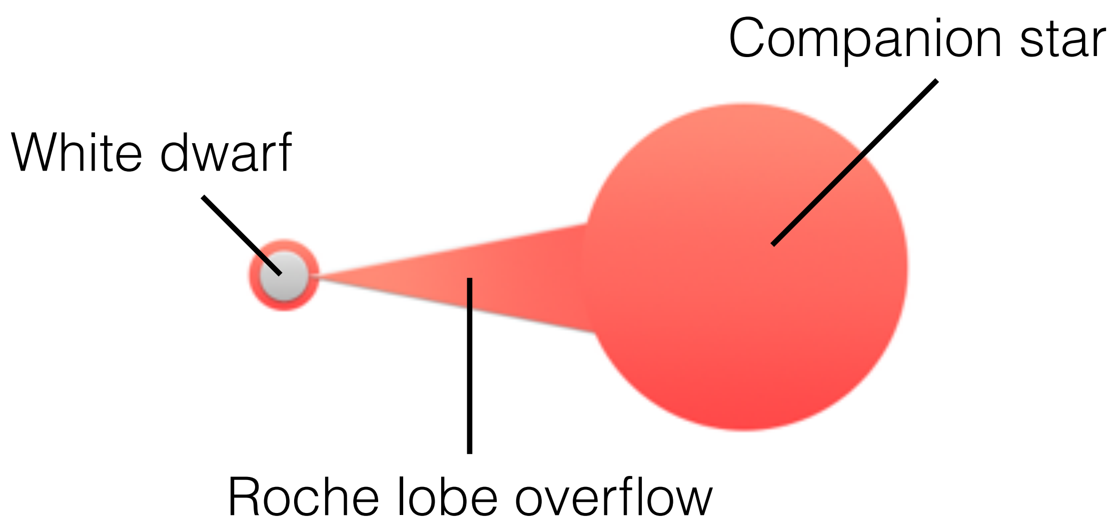
Nova wind acceleration in early SSXS phase

RIKEN-RESCEU joint seminar
25th July 2016
Shigeyama Lab. D2
Kentaro Wada

Evolution channels of accreting white dwarfs



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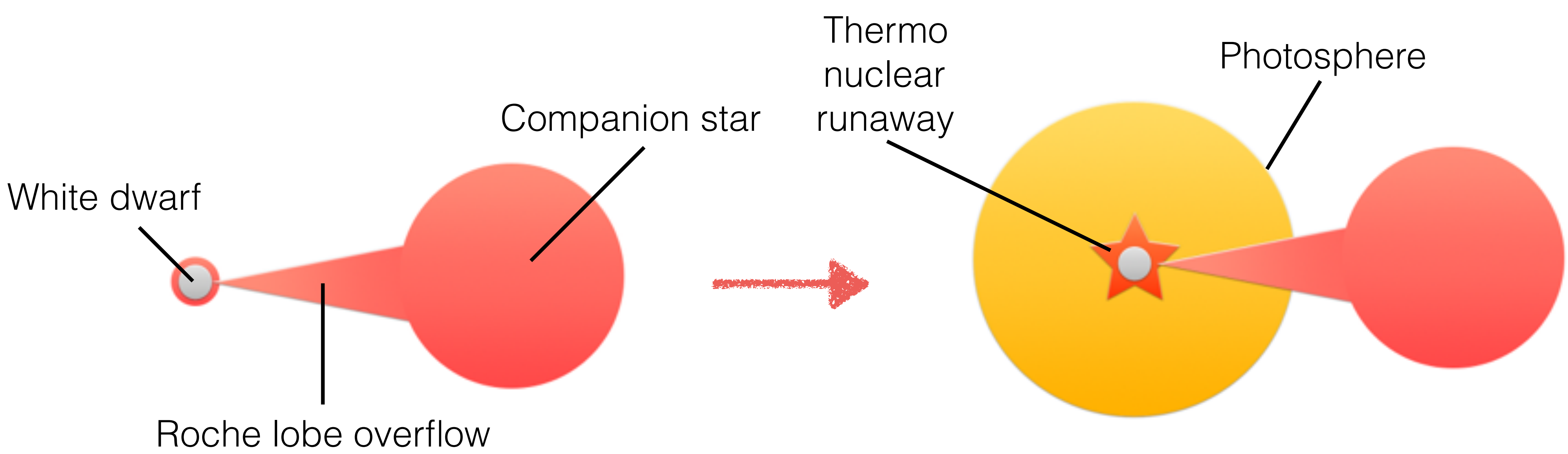

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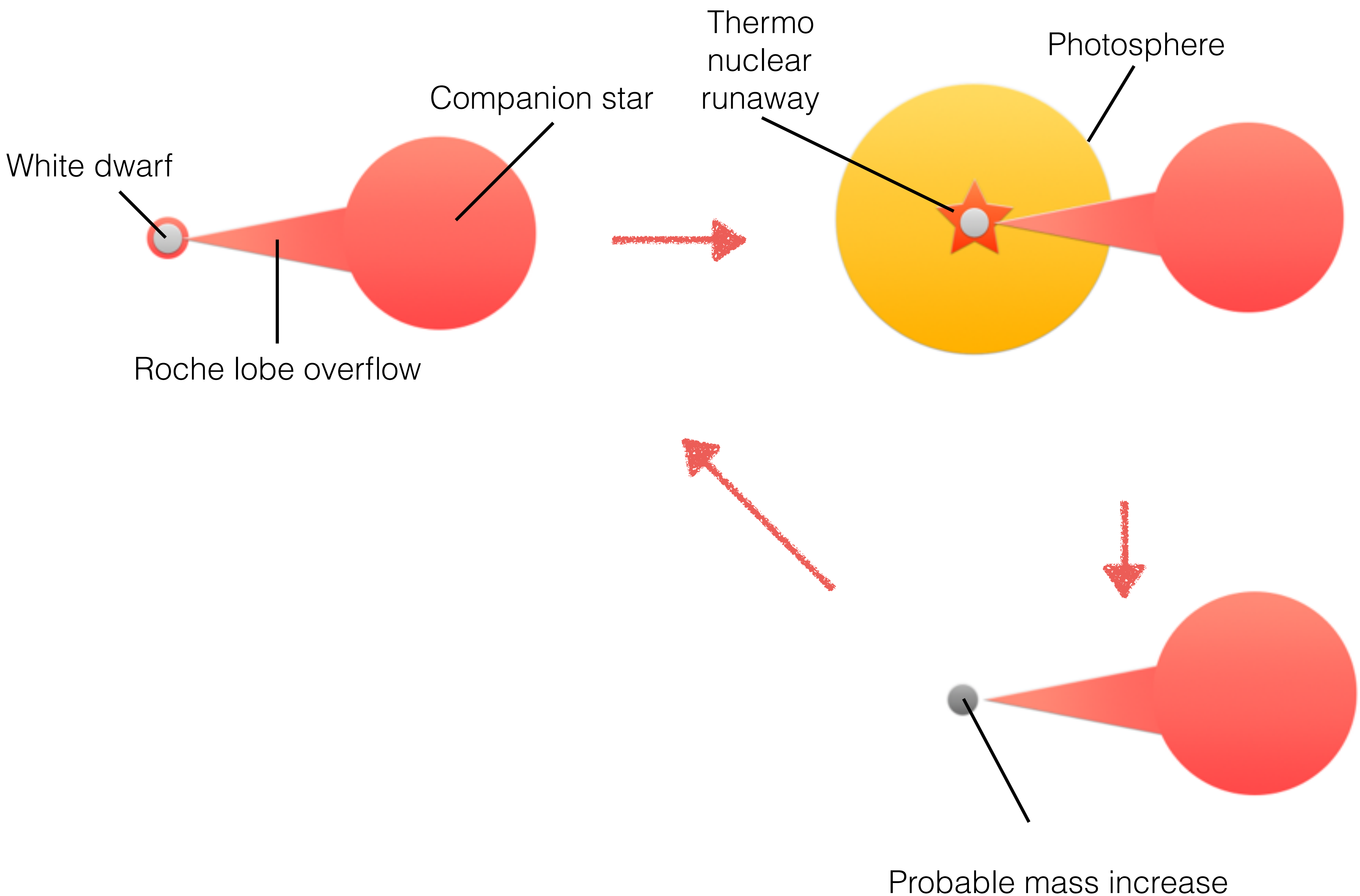

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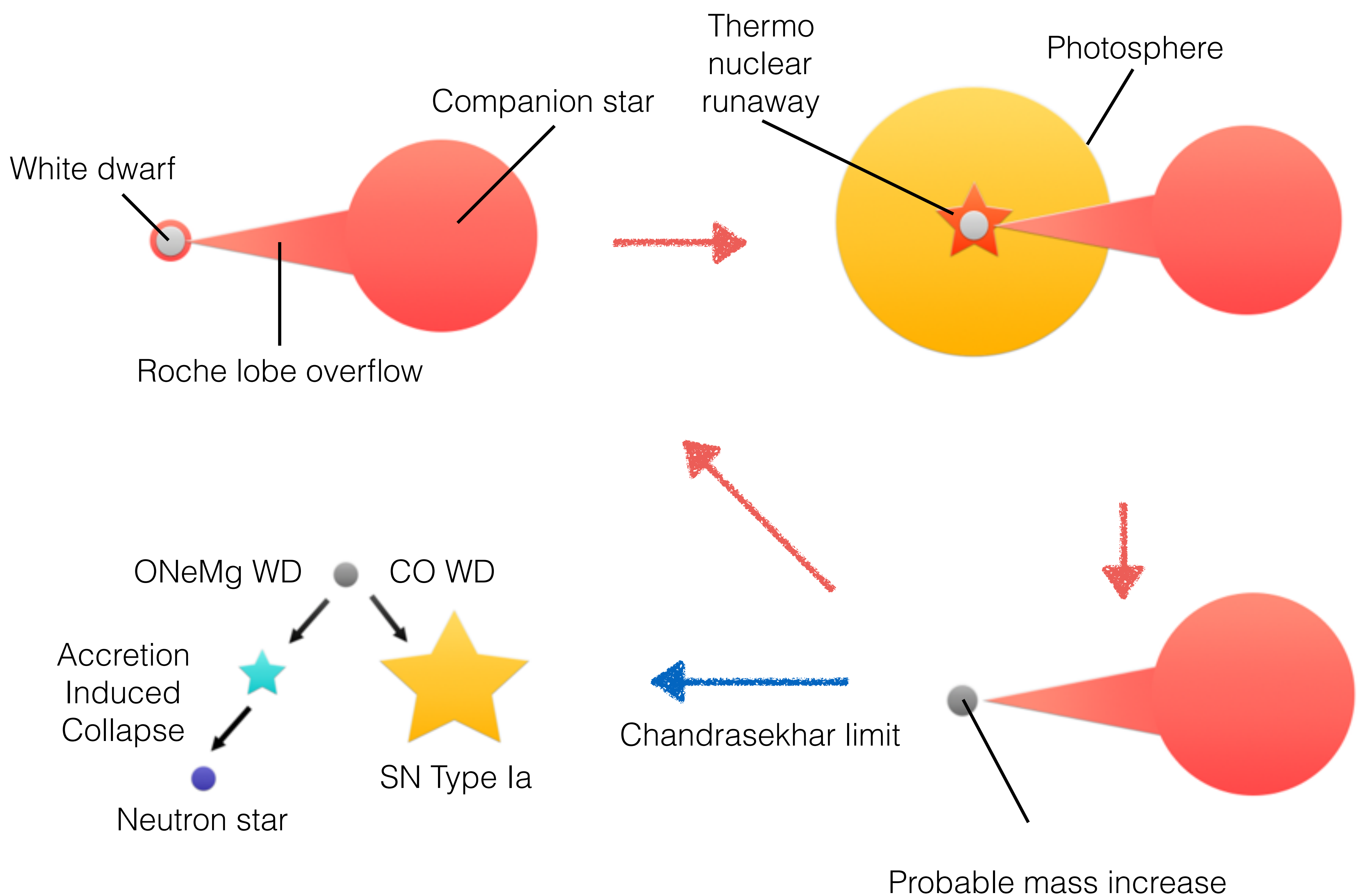
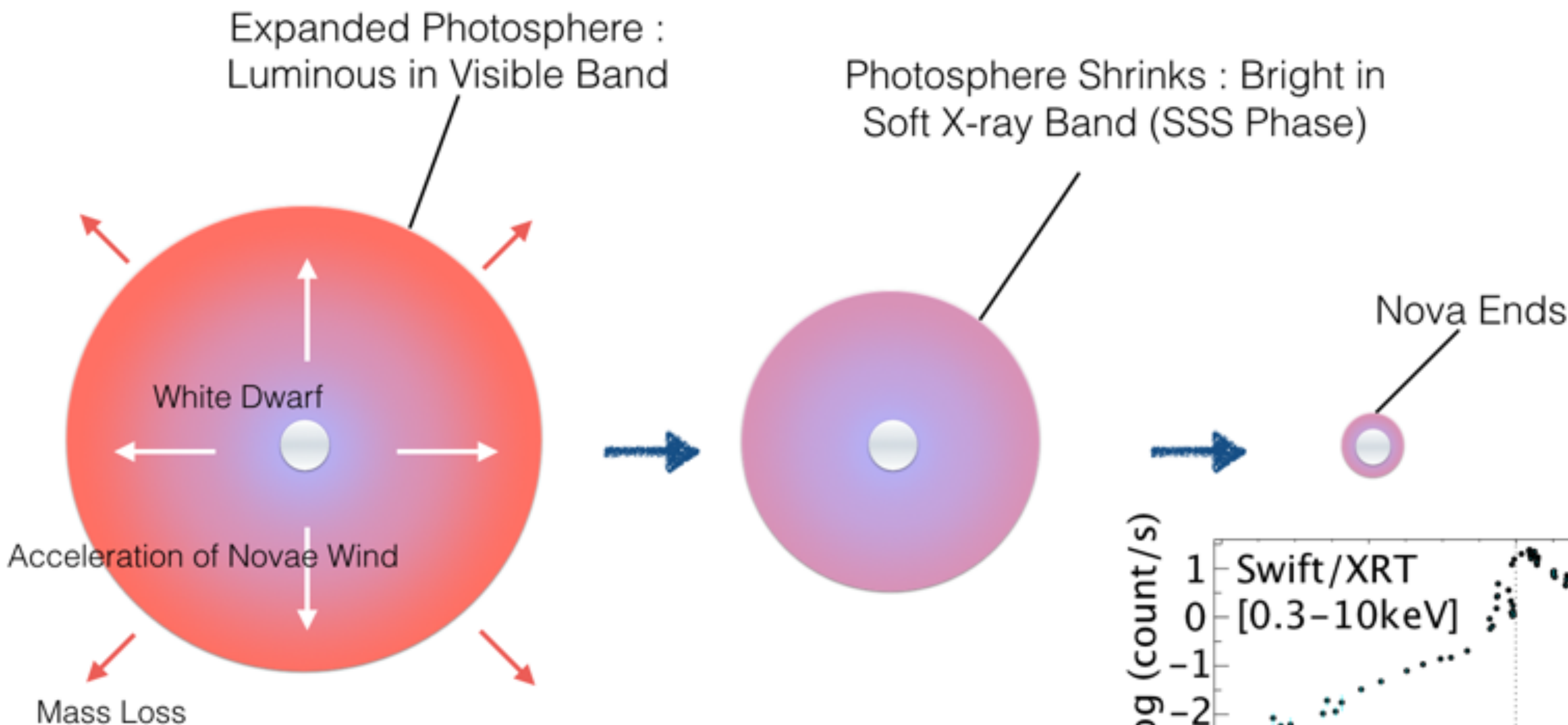
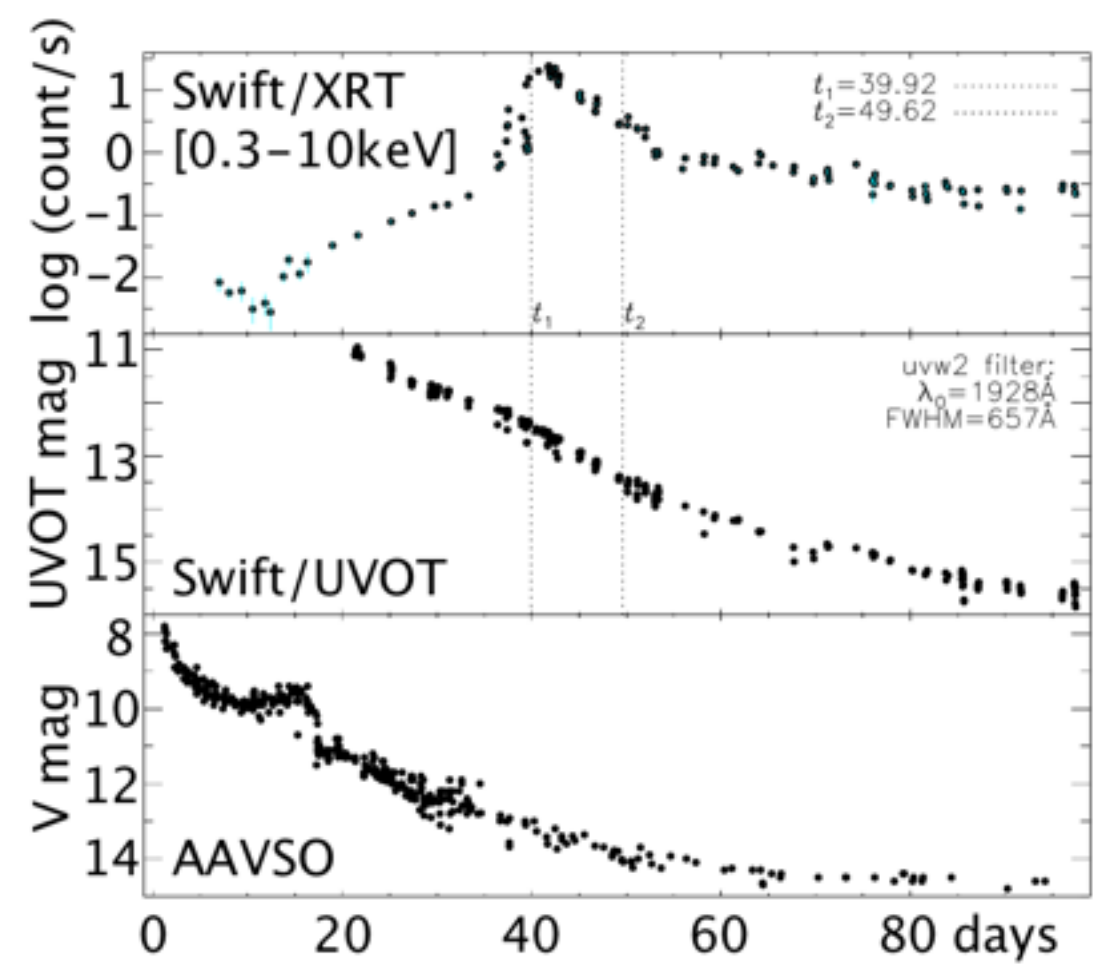


Time variation of photosphere

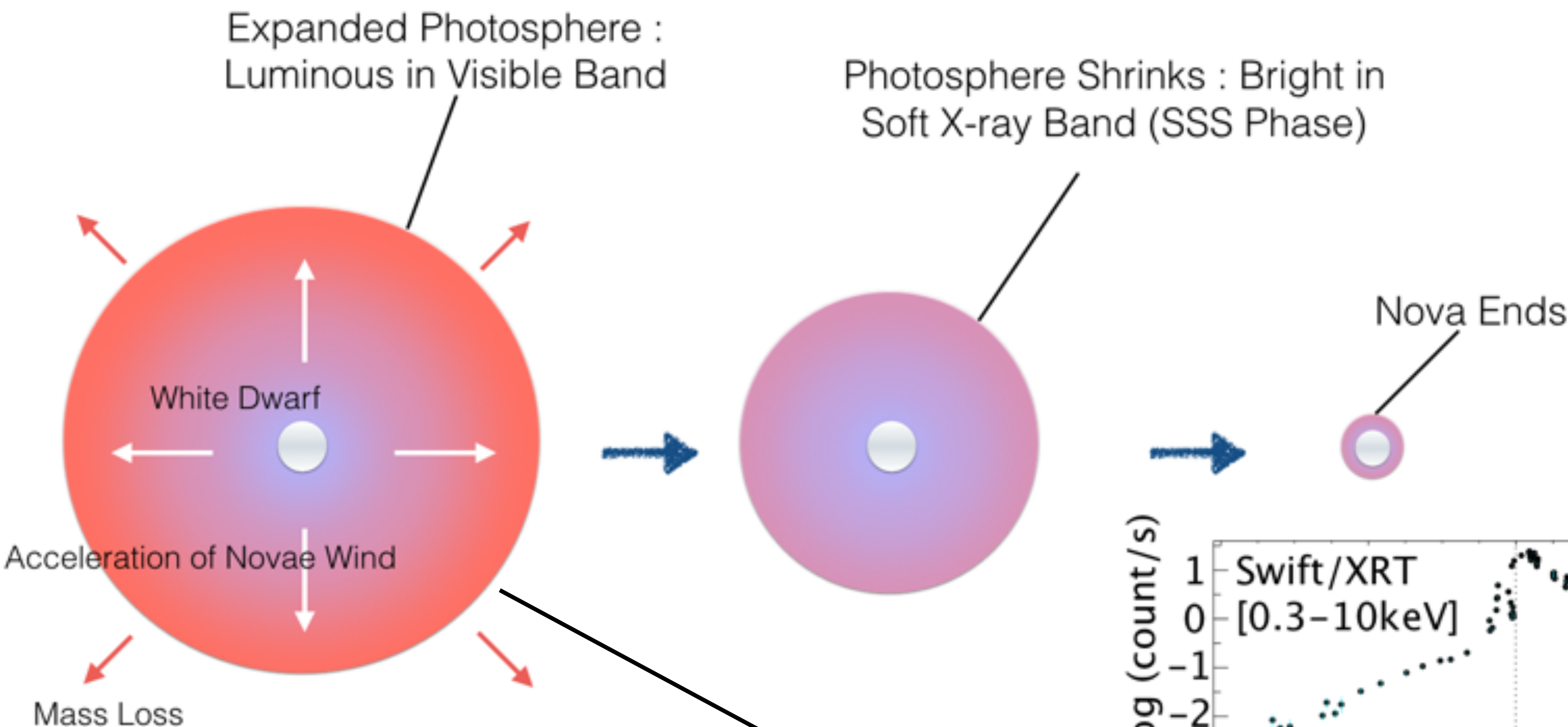


- Heavier WDs produce fast novae due to small ignition mass and intense nuclear reaction.



Light curve of fast nova V2491 Cyg (Ness+ 2014)

Time variation of photosphere



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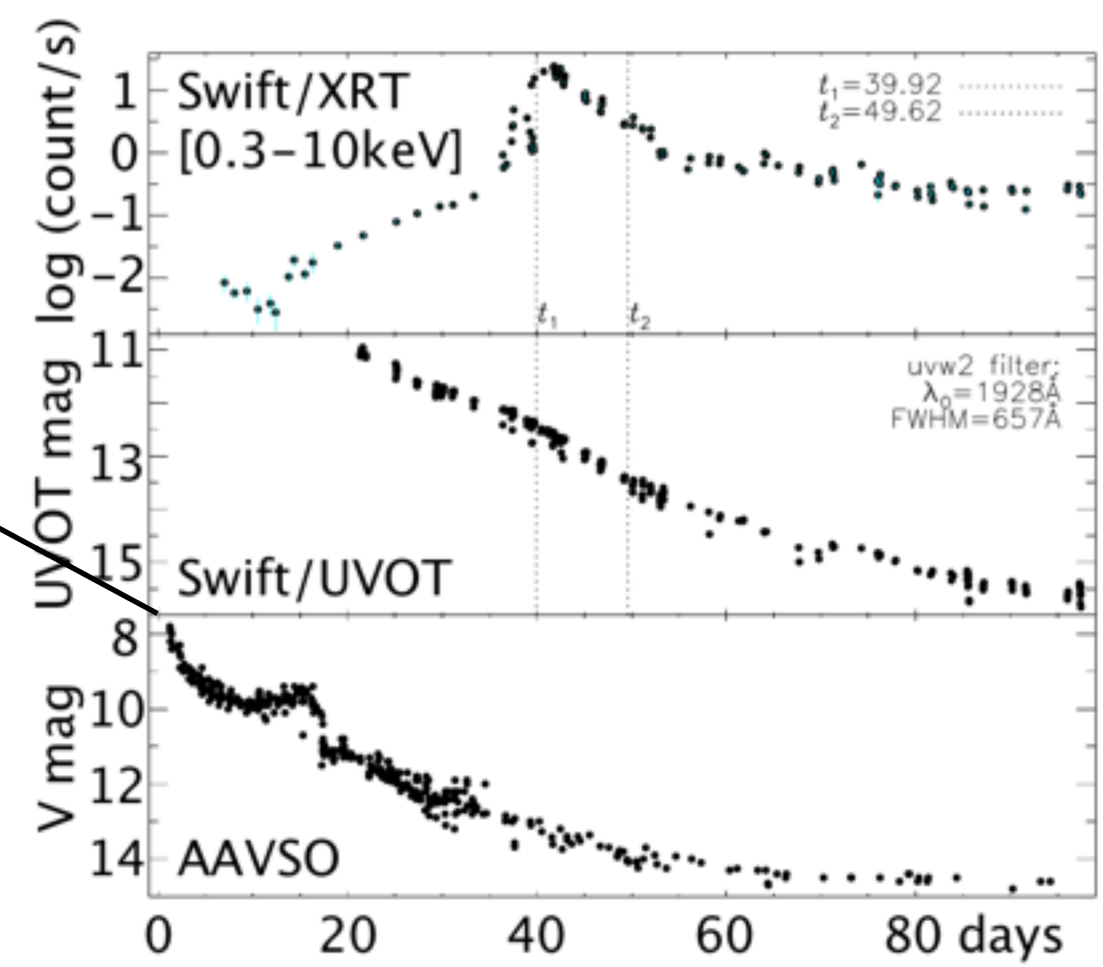

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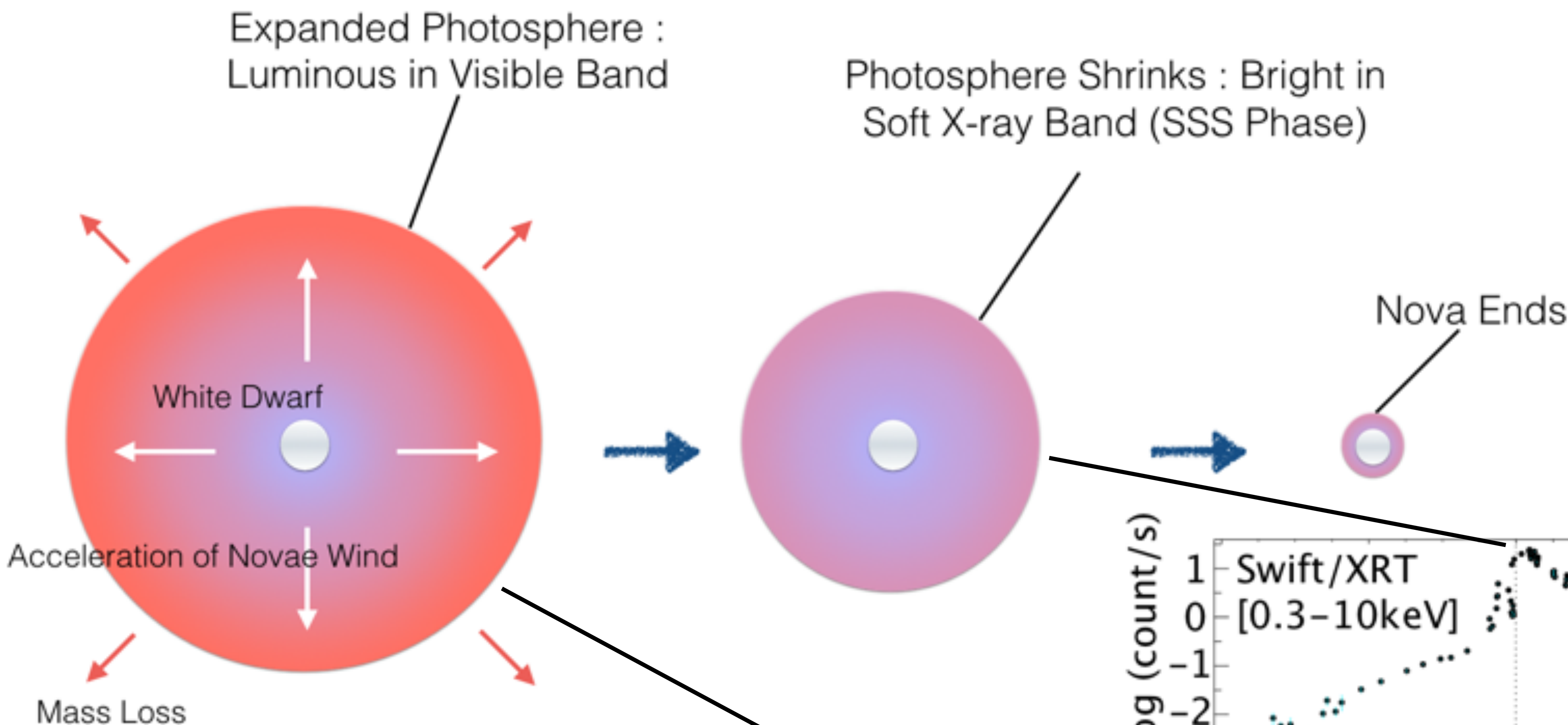

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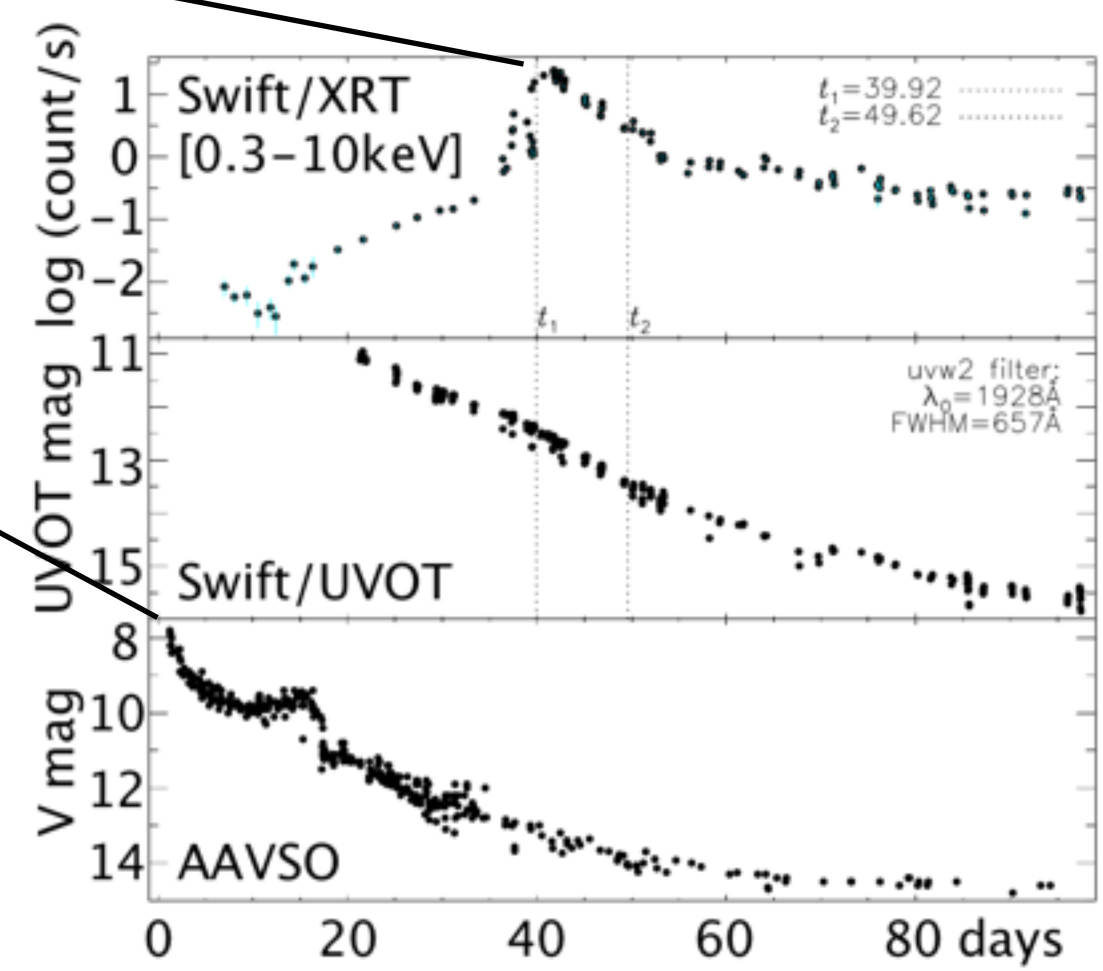


Light curve of fast nova V2491 Cyg (Ness+ 2014)

Blue shifted broad lines and mass ejection in SSXS phase

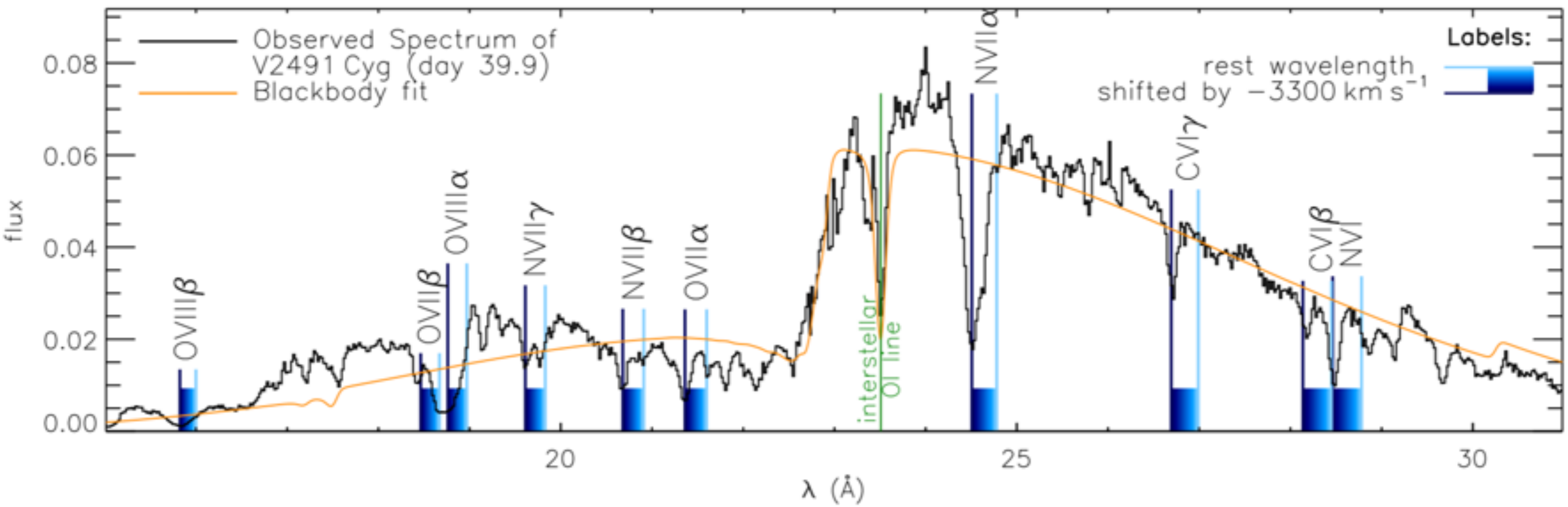


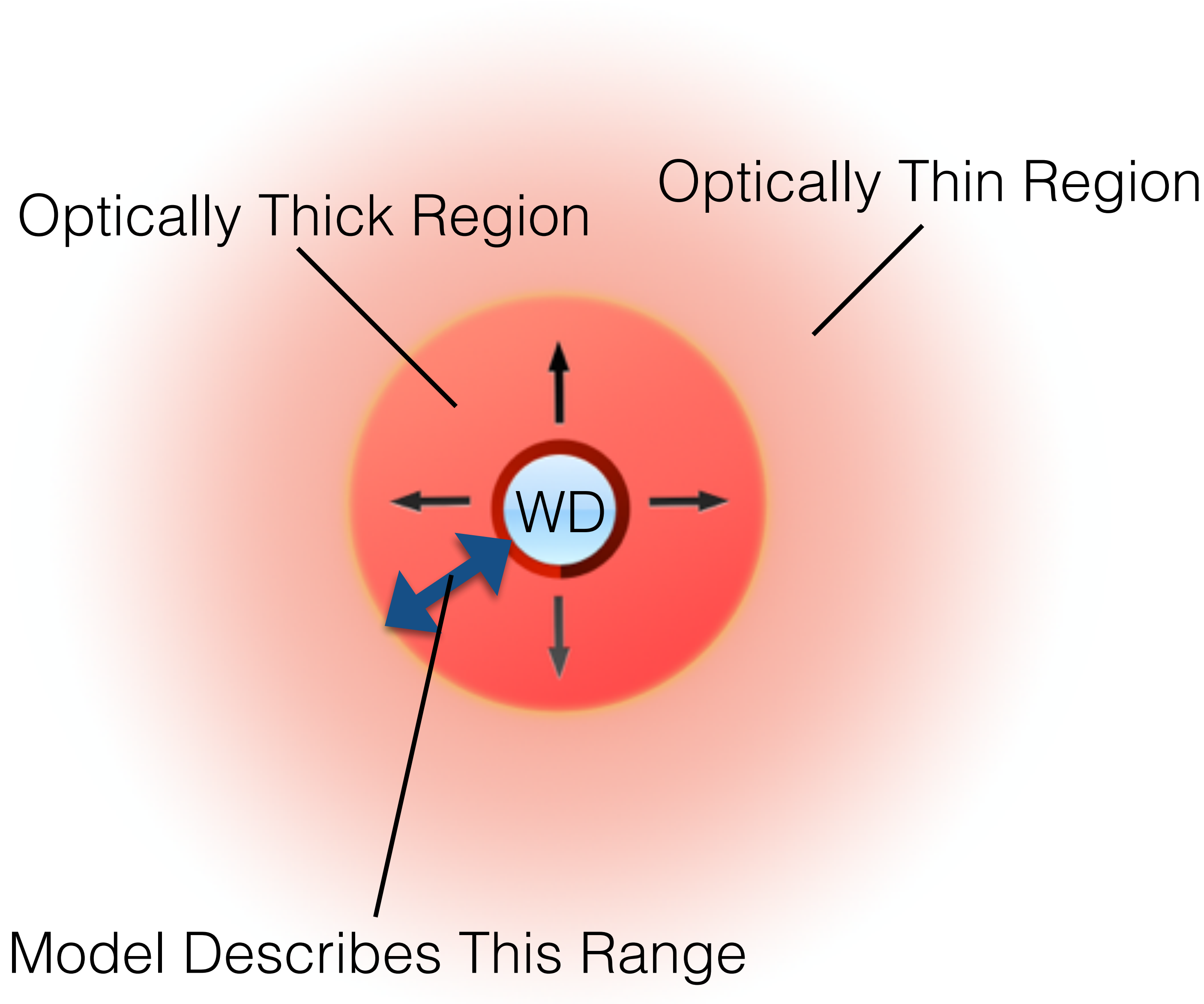
Fig. 2 XMM-Newton RGS spectrum of V2491 Cyg. Flux units are photons $\mathrm{cm^{-2}\,s^{-1}\,\AA^{-1}}$. The continuum resembles a blackbody (orange curve), but in addition, deep absorption lines can be identified. The blackbody curve is corrected for interstellar absorption using the ISM absorption model by Wilms et al. (2000). The blue-shaded boxes indicate a range of blue shifts ranging from rest wavelength (light) up to a velocity of 3300 km $\mathrm{s^{-1}}$ (dark).

Spectrum in SSXS phase of V2491 Cyg (Ness 2010)

- Spectrum of V2491Cyg in SSXS phase indicates mass ejection.
- Recent x-ray observations raise new questions to understand evolutionary channels of accreting WDs: super Eddington luminosity and expansion in SSXS phase.

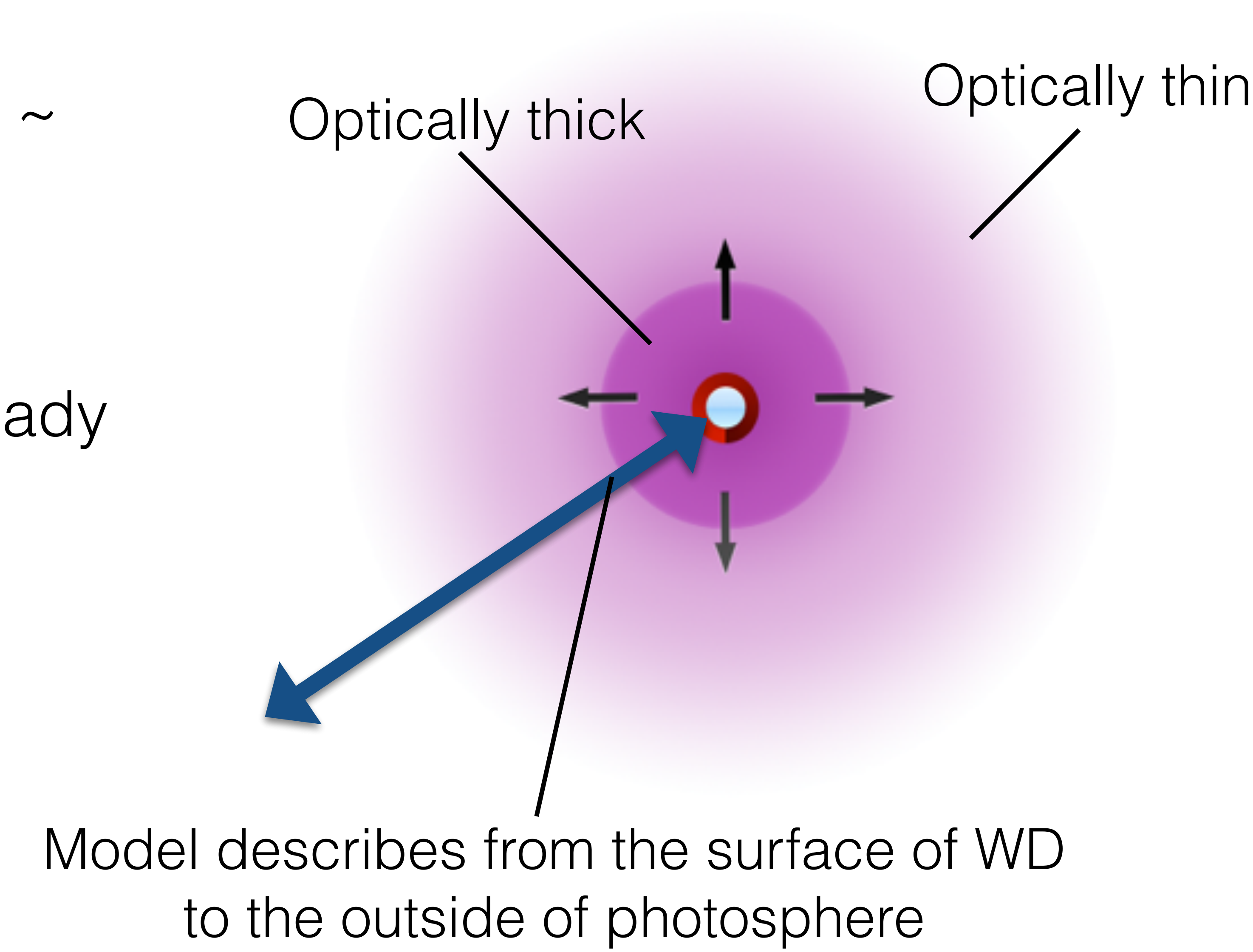
Preceding model: Kato & Hachisu (1994)

- Ongoing nuclear burning and mass loss.
- Spherically symmetric, steady state, diffusion approximation, LTE approximation.
- Model describes optically thick region: surface of WD to photosphere.



Our model: solving beyond photosphere and later phase of nova

- From the surface of WD to ~ 10^9 km (~> 100 times photosphere)
- Spherically symmetric, steady state outflow.
- LTE and grey atmosphere approximation.



Equations

$$4\pi r^2 \rho v = \dot{M}$$ Mass

Gravity

$$\rho v \frac{dv}{dr} + \frac{dp_g}{dr} = \boxed{-\frac{\rho G M}{r^2}} + \boxed{\frac{\kappa_r \rho F_0}{c}}$$ Radiation — Momentum

Nuclear energy generation

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2 v \left(e_g + \frac{1}{2}\rho v^2 \boxed{-\frac{\rho G M}{r}} + p_g + \boxed{P_0 + E_0}\right)\right) + \boxed{\frac{1}{r^2}\frac{d}{dr}(r^2 F_0)} = \boxed{\rho \epsilon}$$ Energy

$$\boxed{\frac{v}{c^2}\frac{dF_0}{dr} + \frac{dP_0}{dr} + \frac{3P_0 - E_0}{r} + \frac{2}{c^2}\left(\frac{dv}{dr} + \frac{v}{r}\right) F_0 = -\frac{\kappa_r \rho F_0}{c}}$$ Radiative Transfer

$$P_0 = \chi E_0$$

$$\chi = \frac{3 + 4f^2}{5 + 2\sqrt{4 - 3f^2}}$$

$$f = \frac{|F_0|}{cE}$$

Variable Eddington factor
M1 closure

Solving both optically thick and thin regions: M1 Closure

P = 1/3 E

Optically thick limit
Isotropic

P = E

Optically thin limit
Free streaming

Radiation energy
Eddington factor
Radiation pressure

$$P_0 = \chi E_0$$

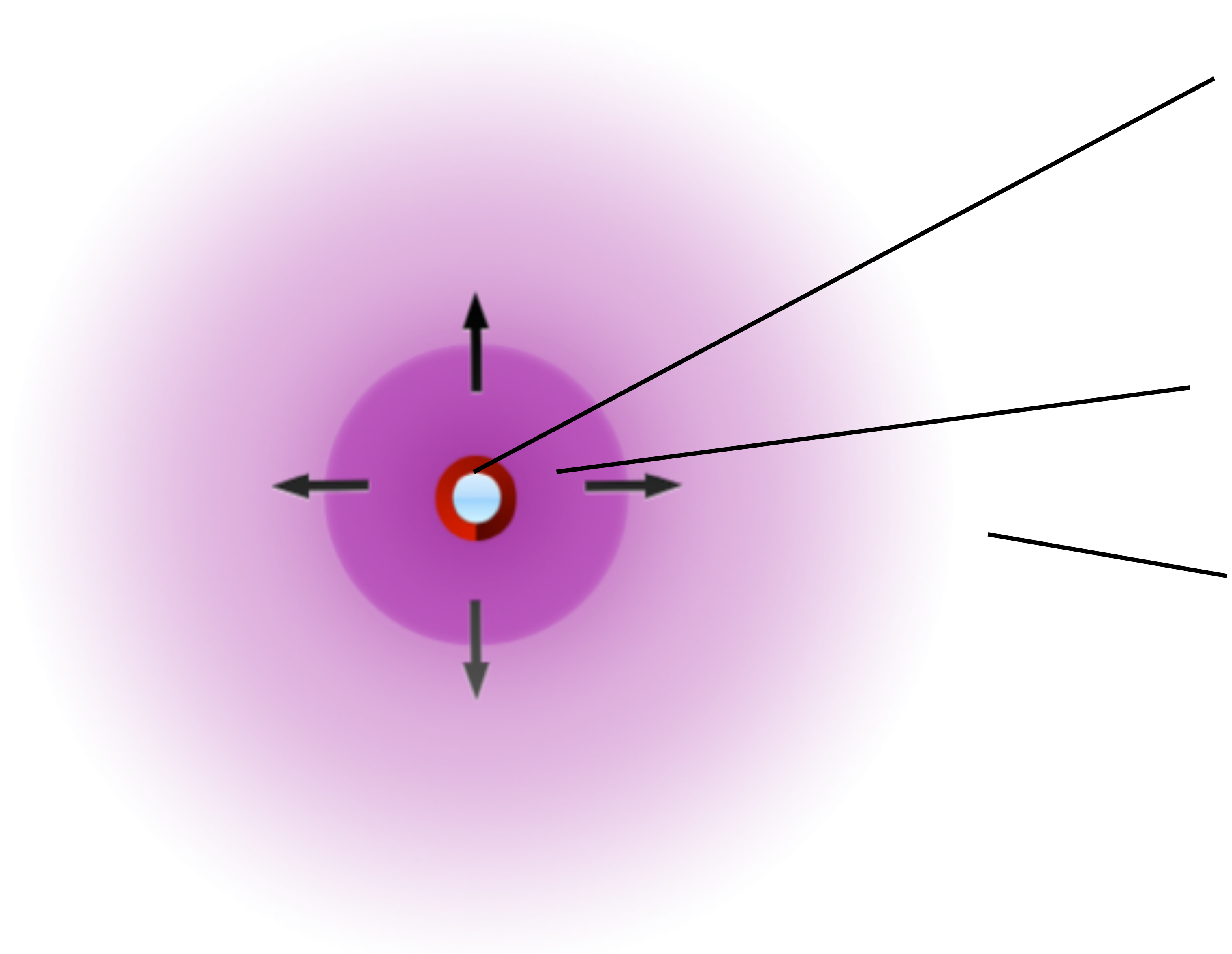
$$\chi = \frac{3+4f^2}{5+2\sqrt{4-3f^2}}$$

$$f = \frac{|F_0|}{cE}$$

- A method to connect optically thick and thin regions variating Eddington factor.
- Several actual formulations are proposed and tested.

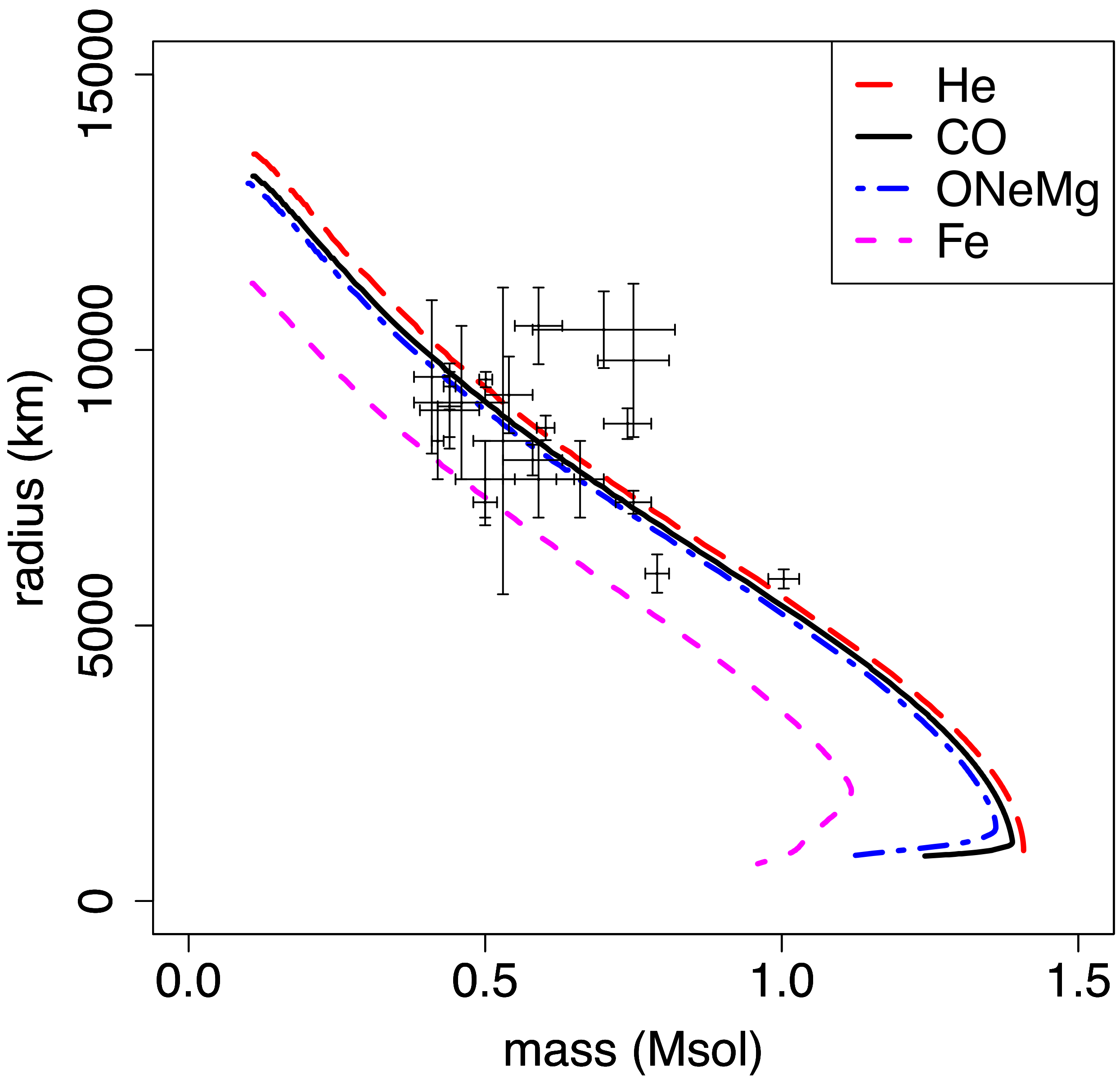
Levermore & Pomraning 1981
Dubroca & Feugeas 1999

Boundary conditions



1. Luminosity balances with nuclear energy generation on the surface of WD
2. Wind passes through the sonic point
3. Wind becomes optically thin at the outermost point
4. Given observed luminosity at the assuming phase

Mass radius relations of white dwarfs



Observation data are from Provencal+ 1998

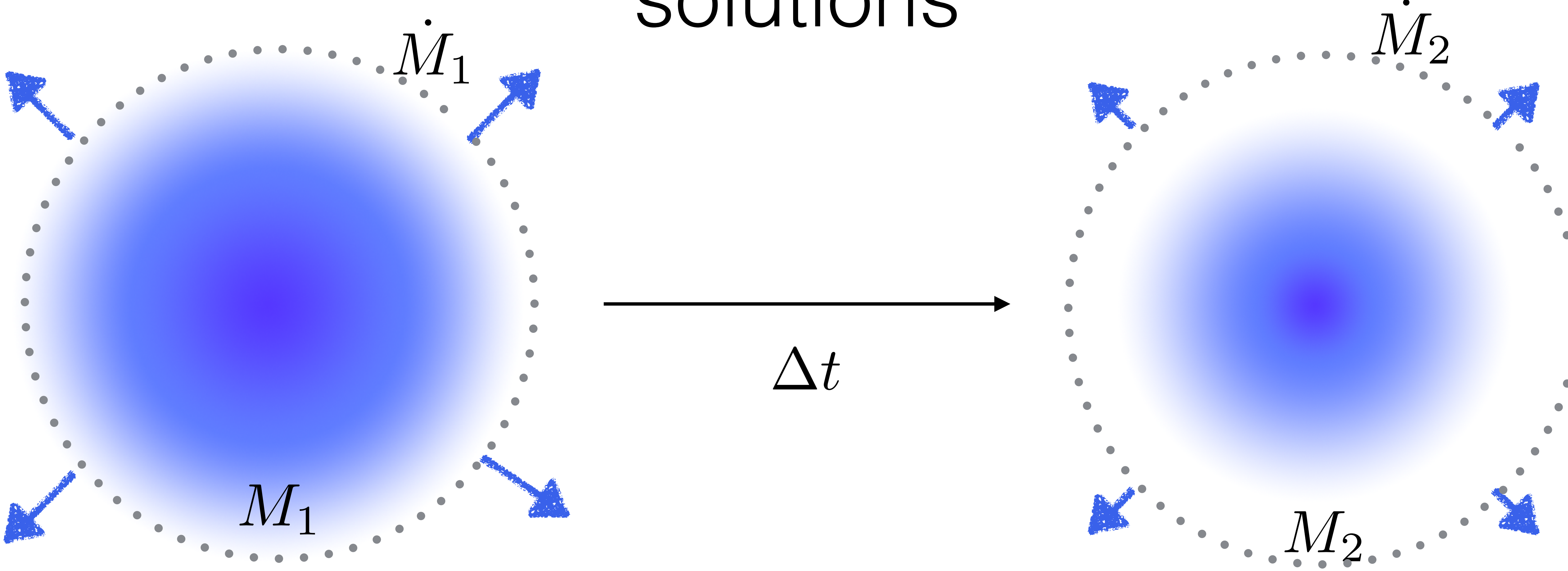
- TOV equation + Salpeter 1961's EOS of WDs
- Degenerated electron pressure + electrostatic effects + β equilibrium

0.08 - 0.64 Msun -> He WDs

0.64 - 8 Msun -> CO WDs

8 - 9 Msun -> ONeMg WDs

Time interval between 2 steady state solutions



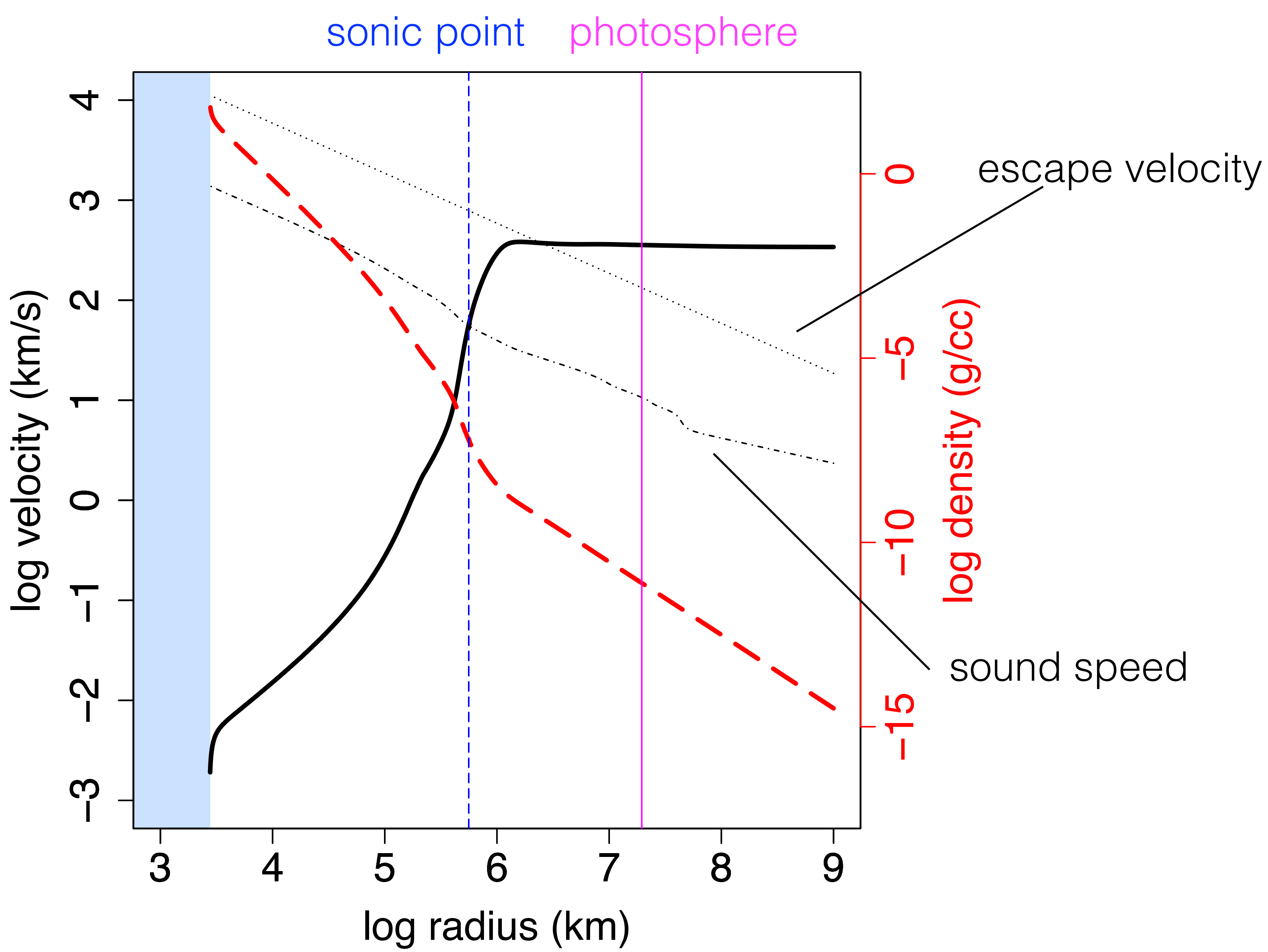
decreased wind mass appears as change in profile

$$M_2 - M_1 = \bar{\dot{M}} \Delta t$$

ejected mass

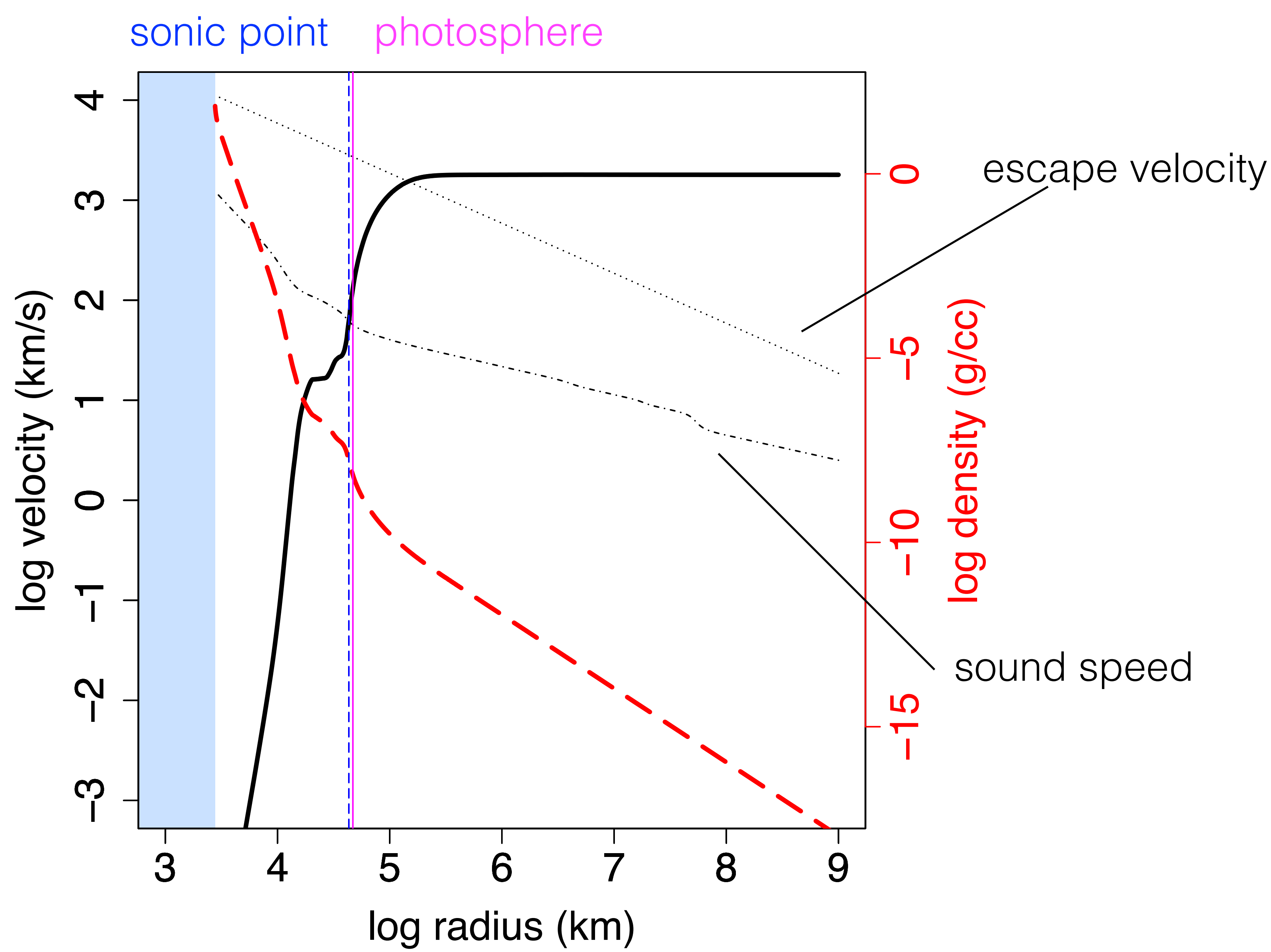
- Mass of outer layer for each solution is numerically calculated. Assuming the difference of mass between 2 solutions is equals to ejected mass between the solutions, time interval can be calculated.
- Nuclear reactions is considered and mass accretion is ignored. Both effects are negligible.

Profiles: velocity and density



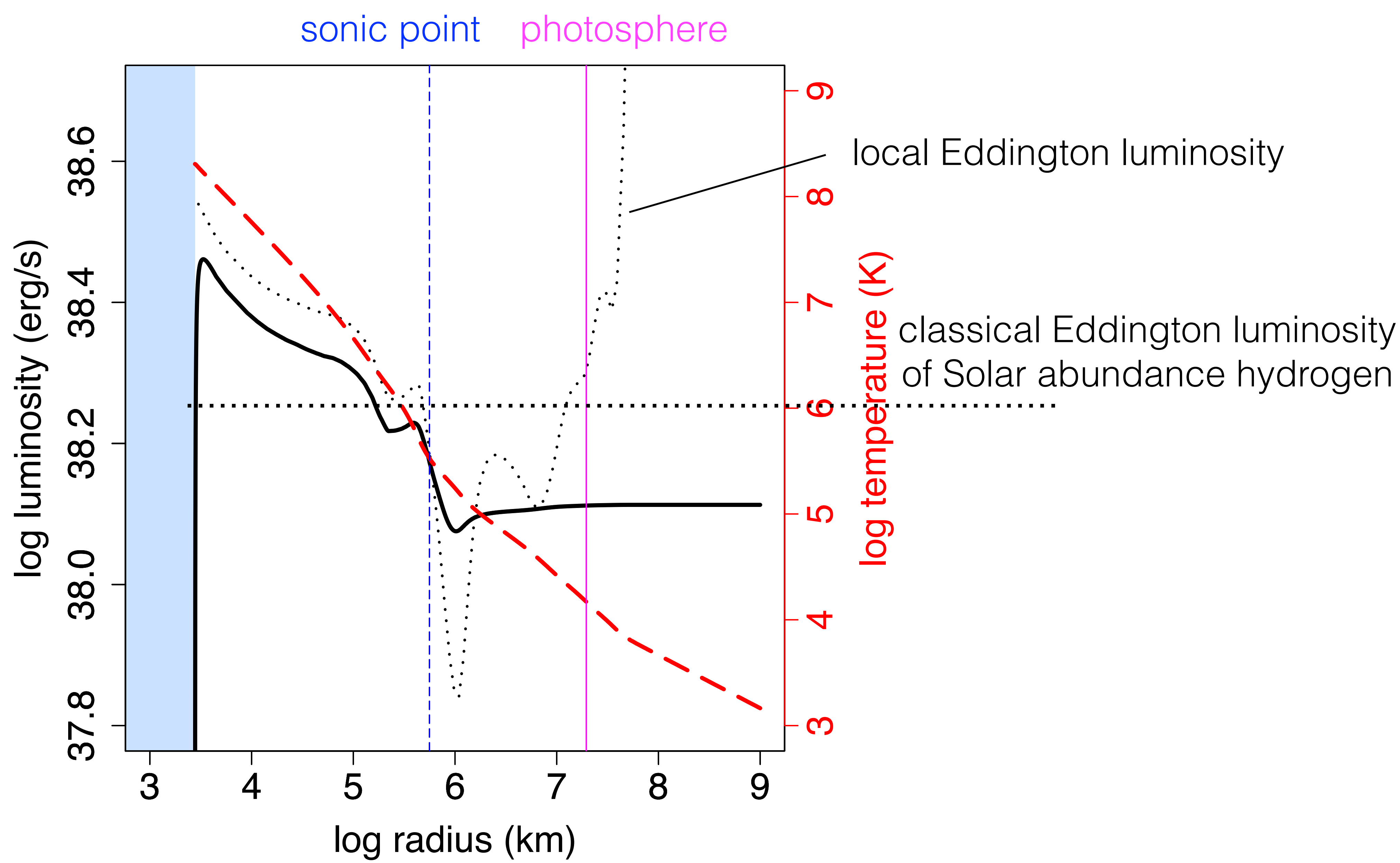
- Sonic point and photosphere move toward inside and get closer.
- Density profile becomes steep and terminal velocity increases.

Profiles: velocity and density



- Sonic point and photosphere move toward inside and get closer.
- Density profile becomes steep and terminal velocity increases.

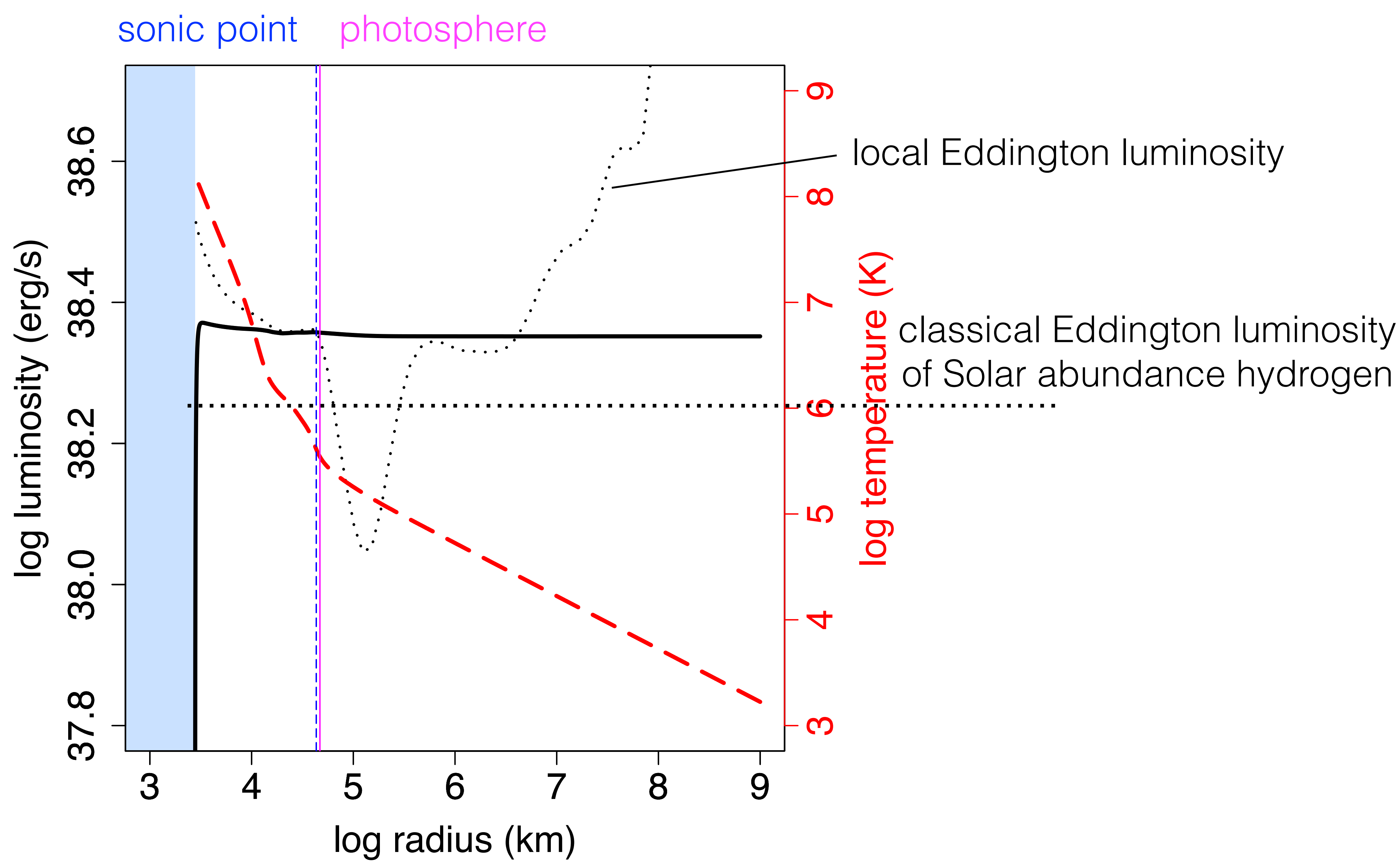
Profiles: luminosity and temperature



- Luminosity on the surface of WD decreases to a certain degree. However, observed luminosity increases since radiation accelerates dilute nova wind spending a small amount of its energy.

- Temperature of the photosphere increases to emit soft X-ray

Profiles: luminosity and temperature



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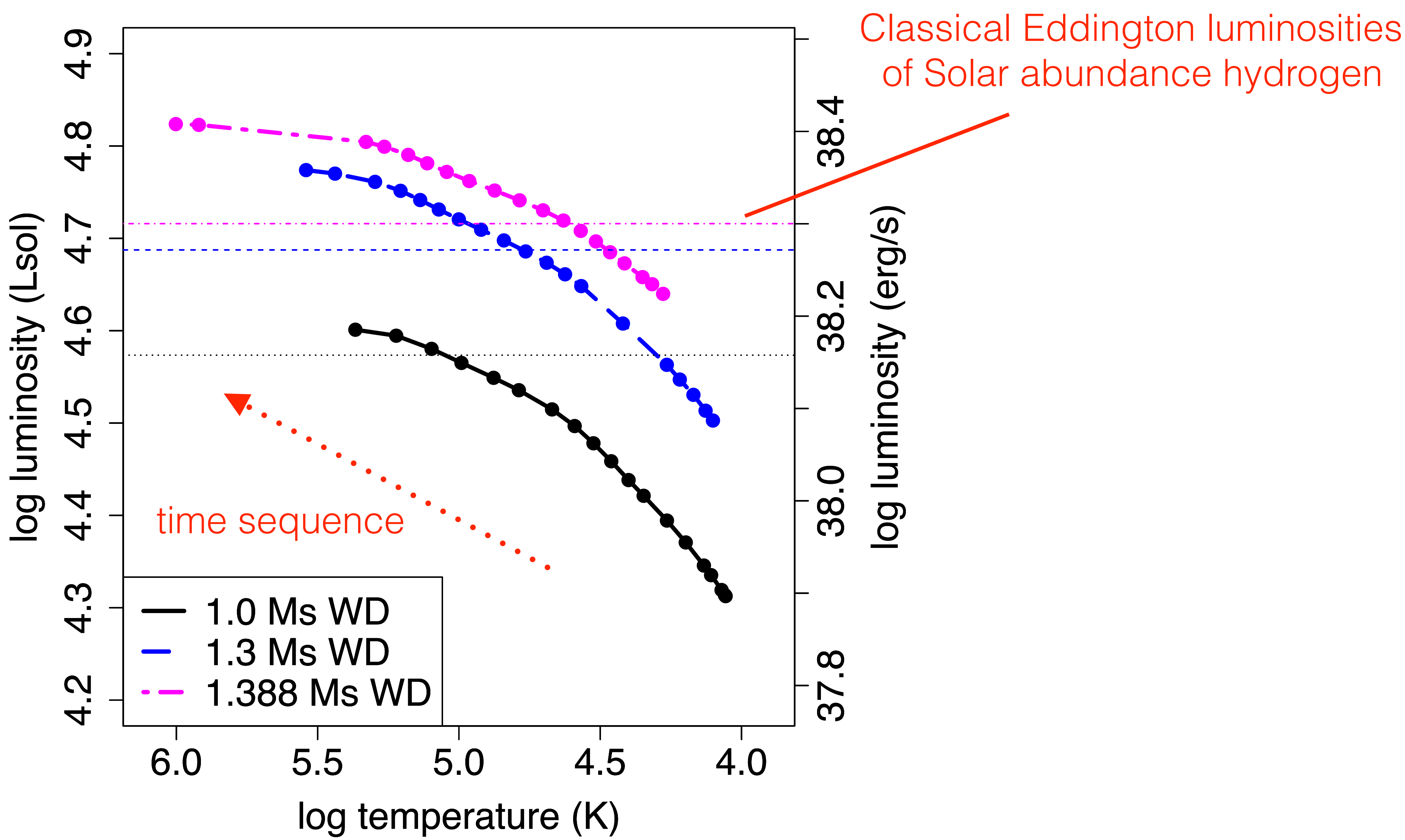
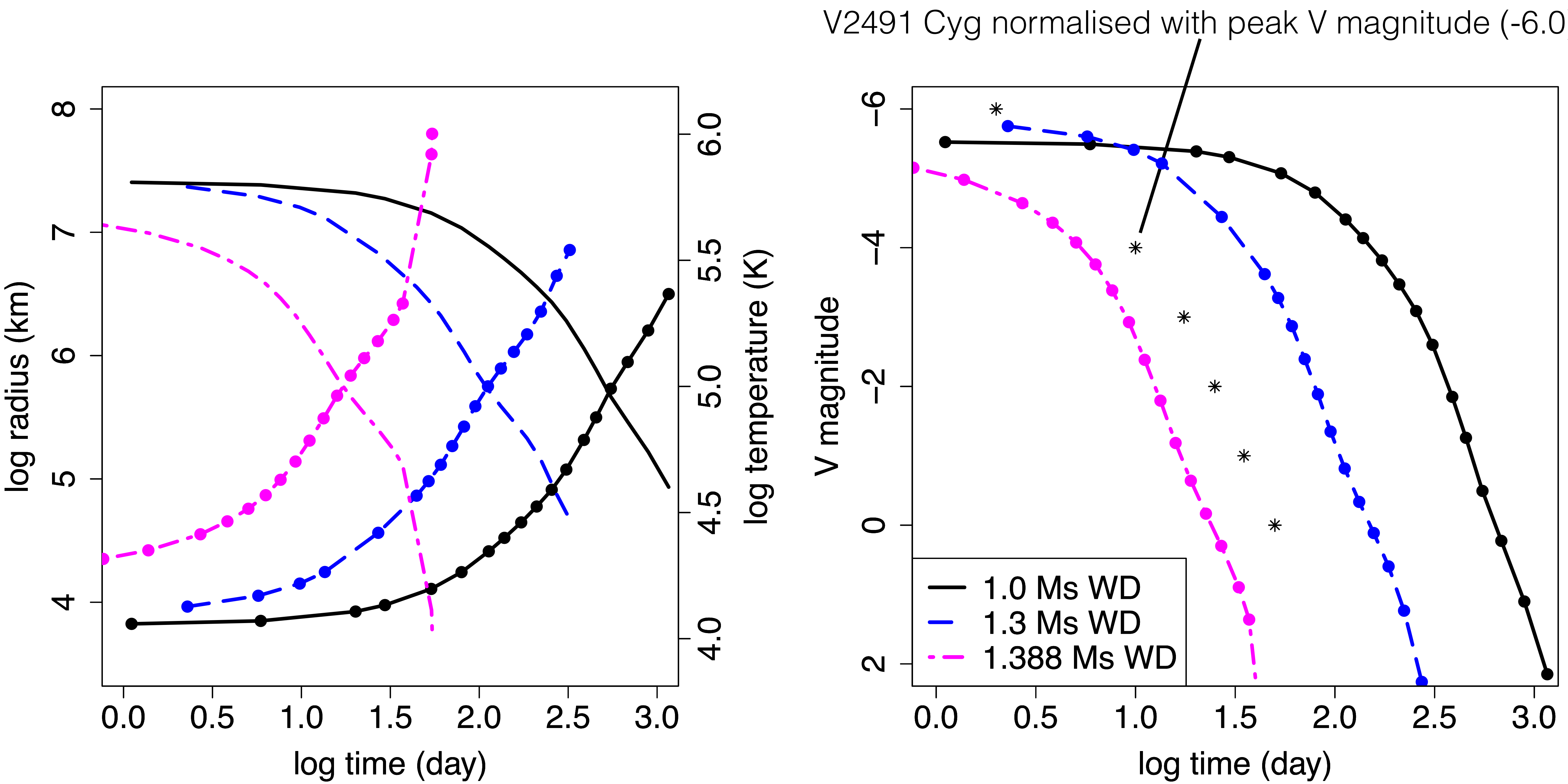
- Temperature of the photosphere increases to emit soft X-ray

Time sequence of photosphere: temperature increases while bolometric luminosity increases slightly



- Each steady state solution is the point on the line.
- Time variation can be traced giving increasing luminosity.
- Heavier WDs produce faster terminal velocity and brighter luminosity in the end.

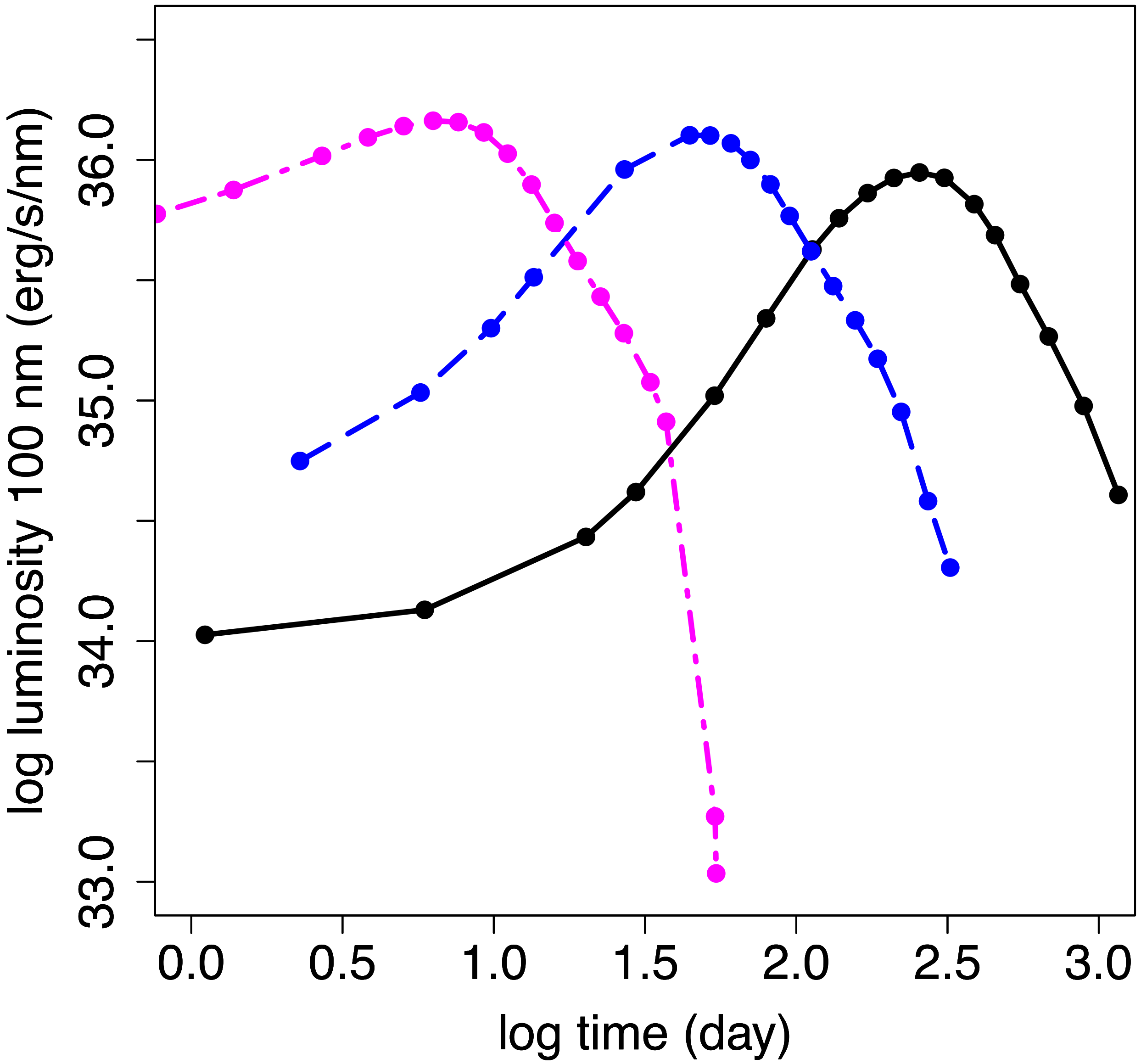
Photosphere shrinks while its temperature increases



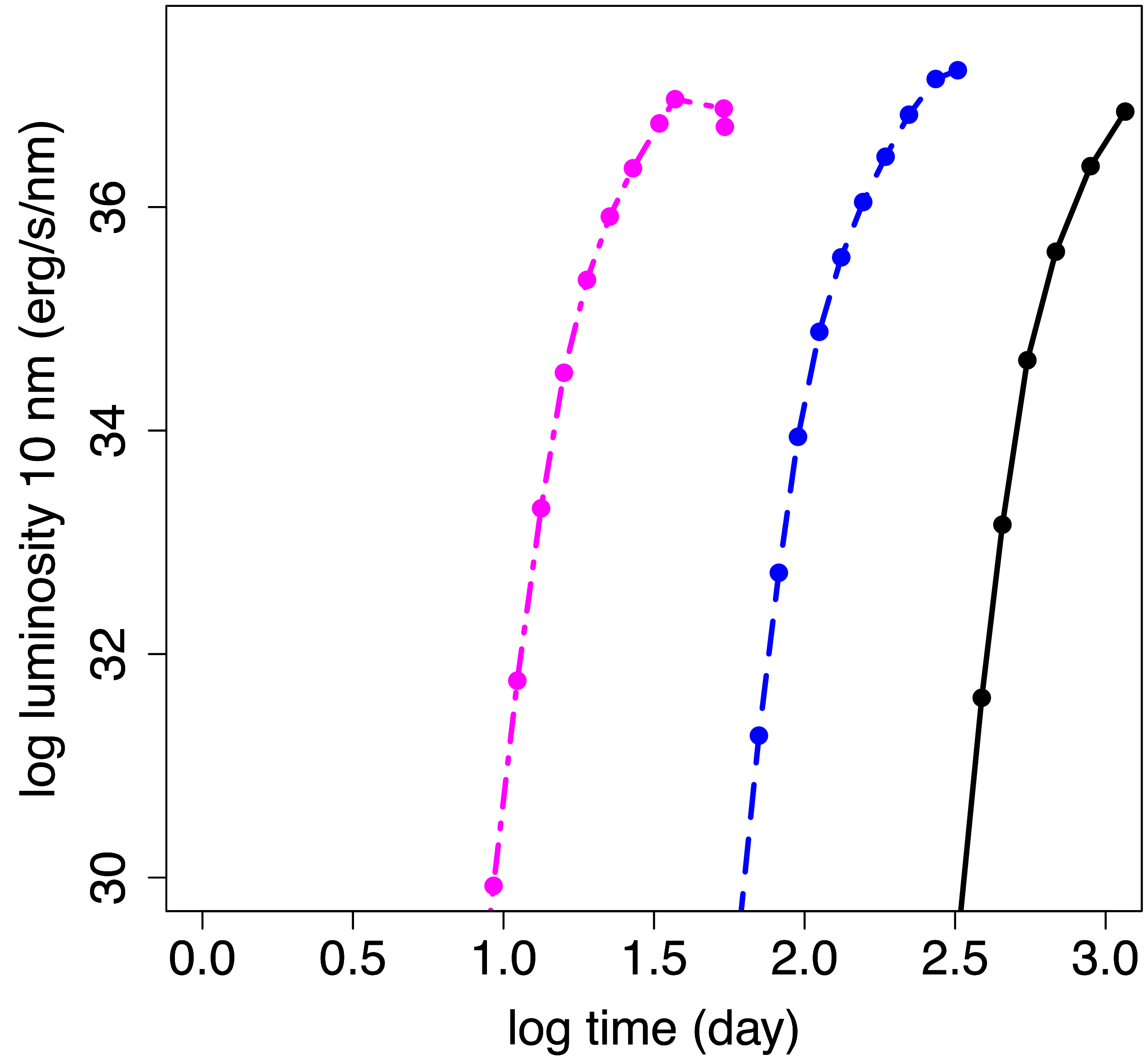
- Radius of photosphere decreases while its temperature increases.

- The shape of light curve is similar between all models in log time plot except their time scale.

Light curves



UV

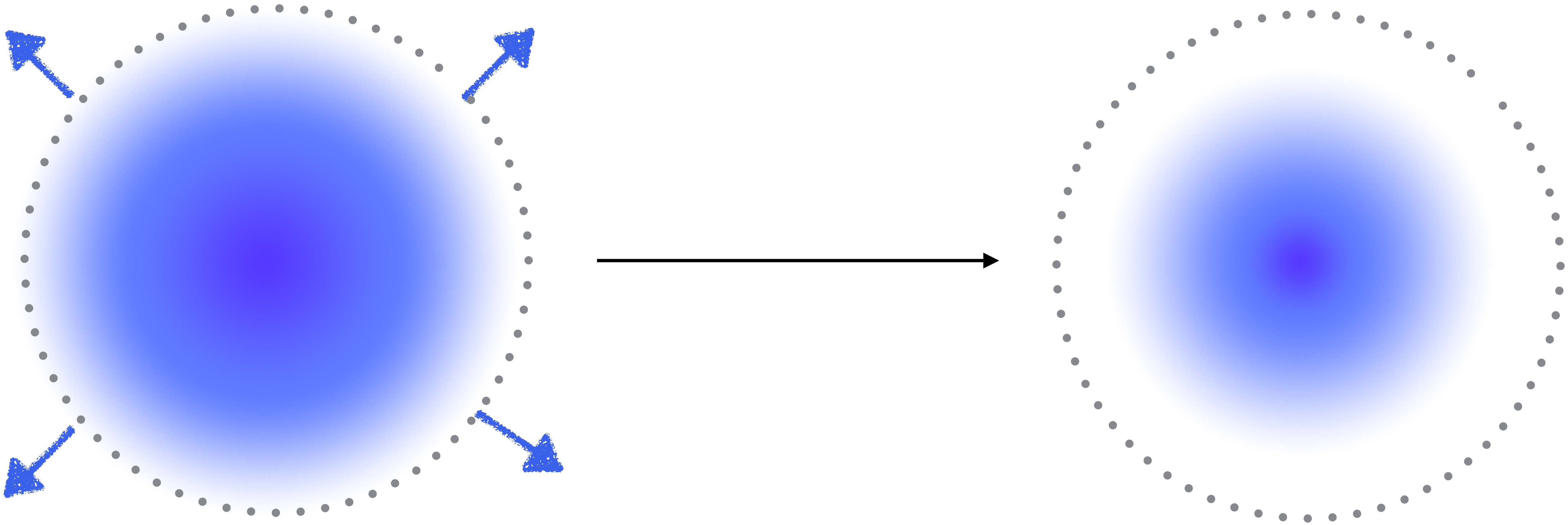


soft X-ray

- light curve follows changes in radius and temperature of photosphere.
- Heavier WDs produce faster novae.

WD mass balance

ignition → wind ends



$$M_{ign} = M_{acc} + M_{fwd}$$

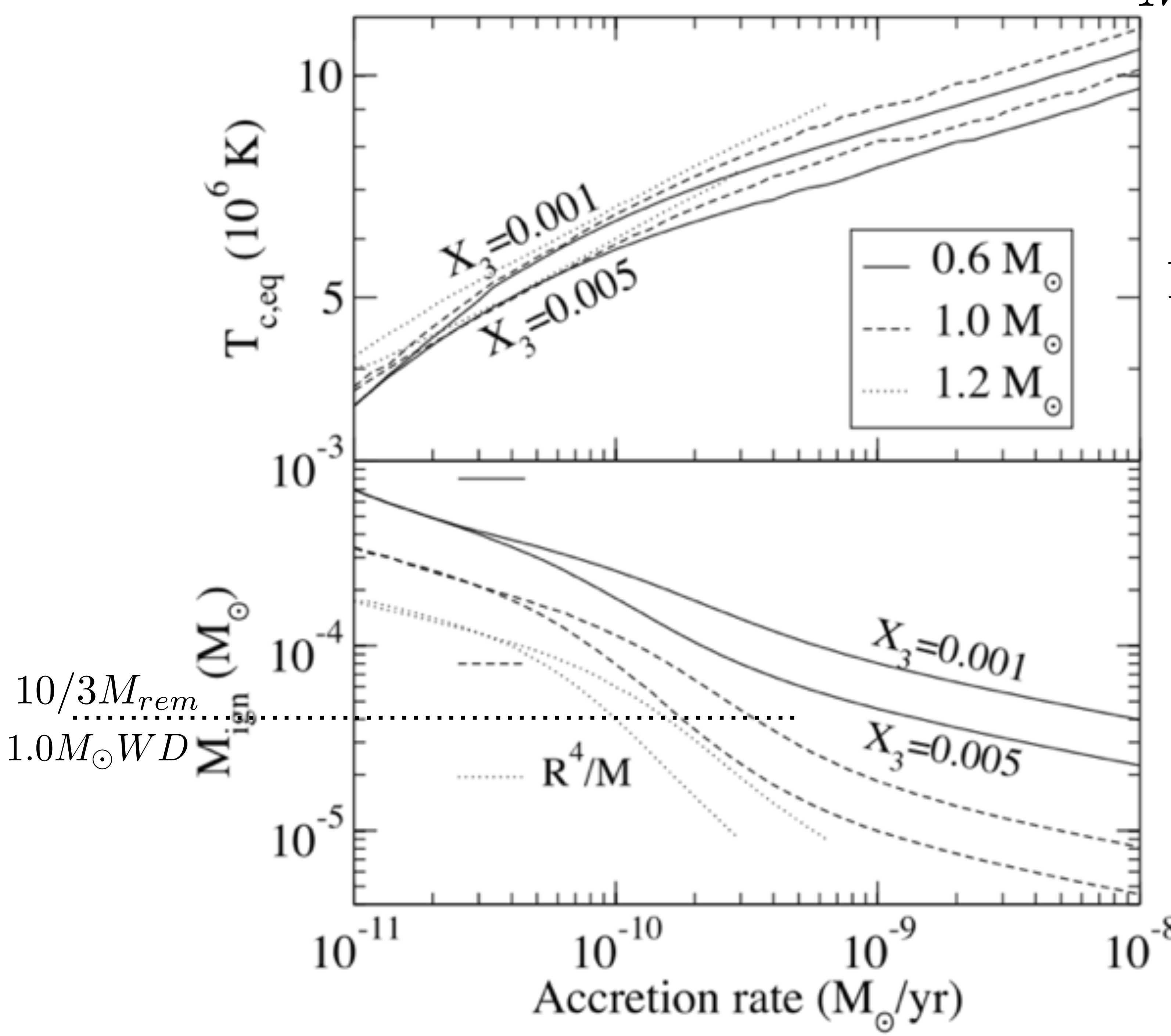
$$0.7 : 0.3$$

$$M_{rem}$$

- Compare WD matter contribution to wind mass and remaining mass

$$\Delta M_{WD} = M_{rem} - M_{fwd}$$
$$= M_{rem} - 0.3 M_{ign}$$

Ejected mass and ignition mass



Townsley & Wildsten 2004

$$M_{rem} =$$

$$1.0 M_\odot \mathrm{WD} : 9.86 \times 10^{-6}$$

$$1.3 M_\odot \mathrm{WD} : 8.66 \times 10^{-7}$$

$$1.388 M_\odot \mathrm{WD} : 3.96 \times 10^{-8} \; M_\odot$$

- Remaining wind mass of the latest steady state solution is comparable to WD mass in ignition mass.
- Observed CNO enhanced composition of wind suggests considerable WD matter contribution in the wind.

Summary

- Nova wind is accelerated also in early SSXS phase and mass loss occurs
- Especially in later phase, wind is accelerated through photosphere and super Eddington luminosity realises
- WD might gain mass only if higher mass accretion rate but further investigation of ignition conditions are required