A POSSIBLE EVOLUTIONARY SCENARIO OF HIGHLY MAGNETIZED SUPER-CHANDRASEKHAR WHITE DWARFS: PROGENITORS OF PECULIAR TYPE Ia SUPERNOVAE

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Received 2012 December 31; accepted 2013 March 12; published 2013 March 28

ABSTRACT

Several recently discovered peculiar Type Ia supernovae seem to demand an altogether new formation theory that might help explain the puzzling dissimilarities between them and the standard Type Ia supernovae. The most striking aspect of the observational analysis is the necessity of invoking super-Chandrasekhar white dwarfs having masses ~2.1–2.8 M☉, M☉ being the mass of Sun, as their most probable progenitors. Strongly magnetized white dwarfs having super-Chandrasekhar masses have already been established as potential candidates for the progenitors of peculiar Type Ia supernovae. Owing to the Landau quantization of the underlying electron degenerate gas, theoretical results yielded the observationally inferred mass range. Here, we sketch a possible evolutionary scenario by which super-Chandrasekhar white dwarfs could be formed by accretion on to a commonly observed magnetized white dwarf, invoking the phenomenon of flux freezing. This opens multiple possible evolution scenarios ending in supernova explosions of super-Chandrasekhar white dwarfs having masses within the range stated above. We point out that our proposal has observational support, such as the recent discovery of a large number of magnetized white dwarfs by the Sloan Digital Sky Survey.

Key words: accretion, accretion disks – equation of state – novae, cataclysmic variables – stars: magnetic field – supernovae: general – white dwarfs

1. INTRODUCTION

Identifying the progenitors of Type Ia supernovae is an extremely important and ongoing research issue (Howell 2011). These supernovae are considered to be standard candles for cosmic distance measurements and hence are probes for studying the expansion history of the universe (Perlmutter et al. 1999). According to the general consensus, a carbon–oxygen white dwarf in a binary system accretes matter from a companion star and gradually approaches the Chandrasekhar mass limit of 1.44 M☉ (Chandrasekhar 1935), M☉ being the mass of Sun. This further triggers a thermonuclear instability in the white dwarf, resulting in a violent and extremely energetic explosion, which we observe as a Type Ia supernova. However, far less is known about the nature of the companion star (Parthasarathy et al. 2007).

Adding to the puzzle further is the recent discovery of several peculiar Type Ia supernovae—SN 2006gz, SN 2007if, SN 2009dc, and SN 2003fg (Scalzo et al. 2010). These supernovae are distinctly overluminous, powered by a higher than usual production of nickel, and have very low ejecta velocity compared to their standard counterparts (Howell et al. 2006). They also violate the luminosity–stretch relation (Phillips 1993; Goldhaber et al. 2001) which prohibits them from being categorized as standard candles. Interestingly, however, these anomalies seem to rule out the standard theory one invokes super-Chandrasekhar-mass white dwarfs, with masses 2.1–2.8 M☉, as their progenitors (Scalzo et al. 2010; Howell et al. 2006; Hicken et al. 2007; Yamanaka et al. 2009; Silverman et al. 2011; Taubenberger et al. 2011). The leading question now is the origin and stability of these super-Chandrasekhar white dwarfs. There have been a few simulations of accreting binary white dwarfs, which include differential rotation and other parameters (Hachisu et al. 2012), that try to explain the required mass range stated above. In addition, models have been proposed involving mergers of two white dwarfs, namely, the double degenerate scenario (Iben & Tutukov 1984; Scalzo et al. 2010) and core degenerate scenario (Kashi & Soker 2011). However, these scenarios seem to lack detailed theoretical understanding.

On a fundamentally different ground, Das & Mukhopadhyay (2012a, 2012b) have shown that strongly magnetized white dwarfs, having central fields ~1015–1017 G, are capable of having super-Chandrasekhar masses in the range 2–2.6 M☉. The basic idea employed (Das & Mukhopadhyay 2012a, 2012b, hereafter DM1, DM2, respectively) is that, for magnetic fields (B) greater than a critical field Bc = 4.414 × 1013 G, the effect of Landau quantization on the underlying electron degenerate matter becomes significant and as a result the density of states for the electrons changes (Lai & Shapiro 1991). This in turn modifies the corresponding equation of state (EoS) and hence the mass–radius relation of these white dwarfs. Now the additional question is to form white dwarfs with such strong magnetic fields.

In this Letter, we sketch an evolutionary scenario by which highly magnetized white dwarfs could be formed. We concentrate on the single degenerate progenitor scenario. Starting with some reasonable assumptions about the mass and the magnetic field of a normally observed magnetic white dwarf, we demonstrate that by the mechanism of flux freezing and Landau quantization a possible evolutionary link between strongly magnetized supermassive white dwarfs and the observed peculiar Type Ia supernovae could be established. This scenario is compatible with the discovery of several (isolated) magnetized white dwarfs by the Sloan Digital Sky Survey (SDSS) having surface fields 105–109 G (Schmidt et al. 2003; Vanlindingham et al. 2005) and the fact that 25% of the observed cataclysmic variables (CVs) have surface field strengths as high as 107–108 G (Wickramasinghe & Ferrario 2000).

This Letter is organized as follows. In Section 2, we describe how a magnetized, sub-Chandrasekhar, accreting white dwarf evolves into a super-Chandrasekhar white dwarf. We subsequently discuss the steps that lead to the formation of multiple
evolutionary tracks in the mass–radius plane, which in turn help to explain the observed super-Chandrasekhar (progenitor) mass range of the peculiar Type Ia supernovae. In Section 3, we study the timescale of evolution of these magnetized accreting white dwarfs. Finally, we conclude in Section 4 with a discussion about the observational evidence supporting our proposed evolutionary scenario.

2. EVOLUTIONARY PATH FROM A SUB-CHANDRASEKHAR TO A SUPER-CHANDRASEKHAR WHITE DWARF

We consider a white dwarf having a central field several orders of magnitude higher than that of the surface, with a typical mass and radius to be \( M_0 \sim 0.2 M_{\odot} \) and \( R \sim 15,000 \text{ km} \), respectively. Note, as justified in Section IV.C of DM1, that the magnetic field might be approximately constant in a range of radii around the center of the white dwarf, which we define as the internal magnetic field. This is a quite plausible assumption, since the original star collapsing to form a white dwarf might have a very large interior magnetic field compared to that observed on its surface, as has been the case for the Sun (Gough & McIntyre 1998). Thus, it is quite likely that the values of the central and surface magnetic fluxes (in the initial star and hence \( \sim 10^{12} \text{ G} \) along with a surface field \( B_s \), at least three orders of magnitude lower than \( B_\text{int} \). Such a white dwarf still has \( B < B_s \) and it lies on Chandrasekhar’s (non-magnetic) mass–radius relation having an EoS similar to that of a nonmagnetic case. Now as the white dwarf accretes matter, there is an amplification of its central magnetic field as a consequence of the increase in central density (via flux freezing theorem) due to the contraction in size of the white dwarf (Cumming 2002). This leads the central magnetic field to eventually exceed \( B_s \). Hence, the EoS of the underlying electron degenerate gas and the mass–radius relation of the underlying white dwarf modify, as shown in DM1 and DM2. As a result, the white dwarf transits from the mass–radius curve for the nonmagnetic EoS to that for a magnetic EoS. As the outward modified pressure counteracts the inward gravitational force, a quasi-equilibrium state attains, which is determined by the degree of Landau quantization of the system. The larger the magnetic field, the smaller the number of Landau levels occupied by the electrons will be, leading to more massive white dwarfs (DM1, DM2). Hence, as accretion continues, the mass–radius curve of the white dwarf deviates more and more from that of Chandrasekhar’s. In Figure 1, we show three mass–radius relations (solid curves marked with squares) following DM1, for magnetized white dwarfs with three different values of \( B_\text{int} = 1.7 \times 10^{13} \text{ G}, 4.4 \times 10^{15} \text{ G}, \) and \( 8.8 \times 10^{17} \text{ G} \), for the top to bottom curves, respectively, through which the evolving white dwarf, with initial mass, radius, and magnetic fields mentioned above, passes at different intermediate stages.

Following Bandyopadhyay et al. (1997), we adopt a profile for the magnetic field in our study assuming that the surface and central magnetic fluxes of the initial and final white dwarfs are individually conserved as the evolution progresses. For example, for a white dwarf with \( B_\text{int} = 8.8 \times 10^{17} \text{ G} \) and \( R = 69.5 \text{ km} \) (which is the maximum possible radius for the corresponding mass–radius relation), if we consider \( B_\text{int} \) to be confined until \( R_\text{int} = R/10 \) (corresponding to a profile with parameters \( \beta = 0.01, \gamma = 3.6 \); Bandyopadhyay et al. 1997), then the above assumption holds true with surface and central fluxes, respectively, \( 1.46 \times 10^{27} \text{ G cm}^2 \) and \( 4.25 \times 10^{29} \text{ G cm}^2 \). Note, however, that the extent of \( B_\text{int} \) adjusts accordingly as the white dwarf evolves and hence \( R_\text{int} \) need not be the same for the initial and final white dwarfs. Figure 1 shows how an initial mass \( M_0 \) of the white dwarf could possibly evolve to three different final limiting masses, namely, \( 2.01 M_{\odot}, 2.33 M_{\odot}, \) and \( 2.58 M_{\odot} \). Once the corresponding final mass is reached, further accretion induces a runaway thermonuclear reaction, causing the white dwarf to explode at that mass, leading to a super-Chandrasekhar supernova. We note that, although we show only three tracks in Figure 1, any number of tracks are possible resulting in different final limiting masses \( \lesssim 2.58 M_{\odot} \). In the following subsection, we explain in detail how we obtain these multiple tracks.

2.1. Multiple Evolutionary Tracks

When the electrons occupy the ground Landau level, pressure increases monotonically as a function of density. This corresponds to a mass–radius relation where initially the mass increases with increasing radius (let us call it the first branch of the mass–radius relation). If the magnetic field is sufficiently high, then the radius becomes nearly independent of mass at higher central densities in this branch. From DM1, we note that whenever there is a transition from a lower Landau level to the next higher level, a kink appears in the EoS, followed by a plateau—which is a small region where the pressure becomes nearly independent of the density (see Figure 1 of DM1). For a given magnetic field, the central density of the white dwarf corresponding to the kink in the EoS, arising at the transition from the ground to first Landau levels, corresponds to a white dwarf having the maximum possible radius. Note that the systems having more than one occupied Landau level exhibit multiple branches in their mass–radius relations including the “first branch” (for details see DM1). For example, the mass–radius relation of white dwarfs having central densities corresponding to the plateau of the EoS shows a turning point and subsequent decrease of mass with decreasing radius (see Figure 2 of DM1).

Now, let us consider a white dwarf lying on an intermediate mass–radius relation in its early stage of evolution (e.g., the top most solid curve marked with squares in Figure 1), such that it has the maximum possible radius at that B. As it evolves via accretion, its magnetic field and mass increases with decreasing
radius, such that when the white dwarf transits to the next mass–radius relation, it still has the corresponding maximum radius satisfying the flux freezing condition. For a sufficiently high field, the white dwarf with the maximum radius also corresponds to the maximum possible mass. Thus, in Figure 1, we show that the evolution of such a white dwarf gives rise to the track corresponding to the limiting mass of 2.58 $M_\odot$, which corresponds to the new mass limit for white dwarfs proposed by Das & Mukhopadhyay (2013). Hence, this track demarcates a zone in the mass–radius plane, beyond the right-hand side of which no further track is possible.

From the bottom two mass–radius relations (representing further intermediate masses and radii of the evolving white dwarf in Figure 1), we note that the evolving white dwarf passing through them may lie anywhere in a zone where the radius is independent of mass satisfying the flux freezing condition. This zone is a part of the “first branch” of the corresponding mass–radius relation. This happens at a sufficiently high field $\gtrsim 1.7 \times 10^{14}$ G (which corresponds to a 5000-Landau-level system), when a part of EoS can be described by a polytropic relation of the form

$$P = K \rho^\Gamma, \quad \text{when } \Gamma = 2,$$

where $P$ and $\rho$ are, respectively, the pressure and density of the electron gas, $\Gamma$ is the polytropic index, and $K$ is a constant depending on the magnetic field. Now on solving the magnetostatic equilibrium condition by Lane–Emden formalism, one obtains the following scaling laws (DM1) for radius ($R$) and mass ($M$):

$$R \propto \rho_c^{(\Gamma-2)/2} \quad (2)$$

and

$$M \propto \rho_c^{3\Gamma-4)/2}. \quad (3)$$

where $\rho_c$ is the central density of the white dwarf. Thus when $\Gamma = 2$, the radius becomes independent of the central density, while the mass becomes proportional to the central density. This indicates that the same magnetic field leads to a white dwarf having different possible masses with the same radius. Hence, once the above polytropic relation holds true, the flux freezing condition opens the multiple possible evolutionary tracks.

3. TIMESCALE OF MASS EVOLUTION

Here, we explore the typical timescale of evolution of the accreting magnetic white dwarf systems with assumed parameters quite close to the class of magnetic CVs called the intermediate polars (IPs).

3.1. Constant Mass Accretion Rate

Figure 2 shows the evolution of an initial white dwarf of mass 0.2 $M_\odot$ and a radius of 15,000 km into the three super-Chandrasekhar white dwarfs with $M \geq 2 M_\odot$ corresponding to Figure 1. Here, we assume a constant mass accretion rate ($\dot{M}$), represented by the constant slopes of the three lines in Figure 2, for each case, such that they explode at the same time. The values of $M$ (typical of IPs) are $2.38 \times 10^{-9} M_\odot \, yr^{-1}$, $2.15 \times 10^{-9} M_\odot \, yr^{-1}$, and $1.83 \times 10^{-9} M_\odot \, yr^{-1}$ for the exploding masses of 2.58 $M_\odot$, 2.33 $M_\odot$, and 2.01 $M_\odot$, respectively. We see that the system with a higher $M$ accumulating more mass in the same time (roughly a billion year) gives rise to a more massive supernova explosion.

Figure 3(a) shows how the exploding mass of 2.33 $M_\odot$ is attained by three different $M$s—$3 \times 10^{-9} M_\odot \, yr^{-1}$, $2.5 \times 10^{-9} M_\odot \, yr^{-1}$, and $2 \times 10^{-9} M_\odot \, yr^{-1}$—resulting in the explosions occurring at different times.

3.2. Varying Mass Accretion Rate

The most favored models for Type Ia supernova progenitors invoke a very high $M \gtrsim 10^{-7} M_\odot \, yr^{-1}$, such that the accreted hydrogen and helium can burn steadily (Cumming 2002). These values of $M$ are observed in supersoft X-ray sources and symbiotic binaries (Cumming 2002; Parthasarathy et al. 2007). At lower $M$s, hydrogen burning is unstable and occurs in flashes, while at higher rates an extended envelope is formed (van den Heuvel et al. 1992).

We now plan to invoke a range of $\dot{M}$s, low to high, in a single model evolution of the white dwarf and hence consider

$$\dot{M} = \left( \frac{M}{M_0} \right)^\alpha \times 10^{-9} M_\odot \, yr^{-1}, \quad (4)$$

where $\alpha$ is a parameter that determines the functional dependence of $M$ on the instantaneous mass ($M \geq M_0$) of the white dwarf.
In Figure 3(b), we show two cases corresponding to $\alpha = 1$ and $\alpha = 2$, having the same final exploding mass, namely, $2.33 \, M_\odot$. In the case with $\alpha = 1$, $M$ varies from $10^{-9} \, M_\odot \, \text{yr}^{-1}$ to $1.3 \times 10^{-8} \, M_\odot \, \text{yr}^{-1}$. The evolution is slow in this case and the supernova explosion occurs in $\sim 5 \times 10^8 \, \text{yr}$. In the case with $\alpha = 2$, $M$ varies from $10^{-9} \, M_\odot \, \text{yr}^{-1}$ to $1.7 \times 10^{-7} \, M_\odot \, \text{yr}^{-1}$ and the supernova explosion occurs in $\sim 2 \times 10^9 \, \text{yr}$. Hence, $\alpha \geq 2$ is supposed to validate the underlying white dwarfs as progenitors of the observed peculiar Type Ia supernovae.

### 4. DISCUSSION AND CONCLUSIONS

Based on the theoretical work on strongly magnetized white dwarfs having super-Chandrasekhar masses (DM1, DM2), we have discussed possible evolutionary paths that lead from magnetized accreting white dwarf binaries to the peculiar Type Ia supernova explosions. Multiple evolutionary tracks are possible in the mass–radius plane, which covers a mass range $\sim 2$–$2.6 \, M_\odot$, that lies within the observational limits. We have considered both constant as well as varying $M$ in order to estimate the timescale of occurrence of the supernova events.

Highly magnetized white dwarfs have been discovered by the SDSS having surface fields in the range $10^5$–$10^7 \, \text{G}$ (Schmidt et al. 2003; Vanlindingham et al. 2005; Wickramasinghe & Ferrario 2000). Note that their central fields are expected to be a few orders of magnitude higher. The properties that we have assumed in our computation are similar to those seen in IPs. They have surface magnetic fields ranging $10^5$–$10^7 \, \text{G}$ and they are high accretors with $M \approx (0.2$–$4) \times 10^{-9} \, M_\odot \, \text{yr}^{-1}$ (Warner 1995). Cumming (2002) studied the evolution of magnetic fields in accreting white dwarfs and found that surface magnetic fields are reduced significantly for $M > M_c \approx (1$–$5) \times 10^{-10} \, M_\odot \, \text{yr}^{-1}$, due to the advection of the field into the interior of the white dwarf by the accretion flow. This presumably increases the central magnetic field (Cumming 2002). Further, certain dwarf novae (a subclass of CVs), such as RU Peg, are expected to show short- and long-term variations in $M_s$, ranging from as low as $(1$–$2) \times 10^{-9} \, M_\odot \, \text{yr}^{-1}$ to as high as $10^{-7} \, M_\odot \, \text{yr}^{-1}$ (Parthasarathy et al. 2007). Hence, it is quite conceivable that IPs with high internal fields and low surface fields with an increasing $M$ can lead to super-Chandrasekhar white dwarfs causing the peculiar supernova Ia explosions. Moreover, for $\alpha = 2$ according to our chosen model, the desired $M$ for a Type Ia supernova explosion to occur is attained starting from an initial, lower rate, typically observed in IPs. Note that peculiar Type Ia supernovae arise, according to our argument, from highly magnetized CVs, which are presumably 10% of all magnetized CVs. Hence about 2.5% of all CVs should lead to super-Chandrasekhar objects, which is consistent with the observed rate (1%–2%) of peculiar Type Ia supernovae (Scalzo et al. 2012).

Besides the advection of the magnetic field into the interior caused by accretion, there are other ways of generating such strong fields. Interestingly, recent observations of magnetic Ap and Bp stars indicate that they have a magnetic flux in the range $10^{26}$–$10^{27} \, \text{G} \, \text{cm}^2$, which is very similar to that observed in magnetized white dwarfs (Ferrario & Wickramasinghe 2005). This strongly points toward the fact that the magnetic fields of highly magnetized white dwarfs are fossil remnants from their main-sequence progenitor stars (Tout et al. 2004). Simulations of magnetic field evolution in Ap stars strongly support the idea that this field is a fossil remnant from the interstellar medium, generated during the process of star formation (Braithwaite & Spruit 2004). In order for the results of these simulations to hold true, the new born star is required to have an initial field mainly confined to the core, which can be justified from the flux freezing theory during its formation (Braithwaite & Nordlund 2006). Moreover, the contraction of a typical interstellar cloud with a radius of $\sim 0.1 \, \text{pc}$, mass $\sim M_\odot$, and having a frozen-in magnetic field $\sim 3 \times 10^{-6} \, \text{G}$ could give rise to a field $\sim 10^8 \, \text{G}$ in the resulting star (Shapiro & Teukolsky 1983) with solar radius. Thus, a star with such a high centrally concentrated field is a plausible progenitor of the strongly magnetized super-Chandrasekhar white dwarfs discussed in this Letter. These stars also have convective cores and in some special cases a dynamo mechanism might occur to generate a high magnetic field therein, leading to a (central) magnetic flux as high as $\sim 10^{20} \, \text{G} \, \text{cm}^2$, similar to that of the magnetized white dwarfs mentioned in Section 2. The incidence of such main-sequence magnetic stars might be rare, but so are the super-Chandrasekhar supernova events.

If the single-degenerate accreting scenario is the correct progenitor model for the overluminous (peculiar) Type Ia supernovae, then observationally such high magnetic, high-mass white dwarfs with small radii (also with high $M$) could be one of the plausible progenitors of these supernovae. However, a detailed investigation needs to be carried out in order to understand the physics of explosions of these white dwarfs and if they indeed produce the light curves similar to that of the peculiar Type Ia supernovae.

Now the white dwarfs would be seen as peculiar, super-Chandrasekhar objects only during a small fraction of their lifetimes, which is $\sim 0.05$ for $\alpha = 2$. Hence, about $\sim 12\%$ of the CVs with varying $M$ would be likely candidates for peculiar objects. The varying $M$ is further justified by astronomical indications, which imply higher accretion rates at later times of the evolution of magnetized massive white dwarfs (Wang & Han 2012; Toonen et al. 2013; Nomoto 2007). We speculate that these white dwarfs will have X-ray luminosity in between commonly observed accreting white dwarfs and accreting neutron stars (in the range of $10^{35}$–$10^{38} \, \text{erg} \, \text{s}^{-1}$). Bright X-ray selected CVs (and other objects) might harbor some of these peculiar super-Chandrasekhar objects.

This work is partly supported by ISRO project Grant No. ISRO/RES/2/367/10-11. U.D. thanks CSIR, India for financial support. The authors thank Arnab Rai Choudhuri of IISc for discussion.

### REFERENCES

Bandyopadhyay, D., Chakrabarty, S., & Pal, S. 1997, PhRvL, 79, 2176
Braithwaite, J., & Nordlund, Å. 2006, A&A, 450, 1077
Braithwaite, J., & Spruit, H. C. 2004, Natur, 431, 819
Chandrasekhar, S. 1935, MNRAS, 95, 207
Cumming, A. 2002, MNRAS, 333, 589
Das, U., & Mukhopadhyay, D. 2012a, PhRvD, 86, 042001 (DM1)
Das, U., & Mukhopadhyay, D. 2012b, JMPo, 21, 124001 (DM2)
Das, U., & Mukhopadhyay, D. 2013, PhRvL, 110, 071102
Ferrario, L., & Wickramasinghe, D. T. 2005, MNRAS, 356, 615
Goldhaber, G., Groom, D. E., Kim, A., et al. 2001, ApJ, 558, 359
Gough, D. O., & McIntyre, M. E. 1998, Natur, 394, 755
Hachisu, I., Kato, M., Saio, H., & Nomoto, K. 2012, ApJ, 744, 69
Hicken, M., Garnavich, P. M., Prieto, J. L., et al. 2007, ApJL, 669, L17
Howell, D. A. 2011, NatCo, 2, 350
Howell, D. A., Sullivan, M., Nugent, P. E., et al. 2006, Natur, 443, 308
Iben, I., & Tutukov, A. V. 1984, ApJS, 54, 335

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3 However, see the Appendix of DM1, which discusses that even a relatively weaker field than that considered here can give rise to the super-Chandrasekhar masses.
Kashi, A., & Soker, N. 2011, MNRAS, 417, 1466
Lai, D., & Shapiro, S. L. 1991, ApJ, 383, 745
Nomoto, K., Saito, H., Kato, M., & Hachisu, I. 2007, ApJ, 663, 1269
Parthasarathy, M., Branch, D., Jeffery, D. J., & Baron, E. 2007, NewAR, 51, 524
Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ, 517, 565
Phillips, M. M. 1993, ApJL, 413, L105
Scalzo, R. A., Aldering, G., Antilogus, P., et al. 2010, ApJ, 713, 1073
Scalzo, R. A., Aldering, G., Antilogus, P., et al. 2012, ApJ, 757, 12
Schmidt, G. D., Harris, H. C., Liebert, J., et al. 2003, ApJ, 595, 1101
Shapiro, S. L., & Teukolsky, S. A. 1983, Black Holes, White Dwarfs, and Neutron Stars: The Physics of Compact Objects (New York: Wiley)
Silverman, J. M., Ganeshalingam, M., Li, W., et al. 2011, MNRAS, 410, 585

Taubenberger, S., Benetti, S., Childress, M., et al. 2011, MNRAS, 412, 2735
Toonen, S., Nelemans, G., Bours, M., & Portegies Zwart, S. 2013, arXiv:1302.0837
Tout, C. A., Wickramasinghe, D. T., & Ferrario, L. 2004, MNRAS, 355, L13
van den Heuvel, E. P. J., Bhattacharya, D., Nomoto, K., & Rappaport, S. A. 1992, A&A, 262, 97
Vanlandingham, K. M., Schmidt, G. D., Eisenstein, D. J., et al. 2005, AJ, 130, 734
Wang, B., & Han, Z. 2012, NewAR, 56, 122
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge Univ. Press)
Wickramasinghe, D. T., & Ferrario, L. 2000, PASP, 112, 873
Yamanaka, M., Kawabata, K. S., Kinugasa, K., et al. 2009, ApJL, 707, L118