On the mass-transfer problem in symbiotic binaries

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1. Introduction to symbiotic stars

2. Mass-transfer problem:
   Large energetic output from the accreting white dwarf
   versus
   its fueling from the cool giant wind

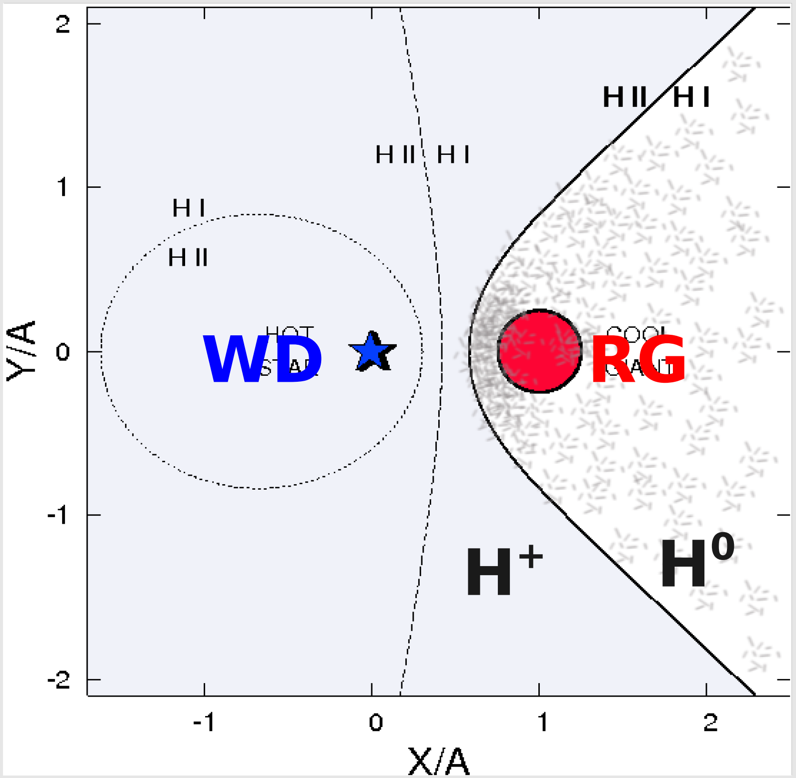
3. Solution: focusing of the wind. Its indication

4. Summary

Symbiotic Binaries

The widest interacting binary systems: Red giant + White dwarf
P ~ 100 x (days - years)

Basic interaction: Mass loss from the RG + Accretion by the WD



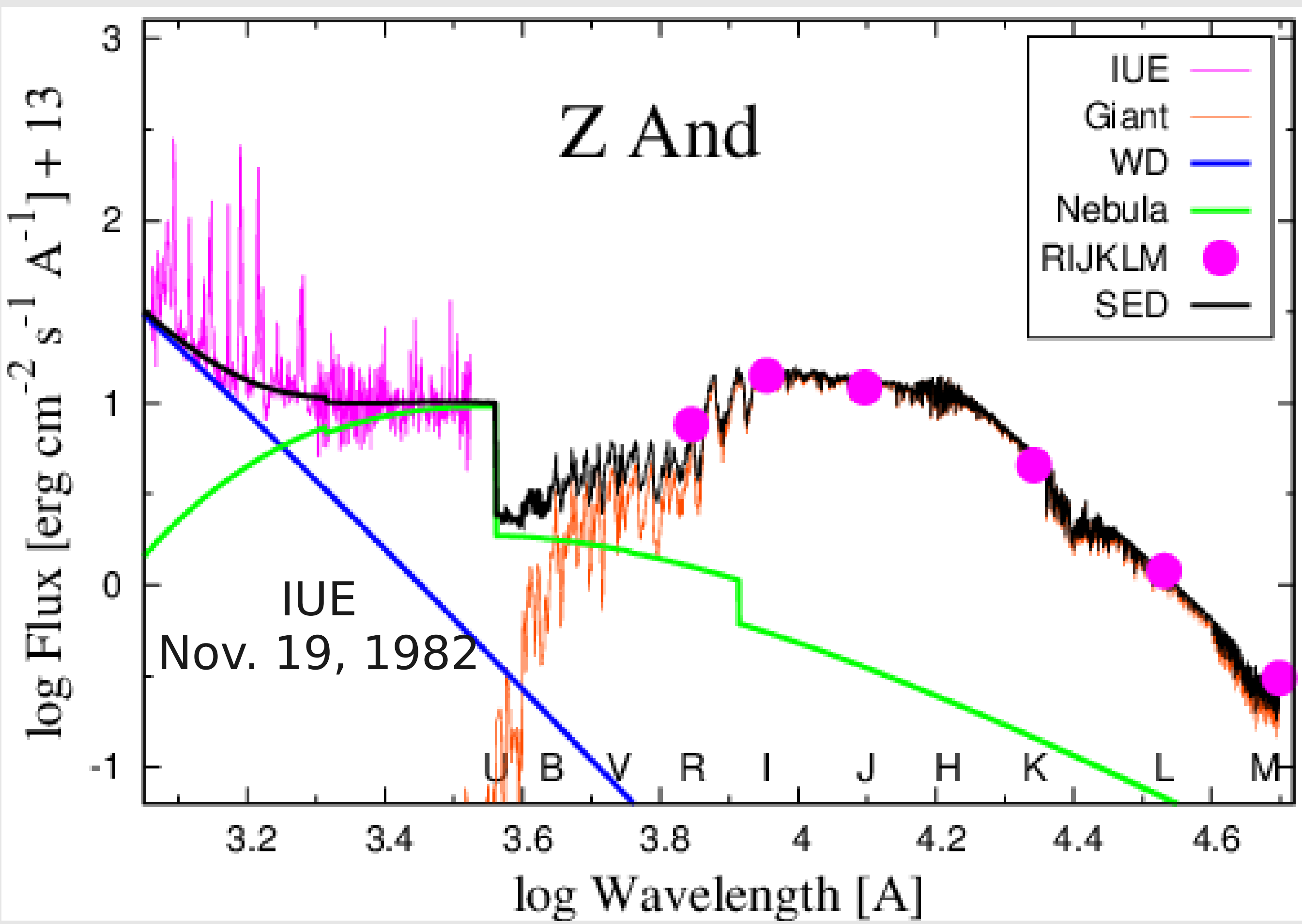
Seaquist, Taylor & Button, 1984: **STB model**)

Accretion from the RG wind
(at 10^{-8}–10^{-7} M_{Sun}/yr)
==>
Hot & Luminous WD
==>
Ionization of the RG wind
==>
Symbiotic nebula

Composite spectrum of symbiotic stars: physical parameters

Z And: M4.5III + WD

P_{orb}~758 days, E_{B-V} = 0.3, d~1.5 kpc



WD:

$L_{WD} = 2300\, L_{Sun}$ (!)

$T_{WD} = 120{,}000$ K

$R_{WD} = 0.11\, R_{Sun}$

Nebula:

$EM = 9.8 \times 10^{59}$ cm^{-3}

$T_e = 20{,}500$ K,

Giant: M4.5 III

$L_G = 1400\, L_{Sun}$

$T_{eff} = 3400$ K

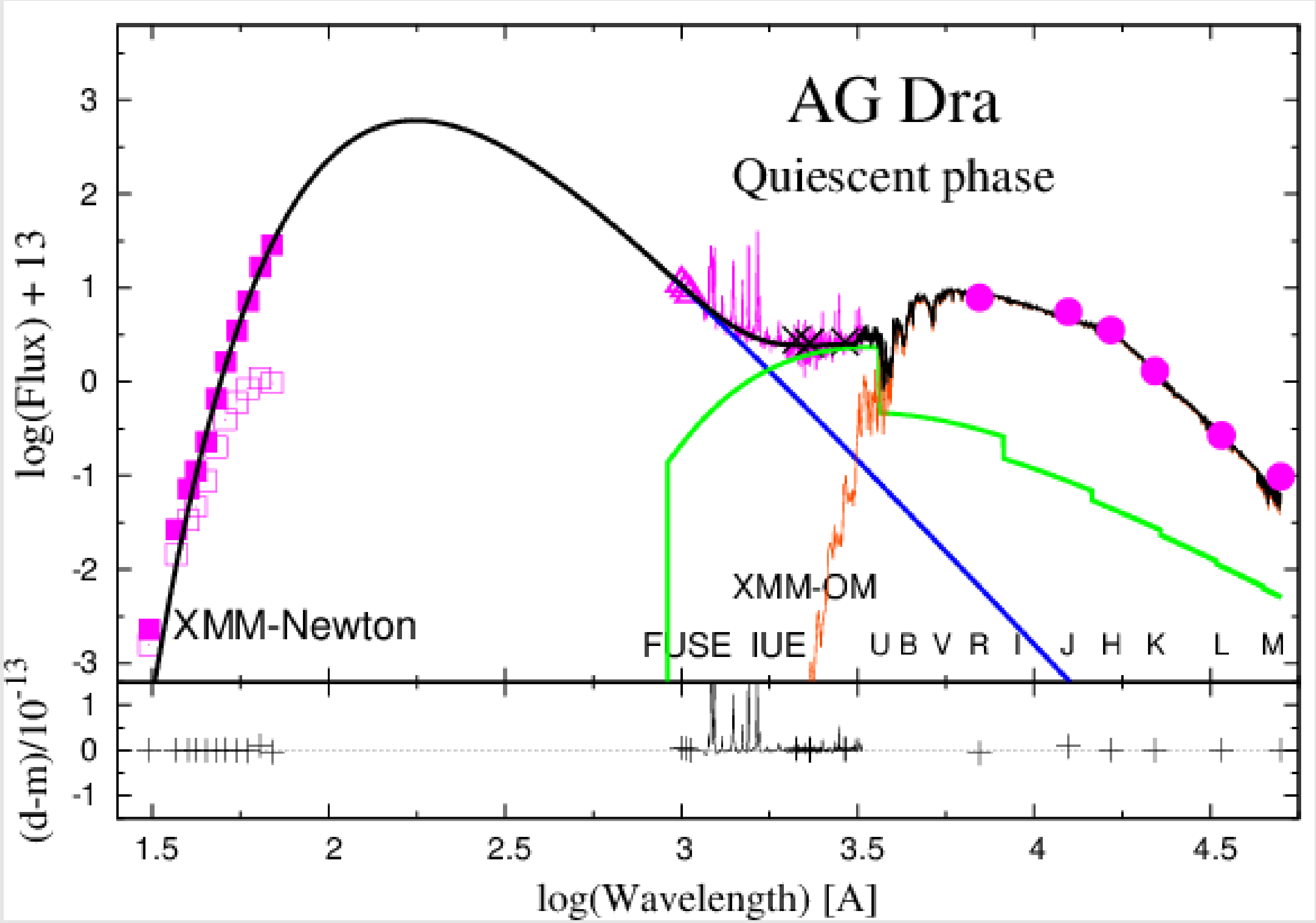
$R_G = 106\, R_{Sun}$

(adapted from Skopal, 2005, A&A, 440, 995)

Composite spectrum of symbiotic stars: physical parameters

AG Dra: K2III + WD,

P_{orb}~550 days, E_{B-V} = 0.08, d~1.1 kpc



WD:

$L_{WD} = 630\, L_{Sun}$

$T_{WD} = 165{,}000$ K

$R_{WD} = 0.03\, R_{Sun}$

$N_H = 3.13 \times 10^{20}\, \mathrm{cm}^{-2}$

Nebula:

$EM = 1.3 \times 10^{59}\, \mathrm{cm}^{-3}$

$T_e = 21{,}000$ K,

Giant: K2 III

$L_G = 360\, L_{Sun}$

$T_{eff} = 4300$ K

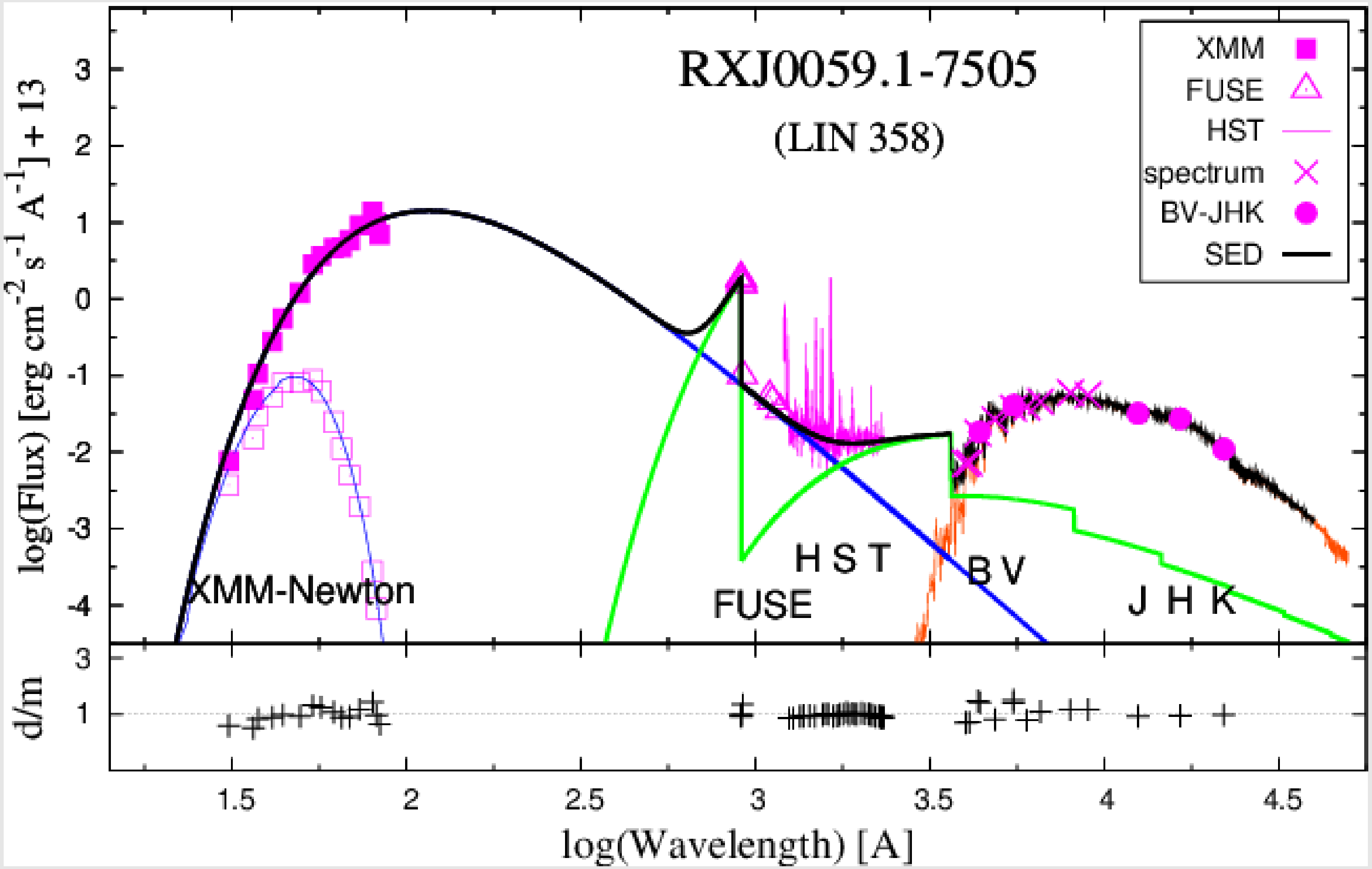
$R_G = 33\, R_{Sun}$

(adapted from Skopal et al. 2009, A&A, 507, 1531)

Composite spectrum of symbiotic stars: physical parameters

LIN-358: MIII + WD (?)

P_{orb} = ?, E_{B-V} < 0.1, d_{SMC} = 60 kpc



Skopal (2015), New Astronomy, 36, 116

WD:
$L_{WD} \sim 28\,000\ L_{Sun}$ (!)
$T_{WD} \sim 250{,}000\,K$
$R_{WD} \sim 0.09\,R_{Sun}$
$N_H \sim 6.1 \times 10^{20}\,cm^{-2}$

Nebula:
$EM \sim 2.4 \times 10^{60}\,cm^{-3}$
$T_e \sim 18{,}000\,K$

Giant: M III
$T_{eff} = 4000\,K$
$R_G = 178\,R_{Sun}$
$L_G = 7300\,L_{Sun}$

Mass-transfer problem

$$L_{WD} \sim a\ few \times 10^3 L_{Sun}\ !$$

The only fuel for this energy is the wind from the RG.

(RG: mass-loss rates ~10^{-8}– 10^{-7} M_{Sun}/year; efficiency: 1-2%)

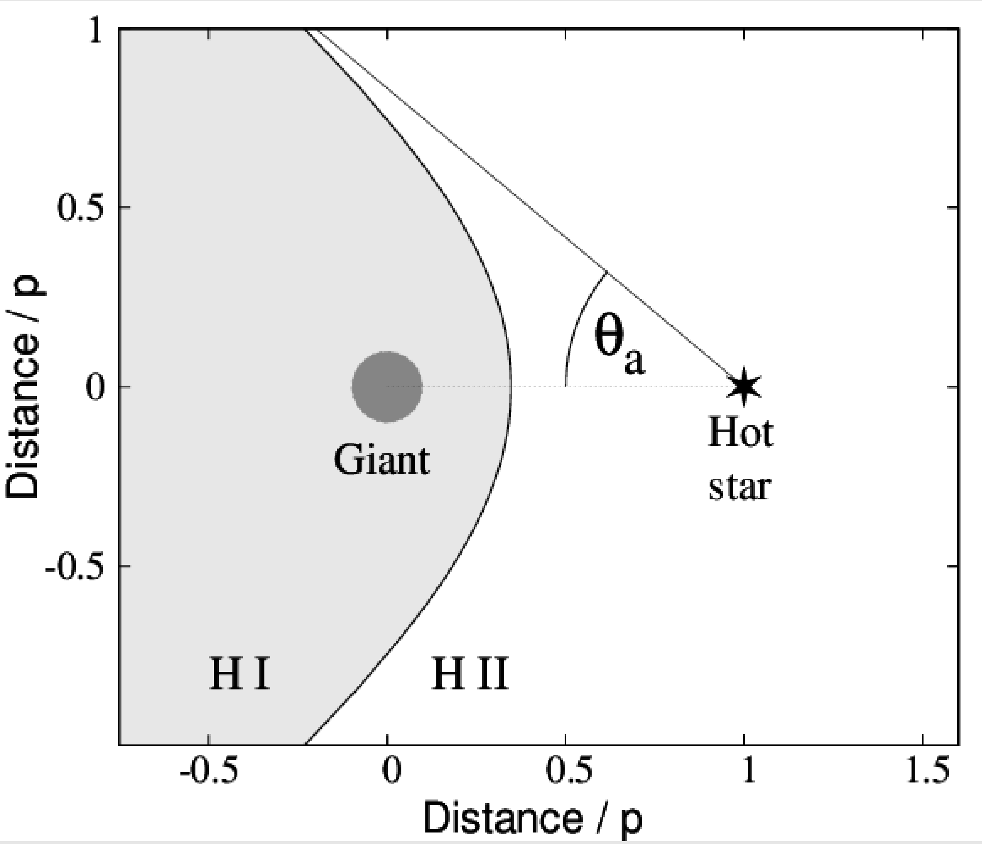
The long-standing problem:

"How do RGs, well within their Roche lobes, lose sufficient mass to produce the symbiotic phenomenon?"

(Kenyon & Gallagher, 1983)

- What is the mass-loss rate from the RG?
- What is the energy output from the accreting WD ?
- How the wind is transferred onto the WD?

Mass-loss rate from M giants in symbiotic binaries



Equilibrium between flux of ionizing photons and recombinations along the direction 'theta' defines the boundary 'r0' between the HI and HII:

$$L_{ph} \frac{\Delta \theta}{4\pi} = \Delta \theta \int_0^{r0} N(r)_p N(r)_e \alpha_B(H, T_e) r^2 \, dr$$

Then the ionized zone can be obtained from a parametric equation

$$f(r, \theta) = X(L_{\mathrm{ph}}, p, v_\infty, \dot{M}_{\mathrm{G}})$$

Nebular emission $\propto \dot{M}_{\mathrm{G}}$

Radio emission (Seaquist + 1993)
UV/optical emission (Skopal, 2005)

$$\dot{M}_{\mathrm{G}} \sim \text{a few} \times 10^{-7} M_{Sun} yr^{-1}$$

$\dot{M}_{\mathrm{G}}$ from the nebular emission in the UV/optical/near-IR

Emission measure, EM, from model SED

$$EM = \int_{HII} n^2(r)\,dV$$

(V from the STB model)

where

$$n(r) = \dot{M}_W / 4\pi r^2 \mu m_H v_w(r)$$

$$\rightarrow \quad EM \propto f(\dot{M}_W)$$

EM from SED + X from L, T, p, (Skopal, 2005, A&A, 440,995)

$$\dot{M}_W \sim a \;\; few \times 10^{-7} M_{Sun}\, yr^{-1}$$

For S-type symbiotic stars

Is the $\dot{M}_G \sim \textbf{a few} \times 10^{-7} M_{Sun}/\,yr$ sufficient to generate L_{WD}?

What is the energy output from the accreting WD ?

Accretion onto the WD:

L_{acc}

$$L_{WD} = \frac{1}{2} G \frac{M_{WD} \dot{M}_{acc}}{R_{WD}}$$

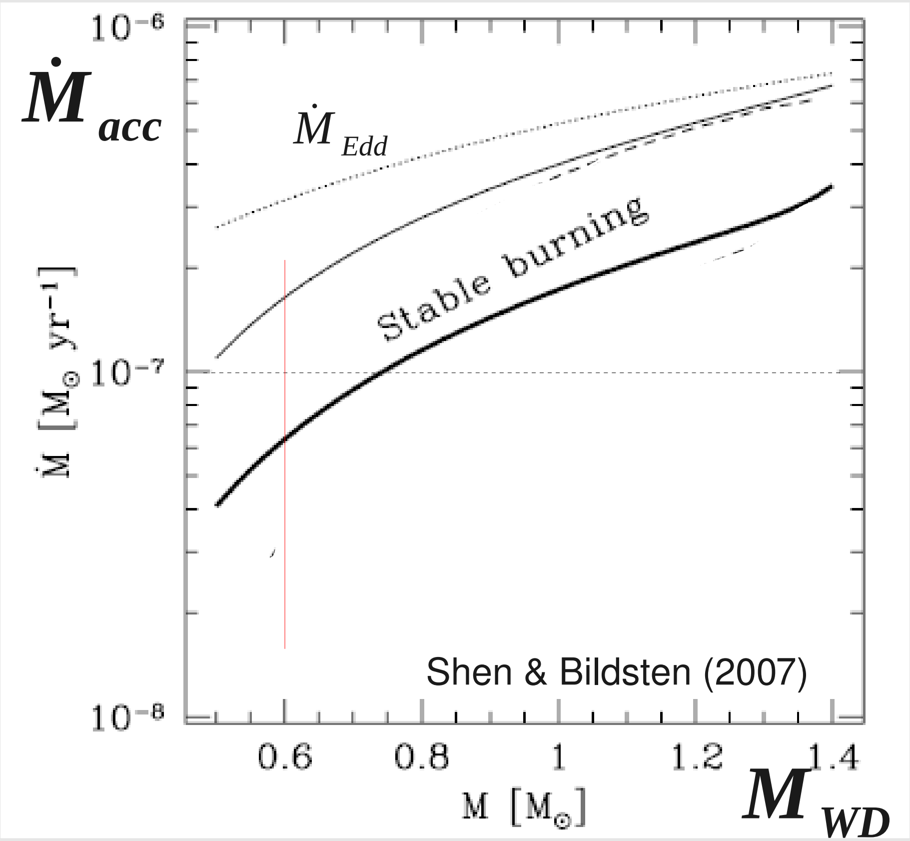
$$M_{WD} \sim 0.6\, M_{Sun}, \quad \dot{M}_{acc} = 10^{-8} M_{Sun}/\mathrm{yr}$$

$$L_{acc} \sim \mathrm{a\ few} \times 10^{0} L_{Sun}$$

L_{WD} ~ a few x 10^3 L_{Sun} cannot be powered solely by the accretion process !

Is the $\dot{M}_W \approx 10^{-7} M_{Sun}/yr$ sufficient to generate L_{WD} ?

What is the energy output from the accreting WD ?



Accretion onto the WD:

L_{acc} + $L_{nuclear}$

$$L_{WD} = \frac{1}{2} G \frac{M_{WD} \dot{M}_{acc}}{R_{WD}} + \eta X \dot{M}_{acc}$$

$$\eta = 6.3 \times 10^{18} \mathrm{erg/g}, \quad X \equiv 0.7$$

$$M_{WD} \sim 0.6 M_{Sun}, \quad \dot{M}_{acc} = 10^{-7} M_{Sun}/\mathrm{yr}$$

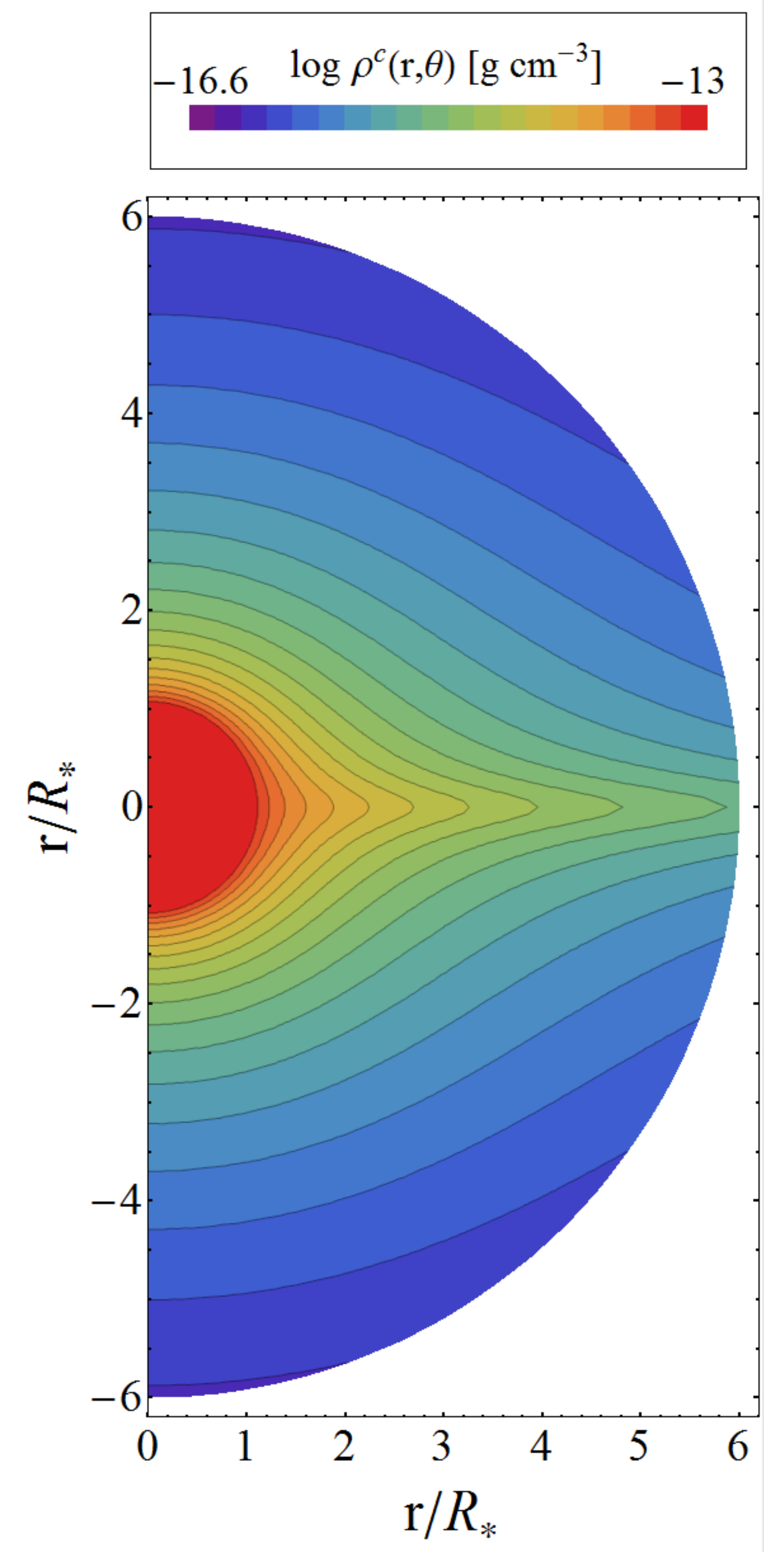
$$L_{nucl.} \sim \text{a few} \times 10^{3} L_{Sun}$$

$$L_{acc} \sim \text{a few} \times 10^{1} L_{Sun}$$

L_{WD} = a few x10^3 Lo can be achieved by $\dot{M}_{acc} \sim 10^{-7} M_{Sun}/\mathrm{yr}$

but $\dot{M}_G \sim \text{a few} \times 10^{-7} M_{Sun}/\mathrm{yr}$!

How the wind from the giant is transferred onto the WD ?



Focusing by the wind compression model

Wind is compressed due to the rotation of the star.
Mass continuity equation
(Bjorkman & Cassinelli,1993):

$$\rho^c(r,\theta) = \frac{\dot{M}}{4\pi r^2 v_r(r)} \left(\frac{d\mu}{d\mu_0}\right)^{-1}$$

$\dot{M}$ – total mass-loss rate from the star
$(d\mu/d\mu_0)^{-1}$ – describes the compression of the wind

Giants in symbiotic stars rotate:

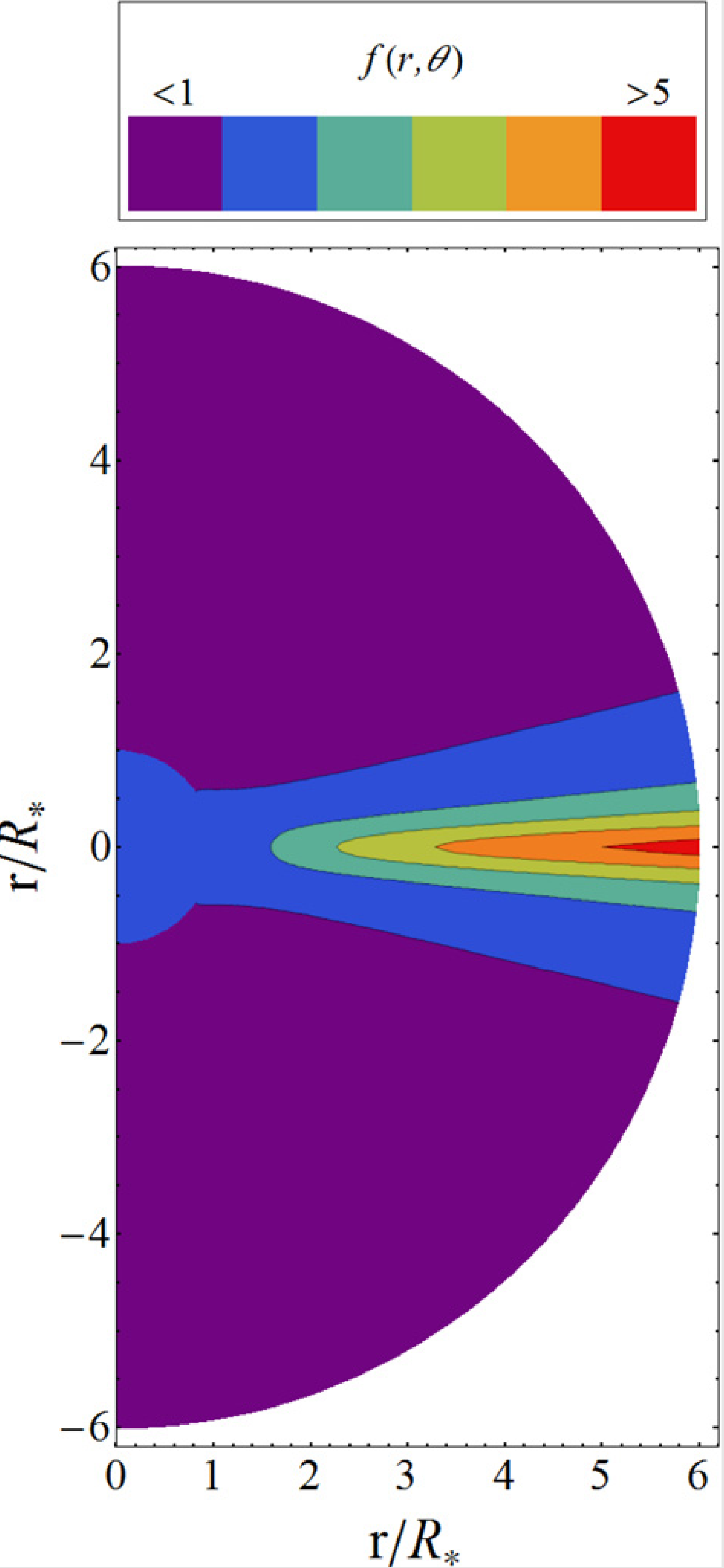
$v_{rot}\sin(i) \sim 6 - 9.5$ km/s

(e.g. Zamanov et al., 2008)

Figure: Density distribution in the model:

$$\dot{M} = 10^{-7} M_{Sun}\, yr^{-1},\quad R_G = 100_{Sun},$$
$$v_{rot} = 6 \text{ km/s},\quad v_\infty = 20 \text{ km/s},\quad f(r=6,\pi/2) = 5.4$$

Thesis of Zuzana Carikova: Carikova & Skopal, 2012
Skopal & Carikova, 2015



Focusing by the wind compression model

Mass-loss ratio:

$$f(r,\theta) = \frac{\dot{M}^c(r,\theta)}{\dot{M}_G} = \frac{\rho^c(r,\theta)}{\rho^{sph}(r)} = \left(\frac{d\mu}{d\mu_0}\right)^{-1}$$

$\dot{M}^c(r,\theta)$ is given by the local density, $\rho^c(r,\theta)$

Accretion rate:

$$\dot{M}_{acc} \approx \eta \times f \times \dot{M}_G$$

$\eta \sim$ a few $\times 0.01$ (B-H efficiency)

$f \sim 5-10$

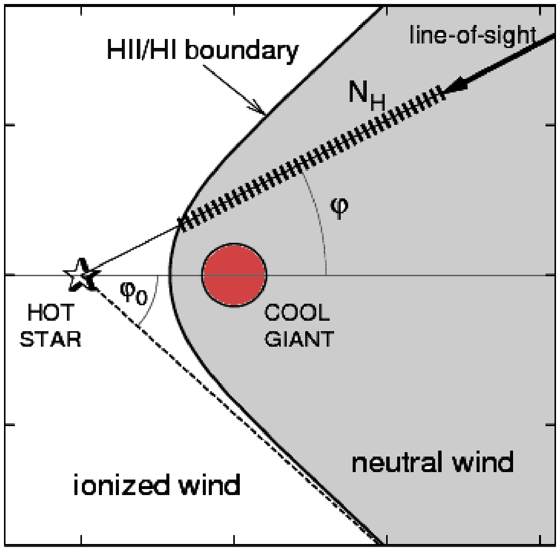
$\rightarrow \dot{M}_{acc} / \dot{M}_G \sim 0.5$

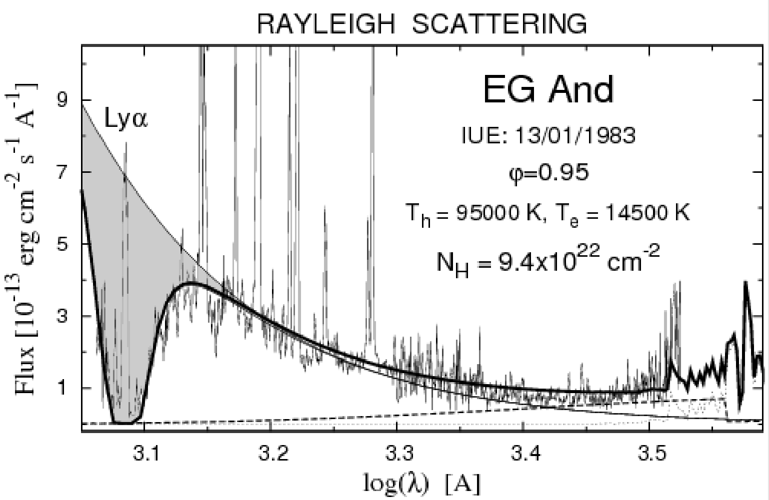
Figure: Mass-loss ratio f(r,theta) for

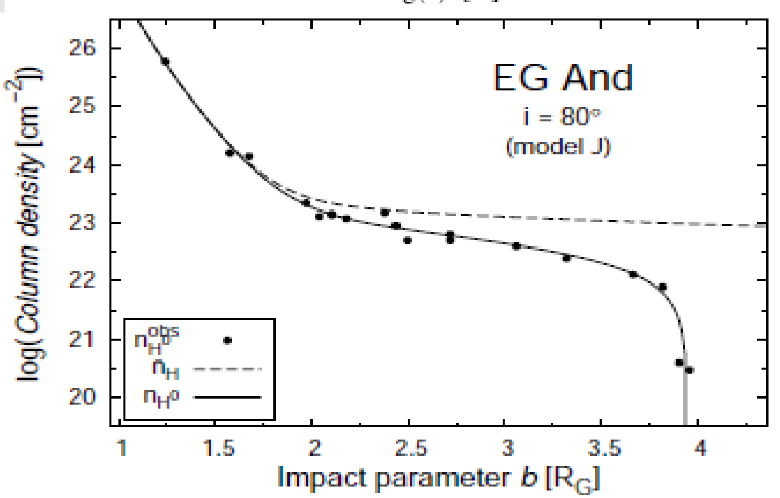
$\dot{M} = 10^{-7} M_{Sun}\, yr^{-1}$, $R_G = 100_{Sun}$,

$v_{rot} = 6$ km/s, $v_\infty = 20$ km/s

(Skopal & Carikova, 2015)







Indication of the wind focusing
in eclipsing systems EG And and SY Mus

Rayleigh scattering:

$$F_\lambda(\varphi) = F_\lambda^0 \exp\left[-n_{H0}^{obs}(\varphi)\sigma_{Ray}(\lambda)\right]$$

From the continuity equation:

$$n_{H0}(\varphi) = \frac{\dot{M}}{4\pi\mu m_H}\int_{-\infty}^{l\varphi}\frac{dl}{r^2 v(r)} \quad \text{to } H^0/H^+$$

Spherical equivalent of the mass-loss rate:

$$\dot{M}_{sp} \sim \text{a few} \times 10^{-6} M_{Sun}\, yr^{-1}$$

---> enhanced wind at the orbital plane: $\uparrow \dot{M}_{acc}$

Thesis of Natalia Shagatova: Shagatova et al. (2016)
Shagatova (2017)

Summary

1. $\dot{M}_{\mathrm{G}}$ from giants in SB is a key parameter for interaction between the binary components via the wind

2. Normal M giants in SB have $\dot{M}_{\mathrm{G}} \sim$ a few $\times 10^{-7} M_{\mathrm{Sun}}\,\mathrm{yr}^{-1}$

3. $\dot{M}_{\mathrm{acc}} \sim 10^{-7}$ is required to generate L_{WD} ~ a few x 10^3 L_{Sun} by stable H-burning on the WD surface

4. Focusing the wind from the giant towards the orbital plane can provide the required high accretion rate!

5. Further modelling and observations are needed to derive accurate dM/dt and understand the mass transfer mode in these wide interacting binaries

Thank you for your attention !