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The common-envelope wind model for type Ia supernovae

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Abstract. We have developed a new version of the SD model for type Ia supernovae (SNe Ia) in which a common envelope (CE) is assumed to form if the mass-transfer rate between a carbon/oxygen white dwarf (CO WD) and its companion exceeds a critical accretion rate. Based on this model, we found that both SN 2002cx-like and SN Ia-CSM objects may share a similar origin, i.e. these peculiar objects may originate from the explosion of hybrid carbon/oxygen/neon white dwarfs (CONe WDs) in SD systems, where SNe Ia-CSM explode in systems with a massive CE of $\sim 1\,M_{\odot}$, while SN 2002cx-like events correspond to events without a massive CE.

Keywords. binaries: close, stars: evolution, supernovae: general, white dwarfs.

1. Introduction

Although type Ia supernovae (SNe Ia) are important in many areas of astrophysics, e.g. as distance indicators to measure cosmological parameters, the nature of their progenitor systems has remained unclear (Riess *et al.* 1998; Perlmutter *et al.* 1999; Maoz *et al.* 2014). SNe Ia originate from the thermonuclear explosion of a carbon/oxygen white dwarf (CO WD) in a binary system, where the companion may be a normal non-degenerate star (the SD model). The most popular SD model is the optically thick wind (OTW) model in which, if the mass-transfer rate between the CO WD and its companion exceeds a critical mass-accretion rate, the WD accretes material at the critical accretion rate, while the remainder is lost from the system as an OTW (Hachisu *et al.* 1996). However, some of the predictions of the model are in conflict with observations. For example, it predicts that there should be no SNe Ia in low-metallicity or high-redshift environments, but many SNe Ia have been found in such environments (Rodney *et al.* 2015).

2. Model

To resolve the shortcomings of the OTW model, we constructed a new version of the SD model. We assume that, when the mass-transfer rate exceeds the critical accretion rate in a WD+MS system, the WD becomes a red-giant-like object and fills and ultimately overfills its Roche lobe, rather than developing an OTW: this leads to the formation of a common envelope (CE), in which the inner region of the CE corotates with the binary, while the angular velocity of the outer region drops off as a power law. The WD gradually increases its mass at the base of CE similarly to how the core grows in a thermally pulsing AGB star. The large nuclear luminosity for stable hydrogen burning drives a CE wind (CEW) from the surface of the CE. Because of the low CE density, the binary system can avoid a fast spiral-in phase and finally re-emerges from the CE as a detached system. The SN Ia may explode in the CE, a stable or weakly unstable hydrogen burning phase.

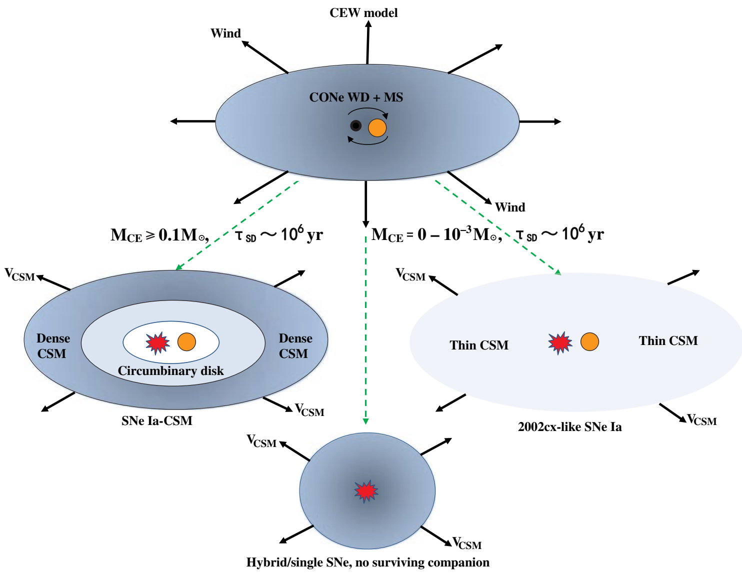

Figure 1. Schematic diagram illustrating the different channels for forming SNe Ia-CSM, SN 2002cx-like, and hybrid/single SNe (the figure is from Meng & Podsiadlowski 2018)

3. Virtues of the CEW model

The model (1) does not depend strongly on metallicity, (2) predicts a low-wind velocity, (3) allows for the self-adjustment of helium and hydrogen burning, (4) may explain the low number of observed supersoft X-ray sources and (5) the properties of recurrent novae, (6) leads to a higher SN Ia rate than the OTW model, (7) may produce 2002ic-like SNe, naturally explains (8) the high-velocity features of SNe Ia, (9) associations with planetary nebulae, and (10) the shape of some supernova remnants. Also (11) the CEW model is quite robust to various input assumptions (Meng & Podsiadlowski 2017).

4. SNe Ia-CSM and 2002cx-like

Based on the CEW model, we found that both SNe Ia-CSM and 2002cx-like objects may originate from systems with a hybrid CONe WD + MS, where those exploding in massive CEs show the properties of SNe Ia-CSM, while those without massive CEs are the progenitor of 2002cx-like SNe Ia (Fig. 1). The model predicts a number ratio of SNe Ia-CSM to SN 2002cx-like objects between 1/3 and 2/3, consistent with observations. Depending on the stage when the explosion occurs, our model produces a sequence of SNe Ia with a range of CSM densities: from SNe Ia-CSM to SN 2002cx-like events and normal SNe Ia, consistent with existing radio constraints. We also find a new subclass of hybrid SNe that share the properties of Type II and Type Ia SNe, without a surviving companion (Meng & Podsiadlowski 2018).

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