Dark
Energy

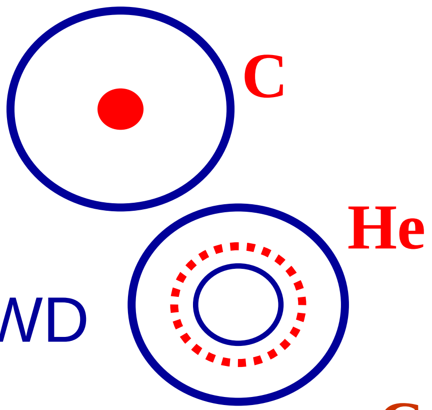
Progenitors of Type Ia Supernovae

K. Nomoto(Univ. of Tokyo)

Supernovae

The Progenitors of Type Ia Supernovae

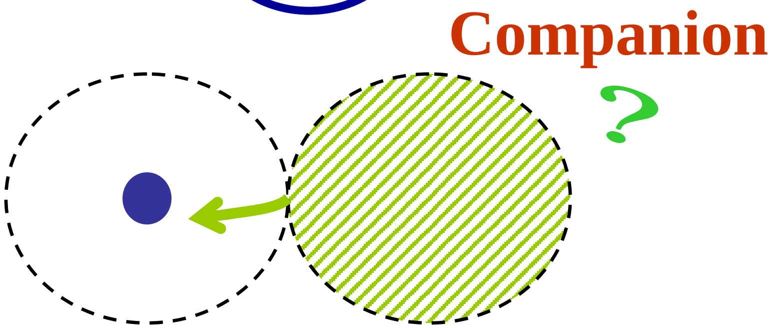
- Single Degenerate
  vs.
  Double Degenerate
- Chandrasekhar Mass WD
  vs.
  Sub-Chandrasekhar Mass WD



$M^{(0)}_{WD} \sim 0.6 - 1.1\ M_O$

↓ ?

$M_{CH} \sim 1.4\ M_O$

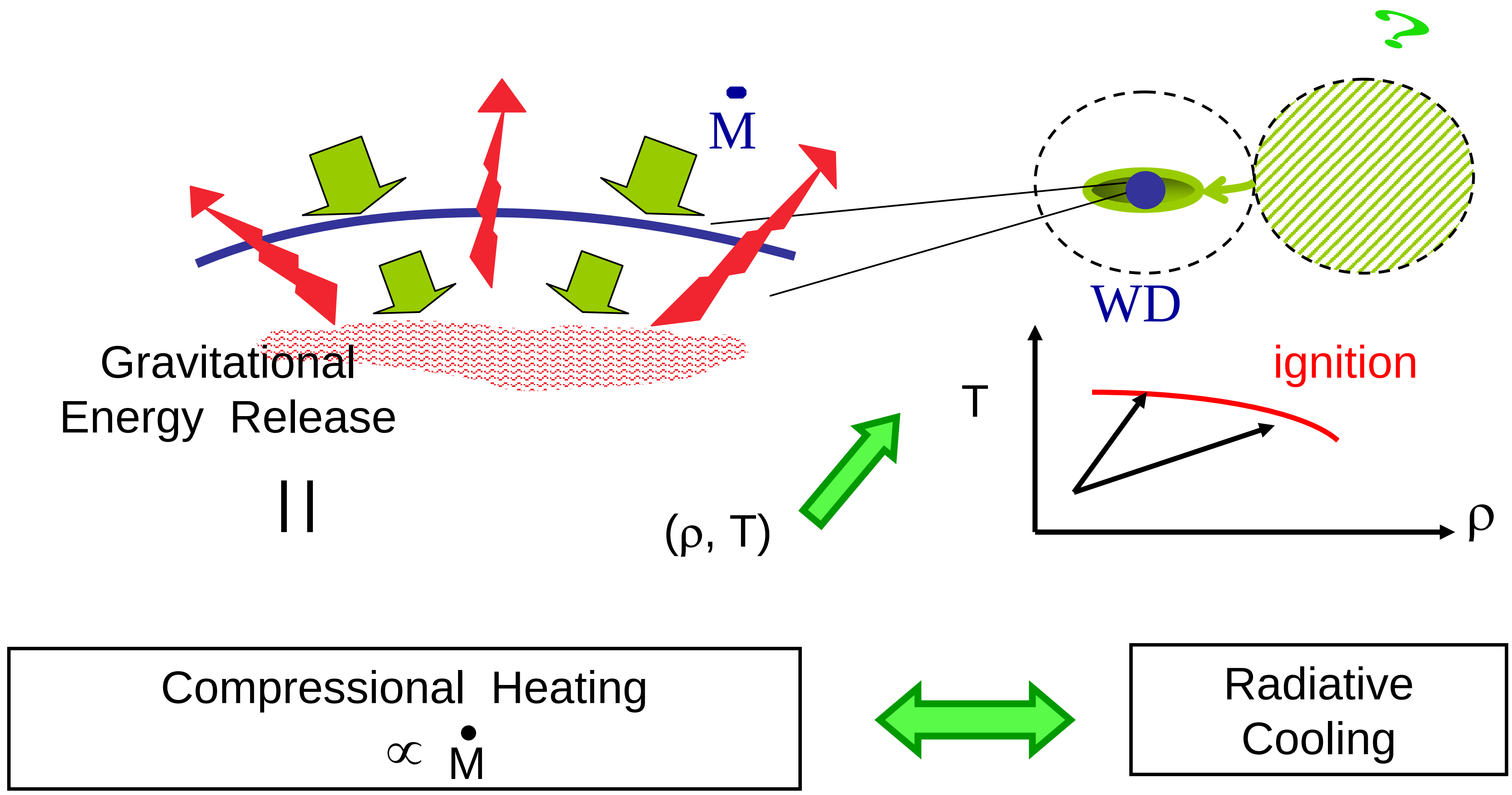


(1) White Dwarf (Mass$^{(0)}$, Metallicity, Rotation)
(2) Companion (Age, Metallicity)

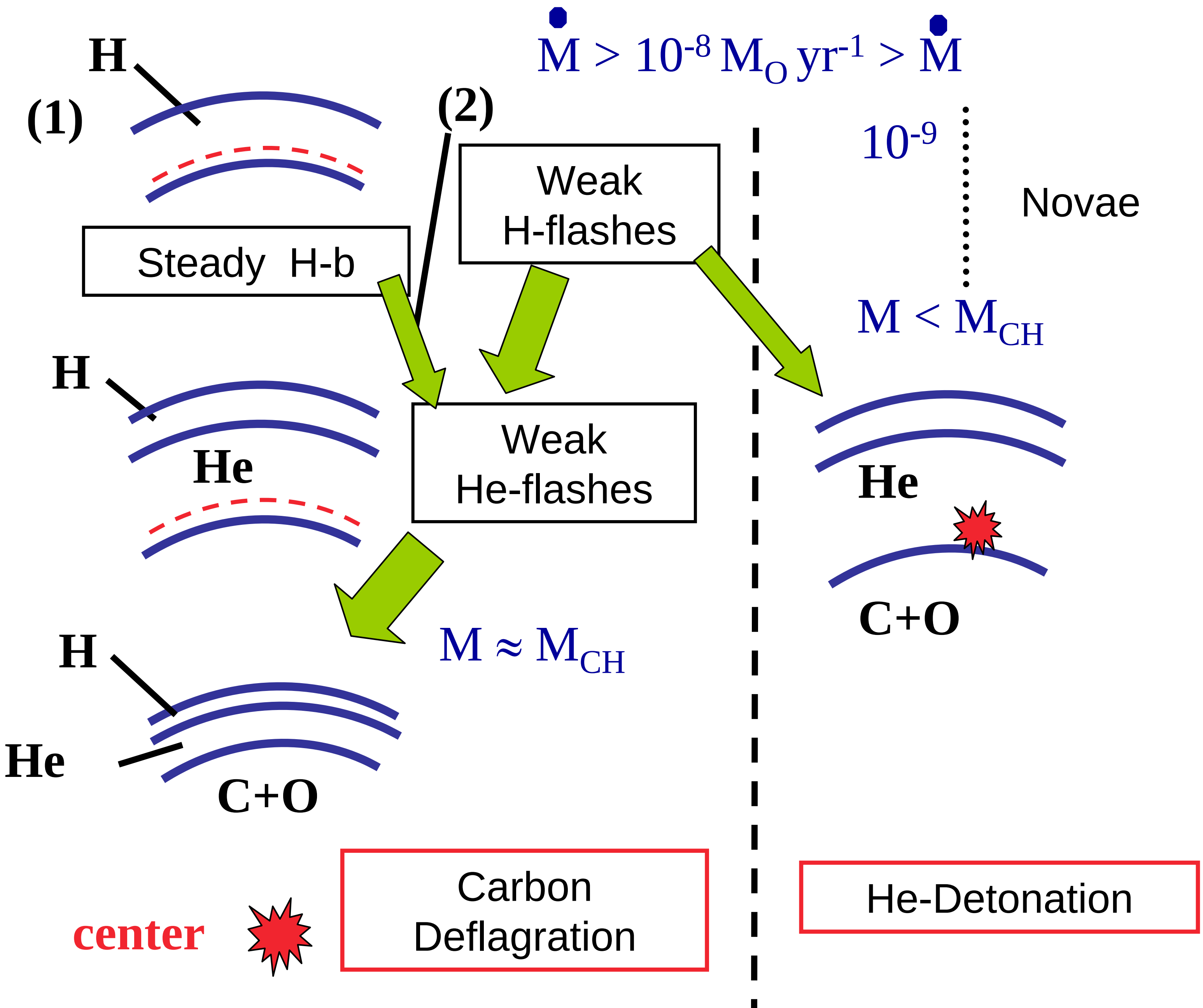
⇨ SNe Ia (E vs. Spiral; **Redshift**) • Rate • **Evolution** ?

- **Circumstellar Interaction**: **SNe 2002ic, 2005ke**

Accreting White Dwarf Models for Type Ia Supernovae



Thermonuclear Explosions ($\dot{M}$)

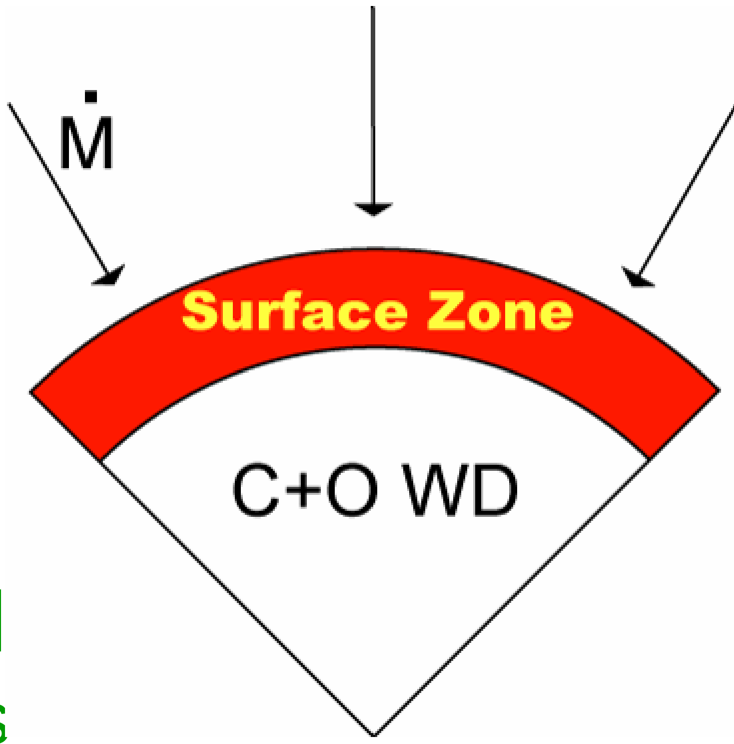


$\dot{M} > 10^{-8} M_{O}\, yr^{-1} > \dot{M}$
(1)
H
Steady H-b
(2)
Weak
H-flashes
10^{-9}
Novae
$M < M_{CH}$
H
He
Weak
He-flashes
He
C+O
H
$M \approx M_{CH}$
He
C+O
center
Carbon
Deflagration
He-Detonation

Stability of H Shell Burning

Thin Shell

- $\Delta M << M$
- $\Delta R << R$
- $P = GM\Delta M / 4\pi R^4$



Positive Specific Heat

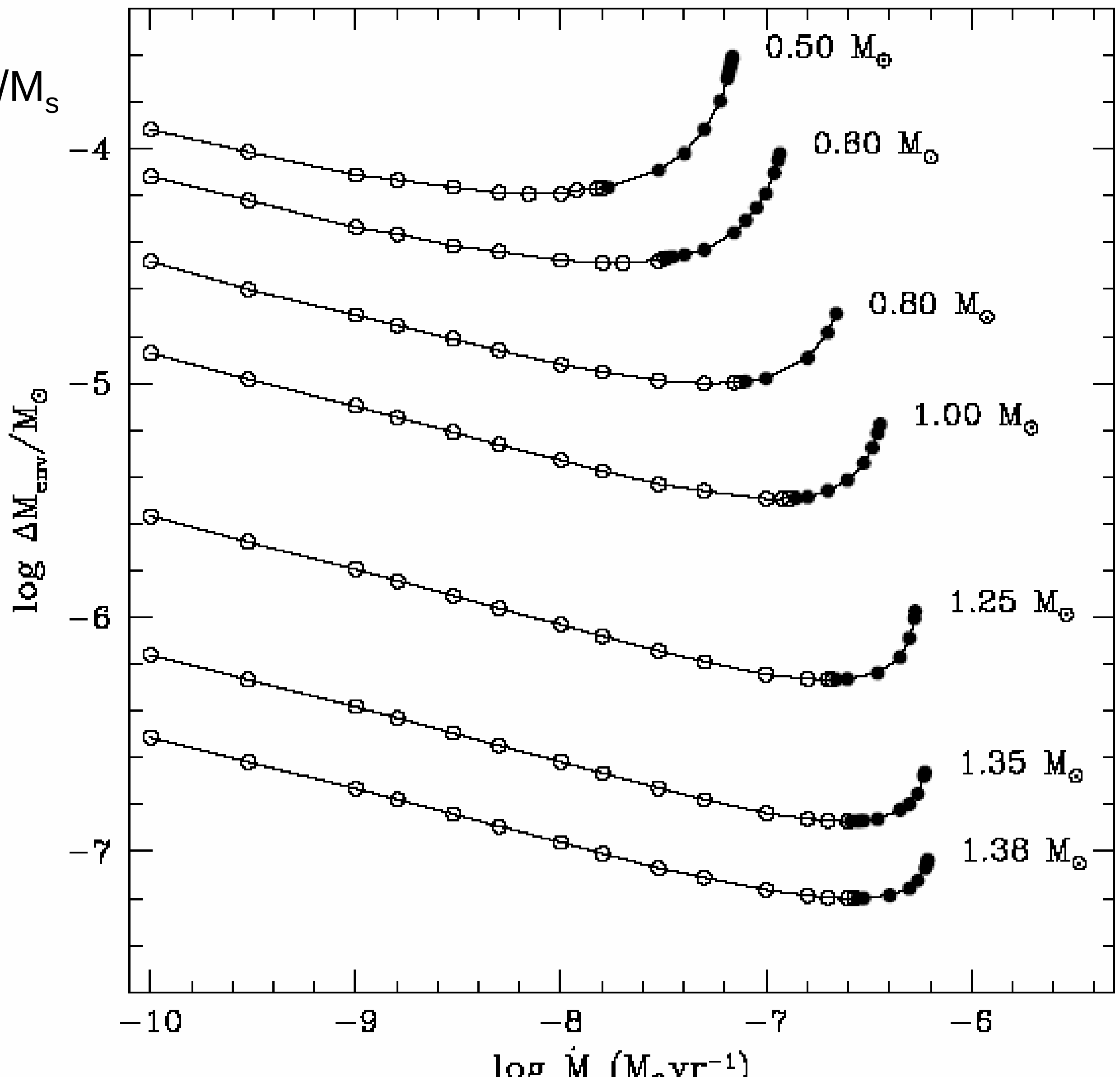
- Geometry: Plane Parallel
- EOS: Degenerate Electrons

→ P (T-independent)

High $\dot{M}$, L --> $\Delta R \sim R$ --> negative C_v

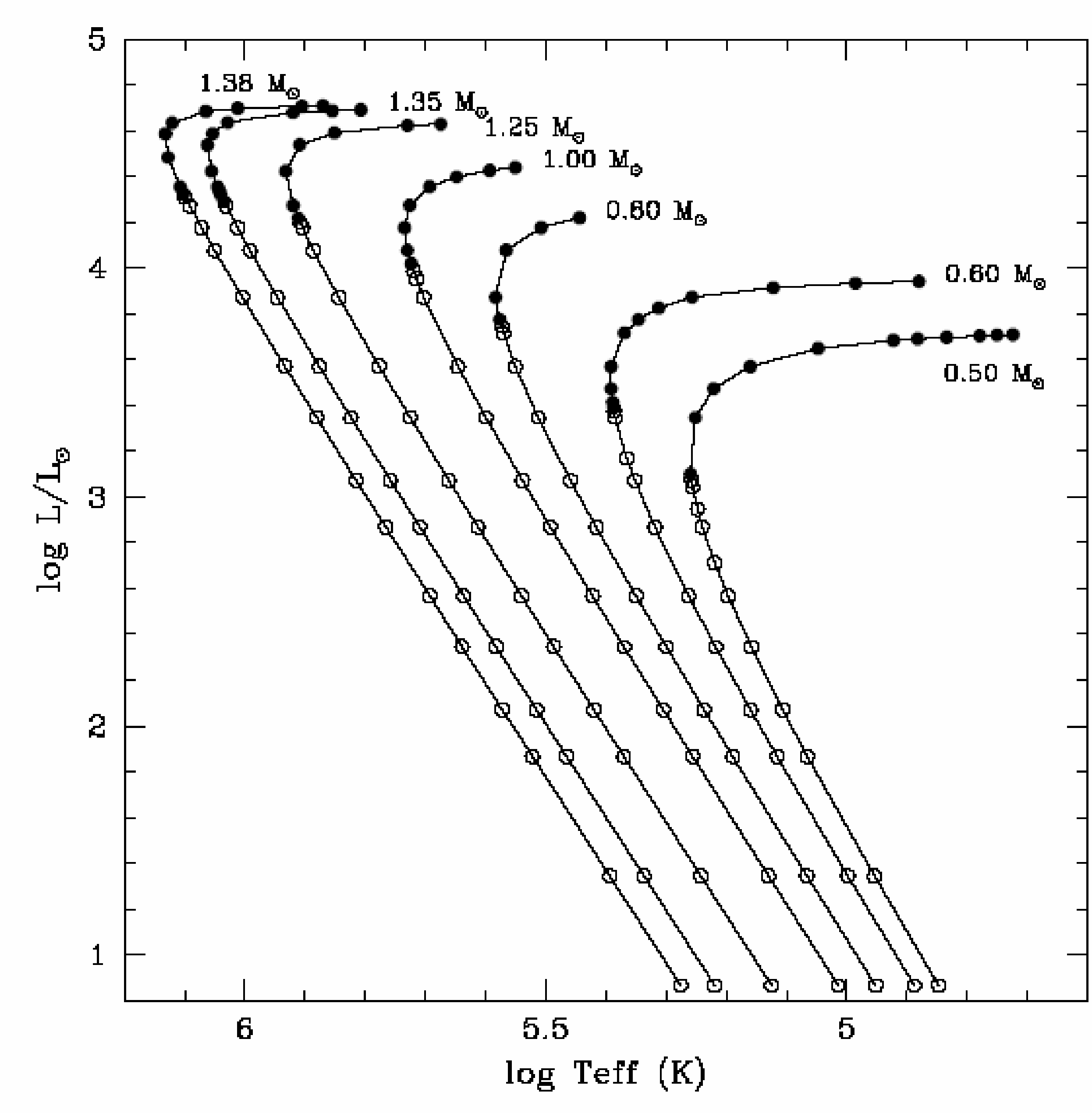
Mass of H-rich Envelope

Log M_{env}/M_s



Nomoto et al. (2006)

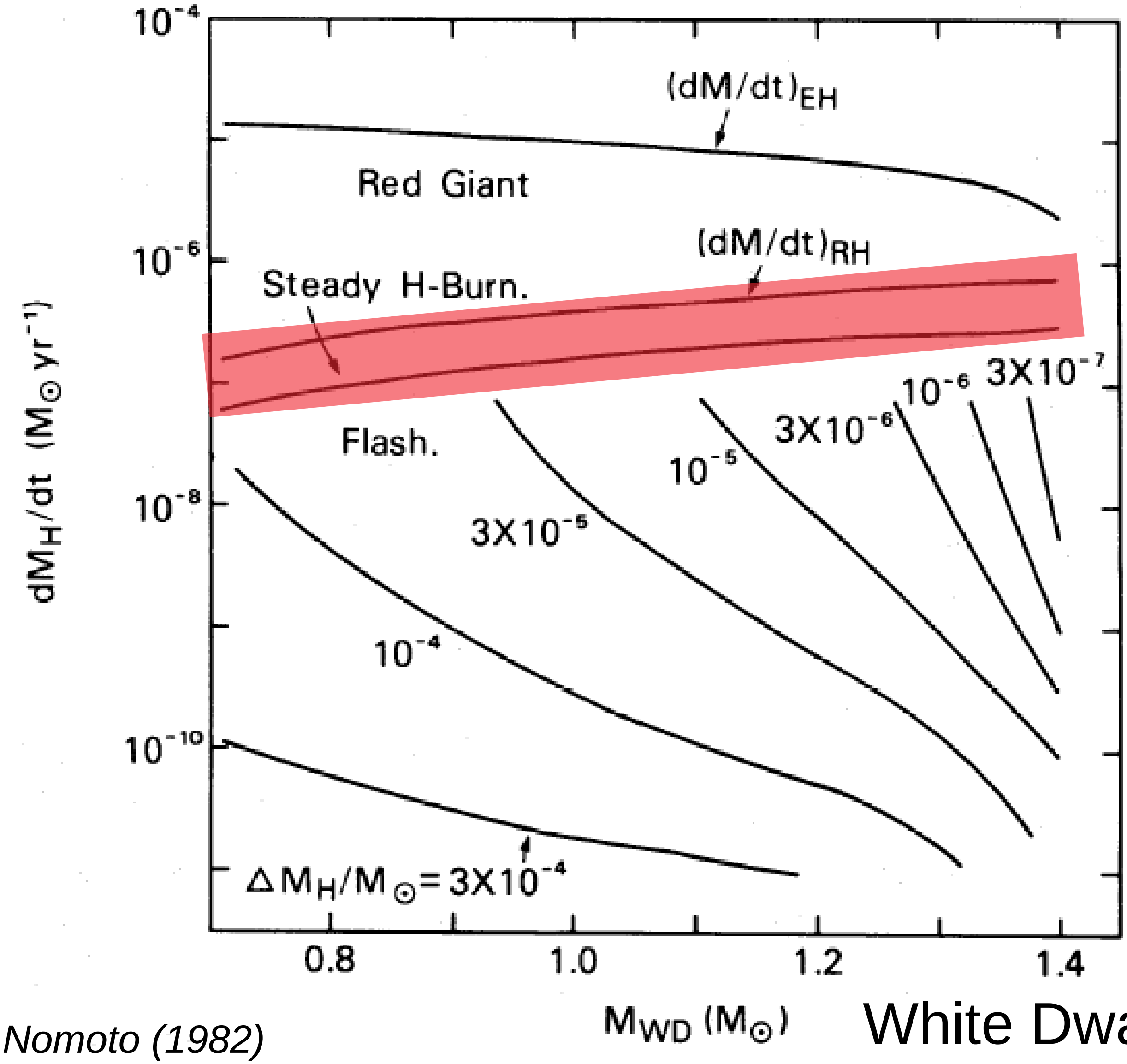
Steady H Burning Models



Nomoto et al. (2006)

Response of WDs to Accretion

Mass Accretion Rate



White Dwarf Mass

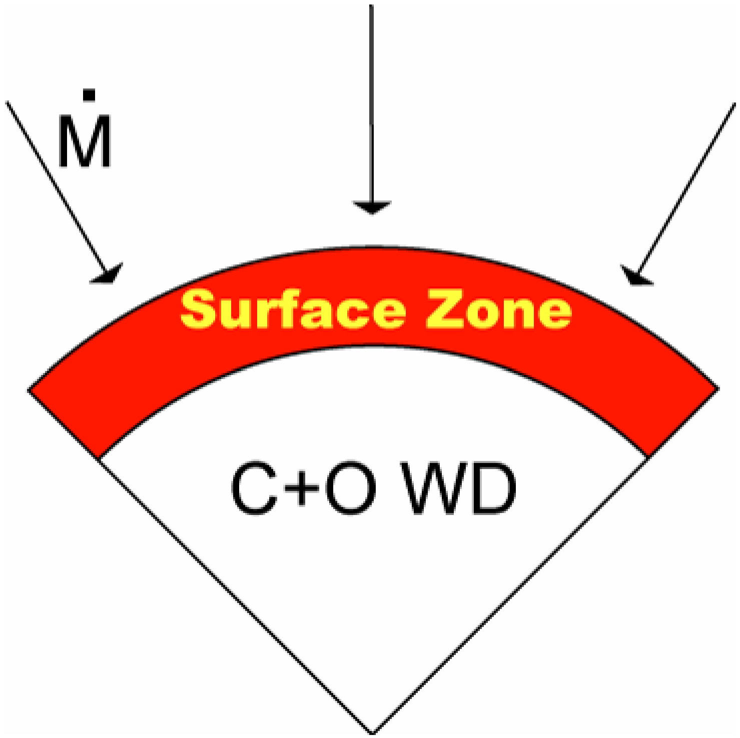
Nomoto (1982)


水素の降着と新星爆発
星B
白色矮星A
1
水素ガス
白色矮星
2
水素ガス
核反応
白色矮星
3
光
ガス
核反応
が暴走
白色矮星
4
水素ガス
白色矮星

Nomoto

Surface H-burning Model

(Starrfield et al. 2004)



$M_{WD}=1.35M_{\odot}$

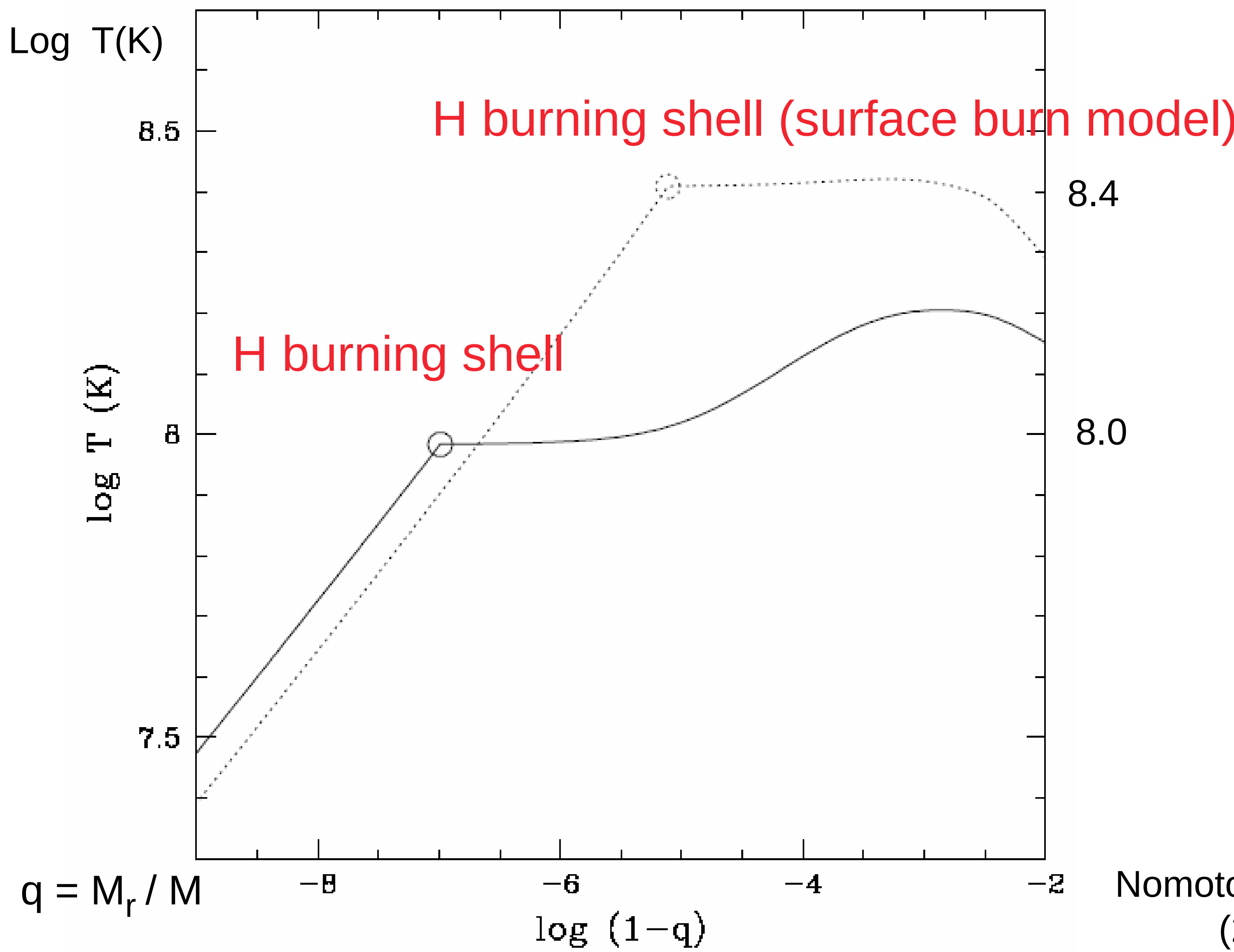
$\dot{M}=2\times10^{-8}\sim8\times10^{-7}M_{\odot}yr^{-1}$

Surface Zone

- $\Delta M_{SZ}=10^{-5}M_{\odot}$ (1 Zone)

- $P_{SZ}=GM\Delta M_{SZ}/4\pi R^4$
- $T_{SZ}=2\text{-}5\times10^{8}K$

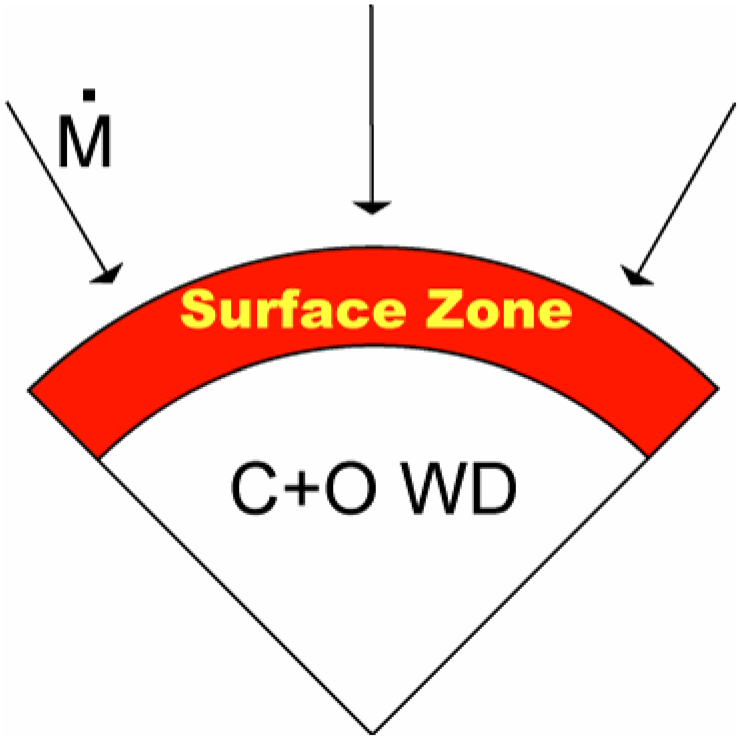
Temperature of H Burning Shell



Nomoto et al. (2006)

Surface H-burning Model

(Starrfield et al. 2004)



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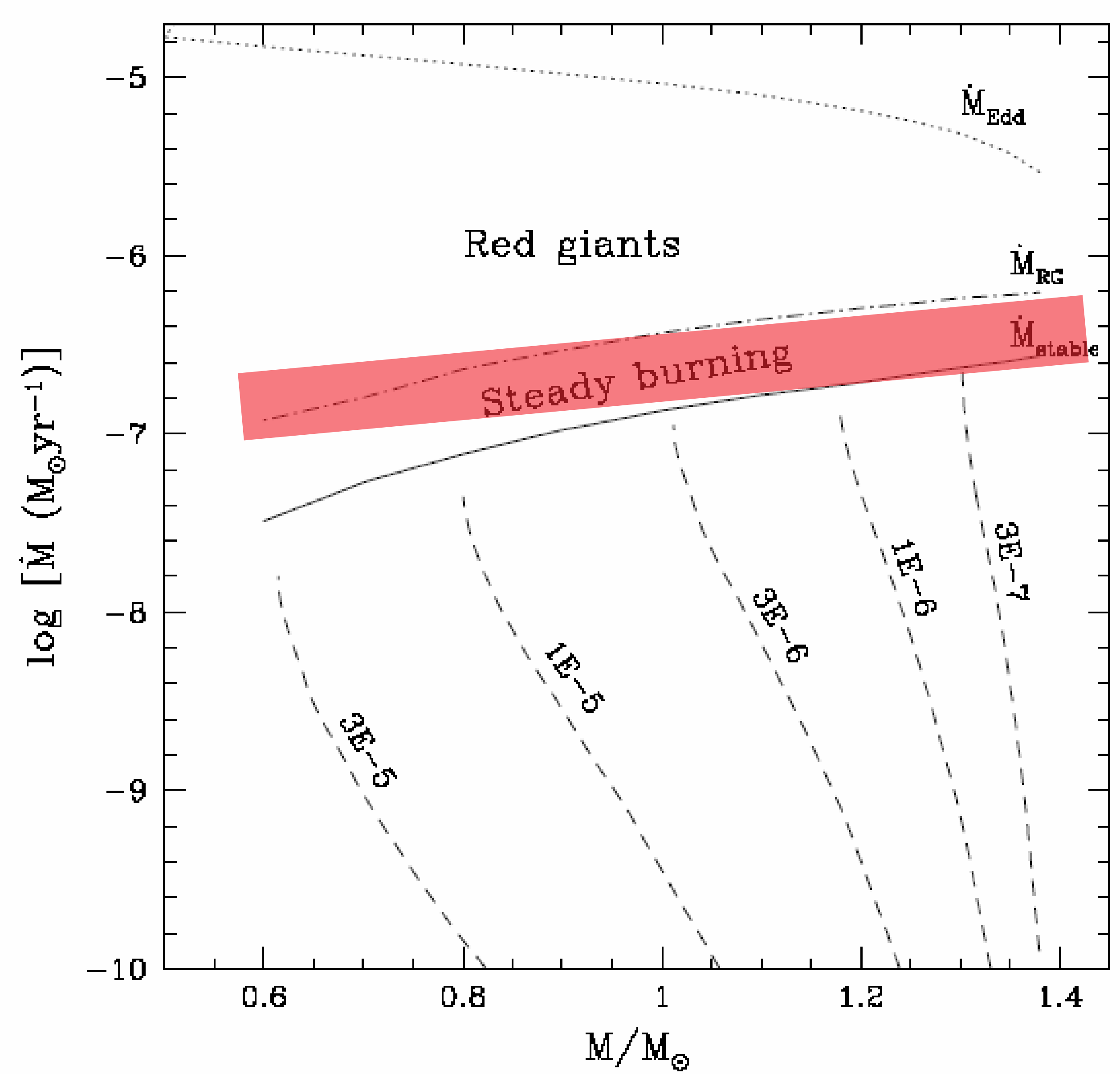
- $\Delta M_{SZ}=10^{-5}M_{\odot}$ (1 Zone)
- $P_{SZ}=GM\Delta M_{SZ}/4\pi R^4$
- $T_{SZ}=2\text{-}5\times10^8K$

- $\varepsilon_{SZ}=\dot{M}E_{(H+He)}/\Delta M_{SZ}$
  (T-independent: stable)

$\Delta M_{SZ}\gg\Delta M_{H,ign}\sim\Delta M_{H\text{-}b}\sim1\text{-}5\times10^{-7}M_{\odot}$

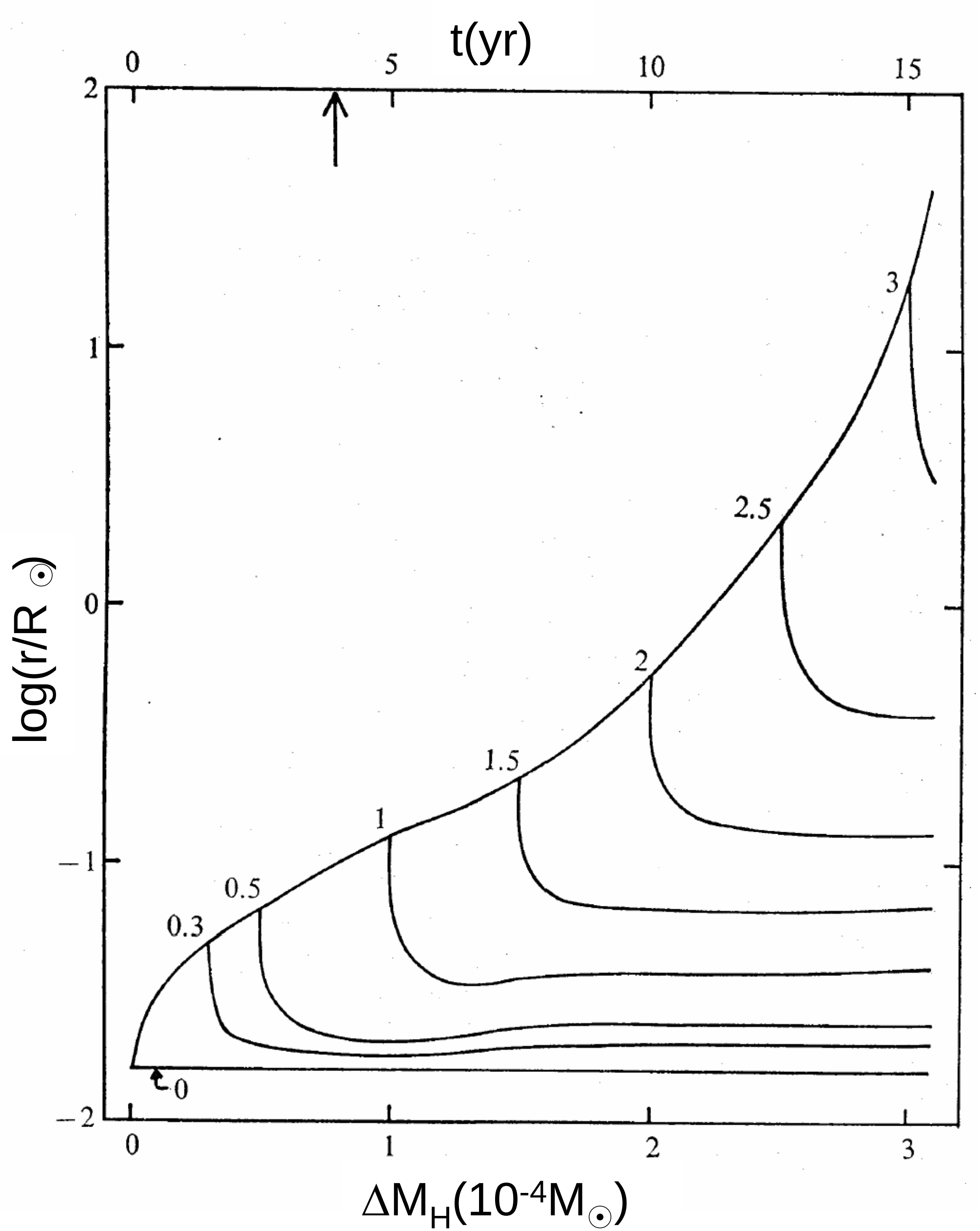
Properties of H Burning Shell



Nomoto et al. (2006)

Rapid Accretion onto White Dwarfs

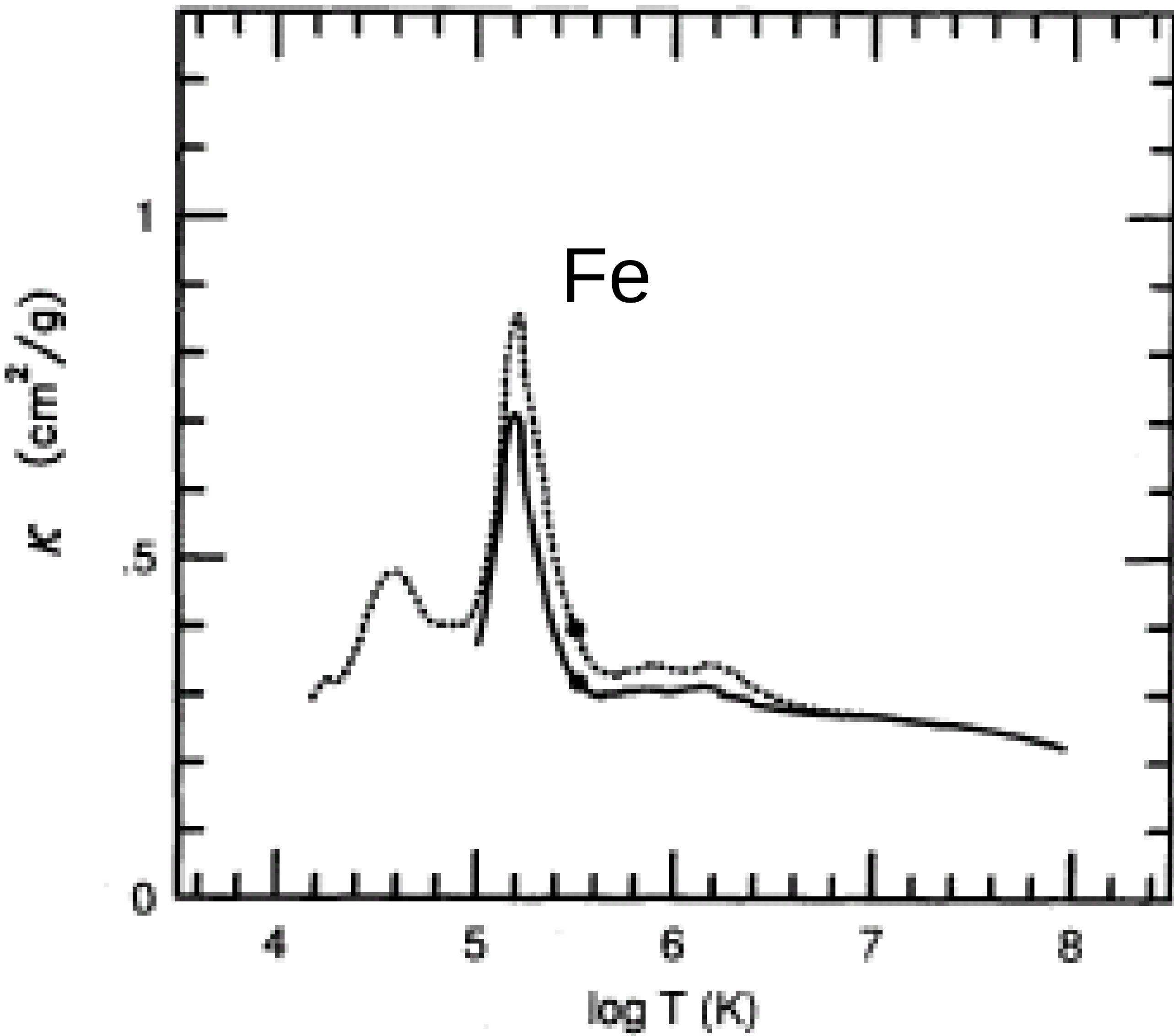
(Nomoto et al. 1979)



$M_{WD}=0.4M_\odot$

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

Opacity

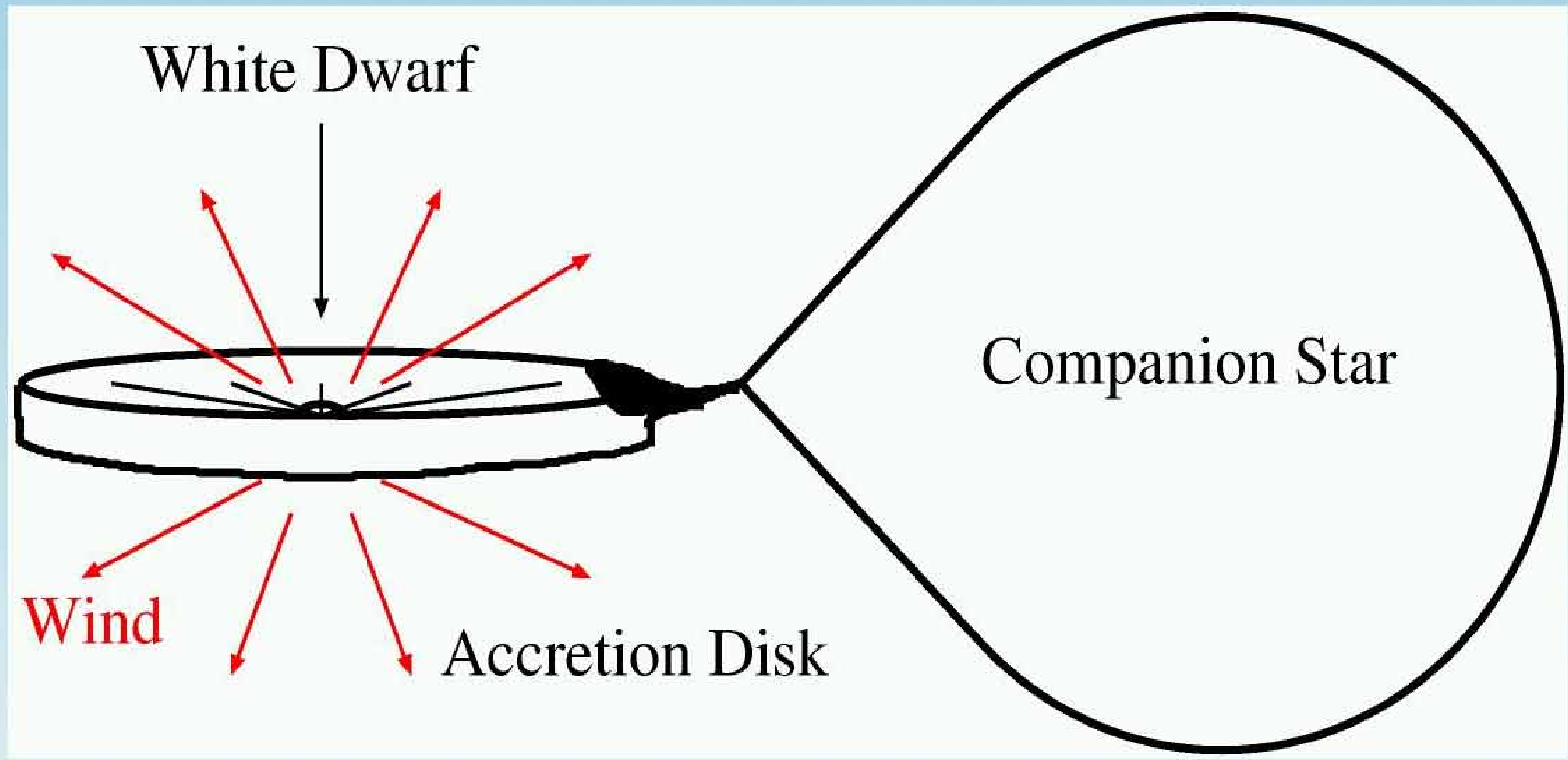


Kato, Hachisu

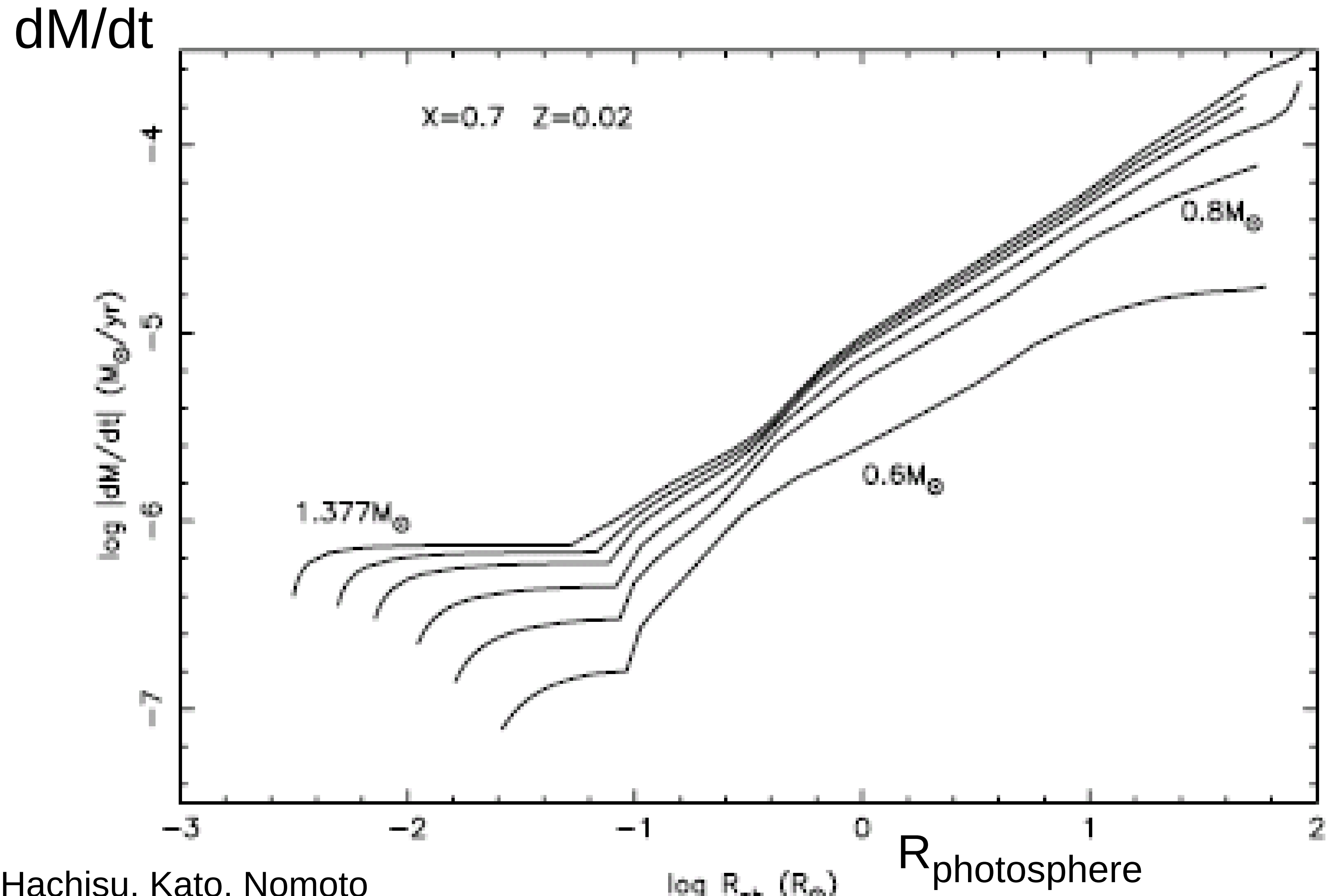
Accretion Wind

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

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



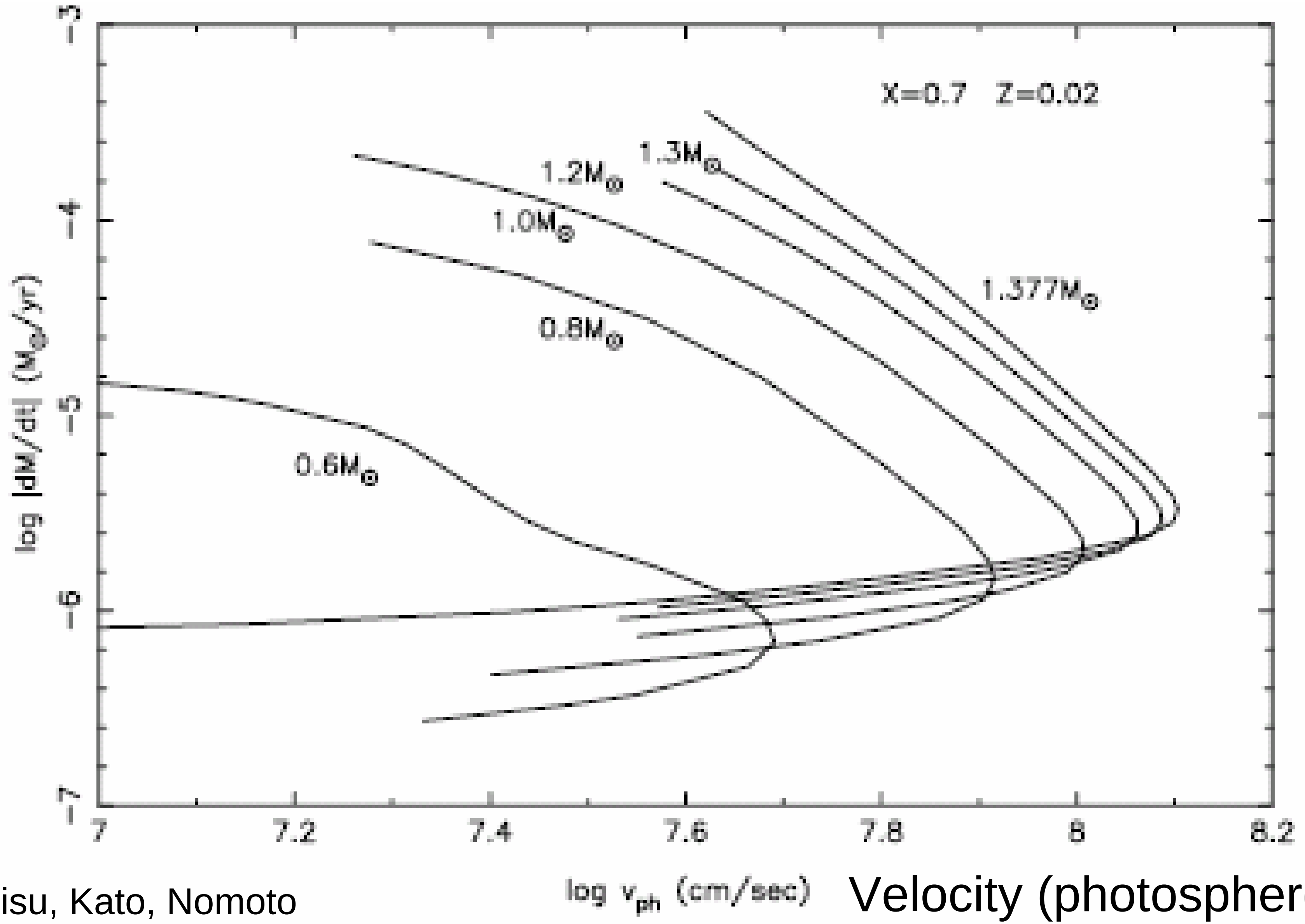
White Dwarf Wind



Hachisu, Kato, Nomoto

White Dwarf Wind

dM/dt

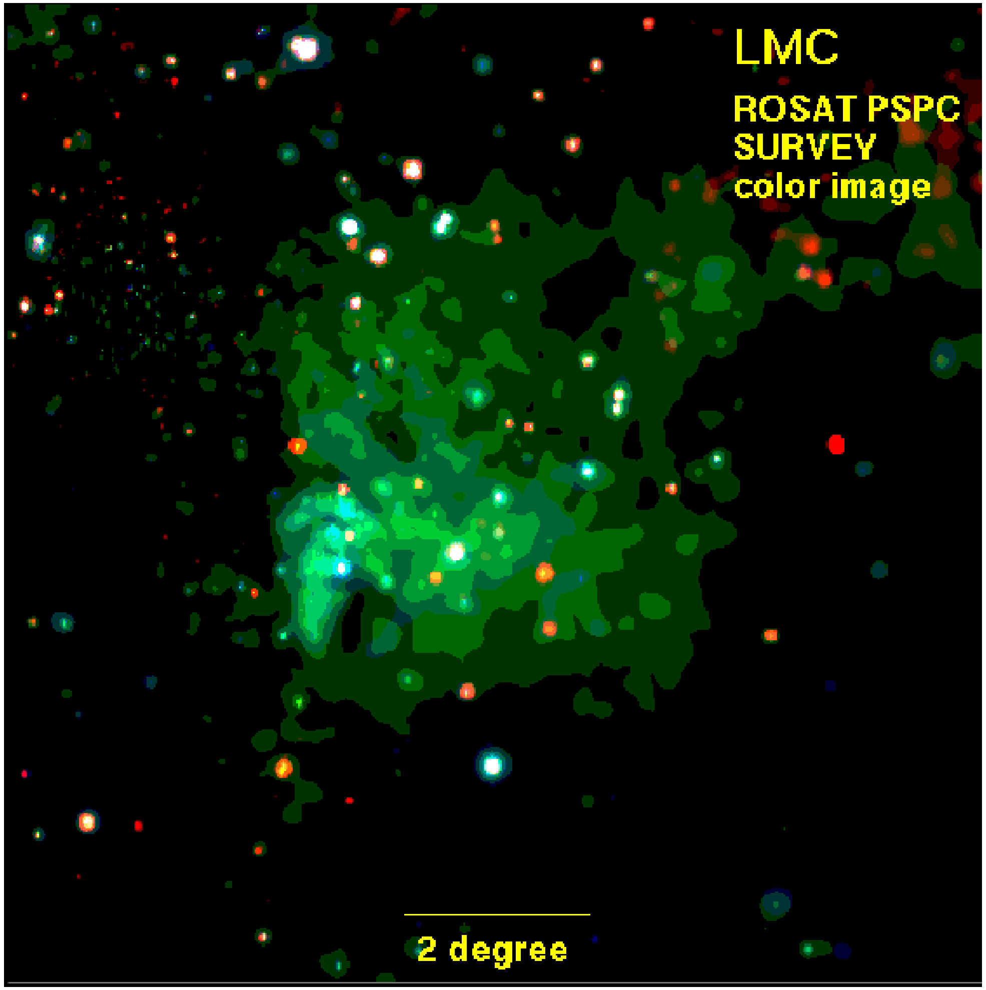


Velocity (photosphere)

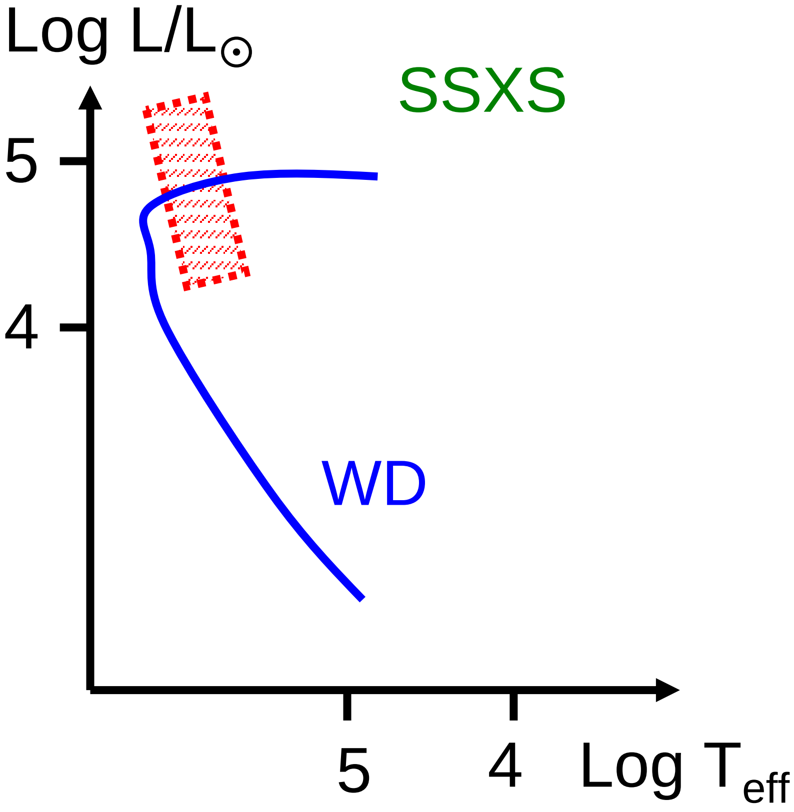
Hachisu, Kato, Nomoto

LMC: X-ray Sources (ROSAT)

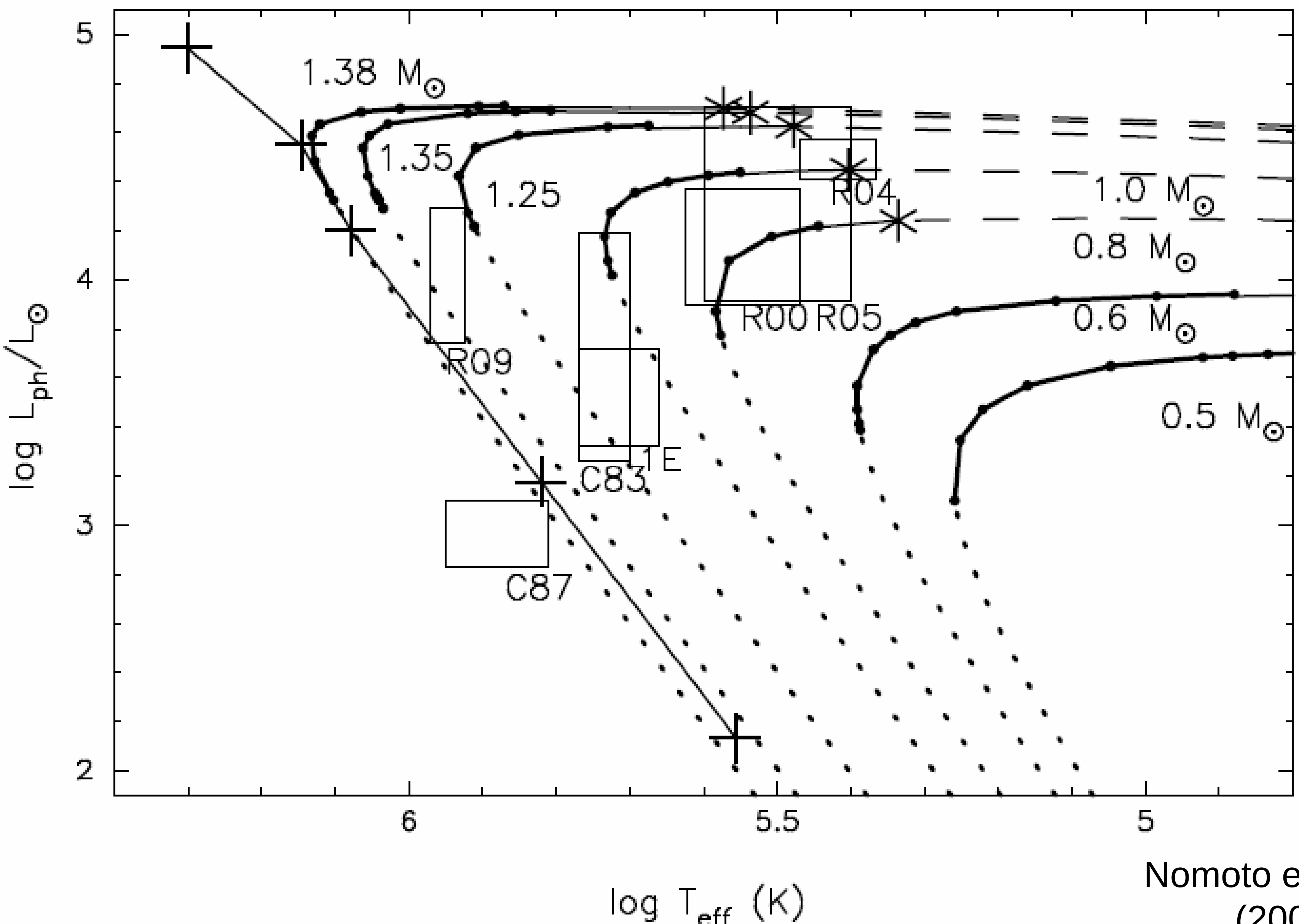
Super-Soft X-ray Sources



Greiner et al.



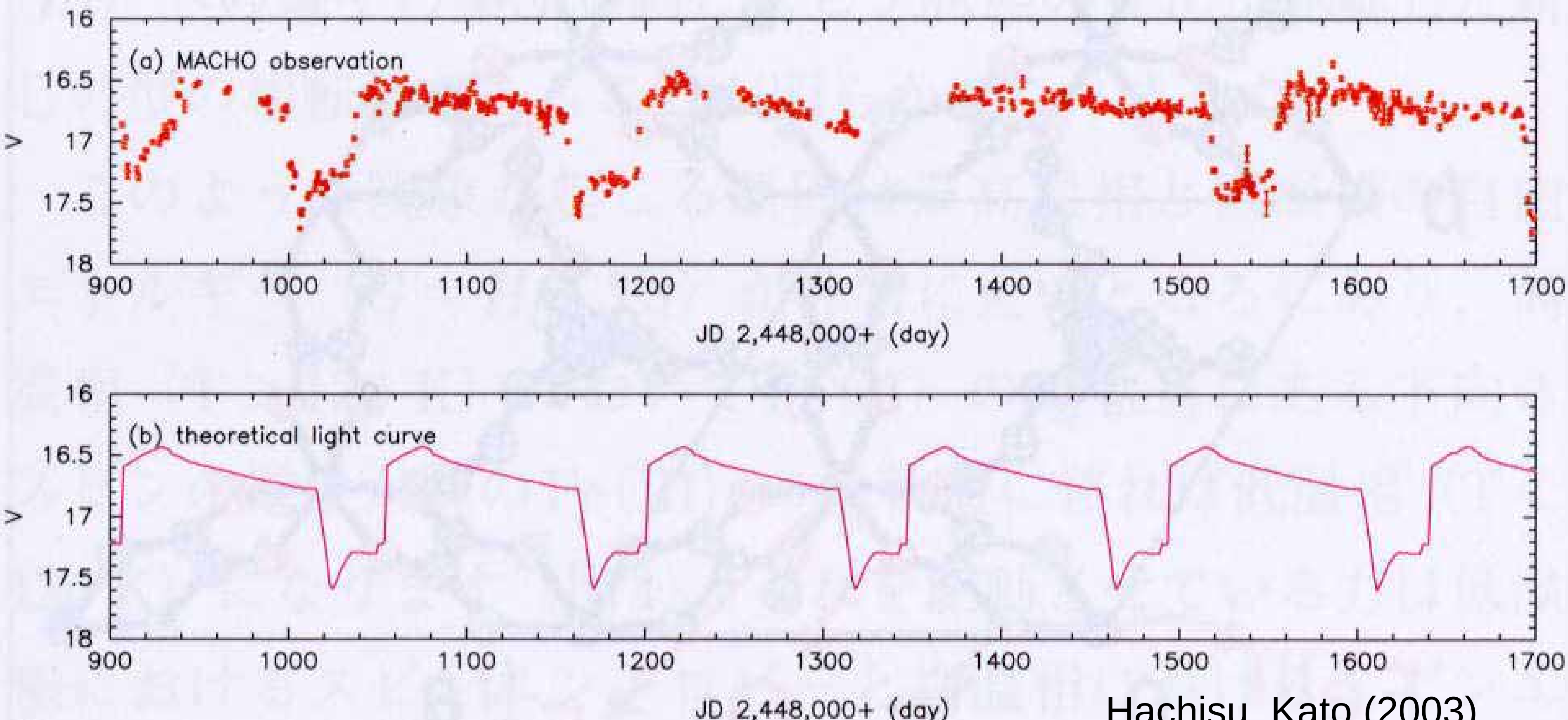
Super-Soft X-Ray Sources



Nomoto et al. (2006)

SSXS in LMC: RX J0513.9-6951

Limit Cycle: Opt-high/Xray-off ➔ Opt-low/Xray-on ➔



Hachisu, Kato (2003)

Candidate Progenitor Systems for Carbon Ignitors

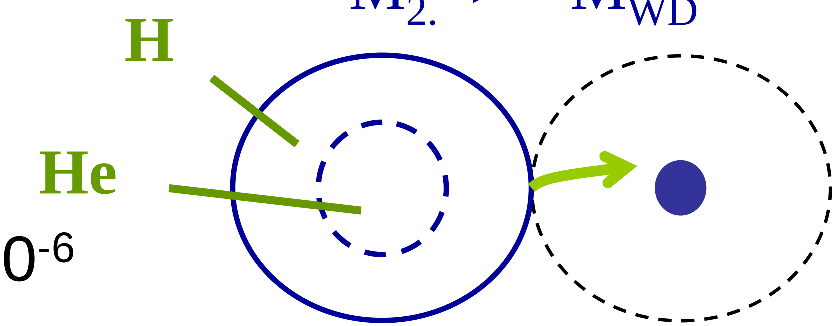
Hachisu, Kato, Nomoto
Li, van den Heuvel
Han, Podsiadlowski

$10^{-7} < \dot{M}\,(M_\odot\,yr^{-1}) < 2 \times 10^{-6}$

Companion

(1) H: leaving M.S.

$M_2 > M_{WD}$



$\dot{M}_2 \sim M_2/\tau_{KH}\ (\sim 3 \times 10^{-8} M_2^{\,4})$

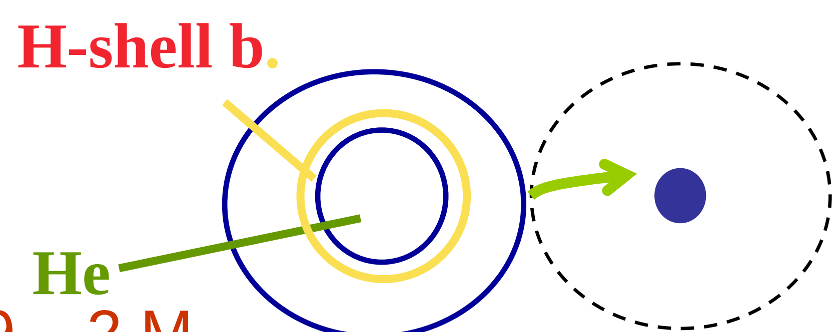
$\sim 3 \times 10^{-8} \quad 5 \times 10^{-7} \quad 2 \times 10^{-6}$

$M_{2,ms} \sim 1M_\odot \quad 2M_\odot \quad 3M_\odot$

Super-Soft X-ray Source

$M_2 < M_{WD}$

(2) H: sub giant, red giant

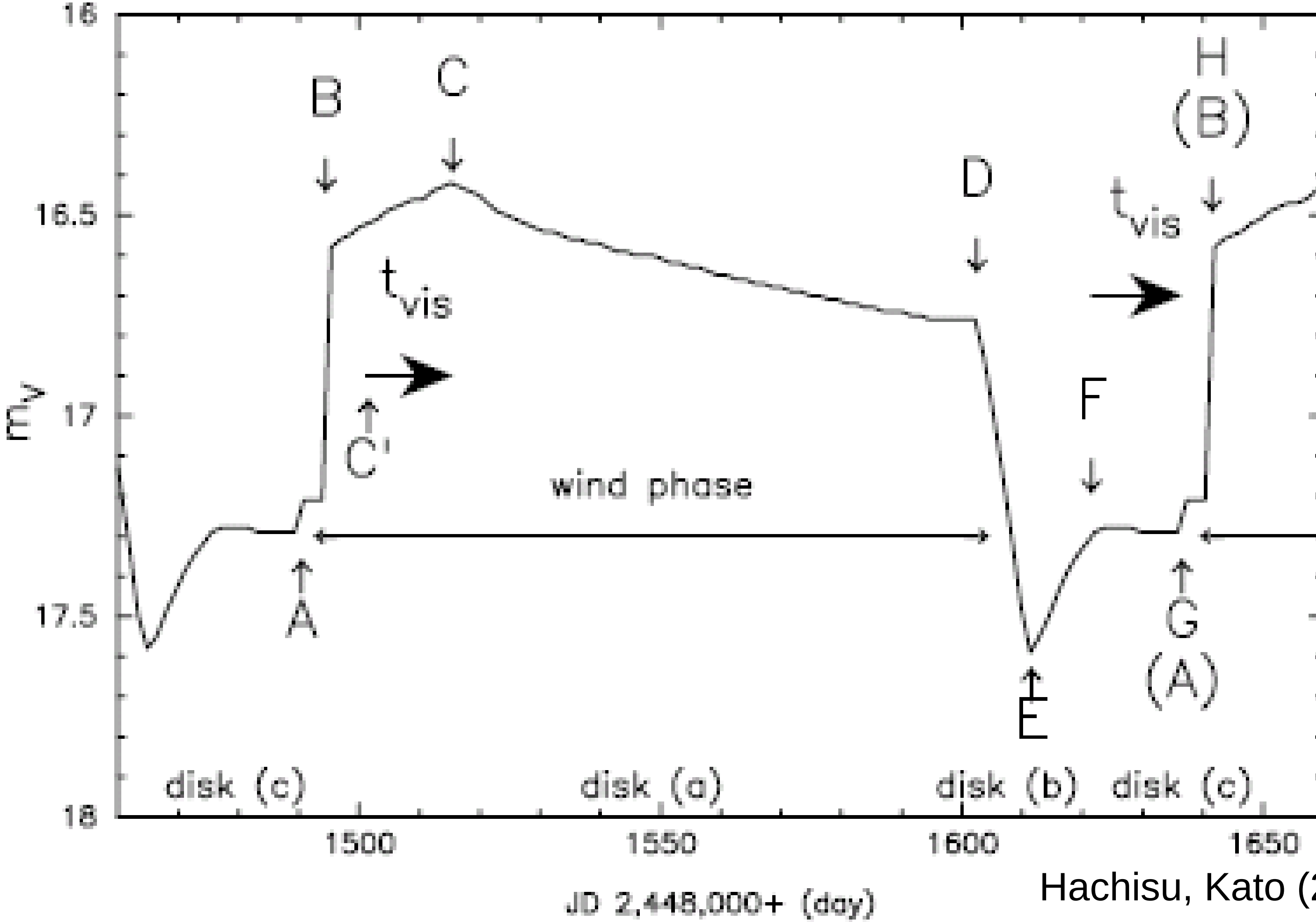


0.9 – 2 $M_\odot$

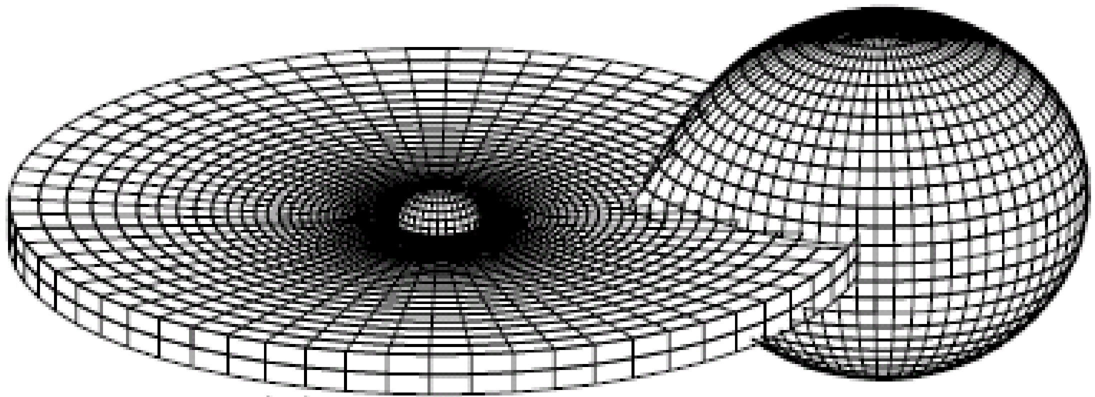
$\dot{M}_2 \sim M_2/\tau_{nuclear}$

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

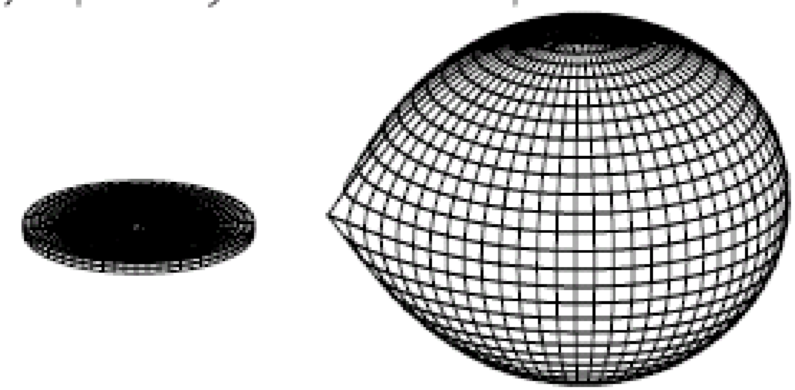
Limit Cycle in SSXS



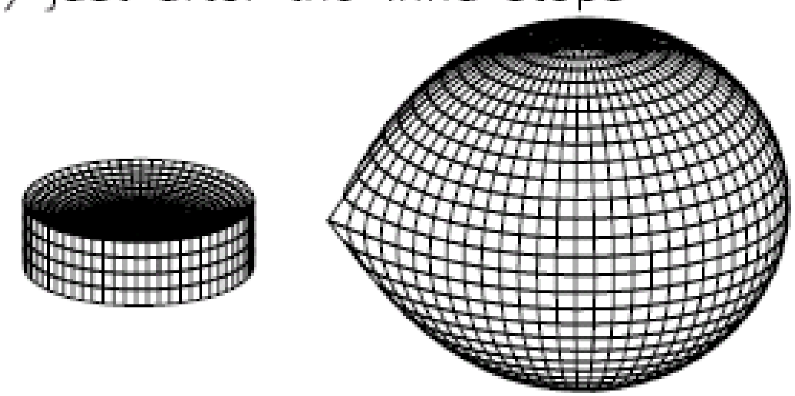
Hachisu, Kato (2003)



(a) optically thick wind phase



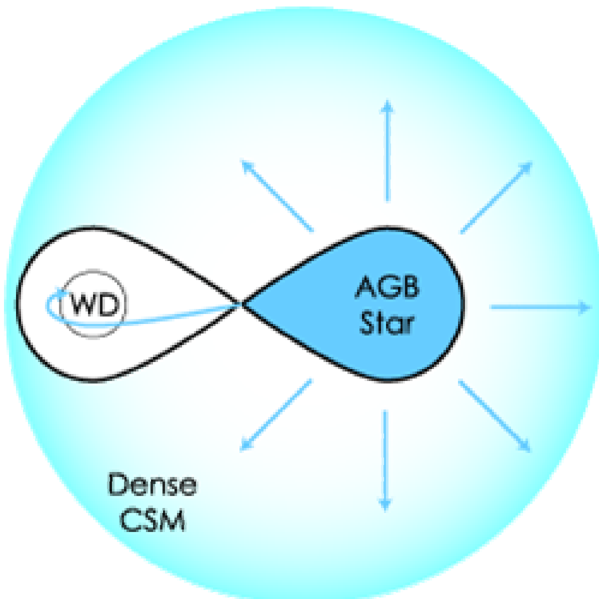
(b) just after the wind stops



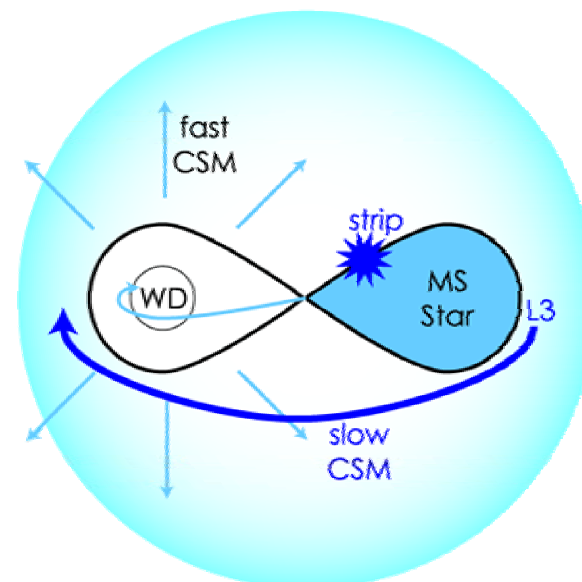
(c) mass accretion makes a spray

Hachisu, Kato (03)

Circumstellar Medium of SN Ia



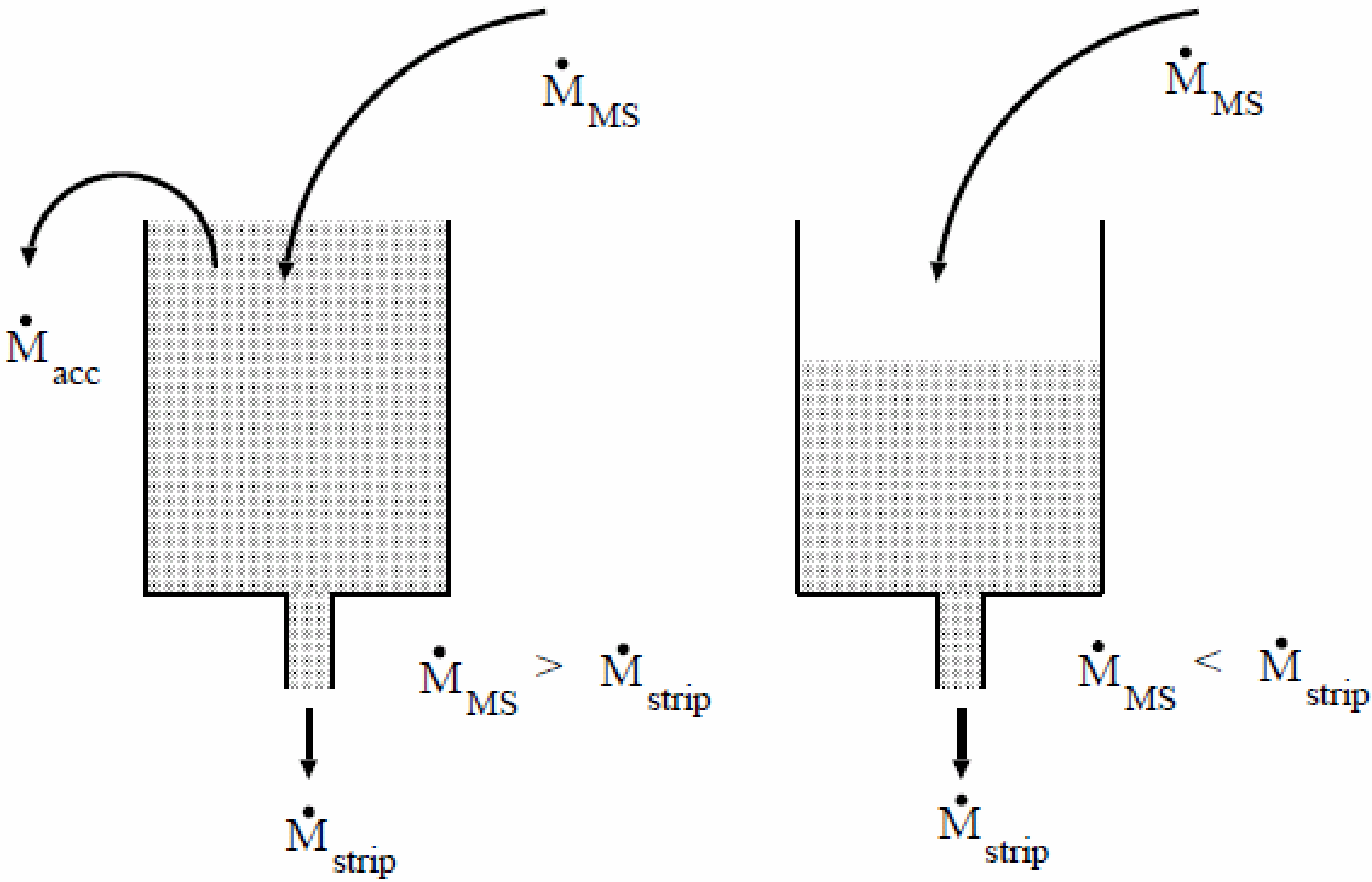
WD+RG?



WD+MS?

WD wind (fast)
Companion star wind (slow)

Mass accretion and Mass tripping

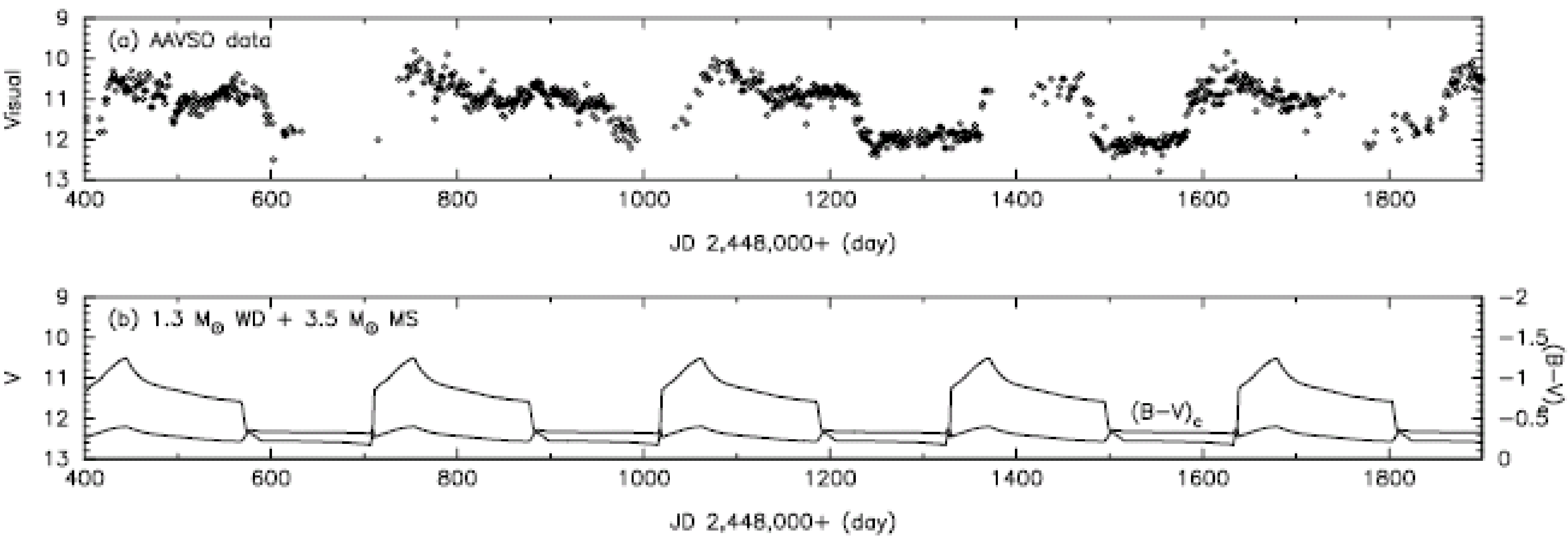


(a) mass accretion on (b) mass accretion off

Hachisu, Kato

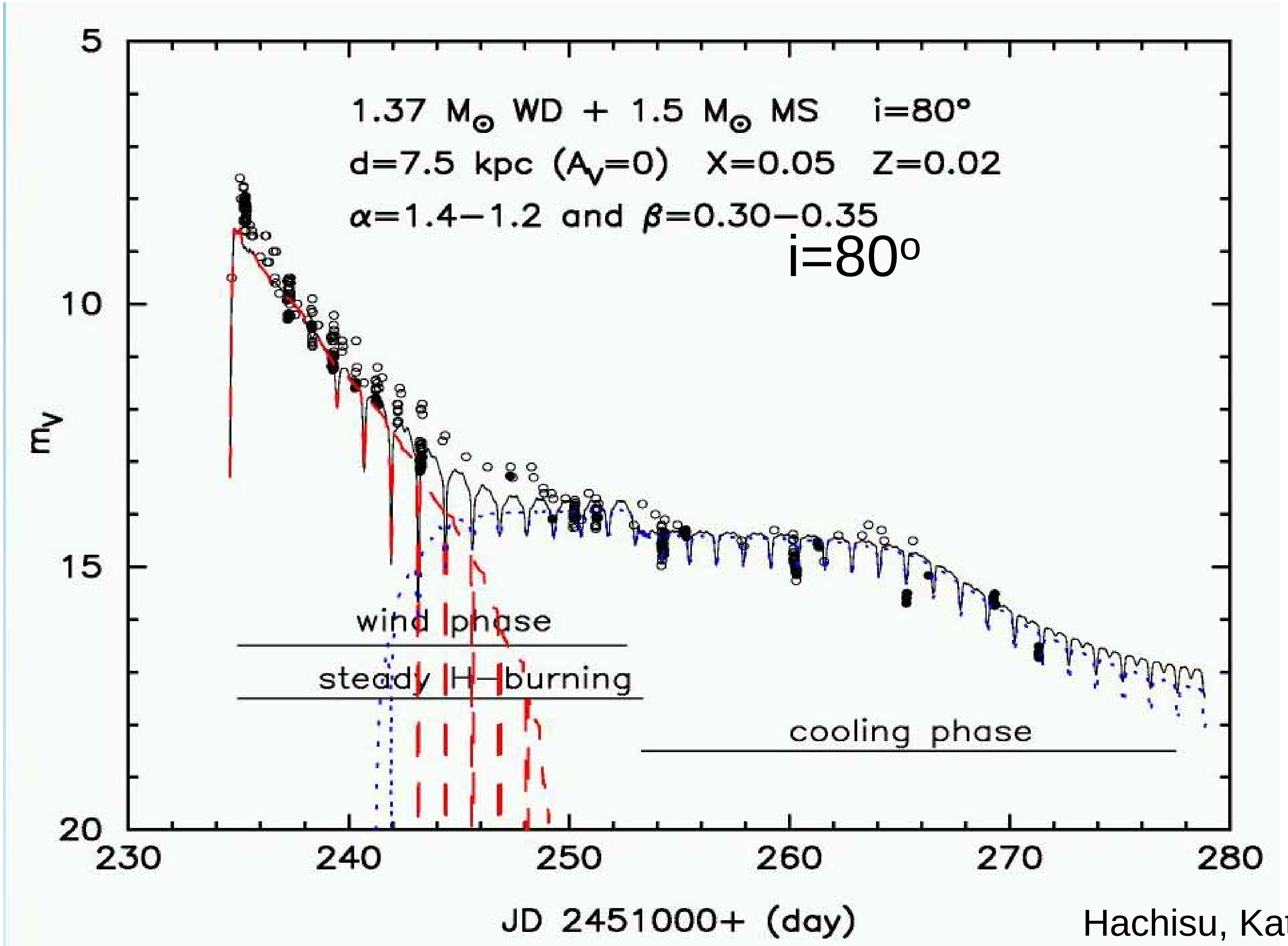
Super Soft Source: V Sge

Limit Cycle: Opt-high/Xray-off ➔ Opt-low/Xray-on ➔



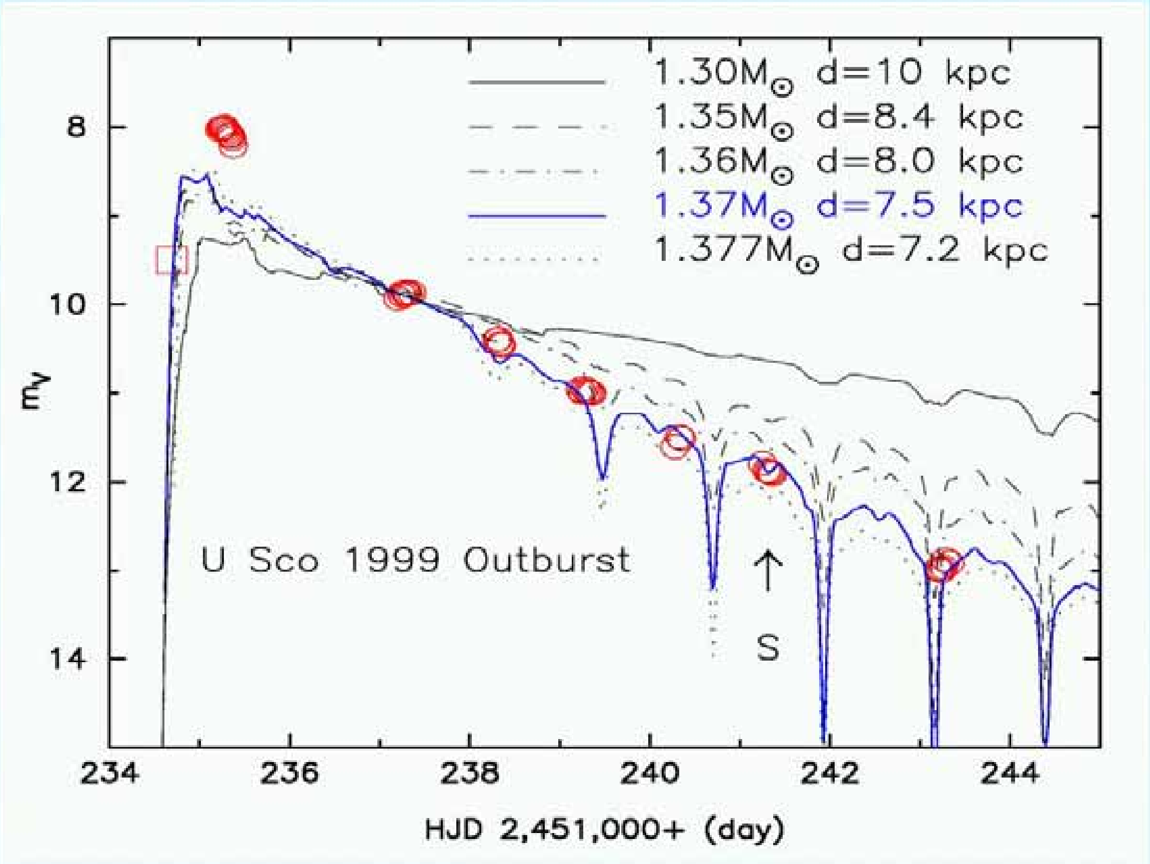
Hachisu, Kato (2003)

Recurrent Nova: U SCo



Hachisu, Kato

Reccurent Nova : U Sco

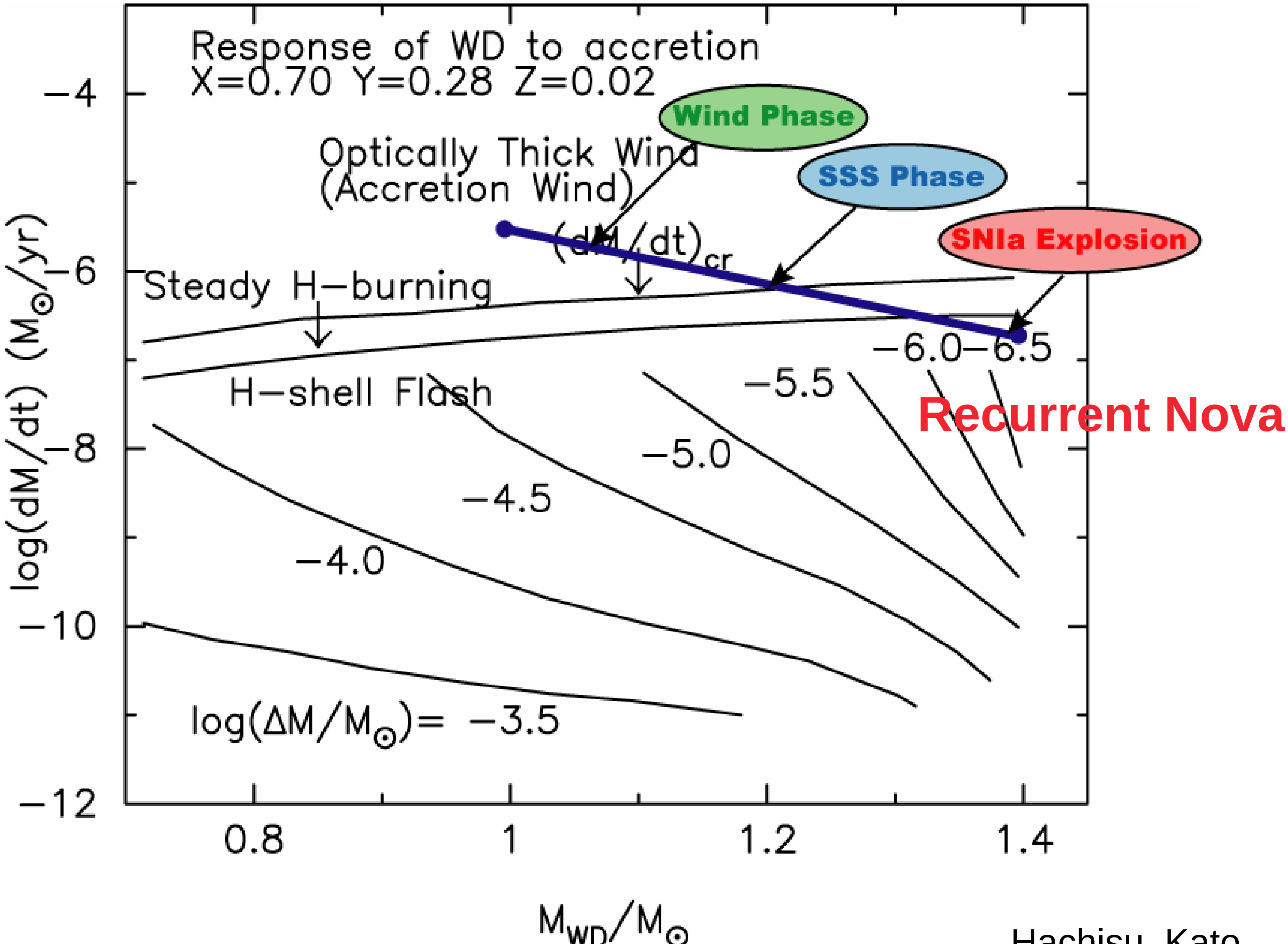


U Sco 1999 outburst $M_{\rm WD} = 1.37 \pm 0.01 M_\odot$

cf. Thoroughgood et al. (2001)

$$M_{\rm WD} = 1.55 \pm 0.24 M_\odot > 1.32 M_\odot$$

Hachisu, Kato



Hachisu, Kato

Candidates of the SN Ia Progenitors

Companions of the Chandrasekhar Mass WDs

- Main-Sequence (**MS**):
  Slightly Evolved 2-3$M_\odot$ stars
  ⇒Young, Spiral
  (t ≥0.5Gyr)
  →Supersoft X-ray Source
  →Recurrent Nova (USCo)

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

Remnant ?

Double Degenerate ?

Search;   Hydrodynamics of Merging

Sub-Chandrasekhar Mass SN Ia?   He in peculiar SN 00cx ?

Circumstellar matter ?

Rotation of accreting WDs → Fate, Diversity ?

SN rate (z)