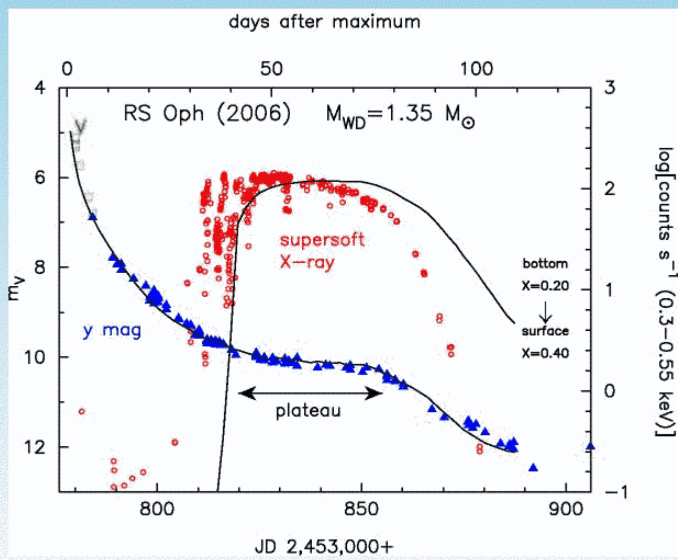
KITP Conference, 2007 March 20, Santa Barbara

Winds from Hydrogen Burning WDs

Izumi Hachisu (Univ. of Tokyo)



Outline

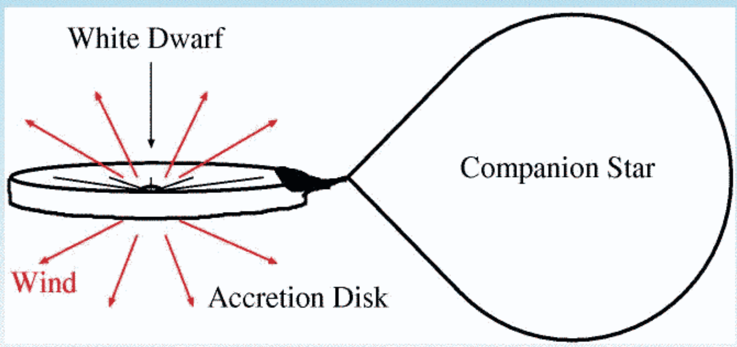
1. Supersoft X-ray sources in winds [RX J0513.9-6951 and V Sge]
   - ○ mass-stripping by winds
   - ○ circumbinary matter
2. Supersoft X-ray Light Curve of RS Oph 2006 outburst
   - ○ WD mass
   - ○ efficiency of mass accretion

Winds from White Dwarfs

"Accretion Wind Evolution"

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

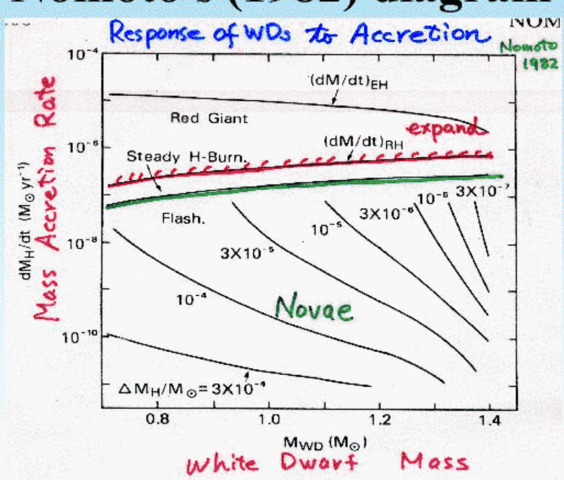
$$\dot{M}_{\rm acc} > \dot{M}_{\rm cr} \sim 1 \times 10^{-6} M_\odot \ {\rm yr}^{-1} \ \rightarrow \ {\rm Winds}$$



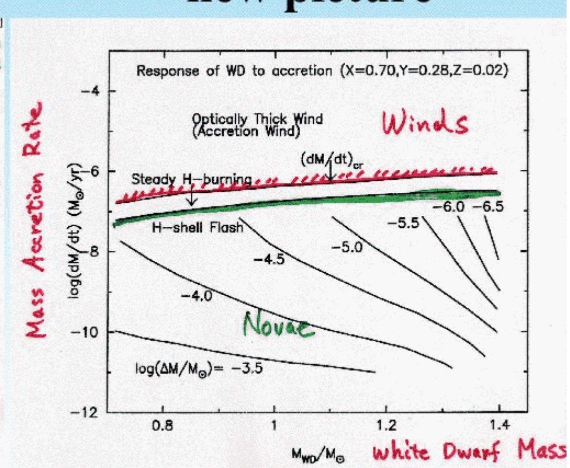
Response of Mass-accreting WDs

○ **WDs do not expand so much; instead, blow a strong wind. → avoid a common envelope**

Nomoto's (1982) diagram



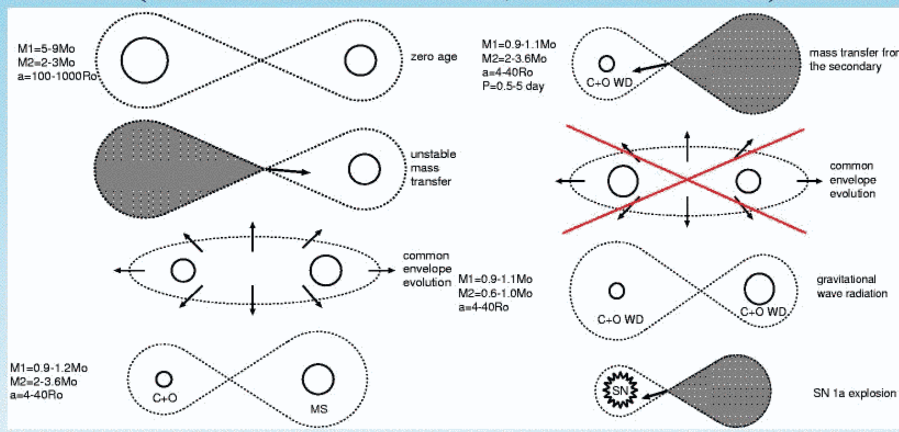
"new picture"



Evolutionary model of SNe Ia

Double Degenerates (DD) Scenario

(Iben & Tutukov 1984, Webbink 1984)

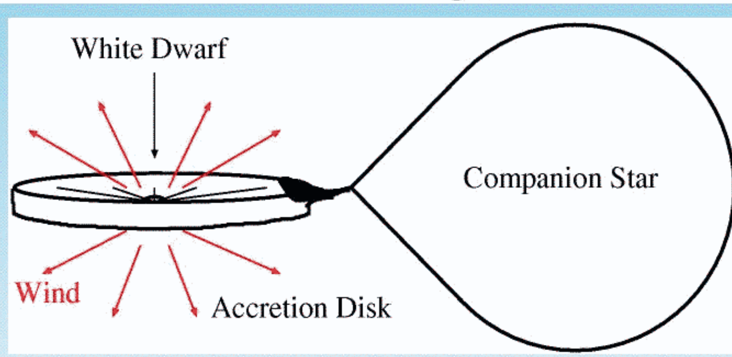


○ The second common envelope evolution is replaced with "the accretion wind evolution"
→ no common envelope formation

Accretion Wind Evolution

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

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



WD blows a wind
and can increase its mass
===> because no common envelope is formed

Do really exist "accretion winds" ?

Do really exist "accretion winds" ?

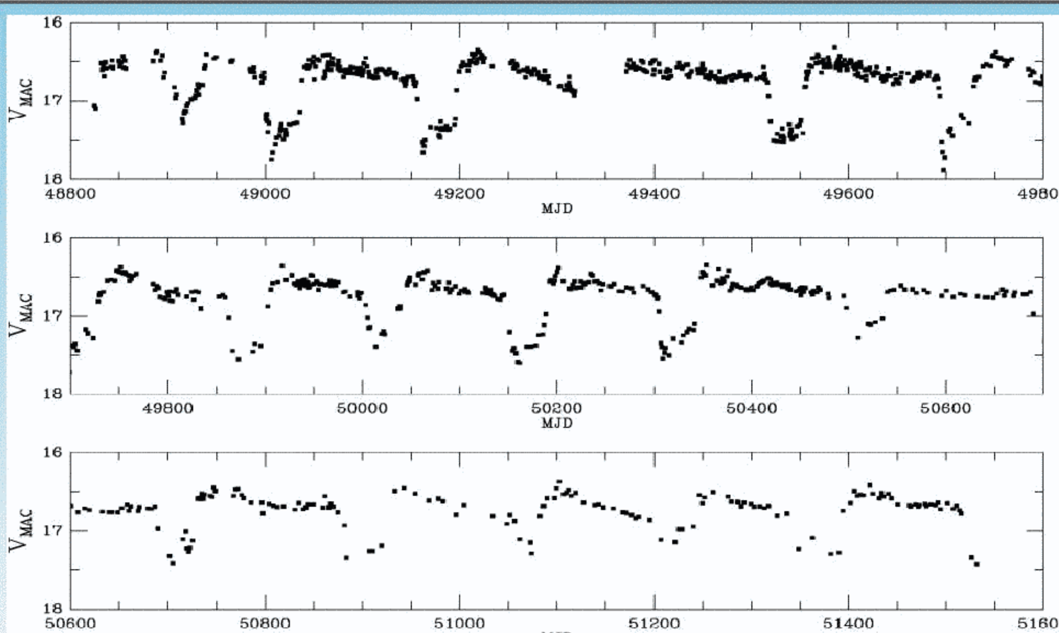
- If our prediction is correct,

  the accretion wind phase really exists.

- Two examples:
  RX J0513.9-6951 and V Sge

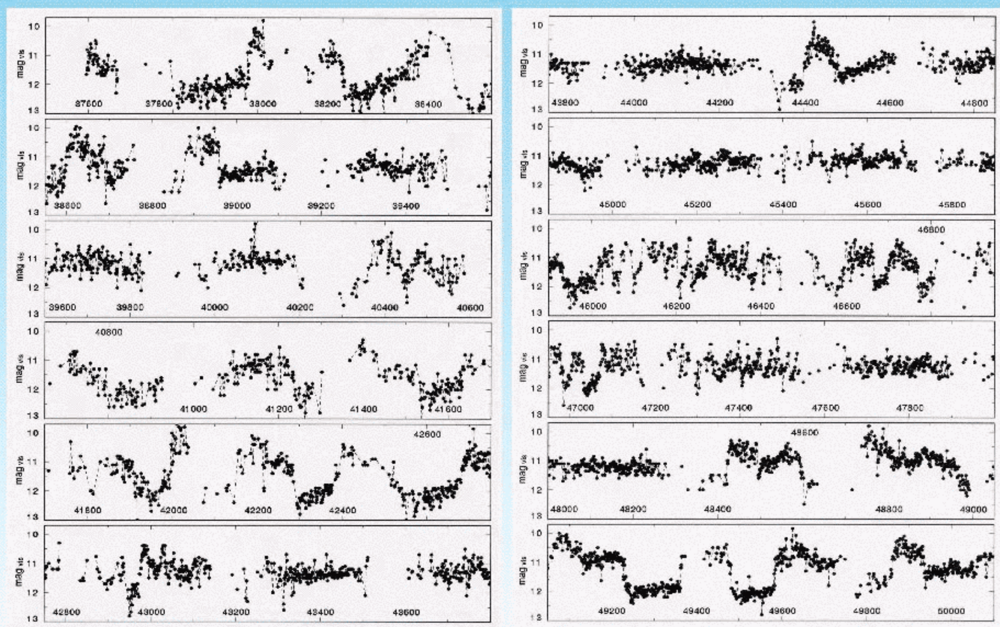
RX J0513.9-6951 (LMC SSS)

RX J0513.9-6951 (LMC SSS)



- Optical high/low states of RX J0513 (Cowley et al. 2002)

V Sge (Galactic SSS)



(Simon and Mattei 2000)

Characteristics of RX J0513 and V Sge

1. orbital periods of 0.5-1.0 days → MS companion
   0.763 days (RX J0513)   0.514 days (V Sge)
   Cowley et al. (2002)   Patterson et al. (1998)

2. optical high/low states with ~1 mag amplitude
   ~120/40 days (RX J0513) ~150/100 days (V Sge)
   Alocock et al. (1996)   Simon and Mattei (1999)

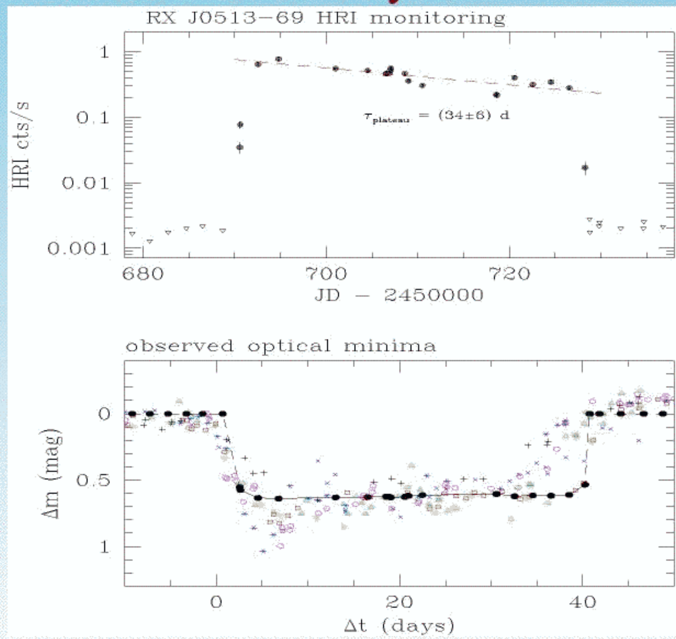
3. supersoft X-rays are detected only during low states

4. radio detection from V Sge indicates → mass-loss
   $\dot{M} \sim 5 \times 10^{-6} M_{\odot}\ \mathrm{yr}^{-1}$ Lockley et al. (1997, 1999)

Transient supersoft X-ray source

Transient supersoft X-ray source

- On/off timescale of 1-2 days (from Reinsch et al. 2000)



Intermittent Winds ???

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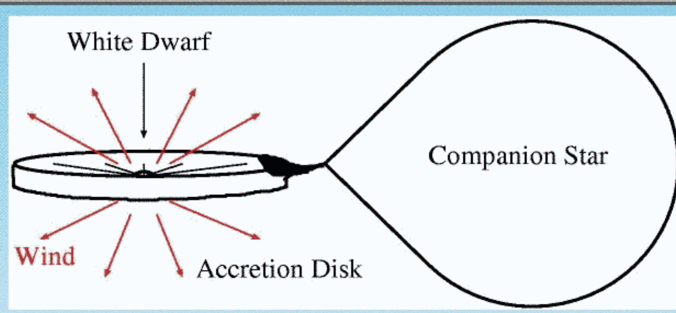
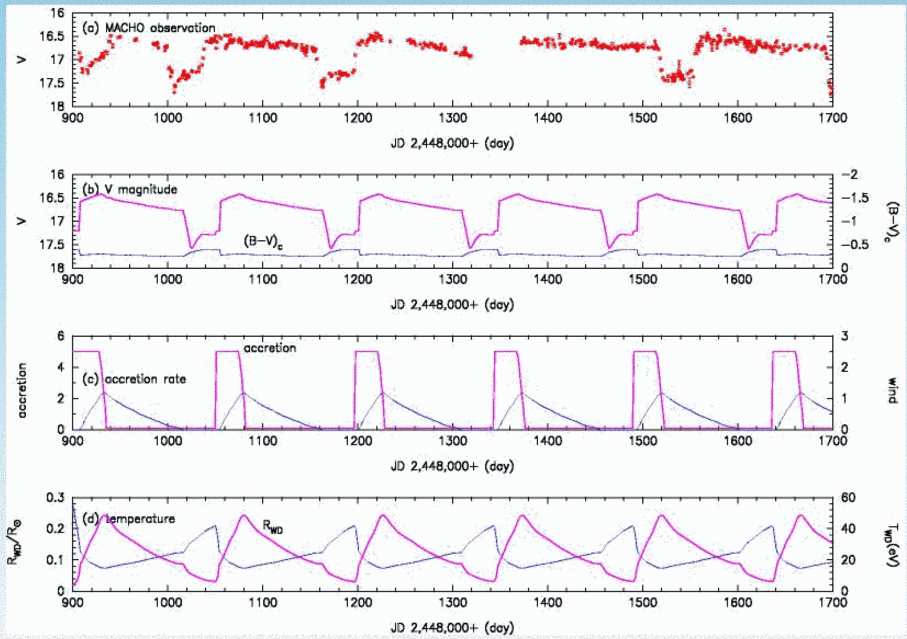


"WD blows winds intermittently !"

* wind collides with the companion
==> strips off the surface layer
==> suppresses the mass transfer rate
==> wind stops (suppression disappears)
==> the mass transfer rate recovers
==> wind blows again ===> *

Numerical Results (RX J0513.9-6951)

(Hachisu and Kato, 2002, ApJ, 590, 455)



RX J0513.9-6951

(Hachisu and Kato, 2002, ApJ, 590, 455)

$M_{\rm WD} = 1.2 - 1.3\ M_\odot$

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

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

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

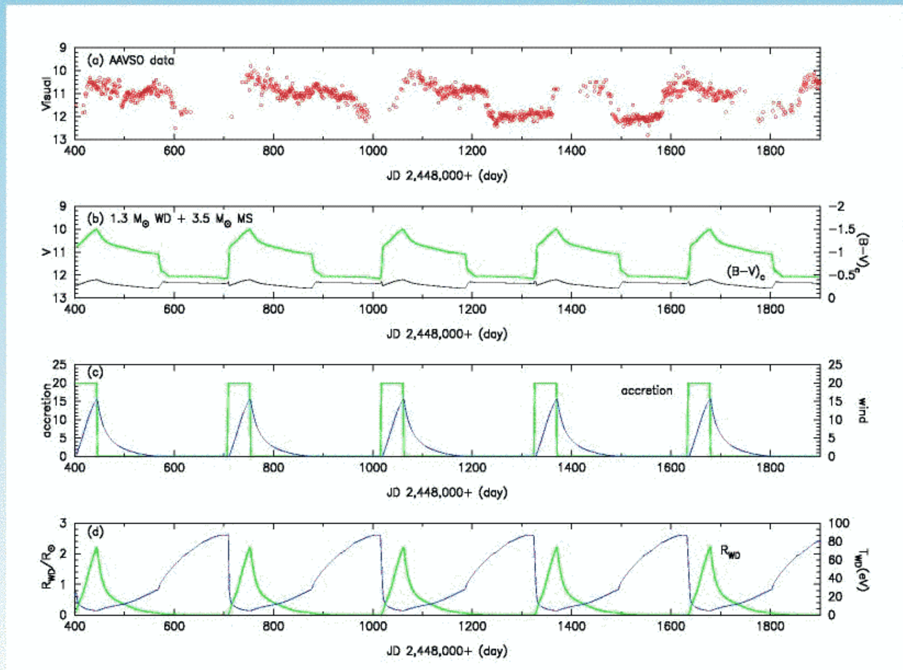
$\dot{M}_{2,{\rm strip}} \sim 4 \times 10^{-6} M_\odot\ {\rm yr}^{-1}$ (time-averaged)

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

○ RX J0513 is a progenitor of SN Ia

Numerical Results for V Sge

(Hachisu and Kato, 2003, ApJ, 598, 527)



V Sge

(Hachisu and Kato, 2003, ApJ, 598, 527)

$M_{\rm WD} = 1.25 \pm 0.05\ M_\odot$

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

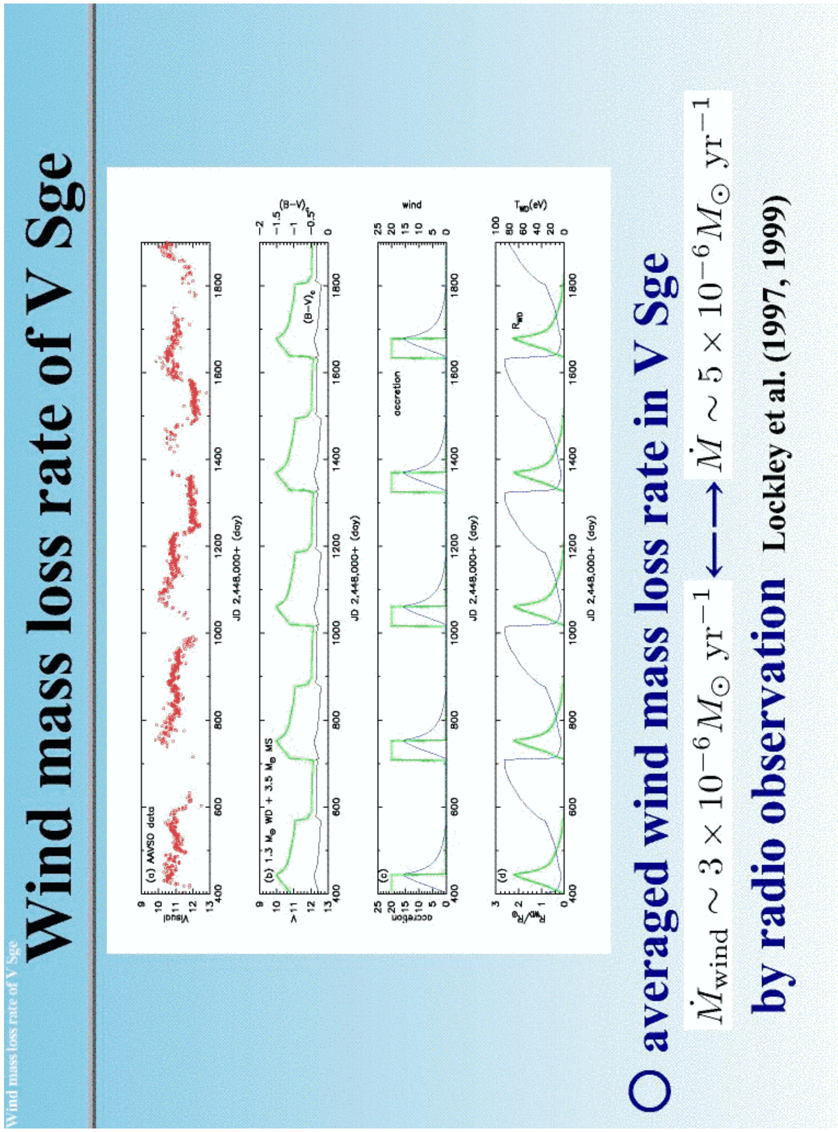
$\dot M_2 \sim 20 \times 10^{-6} M_\odot\ {\rm yr}^{-1}$

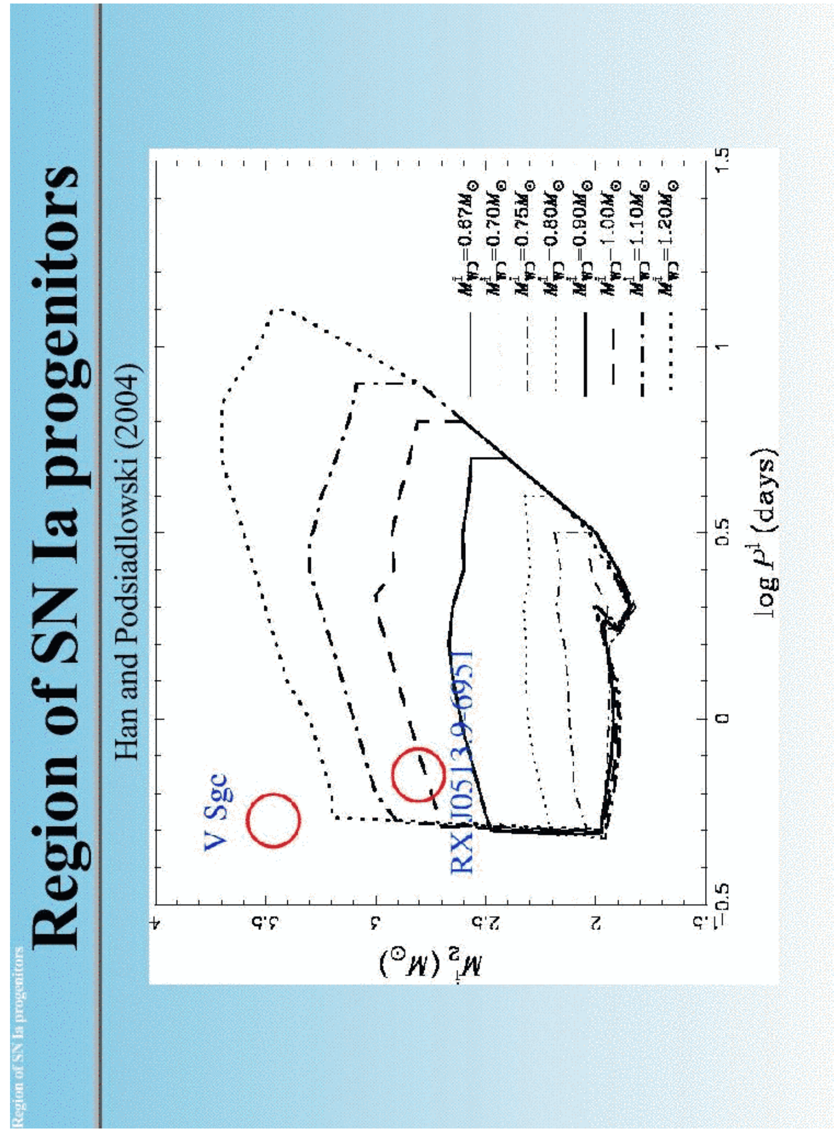
$\dot M_{\rm wind} \sim 3 \times 10^{-6} M_\odot\ {\rm yr}^{-1}$ (time-averaged)

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

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

○ **V Sge is also a progenitor of SN Ia**


Wind mass loss rate of V Sge
Wind mass loss rate of V Sge
○ averaged wind mass loss rate in V Sge
$\dot{M}_{\rm wind} \sim 3 \times 10^{-6} M_\odot \ {\rm yr}^{-1} \longleftrightarrow \dot{M} \sim 5 \times 10^{-6} M_\odot \ {\rm yr}^{-1}$
by radio observation Lockley et al. (1997, 1999)
(a) AAVSO data
(b) 1.3 M WD + 3.5 M MS
JD 2,448,000+ (day)


Region of SN Ia progenitors
Region of SN Ia progenitors
Han and Podsiadlowski (2004)
V Sge
RX J0513.9-6951
log P (days)
$M_2^i (M_\odot)$

Summary (1)

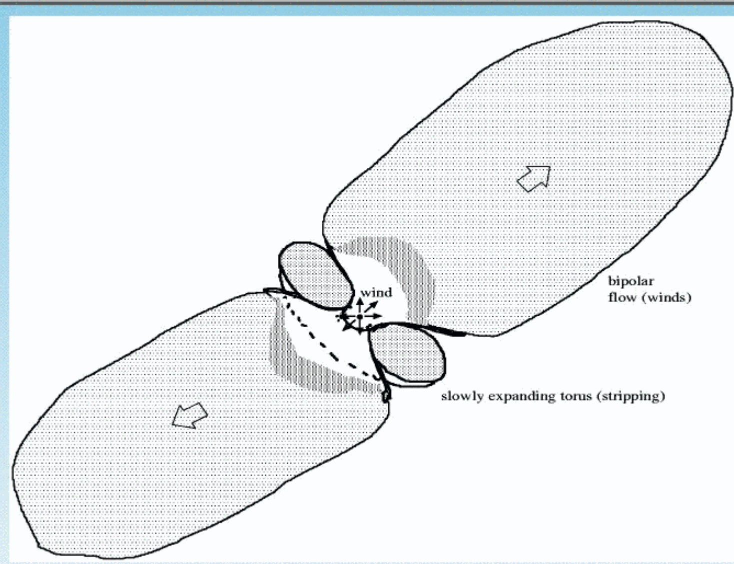
1. "Accretion wind evolution" is a key evolutinary process to Type Ia supernovae.

2. "Accretion winds" blow intermittently when the mass stripping effect is large.

3. RX J0513.9-6951 and V Sge are identified as binary systems in the "intermittent" wind phase.

4. We must include the mass stripping effect (mass and angular momentum losses) in the evolution to Type Ia supernovae.

Prediction of Circumbinary Matter



1. **"slowly expanding torus or disk of 10-100 km/s" can be detected as circumbinary matter (much denser and massive)**

Prediction (continued)

2. No cavity around a binary when a WD explodes in the "accretion wind phase," because there is a circumbinary disk just outside the binary orbit

3. If the stripping works more effectively, a more massive companion is probably OK

$$4 - 4.5\ M_\odot \ \rightarrow \text{age of SNe Ia} \sim 0.2\ \text{Gyr}$$

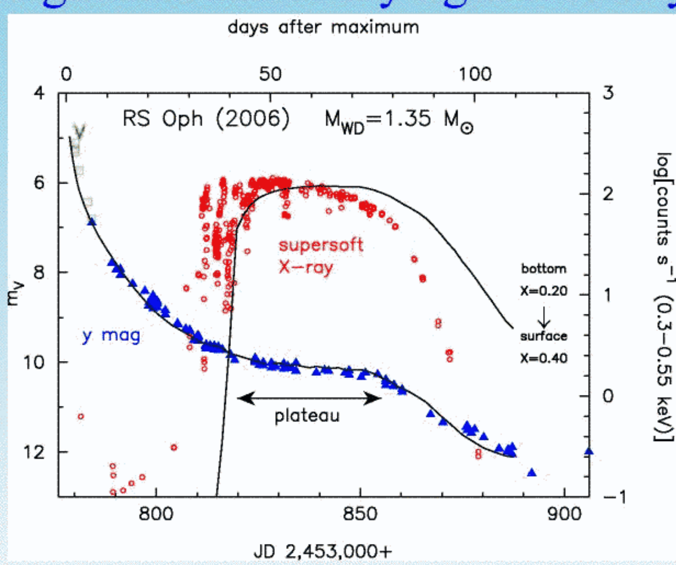
4. The stripped mass reaches as massive as

$$\sim 2 - 3\ M_\odot$$

in such a case

Supersoft X-ray of RS Oph 2006

○ y-magnitude and X-ray light curve by Swift



The Recurrent Nova RS Ophiuchi

1. Outbursts: 1898, 1933, 1958, 1967, 1985, 2006
   → similar light curves
2. Recurrence Period (~10-20 yr)
3. Very Rapid Decline rate (t_3= 9 d)
4. Binary period (P= 457 days)
5. Cool Component: K7--M0III (giant)

Previous Light Curves of RS Oph

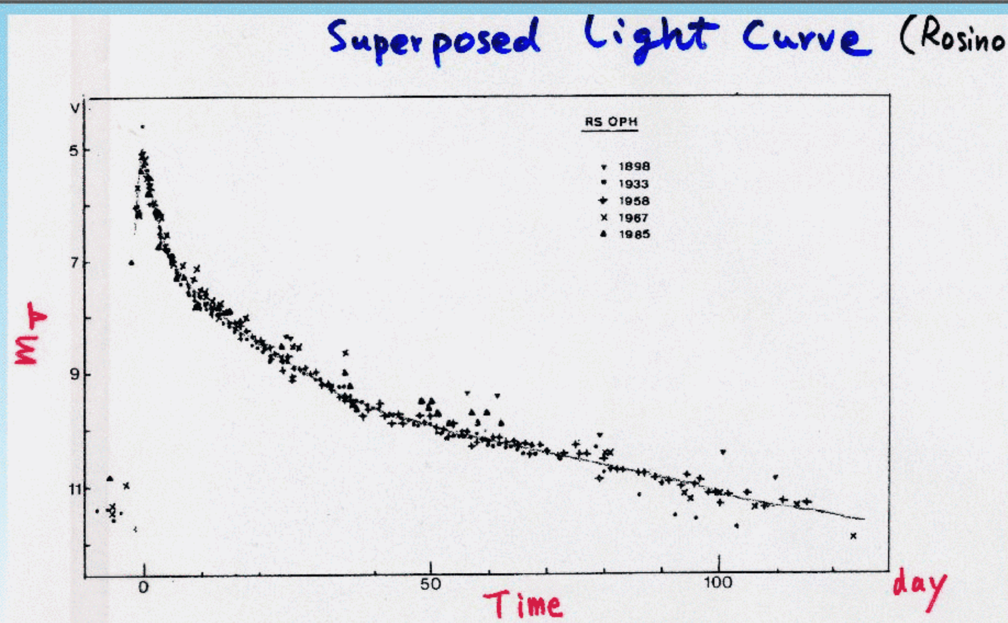


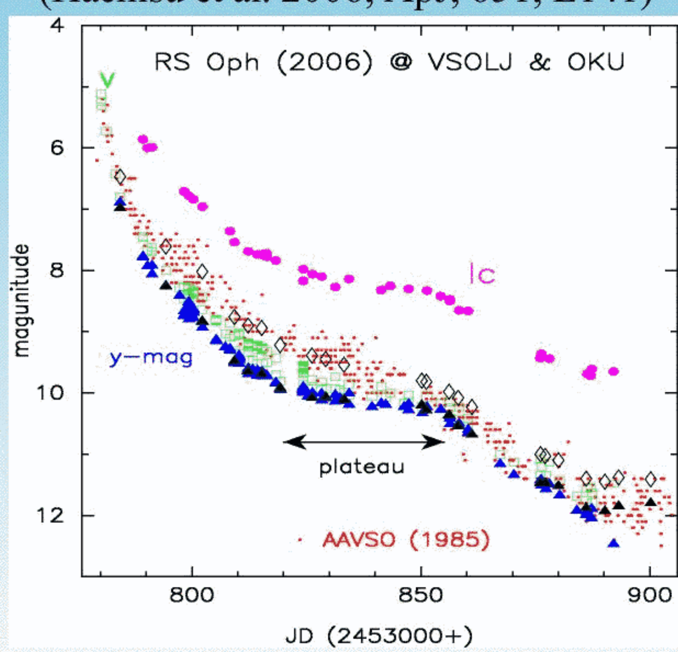
Fig.1 . The five superposed light curves of RS Oph .

Observation by y-band

name of observer	location in Japan	telescope aperture	observed bands	No.of obs. nights(y)
Kiyota	Tsukuba	25cm	BVyRI	24
Kubotera	Odawara	16cm	BVyR	8
Maehara	Kawaguchi	20/25cm	BVyRI	19
Nakajima	Kumano	25cm	BVyRI	55
OKU	Kashiwara	51cm	Vy	25

Plateau in the Light Curve (2006)

(Hachisu et al. 2006, ApJ, 651, L141)



2006 Outburst of RS Ophiuchi

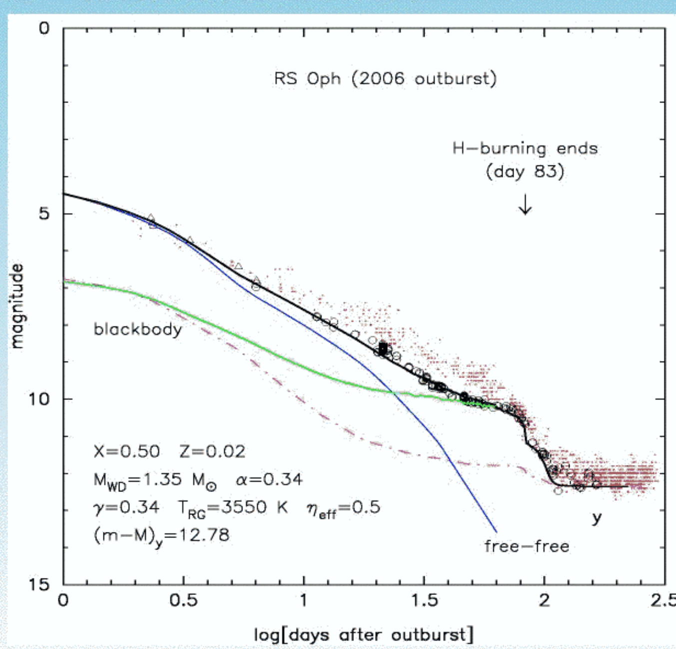
2006 Outburst of RS Ophiuchi

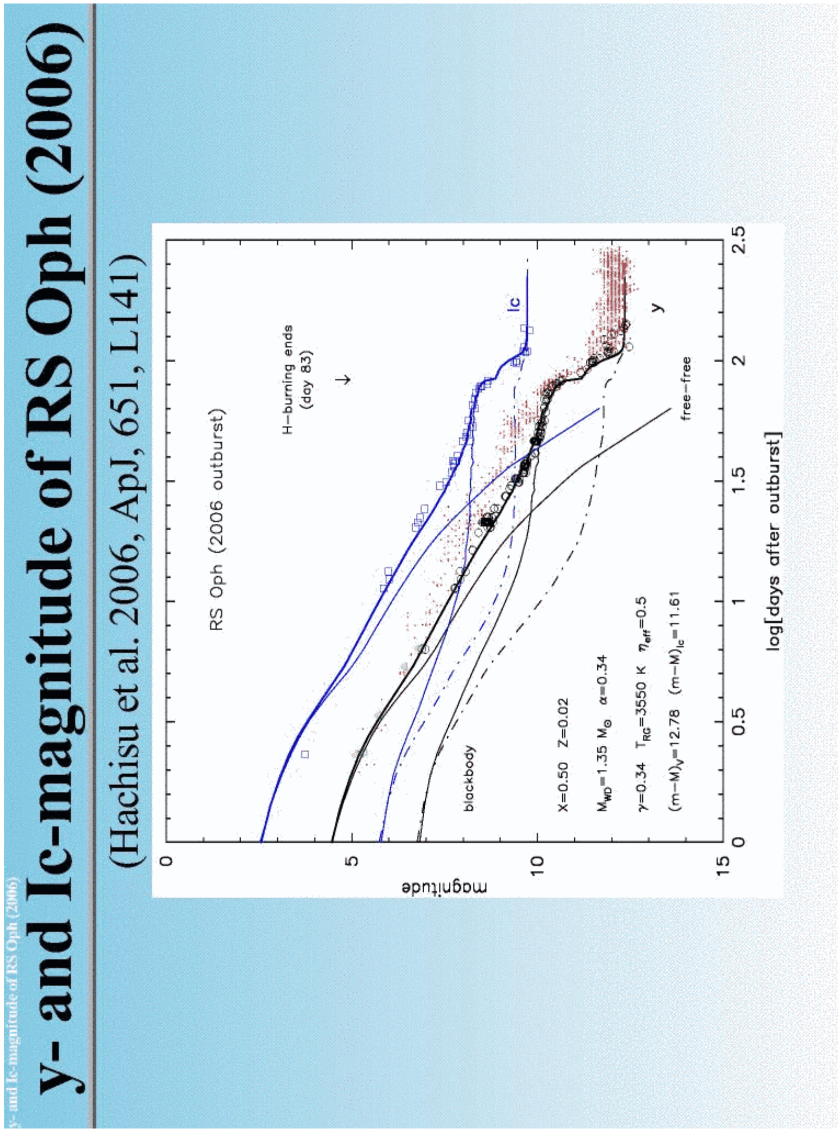
Main contribution to y-magnitude
1. Early phase ← free-free + WD photosphere
2. Plateau phase ← Disk irradiation

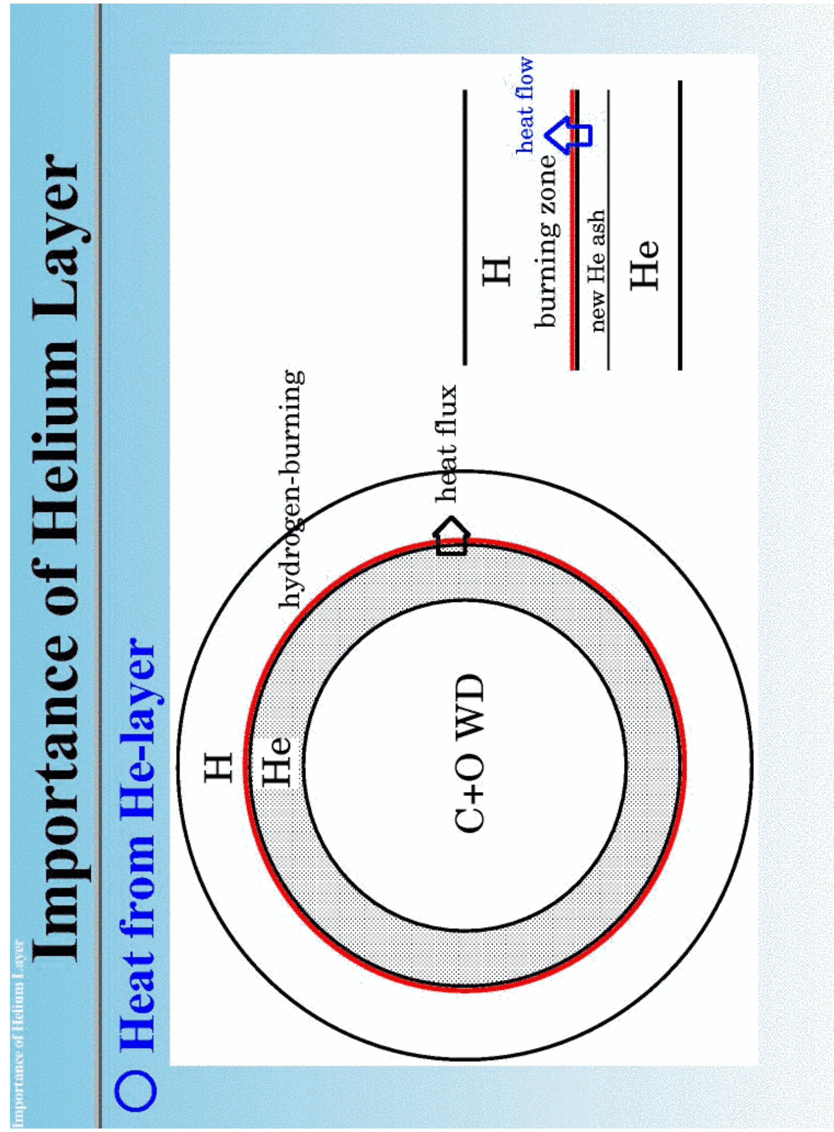
Model light curve of RS Oph (2006)

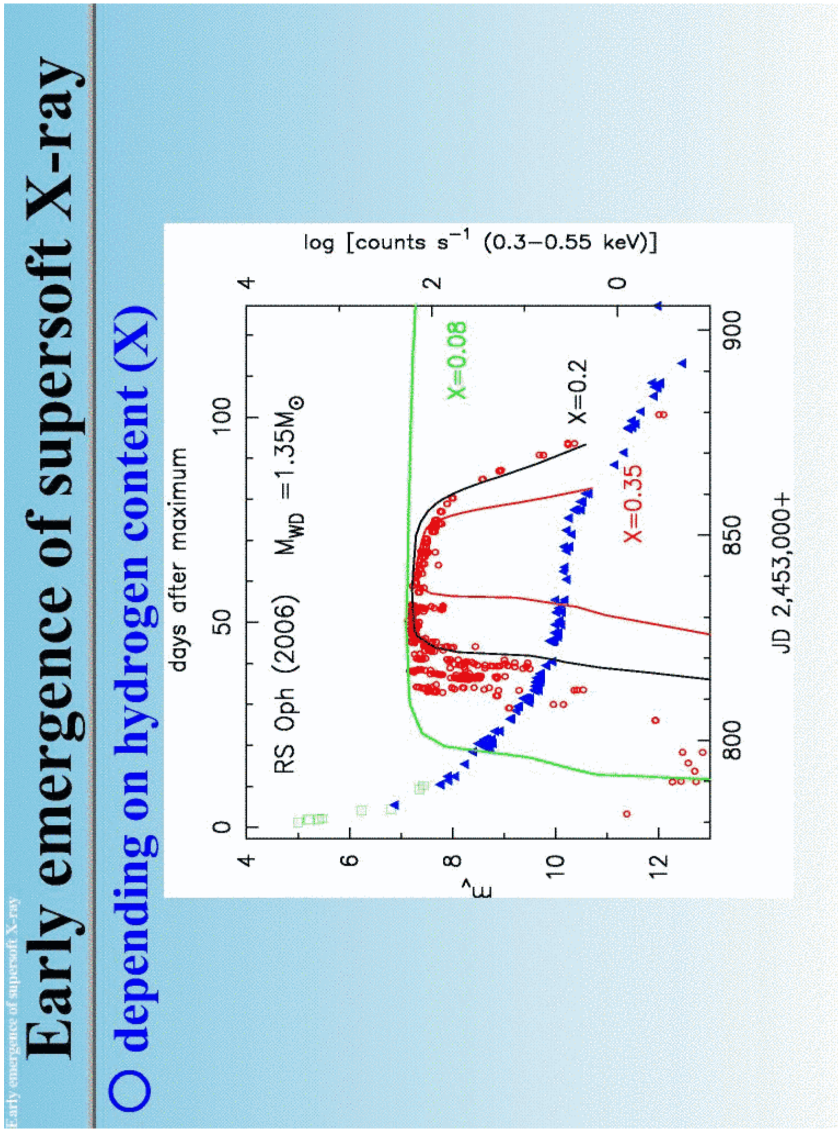
Model light curve of RS Oph (2006)

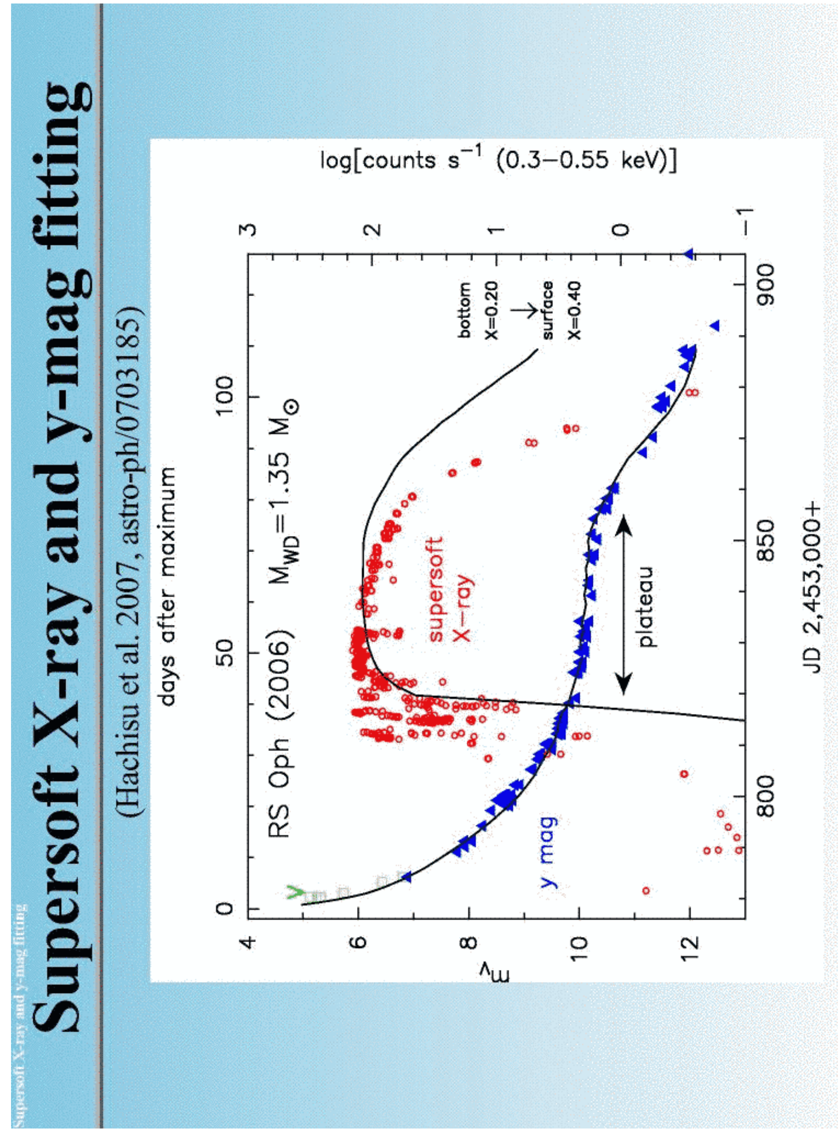
○ free-free + disk irradiation




y- and Ic-magnitude of RS Oph (2006)
(Hachisu et al. 2006, ApJ, 651, L141)
RS Oph (2006 outburst)
H-burning ends
(day 83)
blackbody
X=0.50 Z=0.02
M_WD=1.35 M_⊙ α=0.34
γ=0.34 T_RG=3550 K η_eff=0.5
(m−M)_y=12.78 (m−M)_Ic=11.61
free-free
Ic
y
magnitude
log[days after outburst]


Importance of Helium Layer
Heat from He-layer
H
He
C+O WD
hydrogen-burning
heat flux
H
burning zone
heat flow
new He ash
He


Early emergence of supersoft X-ray
depending on hydrogen content (X)
log [counts s^{-1} (0.3−0.55 keV)]
days after maximum
RS Oph (2006) M_{WD} =1.35$M_\odot$
X=0.08
X=0.2
X=0.35
JD 2,453,000+
m_v


Supersoft X-ray and y-mag fitting
(Hachisu et al. 2007, astro-ph/0703185)
log[counts s^{-1} (0.3−0.55 keV)]
days after maximum
RS Oph (2006) M_{WD}=1.35 $M_\odot$
bottom X=0.20 → surface X=0.40
supersoft X−ray
plateau
y mag
JD 2,453,000+
m_v

Summary of RS Ophiuchi (1)

(Hachisu et al. 2007, astro-ph/0703185)

1 . **White Dwarf Mass**

$$M_{\rm WD} = 1.35 \pm 0.01 M_\odot \ \ {\rm for} \ X = 0.20$$

2 . **Envelope mass at the optical peak**

$$\Delta M \approx 4 \times 10^{-6} M_\odot$$

3 . **Mass accretion rate before the 2006 outburst**

$$\dot M_{\rm acc} \approx 2 \times 10^{-7} M_\odot \ {\rm yr}^{-1}$$

during 21 years

Summary for RS Ophiuchi (2)

4 . **Ejected mass during the wind phase**

$$\Delta M_{\rm wind} \approx 2.8 \times 10^{-6} M_\odot \quad (70\%)$$

consistent with near IR observation

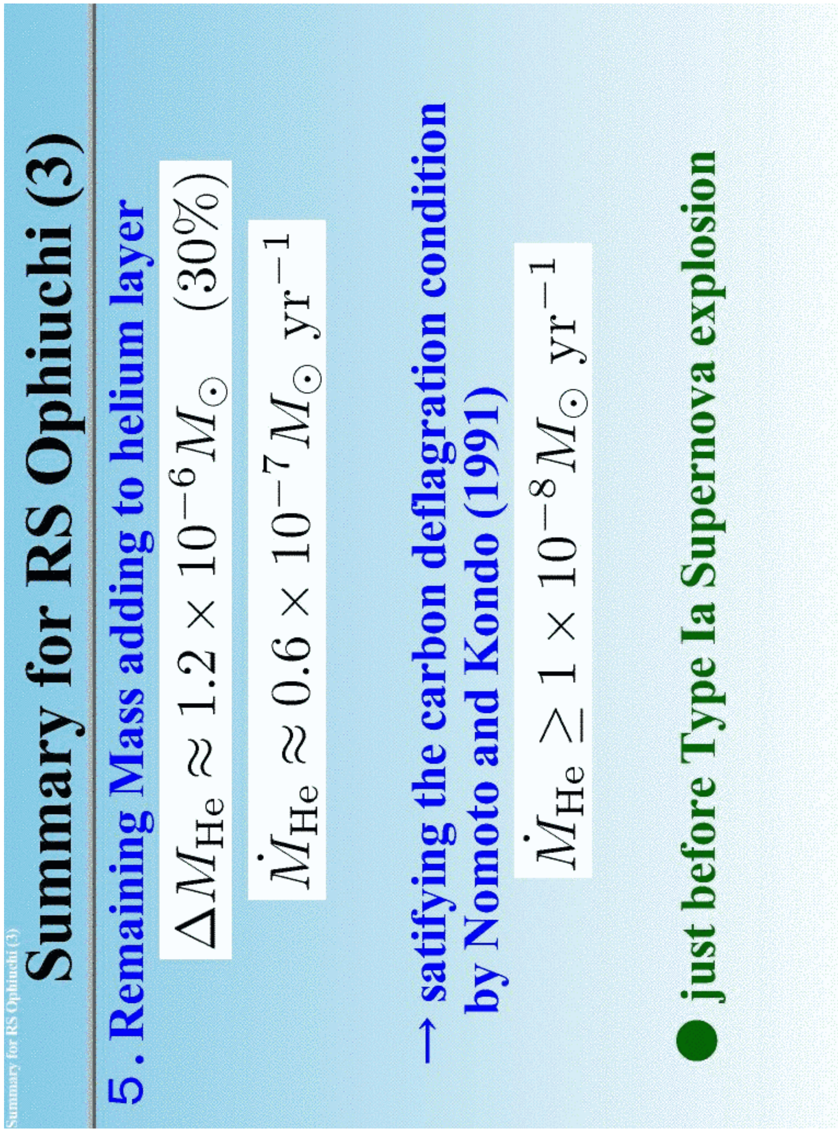
$$\Delta M_{\rm ejecta} \sim 3 \times 10^{-6} M_\odot$$

(Das et al. 2006, Lane et al. 2007)

but not consistent with early X-ray observation

$$\Delta M_{\rm ejecta} \sim 1 \times 10^{-7} M_\odot$$

(Sokoloski et al. 2006)


Summary for RS Ophiuchi (3)
Summary for RS Ophiuchi (3)
5. Remaining Mass adding to helium layer
$\Delta M_{\rm He} \approx 1.2 \times 10^{-6} M_\odot \quad (30\%)$
$\dot M_{\rm He} \approx 0.6 \times 10^{-7} M_\odot \ {\rm yr}^{-1}$
→ satisfying the carbon deflagration condition by Nomoto and Kondo (1991)
$\dot M_{\rm He} \geq 1 \times 10^{-8} M_\odot \ {\rm yr}^{-1}$
● just before Type Ia Supernova explosion