Type Ia supernovae from very long delayed explosion of core–white dwarf merger

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ABSTRACT

We study the spinning down time-scale of rapidly rotating white dwarfs (WDs) in the frame of the core-degenerate (CD) scenario for type Ia supernovae (SNe Ia). In the CD scenario, the Chandrasekhar or super-Chandrasekhar mass WD is formed at the termination of the common envelope phase or during the planetary nebula phase, from a merger of a WD companion with the hot core of a massive asymptotic giant branch star. In the CD scenario, the rapidly rotating WD is formed shortly after the stellar formation episode, and the delay from stellar formation to explosion is basically determined by the spin-down time of the rapidly rotating merger remnant. We find that gravitational radiation is inefficient in spinning down WDs, while the magnetodipole radiation torque can lead to delay times that are required to explain SNe Ia. To explain the delay-time-distribution of SNe Ia, the merger remnants distribution should be $dN/d \log (B \sin \delta) \approx$ constant, for $10^6 \lesssim B \sin \delta \lesssim 10^8$ G, where B is the dipole magnetic value and δ the angle between the magnetic dipole axis and rotation axis.

Key words: supernovae: general.

1 INTRODUCTION

Type Ia supernovae (SNe Ia) are widely thought to be the thermonuclear detonations of carbon–oxygen white dwarfs (WDs) whose masses are near the Chandrasekhar limit (Hoyle & Fowler 1960). The route to achieve this mass and the conditions for explosion are in dispute (see reviews by, e.g., Livio 2001 and Hillebrandt & Niemeyer 2000). Two main routes are discussed in the literature. In the single degenerate (SD) scenario (e.g. Whelan & Iben 1973; Nomoto 1982; Han & Podsiadlowski 2004), a WD grows in mass through accretion from a non-degenerate stellar companion. In the double degenerate (DD) scenario (Iben & Tutukov 1984; Webbink 1984; see van Kerkwijk, Chang & Justham 2010, for a recent paper on sub-Chandrasekhar mass remnants), two WDs merge after losing energy and angular momentum through the radiation of gravitational waves. Observations and theoretical studies cannot teach us yet whether both models for SNe Ia can work, only one of them, or none (see recent summary by Maoz 2010).

The observations and theoretical results that favour and disfavour each scenario for the progenitors of SNe Ia are summarized by, e.g., Livio (2001) and more recently by Howell (2011). The main problem for the DD scenario (see review by Howell 2011) is that in many cases an off-centre carbon ignition occurs (e.g. Saio & Nomoto 2004) leading to accretion-induced collapse, where a neutron

star (NS) is formed rather than an SNe Ia. Yoon, Podsiadlowski & Rosswog (2007) raised the possibility that in a merger process where the more massive WD is hot, off-axis ignition of carbon is less likely to occur. The reason is that a hot WD is larger, such that its potential well is shallower and the peak temperature of the destructed WD (the lighter WD) accreted material is lower. Hence, in such a case the supercritical mass remnant is more likely to ignite carbon in the centre at a later time, leading to an SN Ia. Namely, the merger remnant becomes a rapidly rotating massive WD, which can collapse only after it loses sufficient angular momentum.

Motivated by the possibility raised by Yoon et al. (2007), Kashi & Soker (2011) suggested recently that some SNe Ia might originate from a DD merger that occurs at the end of the common envelope (CE) phase, rather than a long time after the CE phase as in the canonical DD scenario. Practically, the merger is of a companion WD with the core of an asymptotic giant branch (AGB) star. The merger of a WD with the core of an AGB star was proposed by Sparks & Stecher (1974). They consider the outcome to be an SN explosion that forms an NS, e.g. type II SN explosion. More relevant to this paper is the suggestion of Livio & Riess (2003) that the merger of the WD with the AGB core leads to an SN Ia that occurs at the end of the CE phase or shortly after. In that case, hydrogen lines will be detected. As Livio & Riess (2003) aim was to explain the presence of hydrogen in an SN Ia, they did not consider a delayed explosion. In this paper, we discuss delayed explosion. Livio & Riess (2003) noted also that for such a merger to occur the AGB star should be massive (also Kashi & Soker 2011). Tout et al. (2008) consider a merger of a WD with a core of an AGB

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star to explain the formation of massive rotating WDs with strong magnetic fields. Wickramasinghe & Ferrario (2000) commented that such WDs might be more likely to form SNe Ia.

Either the companion WD is destructed and forms a disc around the hot core or the more massive core is destructed (because it is hot and large) and forms an accretion disc around the WD. In the latter case, the lower mass WD has a shallower gravitational potential, hence the temperature in the accretion disc does not reach ignition temperature. Kashi & Soker (2011) termed this the core-degenerate (CD) scenario. In the CD scenario, the merger occurs in a CE with a massive AGB star, or shortly ($\lesssim 10^5$ yr) after the CE phase, i.e. during the planetary nebula phase. Because of its rapid rotation, the super-Chandrasekhar WD does not explode (e.g. Anand 1965; Ostriker & Bodenheimer 1968; Uenishi, Nomoto & Hachisu 2003; Yoon & Langer 2005). It will explode long after the merger, only after it has spun down to allow explosion. The CD scenario, including findings from this paper, is summarized schematically in Fig. 1. This scenario is completely different from the model of an explosion inside a CE with a low-mass evolved star as proposed by Hachisu, Kato & Saio (1989) that was subsequently criticized by Applegate (1991).

There are three key ingredients in the CD scenario, in addition to the common condition that the remnant mass be $\gtrsim 1.4\,M_\odot$. (1) The hot core is more massive than the companion cold WD. In a future paper, we will conduct a population synthesis to find the expected number of such systems. (2) The merger should occur while the core is still large, hence hot. This limits the merger to occur within $\sim 10^5$ yr after the CE phase. Kashi & Soker (2011) showed that this condition can be met when the AGB star is massive, and some of the ejected CE gas falls back. (3) The delay between merger and explosion should be up to $\sim 10^{10}$ yr if this scenario is to account for SNe Ia in old stellar populations, in addition to SNe Ia in young stellar populations. This is the subject of this paper.

In Section 2, we examine the spinning-down time by gravitational waves. Contrary to previous claims, we find that this time is very long, and might not be relevant to spin-down WDs, despite being
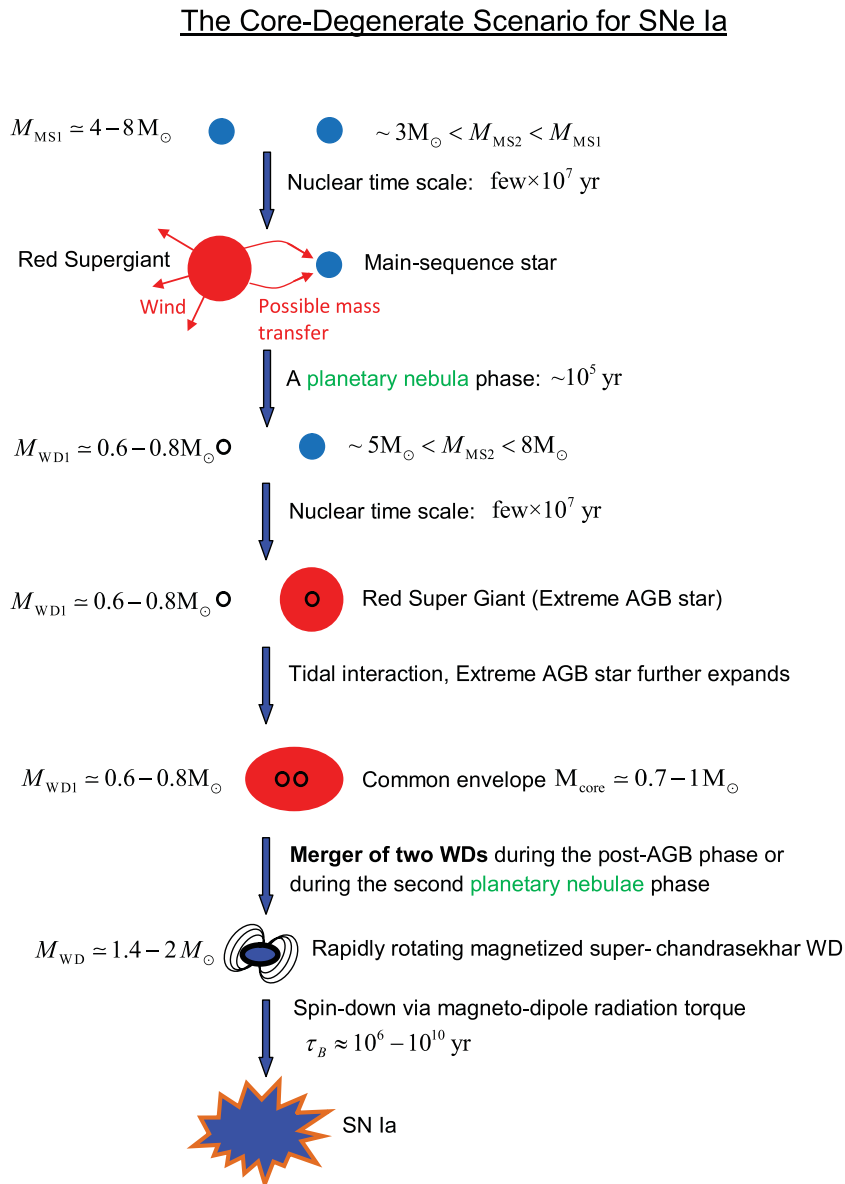
The Core-Degenerate Scenario for SNe Ia

Figure 1. A schematic summary of the CD scenario for SNe Ia (Kashi & Soker 2011). This paper deals with the spin-down process.

very efficient in spinning down NSs. In Section 3, we show that it is quite plausible that magnetodipole radiation torque can lead to a long delay of the explosion, up to ∼10^{10} yr. In Section 4, we constrain the properties of the core–WD merger product if the CD scenario is to account for a large fraction of SNe Ia. Our discussion and summary are in Section 5.

2 THE LIMITED ROLE OF GRAVITATIONAL RADIATION

As done by many authors (e.g. Andersson, Kokkotas & Stergioulas 1999; Yoon & Langer 2004, 2005; Yoon et al. 2007; Di Stefano, Voss & Claeys 2011; Justham 2011), we consider the emission of gravitational waves due to r modes in rotating WD progenitors of SNe Ia, but contrary to most of these and other works, we will find this mechanism to be inefficient. We note that Piersanti et al. (2003a,b) considered gravitational waves from WDs that have rotational to binding energy ratio of $T/W = 0.14$, and therefore are highly deformed. The WDs we consider cannot reach values of $T/W = 0.14$ (Yoon & Langer 2005).

We follow the derivation given by Lindblom, Owen & Morsink (1998), where the assumptions and approximation can be found. We will take the mode $l = m = 2$, which is the most significant one. The velocity perturbation of the r mode is

$$\delta \boldsymbol{v} = \alpha R \Omega \left(\frac{r}{R}\right)^l Y_{ll}^B e^{i\omega t}, \tag{1}$$

where Y_{ll}^B is the magnetic type vector spherical harmonic; the frequency is given by

$$\omega = -\frac{(l-1)(l+2)}{l+1}\Omega, \tag{2}$$

where Ω and R are the stellar angular velocity and radius, respectively, and α is the amplitude of the mode. From equations (14)–(17) in Lindblom et al. (1998), we derive the power, W_{GW}, of the gravitational radiation (for $l = m = 2$, and written in a form that can be traced to their formulae):

$$W_{GW} = \frac{32\pi G}{(5!!)^2 c^7}\left(\frac{4}{3}\right)^6 \left(\int_0^R \rho(r) r^6 dr\right)^2 R^{-2}\Omega^8\alpha^2. \tag{3}$$

We define the structural constant β by

$$\int_0^R \rho(r) r^6 \, dr = \frac{3}{28\pi}\beta M R^4, \tag{4}$$

where $\beta = 1$ for a constant density sphere of mass M and radius R. We also define the ratio of the angular velocity to the breakup angular velocity (the Keplerian angular velocity on the stellar equator Ω_{Kep}):

$$\tilde{\Omega} \equiv \frac{\Omega}{\Omega_{Kep}} = \frac{\Omega}{(GM/R^3)^{1/2}}. \tag{5}$$

With these definitions, the gravitational radiation power becomes

$$W_{GW} = \frac{2^{13}}{7^2 \times 5^2 \times 3^6\pi}\frac{G^5}{c^7}M^6 R^{-6}\tilde{\Omega}^8\beta^2\alpha^2. \tag{6}$$

The moment of inertia is parametrized with the structural constant β_I:

$$I = 0.4\beta_I M R^2, \tag{7}$$

where for a constant density sphere $\beta_I = 1$. We integrate for the structure of a massive WD model taken from Yoon & Langer (2005), and find $\beta \simeq 0.12$ and $\beta_I \simeq 0.27$. Assuming that all the power of the gravitational waves comes from the rotational kinetic energy, the

spin-down time-scale of the WD is given by integrating the equation $d(I\Omega^2/2)/dt = W_{GW}$, where a solid body rotation is assumed here. This gives the time-scale for spinning down from an initial fast rotation $\tilde{\Omega}_0$ down to a critical (scaled) angular velocity $\tilde{\Omega}_c$:

$$\tau_{GW} = \frac{I\Omega_c^2}{6W_{GW}(\Omega_c)}\left[1 - \left(\frac{\tilde{\Omega}_0}{\tilde{\Omega}_c}\right)^{-6}\right]$$

$$= 10^{11}\left(\frac{\beta_I/\beta^2}{10}\right)\left(\frac{M}{1.5\,M_\odot}\right)^{-4}$$

$$\times \left(\frac{R}{4000\,km}\right)^5 \left(\frac{\tilde{\Omega}_c}{0.7}\right)^{-6}\left(\frac{\alpha}{10^{-2}}\right)^{-2}\left[1 - \left(\frac{\tilde{\Omega}_0}{\tilde{\Omega}_c}\right)^{-6}\right]\;yr. \tag{8}$$

In spinning-down rapidly rotating NSs, which have a much smaller radius than WDs, gravitational radiation emitted by the r modes is very efficient. For the gravitational radiation to play any role in spinning-down WDs, the amplitude of the r modes must become $\alpha \gtrsim 0.1$. This is quite large. Here we raise the possibility that magnetic fields limit the growth of the r mode to a degree that makes the gravitational radiation insignificant in spinning down WDs. Cuofano & Drago (2010) find that as the magnetic fields in NSs become stronger, the lower limit on the rotation frequency for the development of r-modes instability becomes larger. In other cases, the magnetic field limits the amplitude of the r modes. In the calculations of Cuofano & Drago (2010), an equipartition between the magnetic pressure and the mode energy density in the outer region is achieved where the density is about 1 per cent of the average density $\rho \sim 0.01\rho_{av}$. Using the same approximate equipartition, $(1/2)\rho(\alpha\Omega_{rot}R)^2 \approx B^2/8\pi$, we obtain

$$B \approx 10^{10}\left(\frac{\alpha}{10^{-2}}\right)\left(\frac{\tilde{\Omega}_c}{0.7}\right)\left(\frac{R}{4000\,km}\right)^{-2}\left(\frac{M}{1.5\,M_\odot}\right)\;G. \tag{9}$$

This is a huge magnetic field for a WD. Before reaching this value the magnetic field will dissipate, and is likely to prevent the growth of the r-mode amplitude to a value of $\alpha \sim 0.01$. Our conclusion is that most likely gravitational waves from r modes are not significant in spinning down WDs.

3 VERY LONG DELAYED EXPLOSION BY MAGNETIC BREAKING

A misalignment between the magnetic axis and the rotation axis leads to a spin-down process due to magnetodipole radiation torque that is commonly used for pulsars (e.g. Benacquista et al. 2003; Contopoulos & Spitkovsky 2006). This mechanism was used for WDs by Benacquista et al. (2003), with the following expression for the spin-down time from an initial fast rotation $\tilde{\Omega}_0$ down to a critical angular velocity $\tilde{\Omega}_c$:

$$\tau_B \simeq \frac{Ic^3}{B^2 R^6 \Omega_c^2}\left[1 - \left(\frac{\tilde{\Omega}_0}{\tilde{\Omega}_c}\right)^{-2}\right](\sin\delta)^{-2}$$

$$\approx 10^8\left(\frac{B}{10^8\,G}\right)^{-2}\left(\frac{\tilde{\Omega}_c}{0.7\Omega_{Kep}}\right)^{-2}$$

$$\times \left(\frac{R}{4000\,km}\right)^{-1}\left(\frac{\sin\delta}{0.1}\right)^{-2}\left(\frac{\beta_I}{0.3}\right)\left[1 - \left(\frac{\tilde{\Omega}_0}{\tilde{\Omega}_c}\right)^{-2}\right]\;yr, \tag{10}$$

where δ is the angle between the magnetic axis and the rotation axis, and β_I is defined in equation (7). The scaling of $\tilde{\Omega}_c$ at which the WD explodes is based on the results of Yoon & Langer (2005) for

WD in the lower range (1.4–1.5 M$_\odot$; also Ostriker & Bodenheimer 1968). The angular velocity distribution is not considered here in detail; only in calculating the total angular momentum a solid body rotation is assumed. In a future paper, this assumption will be relaxed. However, we do note that magnetic fields might enforce a solid body rotation in the WD (Piro 2008).

Stabilizing rapidly rotating super-Chandrasekhar WDs is a delicate matter (e.g. Yoon & Langer 2004; Chen & Li 2009; Hachisu et al. 2011 in the SD scenario). The strong magnetic fields required in the present model most likely will enforce a rigid rotation within a short time-scale due the WD being a perfect conductor. The critical mass of rigidly rotating WDs is 1.48 M$_\odot$ (Yoon & Langer 2004, and references therein). This implies that in the case of a strong dipole field that exists in most of the their interior, WDs more massive than 1.48 M$_\odot$ will explode in a relatively short time. The exact time will be estimated in a future study. The similarity of most SN Ia suggests that their progenitors indeed come from a narrow mass range. This is ~1.4–1.48 M$_\odot$ in the CD scenario.

Equations (8)–(10) bring us to consider the following scenario. Massive WDs, $M_{WD} \gtrsim 1.5$ M$_\odot$ that can explode (or collapse) with higher angular momentum do so on a typical time-scale of $<10^9$ yr, most within a much sorter time. WDs in the lower mass domain ($M_{WD} \simeq 1.4$–1.48 M$_\odot$) that explode with lower angular momentum and that on average have weaker magnetic fields might survive for a time of $>10^9$ yr from their formation in a merger process. The exact time of explosion depends strongly on the magnetic field of the WD and the inclination angle. We cannot constrain the value of these parameters and the evolution of the magnetic field during the spin-down process, as, for example, r modes might amplify the magnetic field. However, in the next section we crudely constrain the distribution of the relevant parameters.

4 DELAY TIME DISTRIBUTION

In the previous two sections, we have studied the evolution of a massive rapidly rotating WD that is a merger product of two WDs, or an AGB core with a WD, termed CD scenario for SNe Ia. The rapidly rotating WD does not collapse because of the centrifugal forces. Once it spins down below the critical angular velocity Ω_c, it becomes unstable and explodes as an SN Ia (Yoon & Langer 2005). We now check the possibility that most of the SN Ia are formed by the CD scenario, and use observations to constrain the properties of these SN Ia progenitors.

Equation (10) for the spin-down time depends on four physical variables. The radius R and the critical angular velocity $\tilde{\Omega}_c$ will not differ much from one WD to another, as we are mainly interested in WDs of masses ~1.5 M$_\odot$ that are rapidly rotating. The magnetic field and the inclination angle can vary by more than two orders of magnitude between different WDs. For that, we write the spin-down time from equation (10) in the form

$$\tau_B = F(\tilde{\Omega}_c, R)\eta^{-2}, \tag{11}$$

where we defined what we term the magnetic dipole parameter:

$$\eta \equiv B \sin \delta. \tag{12}$$

We now try to use observations to estimate the distribution of WDs that are the remnants of CD mergers with respect to η, under the assumption that most (all) SNe Ia are formed through this channel. Maoz et al. (2011; see also Maoz, Sharon & Gal-Yam 2010; Graur et al. 2011; Ruiter et al. 2011) summarize the SN Ia rate versus time – the delay time distribution (DTD) – as found from observations:

$$\frac{dN}{dt} \propto t^\epsilon, \tag{13}$$

with $\epsilon \simeq -1$, and where t is the time since the star formation event that formed the binary system that later became the SN progenitor. The last equation can be written as

$$\frac{dN}{dt} = \frac{dN}{d\eta}\frac{d\eta}{dt} = t^\epsilon. \tag{14}$$

From equation (11) with $\tau_B \to t$, we have

$$\frac{d\eta}{dt} \propto t^{-\frac{3}{2}}, \tag{15}$$

which when substituted into equation (14) gives

$$\frac{dN}{d\eta} \propto t^{\frac{3}{2}+\epsilon} \propto \eta^{-3-2\epsilon} \sim \eta^{-1}. \tag{16}$$

We recall that this result holds only for the massive WDs that were formed from the merger of two lower mass WDs during or shortly after a CE phase under the assumption that most SNe Ia are formed via the CD channel. Equation (16) can be also written explicitly as

$$\frac{dN}{d\log(B \sin \delta)} = \text{constant} \qquad \text{for} \qquad 10^6 \lesssim B \sin \delta \lesssim 10^8 \text{ G}, \tag{17}$$

where the range of $\eta = B\sin\delta$ comes from the range of $10^7 \lesssim t \lesssim 10^{10}$ yr of the observed SNe rate (Maoz et al. 2011) and equation (10). We note that magnetic fields in massive WDs might be $\gtrsim 10$ per cent of their initial value at age of 10^{10} yr (Muslimov, van Horn & Wood 1995). If true, then the decay of the magnetic field should be taken into account for long delay times, but it does not pose a problem to the model.

Let us compare this results with observations. Wickramasinghe & Ferrario (2000) review the subject of magnetic WDs. Magnetic WDs have magnetic fields in the range 3×10^4–10^9 G. This overlaps with the value assumed here. Although many of them are called rapid rotators because they are much faster rotators than most WDs, they are much slower than the spin rate required here. It is quite possible that super-Chandrasekhar magnetic WDs can be stabilized even if the surface spinning rate is lower than that assumed here, if a differential rotation is maintained inside the WD (Yoon & Langer 2005).

Another encouraging observational result is that magnetic WDs tend to be more massive that non-magnetic WDs (Wickramasinghe & Ferrario 2000). Indeed, out of the 16 magnetic WDs with well-determined mass reported by Wickramasinghe & Ferrario (2000), two have masses of $M > 1.3$ M$_\odot$. This fraction is further discussed in the next section.

5 DISCUSSION AND SUMMARY

In this paper, we examined the delay time from merger to explosion of the CD scenario for SNe Ia. A key ingredient in this scenario is that the merger occurs while the more massive degenerate component is the core of an AGB star or a planetary nebulae, e.g. at the end of the CE phase or shortly after. Earlier studies of the merger of a WD with the core of an AGB star are Sparks & Stecher (1974) as a way to make an NS, Livio & Riess (2003) as an evolutionary route for SNe Ia with hydrogen lines, Tout et al. (2008) as a way to make magnetic WDs and Kashi & Soker (2011) in relation to SNe Ia with long delay times as studied here.

Such a merger where the more massive WD is still hot, hence larger, is more likely to avoid an early off-centre ignition of carbon (Yoon et al. 2007); an early off-centre ignition leads to an NeMgO WD instead of an SN Ia. The problem of off-centre carbon ignition during merger of cold WDs is the most severe problem of the DD scenario for SNe Ia (Howell 2011). The CD scenario avoids this problem. The remnant of the CD merger is a rapidly rotating WD. If its mass is supercritical, it will explode after spinning down to a critical angular velocity Ω_c (Yoon & Langer 2005), and not necessarily in a very short time delay as in the scenario of Livio & Riess (2003) where one is expect to observe hydrogen lines.

In Section 2, we examined the spinning-down time by the commonly used gravitational waves mechanism. Although this mechanism is known to be very efficient in spinning down NSs, we found that this mechanism is not efficient in spinning down WDs (equation 8). It can be efficient only if the amplitude of the r modes becomes $\alpha \gtrsim 0.1$. This is a very large amplitude and the modes are likely to be damped by magnetic fields before reaching this value (equation 9). On the other hand, in Section 3 we estimated the spinning-down time due to magnetodipole radiation torque (equation 10), and found it to operate over the required time-scale of $\sim 10^6$–10^{10} yr for plausible parameters of the massive rapidly rotating WD remnant of the CD merger.

If the CD scenario for SNe Ia is to explain most (all) SNe Ia, it should account for the DTD, i.e. the SNe Ia rate versus time since their progenitor formation. Using the observations as summarized by Maoz (2010), we derive a crude distribution of the dipole parameter $\eta \equiv B\sin\delta$, where B is the magnetic field and δ the inclination angle between the magnetic dipole axis and the rotation axis. This is given in equation (17).

Before the CD scenario can be accepted as one of the channels to form SNe Ia, more detailed calculations should be done. We end with a summary of these calculations, and with some possible promising properties of this scenario.

(i) The claim of Yoon et al. (2007) that when the massive WD in a merger is hot (in the CD scenario it is the core of an AGB star or of a planetary nebula) the off-centre ignition of carbon is likely to be avoided should be studied in more detail. This study should include the process where the more massive core is destructed (because of its larger radius) and the lower mass WD becomes the core of the remnant.

(ii) A population synthesis study is required to determine the number of core–WD mergers that lead to Chandrasekhar and super-Chandrasekhar mass remnants. This is a subject of a future paper. The first step was carried by Kashi & Soker (2011), who argued that the core–WD merger can be a common outcome of the CE phase with massive AGB stars, ~ 5–$8\,M_{\odot}$. Tout et al. (2008) estimated that about three times as many CE events lead to a merged core as to a cataclysmic variable. This is a high fraction. Wickramasinghe & Ferrario (2000) estimated that ~ 5 per cent of all WDs are magnetic WDs. Even if a small fraction of these merger products lead to SNe Ia, the CD scenario can account for a large faction of SNe Ia. The exact numbers will be derived in a forthcoming paper. The large fraction of massive stars that are in binary systems gives us hope that indeed the number of such systems might be adequate to explain most (all) SNe Ia. We note here that SNe Ia from WDs masses much above the Chandrasekhar mass, as observed in some cases, e.g. Howell (2001), are accounted for in the CD scenario.

(iii) A detailed study of the spin-down time of the merger remnant due to the magnetodipole radiation torque is required. Here we

showed that this can be a promising mechanism. The evolution of the magnetic field with time should be examined as well.

(iv) It is expected that less massive remnant (but still super-Chandrasekhar) will take longer time on average to spin down and explode. This might account for the finding that SNe Ia in older populations are less luminous (e.g. Howell 2001). This should be studied after the magnetodipole radiation torque process is better explored.

(v) Rapidly rotating WDs have shallow density profile near the equatorial plane (Yoon & Langer 2005). Shallow density profile favours incomplete silicon burning that is required by observations (Pakmor et al. 2010). This process deserved to be studied.

(vi) Eventually, rapidly rotating massive WDs should be found. Claims for massive rapidly rotating and strongly magnetized WDs have already been made, e.g. see discussion by Malheiro, Rueda & Ruffini (2011) and Wickramasinghe & Ferrario (2000). We can crudely estimate the expected number of such WDs if the CD scenario account for most of SNe Ia, in the following way (Maoz, private communication). The SN Ia rate per unit stellar mass in Sbc galaxies is $\sim 1.5 \times 10^{-13}$ yr^{-1} M$_{\odot}^{-1}$ (Li et al. 2011). From the local stellar density of 0.085 M$_{\odot}$ pc^{-3} (McMillan 2011) and the local WD density of 0.0046 pc^{-3} (Harris et al. 2006), a number of stellar mass per WD of 18.5 M$_{\odot}$WD^{-1} in the solar neighbourhood is obtained. If these WDs are to explode within $\sim 10^{10}$ yr with a time delay distribution of t^{-1} in the range 10^7–10^{10} yr, then their average age is $\sim 1.5 \times 10^9$ yr, and the fraction of SN Ia progenitors should be ~ 0.4 per cent of all WDs. Namely, in a sample of 10^4 WDs in the solar neighbourhood the number of rapidly rotating massive WDs should be ~ 40. As ~ 5 per cent of all WDs are magnetic (Wickramasinghe & Ferrario 2000), it is expected that ~ 10 per cent of the magnetic WDs will be massive enough to become SNe Ia. This is a prediction of this model. Indeed, out of the 16 magnetic WDs with well-determined mass reported by Wickramasinghe & Ferrario (2000), two have masses close to the Chandrasekhar limit, $M > 1.3$ M$_{\odot}$. The study of large samples of WDs is the subject of a future paper.

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