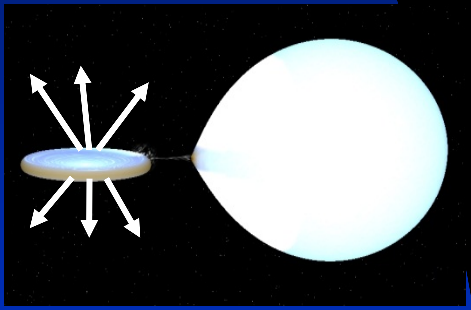
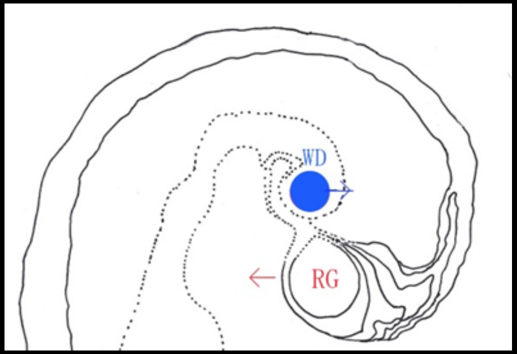
Progenitors of Type Ia supernovae:

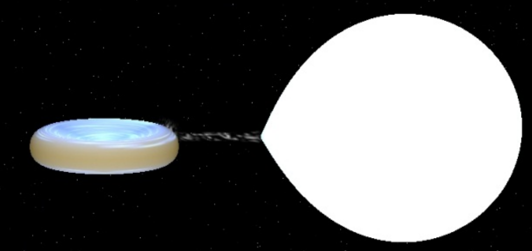
Accretion Wind Evolution, Supersoft X-ray Sources and Recurrent Novae



V Sge



SMC3



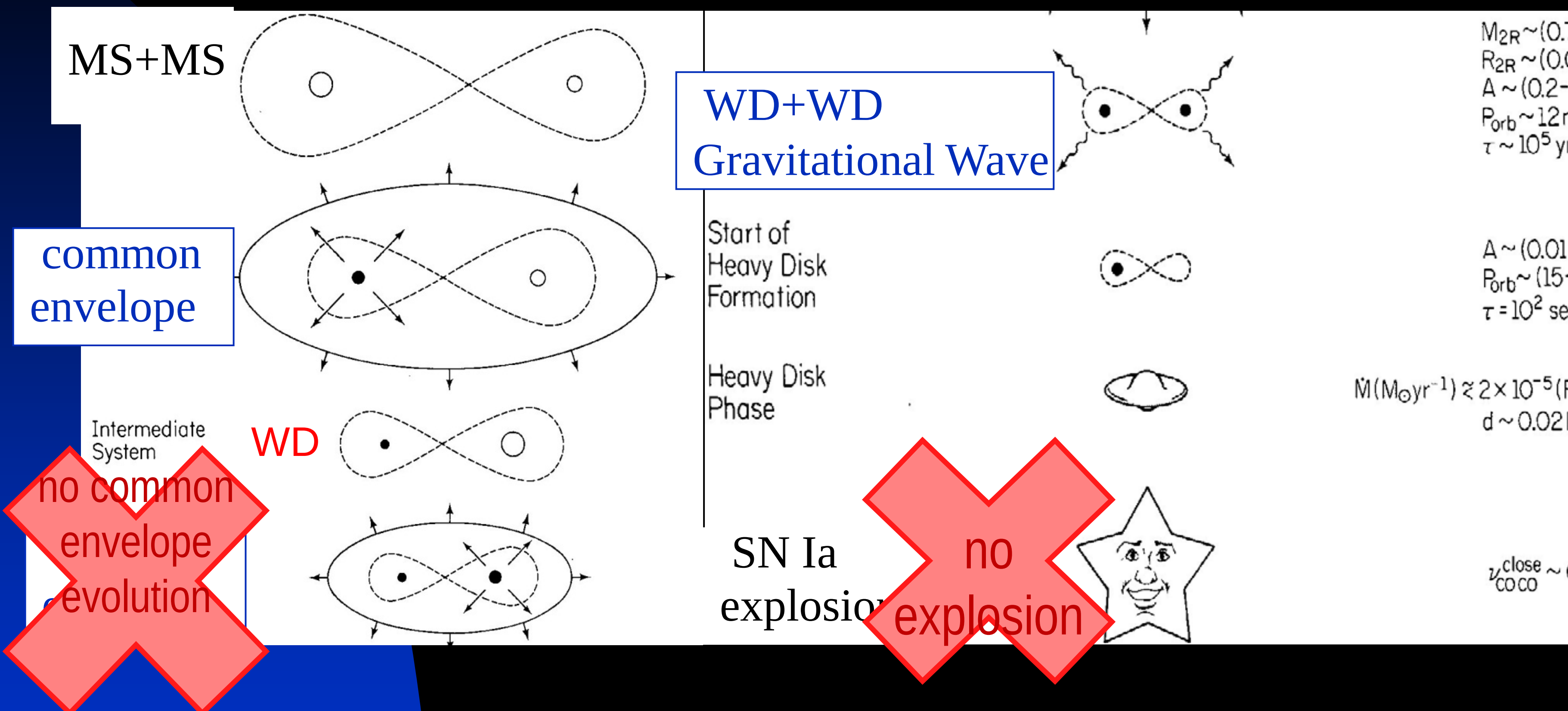
U Sco

Mariko Kato

IPMU 2012.11.29

DD scenario (Double Degenerate)

Webbink (1984), Iben & Tutukov (1984)

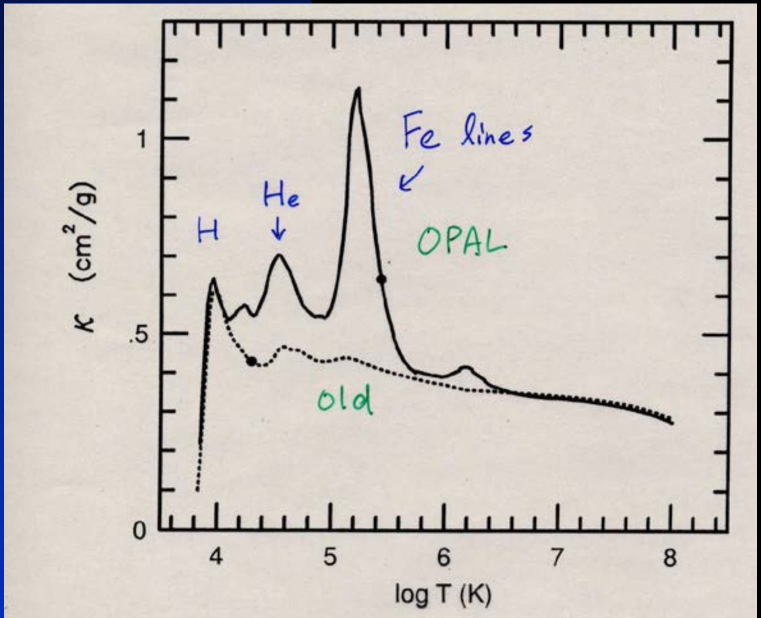


- contains *uncertain* parameters e.g.common envelope evol.
- *cannot* produce *RS Oph objects* Webbink (2008)

New opacity in 1990'

OPAL:Iglesias & Rogers

Solve stellar pulsation problem
Change interior *structure*



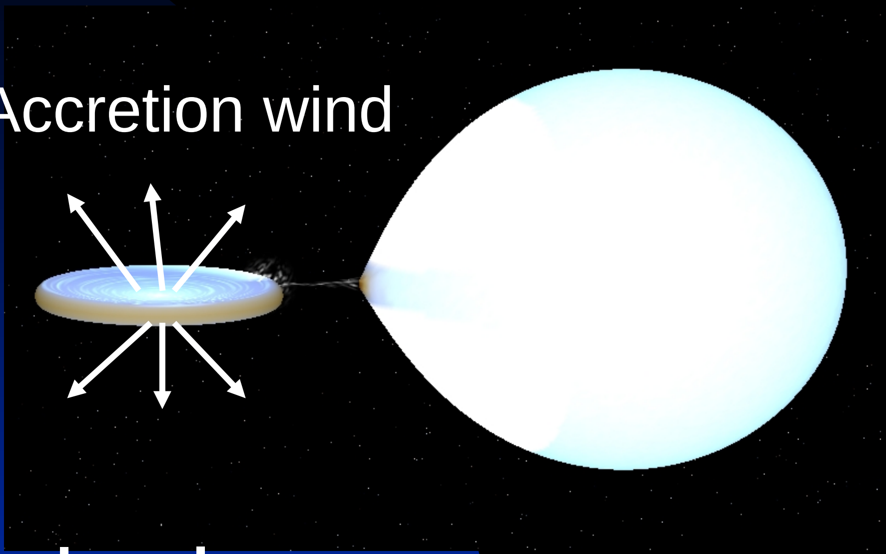
Kato & Hachisu (1994)

DD papers ***still use*** *old opacity*

Iben, Tutukov, Yungelson,
Cassisi, Piersanti, Tornambe,
Webbink

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

after New Opacity

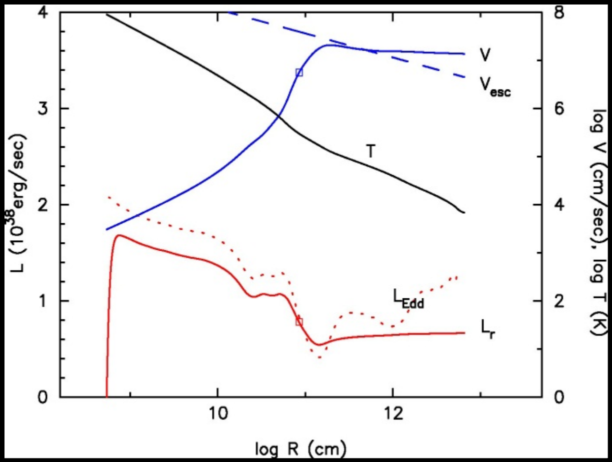


$\dot{M}_{acc} > \dot{M}_{cr}$

$\sim(0.75\text{-}1.2)\times10^{-6}(M_{WD}/M_o - 0.4)\ M_o/yr$

→ Winds

structure of a wind



mass transfer is stabilized

stability condition

$q < 0.79$

↓

$q < 1.15$ (stabilized)

$(q = M_{comp}/M_{WD})$

2nd common-envelope evolution does *not occur*

Hachisu, Kato & Nomoto (1996)

New *(correct)* evolutional scenarios

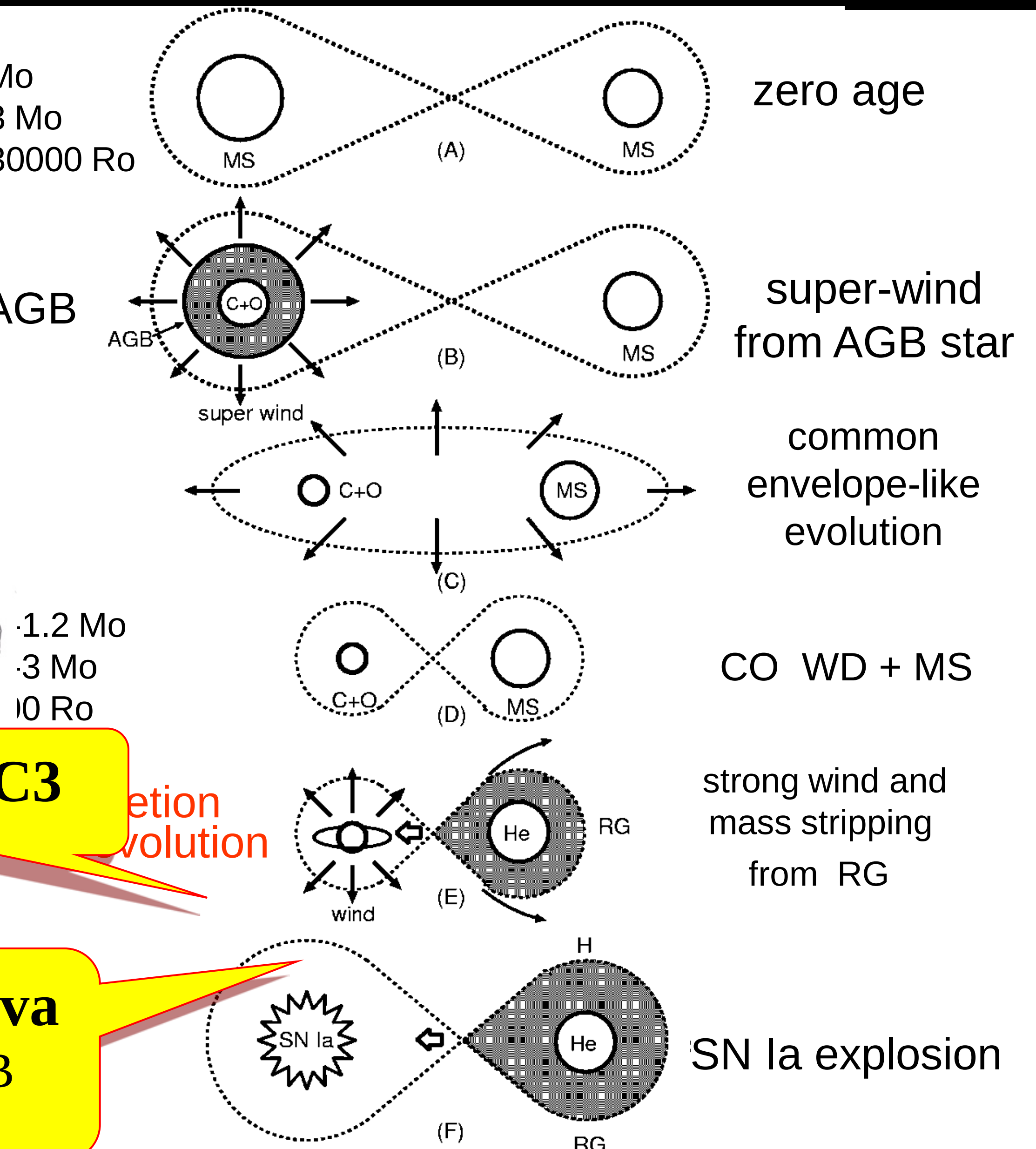
Original idea of SD
Whelan & Iben (1973)
denied by Iben himself

- Hachisu, Kato & Nomoto (1996)
- Li & van den Heuvel (1997)
- Hachisu, Kato & Nomoto (1999)
- Hachisu, Kato, Nomoto & Umeda (1999)

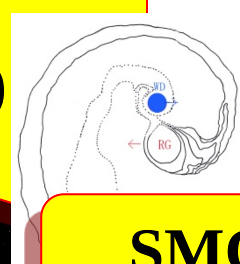
SD scenario (single degenerate)

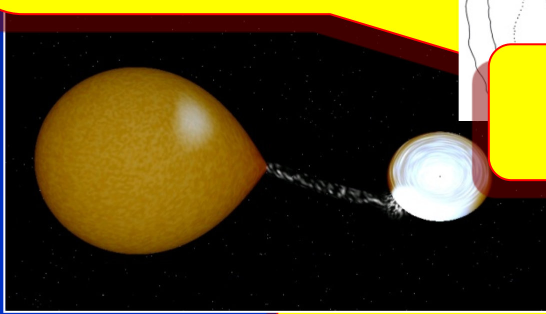
- Symbiotic channel
- WD + MS channel

Symbiotic channel in SD scenario



supersoft X-ray sources in E-Galaxes (Gilfanov&Bogdan)





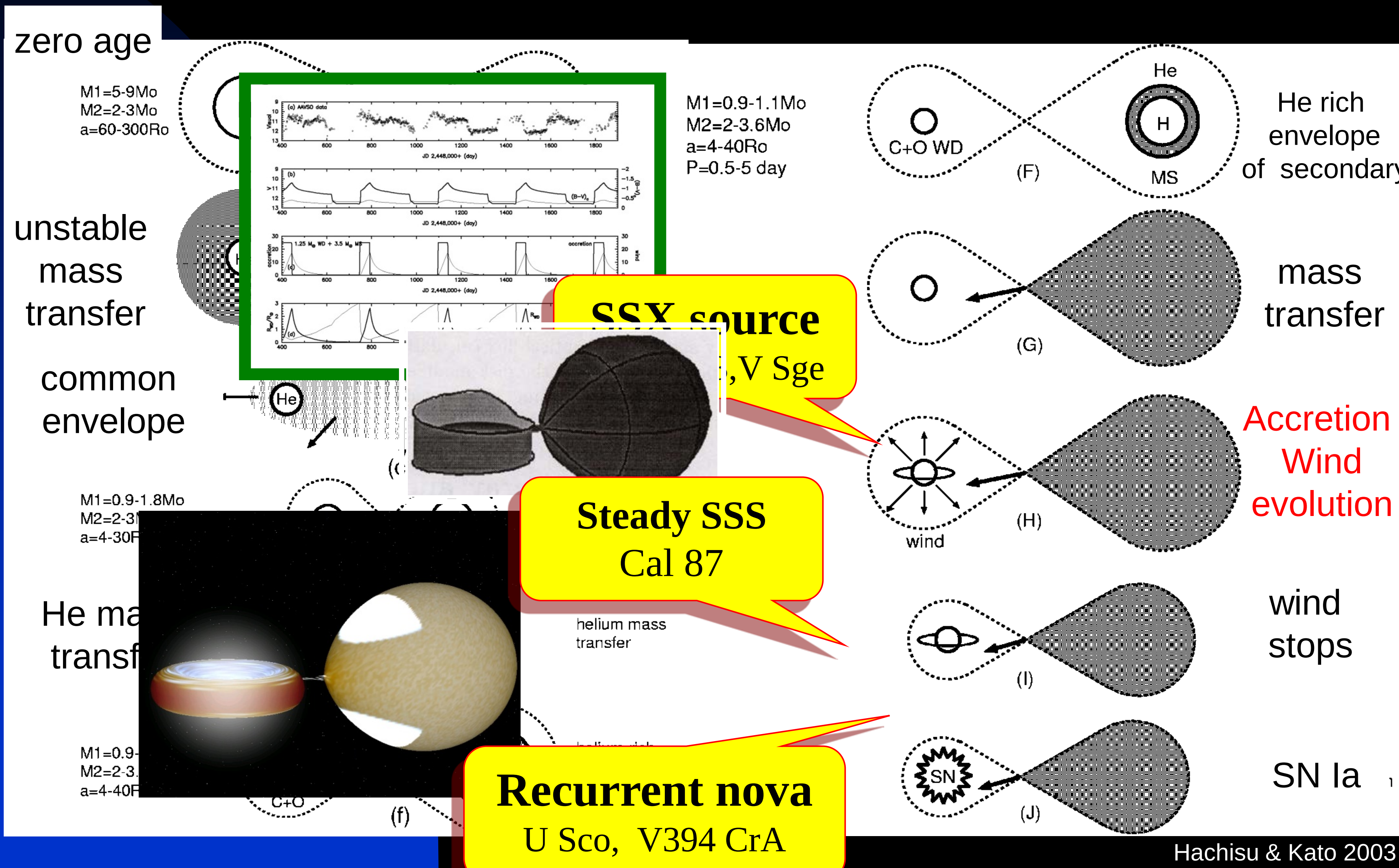
SMC3

Recurrent nova

RS Oph, T CrB

Hachisu et al 19

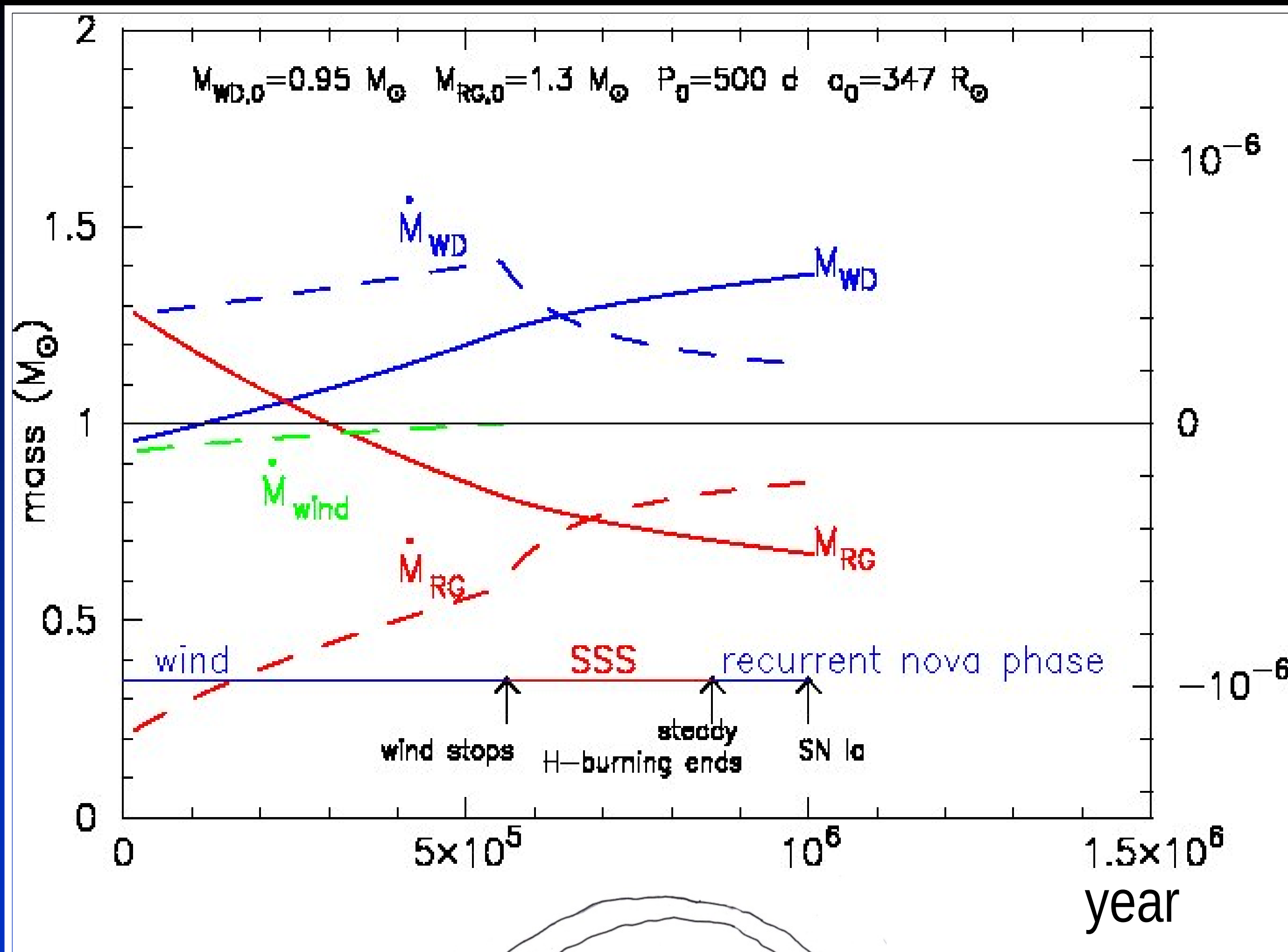
WD+MS channel in SD scenario

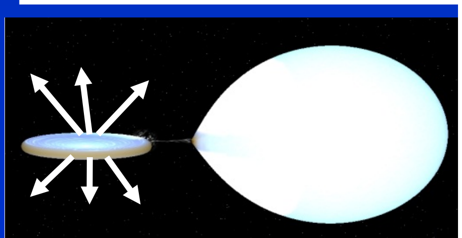


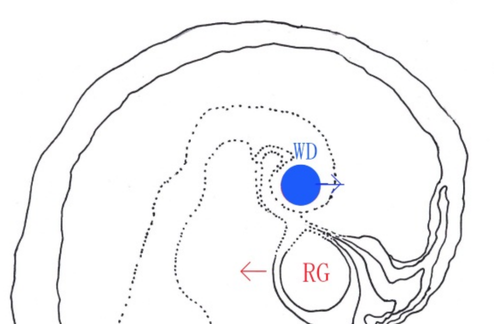
Hachisu & Kato 2003

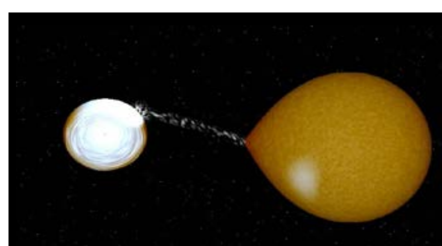
Evolution of a binary

Hachisu et al.

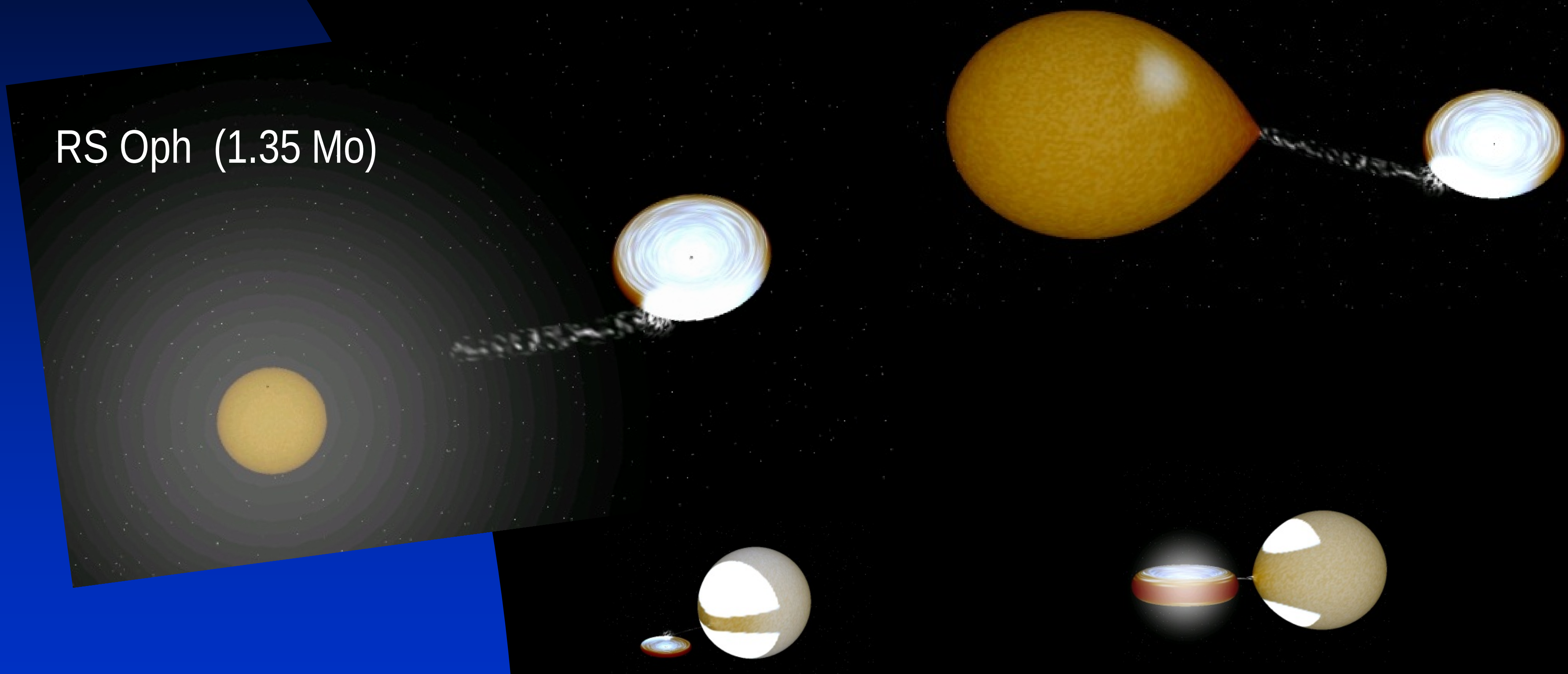






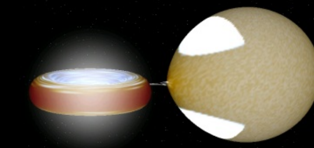


How can we find *massive* WDs ?



WD Mass determined from 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)

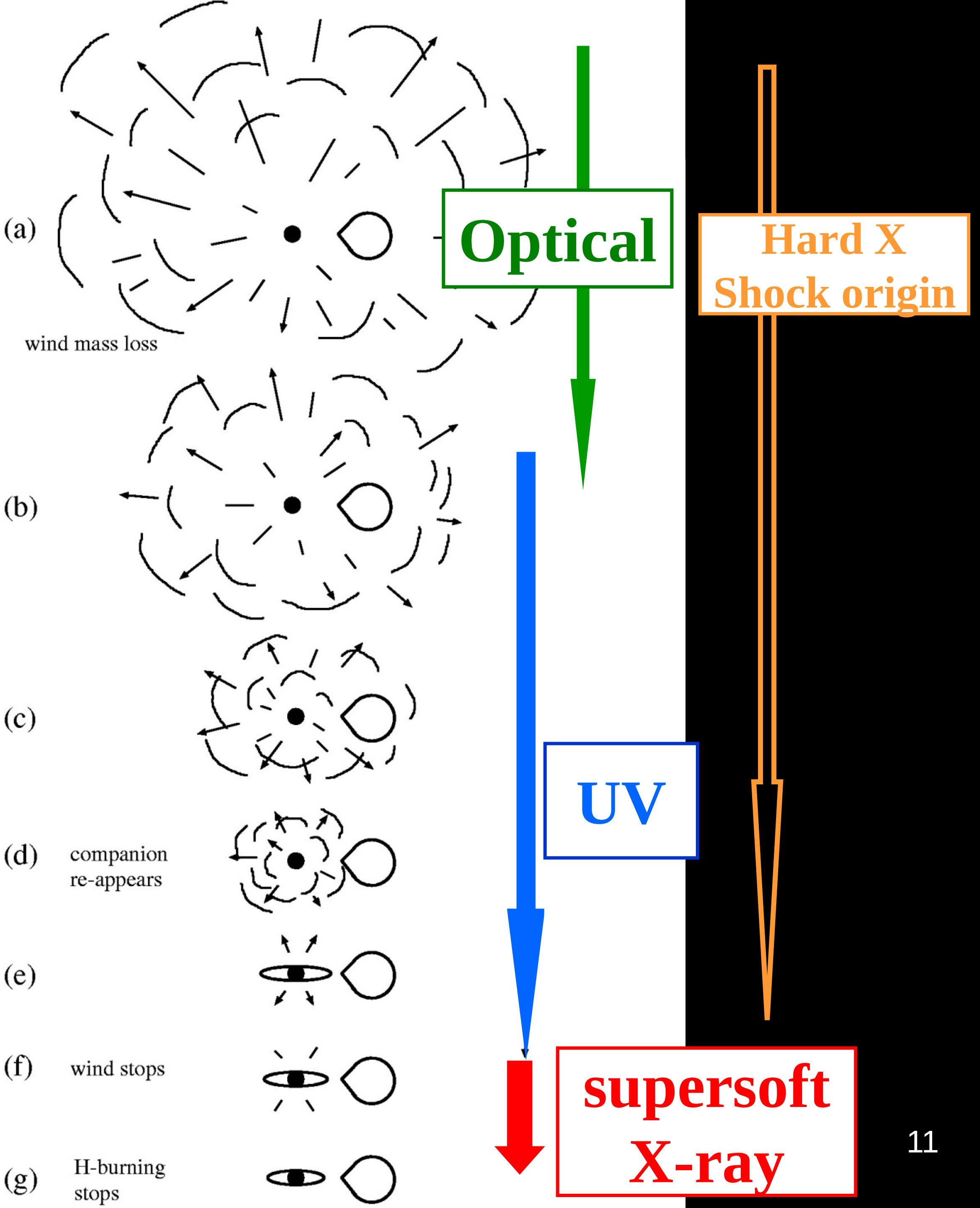
- Recurrent Nova

U Sco (>1.37 M_o), V394 CrA (1.37M_o), LMC1990#2 (1.37Mo),
T CrB (>1.37 Mo), RS Oph (1.35 Mo), V745 Sco (1.35 Mo)
V3890 Sgr (1.35 Mo)
T Pyx (>1.2 Mo) , CI Aql (> 1.2 Mo)

nova evolution

- Luminosity ~constant
- T_{ph} increases

- Wind mass loss continuously occurs



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

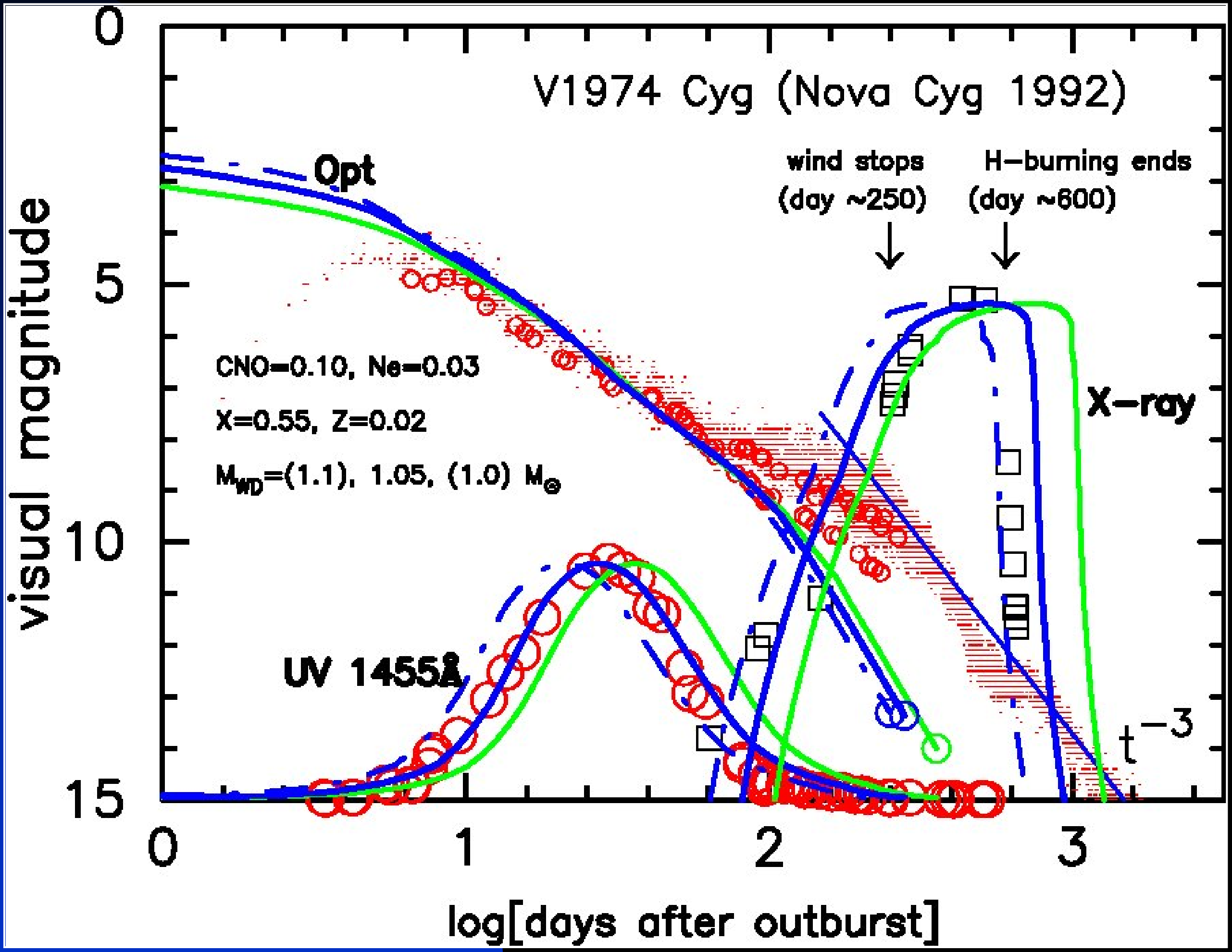
obtain accurate mass-loss rate, T_{ph}, L_{ph}

light curve :optical & IR: free-free emission

UV 1455A & X-ray: blackbody emission

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

V1974 Cyg: *light curve fitting*



determine WD mass

1.0 +- 0.05 M_o

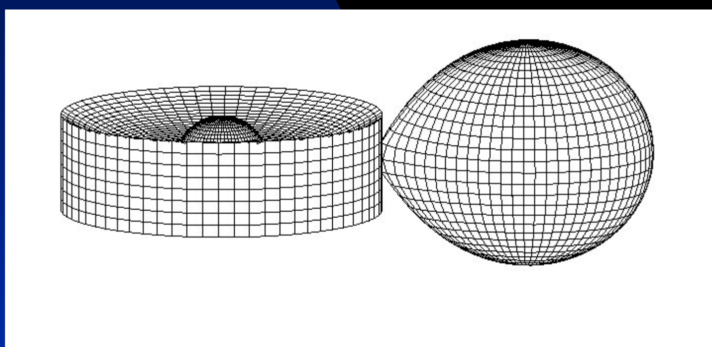
Hachisu & Kato (2005,2006)

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

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

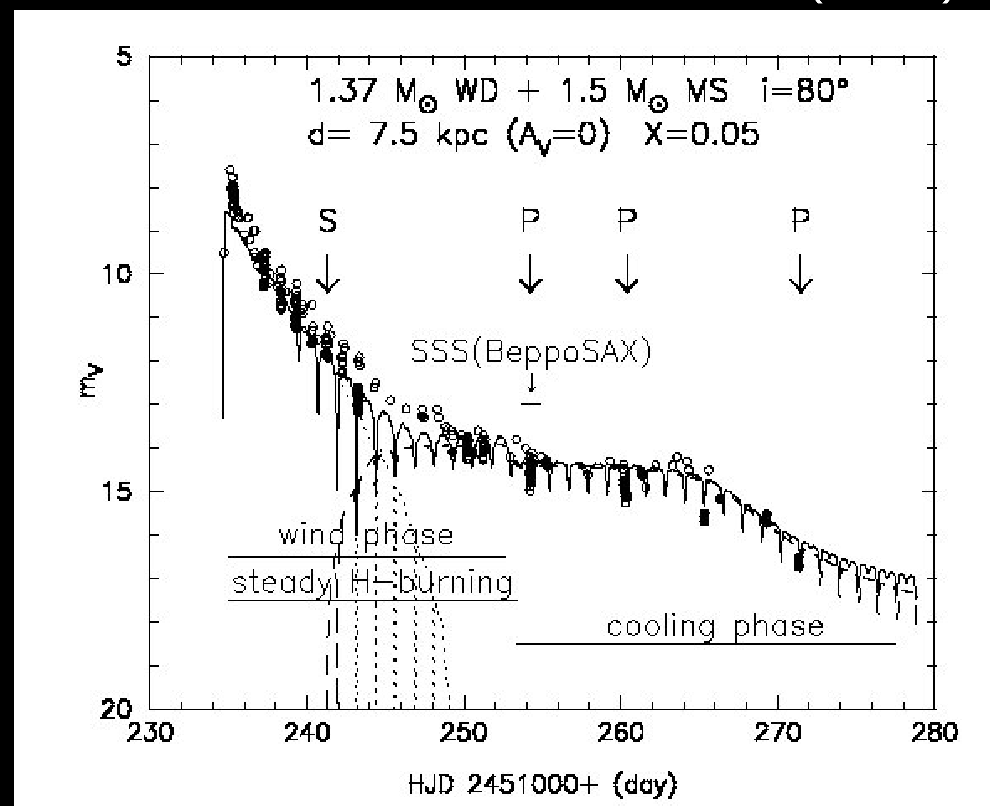
U Sco : Recurrent nova

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



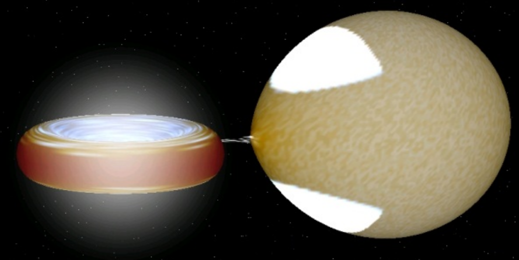
P_{orb}=1.23 d

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

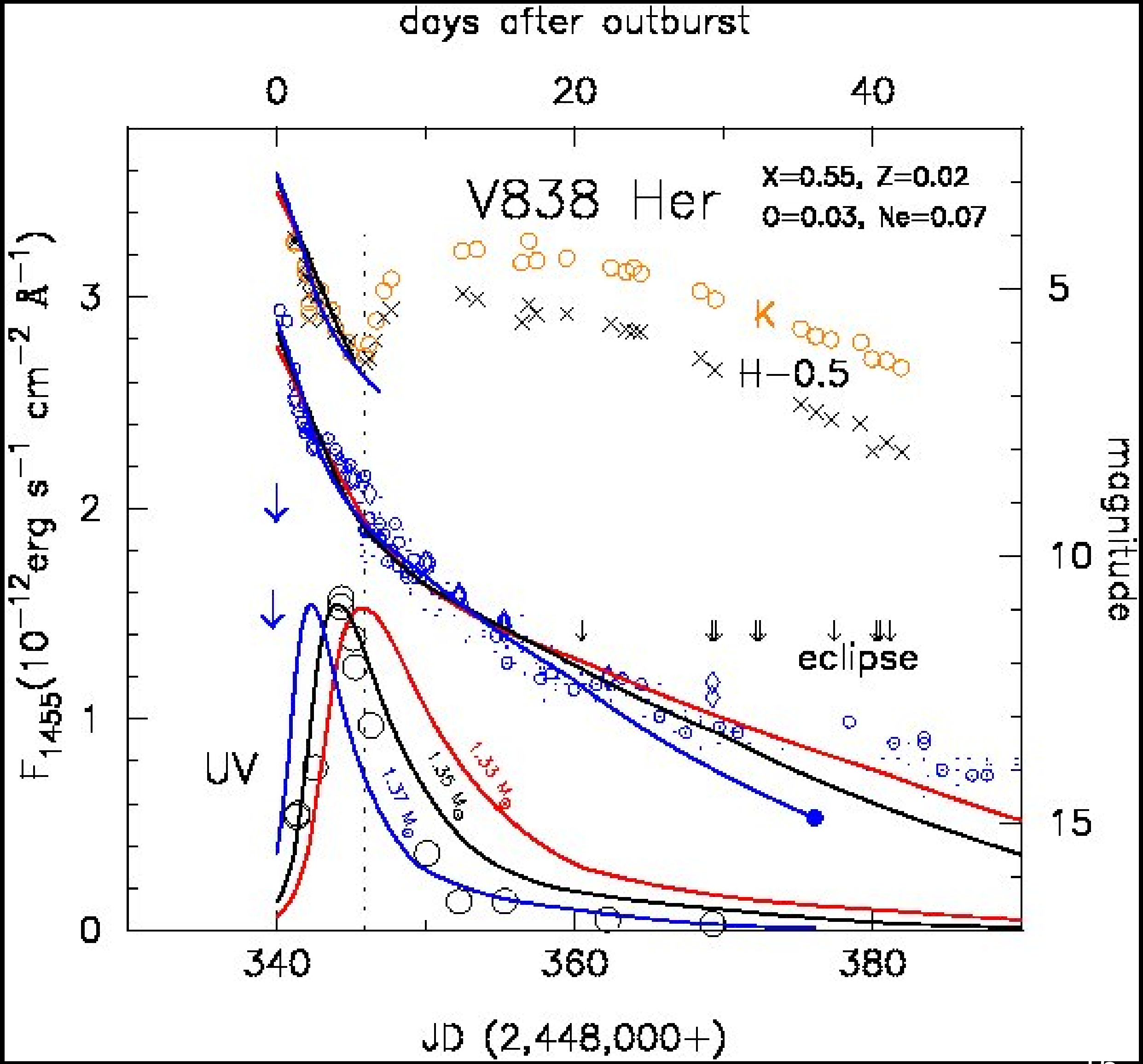
ejected matter = $1.8x10^{-6}$ M_o

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

Candidate of Type Ia SN

V838 Her (1991)

Massive WD
but not
a candidate



WD mass
$1.35\ M_o$

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

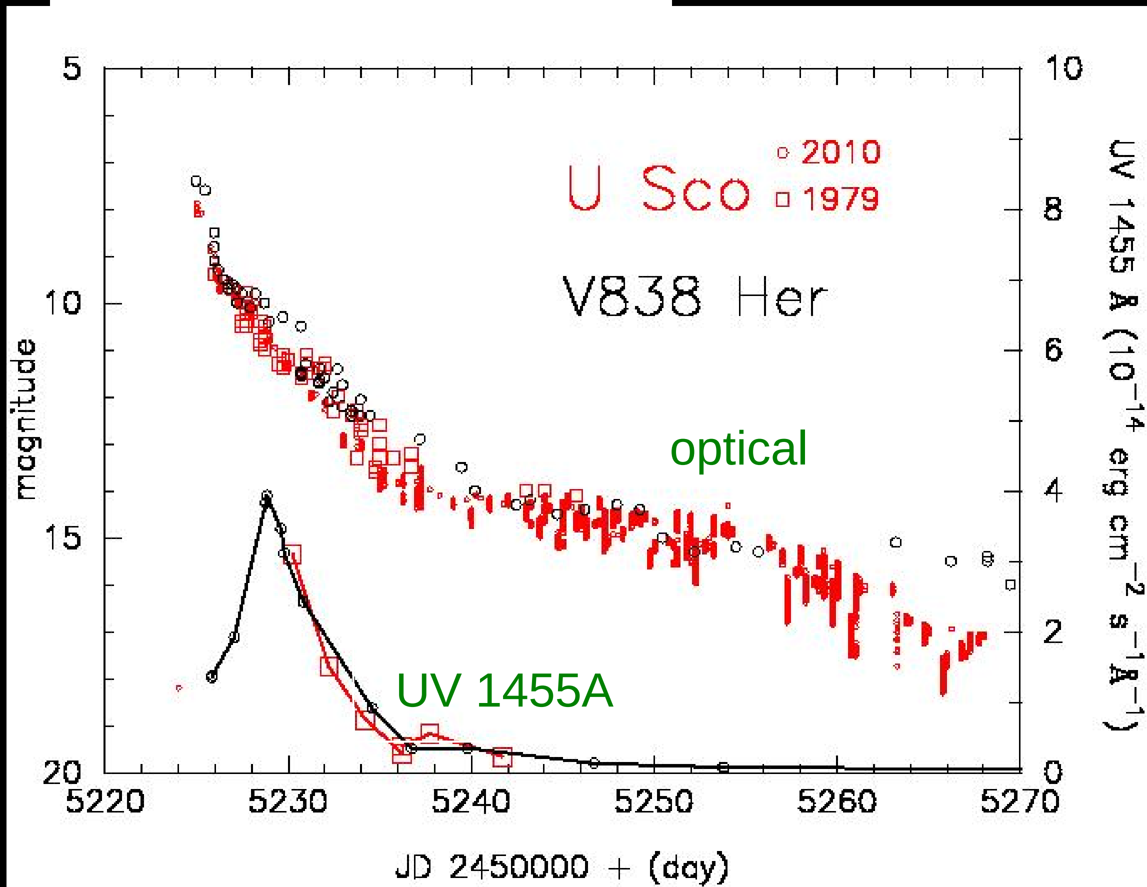
M_{WD} ↗

V838 Her (CN)

Classical nova

~1.35 M_o

M_{WD} ↘



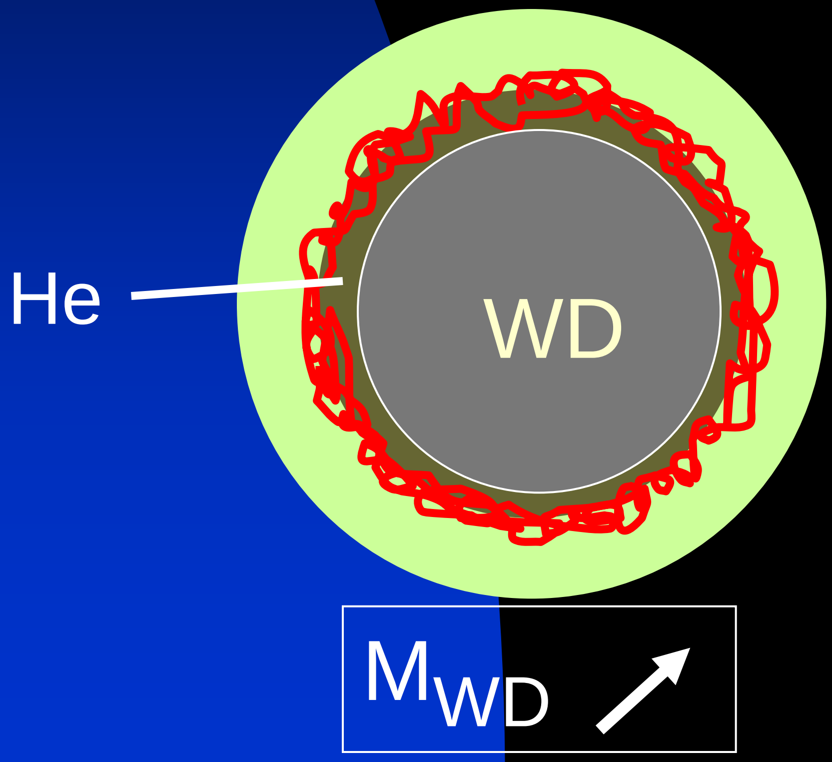
Ejecta composition in recurrent novae and *classical* novae

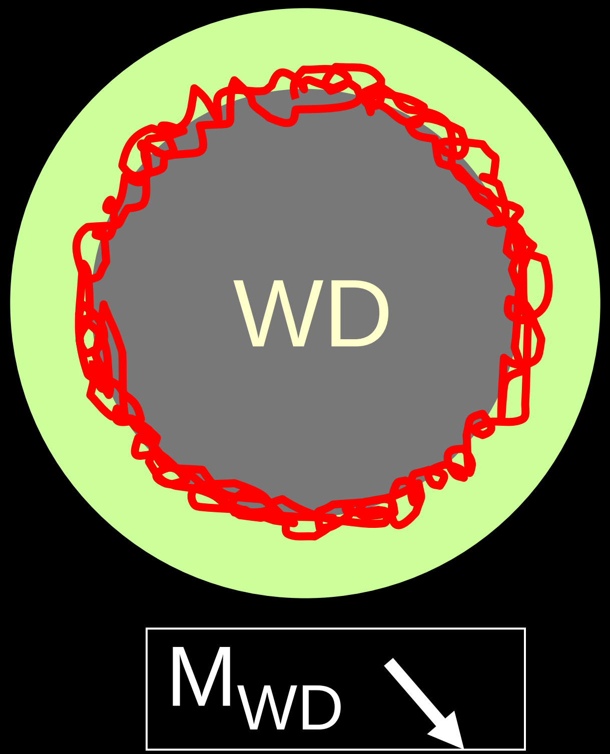
RN

CN

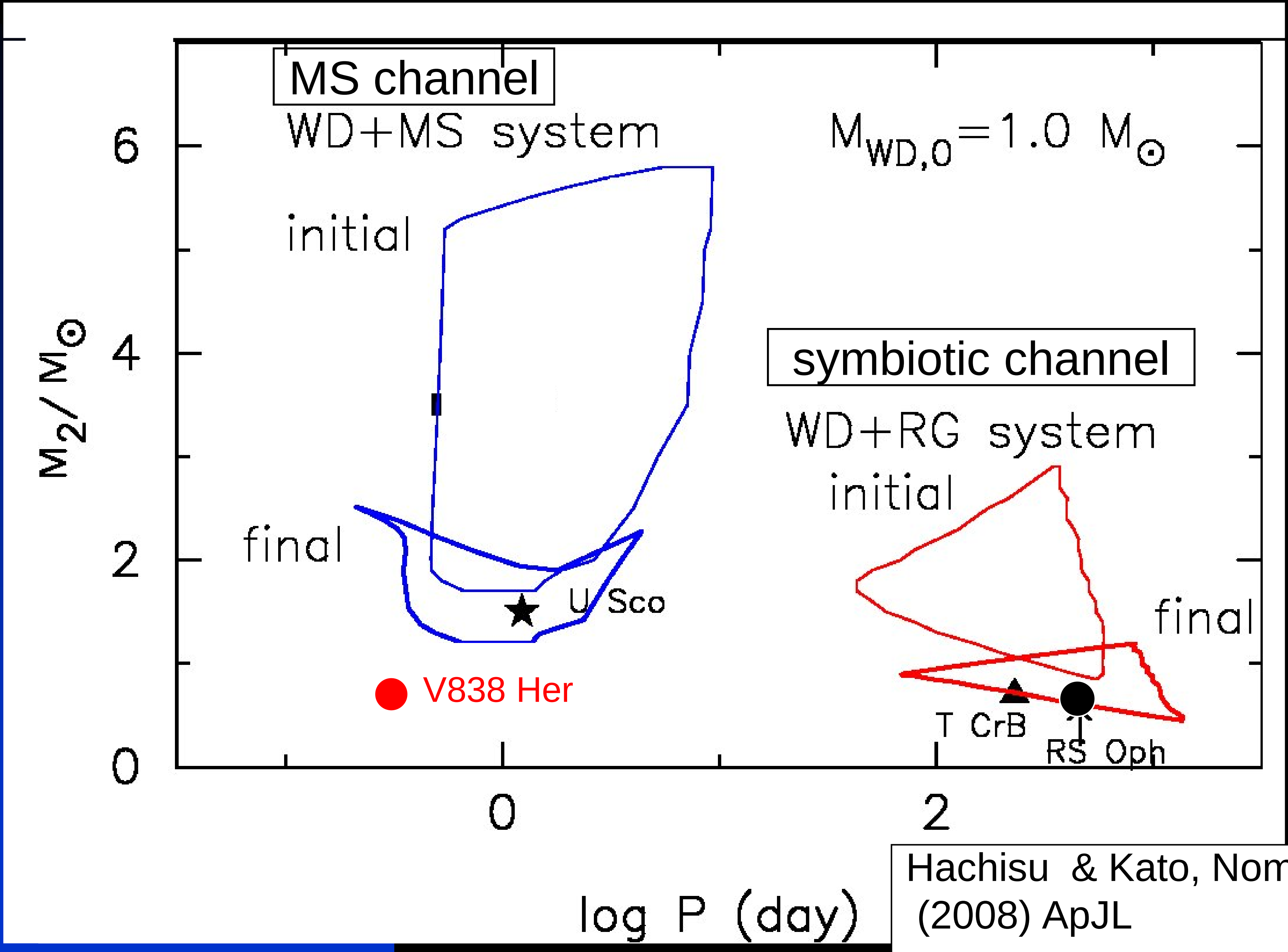
Ejecta : *Solar abundance*

CO/ONeMg-rich



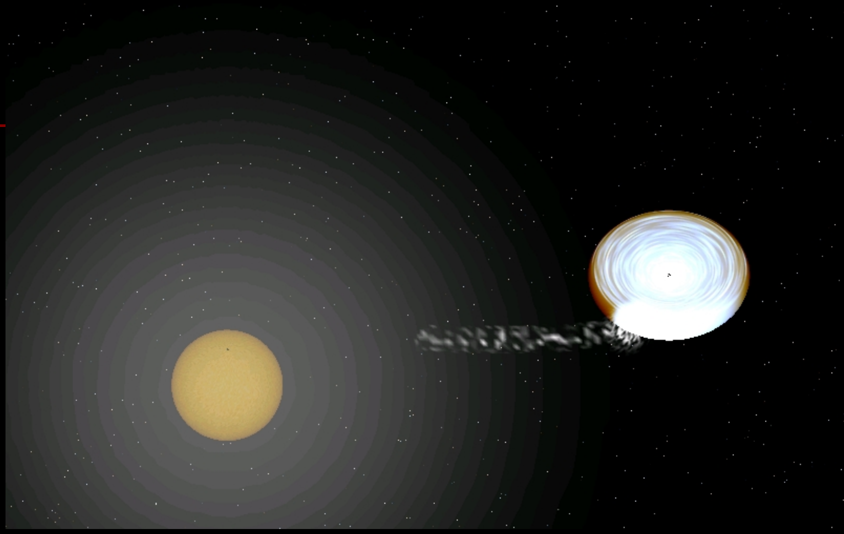


SN Ia : initial and final state of binary



Hachisu & Kato, Nomoto (2008) ApJL

RS Oph : Recurrent Nova



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

P_{orb} : 453 days (Brandi et al. 2009)

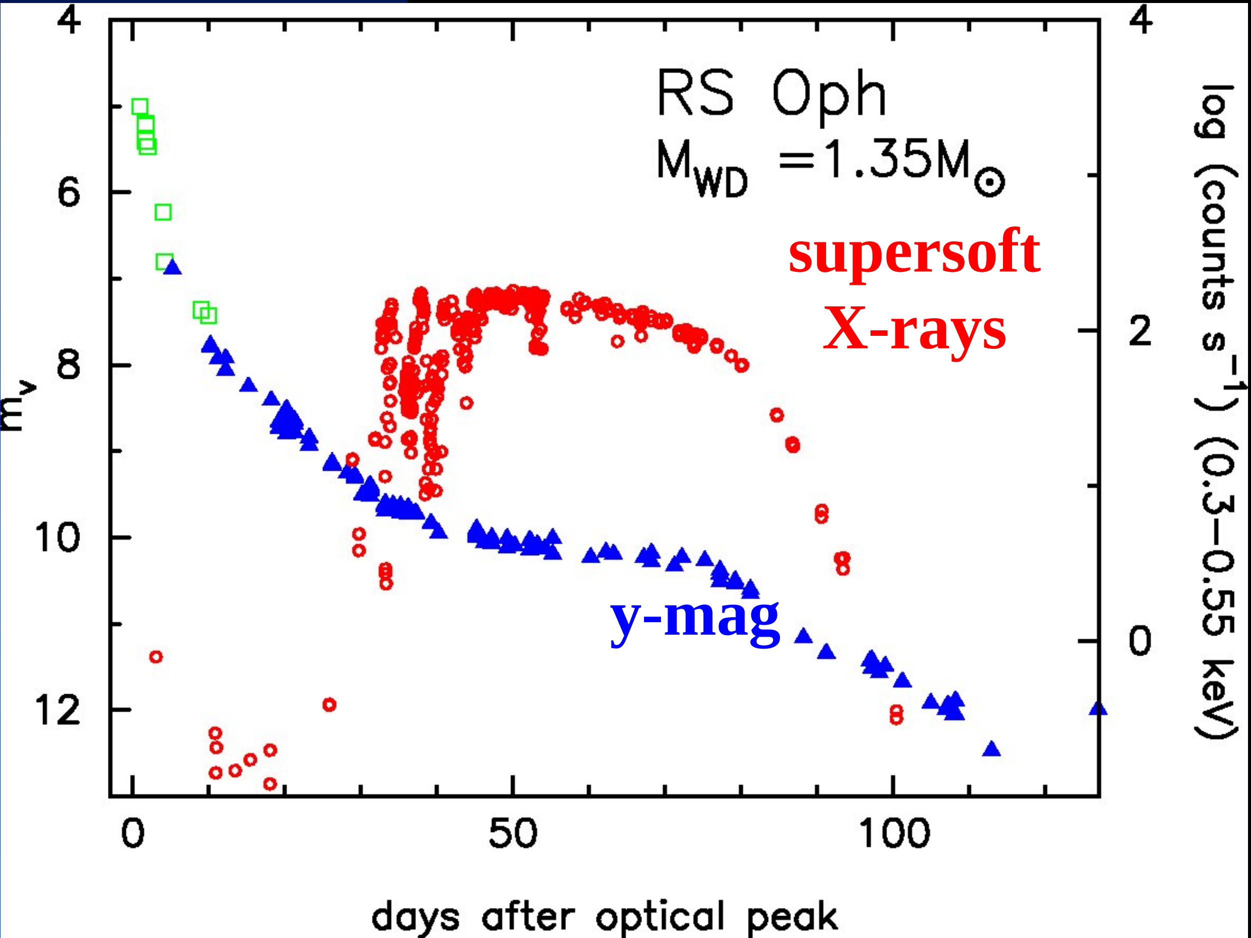
i : ~40-50 deg

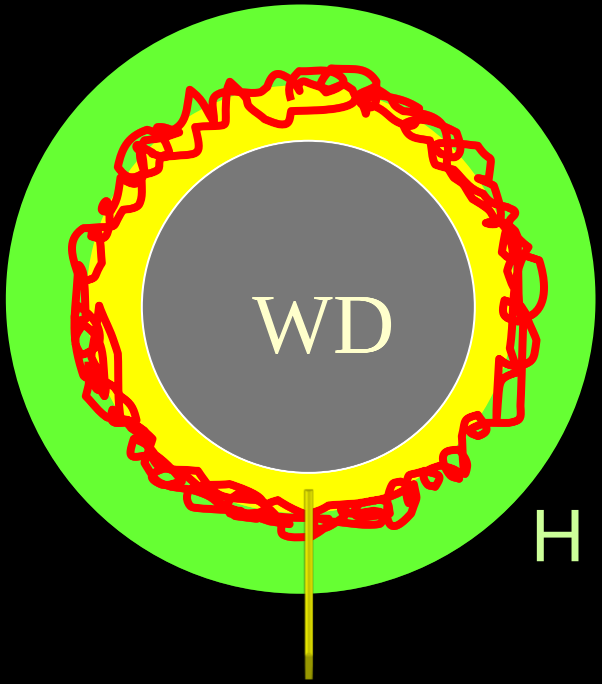
RG : M0 (Anupama & Mikolajewska 1999)

MIII (Evans et al. 1988)

well observed : radio ~ *X*-ray

RS Oph: 2006 outburst





hot *He* layer
(heat reservoir)

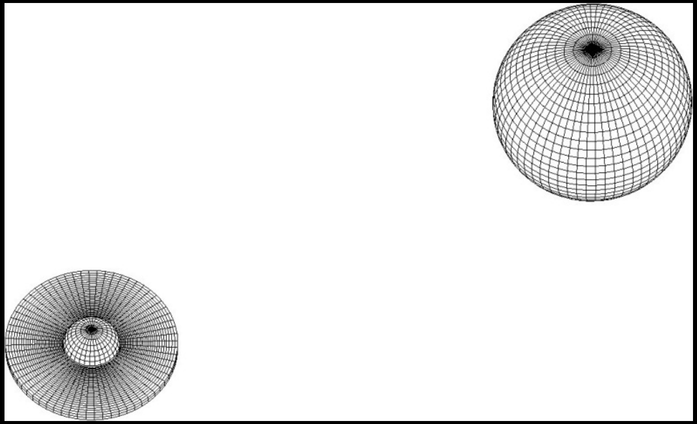
optical:

Hachisu et al. 2006 ApJL

X-ray :

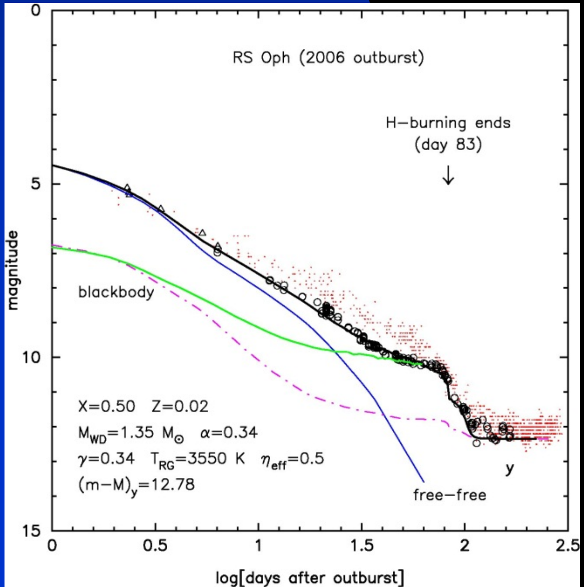
Hachisu et al. 2007 ApJL

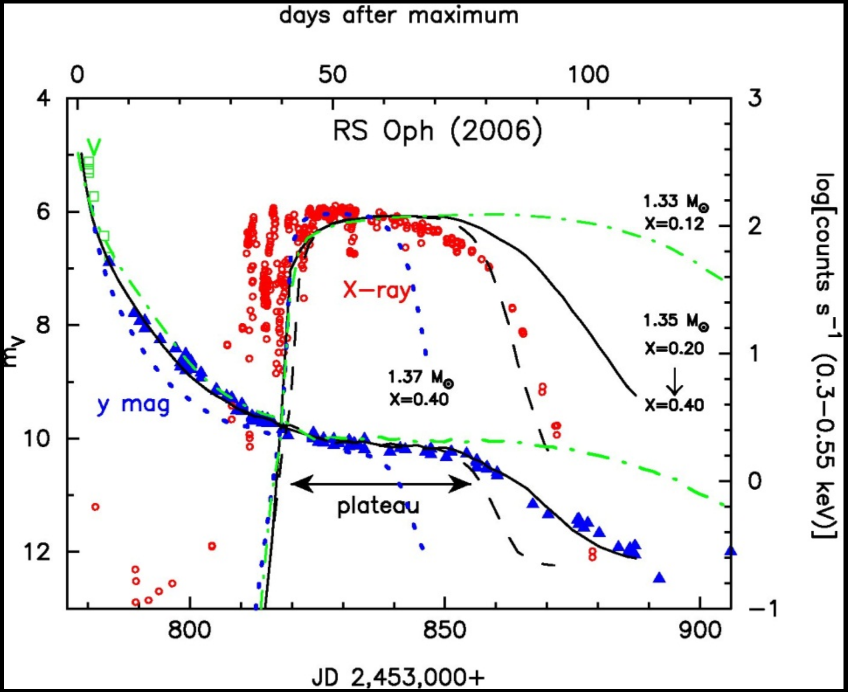
Light curve model



model: WD + disk + companion

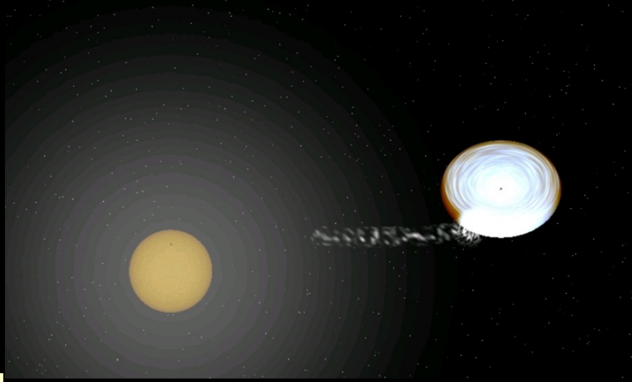
WD: free-free emission
disk : irradiated (local T_{BB})
companion : irradiated





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

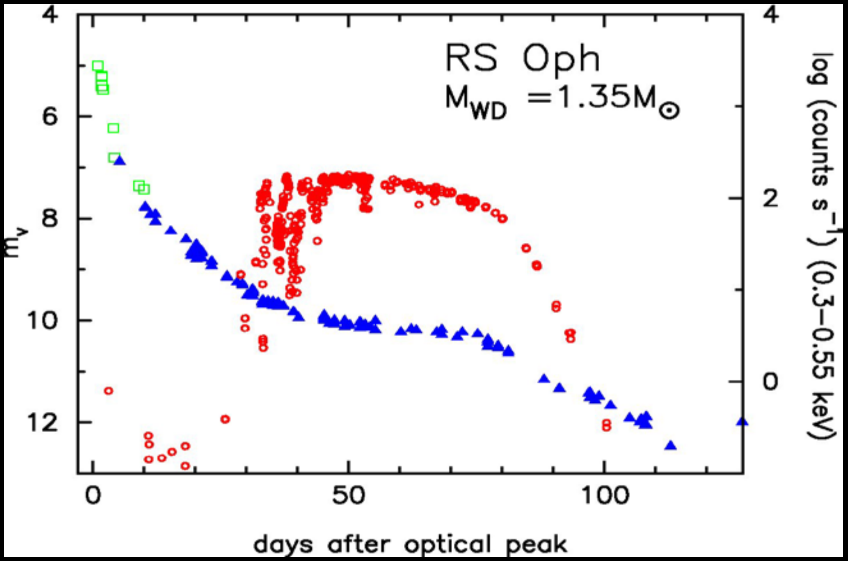
Similar in optical, but very different in X-rays

RS Oph

$M_{WD} \sim 1.35\ M_o$ ↗

No metal rich

RN



V2491 Cyg

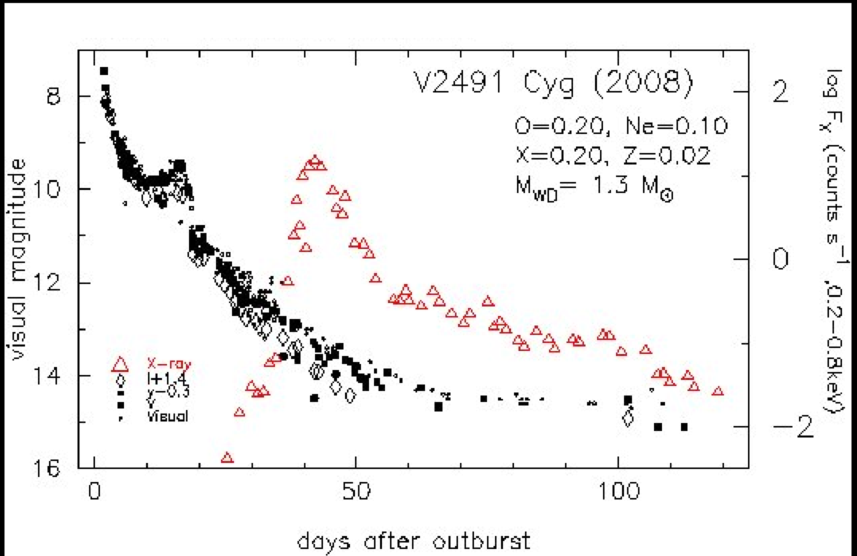
$M_{WD} \sim 1.3\ M_o$ ↘

metal rich

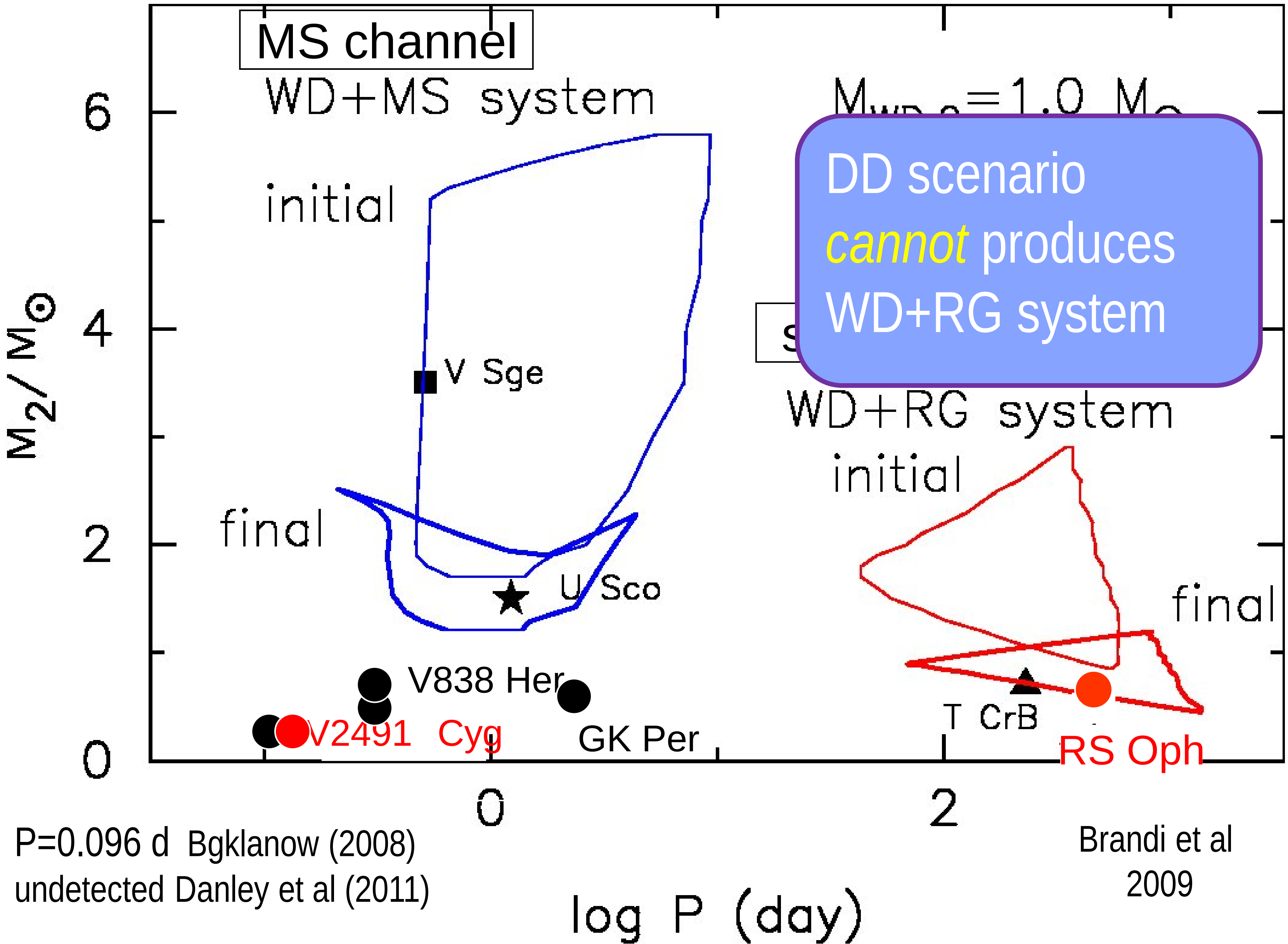
(CO=0.12, .Ne=0.015)

Munari et al. (2011)

CN



SN Ia : *initial* and *final* state of binary



DD scenario
cannot produces
WD+RG system

P=0.096 d Bgklanow (2008)
undetected Danley et al (2011)

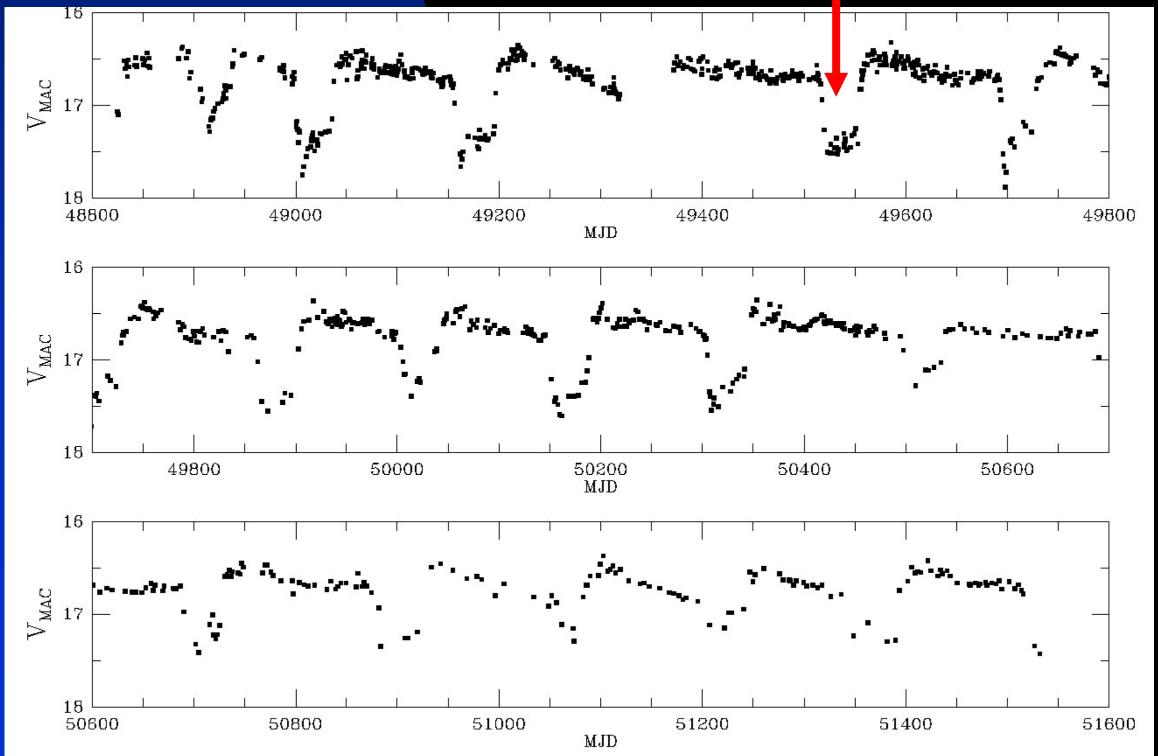
Brandi et al
2009

Evidence of { accretion wind evolution / stripping effects of companion

RX J0513-69 (LMC SSS)

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

supersoft X-ray



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

$\dot{M}_{acc} > \dot{M}_{cr} \sim 0.75\times10^{-6}(M_{WD}/M_o - 0.4)\ M_o/yr$ → Winds

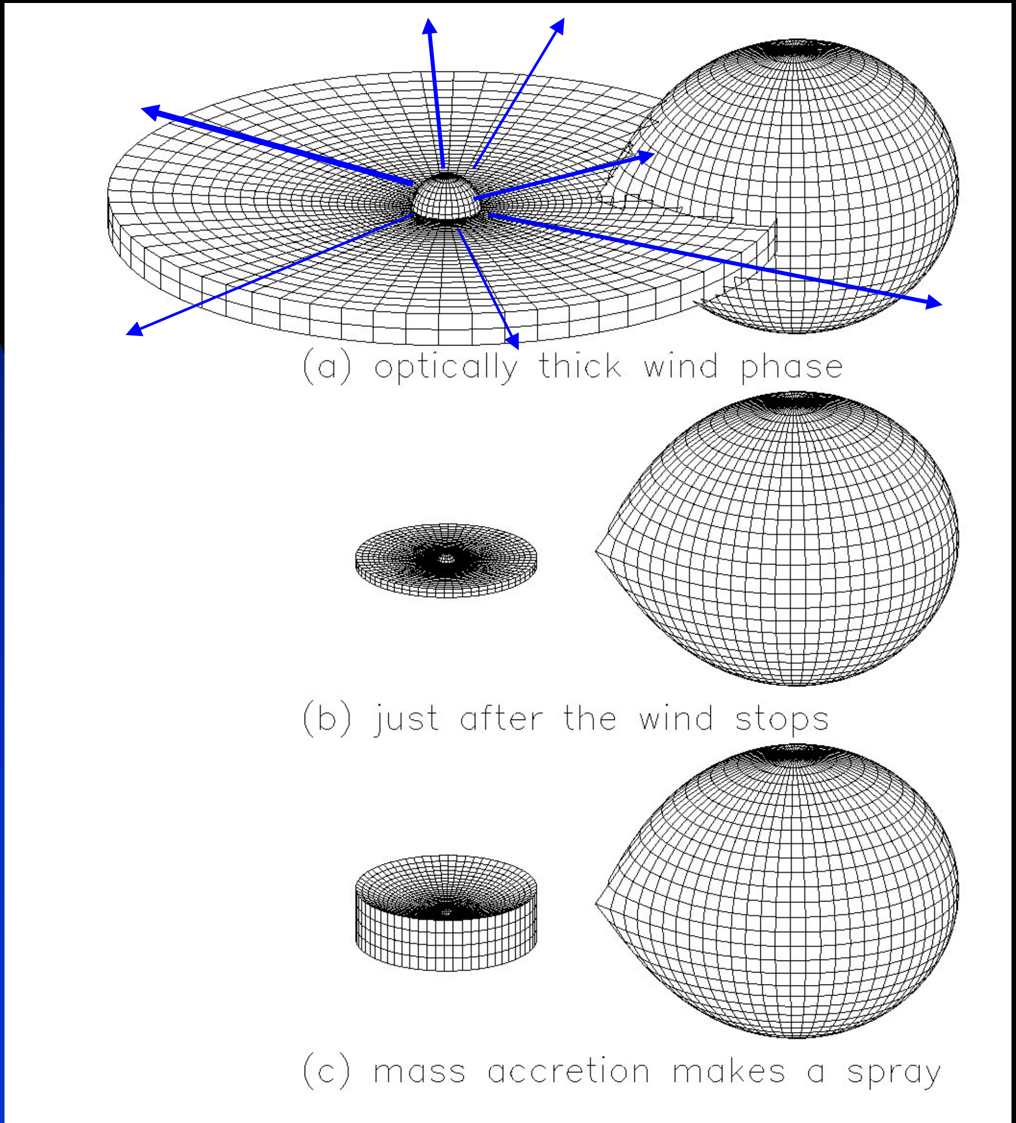
disk and companion are spattered by the wind

companion surface is stripped

↓

mass transfer stops

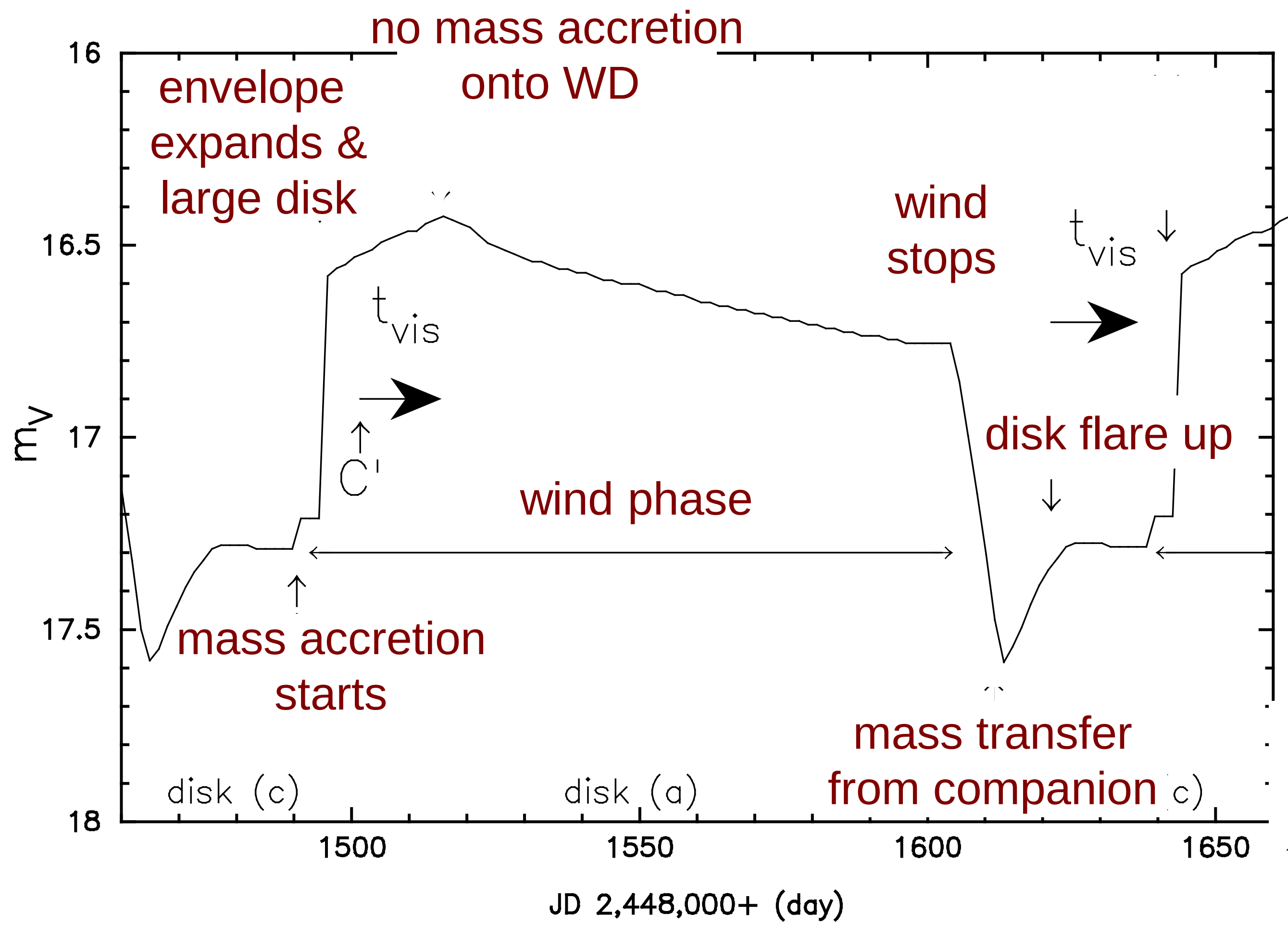
mass accretion makes a spray



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

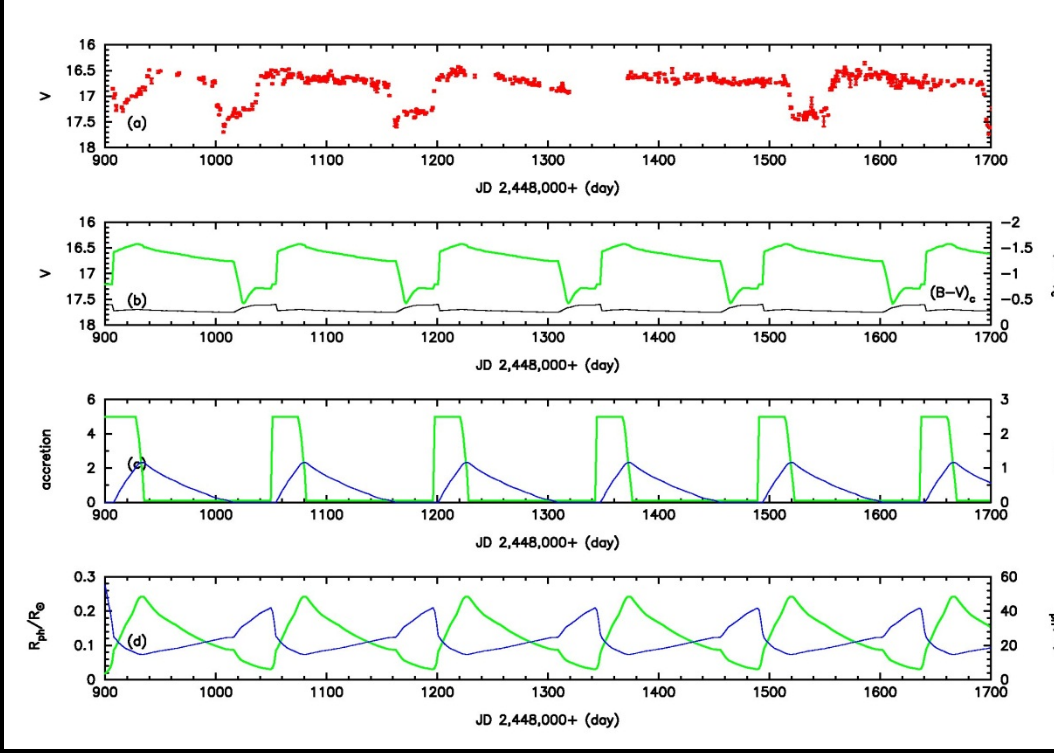
$$M_{\rm MS} = 2.5 - 3.0\ M_\odot$$

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

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

(time averaged)

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



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

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

$$\dot M_2 \sim 20 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

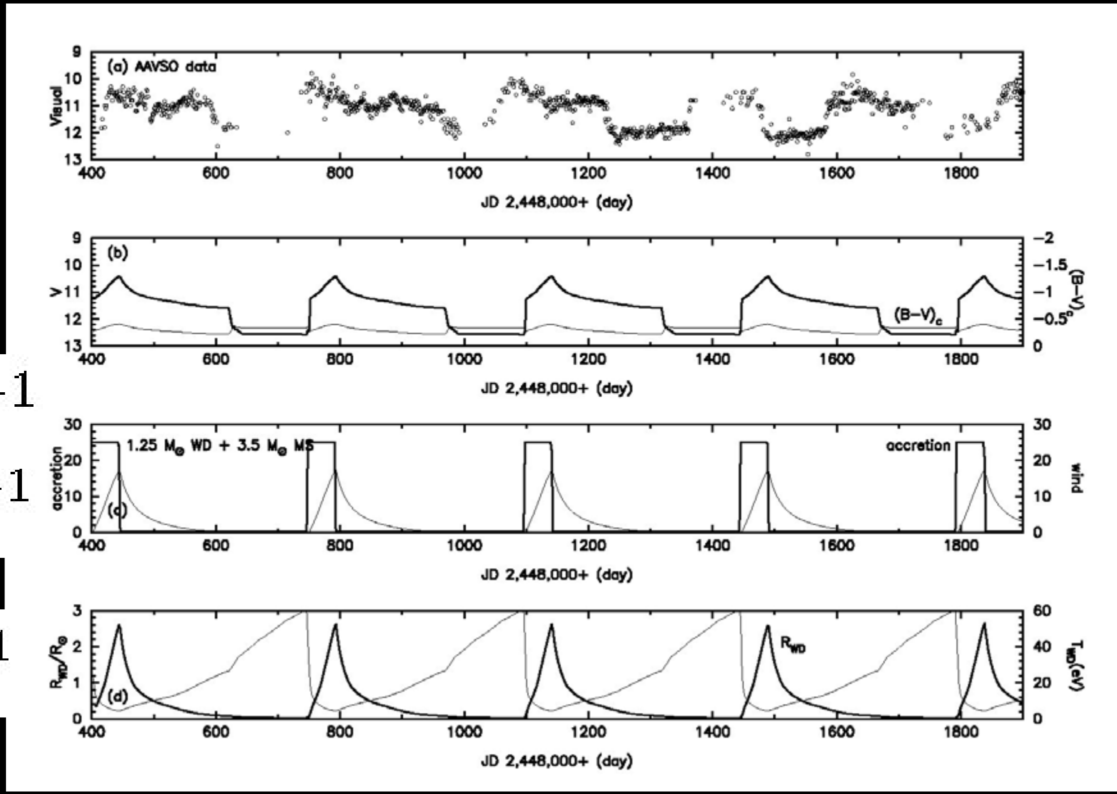
$$\dot M_{\rm wind} \sim 3 \times 10^{-6}\ M_\odot {\rm yr}^{-1}$$

(time averaged)

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

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