Dark
Energy

Progenitors of Type Ia Supernovae

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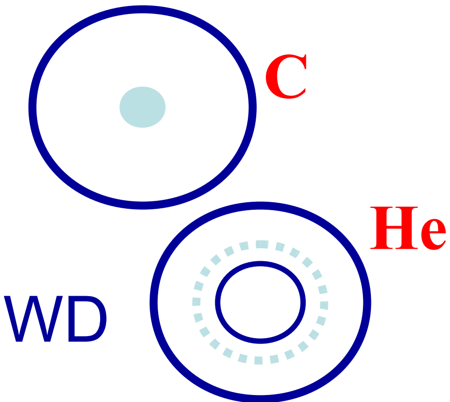
Supernovae

The Progenitors of Type Ia Supernovae

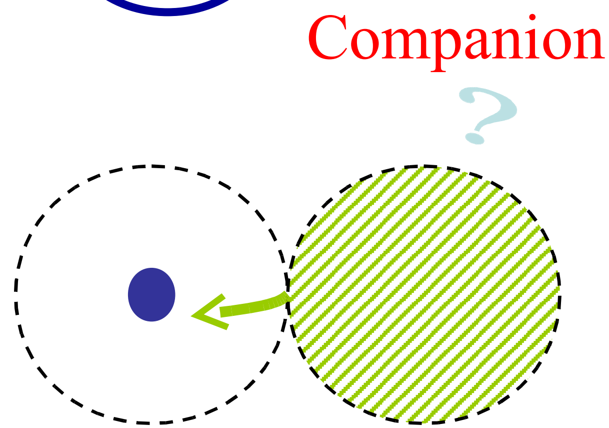
- **Single Degenerate**
  vs.
  Double Degenerate

- **Chandrasekhar Mass WD**
  vs.
  Sub-Chandrasekhar Mass WD



Single Degenerate Scenario

White Dwarf Winds

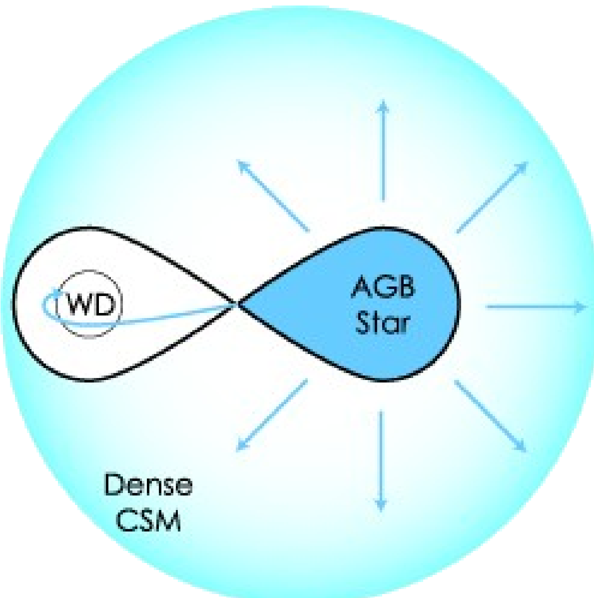


⇨ **Young Population**

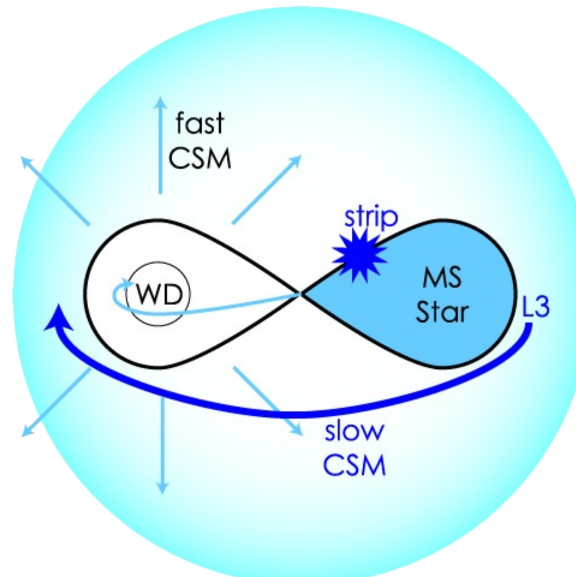
Delay Time Distribution

Single Degenerate Scenario

Accretion➔ WD Wind ➔ Stripping➔



WD+RG?



WD+MS?

Constraints on the Population of Companion Stars

Evolution of Accreting WDs

(1) Compressional Heating

(vs. radiative cooling)

(2) Nuclear Burning (vs. neutrino cooling)

(3) Radiation-driven WD Winds

(4)Mass-Stripping of Companion Star by Wind

(5) Reduction of Mass Transfer Rate

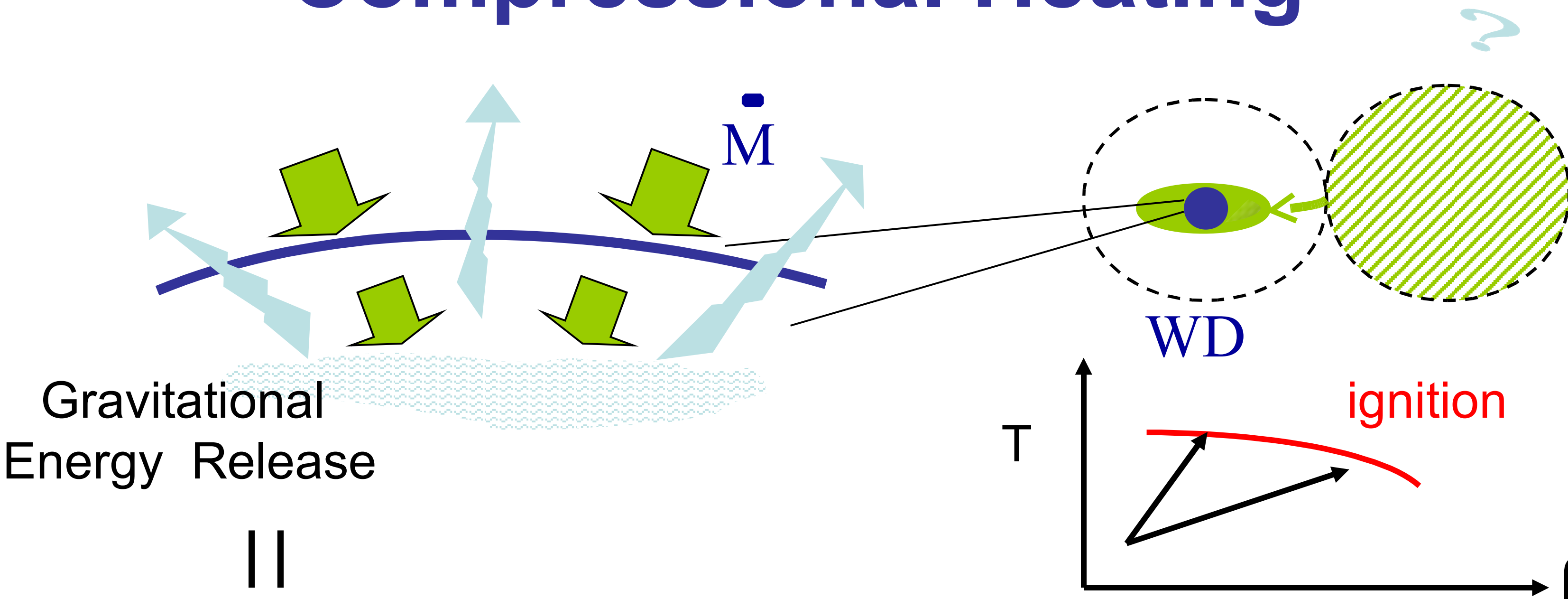
➔

(6) Population(M_2,P); Delay Time Distribution

Circumstellar Matter

(1) Accreting White Dwarf Models

Compressional Heating



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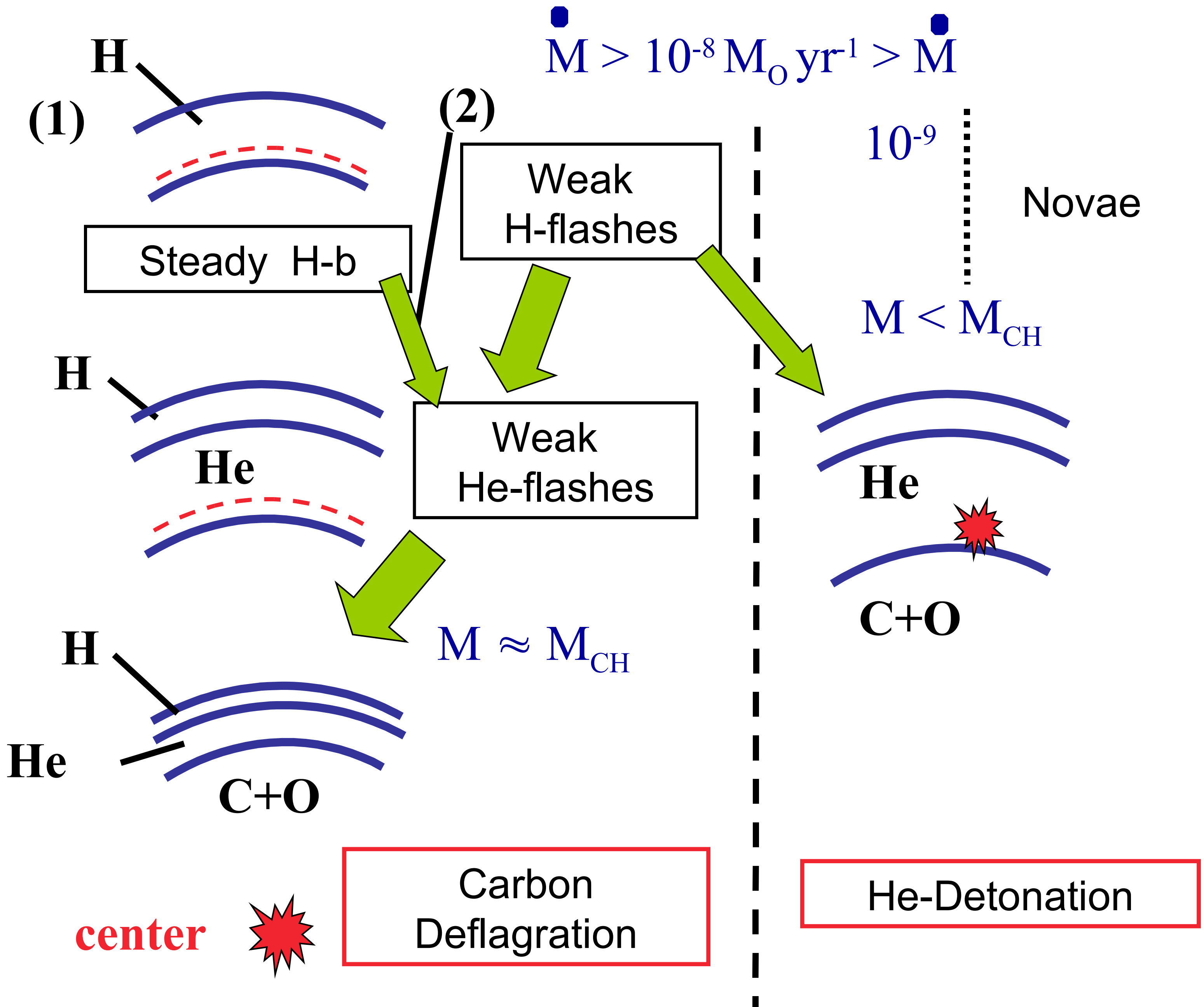
Compressional Heating $\propto \dot{M}$

(ρ, T)

⟷ Radiative Cooling

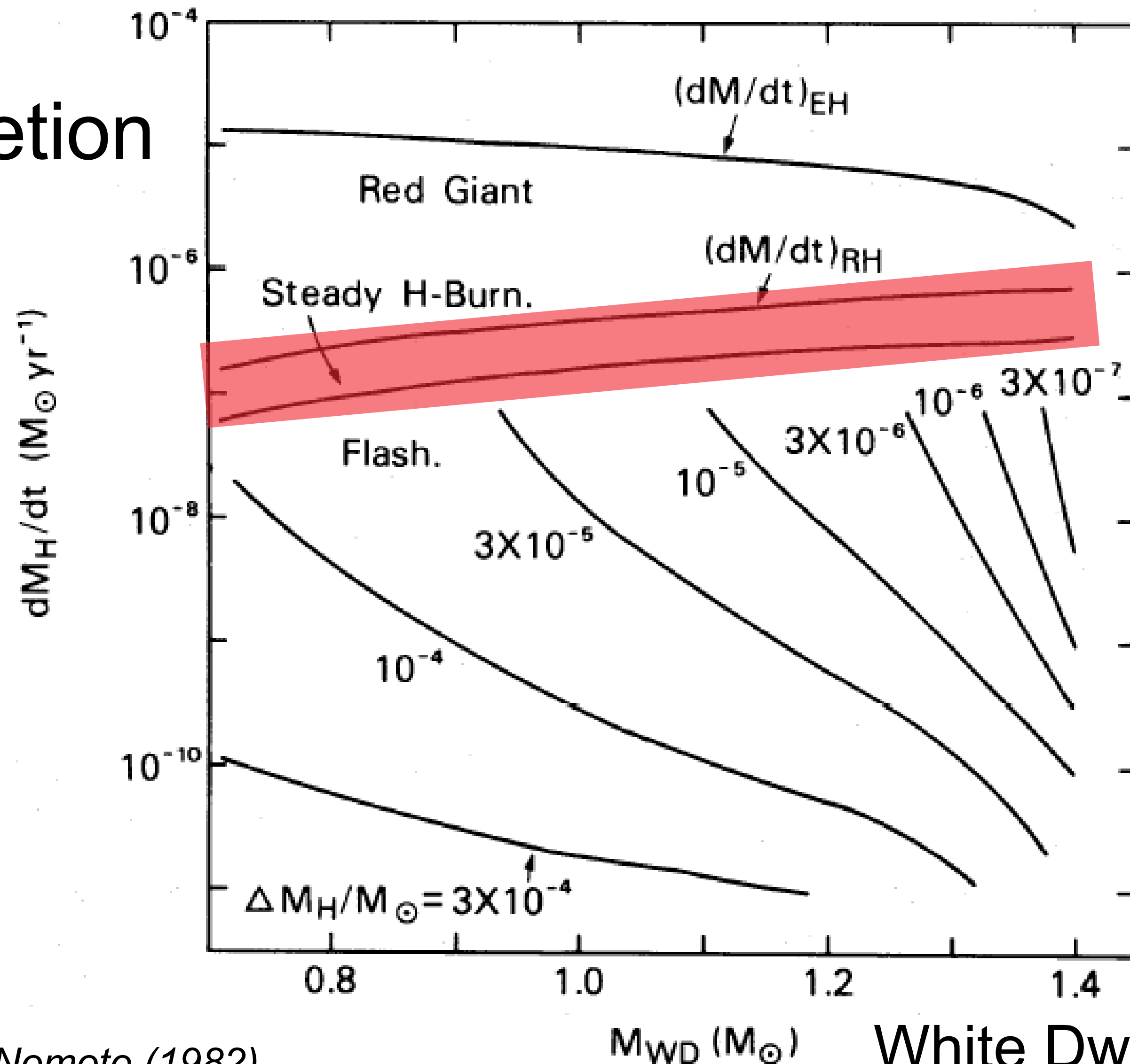
Thermonuclear Explosions ($\dot{M}$)

(2) Nuclear Burning



Hydrogen Burning in Accreting WD

Accretion Rate

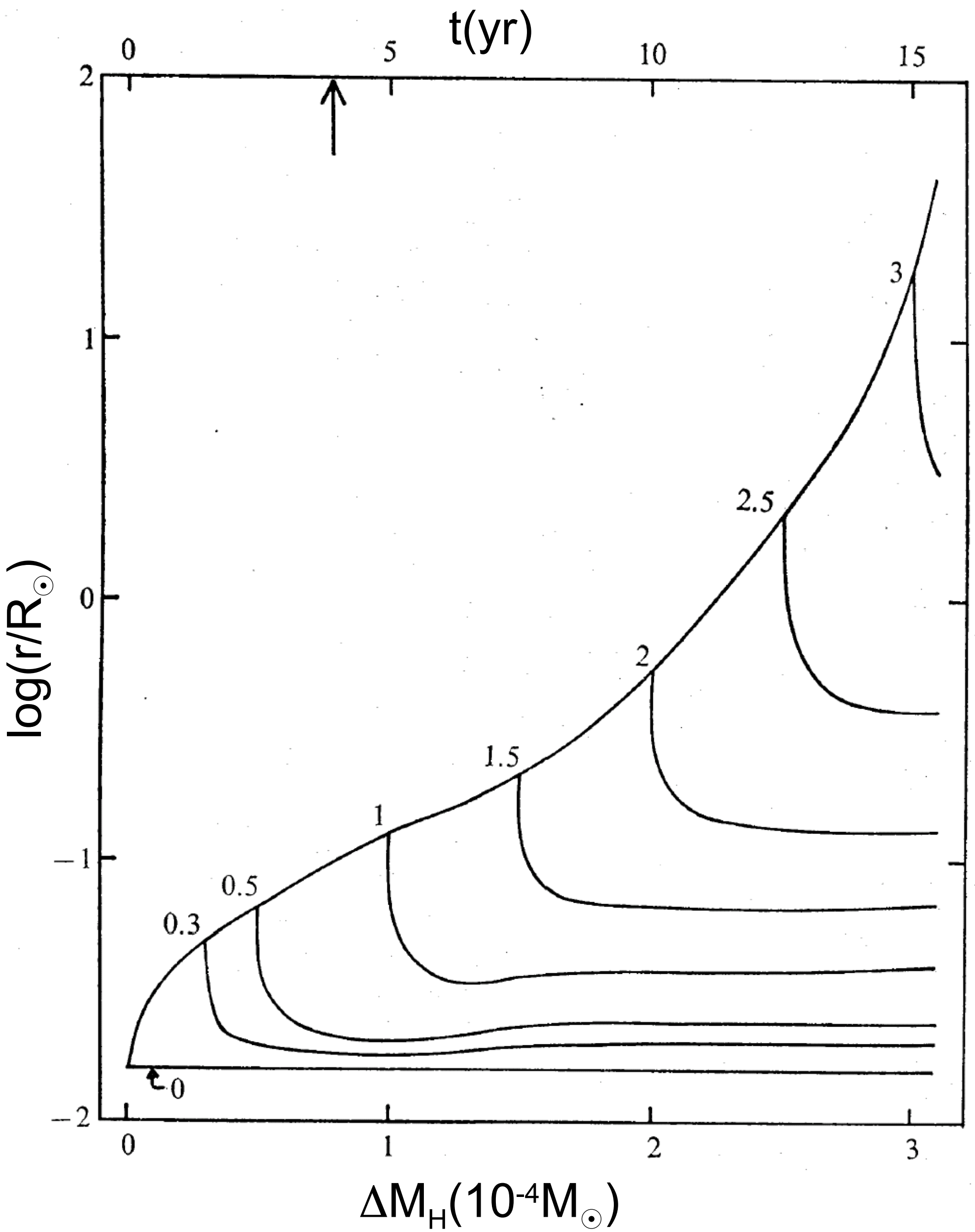


White Dwarf Mass

Nomoto (1982)

Rapid Accretion onto White Dwarfs

(Nomoto et al. 1979)



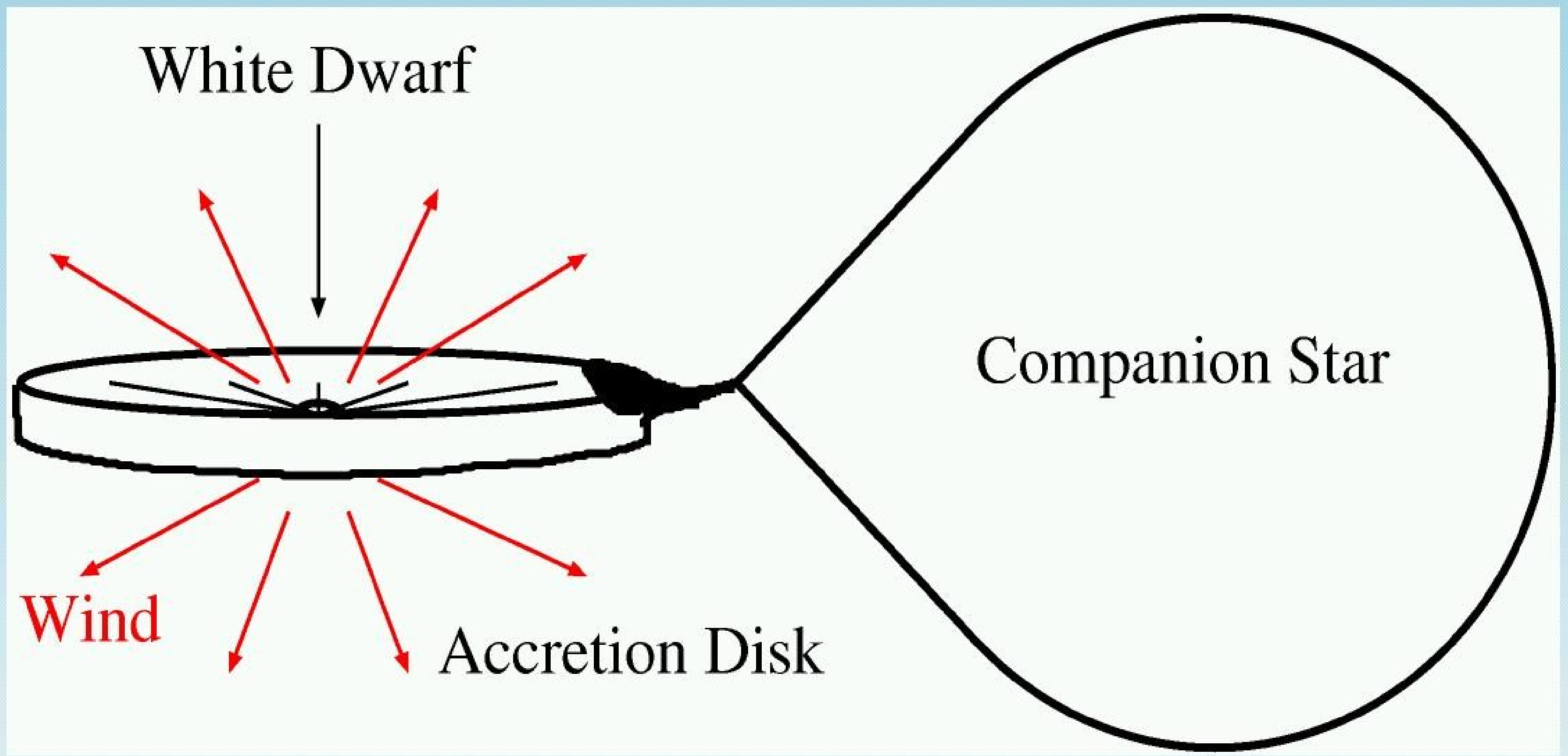
$M_{WD}=0.4M_{\odot}$

$\dot{M}=2\times10^{-5}M_{\odot}yr^{-1}$

(3) White Dwarf Wind

(Hachisu, Kato, & Nomoto 1996)

$$\dot{M}_{\rm acc} > \dot{M}_{\rm cr} \rightarrow \text{Winds}$$



White Dwarf Wind

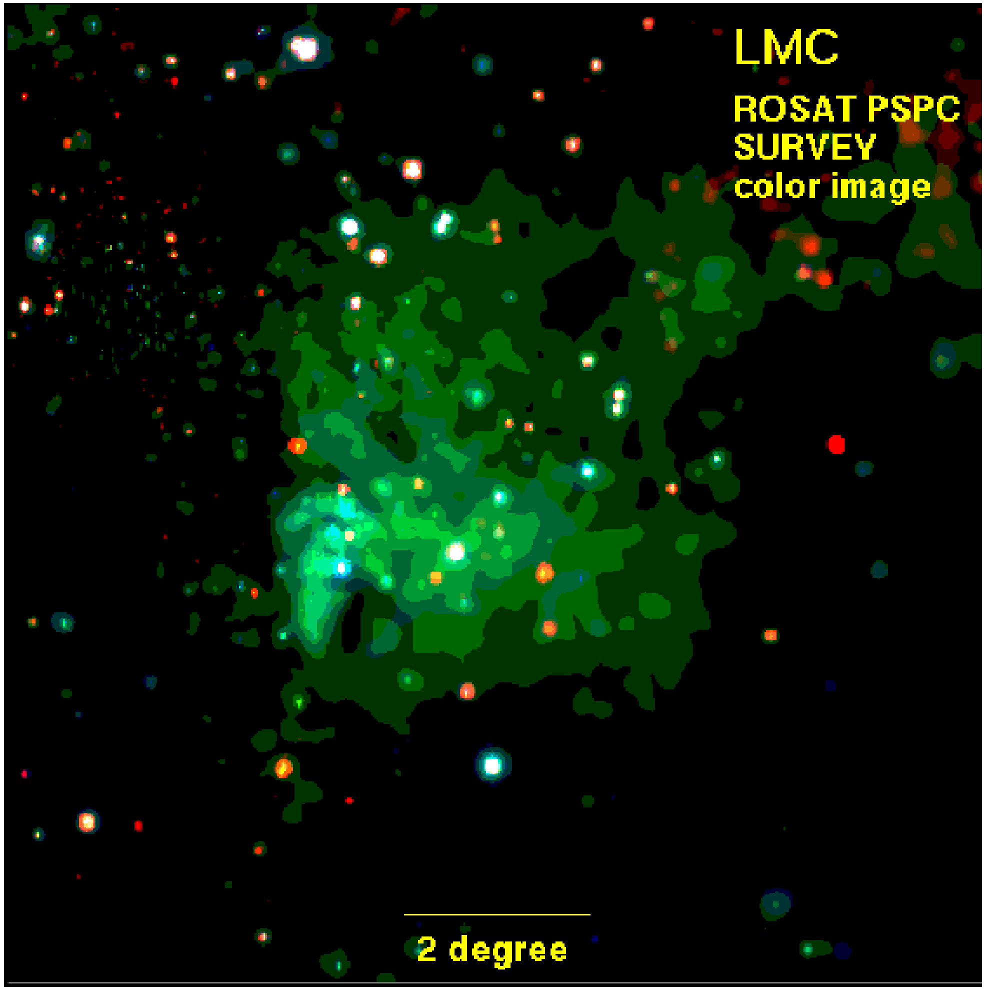
(1) Suppress of WD Radius Expansion

- ➔ Super Soft X-ray Sources
- ➔ $\dot{M} > \dot{M}_{RG}$ is allowed

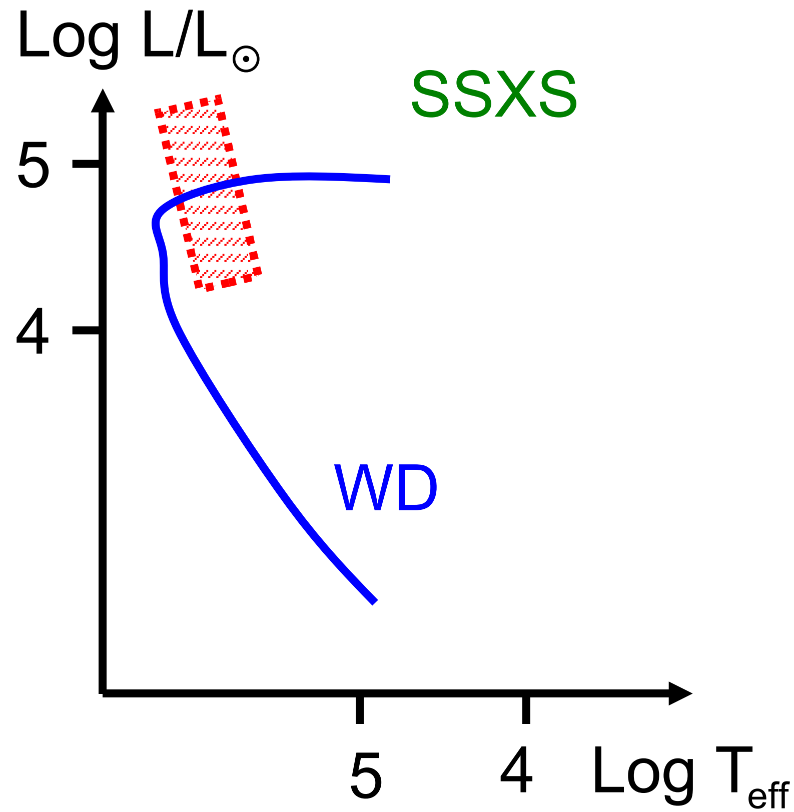
(2) Mass Stripping from the Companion

- ➔ Reduction of Mass Transfer Rate
- ➔ $M_2 \sim 6 - 8\ M_\odot$ is allowed

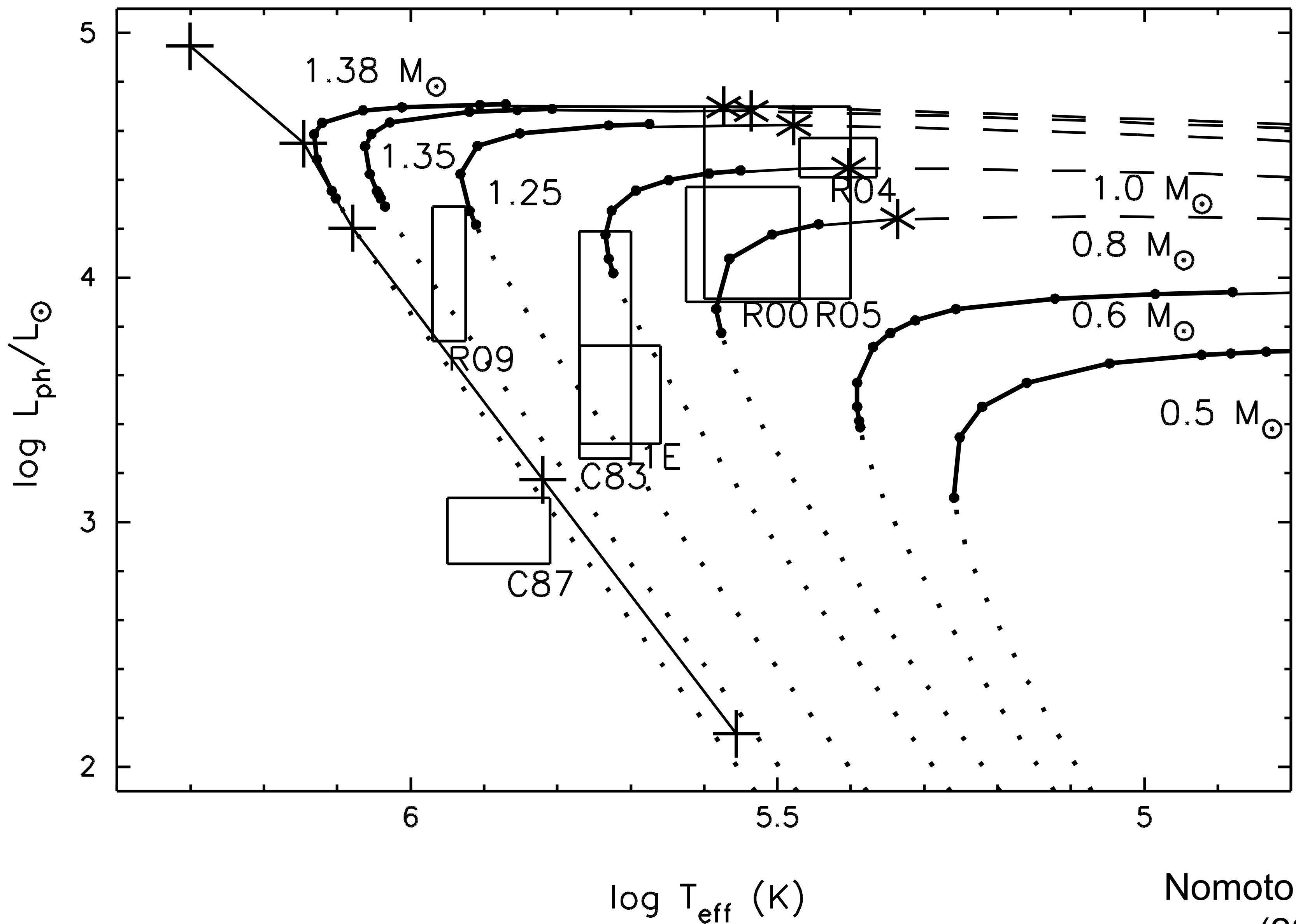
Super-Soft X-ray Sources in the LMC



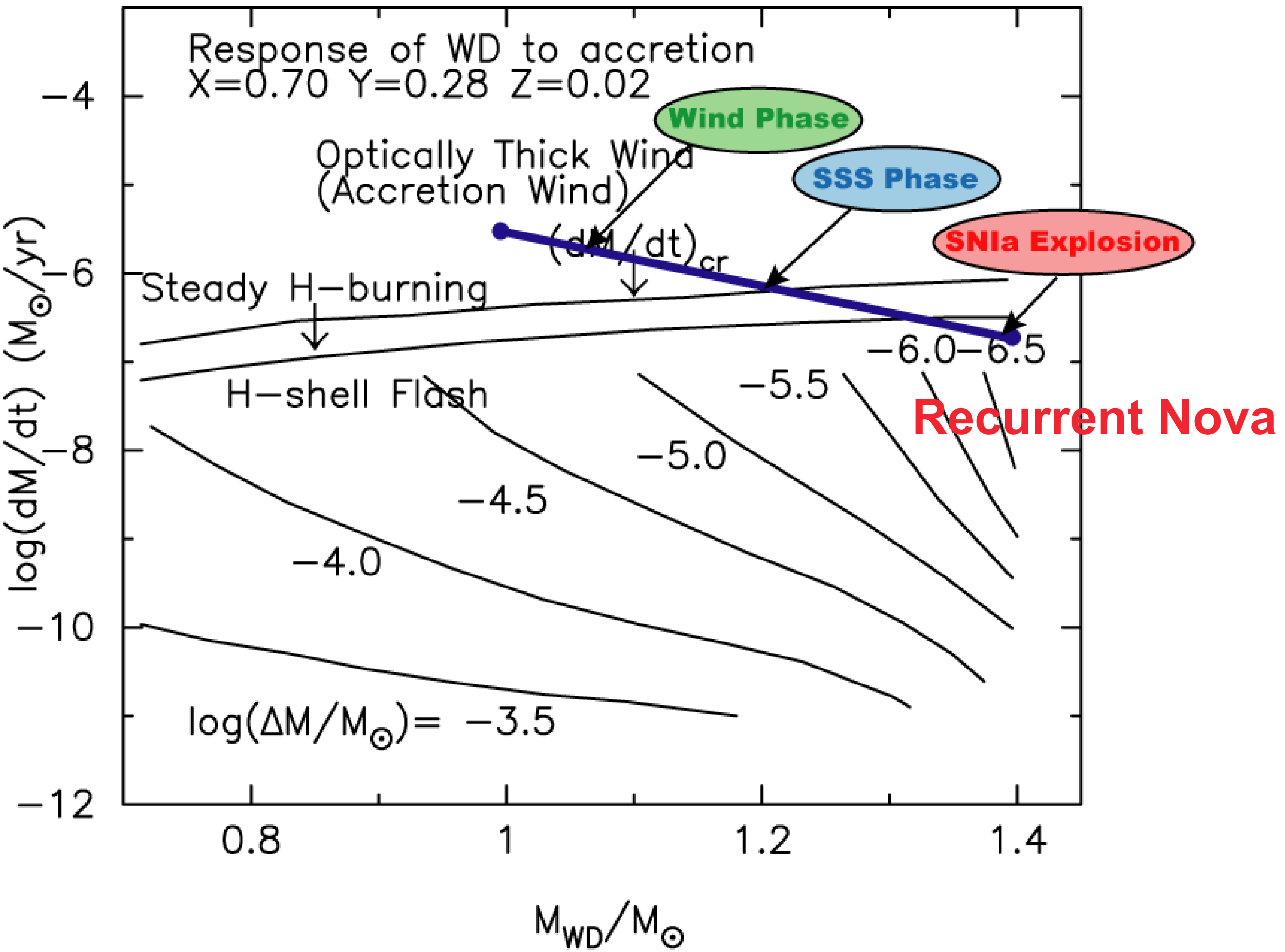
Greiner et al.



Super-Soft X-Ray Sources

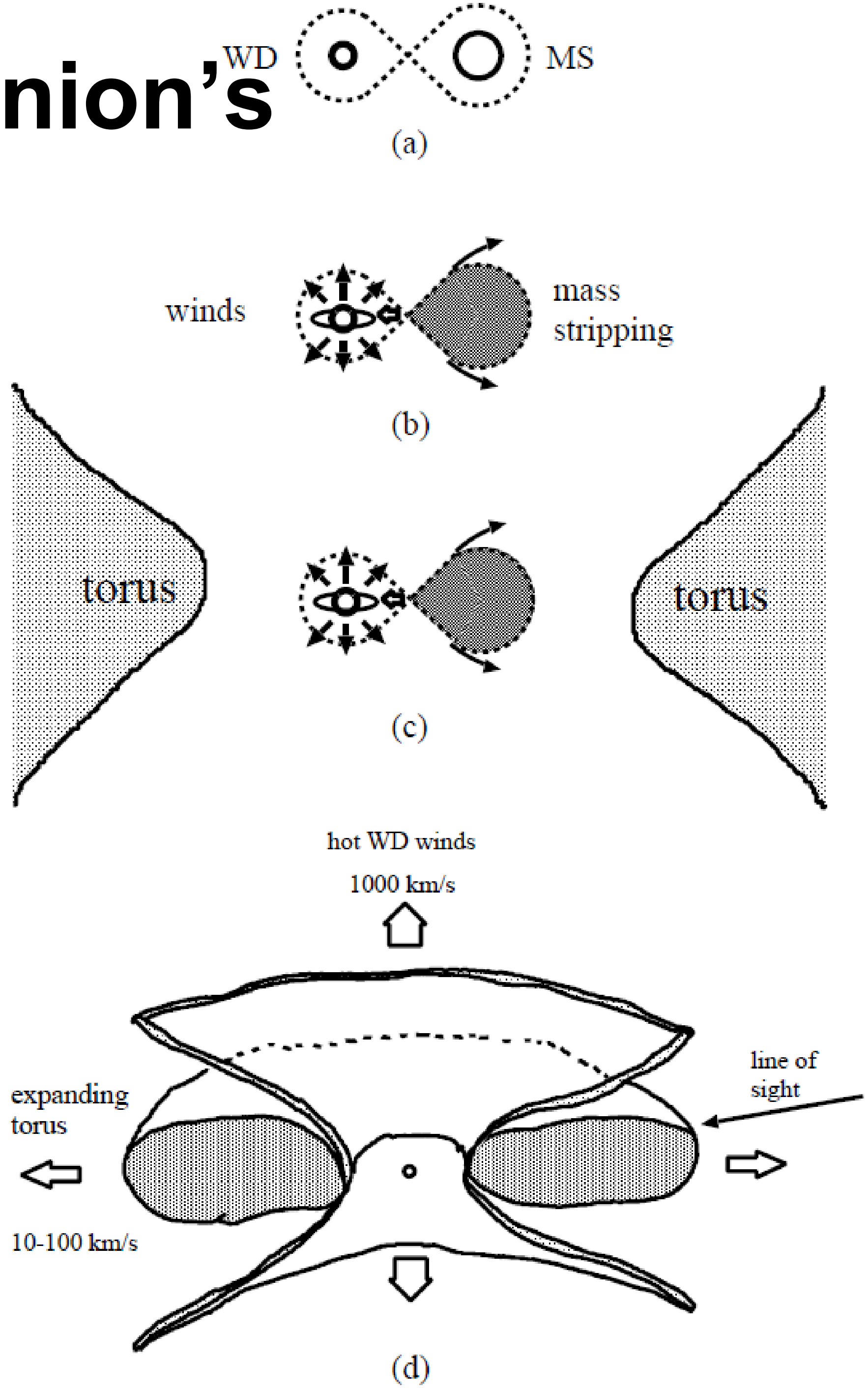


Nomoto et al. (2006)



Response of WD to accretion
X=0.70 Y=0.28 Z=0.02
Wind Phase
SSS Phase
SNIa Explosion
Optically Thick Wind
(Accretion Wind)
(dM/dt)cr
Steady H−burning
H−shell Flash
Recurrent Nova
−6.0
−6.5
−5.5
−5.0
−4.5
−4.0
log(ΔM/M⊙)= −3.5
log(dM/dt) (M⊙/yr)
−4
−6
−8
−10
−12
0.8
1
1.2
1.4
MWD/M⊙

(4)Stripping of Companion's Mass



→ Mass Transfer Rate reduced

→ Massive (young) Companion → SN Ia

→ Circumstellar Matter 10-100 km/s

Hachisu, Kato, Nomoto (2008a) ApJ 679, 1390

Candidate Progenitor Systems for Carbon Ignitors

Hachisu, Kato, Nomoto
Lee, van den Heuvel
Han, Podsiadlowski

$4\times10^{-8} < \dot{M}\,(M_\odot\,yr^{-1}) < 2\times10^{-6}$

Companion

(1) H: leaving M.S.

$\dot{M}_2 \sim M_2/\tau_{KH}\ (\sim 3\times10^{-8} M_2^{\,4})$

$\sim\ 3\times10^{-8}\quad 5\times10^{-7}\quad 2\times10^{-6}$

$M_{2,ms} \sim\ 1M_\odot\quad 2M_\odot\quad \sim 8M_\odot$

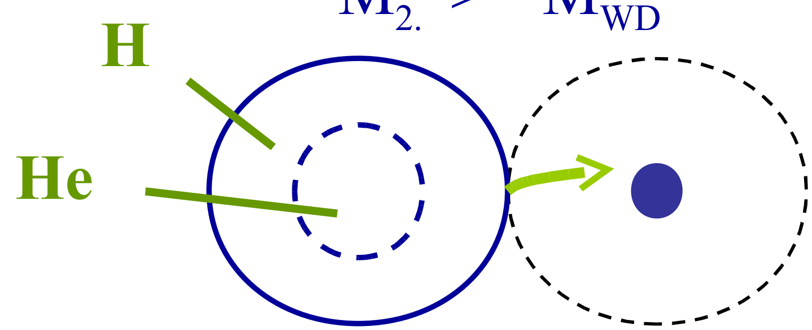
Super-Soft X-ray Source

(2) H: sub giant, red giant

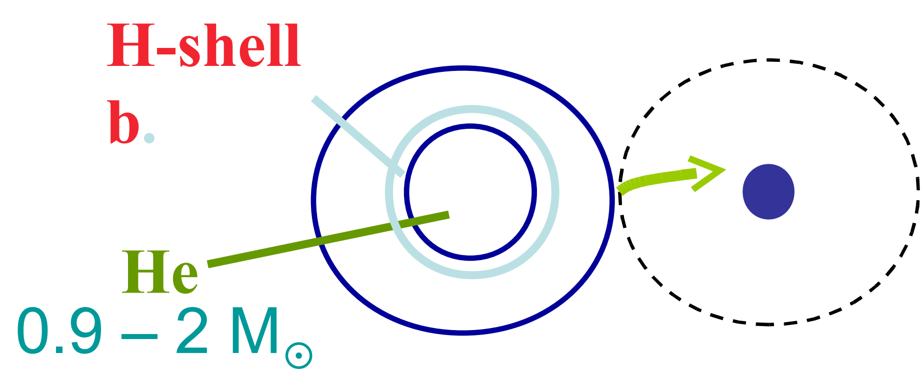
$\dot{M}_2 \sim M_2/\tau_{nuclear}$

$\sim 10^{-8} \sim 10^{-6}\ M_\odot/yr$

$M_2 > M_{WD}$



$M_2 < M_{WD}$



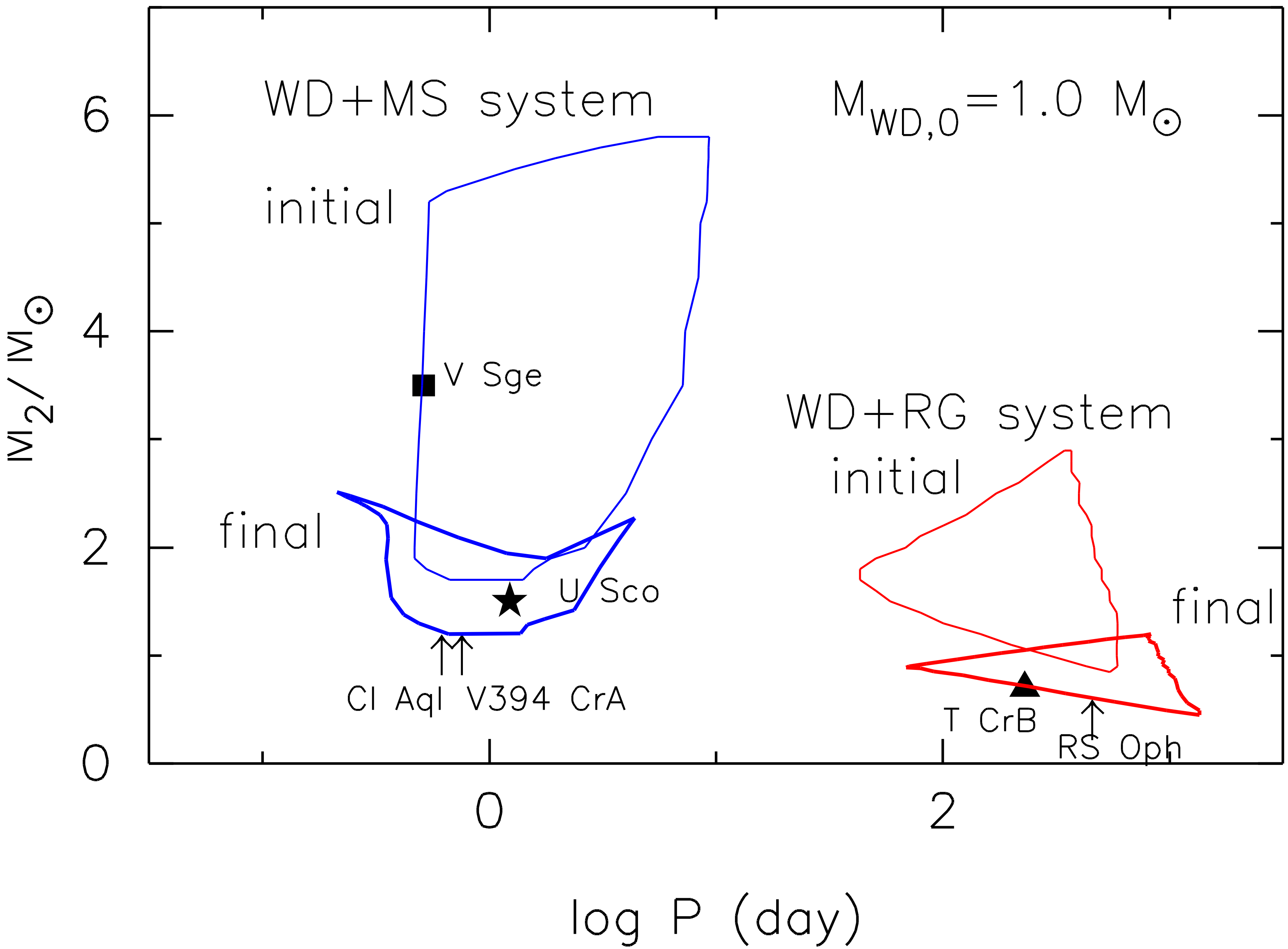
Candidates of the SN Ia Progenitors

- Companions of the Chandrasekhar Mass WDs

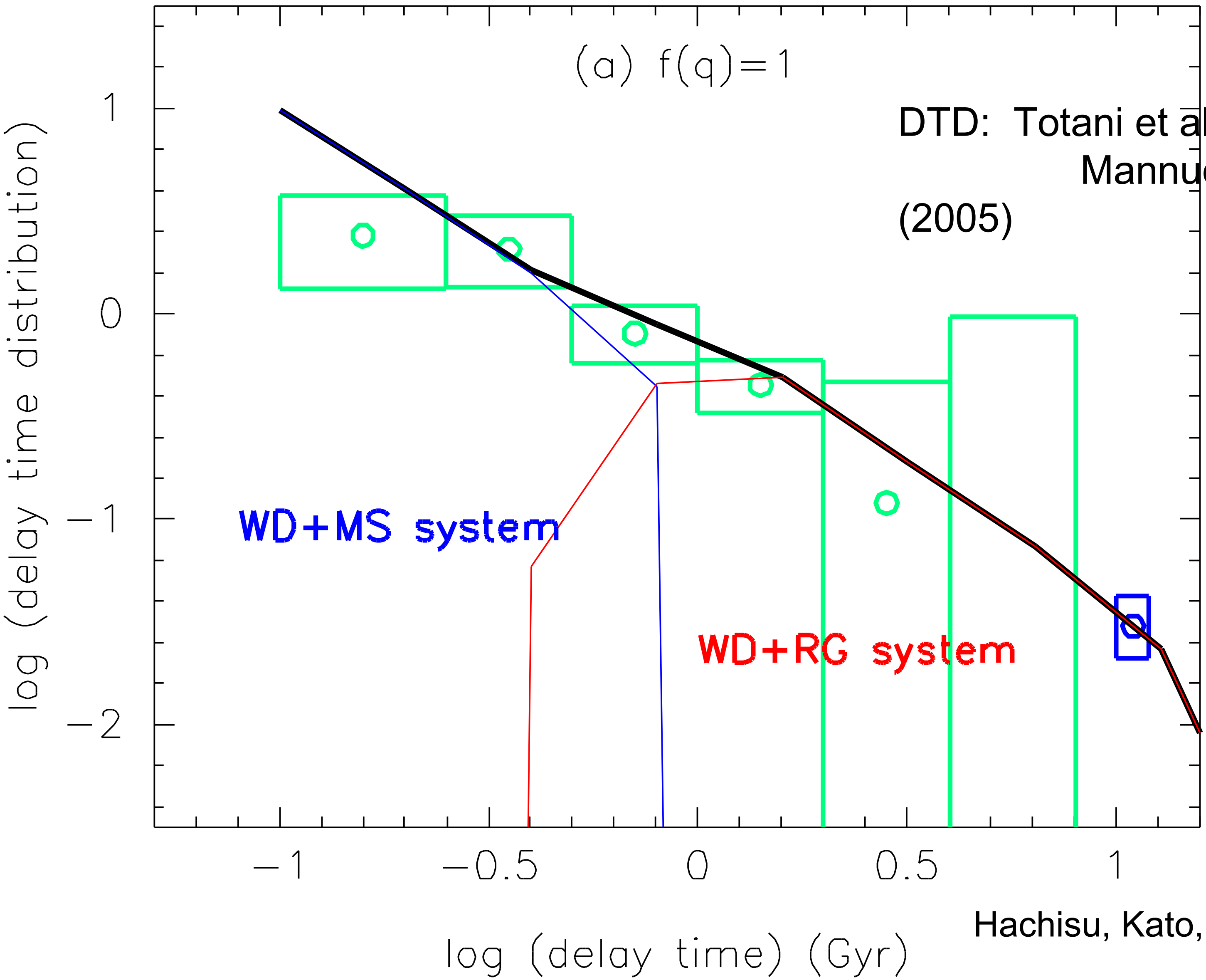
•Main-Sequence (MS):
Slightly Evolved 2 - 8$M_\odot$ stars
⇒Young, Spiral
(t ~ 0.1 Gyr)
→Supersoft X-ray Source
→Recurrent Nova (USCo)

•Red Giant (RG):
1 - 2$M_\odot$ stars
⇒Old, Spiral & Elliptical
(t $\geq$ 3 Gyr)
→Symbiotic Stars?
→Recurrent Novae (TCrB)

SN Ia Progenitor System(MS, RG)



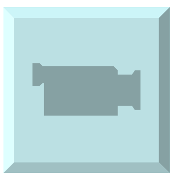
Delay Time Distribution

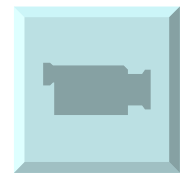


DTD: Totani et al. (2008)
Mannucci et al. (2005)

Hachisu, Kato, Nomoto (2008b)
ApJ 683, L127

Merging of Double Degenerates and Carbon Ignition





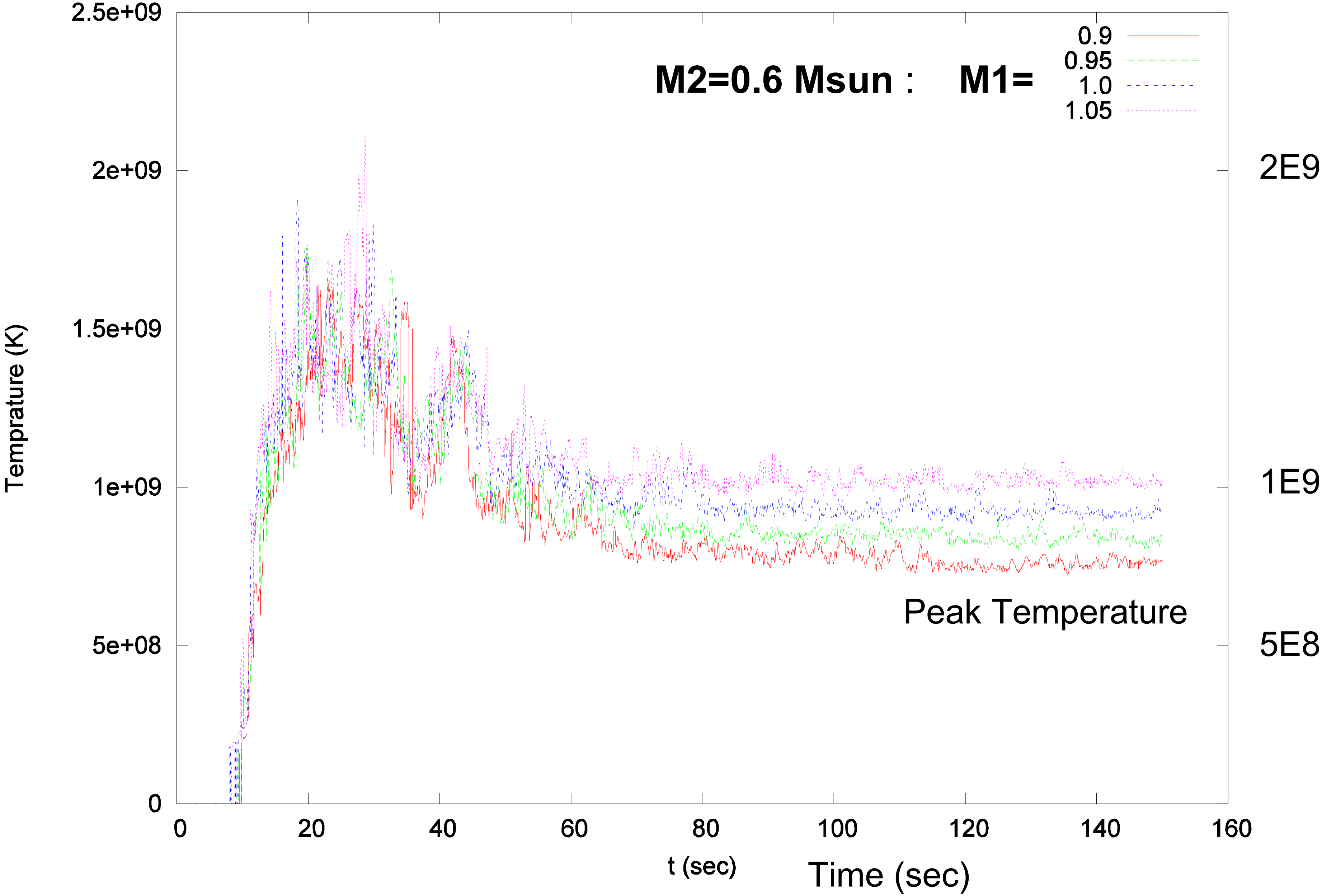
CO +CO

GRAPE-SPH simulation: N=250,000

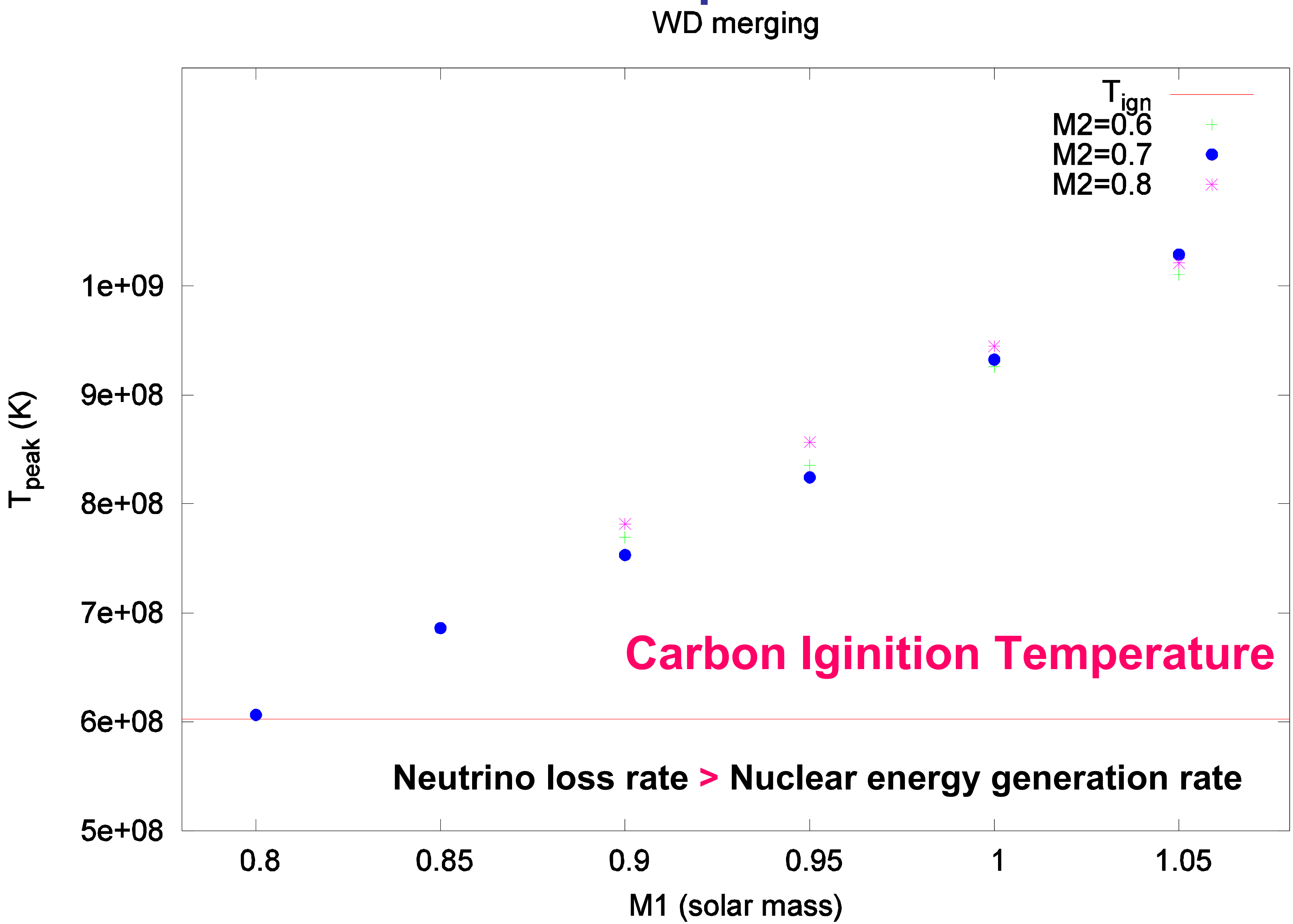
(Nakasato & Nomoto 2008)

(see Benz+, Segretain+, Rosswog+, Guerrero+, Shioya+, Yoon+, Dan+)

Peak Temperature (K)

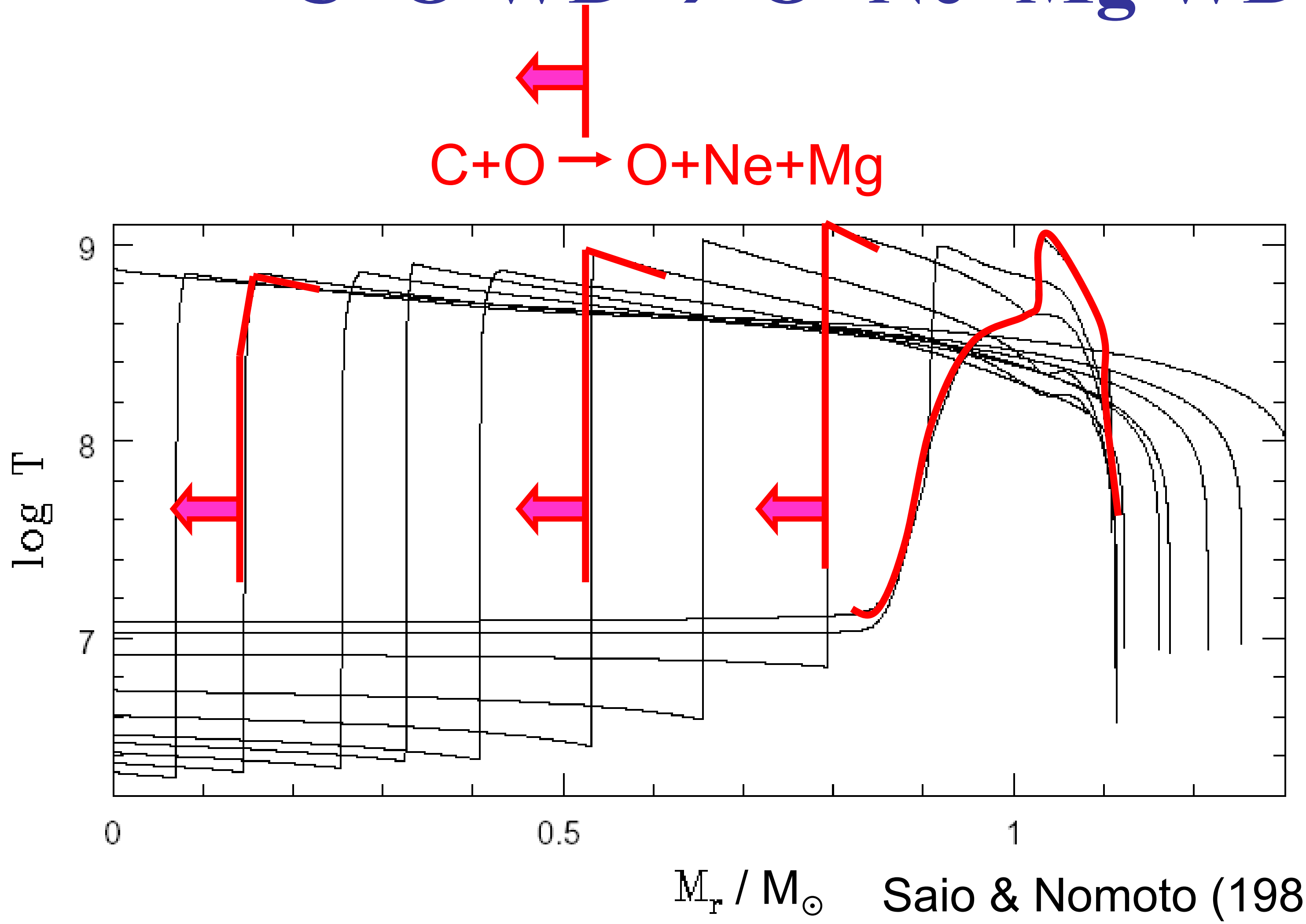


Peak Temperature



Carbon Flame

C+O WD → O+Ne+Mg WD



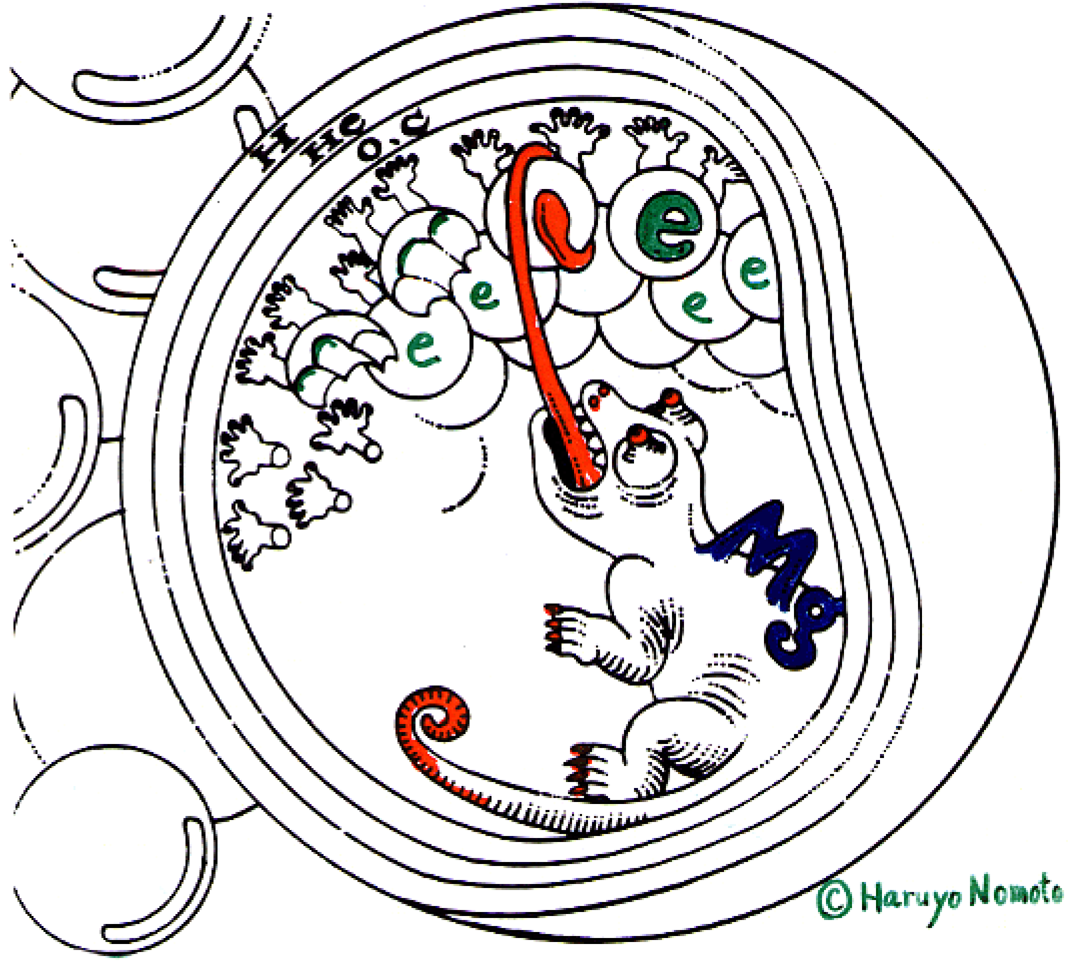
Saio & Nomoto (1985, 1998)
A&A, ApJ

Electron Capture in ONeMg WD

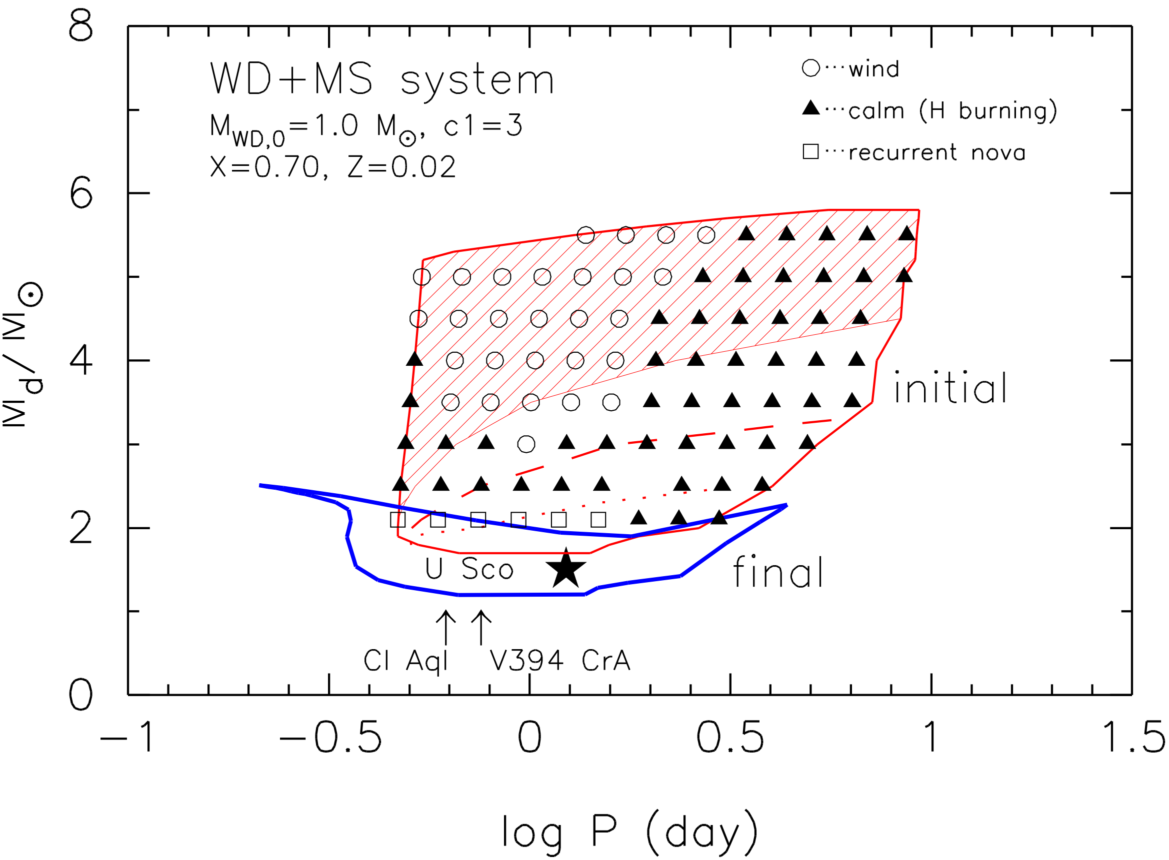
- ^{24}Mg(e^{-},ν)^{24}Na (e^{-},ν)^{24}Ne

∀ $\rho > 4.0 \times 10^{9}$ gcm^{-3}

- →**collapse**



Pre-SN Winds & CSM



WIND

CSM Interaction

SN Ia/IIn (IIa)

2002ic, 2005gj

SN 1604 (Kepler) ?

CALM

CSM

SN 2006X (Patat et al.)

no CSM(geometry?)

SN 200af

RN (Recurrent Nova)

Circumstellar Medium of SN Ia

White Dwarf Wind

$v_W > 1{,}000$ km s^{-1}

$\dot{M} \sim 10^{-6} - 10^{-7}\ M_\odot yr^{-1}$

$$\frac{\dot{M}}{v_{10}} \sim 10^{-8}\ M_\odot yr^{-1}$$

Recurrent Nova Wind

$v_W \sim 4{,}000$ km s^{-1}

➔ Nova Cavity

(Wood-Vasey & Sokoloski)

Stripped Matter from Companion Star

$v_W \sim 10 - 100$ km s^{-1} : t_{calm} $0 \sim 3 \times 10^5$ yr ago

⇨ **Circumstellar Interaction in SNe Ia ?**

(e.g., Badenes et al. 2007)

Progenitors of Type Ia Supernovae

Single Degenerate

WD winds & Mass Stripping

→ Young Population

Delay Time Distribution

Circumstellar Matter (10 – 1000 km/s)

SN Ia, Recurrent Nova, Nova

Double Degenerate → ONeMg WD