Hiding Surviving Companions in Type Ia Supernova Remnants

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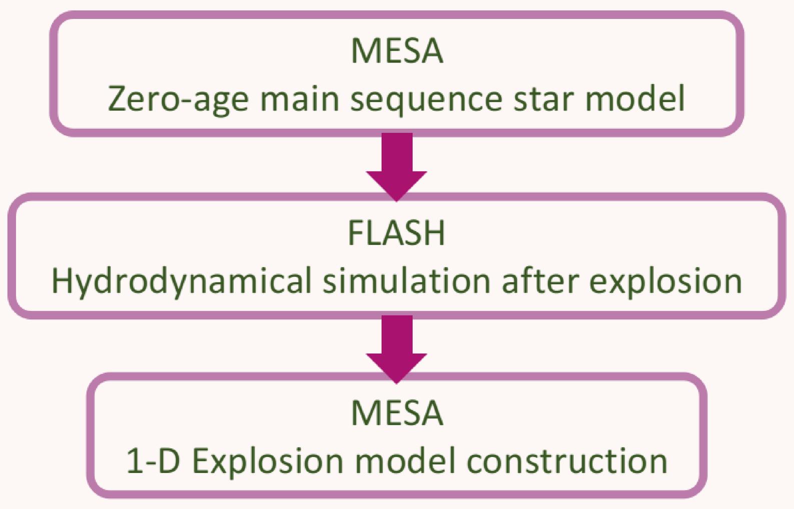
Abstract

Recent theoretical and numerical studies of Type Ia supernova explosion within the single-degenerate scenario suggest that non-degenerate companions could survive and the supernova impact could be luminous after the explosion. However, the surviving ex-companions are still not firmly detected in observations of nearby type Ia supernova remnants. In this project, we investigate the response of surviving companions via two-dimensional hydrodynamics simulations of supernova ejecta on binary companions and the subsequent long-term stellar evolution of surviving companions. We consider a wide range of possible hydrogen-rich companions and characterize the companion response systematically. Our results suggest that some of the single degenerate channels would favor low mass ($\leq 1M_\odot$) companion and close binary separation at the onset of the explosion, to explain the non-detection of surviving companions in nearby supernova remnants.

Introduction

The single degenerate scenario (SDS) for Type Ia supernova remains one of the most popular models which could explain several observational signatures of its spectra and kinetics. In the SDS, the explosion of the carbon-oxygen white dwarf (WD) is triggered by accretion from a non-degenerate companion star, such as a main-sequence (MS) star, a red giant, or a helium star, through Roche lobe overflow or winds. In this scenario, the non-degenerate companion has a high chance to be survived after a supernova explosion, and, therefore, might be detectable in nearby supernova remnants(SNRs). Identifying these surviving companions could shed light on the nature of Type Ia supernova progenitors. However, recent observations of young Galactic Type Ia SNRs or SNRS in Large Magellanic Cloud (LMC) ([1], [2]) show no conclusive evidence of such surviving companions, suggesting peculiar channels of SDS might be necessary if the ex-companion was indeed a non-degenerate star.

Simulation Method



Since the detailed binary evolution prior to a Type Ia supernova explosion still has some uncertainty, we use the stellar evolution code MESA (r10398; [3]) to construct four solar metalicity zero-age main-sequence companions of 0.8, 1, 1.5, and 2 $M_\odot$ at the onset of the explosion in this study. We then use the hydrodynamics code FLASH4 [4] to perform supernova simulation with a binary companion. The explosion is described by a W7-like model [5], and the model construction is similar to the setup in [6]. In the standard SDS, the binary separation is about $3R_*$ because of RLOF [7], where R_* is the companion radius. However, if the accreting WD is rotating, a spin-up/down mechanism might cause a delay of explosion [8]. Therefore, the binary separation could vary during the spin-up/down period. This, we consider binary separations from $3R_*$ to $6R_*$ in the supernova impact simulations. By recording the entropy and mass changes during the supernova impact, we conduct the post-impact stellar evolution simulations to predict surviving companions' observables using MESA.

Results

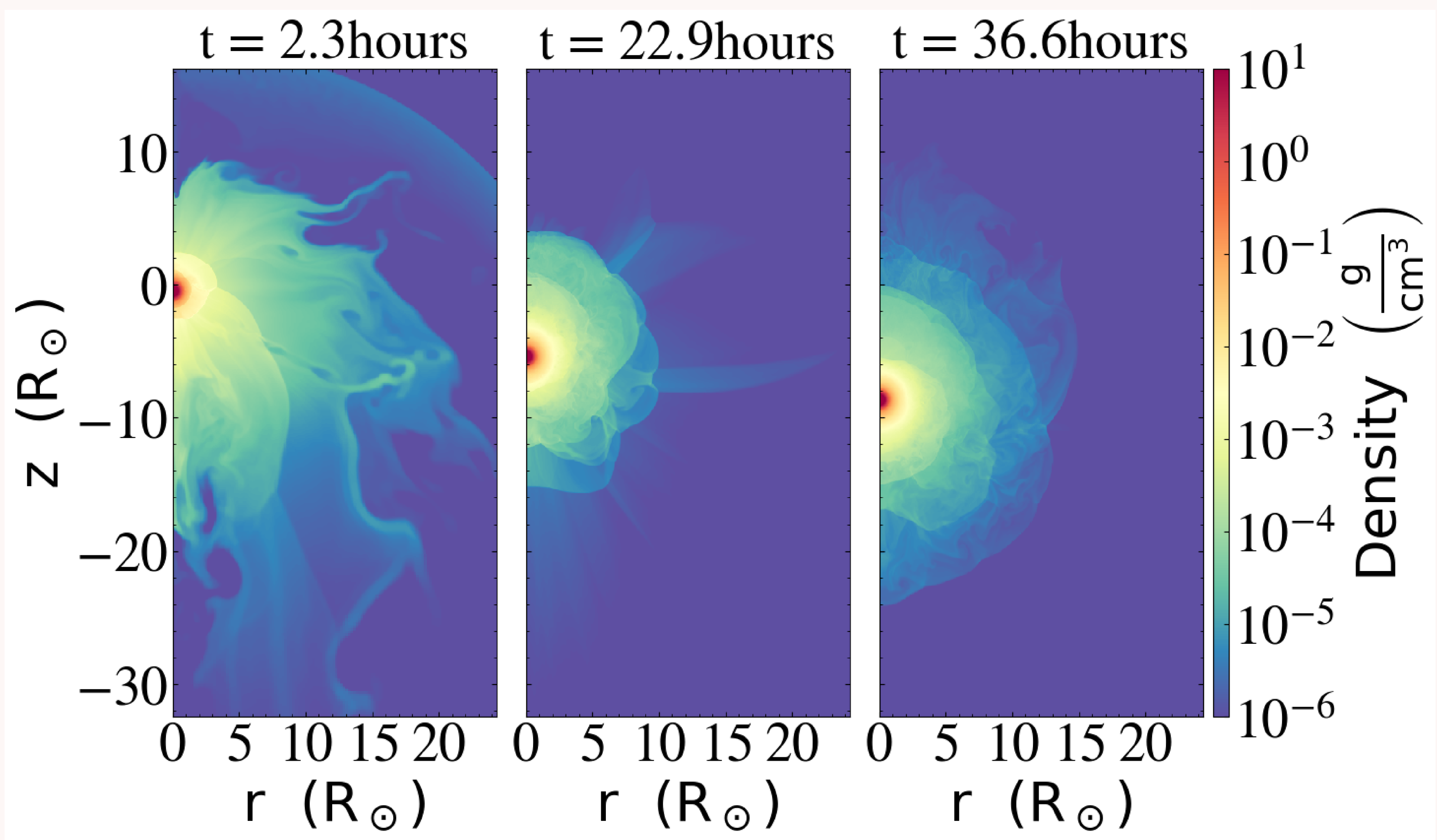


Figure 1: Density slice on the orbital plan for the $2M_\odot$ companion with separation a=$3R_*$ at different time after a supernova explosion. From left to right are t = 2.3, 22.9, 36.6 hours after explosion, corresponding to 5, 50, and 100 dynamical time scale ($\tau_{\rm dym}$).

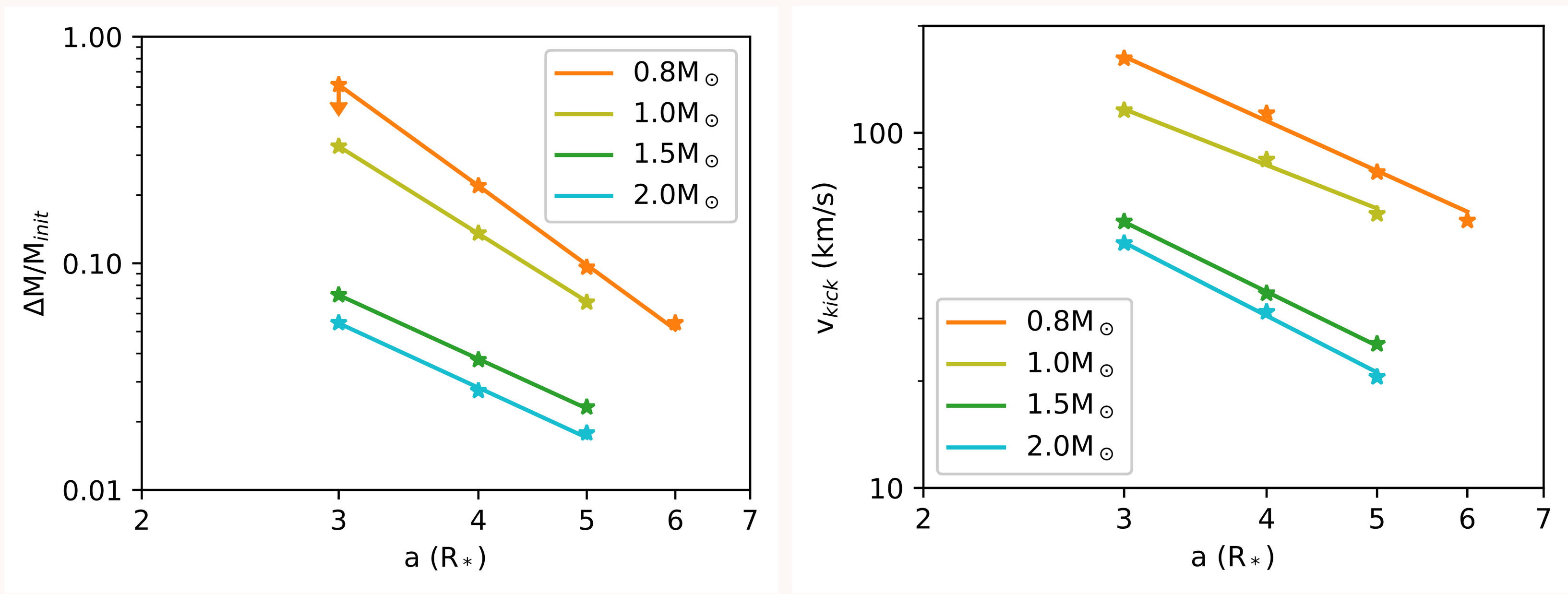


Figure 2: Left panel: Mass loss fraction due to supernova impact as functions of binary separation for each model. Right panel: supernova kick velocity as functions of binary separation for each model.

Figure 1 shows a typical density evolution of the supernova impact on a binary companion. A certain amount of the companion mass will be stripped or ablated by the supernova ejecta during the impact. The surviving companion will be compressed, kicked, and heated as well. The stripped mass and kick velocity of surviving companions with different mass and binary separation are summarized in Figure 2. The post-impact evolution of these surviving companions in the Hertzsprung-Russell (HR) diagram can be seen in Figure 3.

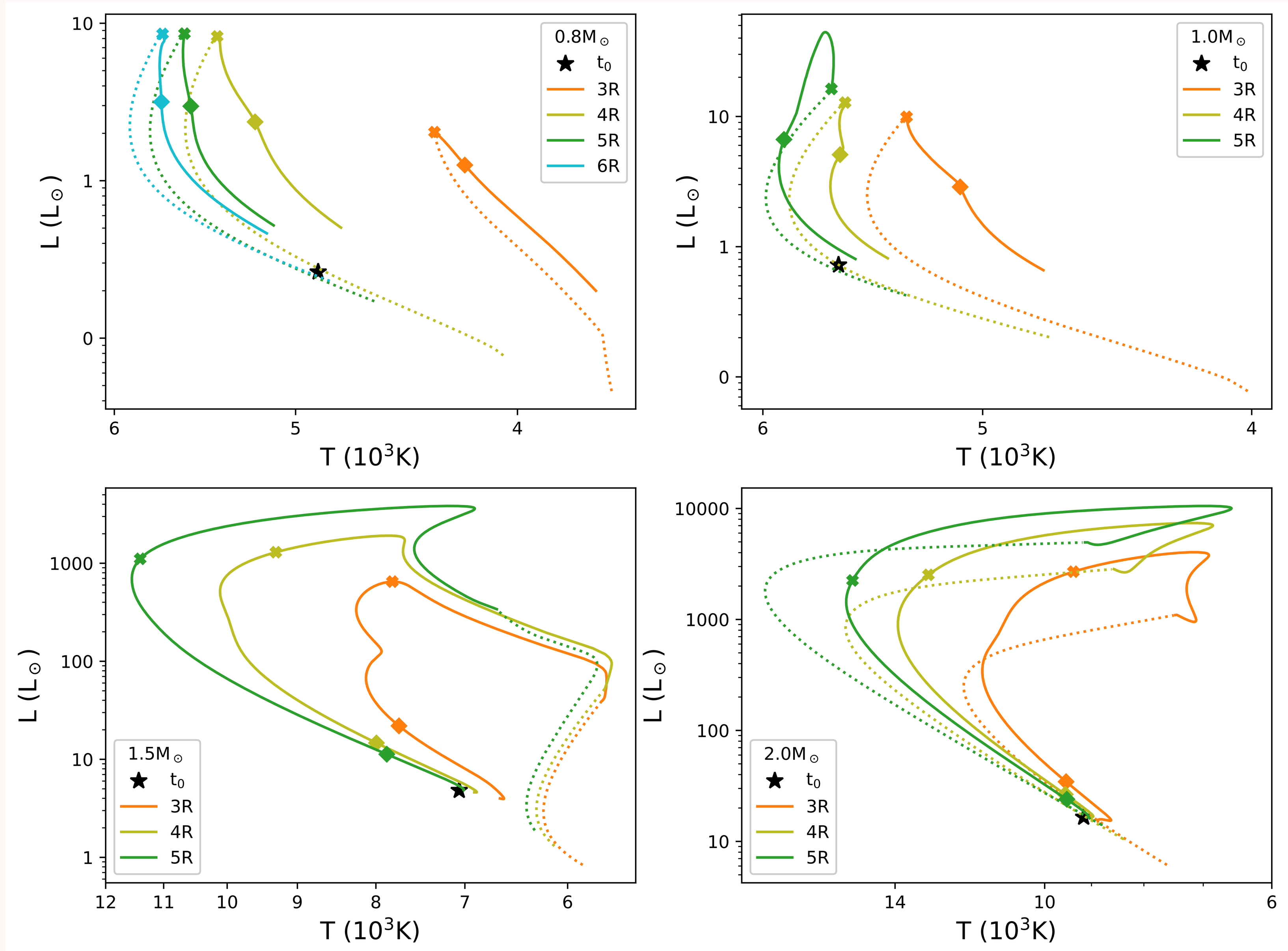


Figure 3: HR diagrams. Dashed lines represent the evolutionary tracks during the supernova heating ($t_{\rm heat} < 1$ yr), and solid lines indicate the post-impact evolutionary tracks up to 10^6 yrs. The squared (diamond) symbols mark the surviving companion status at 30 (3000) years after the supernova explosion.

Conclusions

We have investigated the impact of Type Ia supernova eject on a non-degenerate binary companion with a wide parameter space and perform the long-term post-impact evolution of surviving companions. Our results suggest that the binary separation, which is determined by the spin-up/down timescale, affects mainly on the color of the surviving companion but has little effect on the brightness of the surviving companion. Our models also favor low mass ($M_* < 1M_\odot$) companions at the onset of the explosion.

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