Evolution of Magnetized White Dwarf Binaries to Type Ia Supernovae

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ABSTRACT

With the increasing number of observed magnetic white dwarfs (WDs), the role of magnetic field of the WD in both single and binary star evolutions should draw more attentions. In this study, we investigate the WD/main-sequence star binary evolution with the Modules for Experiments in Stellar Astrophysics (MESA code), by considering WDs with non-, intermediate and high magnetic field strength. We mainly focus on how the strong magnetic field of the WD (in a polar-like system) affects the binary evolution towards type Ia supernovae (SNe Ia). The accreted matter goes along the magnetic field lines and falls down onto polar caps, and it can be confined by the strong magnetic field of the WD, so that the enhanced isotropic pole-mass transfer rate can let the WD grow in mass even with a low mass donor with the low Roche-lobe overflow mass transfer rate. The results under the magnetic confinement model show that both initial parameter space for SNe Ia and characteristics of the donors after SNe Ia are quite distinguishable from those found in pervious SNe Ia progenitor models. The predicted natures of the donors are compatible with the non-detection of a companion in several SN remnants and nearby SNe.

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INTRODUCTION

There are still open questions about the WD binary evolution and origin of SNe Ia.

In the single degenerate (SD) model, a CO WD accumulates mass from a non-degenerate donor star. The survived companion star as predicted by the SD model has not detected yet.

However, it is still too early to conclude that the SD scenario cannot be a major pathway toward SNe Ia.

Some works suggested that something is missing in the WD binary evolution?

Around 10% of the observed WDs are estimated to have the magnetic field . We consider the possible effect of the magnetic field of the WD in the SD model.

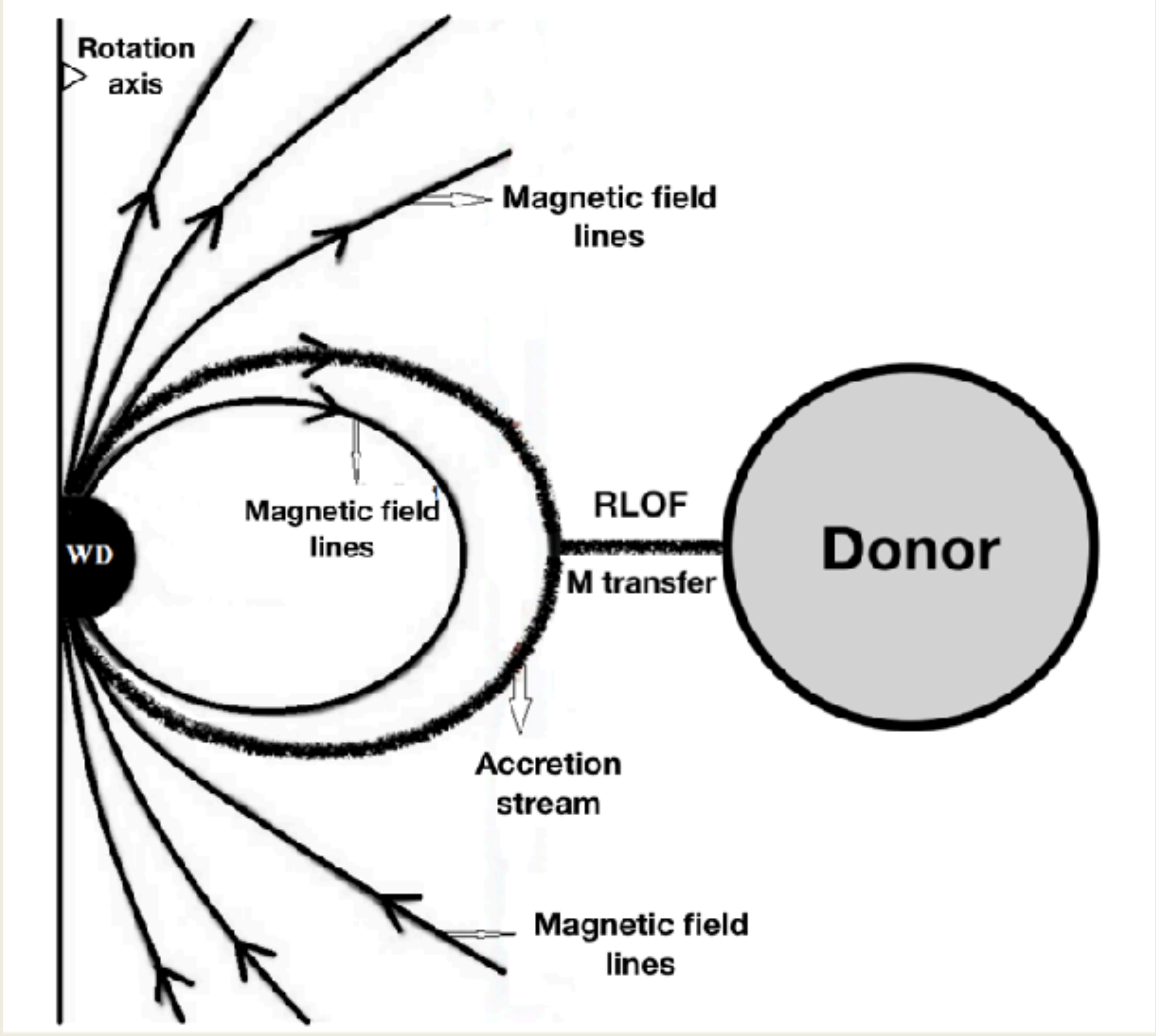


Figure 1. Stream-like accretion in the magnetized WD binary

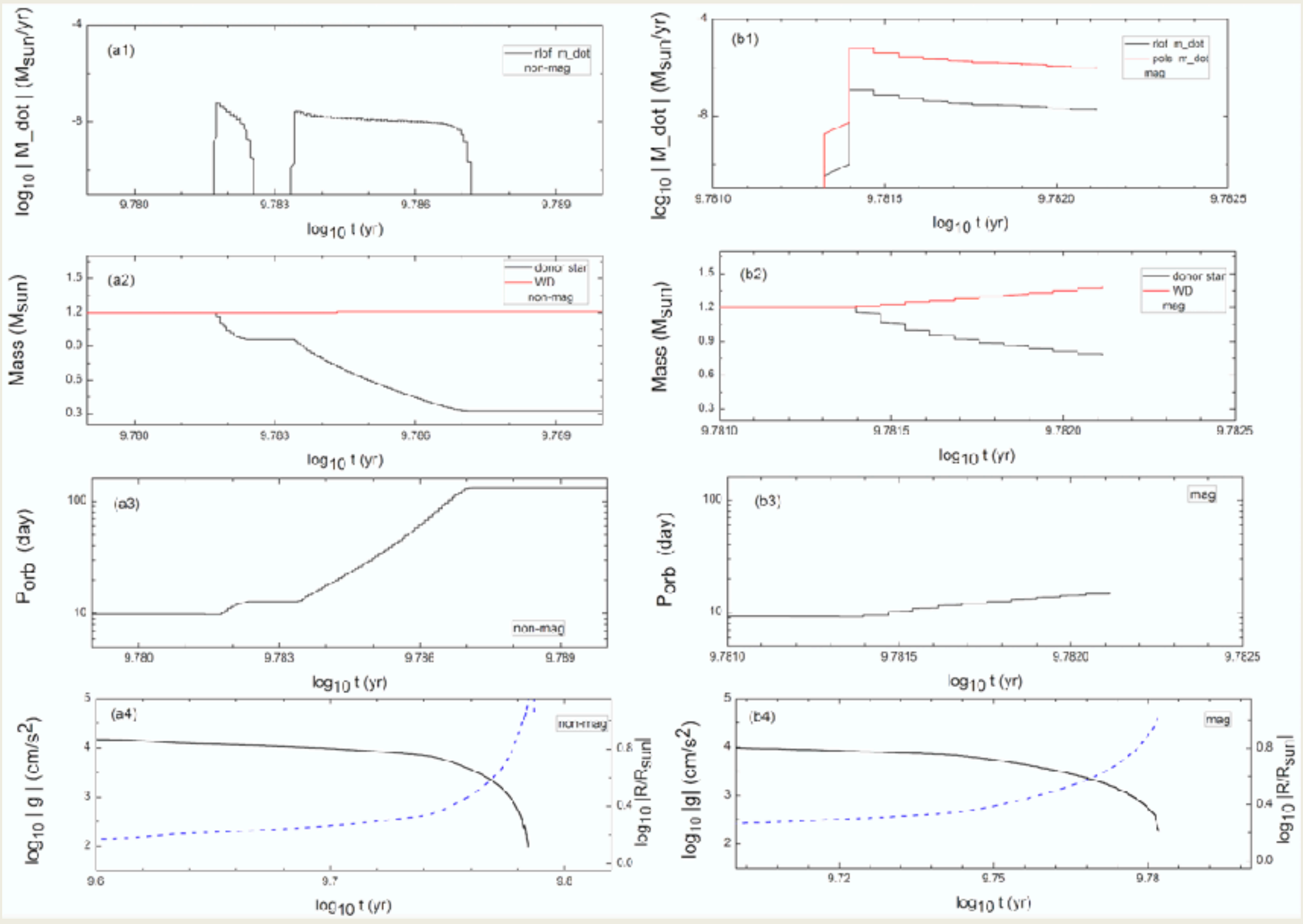


Figure 2. The two binaries have same initial conditions except the case of non-magnetic (left panels) and the magnetic WD (B= 1.1 × 10⁸ G: right panels). The initial masses of the WDs and donor stars are 1.2 $M_\odot$ with the initial orbital periods of 10 days.

METHODS AND MATERIALS

1,In the polar-like systems, the strong magnetic field of the WD lets the binary have a synchronous rotation and prevent the accretion disk formation. The transferred mass falls down onto the polar caps along magnetic lines and can be confined by the high magnetic field (Fig.1).

2, Livio (1983) showed that the magnetic confinement can suppress the nova burst even at the low mass transfer rate. The appropriate physical condition for the magnetic confinement,

$$B \geq 9.3\times10^7 (\frac{R_{WD}}{5\times10^8\,\mathrm{cm}})(\frac{P_b}{5\times10^{19}\,\mathrm{dyne\,cm^{-2}}})^{7/10}(\frac{M_{WD}}{M_\odot})^{-1/2}(\frac{\dot{M}}{10^{-10}\,M_\odot\,\mathrm{yr}^{-1}})^{-1/2}.$$

3, If the accreted matter is confined to the polar column, then the following isotropic pole-mass transfer rate ($\dot{M}_p$) should be compared to the critical mass transfer rate, rather than the usual RLOF mass transfer rate ($\dot{M}$).

$$\dot{M}_p = \frac{S}{\Delta S}\dot{M}.$$

4, The mass transfer rate is important to realize the stable hydrogen and helium burning on the WD, and it will affect the mass retention and growth of the WD.

$$\dot{M}_{WD} = \eta_H \eta_{He} \dot{M}$$

For the WD binaries with the strong magnetic field, $\dot{M}$ in the prescriptions for η_H and η_{He} should be replaced by the isotropic polar-mass transfer rate ($\dot{M}_p$).

Figure 3. Initial parameter space distributions for SNe Ia.

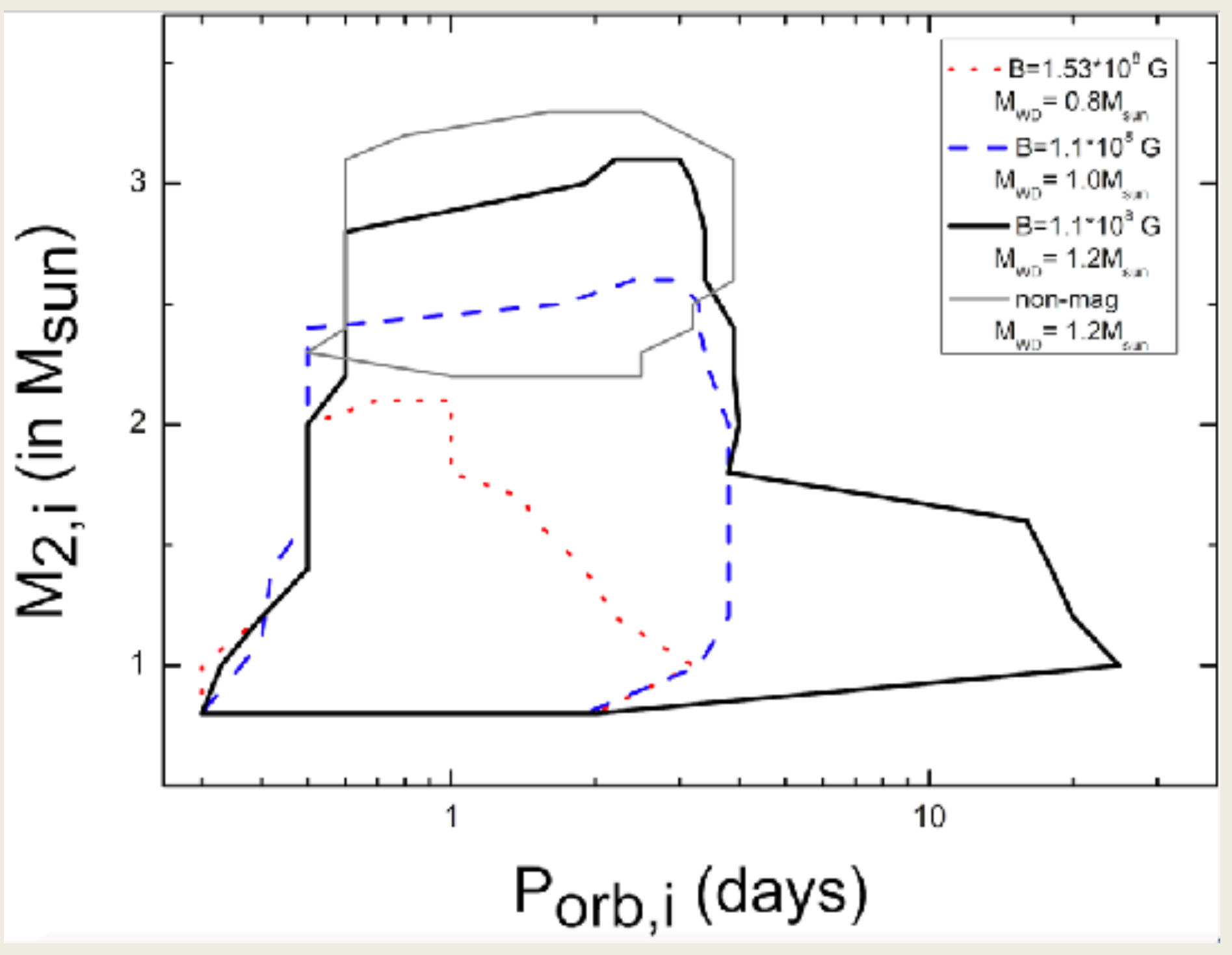
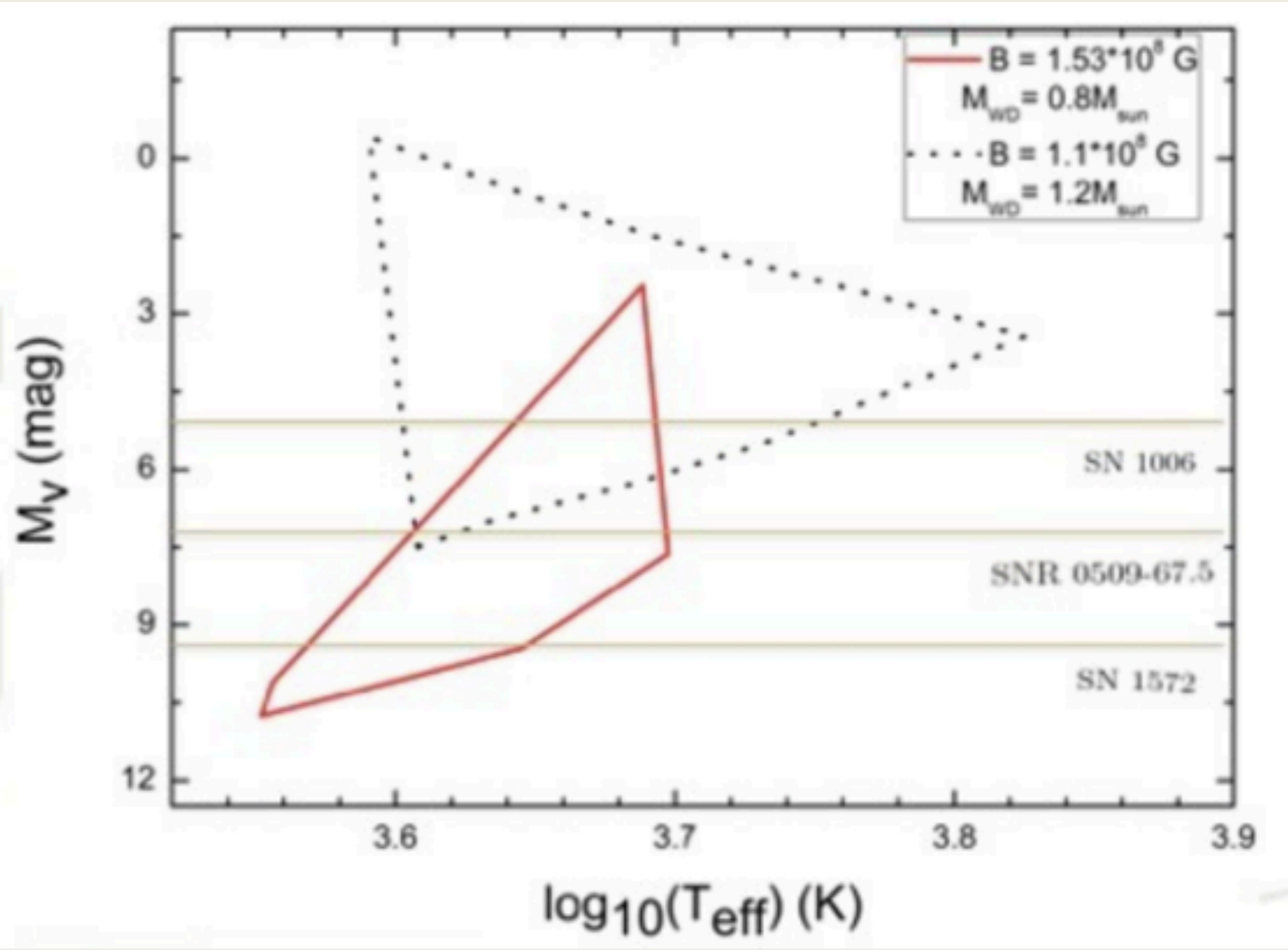


Figure 4. The distributions of the final effective temperature - absolute magnitude of the donor stars



RESULTS

We use the MESA stellar evolution code to test the WD binary evolution under the non, intermediate and high magnetic field cases.

Fig.2 shows that a WD binary evolution ($M_{WD,i}$ = 1.2$M_\odot$, $M_{donor,i}$ = 1.2$M_\odot$ and initial orbital period is 10 days) without and with the magnetic field. Under the magnetic confinement model (right panels), the WD can grow in mass to the limit mass with the low mass donor (it couldn’t happen without the magnetic confinement).

Fig. 3 tells that the initial parameter space for SNe Ia can be larger with the magnetic confinement model (black line) comparing to that of non-magnetic case (gray line). With this model, the lower limit of the initial donor which can drive the WD to the limit mass can be as low as 0.8 $M_\odot$.

The absolute magnitude of the donors ranges from -0.42 to 11 mag (Fig.4). The donor can be as dim as having 11 mag, since the less massive donor can now lead to an SN Ia. Such a faint donor is difficult to detect.

CONCLUSIONS

We mainly focus on the highly magnetized WD binary evolution by using MESA code under the magnetic confinement model to generate SNe Ia.

Under the magnetic confinement model, the initial parameter spaces for producing SNe Ia become larger than the previous studies without the effects of the magnetic field. Especially, the possible initial mass of donor stars can extend to the lower mass region.

The final properties of donors derived in this paper are comparable with non-detection of (surviving) companion stars in nearby SNe and SNRs with the currently reported upper limits (Fig.4. SN 1572; SN 2011fe /PTF11kly; SN 1006). As an extreme example, our model allows a donor as dim as 11 mag in the absolute V -band magnitude.

We find that the delay times from our model are ranged from short ones (~10^8 yr) to 10^{11} yr.

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