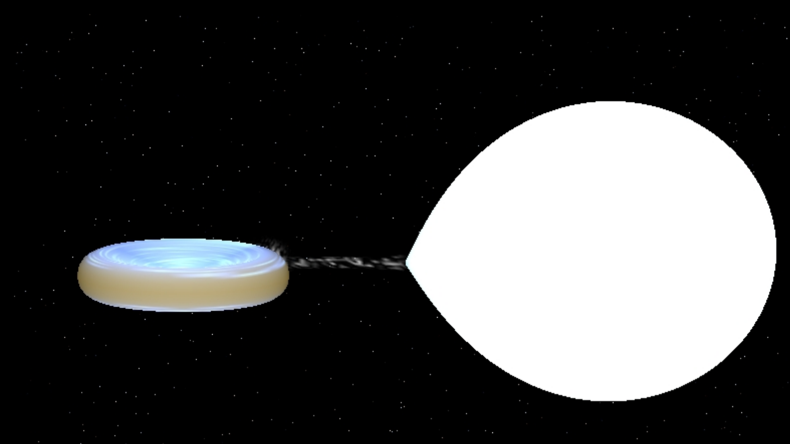
Novae and Accreting WDs as SN Ia Progenitors



U Sco

Mariko Kato (Keio Univ.)

outline

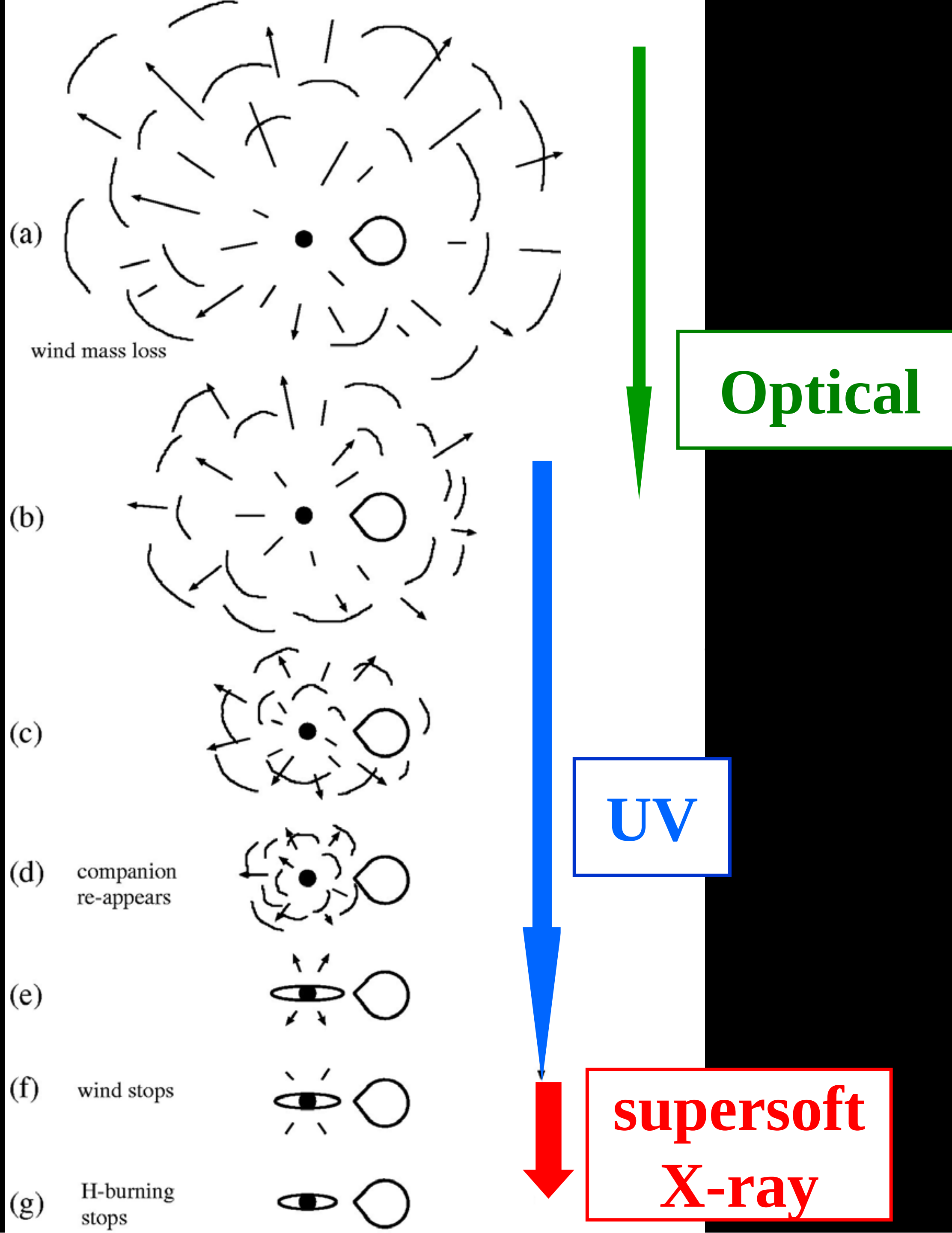
- candidates of SN Ia progenitor
  - optically thick wind theory of nova outburst
  - how to find massive WDs
  - Very massive WDs ; U Sco, RS Oph, V445 Pup
  - position in binary evolution scenarios (SD)
  - RX J0523-69 : accretion wind evolution

- comments on binary evolution scenarios to type Ia SN

nova evolution

Wind mass loss continuously occurs

All novae undergo supersoft X-ray stage



Optically thick wind theory

mass loss: *continuum radiation-driven* wind

Friedjung (1966)

The unique method to calculate nova light-curve

- quasi-evolution: sequence of steady-state solutions
- Solve equations of motion, continuity, diffusion, energy conservation

obtain accurate mass-loss rate, T_{ph}, L_{ph}

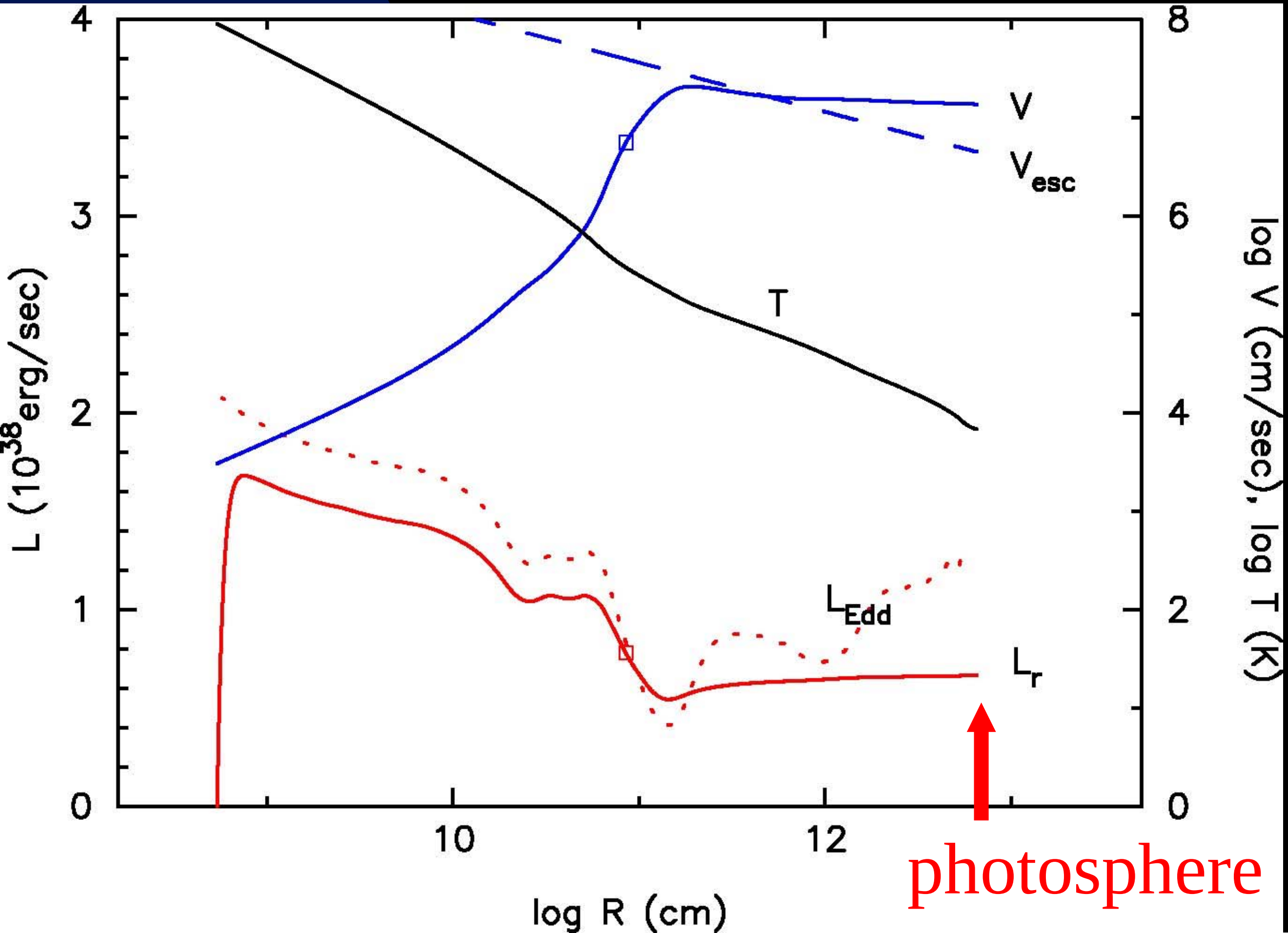
light curve :optical & IR: free-free emission

UV 1455A & X-ray: blackbody emission

Kato & Hachisu (1994), Hachisu & Kato (2006)

The envelope structure

$$L_{\mathrm{Edd}} = \frac{4\pi c G M}{\kappa}$$

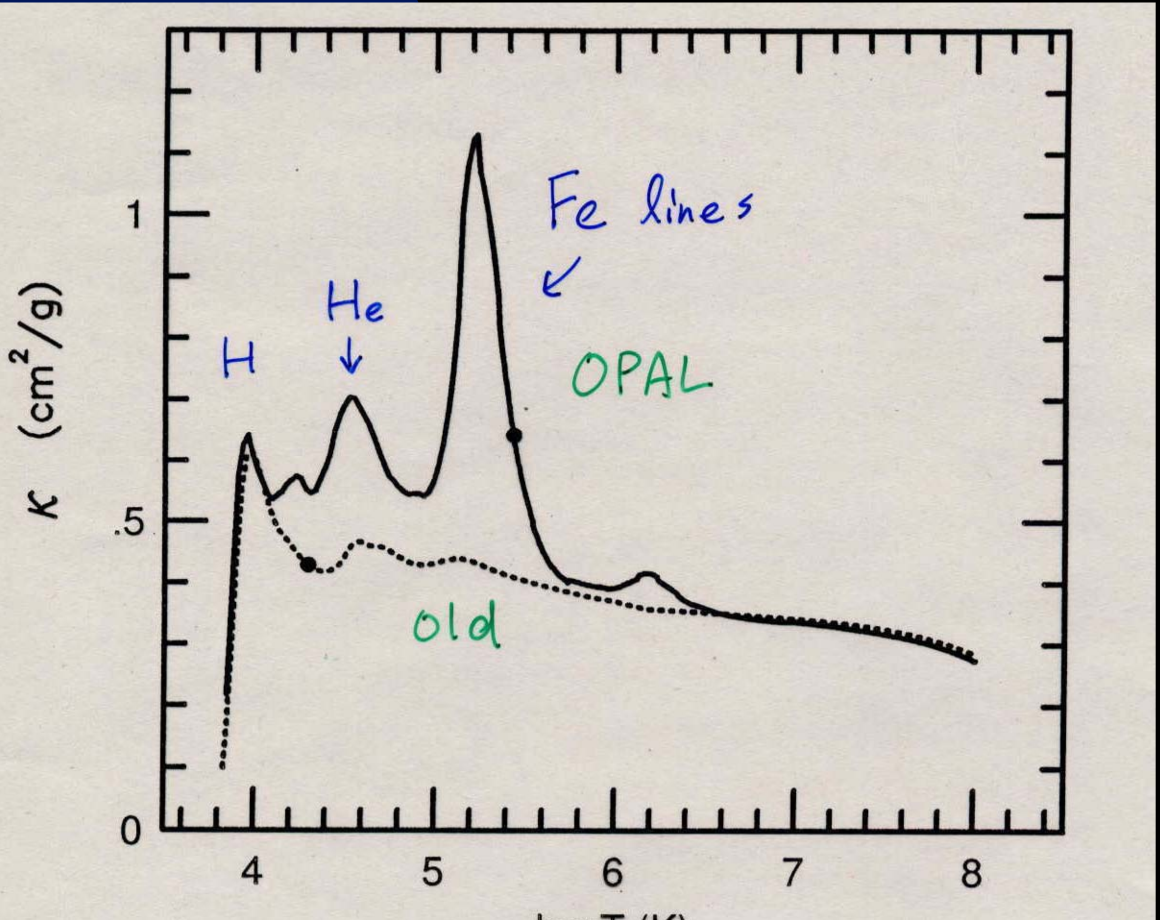


wind is driven by radiation-pressure gradient

not line-driven

OPAL opacity   Iglesias & Rogers (1991)

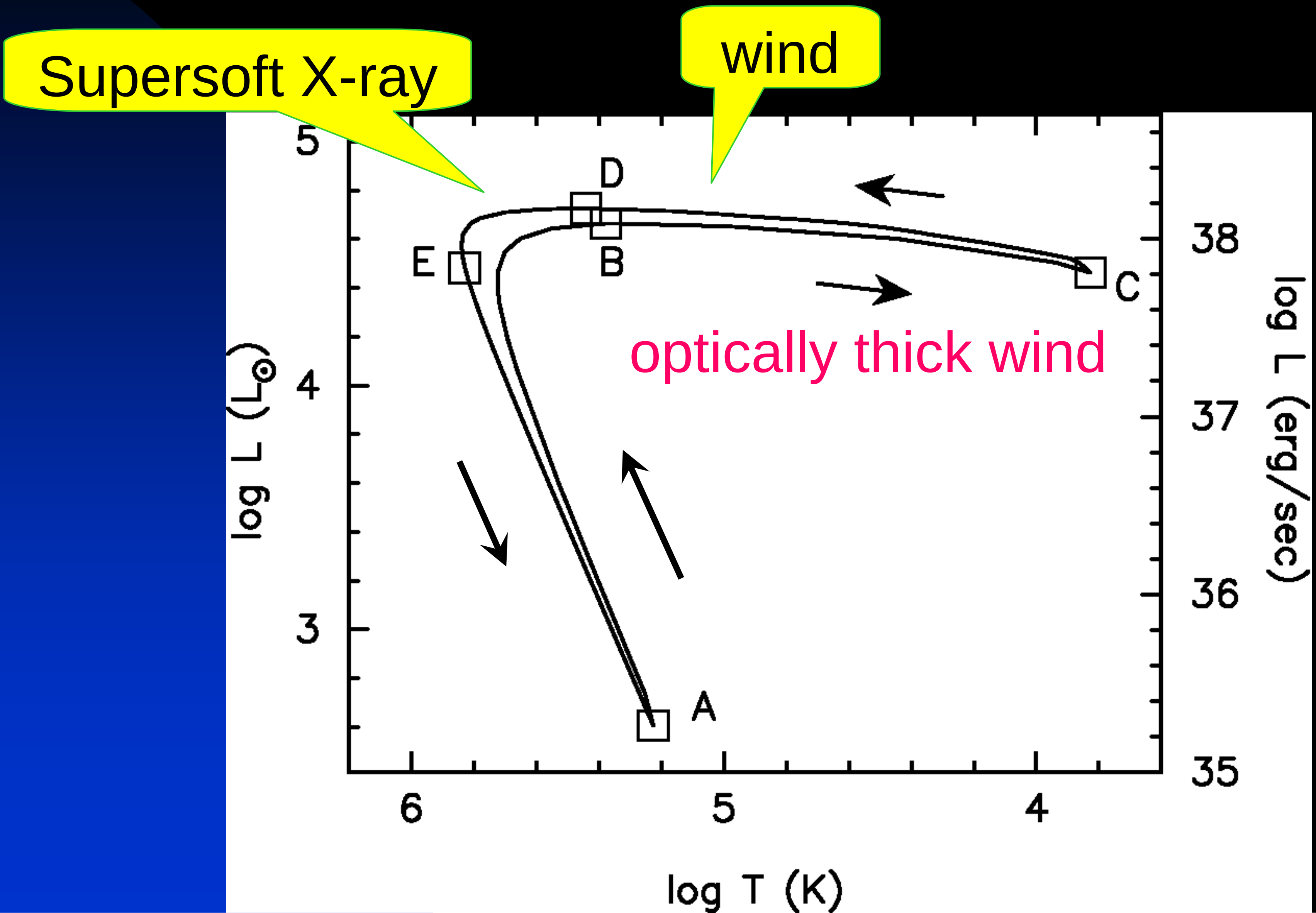
- Accelerate strong winds
- Change in *structure* and *mass-loss rate*



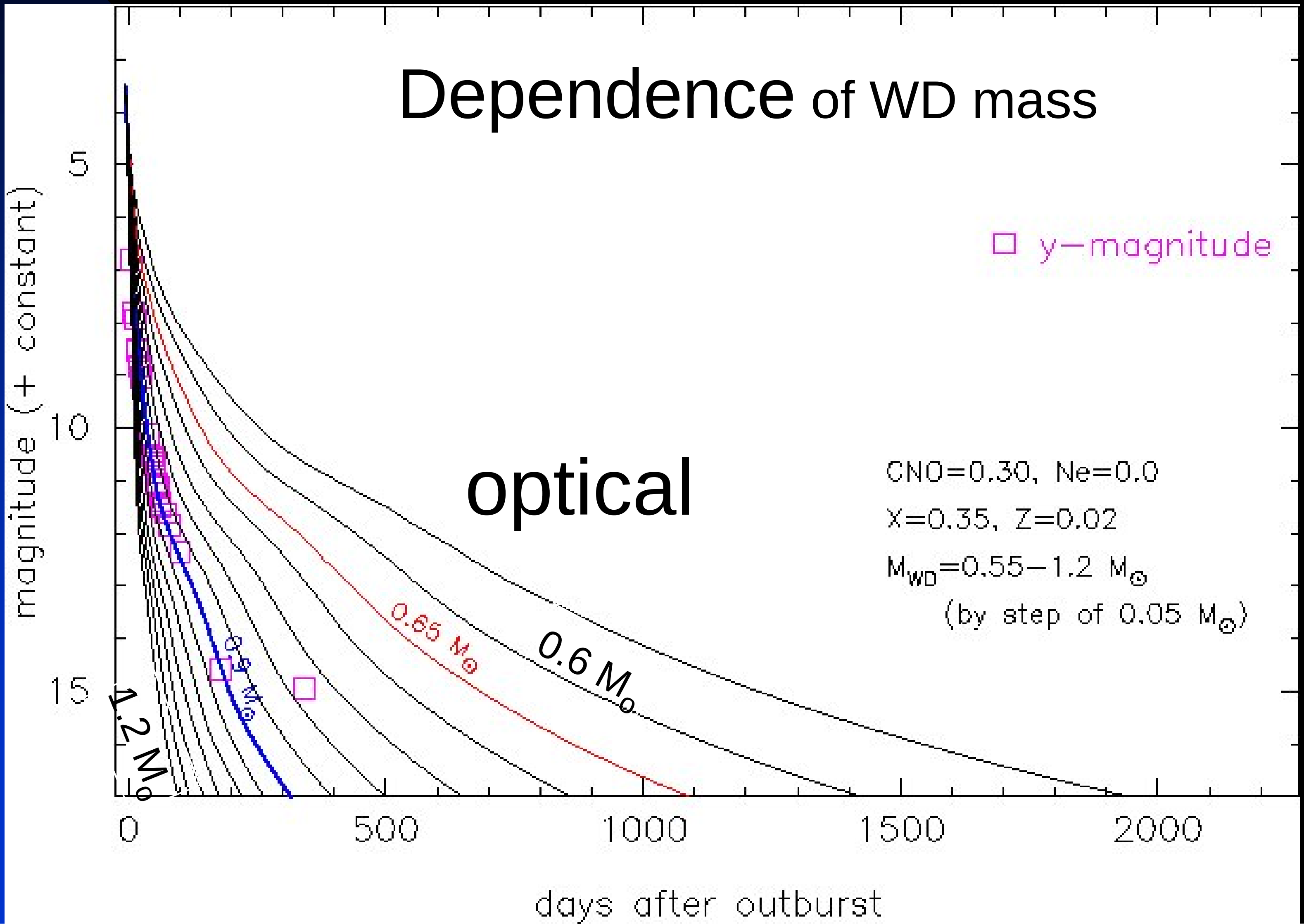
Caution:
DD papers use *old opacity*
Iben, Tutukov, Yungelson

Kato & Hachisu (1994)

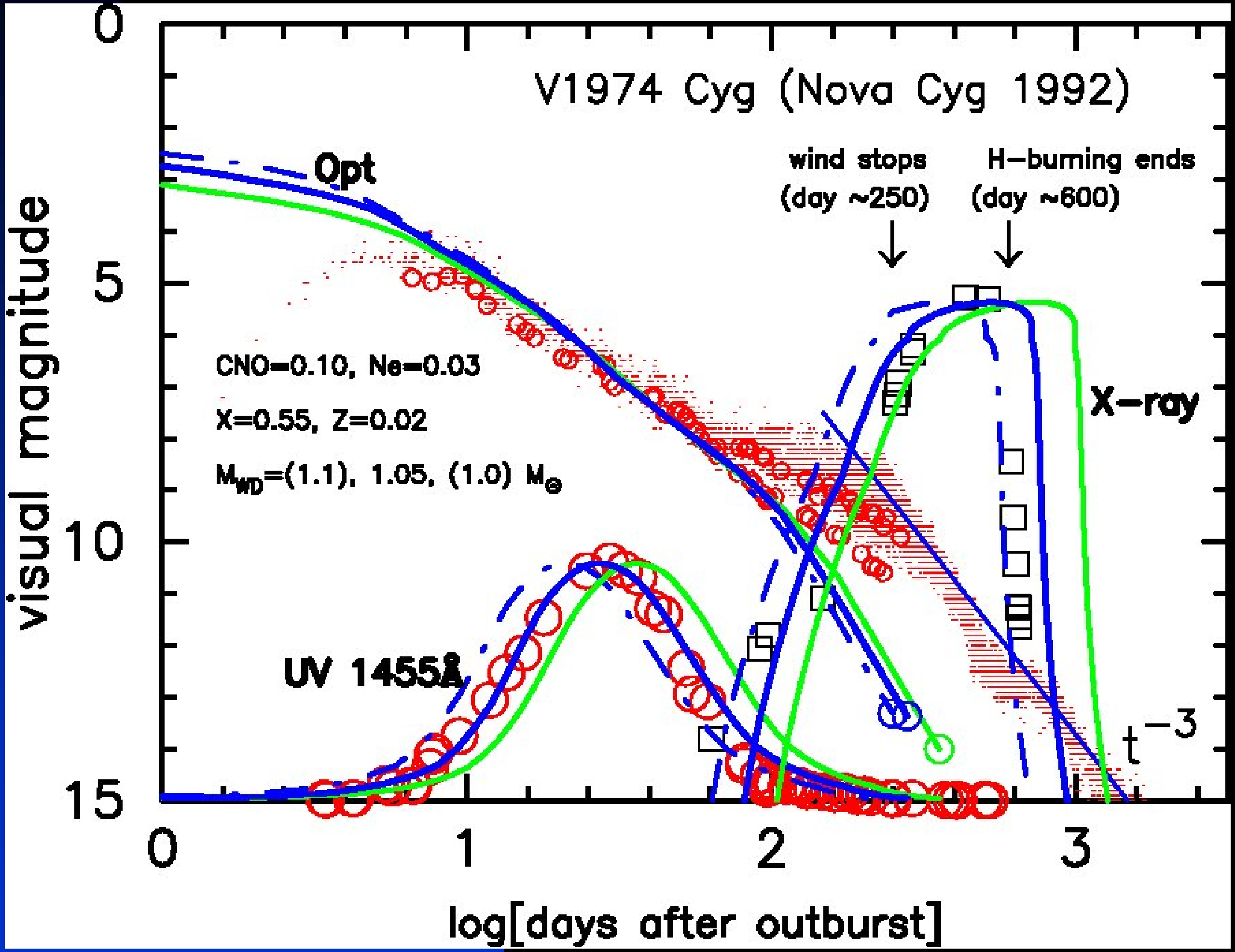
Nova in HR diagram



Theoretical Light Curve of Nova



V1974 Cyg: light curve fitting



determine WD mass

$1.0 \pm 0.05\ M_o$

Hachisu & Kato (2005,2006)

X-ray: *ROSAT*: Orio et al. (2001), Shanley et al (1995)

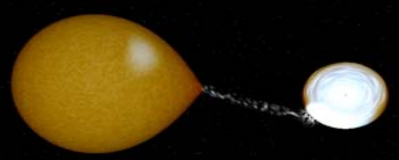
UV *IUE* 1455 Å continuum: Cassatella, Altamore, Gonzalez-Riestra (2002)

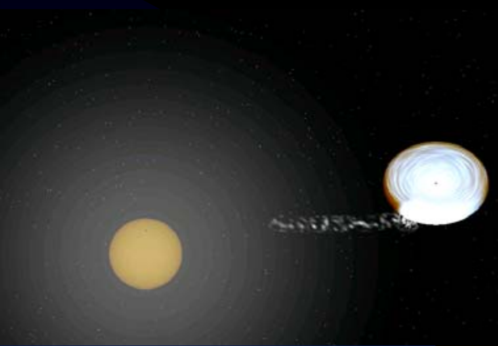
WD Mass determined by light curve fitting

- classical nova

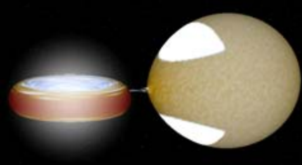
V1500 Cyg (1.15 Mo), V1668 Cyg (0.95 Mo), OS And (1.0 Mo)
V1974 Cyg (1.0 Mo), V838 Her (1.35 Mo), V351 Pup (1.05 Mo)
GK Per (1.15 Mo), V2491 Cyg (1.3 Mo), V693 CrA (1.3 Mo)
V1493 Aql (1.15 Mo), V2362 Cyg (0.7 Mo) , PU Vul (0.6 Mo)
V2361 Cyg (1.05 Mo), V382 Nor (1.15 Mo), V5115 Sgr (1.2Mo)
V378 Ser (0.7 Mo), V5116 Sgr (0.9 Mo), V1188 Sco(1.25 Mo)
V1047 Cen (0.7 Mo), V476 Sct (0.95 Mo), V663 Aql (0.95 Mo)
V477 Sct (1.3 Mo), V598 Pup (1.28Mo), V382 Vel (1.2Mo)
V4743 Sgr (1.15Mo), V1281Sco (1.1 Mo), V597 Pup (1.1Mo)
V2467 Cyg (1.0 Mo), V5116 Sgr (1.07Mo), V574 Pup (1.05Mo)
V458 Vul (0.93Mo)

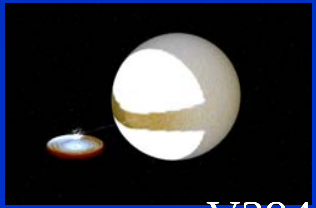
Recurrent nova





U Sco	(1.37 M_o)	Hachisu et al (2000) ApJL
V394 CrA	(1.37 M_o)	HK (2000, 2001) ApJ
LMC1990#2	(1.37Mo)	
T CrB	(1.37 Mo)	HK(2001) ApJ,558,323
RS Oph	(1.35 Mo)	Hachisu et al. (2006, 2007)
V745 Sco	(1.35 Mo)	HK (2001)
V3890 Sgr	(1.35 Mo)	HK(2001)
CI Aql	(> 1.2 Mo)	
T Pyx	(> 1.2 Mo)	

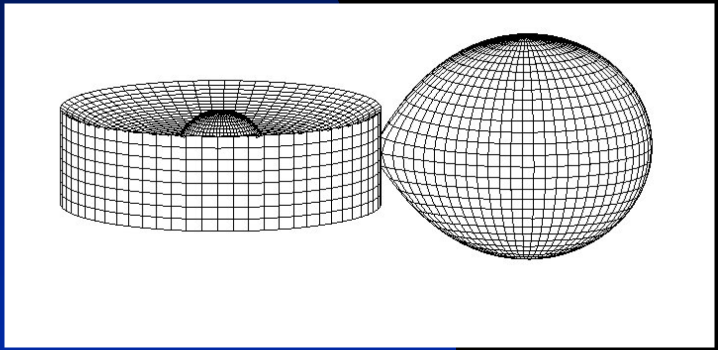




Type Ia supernova candidates

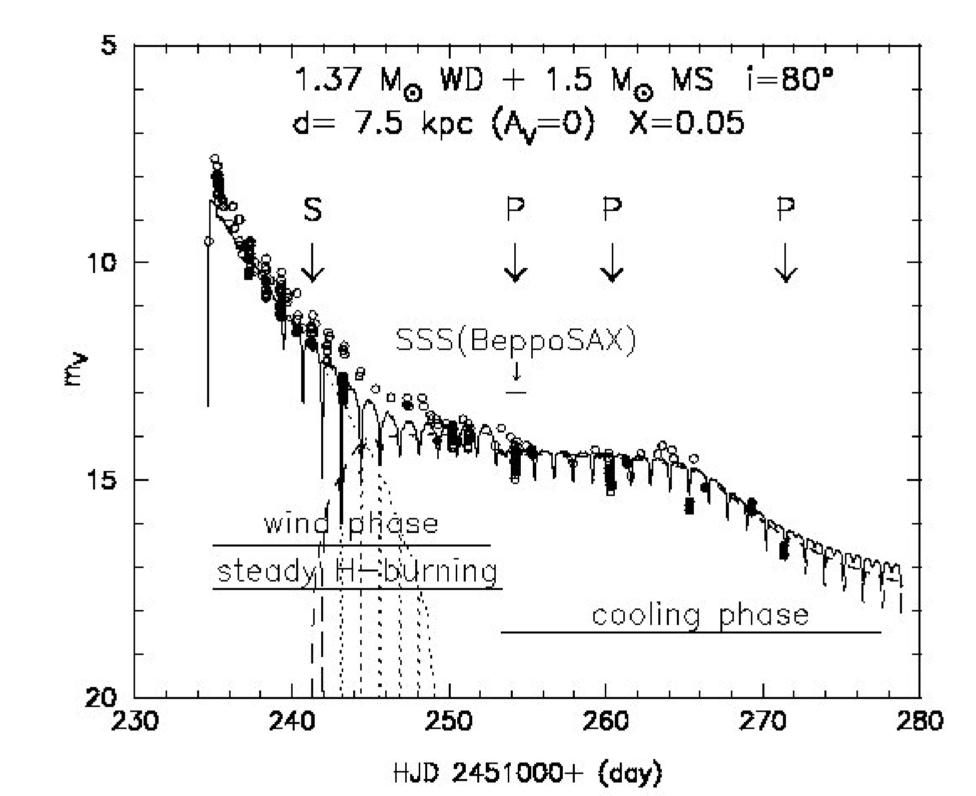
U Sco : Recurrent nova

1863,1906,1936,1979,1987,1999, 2010
(43) (30) (43) (8) (12) (11)



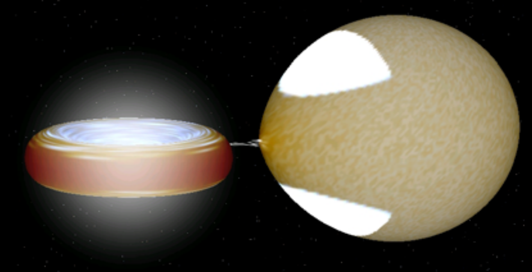
P_{orb}=1.23 d

Hachisu et al. (2000)



Model: WD envelope
+ irradiated Disk
+ irradiated companion
(Hachisu et al. 2000)

U Sco : Recurrent nova



M_{WD}~1.37 M_o

P_{orb}=1.23 d, *i* =80 deg

M_{comp}~1.5 M_o

accreted matter= $3x10^{-6}$ M_o (12 yr)

mean accretion rate =$3x10^{-7}$ M_o/yr

ejected matter = $1.8x10^{-6}$ M_o

net growth rate =$1.0x10^{-7}$ M_o/yr (40 %)

Candidate of Type Ia SN

V838 Her (1991)

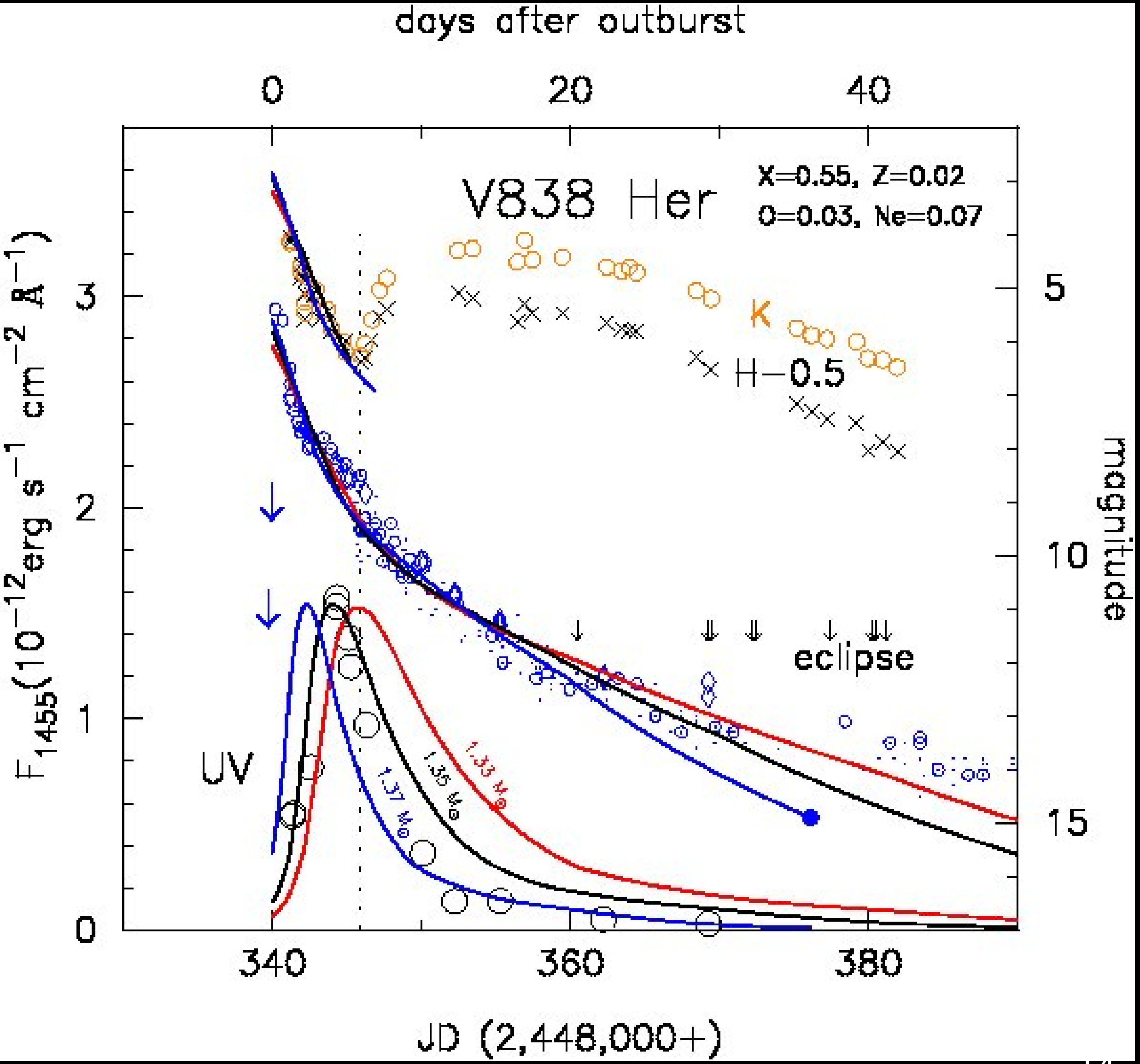
WD mass:

1.33 M_{o}
1.35 M_{o}
1.37 M_{o}

↓

1.35 M_{o}

for X=0.55, O=0.03, Ne=0.07, Z=0.02



Kato, Hachisu & Cassatella (2009) 704,1676

U Sco vs. V838 Her

Very similar light curves

U Sco *RN*

recurrent nova

~1.38 M_o

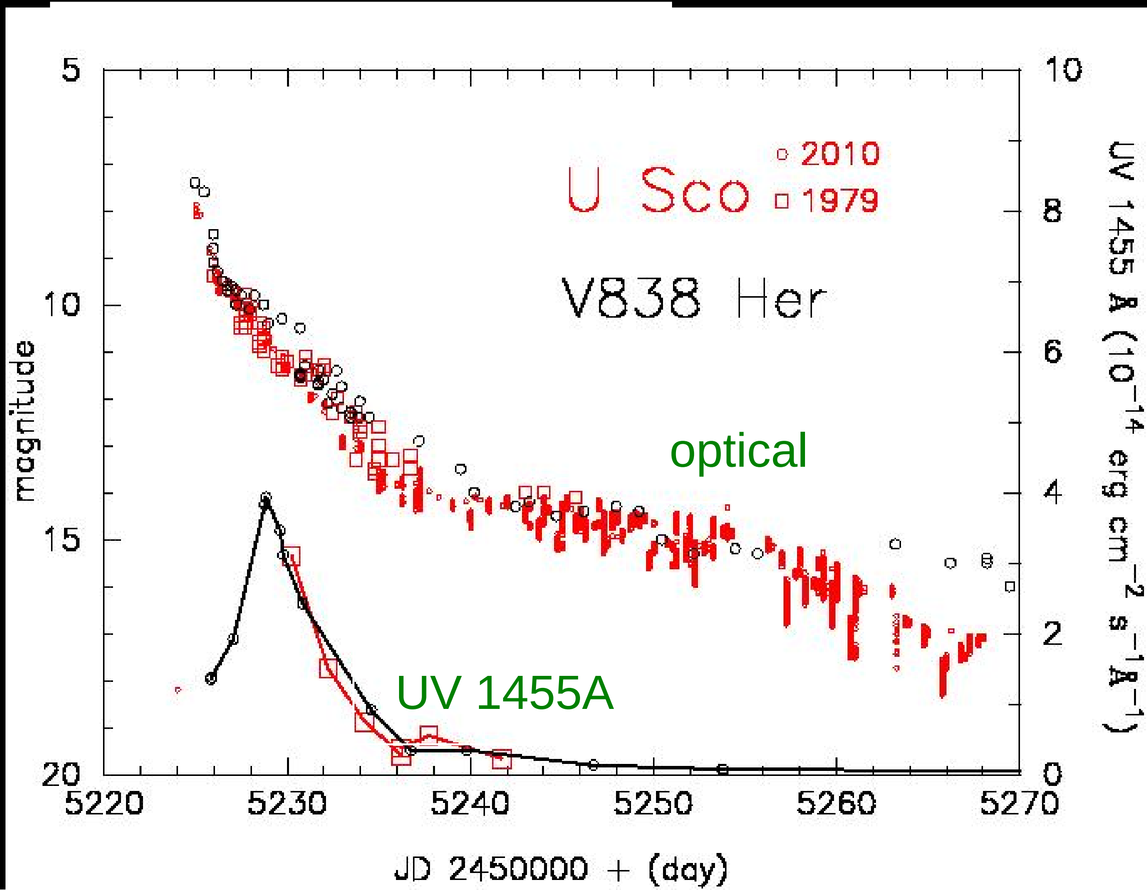
M_{WD} ↗

V838 Her *CN*

Classical nova

~1.35 M_o

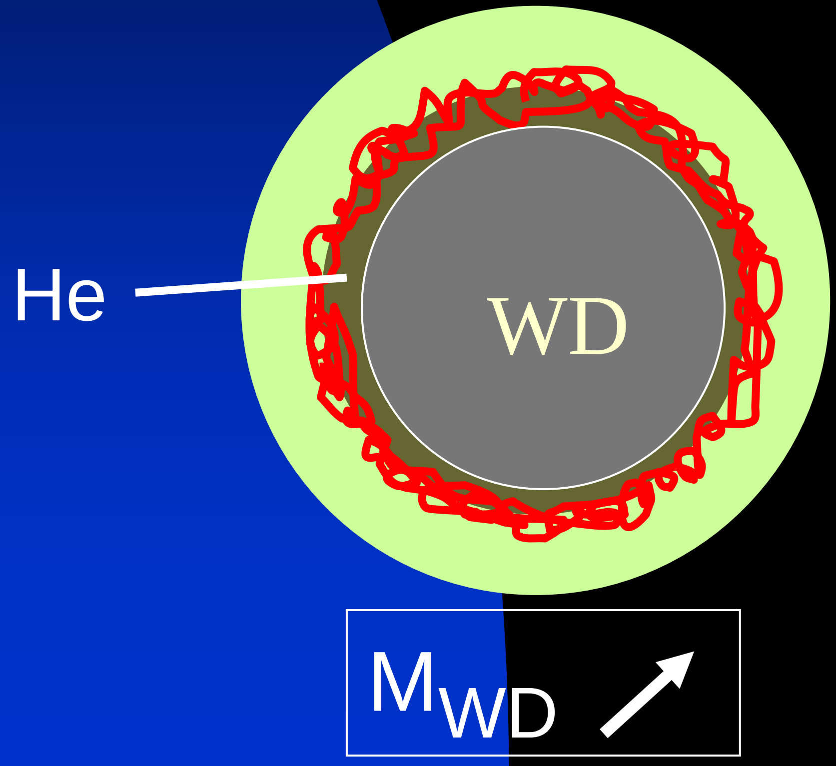
M_{WD} ↘

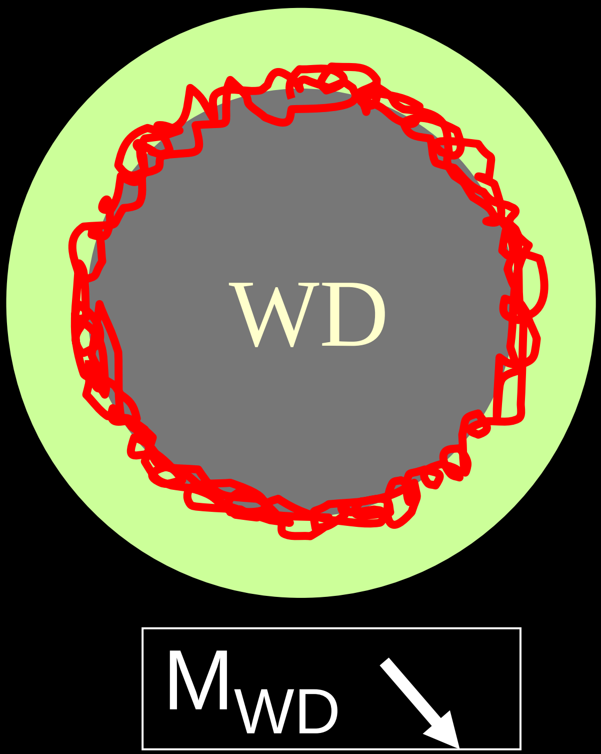


Recurrent nova and *classical* nova

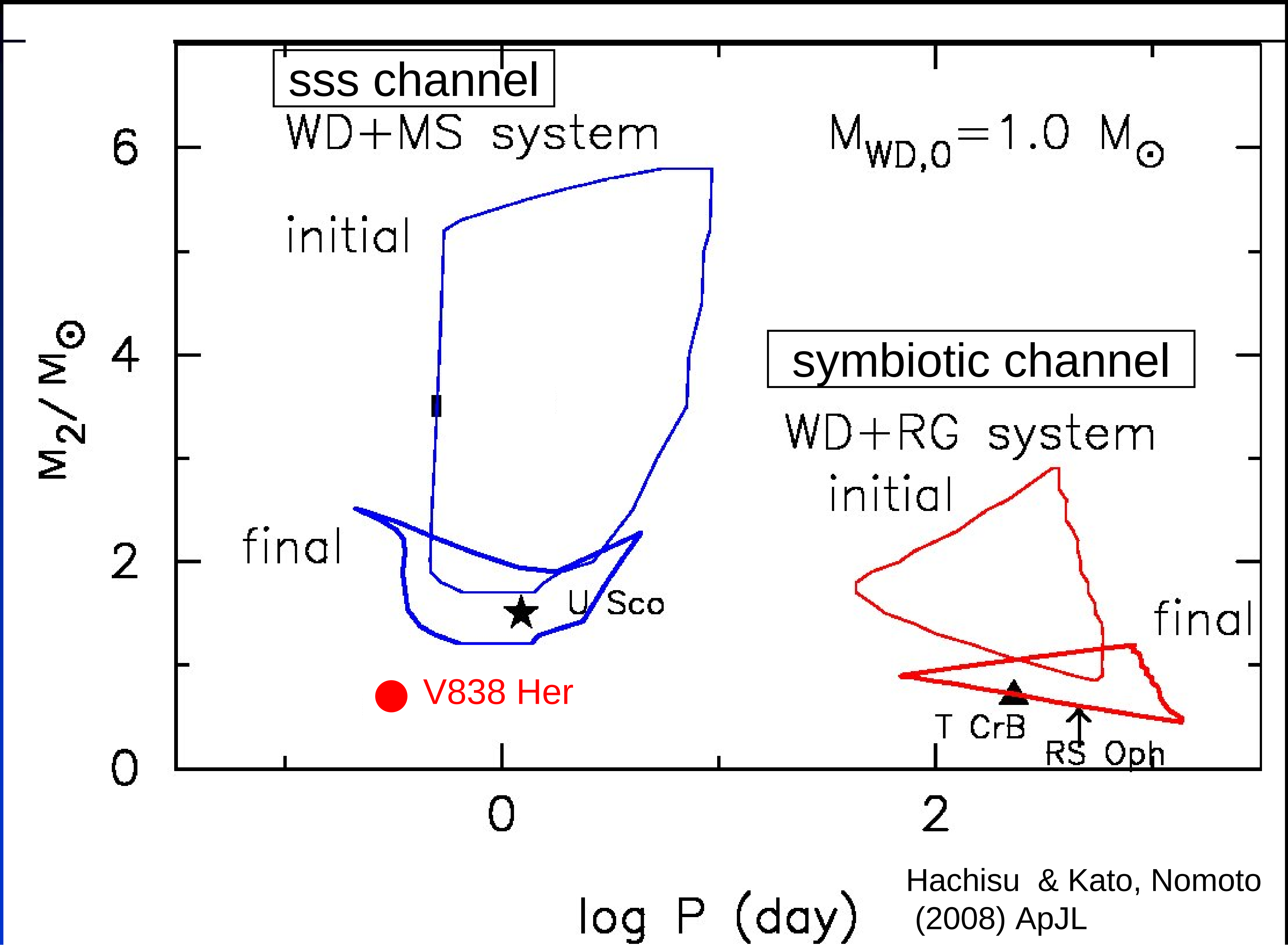
RN | *CN*

Ejecta : *Solar abundance* | *CO/ONeMg*-rich



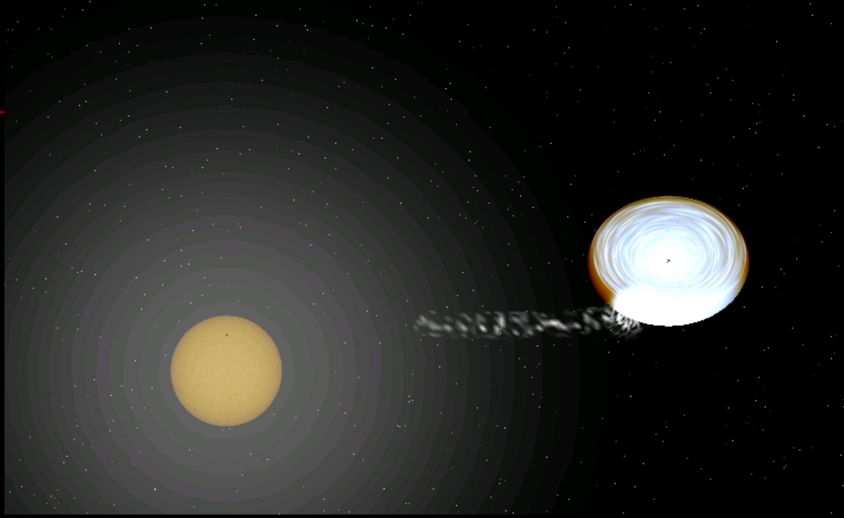


SN Ia : initial and final state of binary



Hachisu & Kato, Nomoto (2008) ApJL

RS Oph (Recurrent Nova)



Outburst: 1898,1933, 1958, 1967, 1985, 2006

P_{orb} : 457 days (Fekel et al. 2000)

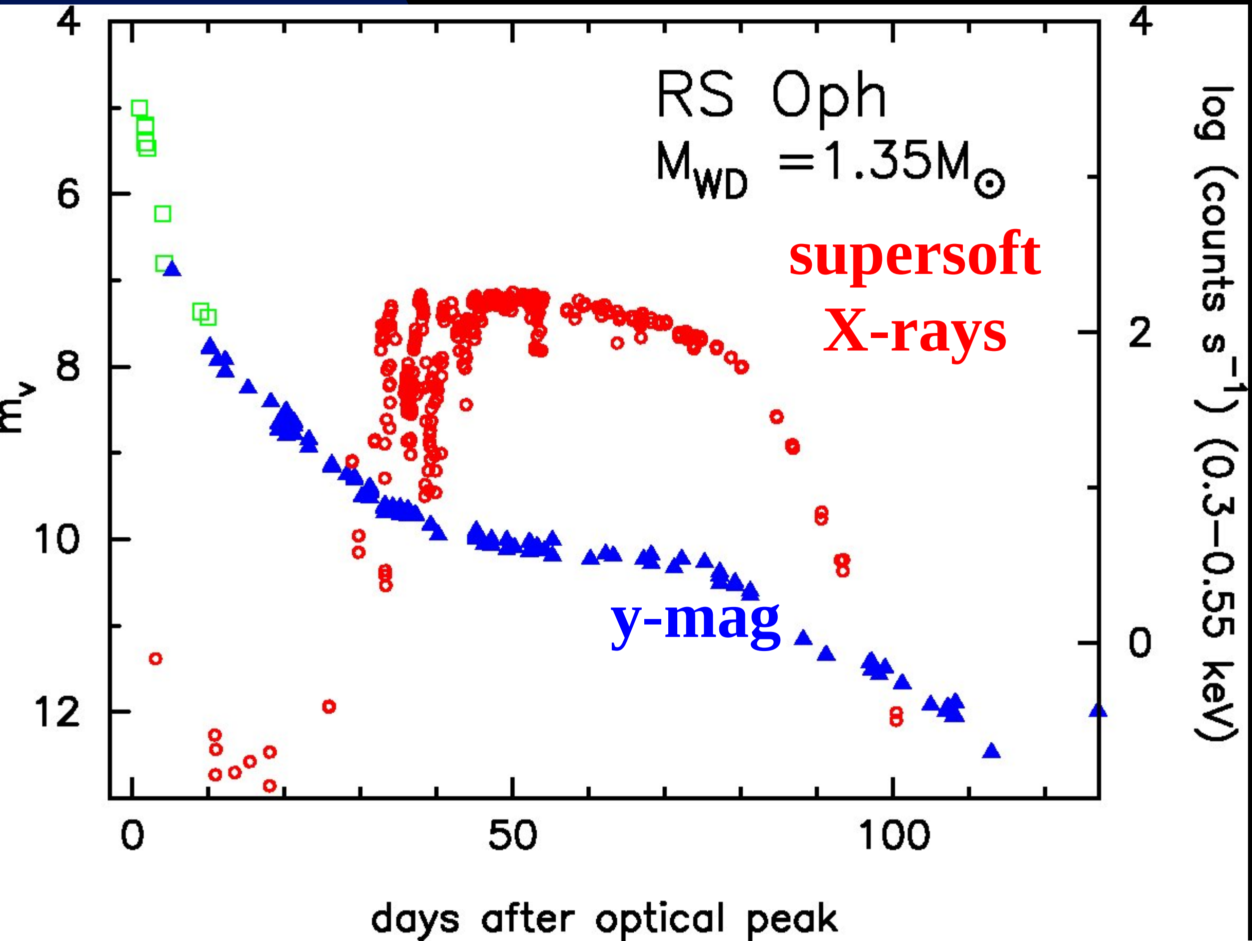
i : ~30-40 °

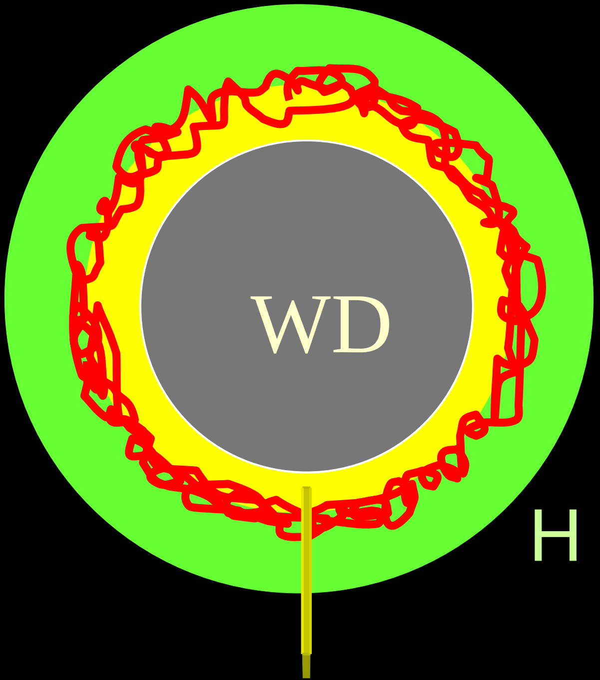
RG : M0 (Anupama & Mikolajewska 1999)

MIII (Evans et al. 1988)

well observed : radio ~ *X*-ray

RS Oph: 2006 outburst





hot *He* layer
(heat reservoir)

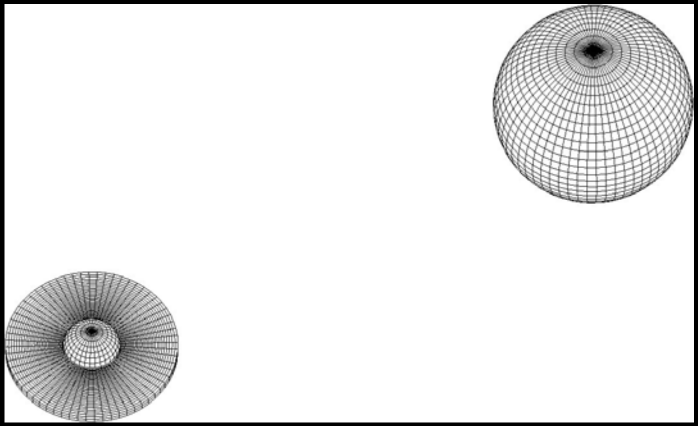
optical:

Hachisu et al. 2006 ApJL

X-ray :

Hachisu et al. 2007 ApJL

Light curve model

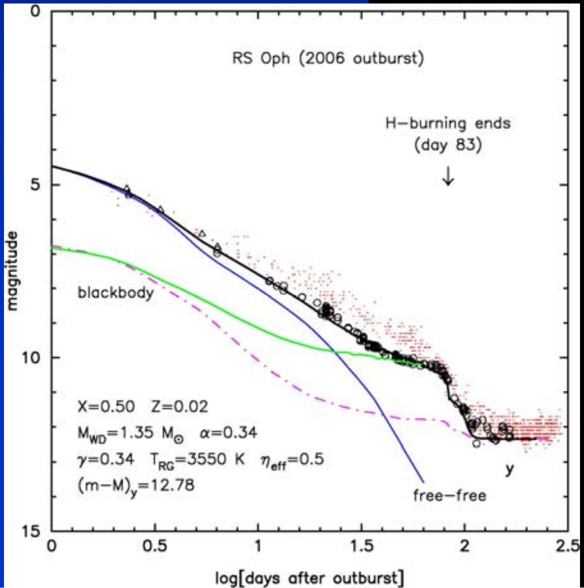


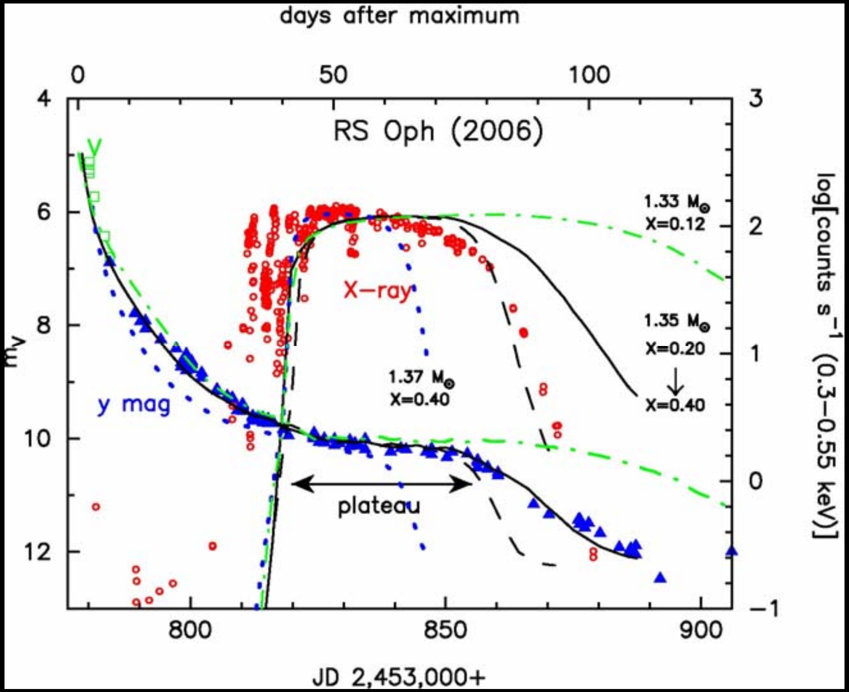
model: WD + disk + companion

WD: free-free emission

disk : irradiated (local T_{BB})

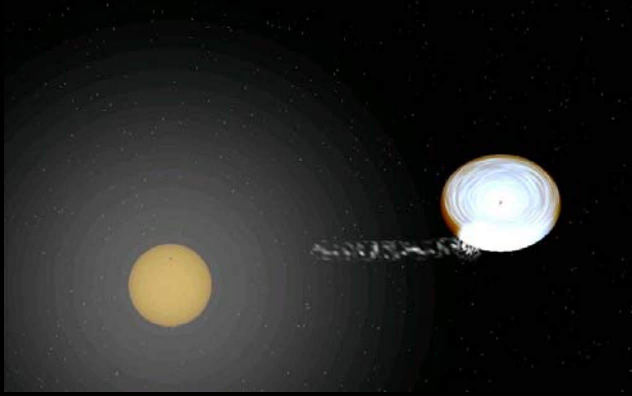
companion : irradiated





Hachisu et al (2006,2007)

RS Oph : summary



- WD mass : 1.35 ± 0.01 M_o
- composition: X=0.2-0.4
- distance : 1.3 – 1.7 kpc
- accreted mass: 4.x10^{-6} M_o (in 21 yrs)

  ejected mass: (2-2.8) x10^{-6} M_o (50-70%)

  remaining mass: (1.2-2) x10^{-6} M_o (30-50%)

  mean accretion rate: 2. x10^{-7} M_o/yr

WD mass: net growth rate (0.6-1) x10^{-7} M_o/yr

candidate of type Ia SN progenitor

RS Oph vs. V2491 Cyg

Similar in optical, but very different in X-rays

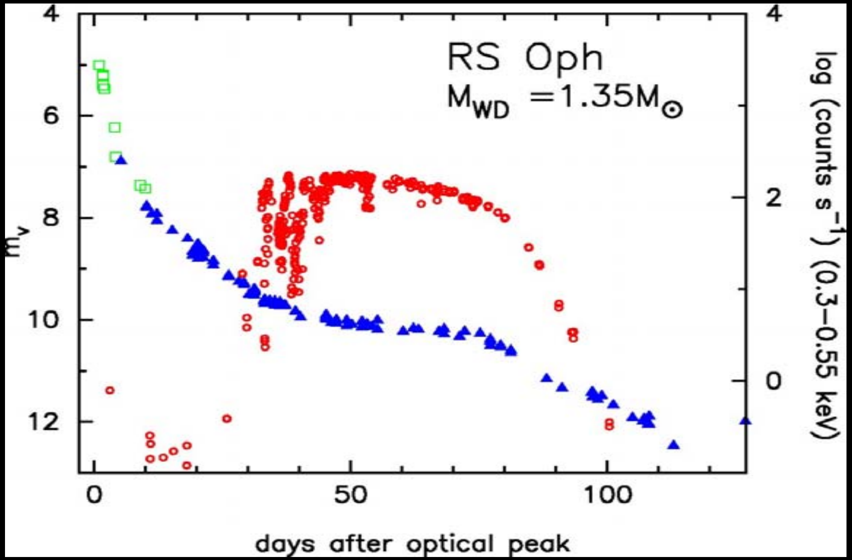
RS Oph

$M_{WD} \sim 1.35\ M_{o}$ ↗

No metal rich

Hachisu et al. (2006, 2007)

RN



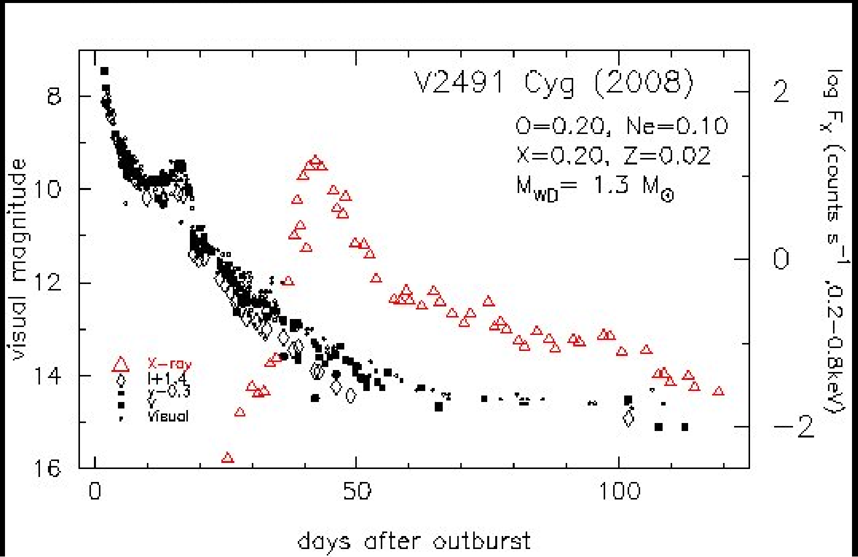
V2491 Cyg

$M_{WD} \sim 1.3\ M_{o}$ ↘

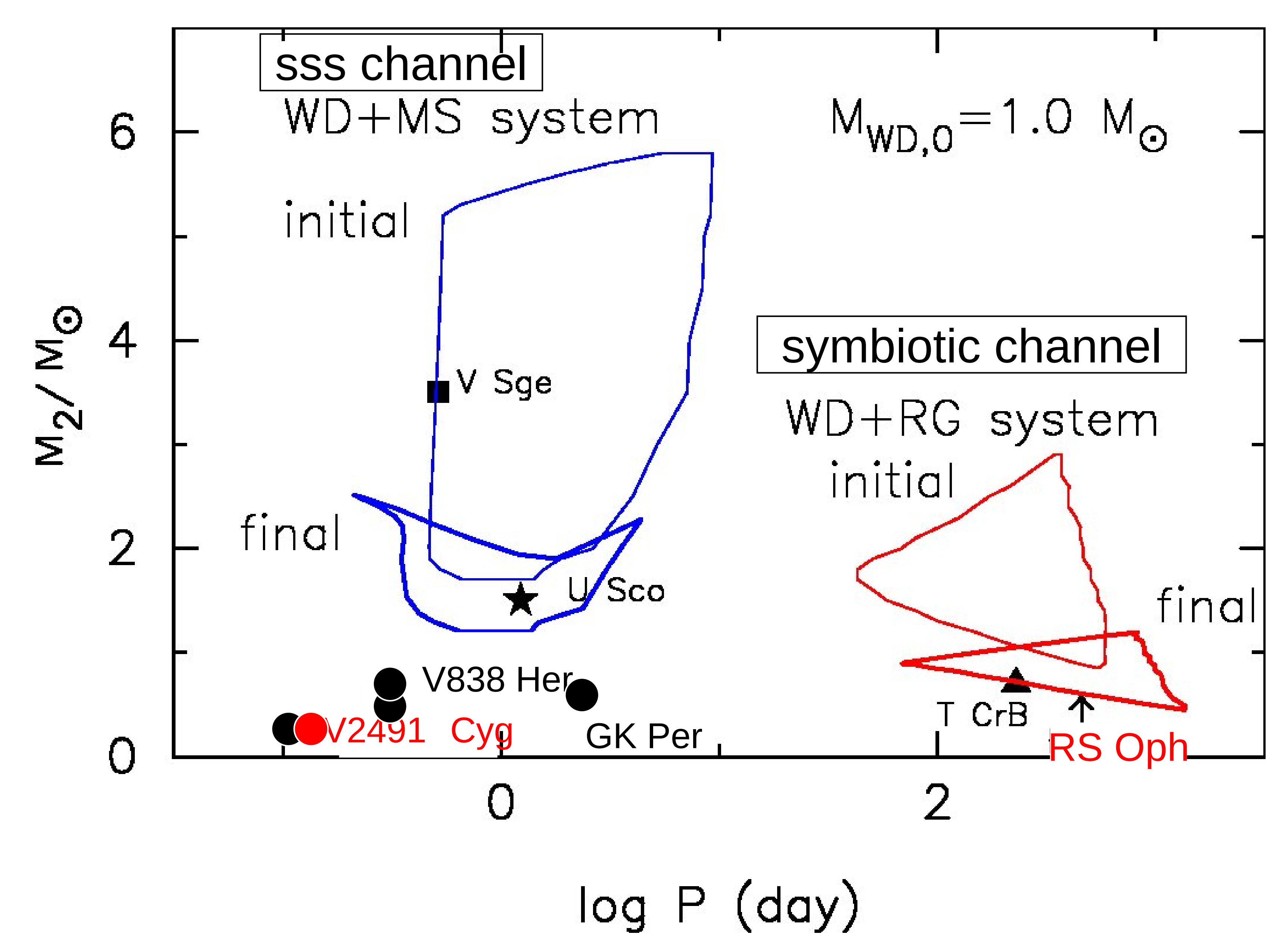
metal rich

Hachisu & Kato (2009)

CN



SN Ia : initial and final state of binary



V445 Pup (2000)
a He nova

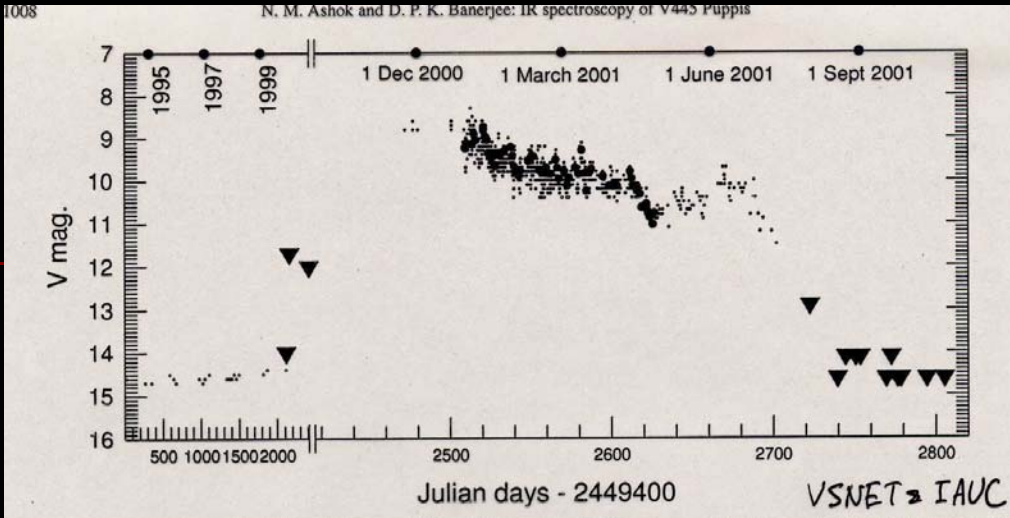


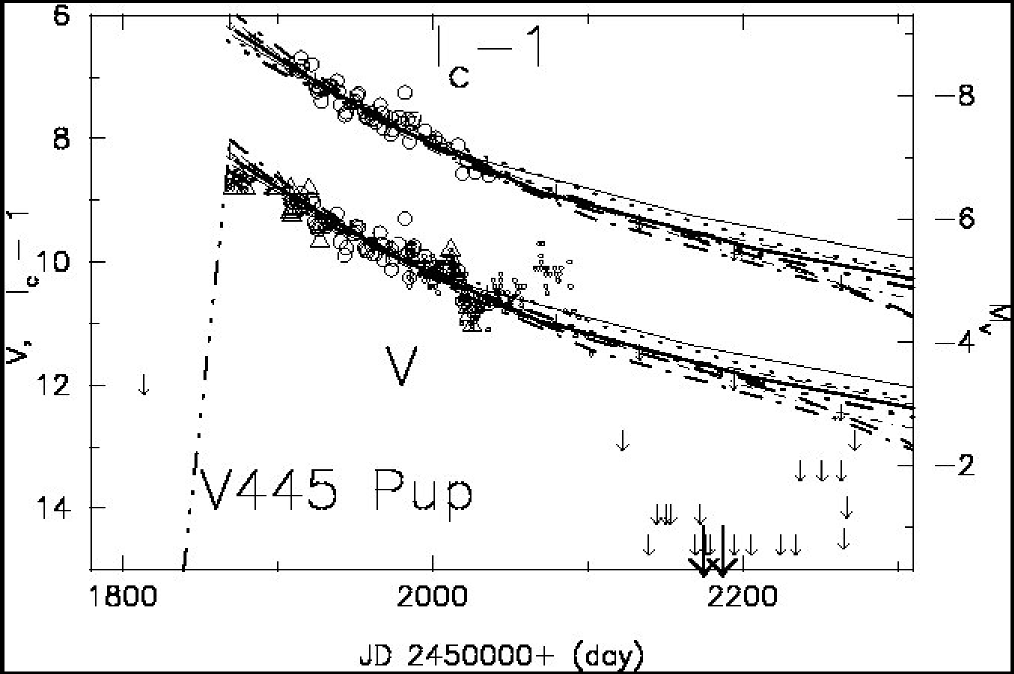
Fig. 1. The V-band lightcurve of V445 Puppis between 1994 to 2001 based on IAU circulars and VSNET reports. The small dots represent visual/photographic estimates and the circles represent photo-electric/CCD values. The triangles give upper limits on the magnitudes.

- no H lines
- strong emission lines C, Na, Fe,Ti, Cr, Si, Mg, etc.
- P Cyg profile
- resemble to slow classical novae => nova

Iijima & Nakanishi (2008) A&Ap

He nova: He burnig

V445 Pup : summary



- WD mass : 1.35 – 1.38 M_o
- Distance : 4-8 kpc
- WD mass : growth rate : ~ 50 %
- Candidate of type Ia SN progenitor

Kato et al (2008) ApJ, 684,1366

RX J0513-69 (LMC SSS)

- optical high & low state
- supersoft X-ray; only in optical low state

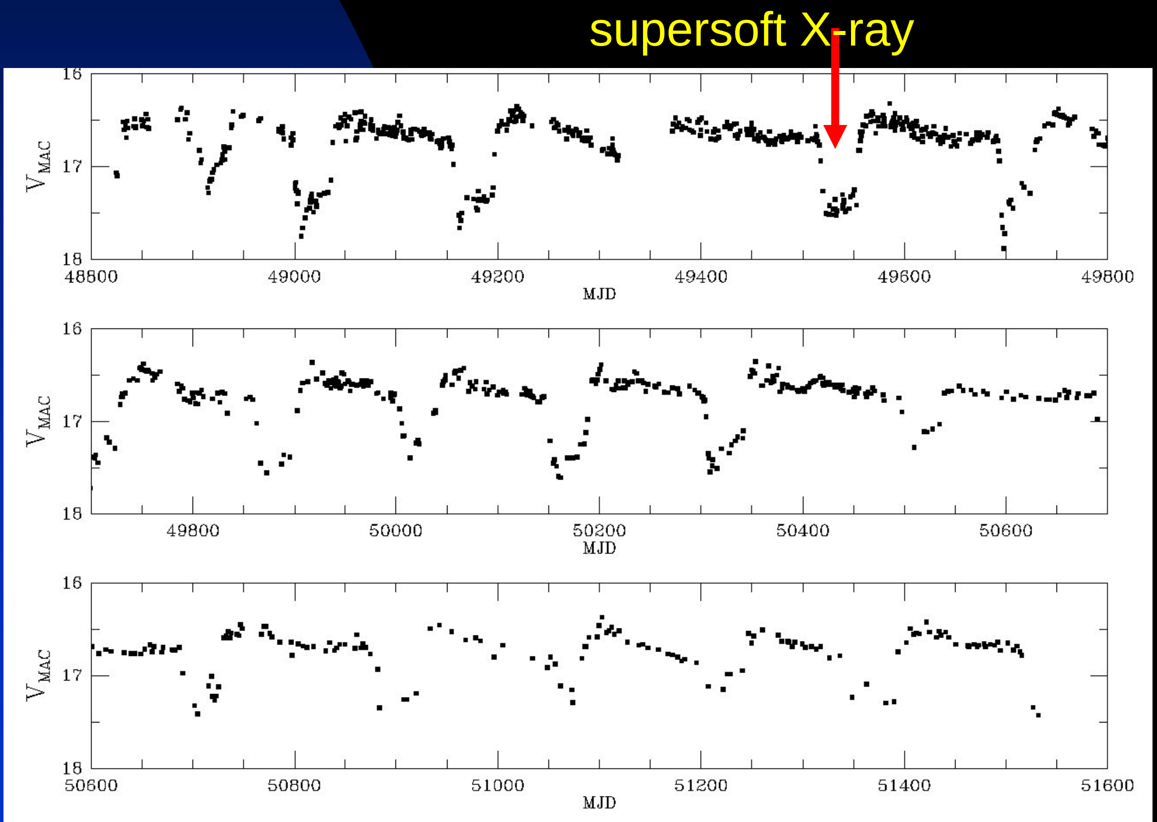


FIG. 1.—Long-term MACHO V_{MAC} light curve of RX J0513.9−6951 showing its high and low optical states.

Schaeidt et al (1993)
Reinsch et al (1996)
Southwell et al（1996)
McGowan et al. (2005)
Burwitz et al. (2008)

Cowley et al. (2002) AJ 124, 2233

Model

Accretion wind

$\dot{M}_{acc} > \dot{M}_{cr} \sim 0.75 \times 10^{-6} (M_{WD}/M_o - 0.4)\ M_o/yr$ → Winds

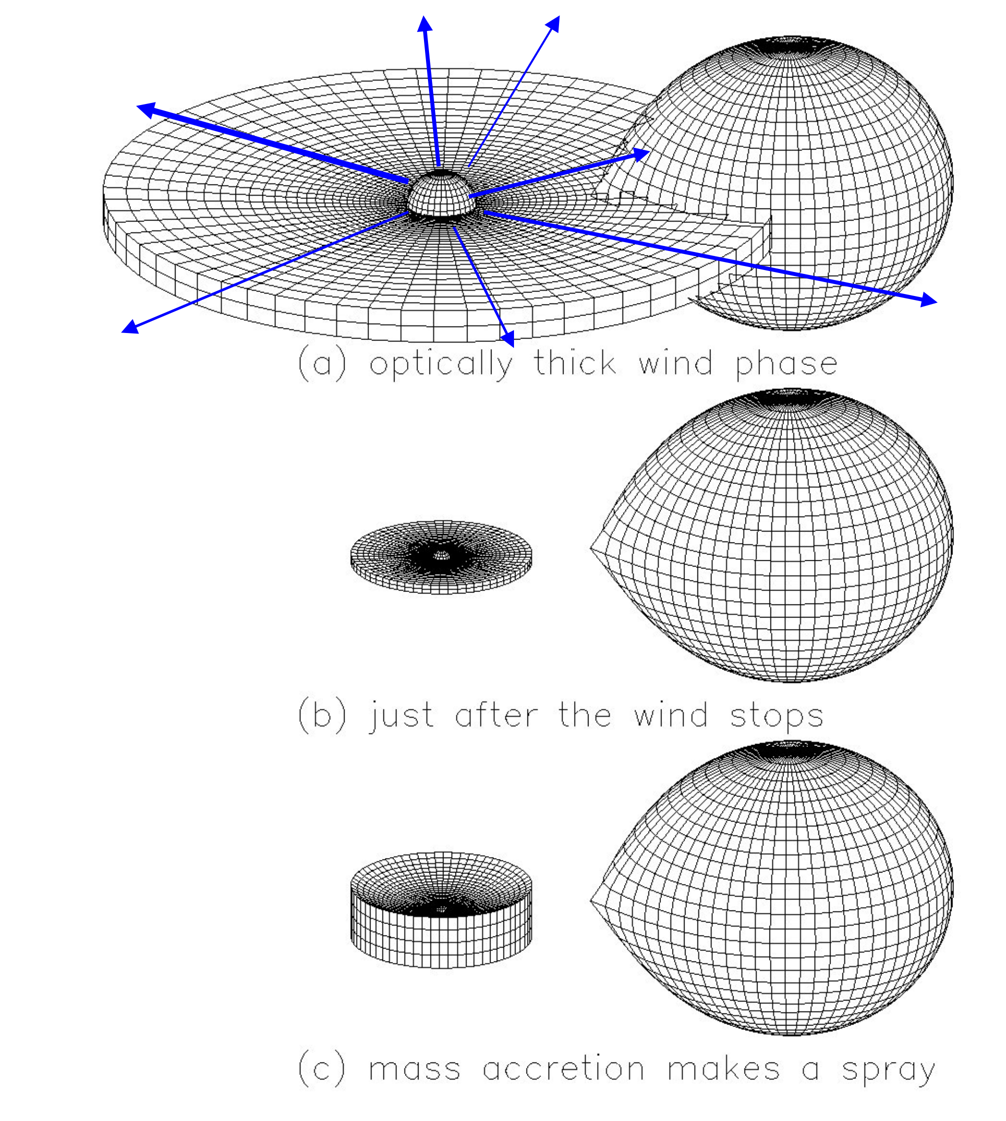
disk and companion are spattered by the wind

companion surface is stripped

↓

mass transfer stops

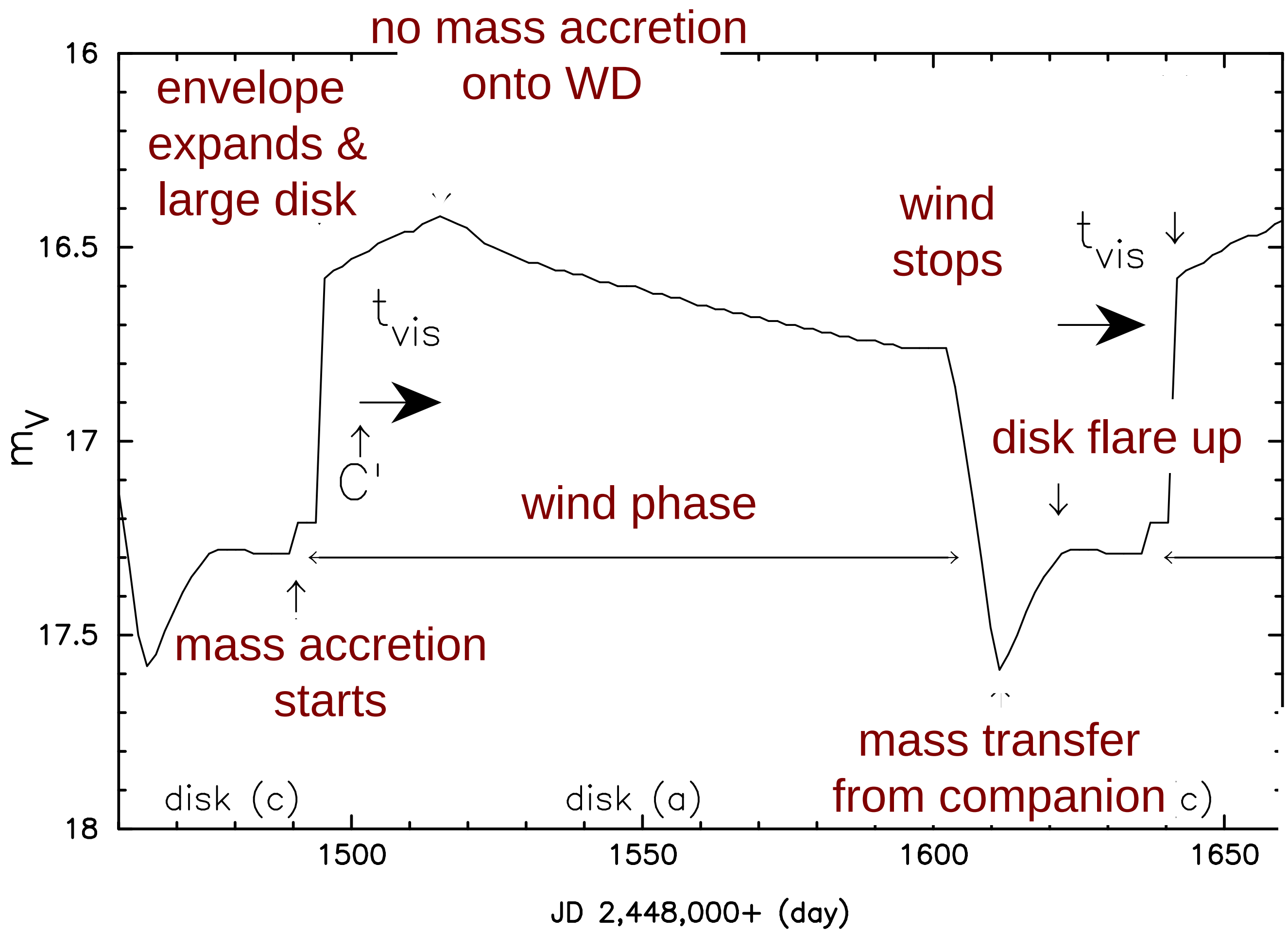
mass accretion makes a spray



optical: bright
no X-ray

optical: dark
X-ray

limit cycle of the light curve



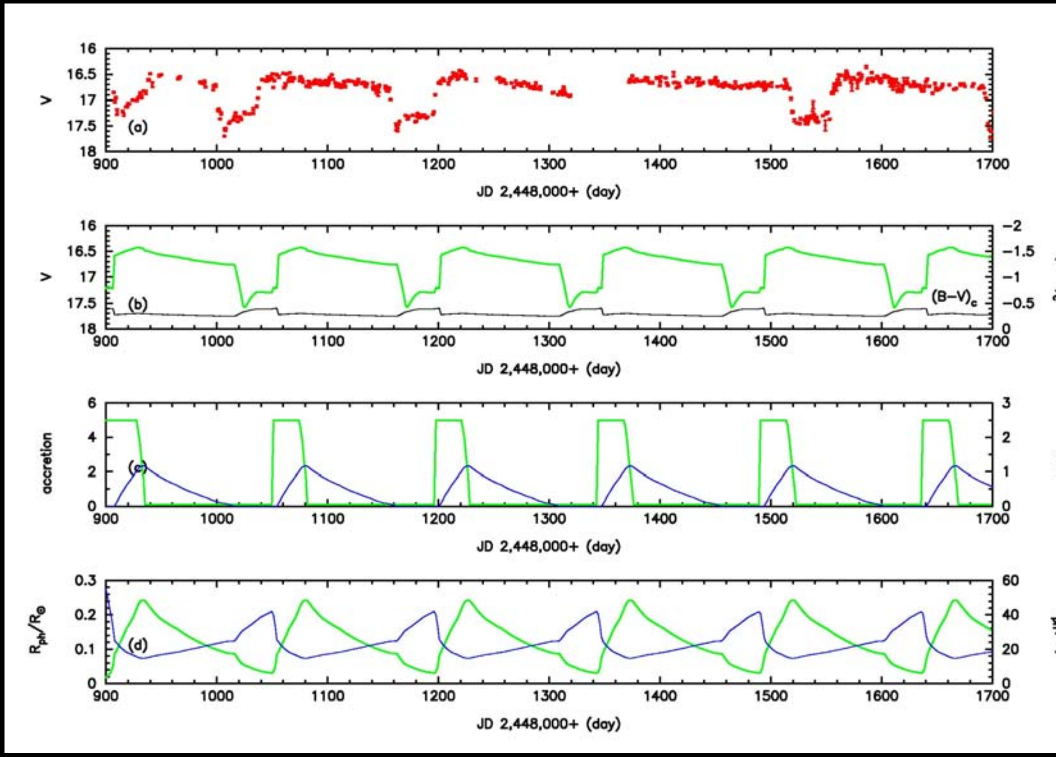
supported by *XMM* observation McGowan et al. (2005)

Hachisu & Kato, 2003, ApJ,590,445

RX J0513-69

Hachisu & Kato (2003) ApJ,590,445

M_{WD} =1.2-1.3 M_o



$$M_{\rm MS} = 2.5 - 3.0\ M_\odot$$

$$\dot{M}_2 \sim 5 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

$$\dot{M}_{\rm wind} \sim 0.4 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

(time averaged)

$$\dot{M}_{\rm 2,strip} \sim 4 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

Net growth rate

$$\dot{M}_{\rm WD} \sim 1 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

RX J0513 is a SN Ia progenitor

V Sge (galactic SSS)

M_{WD} = 1.2-1.3 M_o

$$M_{\rm MS} = 3.0 - 3.5\ M_\odot$$

$$\dot{M}_2 \sim 20 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

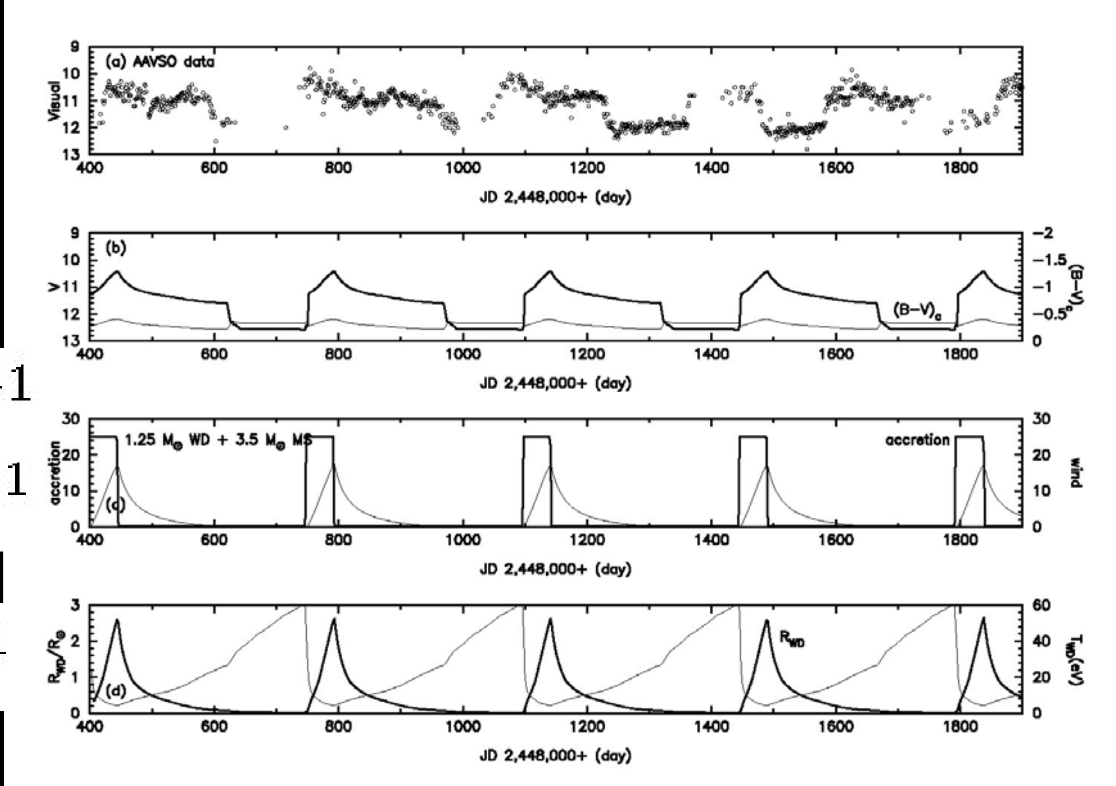
$$\dot{M}_{\rm wind} \sim 3 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

(time averaged)

$$\dot{M}_{2,\rm strip} \sim 16 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

Net growth rate

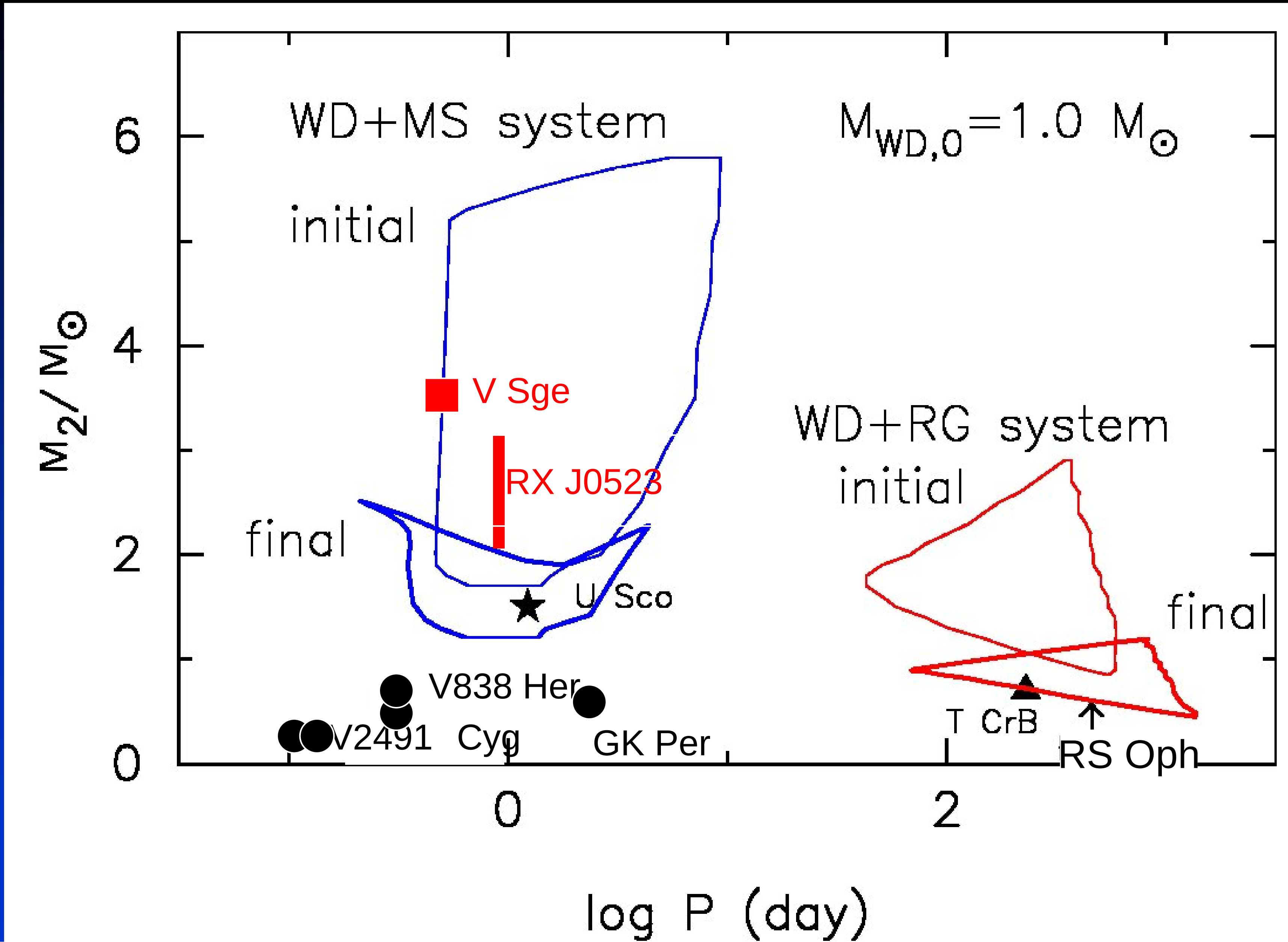
$$\dot{M}_{\rm WD} \sim 1 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$



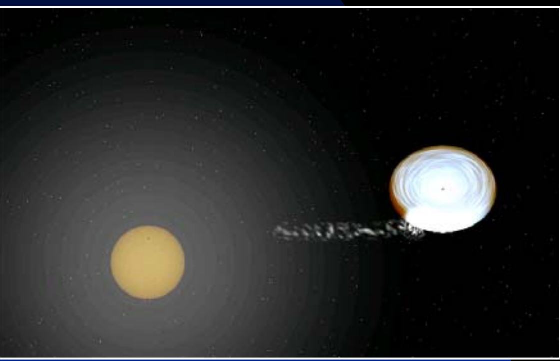
Hachisu & Kato (2003) ApJ, 598,527

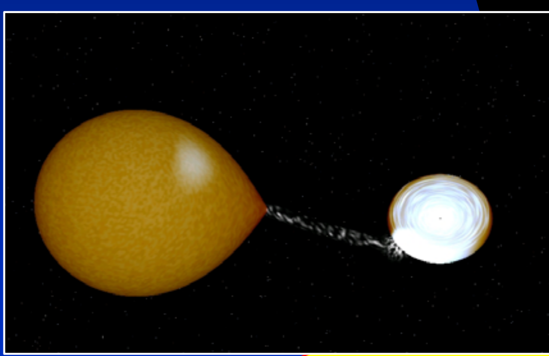
V Sge is a SN Ia progenitor

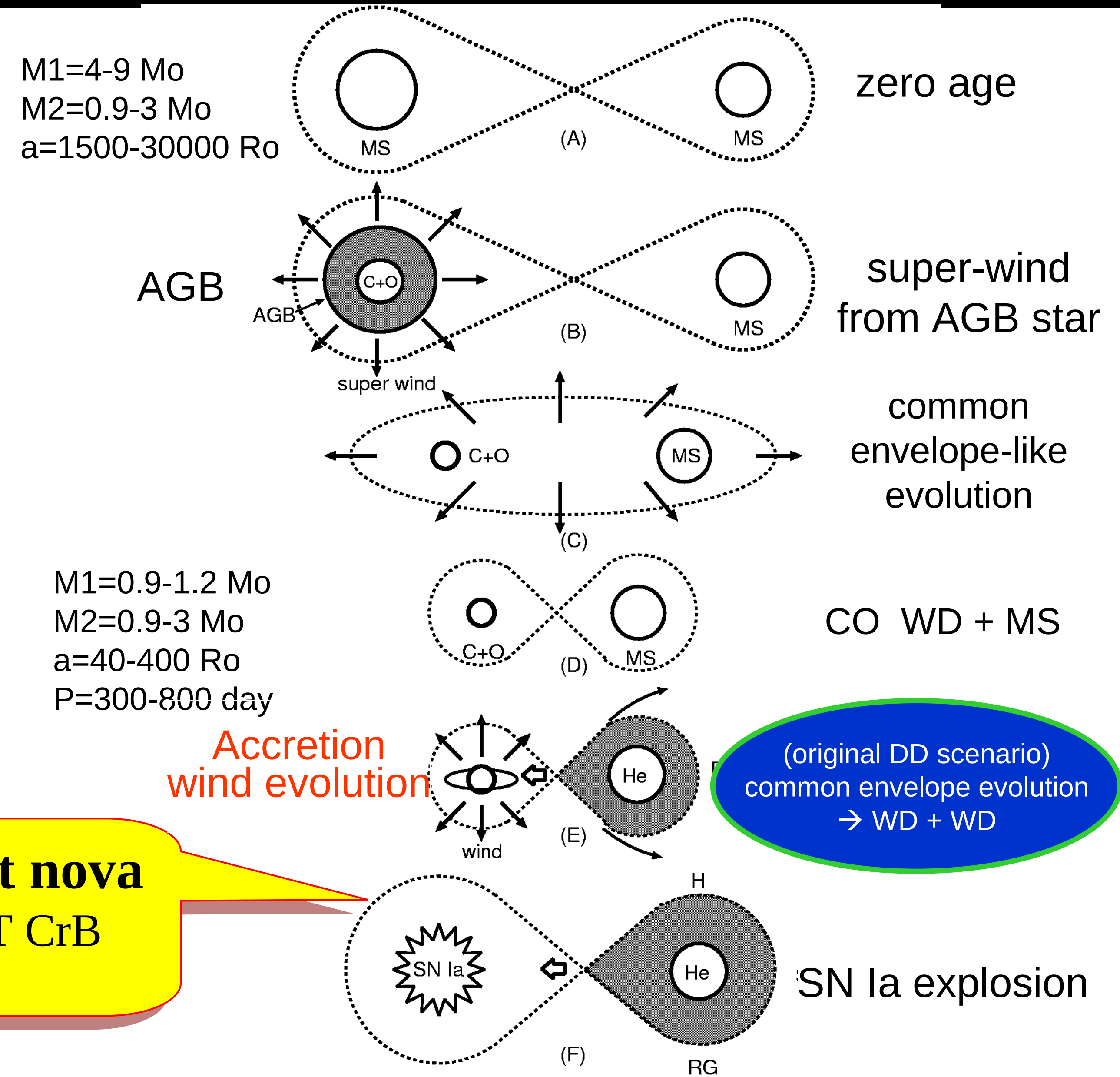
SN Ia : initial and final state of binary



Symbiotic channel in SD scenario





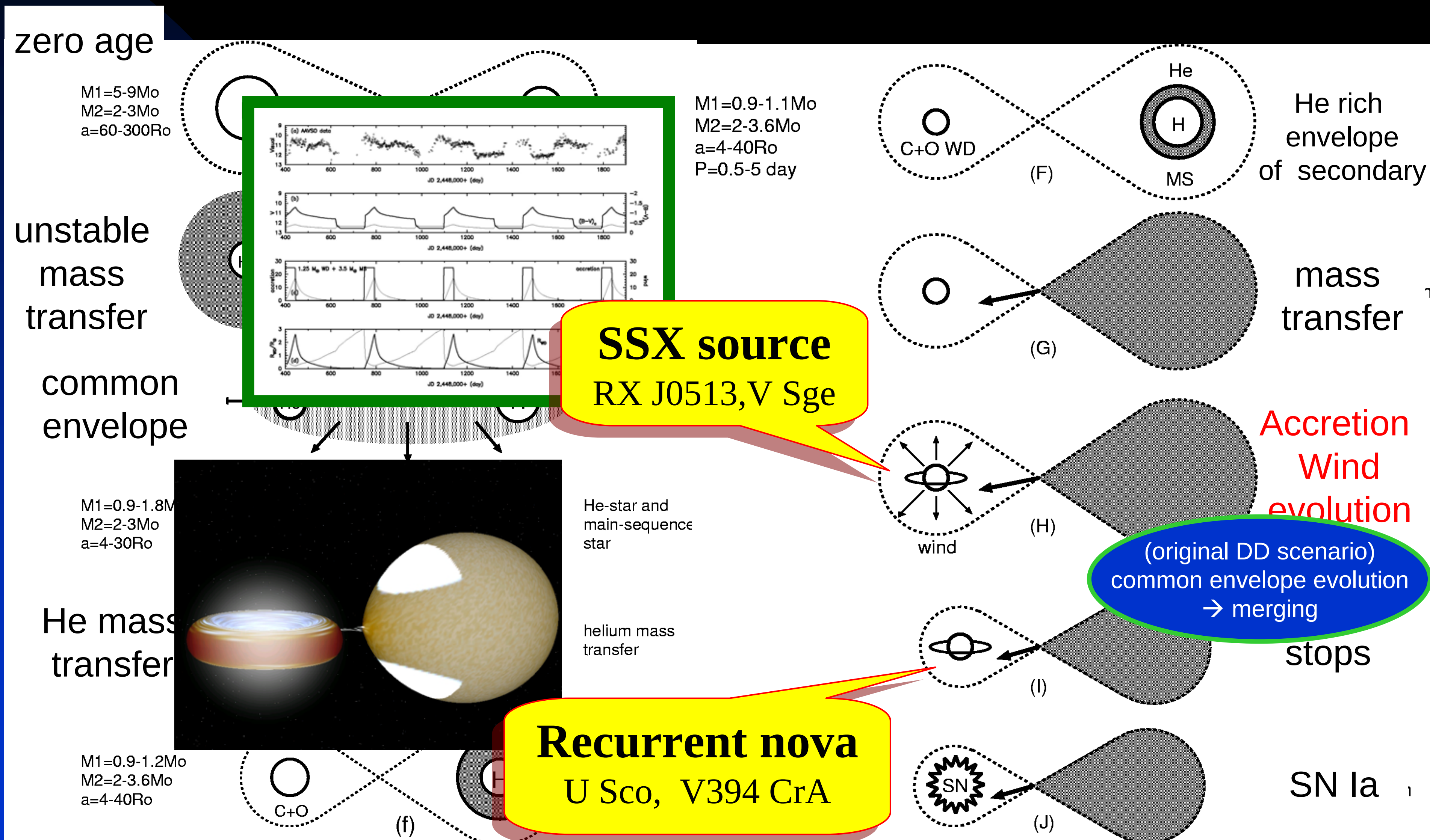


Recurrent nova

RS Oph, T CrB

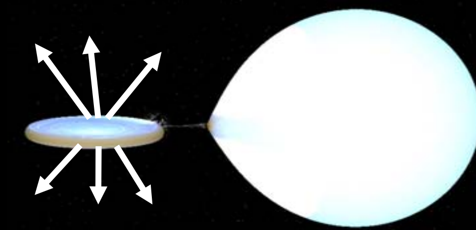
Hachisu et al 1999, ApJ

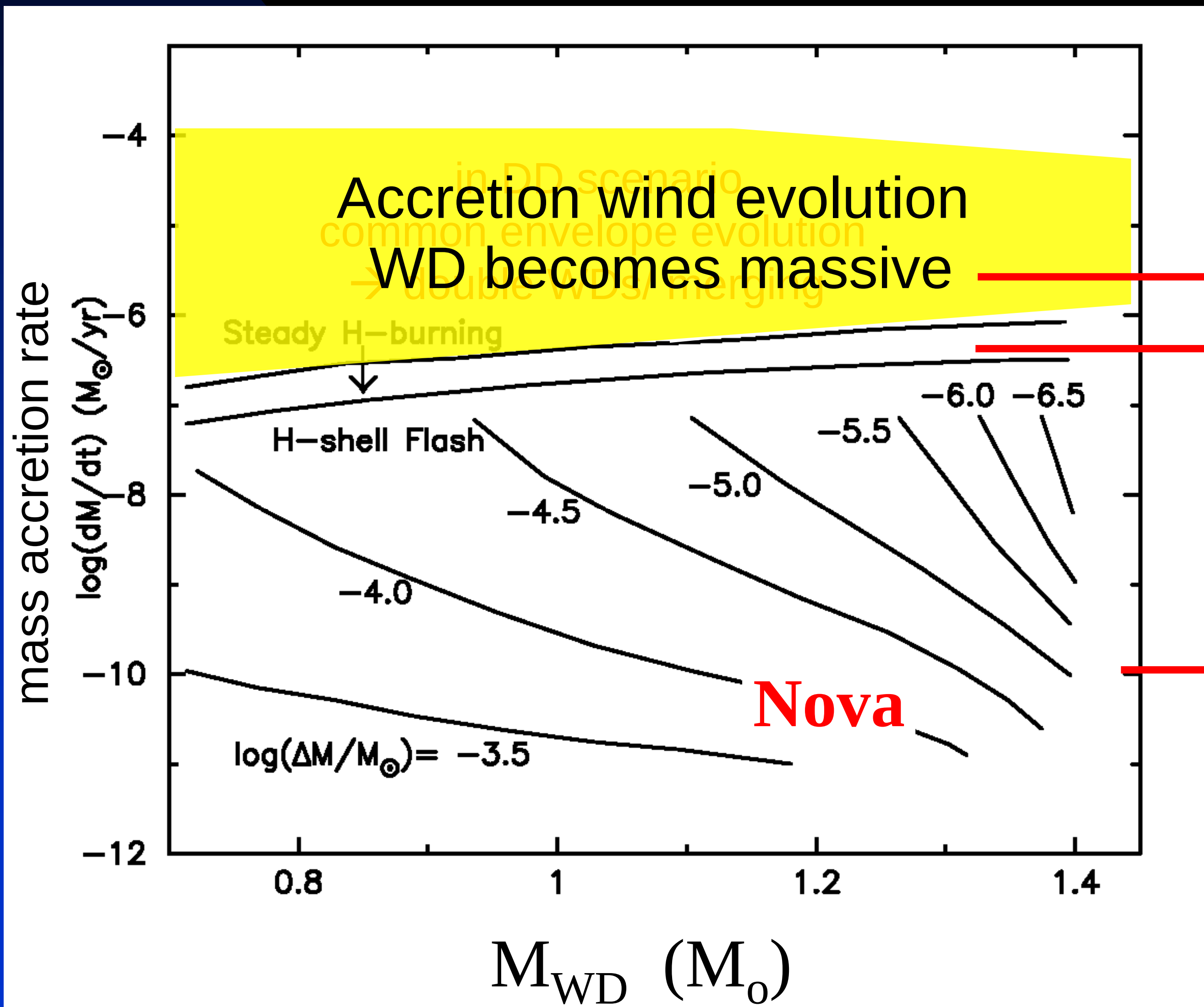
SSS channel in SD scenario



Hachisu & Kato 2003

Response of Accreting WDs





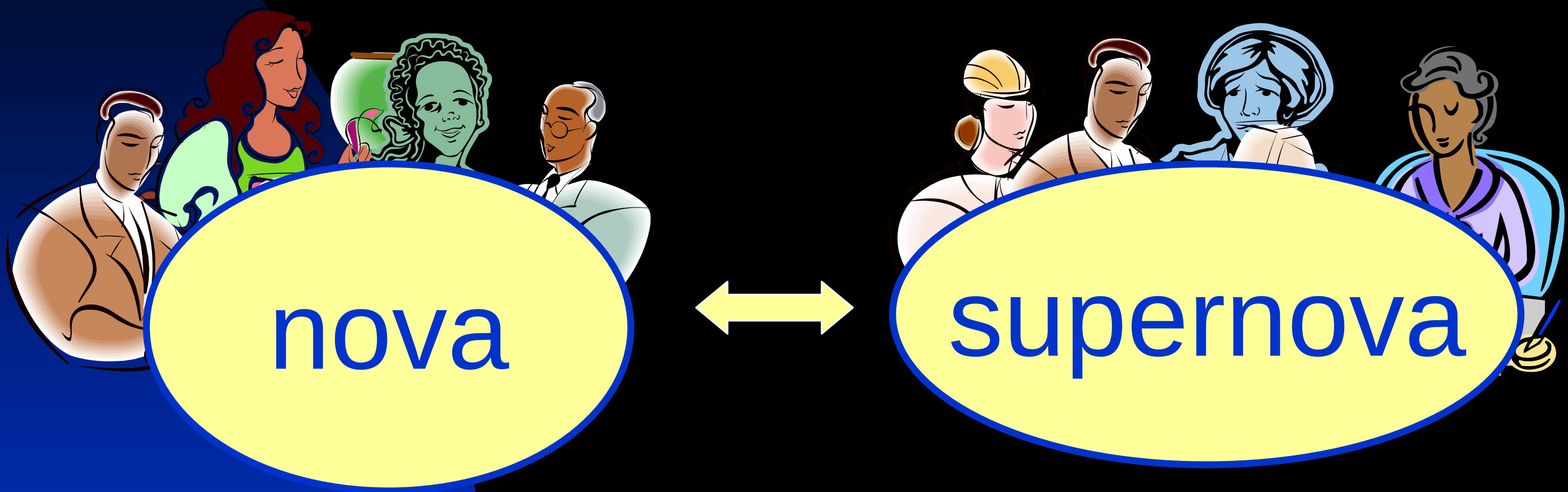
Accretion Wind

SSS source

Nova

Hachisu & Kato (2001)
ApJ 558,323

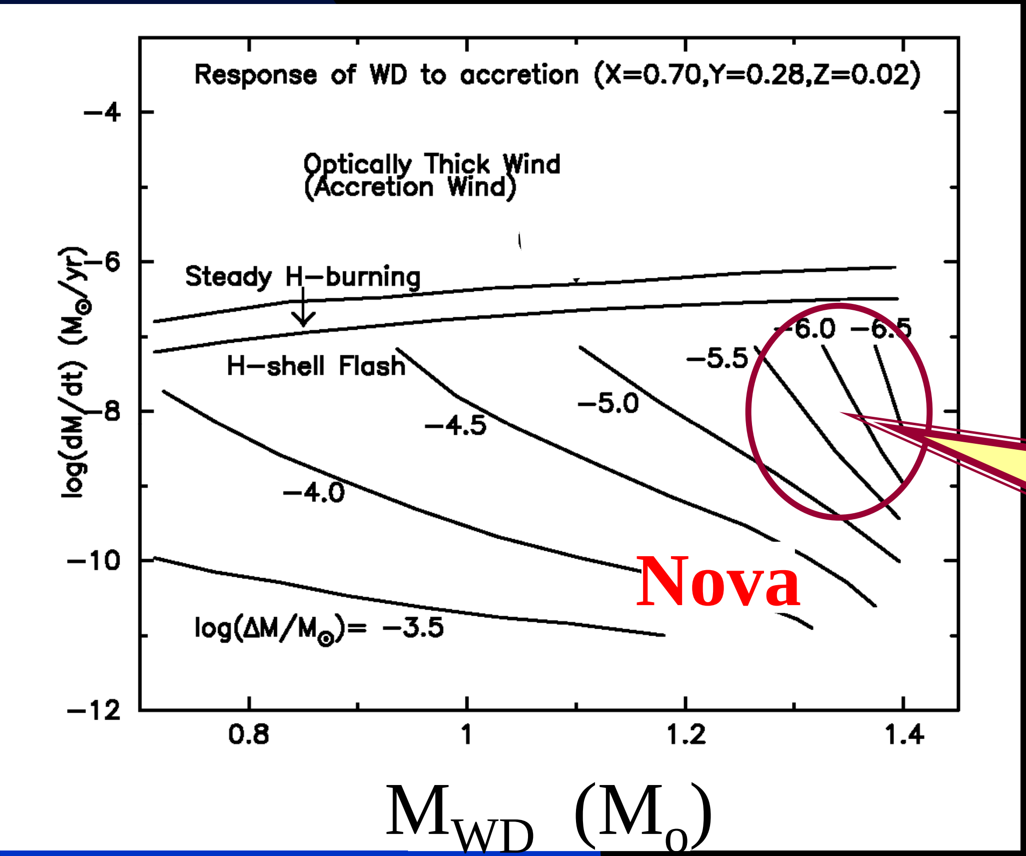
Nova & SN people need more *communication*



Physics of accreting WDs, widely accepted in nova, is *not known* in SN community

Starfield et al. (2004) ApJ, 612,L53

"surface H burning"



He "*found* "
No novae occur

$\dot{M}_{acc}$=10^{-9} - $8x10^{-7}$ M_o/yr

H-burning is stable !

SN Ia

Nomoto, Saio, Kato,& Hachisu (2007) ApJ, 663,1269

Wrong results

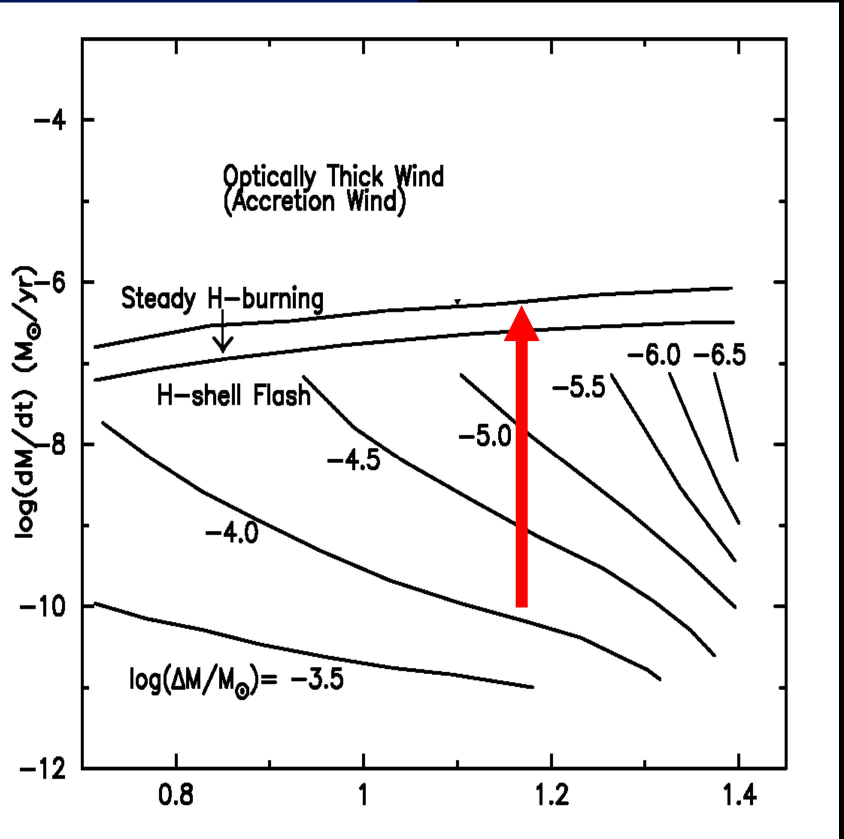
too small mesh point

too large time-step

King et al. (2003) MNRAS, 341, L35

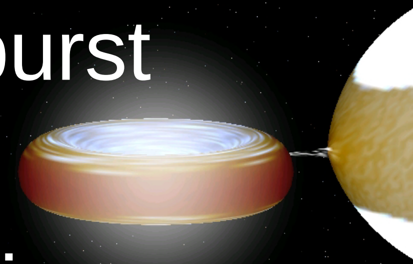
A new evolutionary channel for type Ia SN

"Dwarf nova causes steady H-burning"



M_{WD} (M_o)

Dwarf nova outburst
(disk instability)



$\dot{M}_{acc}$ temporal increase

↓

H steadily burns (no loss)

↓

WD grows → SN

However, H *does not ignite* during dwarf nova outburst

Necessary condition of shell flash

is *not* for the *mass-accretion rate*

but for the *envelope mass*

Shell flash occurs if

$M_{env} > M_{ig}$

$(P_c > P_{cr})$

much larger than M_{disk}

H burning is unstable → Nova → M_{WD} decreases

see also Hachisu et al (2010) ApJL

papers adopted King et al.' idea

population synthesis

during dwarf nova outburst: 100 x $\dot{M}_{acc}$

- Xu & Li (2009) AAp, 495,243
- Wang & Han (2010) RAA, 10, 235
- Wang, Li & Han (2010) MNRAS, 401, 2729

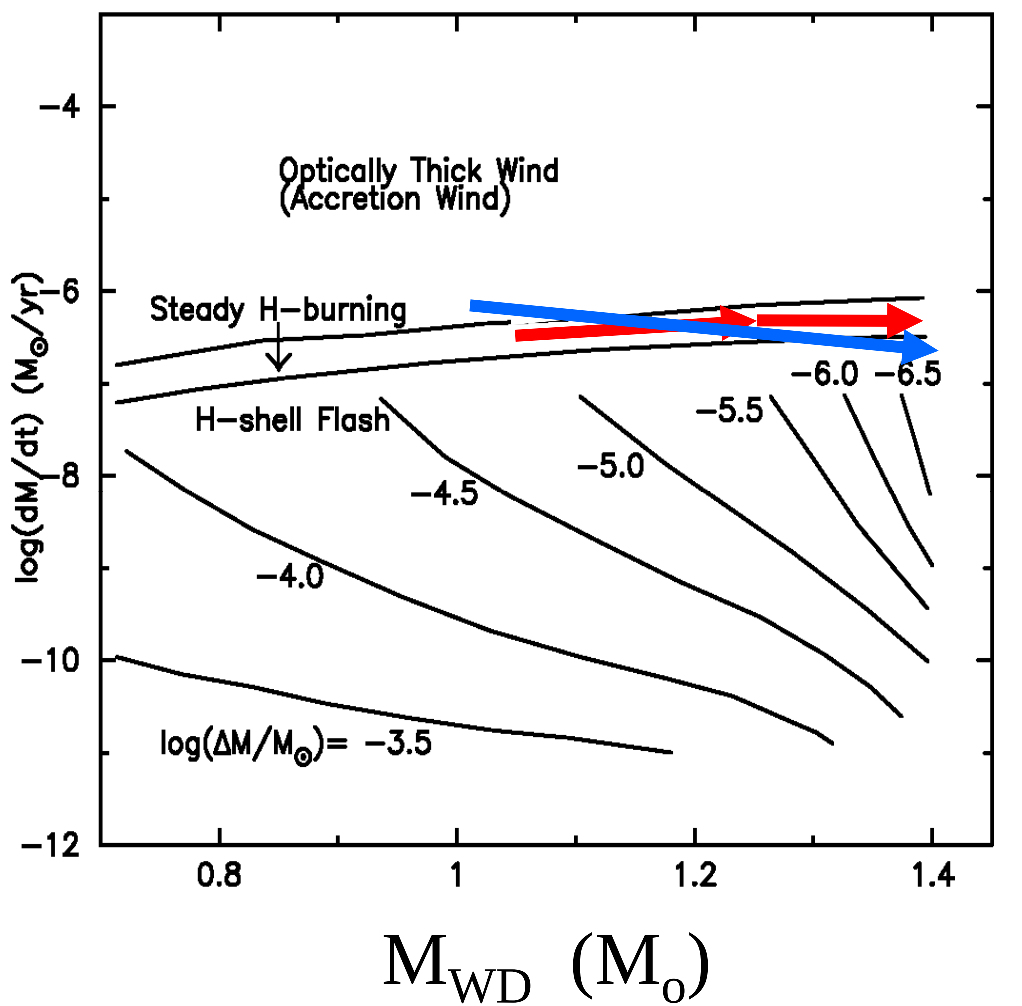
always 100x $\dot{M}_{acc}$

- Meng & Yang (2010) ApJ, 710,1310

These results have no astrophysical meaning

WDs evolve *along with* "steady burning zone" ?

to estimate number of SSS



$\dot{M}_{acc}$ decreases

Hachisu et al. (1999)
ApJ, 519, 314
ApJ, 522, 487

ignore
binary evolution
papers

many papers overestimate SSS phase, e.g.
Di Stefano (except recent)
Yungelson
Gilfanov & Bogdan (2010) Nature,463,924

DD scenario contains *no* supersoft X-ray source ?

DD scenarios predict SSS

- Yungelson (2005) AIPC, 797,1
- Tutukov & Fedorova (2007) AR,51,291
- Podsiadlowski (2010) AN 331,218

DD-merger is a bright supersoft X-ray source

L ~10^{38} erg/s, t ~ 10^5 yr

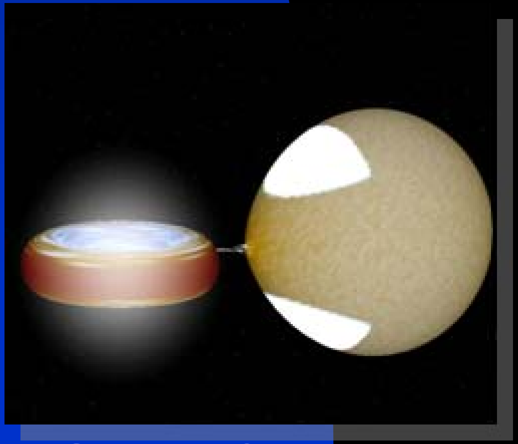
T ~ (0.5-1)x 10^6K

overproduction problem of SSS

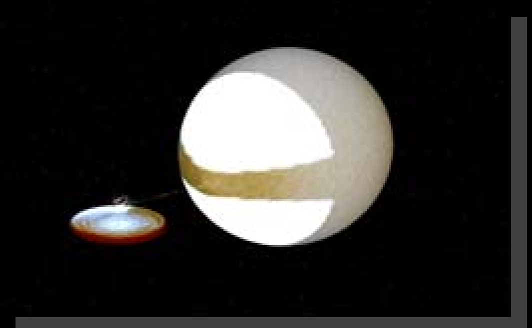
RS Oph : 1.35 Mo

T CrB 1.37 Mo

Thank you



U Sco : 1.37 Mo



V394 CrA : 1.37 Mo