergence* scenario, or in what is called the *Scissors Mechanism* where the detonation shocks in the He shell wrap around the WD and collide at the antipode of the ignition location in the transition layer where some He and CO mixing has occurred (Gronow et al., 2020). Much of the SNe Ia modelling done are full star simulations, often using level-set methods (Dunkley et al., 2013). While having the benefits of capturing the entire stellar system, the accretion stream, and macroscopic characteristics of the explosion, they lose much if not all of the details in the structure of the detonation wave because of the vast scales involved. Casabona and Fisher (2024) and Fisher et al. (2019) have shown a new ignition mechanism present in degenerate He and CO requires finer resolution than previously used in full star simulations, highlighting the need for more resolved modelling of these phenomena. Numerically this presents a challenge because the length scales of the WD are multiple orders of magnitude larger than those of the nuclear reactions. Particularly in the case of the CO core which can have radii on the order of 1000 km and carbon burning at the cm level. Further, the ability of the nuclear reaction networks used in these calculations to recover detonation characteristics is relatively unknown. Our work intends to bridge this gap by modelling the 2D structure of He and CO detonations on the km scale while also resolving the finer scales which are relevant in their respective reaction zones. We have also computed steady detonations with losses due to curvature effects in degenerate He and CO with reaction networks of varying complexity to show the impact on the detonation velocity. The aim of this work is to eventually model a zoomed in section of the shell with varying densities and temperatures much like a WD atmosphere, and upper region of the core to simulate the shock of the initial He detonation wave as it transitions from the shell to the core through either a lone detonation wave as in the edge lit scenario or through the collision of the shock with itself as in the scissors mechanisms. The reduced domain size along with AMR will allow for the resolution of the reaction zones of both He and CO detonations, ultimately to better understand the viability of the numerous proposed mechanisms of sub-Chandrasekhar mass double detonations.

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