**RAA 2014** Vol. **14** No. **9**, 1146–1156 doi: 10.1088/1674–4527/14/9/005
*http://www.raa-journal.org* *http://www.iop.org/journals/raa*

***R**esearch in*
***A**stronomy and*
***A**strophysics*

# Double-detonation model of type Ia supernovae with a variable helium layer ignition mass *

Wei-Hong Zhou[1,2,3], Bo Wang[4,5] and Gang Zhao[1]

[1] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China; *ynzwh@bao.ac.cn*
[2] University of Chinese Academy of Sciences, Beijing 100049, China;
[3] Yunnan University of Nationalities, Kunming 650011, China;
[4] Yunnan Observatories, Chinese Academy of Sciences, Kunming 650011, China; wangbo@ynao.ac.cn
[5] Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650011, China

Received 2014 February 27; accepted 2014 April 8

**Abstract** Although Type Ia supernovae (SNe Ia) play an important role in the study of cosmology, their progenitors are still poorly understood. Thermonuclear explosions from the helium double-detonation sub-Chandrasekhar mass model have been considered as an alternative method for producing SNe Ia. By adopting the assumption that a double detonation occurs when a He layer with a critical ignition mass accumulates on the surface of a carbon–oxygen white dwarf (CO WD), we perform detailed binary evolution calculations for the He double-detonation model, in which a He layer from a He star accumulates on a CO WD. According to these calculations, we obtain the initial parameter spaces for SNe Ia in the orbital period and secondary mass plane for various initial WD masses. We implement these results into a detailed binary population synthesis approach to calculate SN Ia birthrates and delay times. From this model, the SN Ia birthrate in our Galaxy is $\sim 0.4 - 1.6 \times 10^{-3}\,\mathrm{yr}^{-1}$. This indicates that the double-detonation model only produces part of the SNe Ia. The delay times from this model are $\sim 70 - 710\,\mathrm{Myr}$, which contribute to the young population of SNe Ia in the observations. We found that the CO WD + sdB star system CD$-30\,11223$ could produce an SN Ia via the double-detonation model in its future evolution.

**Key words:** binaries: close — stars: evolution — supernovae: general — white dwarfs

## 1 INTRODUCTION

Type Ia supernova (SN Ia) explosions are among the most energetic events observed in the Universe. They are valuable probes for the study of cosmic evolution and are considered to be the main contributor of iron to their host galaxies (e.g., Riess et al. 1998; Perlmutter et al. 1999; Greggio & Renzini 1983). There is a consensus that SNe Ia originate from thermonuclear explosions of carbon–oxygen white dwarfs (CO WDs) in close binary systems (e.g., Nomoto et al. 1997). The CO WD can increase its mass to the Chandrasekhar mass or sub-Chandrasekhar mass by accreting material from

*Supported by the National Natural Science Foundation of China.

its companion star and then exploding as an SN Ia. For recent reviews on this subject see Wang & Han (2012) and Maoz et al. (2014).

The standard Chandrasekhar mass model is currently the favored model to describe progenitors of SNe Ia; for example, the simulated spectra from this model are in good agreement with the early time spectra of most SNe Ia (e.g., Hoeflich & Khokhlov 1996). Two families of SN Ia progenitor scenarios in this model have been proposed to produce the Chandrasekhar mass CO WD, which are the single-degenerate and double-degenerate scenarios. In the single-degenerate scenario, a CO WD can obtain material from a non-degenerate companion star, increase its mass to the Chandrasekhar mass, and then generate a thermonuclear explosion to become an SN Ia. The companion star in this scenario could be a main sequence star, a red giant or a He star (e.g., Nomoto 1982a; Hachisu et al. 1996; Li & van den Heuvel 1997; Han & Podsiadlowski 2004, 2006; Wang et al. 2009a, 2010; Meng et al. 2009; Ablimit et al. 2014). In the double-degenerate scenario, SNe Ia are produced from the merging of two close CO WDs that have a total mass larger than the Chandrasekhar mass limit and coalesce in the Hubble time, (e.g., Webbink 1984; Iben & Tutukov 1984). It has been thought that the double-degenerate scenario likely results in an accretion-induced collapse rather than causing a thermonuclear explosion due to the electron capture on $^{24}$Mg (e.g., Nomoto & Iben 1985). However, it is still too early to exclude this scenario because a few overluminous SNe Ia might be produced via this scenario (e.g., Howell et al. 2006).

A CO WD can also explode as an SN Ia by accumulating a He layer with a mass below the Chandrasekhar mass limit, which is known as the sub-Chandrasekhar mass model (e.g., Woosley et al. 1986). In this model, the He might be ignited off-center at the bottom of the He layer, which leads to an event known as double-detonation (following an outward detonation through the He layer, an inward propagating pressure wave compresses the CO core which ignites off-center in the WD) (e.g., Hoeflich & Khokhlov 1996). An alternative name for this model is the He double-detonation model. However, Nugent et al. (1997) argued that the double-detonation model has difficulties in trying to explain the observational properties of SNe Ia (e.g., light curves and spectra), which is likely due to the thickness of the He layer. Shen & Bildsten (2009) recently claimed that, even for lower masses of the He layer a detonation might be triggered in the He layer. Recent studies have indicated that this model may be consistent with the observed brightness of SNe Ia, although a thin He-layer is required (e.g., Fink et al. 2010; Kromer et al. 2010; Sim et al. 2010). The double-detonation model may be responsible for some subluminous 1991bg-like objects and extremely faint events (.Ia SNe) (e.g., Bildsten et al. 2007; Kasliwal et al. 2008; Foley et al. 2009). Additionally, this model can naturally explain why H has not been observed in SN Ia spectra.

Previous studies of the double-detonation model have often made the simplification that, for sufficiently massive CO WDs, a He layer with mass $0.1\,M_{\odot}$ can ignite and lead to a double detonation (e.g., Ivanova & Taam 2004; Ruiter et al. 2011; Wang et al. 2013). However, the properties of the He layer that lead to He ignition itself are still unknown. The ignition mass of the He layer is expected to be a function of CO WD mass and accretion rate (e.g., Shen & Bildsten 2009).

The purpose of this article is to comprehensively investigate the double-detonation model by adopting a more physical He layer ignition mass, and then to determine the initial parameter spaces for the production of SNe Ia. The numerical code for calculations modeling the binary evolution is described in Section 2, and the corresponding results are shown in Section 3. The binary population synthesis method is shown in Section 4, and its results are presented in Section 5. Finally, a discussion is given in Section 6.

## 2 NUMERICAL CODE FOR BINARY EVOLUTION CALCULATIONS

In the double-detonation model, the progenitor systems are WD + He star binaries. After the He star fills its Roche lobe, it will transfer some of its material onto the surface of the WD, resulting in a mass increase for the WD. By using Eggleton's stellar evolution code (Eggleton 1973), we have modeled the evolution of WD + He star systems. The physical attributes that are inputs to this code have been updated over the past four decades (Han et al. 1994; Pols et al. 1995, 1998). The description of Roche lobe overflow by Han et al. (2000) is adopted. The ratio of mixing length to local pressure scale height is set to be 2.0. The He star models in our calculations are composed of metallicity $Z = 0.02$ and He abundance $Y = 0.98$. Additionally, orbital angular momentum loss owing to gravitational radiation is included by adopting a standard formula presented by Landau & Lifshitz (1971).

According to recent hydrodynamic simulations, the minimum WD mass for carbon burning might be $\sim 0.8\,M_{\odot}$ in double-detonation explosions, since it may not be triggered for lower mass WDs (e.g., Sim et al. 2012). On the other hand, the WD should consist of carbon and oxygen to produce SNe Ia, which constrains the WD mass to be below $1.1\,M_{\odot}$. This happens because a more massive WD consists of oxygen, neon and magnesium, which is an ONeMg WD. Additionally, the WD needs to develop a He layer with a critical ignition mass that results in a double detonation (for a specific He layer ignition mass see the next paragraph). Therefore, we assume that a WD with an initial mass range of $\sim 0.8 - 1.1\,M_{\odot}$ explodes as an SN Ia when it accumulates a He layer with a critical ignition mass.

In the double-detonation model, we assume that the WD can increase its mass when the mass-accretion rate is higher than $4 \times 10^{-8}\,M_{\odot}\,\mathrm{yr}^{-1}$. We adopt $4 \times 10^{-8}\,M_{\odot}\,\mathrm{yr}^{-1}$ as the minimum accretion rate of weak He-shell flashes (Woosley et al. 1986; see also Wang et al. 2009a). If the accretion rate is higher than $4 \times 10^{-8}\,M_{\odot}\,\mathrm{yr}^{-1}$ but less than the minimum accretion rate necessary for stable He-shell burning, He-shell flashes occur and part of the envelope's mass is assumed to be blown off of the surface of the WD. The mass growth rate of WDs in this case is linearly interpolated from a grid computed by Kato & Hachisu (2004). Similar to our previous studies (e.g., Wang et al. 2009a), we assume that the He-shell burning is stable and there is no mass loss when the accretion rate is less than a critical accretion rate but above the minimum accretion rate needed for stable He-shell burning. For mass-accretion rates that are low ($<4 \times 10^{-8}\,M_{\odot}\,\mathrm{yr}^{-1}$), compressional heating at the base of the accreted He layer plays no significant role, and a layer of unburned He can accumulate onto the surface of the WD (see Nomoto 1982b).

However, if the mass-transfer rate is too low (e.g., $10^{-9}\,M_{\odot}\,\mathrm{yr}^{-1}$), the mass of the He layer that is needed for ignition will be too large to normally be reached (e.g., Shen & Bildsten 2009). We assume that a double-detonation occurs when a He layer with a critical mass $M_{\mathrm{ign}}$ accumulates on the surface of the WD. The critical mass for ignition of the He layer is given by Iben & Tutukov (1989),

$$M_{\mathrm{ign}} \simeq 0.04 M_{\odot} \left( \frac{R_{\mathrm{WD}}}{5 \times 10^{8}\mathrm{cm}} \right)^{3.75} \left( \frac{M_{\mathrm{WD}}}{M_{\odot}} \right)^{-0.30} \left( \frac{\dot{M}_2}{10^{-8}\,M_{\odot}\,\mathrm{yr}^{-1}} \right)^{-0.57}, \tag{1}$$

in which $R_{\mathrm{WD}}$ is the WD radius at the base of the accreted envelope. The ignition mass in the He layer in this equation mainly depends on the WD mass and the mass-transfer rate.

## 3 RESULTS OF BINARY EVOLUTION CALCULATIONS

The prescriptions in Section 2 are incorporated into Eggleton's stellar evolution code, and the evolutions of the CO WD + He star systems are monitored. We assume that the mass lost from these systems takes away the specific orbital angular momentum of the WD (e.g., Wang et al. 2010). Finally, large, dense model grids are obtained, in which the star that fills its Roche lobe is a He star.

In Figure 1, we present a typical example of binary evolution calculations for the double-detonation model. Panel (a) shows the mass-transfer rate and the mass of the WD envelope varying with time after the He star fills its Roche lobe, whereas Panel (b) is the evolutionary track of the He donor star, in which we also show the evolution of the orbital period. The binary consisting of the

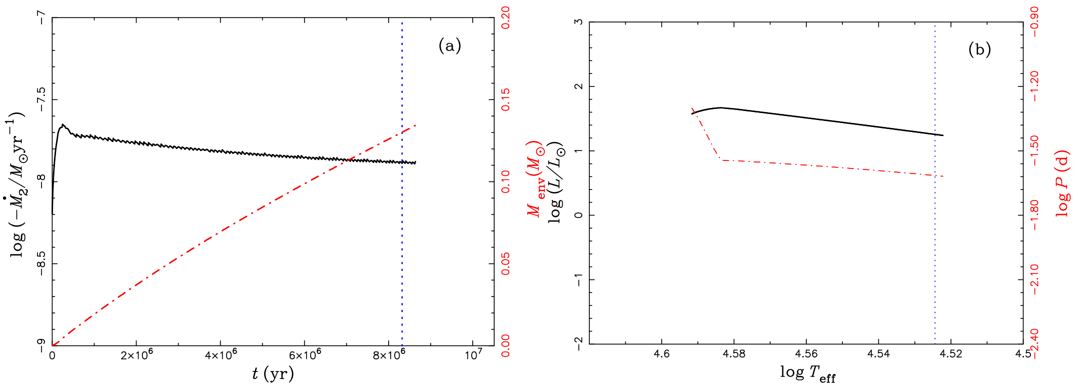


**Fig. 1** A typical example of a binary evolution calculation. (a) The solid and dash-dotted curves show the mass-transfer rate and the mass of the He layer on the WD varying with time after the He star fills its Roche lobe, respectively. (b) The evolutionary track of the donor star is shown as a solid curve and the evolution of orbital period is shown as a dash-dotted curve. In this binary, the initial mass of the WD is $0.9\ M_\odot$, the intial mass of the He star is $0.6\ M_\odot$, and the intial period is about 0.05 d; the final mass of the He star is $0.47\ M_\odot$, and the final period is about 0.025 d when the mass of the envelope increases to $0.13\ M_\odot$.

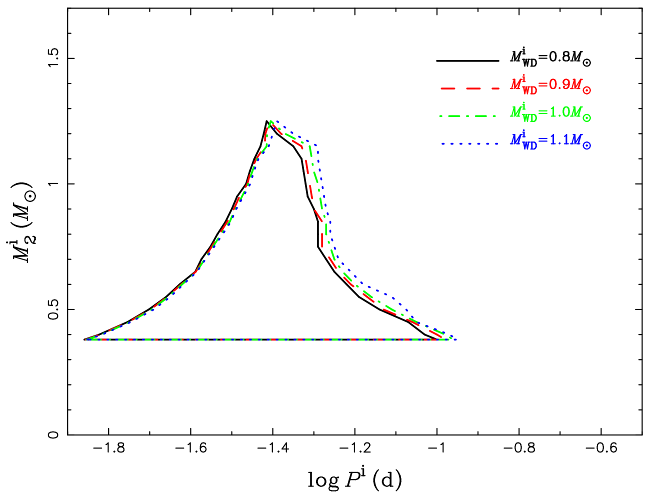


**Fig. 2** Space parameters in the initial orbital period–secondary mass plane (log $P^{\rm i}$, $M_2^{\rm i}$) for CO WD + He star binaries that produce SNe Ia with various initial WD masses.

WD + He star starts with ($M_2^{\rm i}$, $M_{\rm WD}^{\rm i}$, $\log(P^{\rm i}/{\rm day})$) = (0.6, 0.9, −1.3), in which $M_2^{\rm i}$ is the initial mass of the He star, $M_{\rm WD}^{\rm i}$ is the initial mass of the CO WD and $P^{\rm i}$ is the initial orbital period. Due to the short initial orbital period (0.05 d), the angular momentum loss induced by gravitational radiation is large, resulting in rapid shrinking of the orbital separation. After about 26 million years, the He star begins to fill its Roche lobe while it is still in the He-core burning stage. The mass-transfer rate is stable and has a low rate of $\sim 1.3 \times 10^{-8}\ M_\odot\ {\rm yr}^{-1}$, which leads to the formation of a He layer on the surface of the CO WD. After about 9 million years, the mass of the He layer increases to a critical mass (i.e., $0.13\,M_\odot$), at which point a detonation may occur at the base of the He layer, which further produces a double-detonation explosion. At the moment of the SN explosion, the mass of the He star is $M_2^{\rm SN} = 0.47\,M_\odot$ and the orbital period is $\log(P^{\rm SN}/{\rm day}) = -1.61$.

In Figure 2, the initial contours for producing SNe Ia are shown in the $\log P^{\rm i} - M_2^{\rm i}$ plane for various WD masses, i.e. $M_{\rm WD}^{\rm i} = 0.8$, 0.9, 1.0 and $1.1\,M_\odot$. The upper boundaries are constrained by a high mass-transfer rate owing to orbital decay induced by gravitational radiation and a large mass ratio, which results in the WD growing in mass to the Chandrasekhar limit (see Wang et al. 2009a). The lower boundaries are constrained because the masstransfer rate is just enough to produce a He layer with a critical ignition mass on the surface of the CO WD. The binary systems beyond the right boundaries experience a high mass transfer when the He star evolves to the subgiant stage, whereas the left boundaries of the contours are constrained by the condition that the Roche lobe overflow starts when the companion star is in the He ZAMS stage.

## 4 METHOD OF BINARY POPULATION SYNTHESIS

In order to obtain SN Ia birthrates and delay times for the double-detonation model, a series of Monte Carlo binary population synthesis simulations is performed. Similar to our previous studies (e.g., Wang et al. 2009b; Wang & Han 2010a,b), we adopted the following basic parameters for the Monte Carlo simulations:

(1) The initial mass function of the primary star is from Miller & Scalo (1979).
(2) A constant mass-ratio distribution is taken (e.g., Goldberg & Mazeh 1994).
(3) The distribution of initial orbital separations is assumed to be constant in $\log a$ for wide binary systems, where $a$ is orbital separation (e.g., Han et al. 1995).
(4) A circular orbit is assumed for all binary systems.
(5) A constant star formation rate is simply assumed over the past 14 Gyr or, alternatively, it is modeled as a delta function, that is a single instantaneous starburst (a burst producing $10^{11}\,M_\odot$ is assumed in stars).

For each binary population synthesis simulation, we employed Hurley's binary evolution code to simulate the evolution of $10^7$ sample binaries (Hurley et al. 2002). These binaries are followed from star formation to the formation of the CO WD + He star systems based on three binary evolutionary scenarios (see fig. 3 of Wang & Han 2012). The metallicity in these simulations is set to be $0.02$. If the initial parameters of a CO WD + He star system at the start of the Roche lobe overflow are consistent with how SNe Ia are produced (Fig. 2), then a double-detonation explosion is assumed to occur.

In the process of binary evolution, the CO WD + He star binary is most likely produced from the common-envelope evolution of a giant binary system. The way that common-envelope evolution proceeds is still uncertain (e.g., Ivanova et al. 2013). The standard equations describing energy are used to calculate the output during the common-envelope phase (e.g., Webbink 1984). In the common-envelope evolution, there are two unclear parameters, i.e. $\alpha_{\rm ce}$ and $\lambda$, in which $\alpha_{\rm ce}$ is the ejection efficiency of common-envelope energy and $\lambda$ is a stellar structure parameter that is related to the definition of the core-envelope boundary and the evolutionary stage of the donor star. Similar to our previous works (e.g., Wang et al. 2009b), we use a single free parameter $\alpha_{\rm ce}\lambda$ to describe the process of common-envelope ejection and we give the results for two specific values (0.5 and 1.5).

## 5 RESULTS OF BINARY POPULATION SYNTHESIS

By adopting metallicity $Z = 0.02$ and star-formation rate ${\rm SFR} = 3.5\,M_\odot\,{\rm yr}^{-1}$, we give the evolution of Galactic SN Ia birthrates (see Fig. 3). This study returns a Galactic SN Ia birthrate of

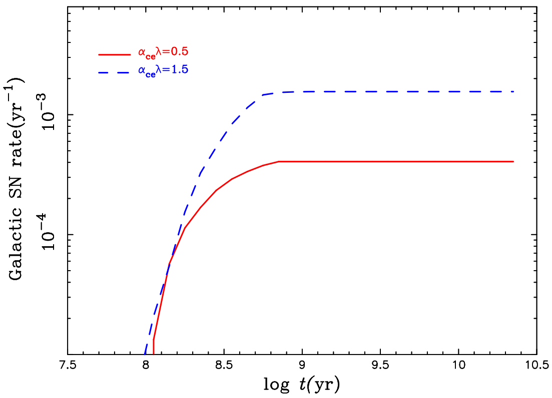


**Fig. 3** Evolution of Galactic SN Ia birthrates for a constant star-formation rate.

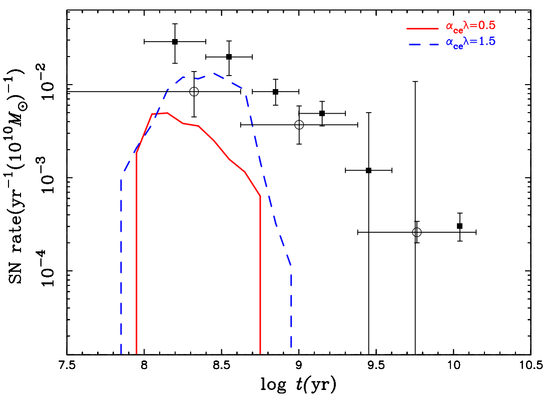


**Fig. 4** Delay time distributions of SNe Ia for the double-detonation model. The open circles and filled squares are taken from Maoz et al. (2011) and Totani et al. (2008), respectively.

$\sim 0.406 - 1.557 \times 10^{-3}\,\mathrm{yr}^{-1}$. This value is lower than that of the inferred Galactic SN Ia birthrate, which is $3-4\times10^{-3}\,\mathrm{yr}^{-1}$ (Cappellaro & Turatto 1997), which indicates that the double-detonation model only produces part of the overall SN Ia birthrate (for a recent review of other potential SN Ia formation channels see Wang & Han 2012). We also found that the SN Ia birthrate from $\alpha_{\rm ce}\lambda = 0.5$ is lower than that of $\alpha_{\rm ce}\lambda = 1.5$. This happens because the parameters of the post common-envelope binaries are more likely to be located in the region where SNe Ia are produced for the case of $\alpha_{\rm ce}\lambda = 1.5$.

The theoretical delay time distribution of SNe Ia can be compared with that of observations, and then used to examine current models of progenitors. Figure 4 displays the SN Ia delay time distributions for the double-detonation model. From this figure, we can see that this model has delay times from $\approx 70\,$Myr to $\approx 710\,$Myr after the starburst. This indicates that these double-detonation explosions make a contribution to the population of young SNe Ia (e.g., Mannucci et al. 2006).

From our binary population synthesis approach, we show some properties of initial parameters in WD + He star systems that produce SNe Ia, which could be helpful in searching for potential progenitor candidates of SNe Ia in observations.

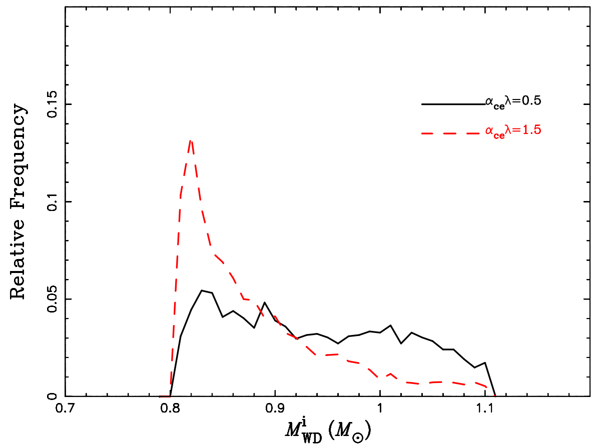


**Fig. 5** Distribution of the initial WD masses in the WD + He star systems that can ultimately produce double-detonation explosions.

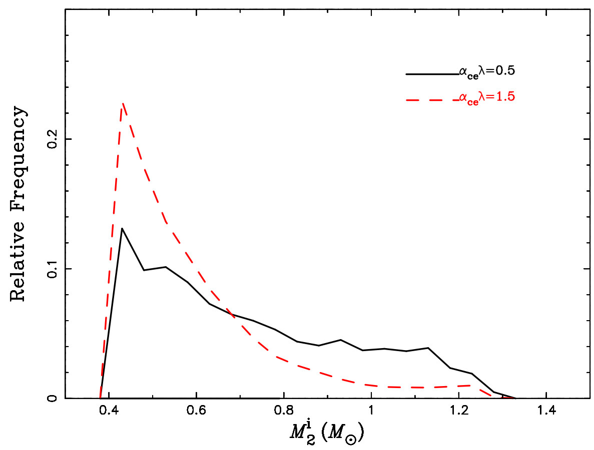


**Fig. 6** Similar to Figure 5, but for the distribution of the initial masses of secondaries in the WD + He star systems.

Figure 5 shows the distribution of initial WD masses in WD + He star systems that can ultimately produce double-detonation explosions in their future evolution. In this figure, we present the results with different cases of $\alpha_{ce}\lambda$ and give a result for the current epoch that has a constant star formation rate. From this figure, we see that a low value of $\alpha_{ce}\lambda$ produces more massive WDs overall. This trend can be understood by scenario A in figure 3 of Wang & Han (2012), which can form massive WDs after the He red giant (with a CO core) experiences stable mass transfer. Most importantly, a low value of $\alpha_{ce}\lambda$ forms more SNe Ia through scenario A than the other two scenarios, based on binary population synthesis simulations.

In Figure 6, we give the initial mass distribution of He donor stars with different values of $\alpha_{ce}\lambda$. In this figure, $\alpha_{ce}\lambda$ with a low value produces a more massive He donor star, which can be

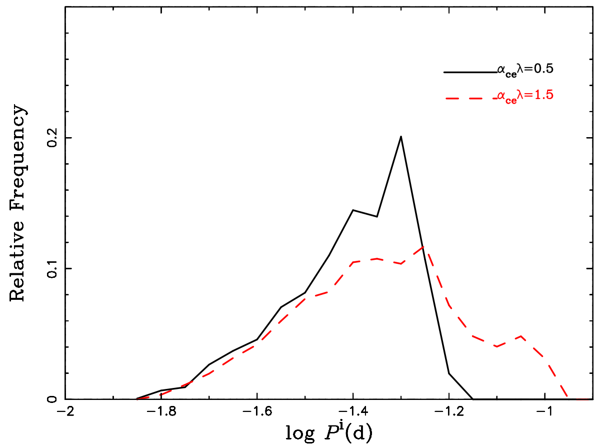


**Fig. 7** Similar to Figure 5, but for the distribution of initial orbital periods of the WD + He star systems.

understood by the stable Roche lobe overflows in scenario A (see fig. 3 of Wang & Han 2012). These mass-transfer processes result in a larger secondary star which contains a more massive He core in the sub-giant stage.

Figure 7 presents the initial orbital period distribution of WD + He star systems with different values for $\alpha_{\rm ce}\lambda$. From this figure, we can see that a high value of $\alpha_{\rm ce}\lambda$ results in WD + He star binaries with wider orbits. This happens because the common envelope that forms during the binary evolution might be ejected if there is a high value of $\alpha_{\rm ce}\lambda$.

## 6 DISCUSSION

Observationally, CD$-$30 11223 is a potential progenitor candidate for the double-detonation model. The binary system has been identified as a CO WD + sdB binary system with a short orbital period of $\sim$1.2 h (e.g., Geier et al. 2013; see also Vennes et al. 2012). The mass of the sdB star was recently constrained to be $\sim 0.51\,M_\odot$ and the mass of the WD companion was found to be $\sim 0.76\,M_\odot$ (Geier et al. 2013).

In Figure 8, we present the results of binary evolution calculations for the binary system CD$-$30 11223. Because of its short orbital period, angular momentum loss from gravitational radiation for the binary system is large. After about 36 million years, the sdB star will begin to fill its Roche lobe when it is in the He-core burning stage. Similar to the binary system in Figure 1, the mass-transfer rate is stable and has a low rate ($\sim 1.6\times 10^{-8}\,M_\odot\,{\rm yr}^{-1}$). This will result in the formation of a He layer on the surface of the CO WD. After about 8.7 million years, the mass of the He layer will increase to $0.14\,M_\odot$, which is the critical He layer ignition mass for this WD. At this moment, a detonation will occur at the base of the He layer, and this will further possibly produce a double-detonation explosion.

Similar to the single-degenerate model of SNe Ia, the mass donor star in the double-detonation model would also survive and potentially be identifiable once the WD is disrupted. More direct evidence for this model would be the identification of the remnants. The progenitor system from the double-detonation model has a relatively short orbital period at the moment that the SN explosion occurs. Thus, the surviving companions from this model might provide an alternative way to explain hypervelocity He-rich stars such as US 708, which was discovered by Hirsch et al. (2005), see

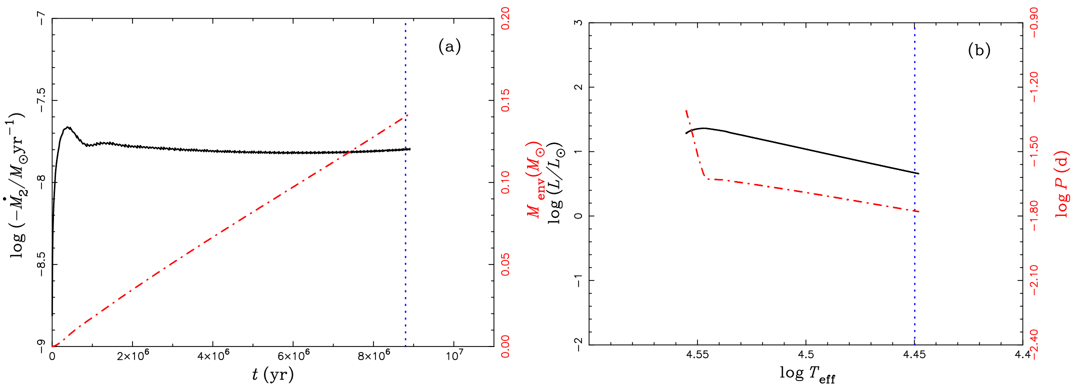


**Fig. 8** Similar to Figure 1, but for the results of binary evolution calculations corresponding to the binary system CD−30 11223. In this binary, the initial mass of the WD is $0.76\,M_\odot$, the intial mass of the He star is $0.51\,M_\odot$, and the intial period is about 0.05 d; the final mass of the He star is $0.37\,M_\odot$, and the final period is about 0.017 d when the mass of the envelope increases to $0.14\,M_\odot$.

also Wang & Han (2009). The orbital velocity of the sdB at the moment that the SN explosion occurs would be about 600 km s$^{-1}$. Thus, Geier et al. (2013) suggested that the WD + sdB star system CD−30 11223 and the hypervelocity star US 708 might represent two different stages of an evolutionary sequence linked by an SN Ia explosion. We are employing the Large sky Area Multi-Object fiber Spectroscopic Telescope to search for more hypervelocity stars that originate from the surviving companion stars of SNe Ia (e.g., Zhao et al. 2012; Deng et al. 2012).

Foley et al. (2013) recently proposed a distinct subclass of sub-luminous SNe Ia, type Iax supernovae (SNe Iax). The prototype event for this type of SNe Ia is SN 2002cx (e.g., Li et al. 2003). Wang et al. (2013) suggested that the overall properties of the population resulting from the double-detonation model seem promisingly consistent with the known collection of most SNe Iax. They also speculated on why binaries with He donor stars might lead to SNe Iax if similar systems with He WD donors do not. However, the double-detonation model finds it hard to explain an extreme member of the SN Iax class, like SN 2008ha, which was inferred to have a very low ejecta mass ($\sim$0.3 $M_\odot$; Foley et al. 2010). This extreme member might be explained by a He-shell explosion, but is unlikely to be caused by a complete double detonation (e.g., Shen & Bildsten 2009; Waldman et al. 2011).

A CO WD could also accrete helium-rich material from a He WD, and then produce an SN Ia through the double-detonation model. CO WD + He WD systems may have a contribution to SN 2005E-like objects that appear to come from old stellar populations. Perets et al. (2010) recently proposed helium-rich thermonuclear explosions from the CO WD + He WD systems as an explanation for these SN 2005E-like objects. In a future work, we will try to study the CO WD + He WD systems via a detailed binary population synthesis approach. In order to set further constraints on the double-detonation model, large samples of progenitor candidates for this model are needed.

**Acknowledgements** We acknowledge the anonymous referee for valuable comments that helped us to improve the paper. This study is supported by the National Basic Research Program of China (973 program, 2014CB845700), the National Natural Science Foundation of China (Nos. 11390371, 11322327, 11103072 and 11233004), the Foundation of Yunnan Province (No. 2013FB083), the Foundation of State Ethnic Affairs Commission (No. 12YNZ008), and the Talent Project of Young Researchers of Yunnan Province.

**References**

Ablimit, I., Xu, X.-J., & Li, X.-D. 2014, ApJ, 780, 80
Bildsten, L., Shen, K. J., Weinberg, N. N., & Nelemans, G. 2007, ApJ, 662, L95
Cappellaro, E., & Turatto, M. 1997, in NATO ASIC Proc. 486: Thermonuclear Supernovae, eds. P. Ruiz-Lapuente, R. Canal, & J. Isern (Dordrecht: Kluwer), 77
Deng, L.-C., Newberg, H. J., Liu, C., et al. 2012, RAA (Research in Astronomy and Astrophysics), 12, 735
Eggleton, P. P. 1973, MNRAS, 163, 279
Fink, M., Röpke, F. K., Hillebrandt, W., et al. 2010, A&A, 514, A53
Foley, R. J., Chornock, R., Filippenko, A. V., et al. 2009, AJ, 138, 376
Foley, R. J., Brown, P. J., Rest, A., et al. 2010, ApJ, 708, L61
Foley, R. J., Challis, P. J., Chornock, R., et al. 2013, ApJ, 767, 57
Geier, S., Marsh, T. R., Wang, B., et al. 2013, A&A, 554, A54
Goldberg, D., & Mazeh, T. 1994, A&A, 282, 801
Greggio, L., & Renzini, A. 1983, A&A, 118, 217
Hachisu, I., Kato, M., & Nomoto, K. 1996, ApJ, 470, L97
Han, Z., & Podsiadlowski, P. 2004, MNRAS, 350, 1301
Han, Z., & Podsiadlowski, P. 2006, MNRAS, 368, 1095
Han, Z., Podsiadlowski, P., & Eggleton, P. P. 1994, MNRAS, 270, 121
Han, Z., Podsiadlowski, P., & Eggleton, P. P. 1995, MNRAS, 272, 800
Han, Z., Tout, C. A., & Eggleton, P. P. 2000, MNRAS, 319, 215
Hirsch, H. A., Heber, U., O'Toole, S. J., & Bresolin, F. 2005, A&A, 444, L61
Hoeflich, P., & Khokhlov, A. 1996, ApJ, 457, 500
Howell, D. A., Sullivan, M., Nugent, P. E., et al. 2006, Nature, 443, 308
Hurley, J. R., Tout, C. A., & Pols, O. R. 2002, MNRAS, 329, 897
Iben, I., Jr., & Tutukov, A. V. 1984, ApJS, 54, 335
Iben, I., Jr., & Tutukov, A. V. 1989, ApJ, 342, 430
Ivanova, N., & Taam, R. E. 2004, ApJ, 601, 1058
Ivanova, N., Justham, S., Avendano Nandez, J. L., & Lombardi, J. C. 2013, Science, 339, 433
Kasliwal, M. M., Ofek, E. O., Gal-Yam, A., et al. 2008, ApJ, 683, L29
Kato, M., & Hachisu, I. 2004, ApJ, 613, L129
Kromer, M., Sim, S. A., Fink, M., et al. 2010, ApJ, 719, 1067
Landau, L. D., & Lifshitz, E. M. 1971, The Classical Theory of Fields (3rd edn.; Oxford: Pergamon Press)
Li, W., Filippenko, A. V., Chornock, R., et al. 2003, PASP, 115, 453
Li, X.-D., & van den Heuvel, E. P. J. 1997, A&A, 322, L9
Mannucci, F., Della Valle, M., & Panagia, N. 2006, MNRAS, 370, 773
Maoz, D., Mannucci, F., Li, W., et al. 2011, MNRAS, 412, 1508
Maoz, D., Mannucci, F., & Nelemans, G. 2014, ARA&A, in press (arXiv:1312.0628)
Meng, X., Chen, X., & Han, Z. 2009, MNRAS, 395, 2103
Miller, G. E., & Scalo, J. M. 1979, ApJS, 41, 513
Nomoto, K. 1982a, ApJ, 253, 798
Nomoto, K. 1982b, ApJ, 257, 780
Nomoto, K., & Iben, I., Jr. 1985, ApJ, 297, 531
Nomoto, K., Iwamoto, K., & Kishimoto, N. 1997, Science, 276, 1378
Nugent, P., Baron, E., Branch, D., Fisher, A., & Hauschildt, P. H. 1997, ApJ, 485, 812
Perets, H. B., Gal-Yam, A., Mazzali, P. A., et al. 2010, Nature, 465, 322
Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ, 517, 565
Pols, O. R., Tout, C. A., Eggleton, P. P., & Han, Z. 1995, MNRAS, 274, 964
Pols, O. R., Schröder, K.-P., Hurley, J. R., Tout, C. A., & Eggleton, P. P. 1998, MNRAS, 298, 525

Riess, A. G., Filippenko, A. V., Challis, P., et al. 1998, AJ, 116, 1009
Ruiter, A. J., Belczynski, K., Sim, S. A., et al. 2011, MNRAS, 417, 408
Shen, K. J., & Bildsten, L. 2009, ApJ, 699, 1365
Sim, S. A., Röpke, F. K., Hillebrandt, W., et al. 2010, ApJ, 714, L52
Sim, S. A., Fink, M., Kromer, M., et al. 2012, MNRAS, 420, 3003
Totani, T., Morokuma, T., Oda, T., Doi, M., & Yasuda, N. 2008, PASJ, 60, 1327
Vennes, S., Kawka, A., O'Toole, S. J., Németh, P., & Burton, D. 2012, ApJ, 759, L25
Waldman, R., Sauer, D., Livne, E., et al. 2011, ApJ, 738, 21
Wang, B., Meng, X., Chen, X., & Han, Z. 2009a, MNRAS, 395, 847
Wang, B., Chen, X., Meng, X., & Han, Z. 2009b, ApJ, 701, 1540
Wang, B., Li, X.-D., & Han, Z.-W. 2010, MNRAS, 401, 2729
Wang, B., & Han, Z. 2009, A&A, 508, L27
Wang, B., & Han, Z. 2010a, A&A, 515, A88
Wang, B., & Han, Z. 2010b, MNRAS, 404, L84
Wang, B., & Han, Z. 2012, New Astron. Rev., 56, 122
Wang, B., Justham, S., & Han, Z. 2013, A&A, 559, A94
Webbink, R. F. 1984, ApJ, 277, 355
Woosley, S. E., Taam, R. E., & Weaver, T. A. 1986, ApJ, 301, 601
Zhao, G., Zhao, Y.-H., Chu, Y.-Q., Jing, Y.-P., & Deng, L.-C. 2012, RAA (Research in Astronomy and Astrophysics), 12, 723