SSS phase of single degenerate type Ia supernova progenitors in early type galaxies

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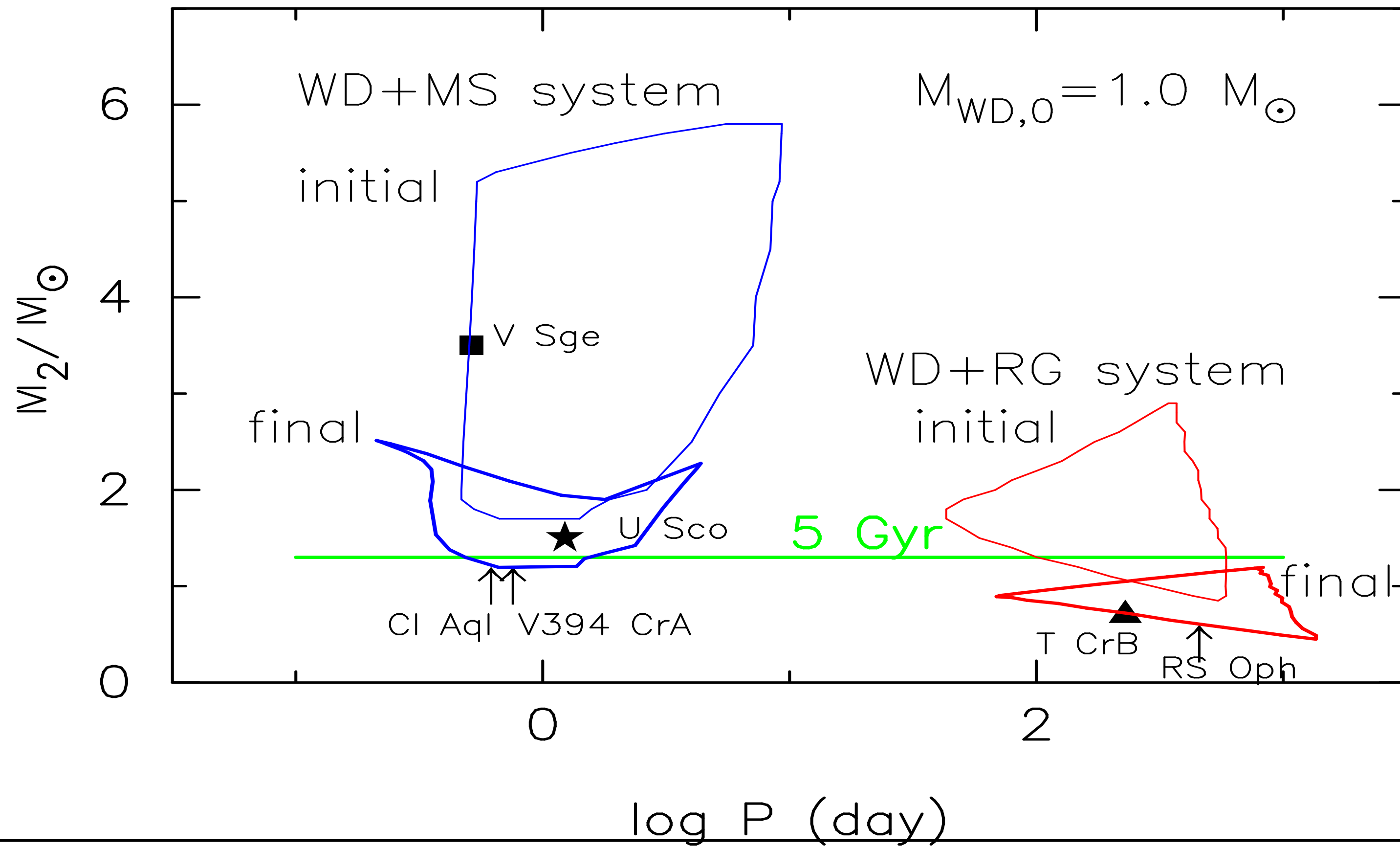


Recent Criticisms on the SD Model

1. Overproduction of SSSs in the SD model

[e.g. Gilfanov & Bogdan 2010]

- ○ G&B showed that the SSS flux in Early Type Galaxies is ~100 times smaller than that expected from the SD scenario.

2. Delay Time Distribution of SNe Ia

[e.g. Totani et al. 2008]

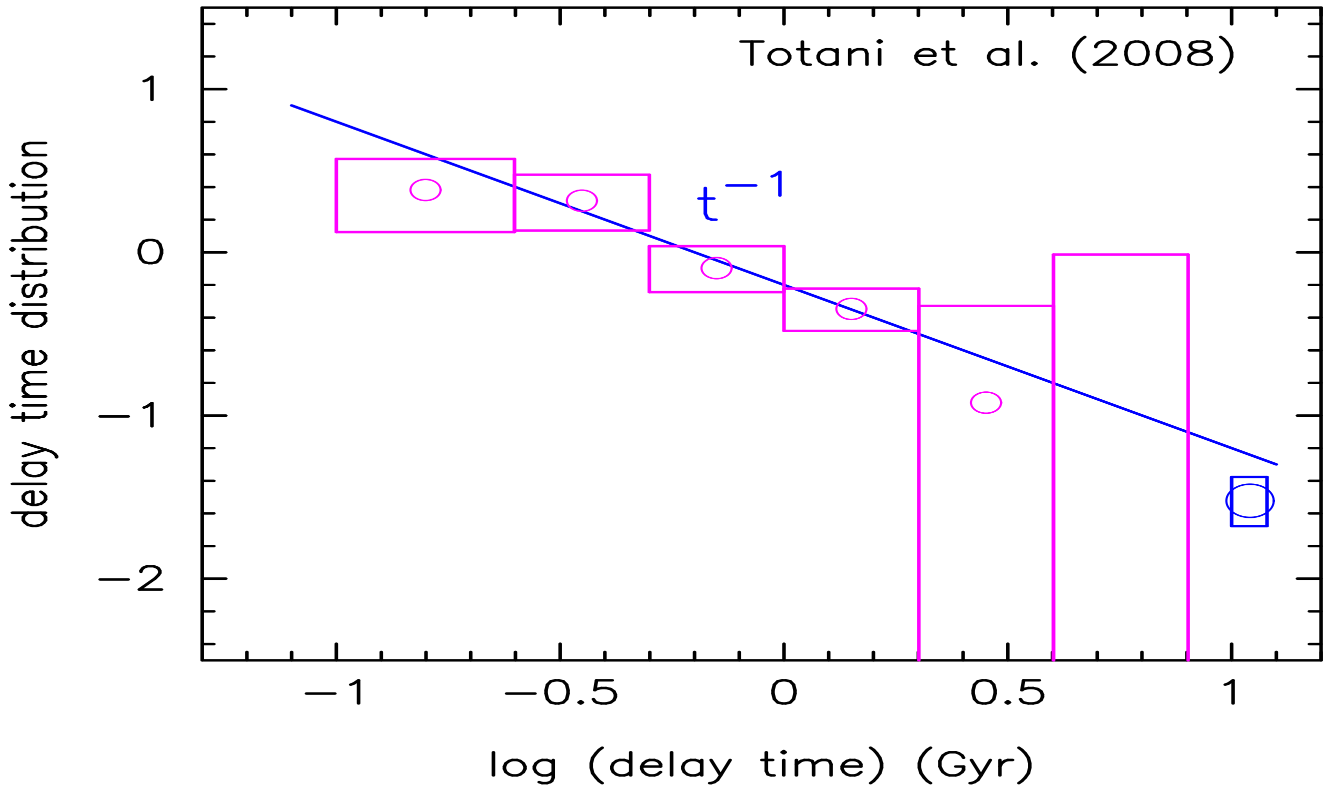
- ○ The SD model cannot reproduce ~t^{-1} over 10 Gyr

Delay Time Distribution of SNe Ia

- SD model cannot reproduce recent Delay Time Distribution observation ???

  [Totani et al. 2008, Maoz et al. 2010]

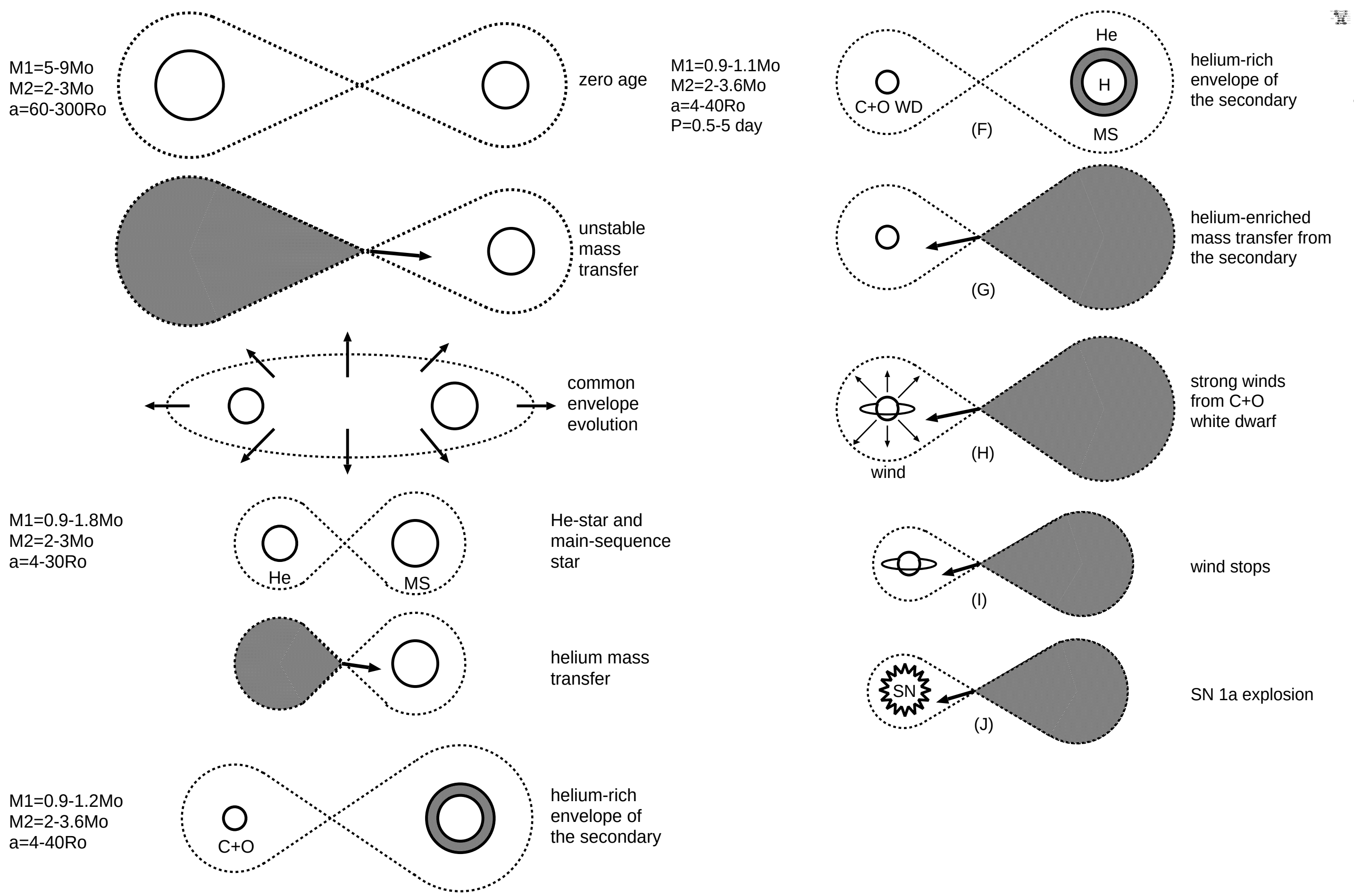
  - ~t^{-1} dependence over 10 Gyr
  - SD model produces only a young population < 1Gyr

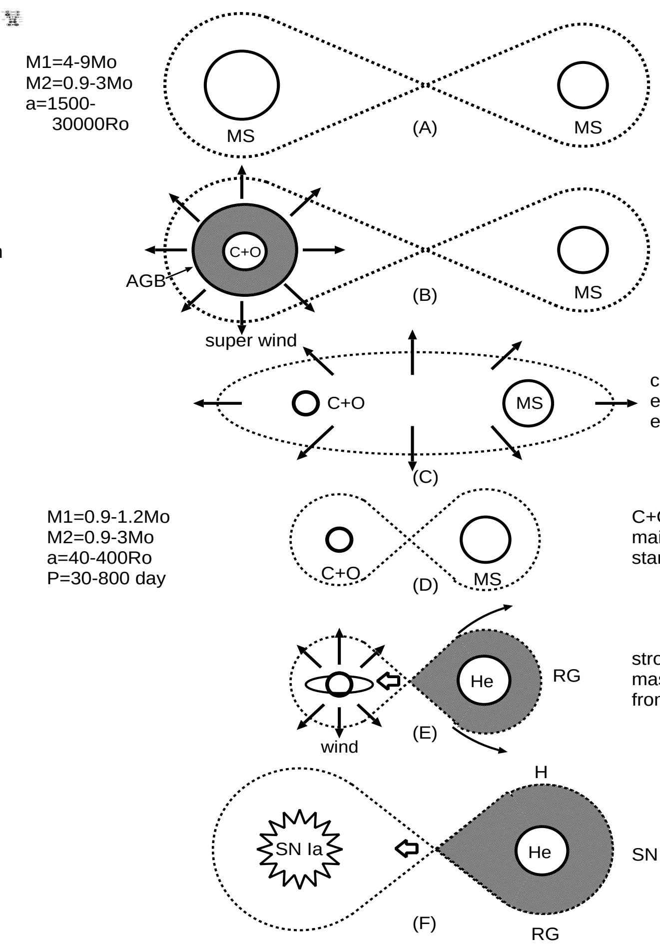


Evolutionary Paths to SNe Ia

Two main paths: "WD + MS" and "WD + RG"

(young) (old)





WD + MS

Hachisu et al. (1999,ApJ,519,314)

WD + RG

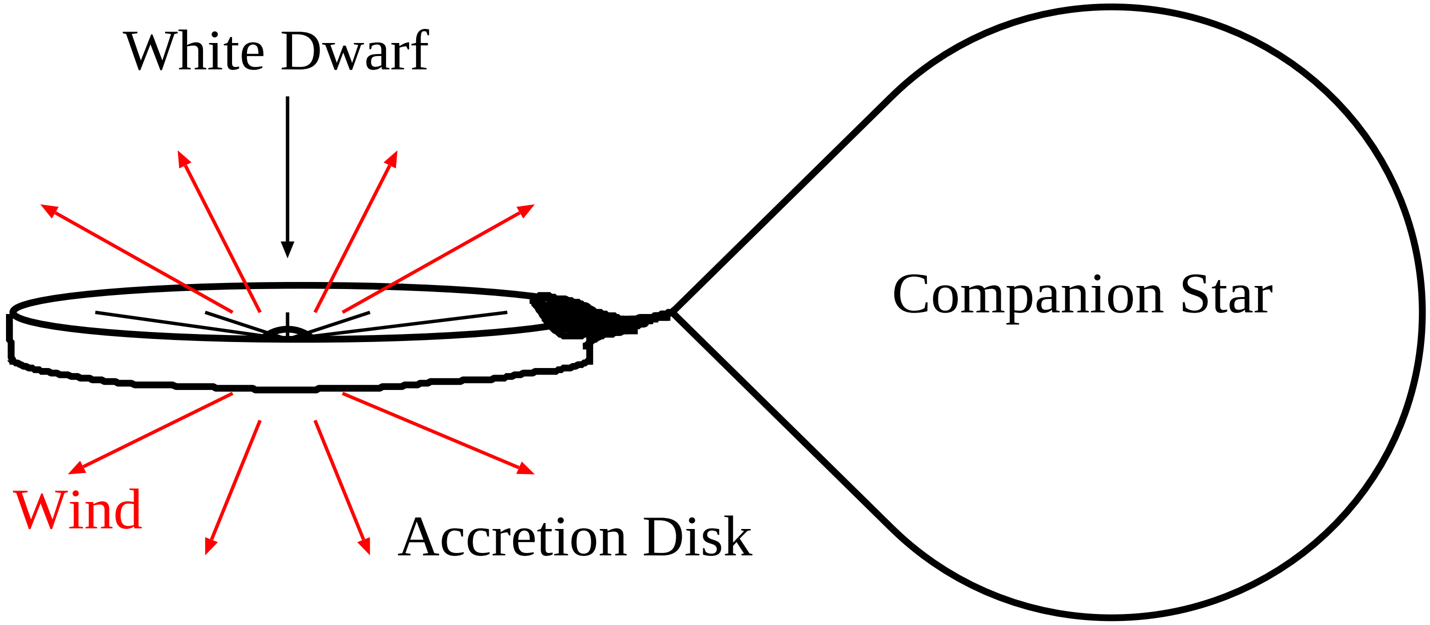
Hachisu et al. (1999,ApJ,522,487)

Winds from White Dwarfs

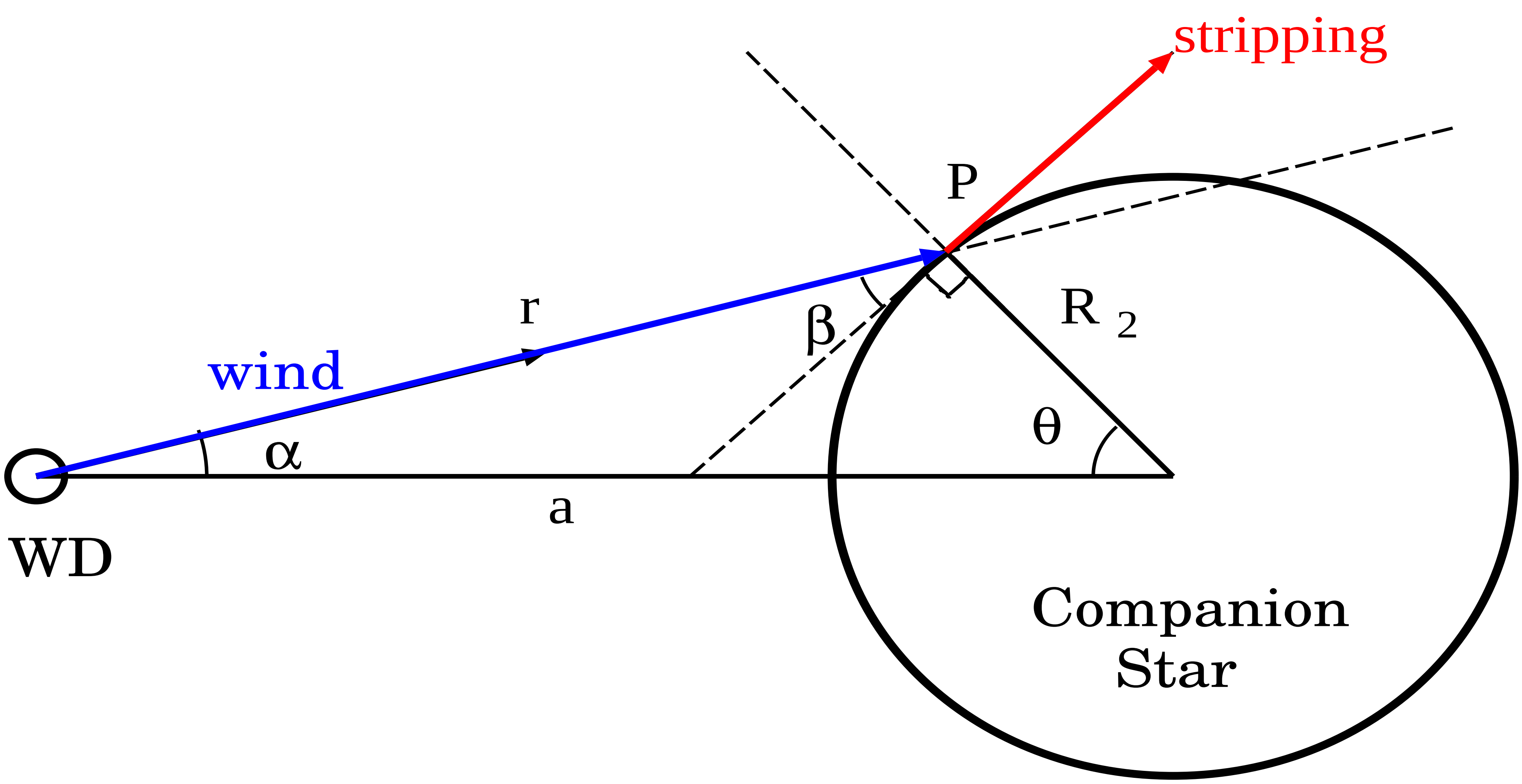
"Accretion Wind Evolution"

(Hachisu, Kato, & Nomoto 1996, ApJ, 470, L97)

$$\dot{M}_{\rm acc} > \dot{M}_{\rm cr} \sim 1 \times 10^{-6} M_\odot \ {\rm yr}^{-1} \ \rightarrow \ {\rm Winds}$$



Winds strip off the companion surface



Winds collide with the companion and strip off the surface

Mass stripping rate

Potential energy difference = Kinetic energy dissipation by shock

$$\frac{GM}{a}\left(\phi_1 - \phi_3\right)\dot{M}_{2,\mathrm{strip}} = \frac{1}{2}v_{\mathrm{wind}}^2\dot{M}_{\mathrm{wind}}\cdot\eta_{\mathrm{eff}}\cdot g(q)$$

g(q) is a function only of the mass ratio q,
including solid angle subtended by the companion
and shock effect by wind

$$\dot{M}_{2,\mathrm{strip}} = c_1\dot{M}_{\mathrm{wind}}$$

$$c_1 = \frac{\eta_{\mathrm{eff}}\cdot g(q)}{\phi_1-\phi_3}\frac{1}{2}v_{\mathrm{wind}}^2\frac{a}{GM}$$

$$\text{where } M = M_1 + M_2, \quad a = \text{separation}$$

Hachisu and Kato (2003)

Large mass stripping effect

- Wind velocity of ~4000 km/s
- Orbital velocity of ~400 km/s for WD+MS

$$c_1 \approx 0.1 \left(\frac{v_{\rm wind}}{v_{\rm orb}} \right)^2 = 0.1 \left(\frac{4000 \ {\rm km/s}}{400 \ {\rm km/s}} \right)^2 \sim 10$$

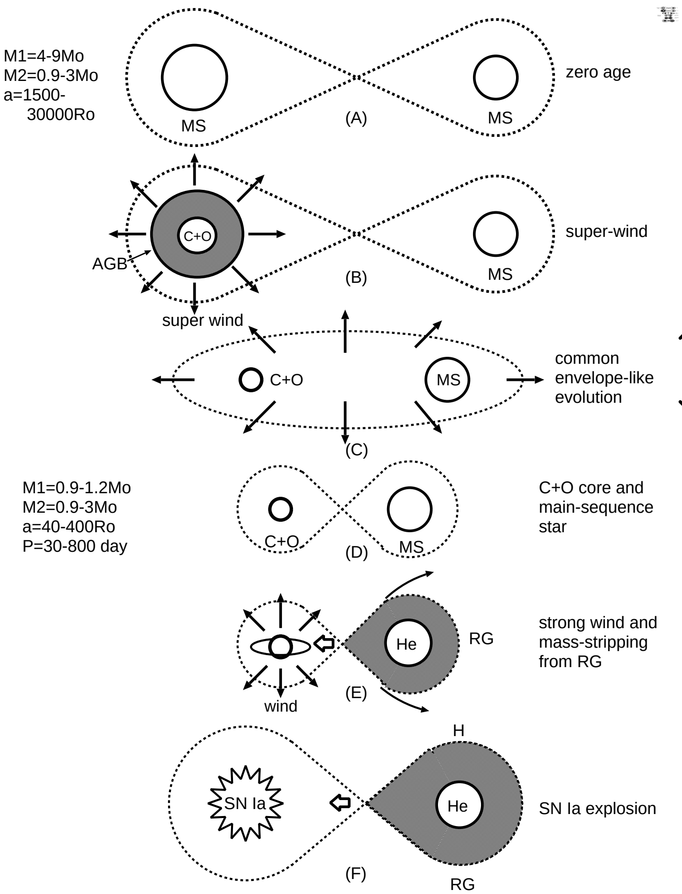
- Wind velocity of ~1000 km/s
- Orbital velocity of ~40 km/s for WD+RG

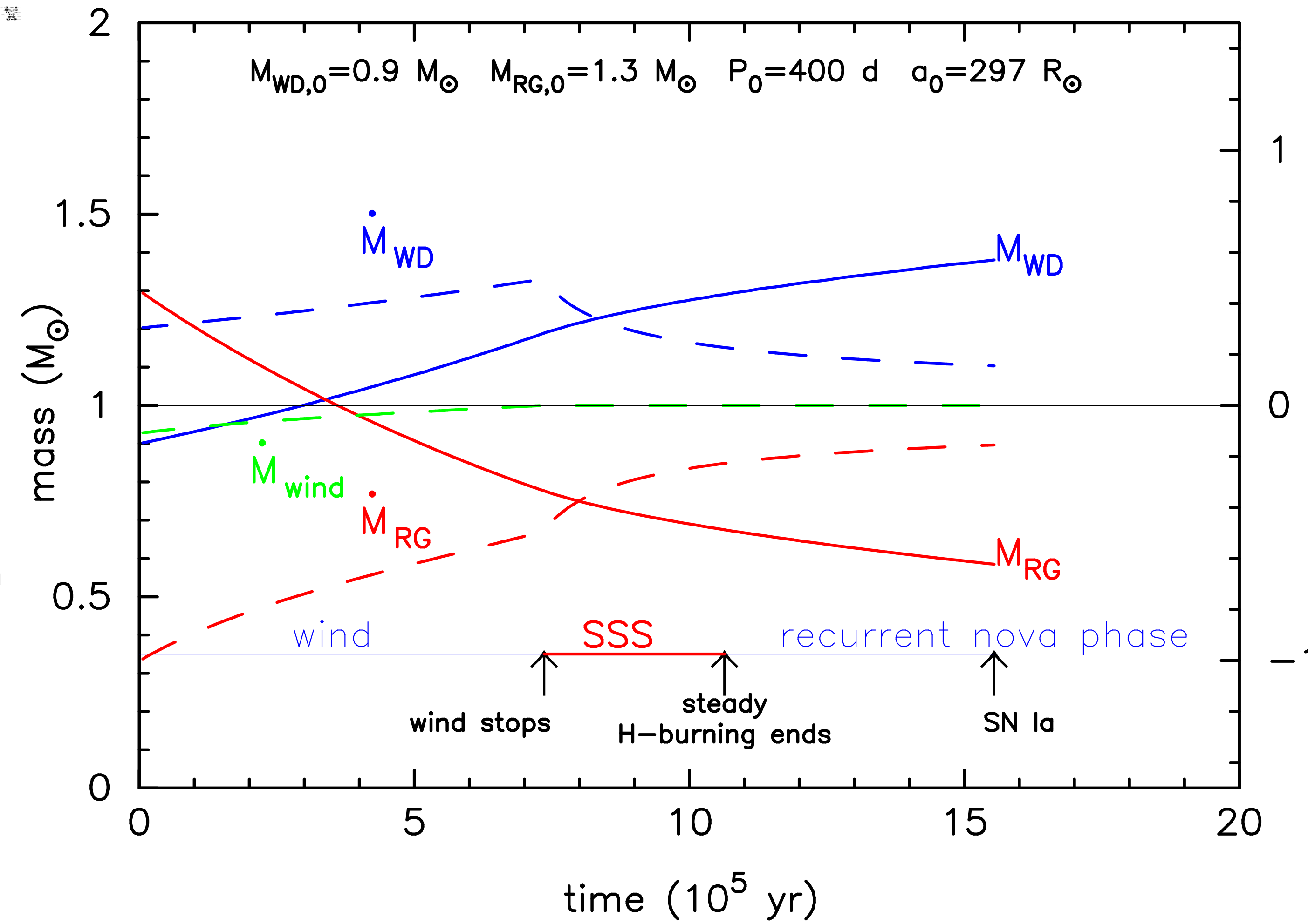
$$c_1 \approx 0.1 \left(\frac{v_{\rm wind}}{v_{\rm orb}} \right)^2 = 0.1 \left(\frac{1000 \ {\rm km/s}}{40 \ {\rm km/s}} \right)^2 \sim 60$$

$$\dot{M}_{2,{\rm strip}} \sim (10 - 60) \ \dot{M}_{\rm wind}$$

Evolution of WD+RG System

- WD winds and its mass-stripping effect
  → stabilize the mass transfer

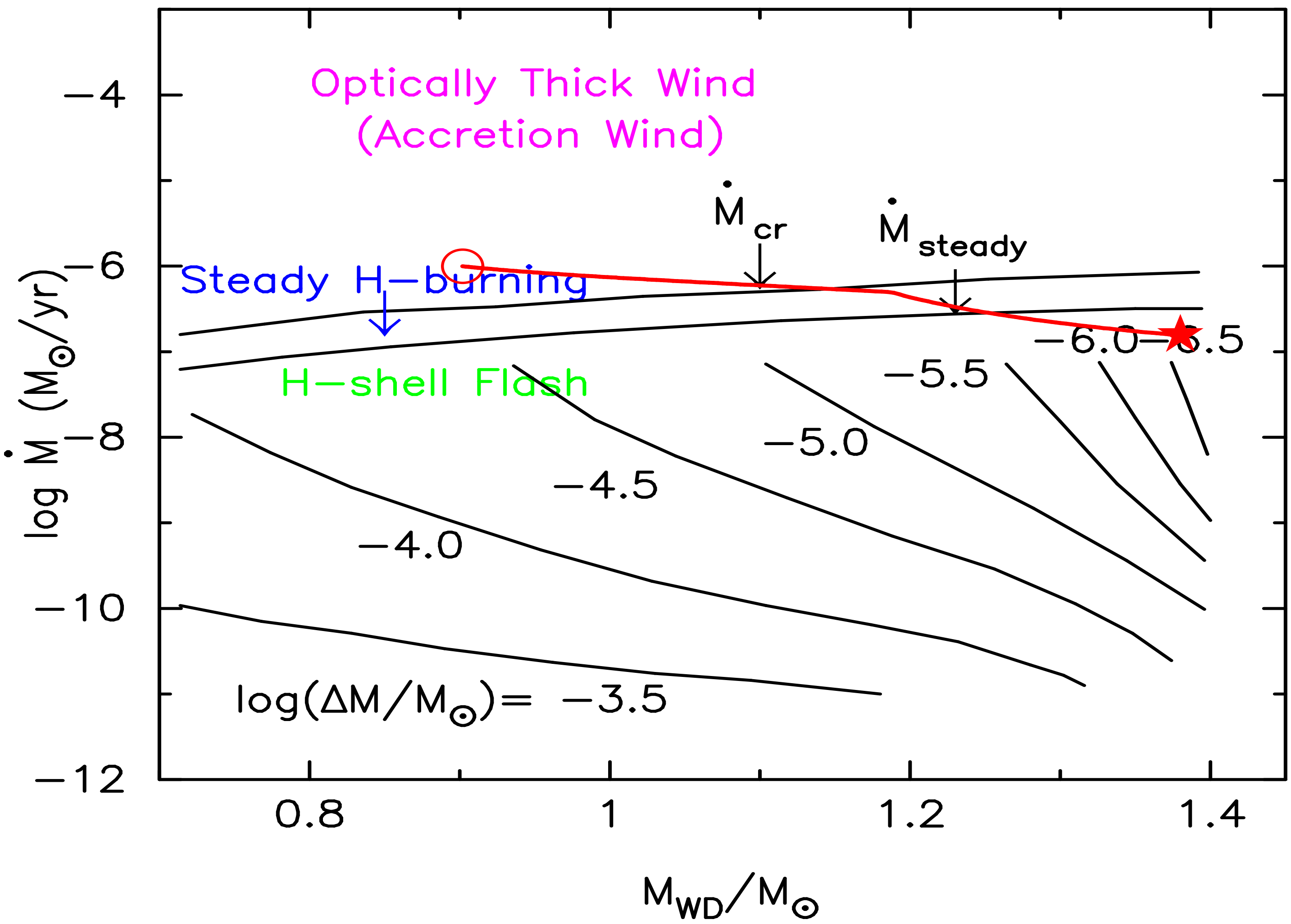




$$\Delta M_{\rm H,RG} \sim 0.1 M_\odot$$

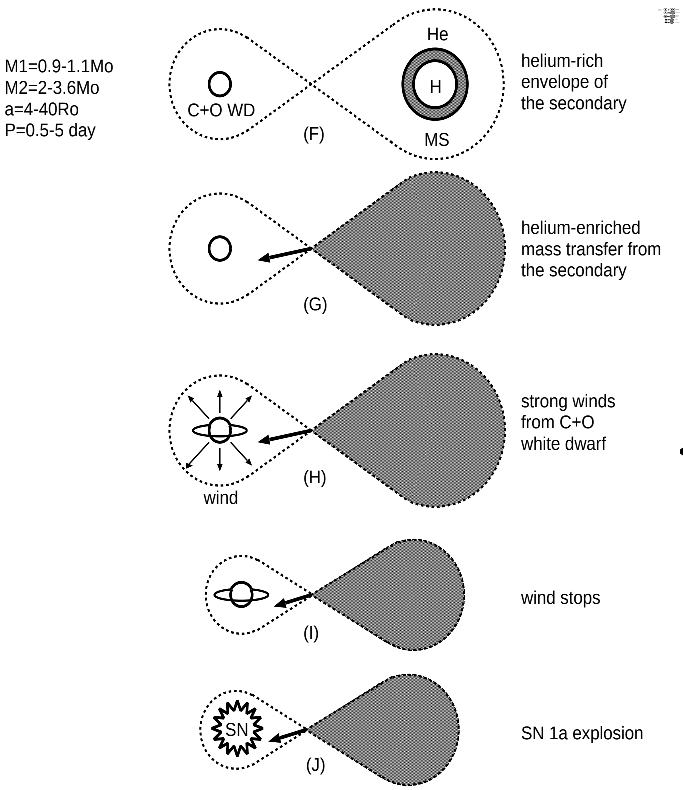
Path on the mass-accretion map

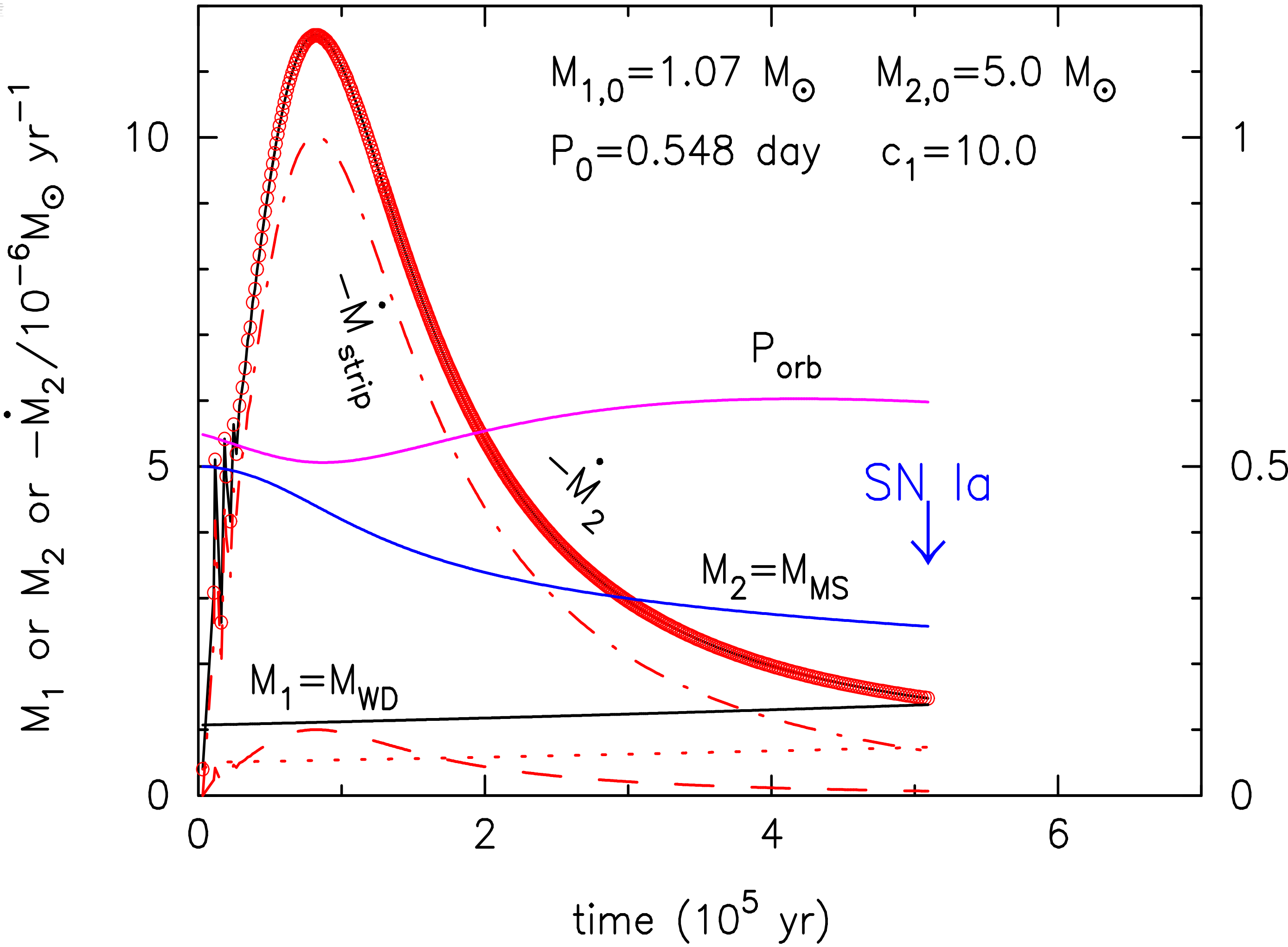
- Large mass-transfer rate in early phase
  → winds stop → recurrent nova



Evolution of WD+MS System

- Mass-transfer rate increases → ~1x10^{-5} Mo/yr → mass-stripping → stabilize mass-transfer

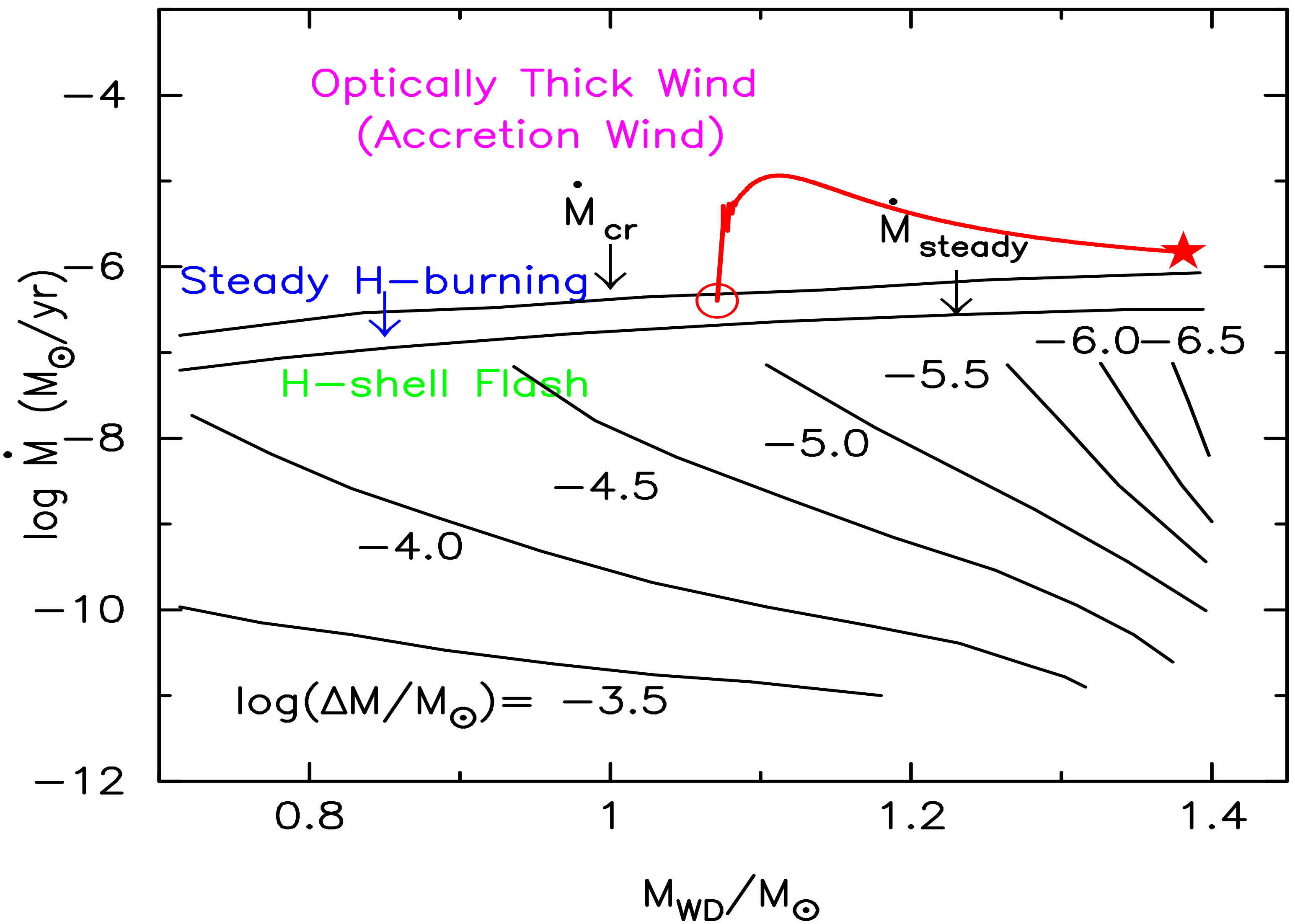


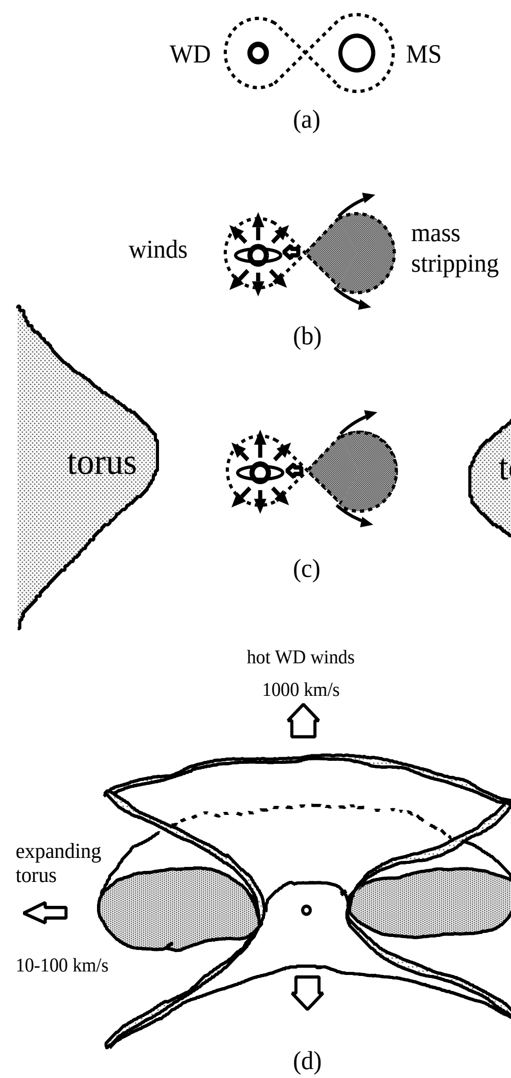


Path on the mass-accretion map

- exploding during the wind phase

→ forming a equatorial circumstellar disk (a few Mo)



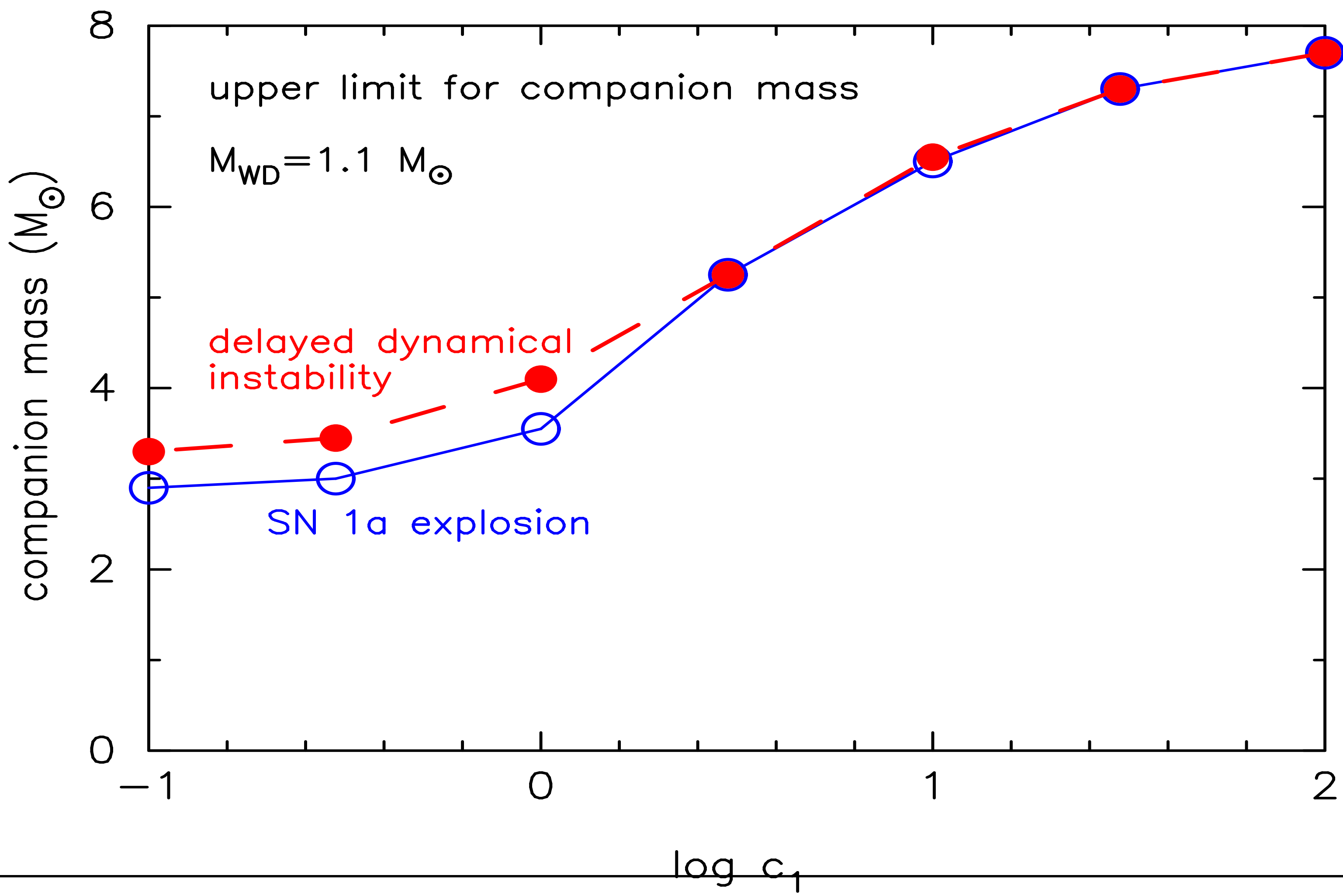


Upper-limit Mass of MS Companion

- Larger c1 stabilizes mass-transfer

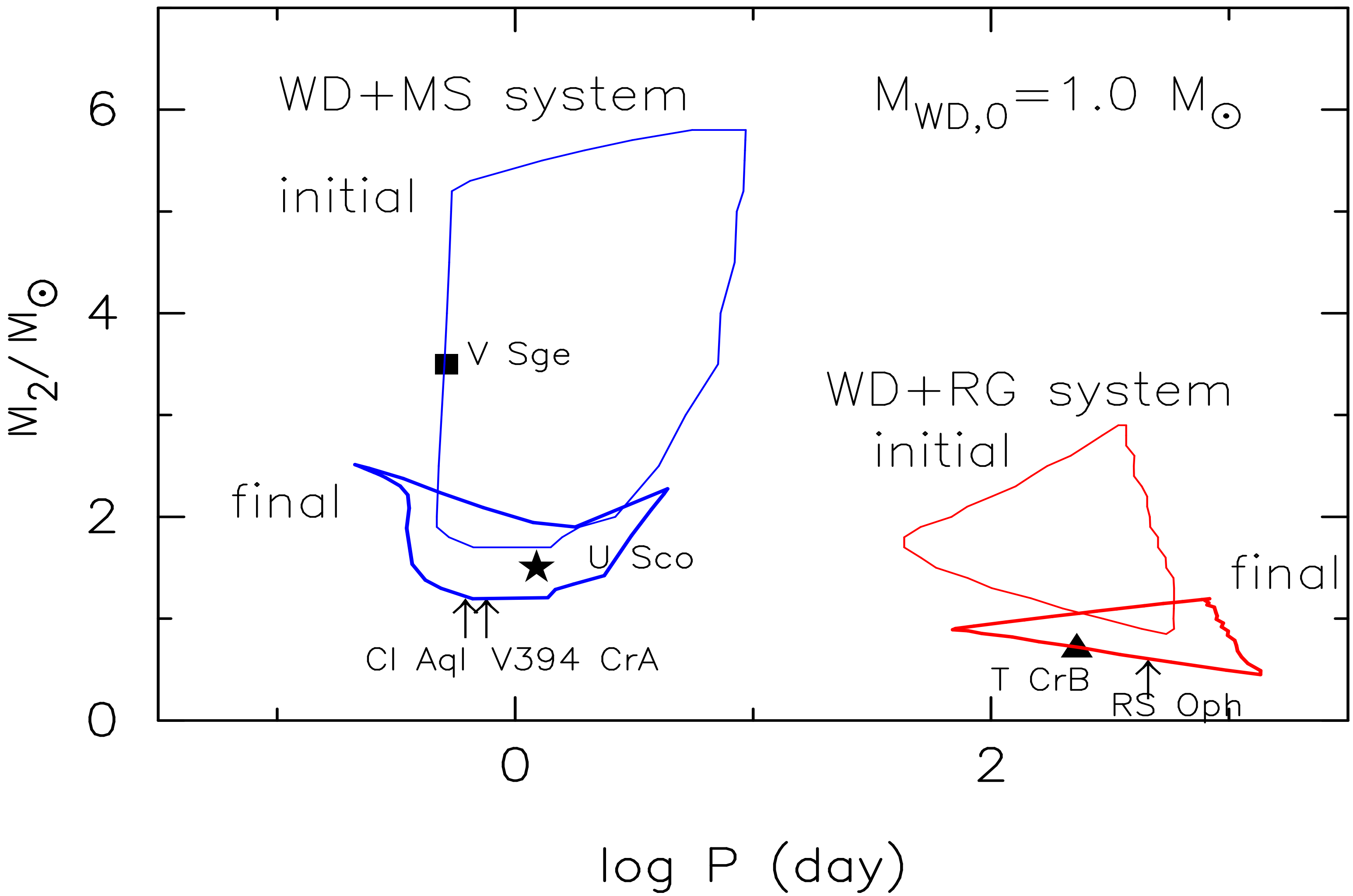
→ more massive companion for SN 1a (WD+MS),

→ delayed dynamical instability region disappears



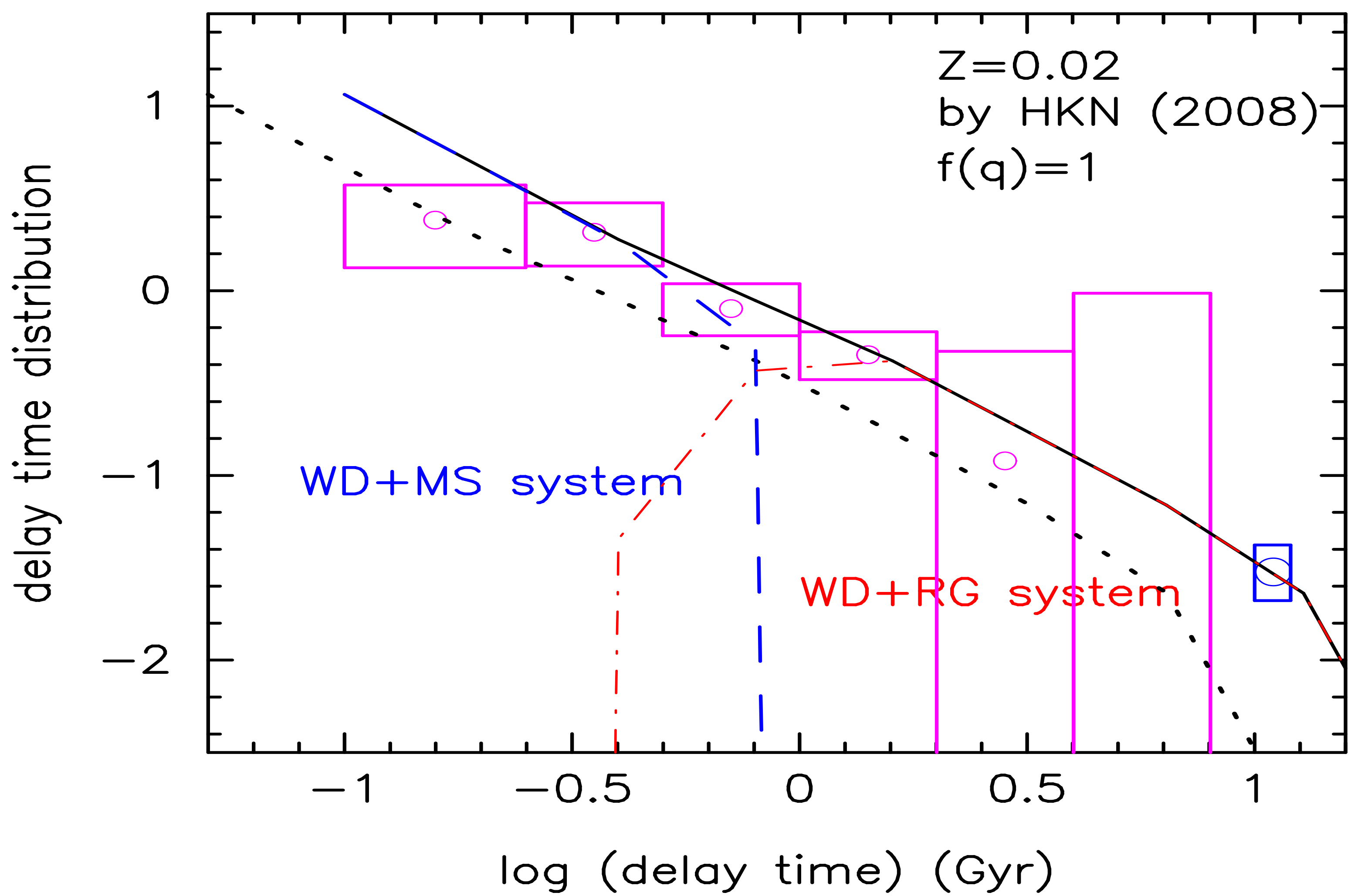
Region of SN Ia Progenitors

- Two regions of "WD+MS" and "WD+RG"
  → up to ~6-7 Mo for "WD+MS" system



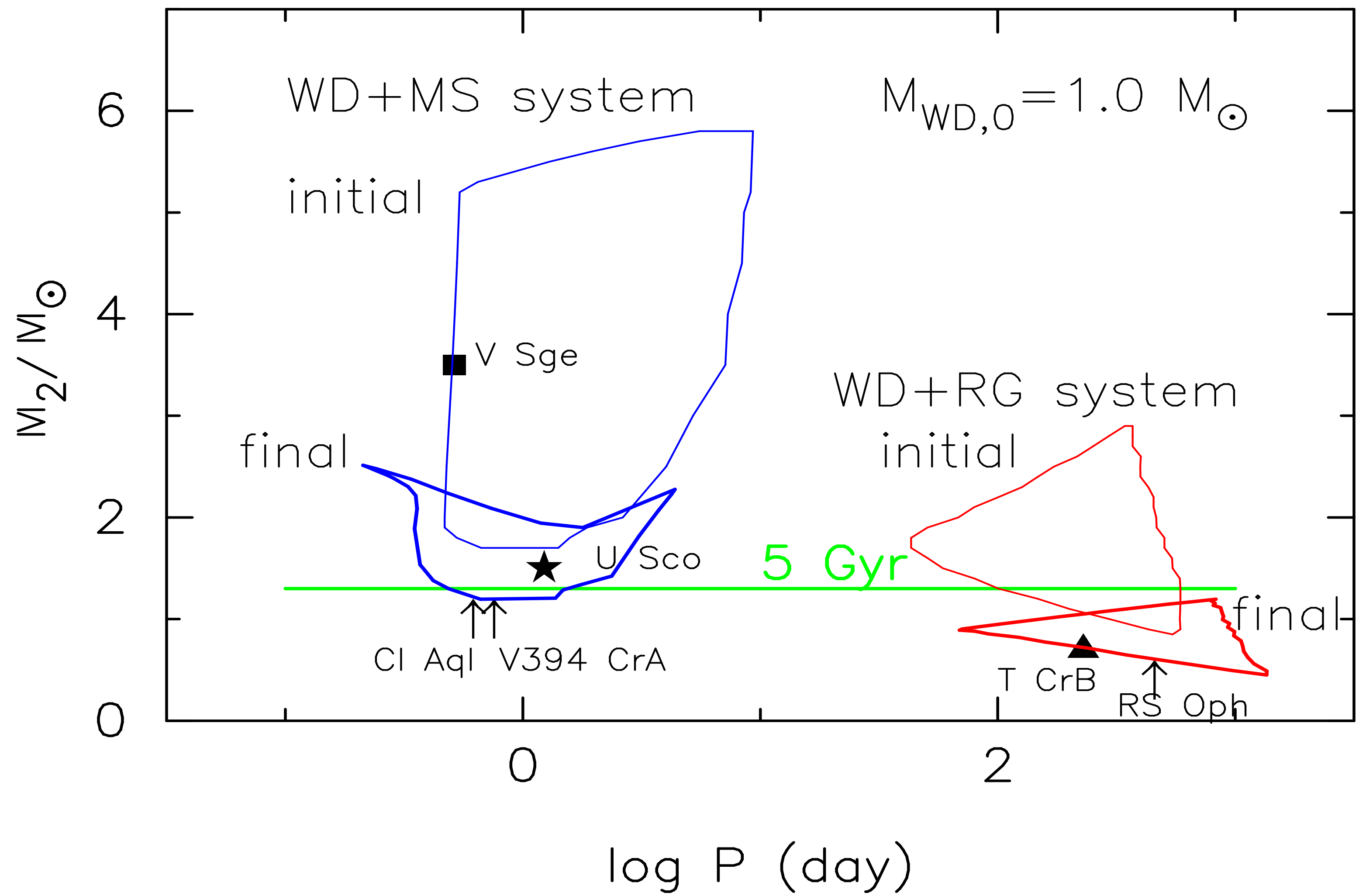
Delay Time Distribution of SD Model

1. young population from "WD+MS"
2. old population from "WD+RG"



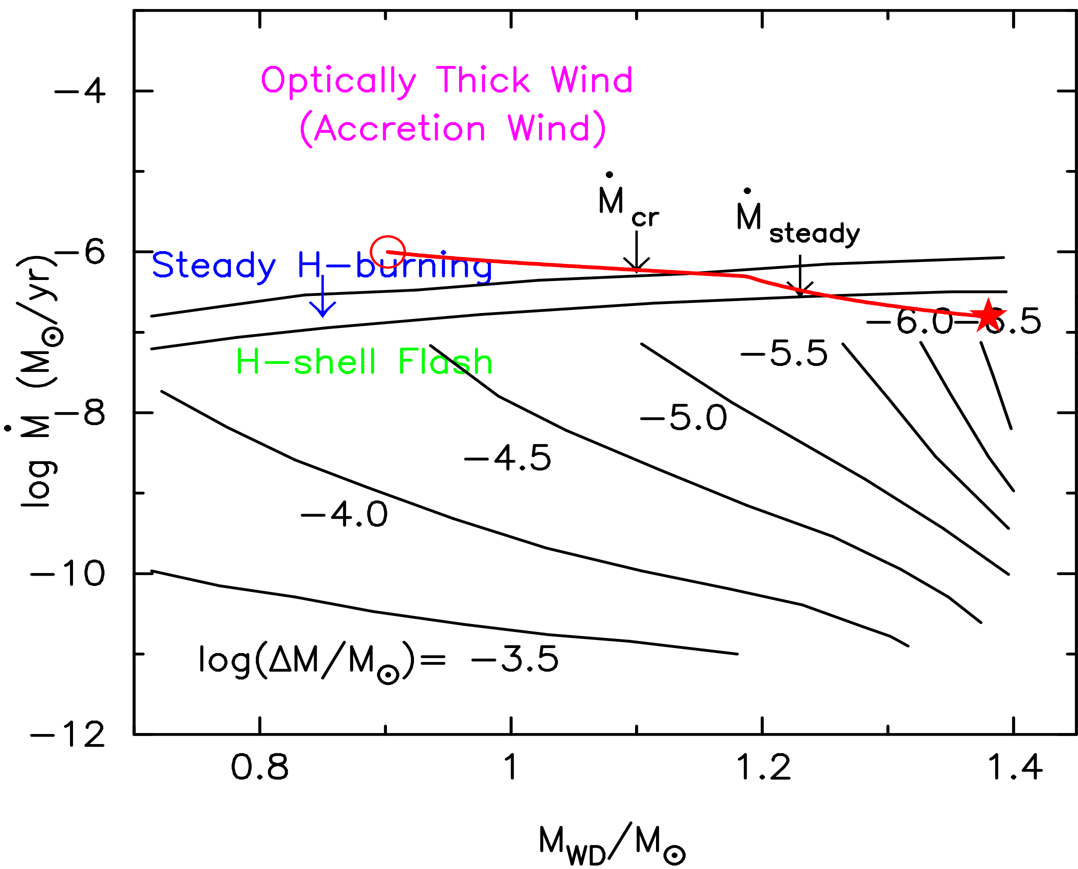
SD Progenitors in early type galaxies

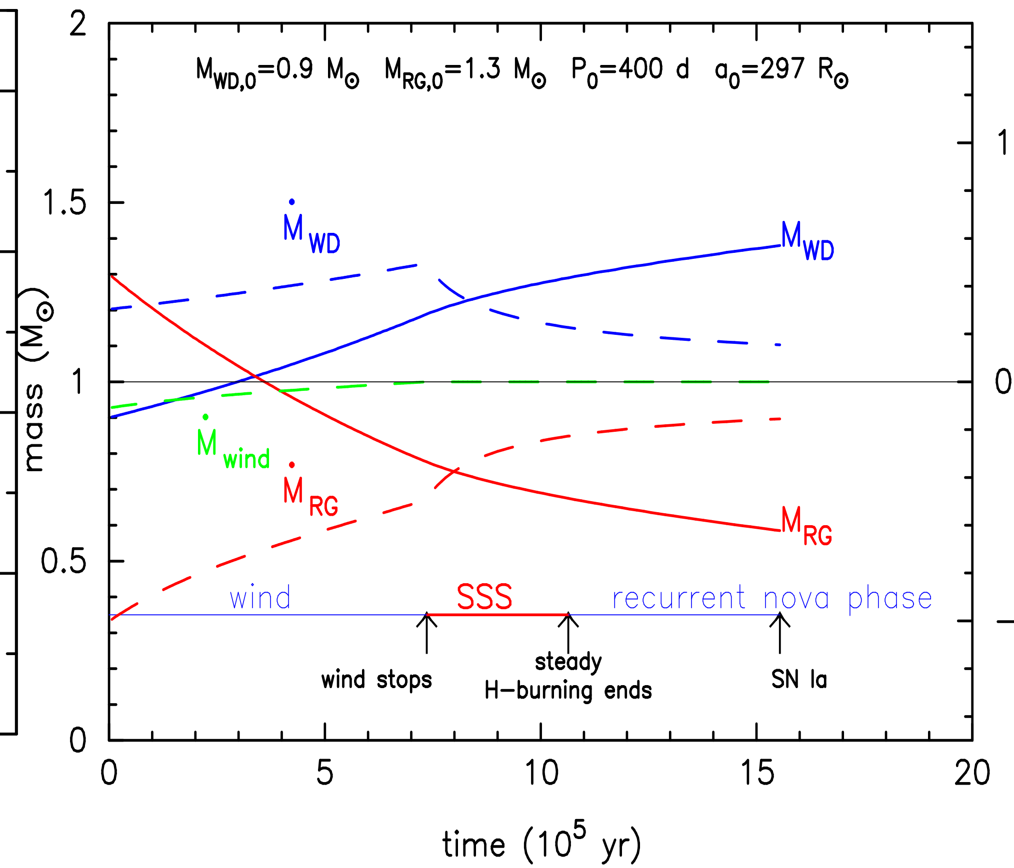
1. ~5 Gyr after star formation stopped
→ companion less massive than 1.3 Mo



SSS duration of a single progenitor

- SSS phase $\dot{M}_{\rm steady} < \dot{M}_{\rm WD} < \dot{M}_{\rm cr}$

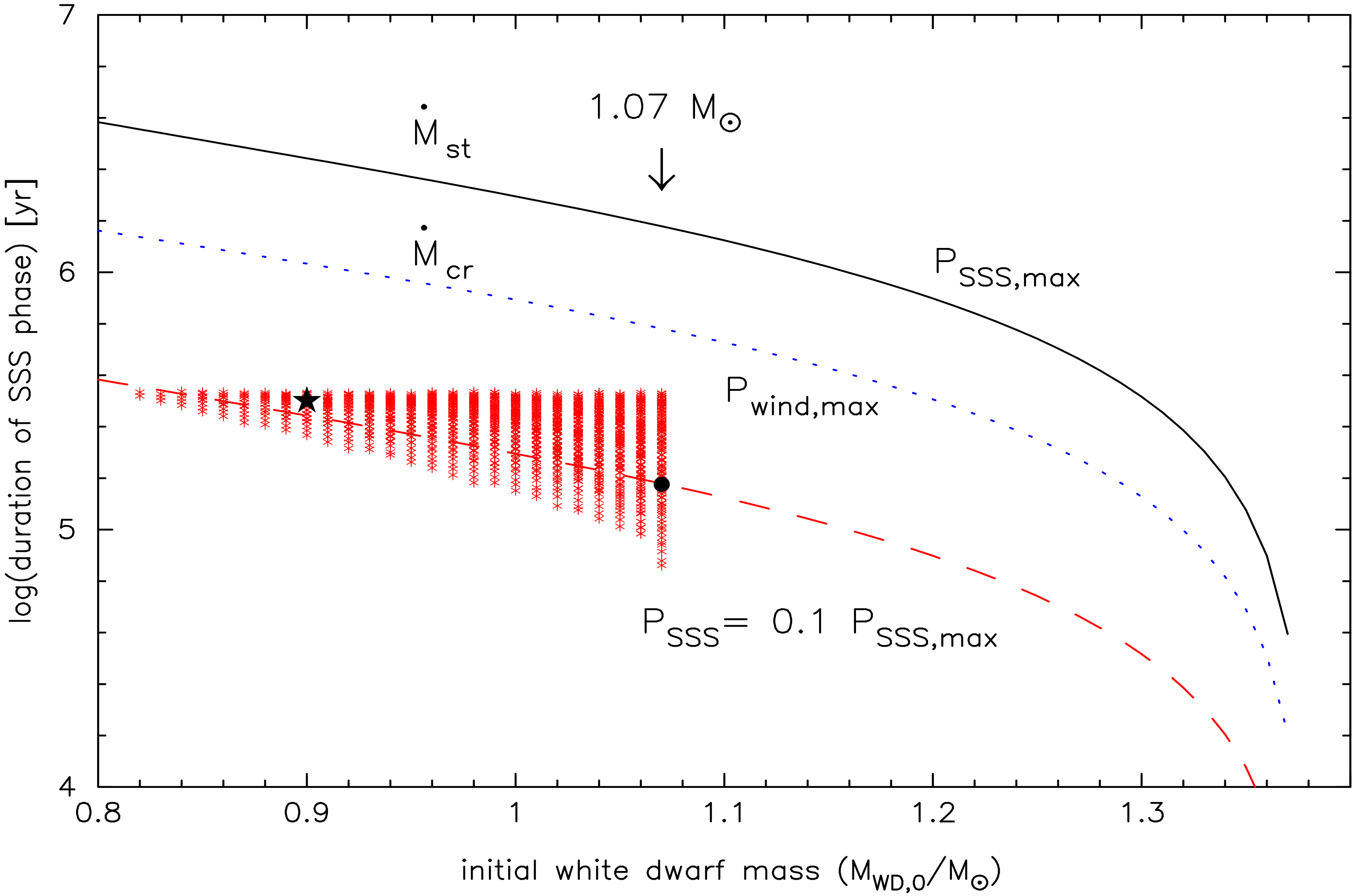




$$P_{\rm SSS} = 2.0 \times 10^5 \ {\rm yr}$$

Average SSS Duration < 1.3 Mo

- duration = ~2.5 x 10^{5} yr



~1500 evolution models of WD+RG systems M2 < 1.3 Mo

Average number of SSSs

- duration of a SSS phase $P_{\rm SSS} \sim 2.5 \times 10^5$ yr

  → ~8 times shorter than Gilfanov & Bogdan's (2010) value

- birth rate of SNe Ia in early type galaxies

$$\dot{N}_{\rm SN1a} \sim \frac{1}{2} \times 3.5 \times 10^{-4} \left(\frac{L_K}{10^{10} L_{K,\odot}} \right) \ {\rm yr}^{-1}$$

[from Gilfanov & Bogdan (2010)]

- total number of WDs in SSS phase

$$N_{\rm WD,SSS} = P_{\rm SSS} \dot{N}_{\rm SN1a} \sim 40 \left(\frac{L_K}{10^{10} L_{K,\odot}} \right)$$

Typical X-ray flux of symbiotic stars

- ○ No correct atmospheric model of mass-accreting white dwarfs
- ○ No full knowledge on the circumstellar matter in symbiotic stars

- ● **absorbed flux of SMC 3**
  brightest SSS in symbiotic stars
  (0.3-0.7 keV band at 61 kpc, NH=several x 10^{20})

$$\ell_{\rm x,obs} \sim 0.8 \times 10^{36}\ {\rm erg\ s}^{-1}$$

[from Jordan et al. (1996); Orio et al. (2003)]

- ● ~10 times smaller flux than Gilfanov & Bogdan’s (2010) value

SSS flux from early type galaxies

- total (0.3-0.7 keV) flux

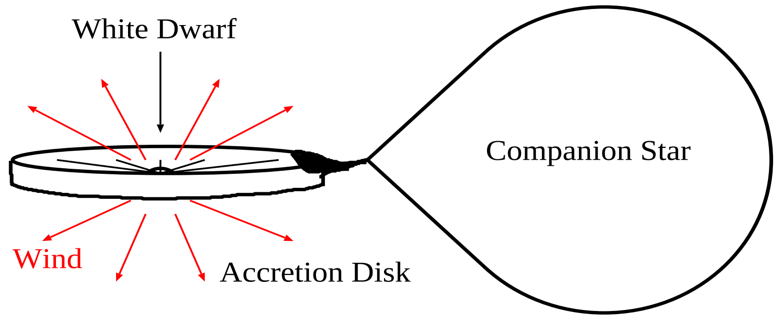
$$L_{\mathrm{X,SSS}} = N_{\mathrm{WD,SSS}} \times \ell_{\mathrm{X,obs}} \sim 3 \times 10^{37}\ \mathrm{erg\ s^{-1}} \left(\frac{L_K}{10^{10} L_{K,\odot}}\right)$$

galaxy	L_K [a] $(10^{10} L_{K,\odot})$	$N_{\mathrm{WD,sss}}$ [a]	$N_{\mathrm{WD,sss}}$ [b]	$L_{\mathrm{X,obs}}$ [a] $(10^{37}\ \mathrm{erg\ s^{-1}})$	$L_{\mathrm{X,sss}}$ [c] $(10^{37}\ \mathrm{erg\ s^{-1}})$
M32	0.085	25	3	0.15	0.25
NGC 3377	2.0	580	80	4.7	6.0
M31 bulge	3.7	1100	150	6.3	11
M105	4.1	1200	160	8.3	12
NGC 4278	5.5	1600	220	15	17
NGC 3585	15	4400	600	38	45

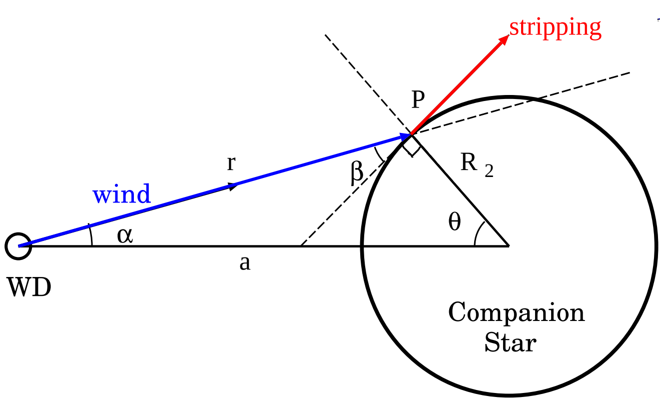
a ... Gilfanov & Bogdan's (2010) results
b,c ... present results

Summary (1)

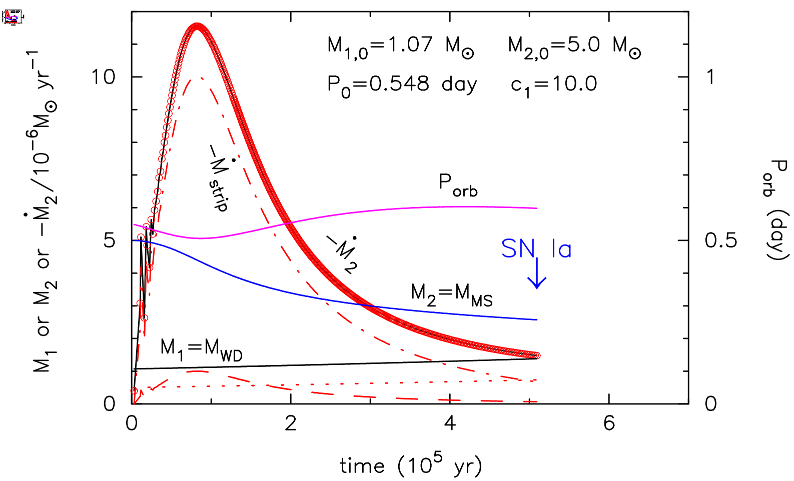
1. "Accretion wind evolution" is a key evolutionary process to Type Ia supernovae.



2. "Stripping effect by winds" also stabilizes the mass transfer in binaries.

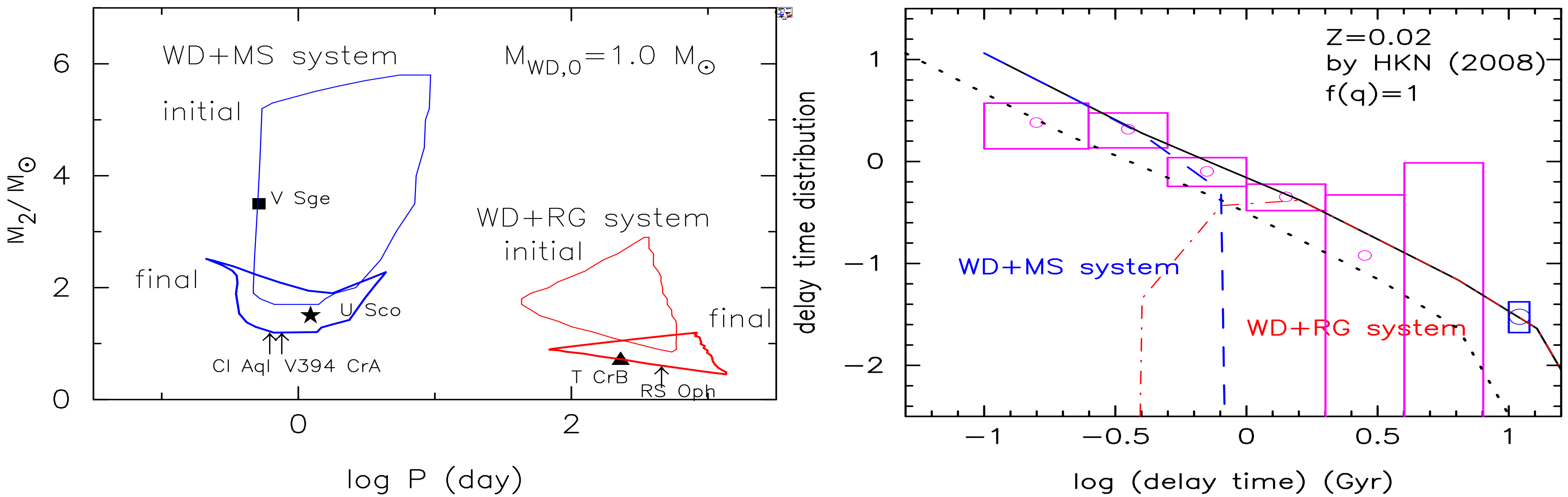


$$\dot{M}_{2,\mathrm{strip}} = c_1 \dot{M}_{\mathrm{wind}}$$



Summary (2)

3. Both "WD+MS" and "WD+RG" systems contribute to the progenitors of SNe Ia, consistent with the observed DTD



Summary (3)

- Supersoft X-ray flux from SD progenitors are consistent with the observation (0.3-0.7 keV), when

(1) duration of SSS phase is $P_{\rm SSS} \sim 2.5 \times 10^5$ yr

(2) SSS flux from an individual source is

$$\ell_{\rm x,obs} \sim 0.8 \times 10^{36} \text{ erg s}^{-1}$$

(3) birth rate of SNe Ia in early type galaxies is

$$\dot{N}_{\rm SN1a} \sim \frac{1}{2} \times 3.5 \times 10^{-4} \left(\frac{L_K}{10^{10} L_{K,\odot}} \right) \text{ yr}^{-1}$$