Properties of the wind outflow from the cool components in symbiotic binaries

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Astronomical Institute, Slovak Academy of Sciences
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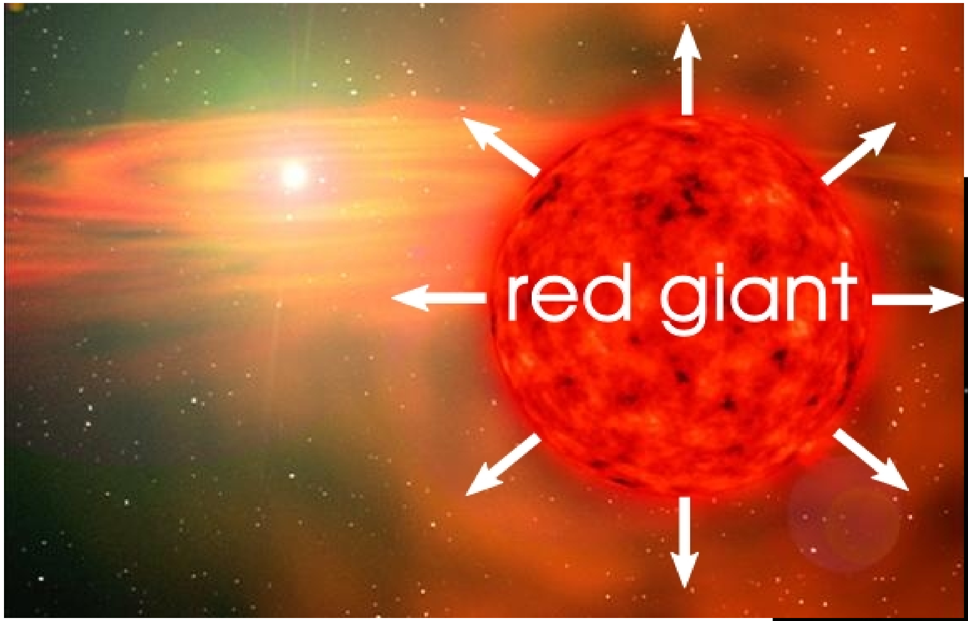
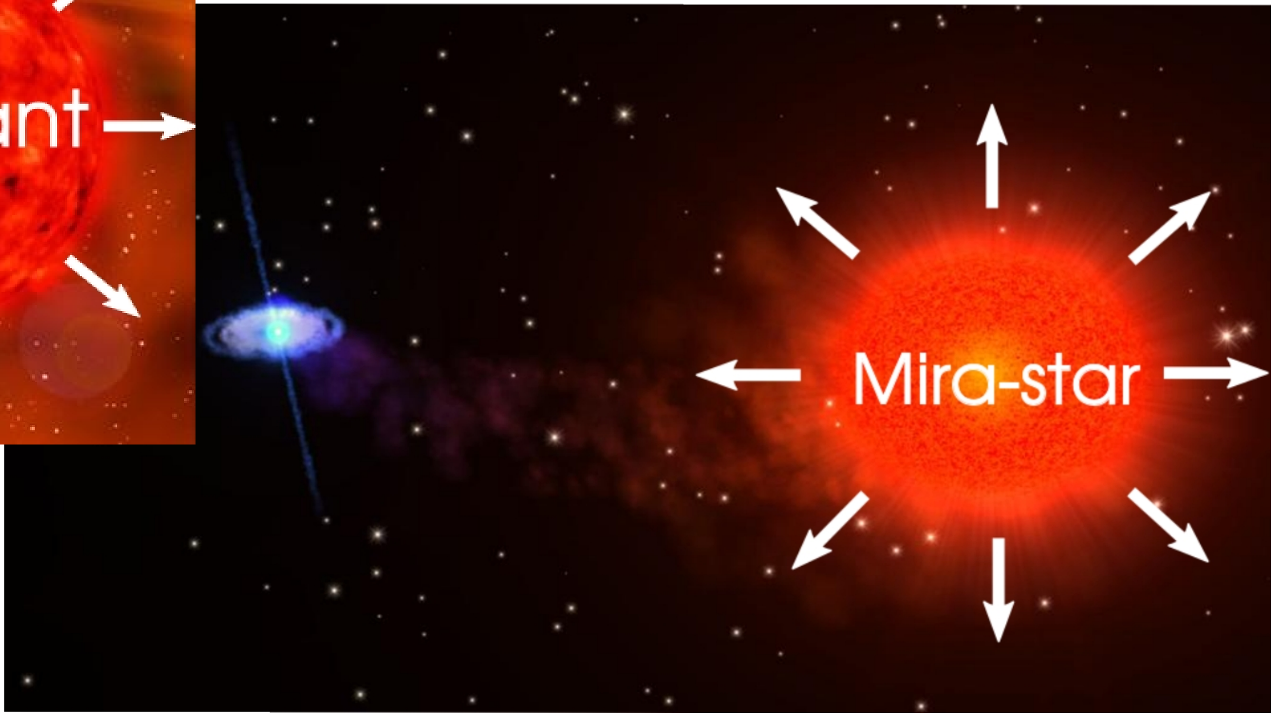
Image credit: NASA

Mass-loss mechanism

S-type systems



D-type systems



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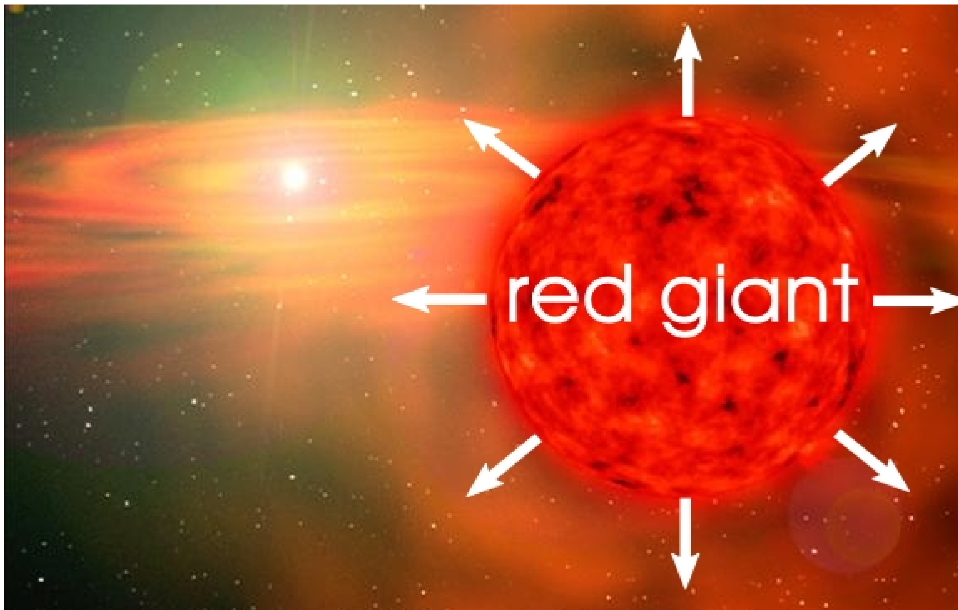

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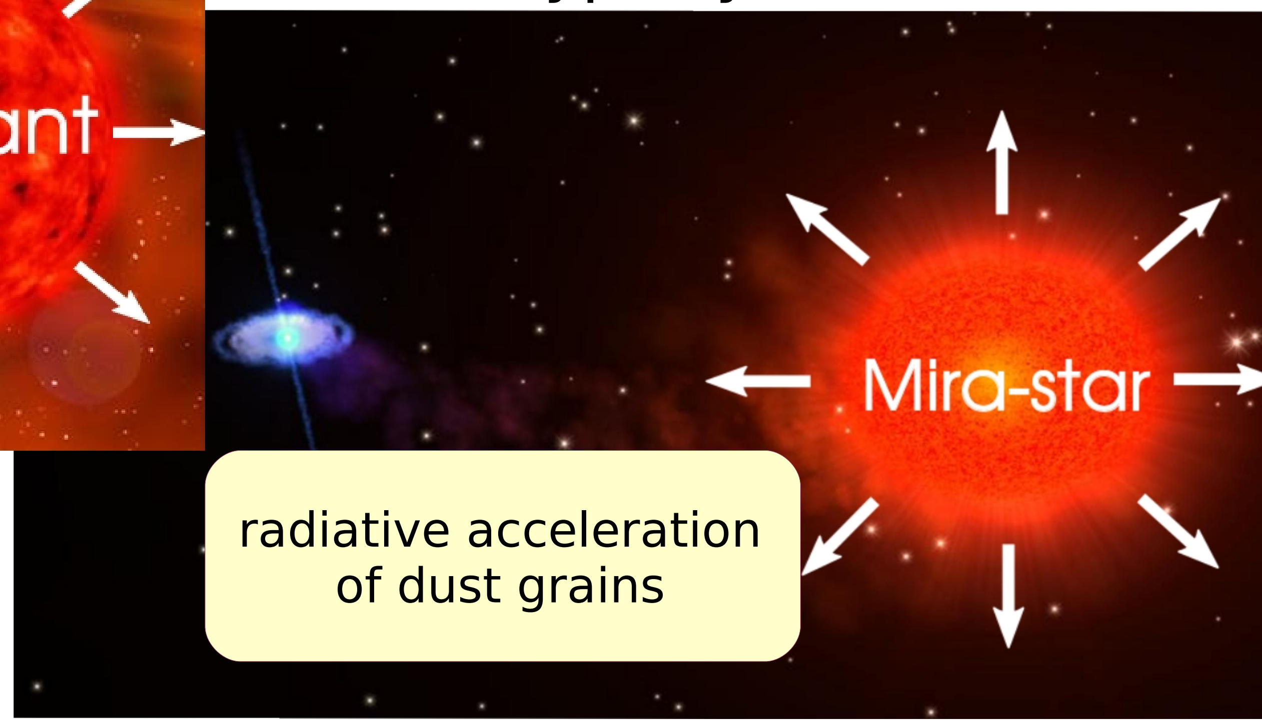

radiative acceleration of dust grains

Höfner 2015, ASP Conf. Ser. 497, 333

Mass-loss mechanism

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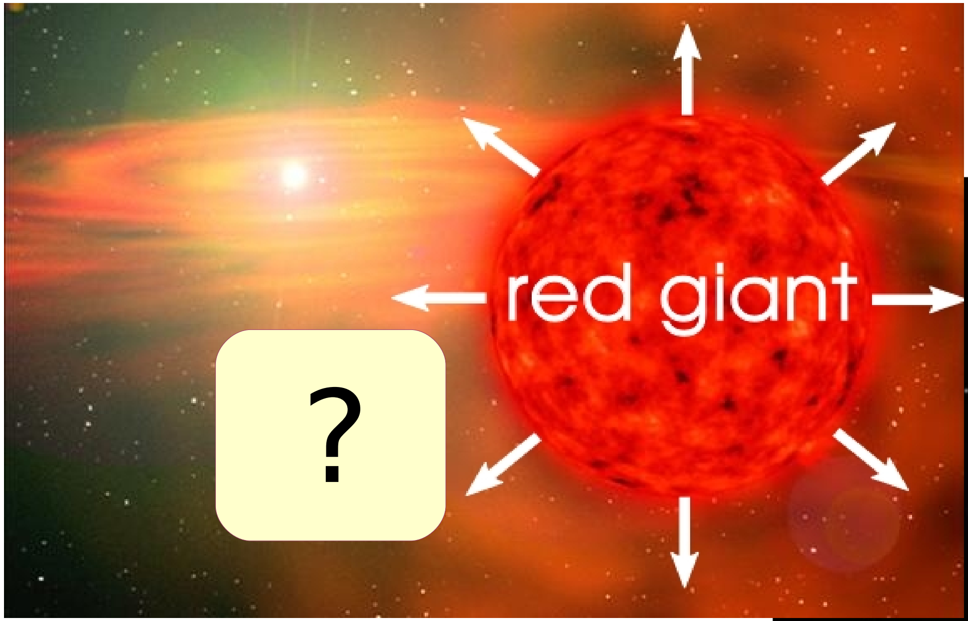

O'Gorman et al. 2013, AJ 146, 98

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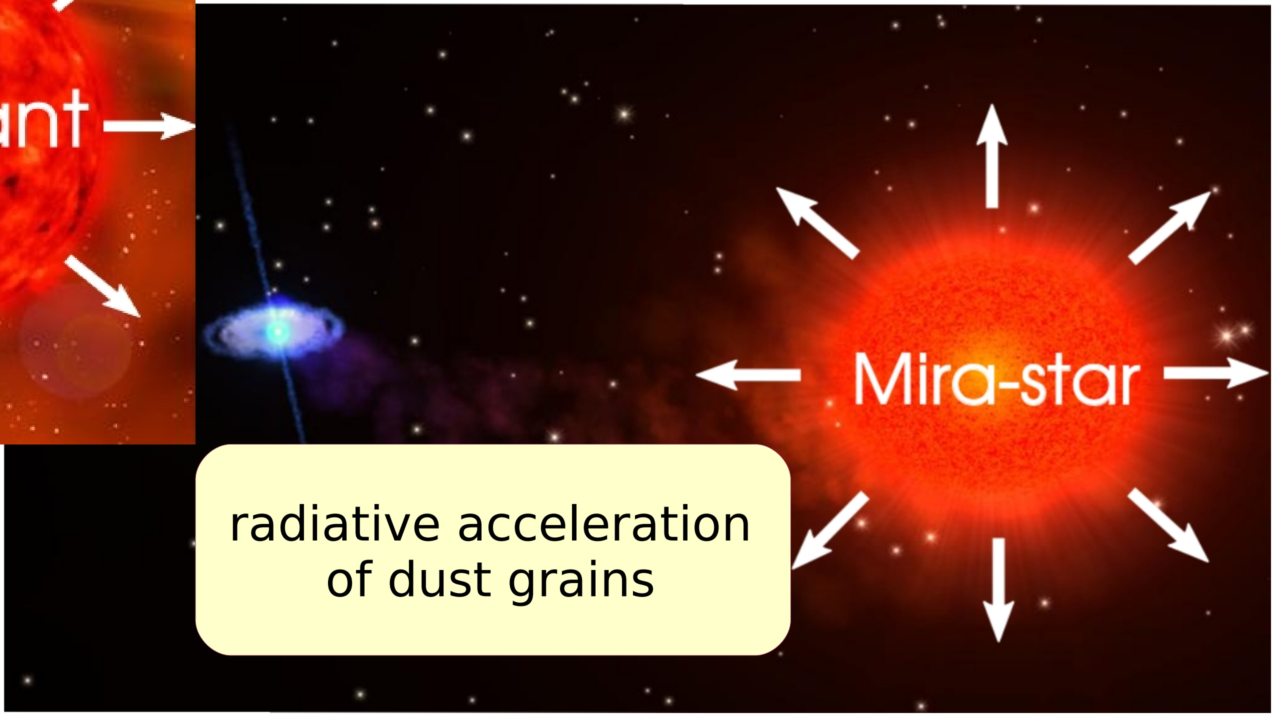
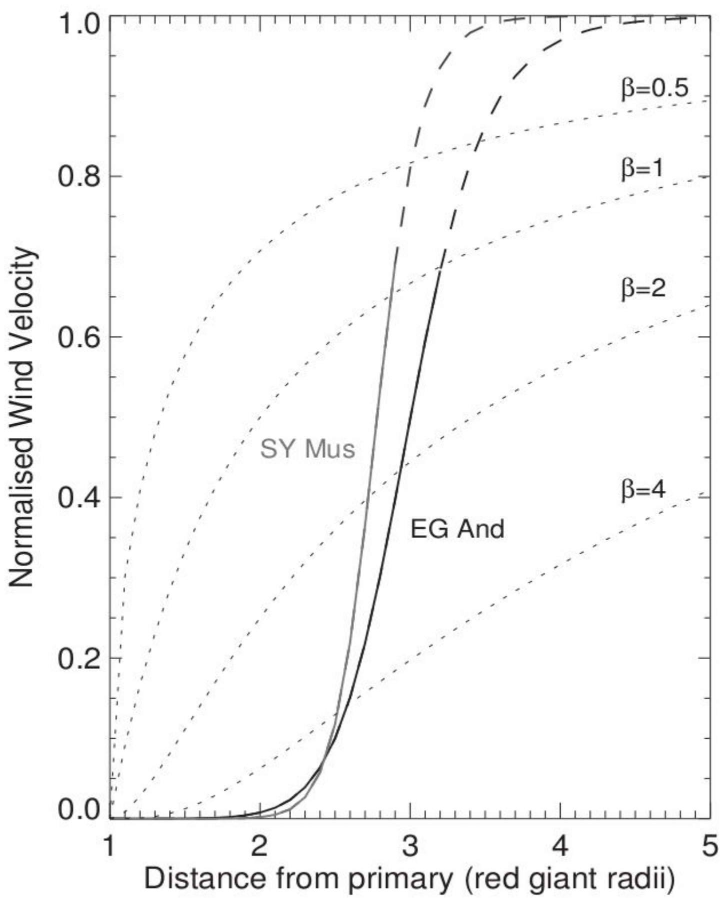


Höfner 2015, ASP Conf. Ser. 497, 333

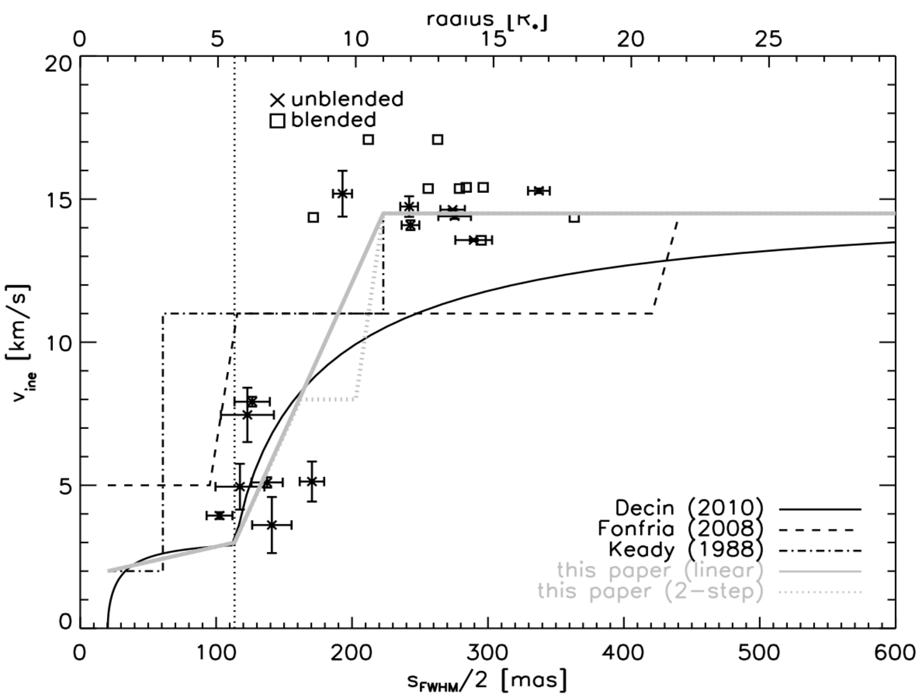
Velocity profile of the wind

- canonical β-law



Crowley & Espey 2010, ASP Conf. Ser. 425, 191

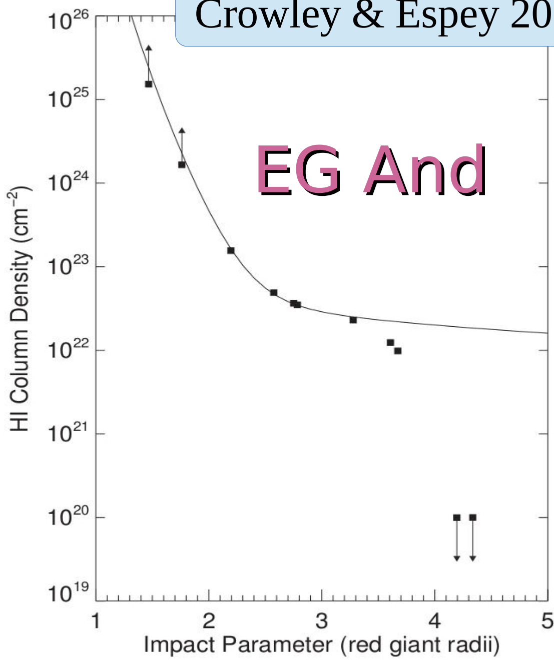
- **steeper** v(r) for cooler stars



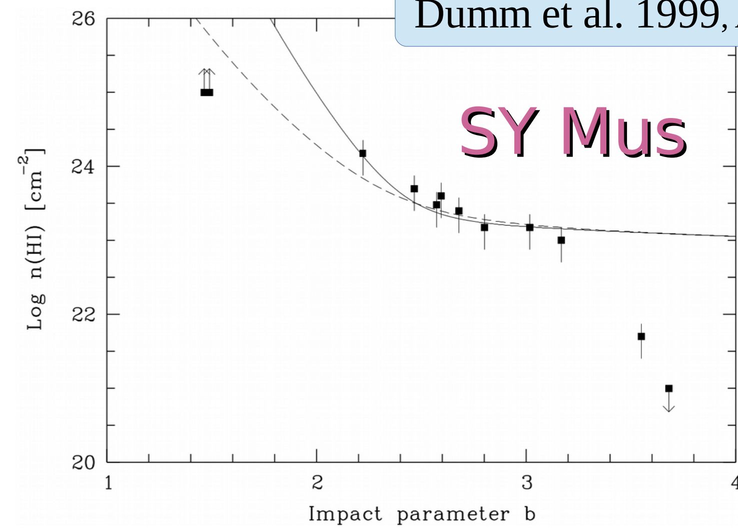
Decin et al. 2015, *A&A 574*, A5

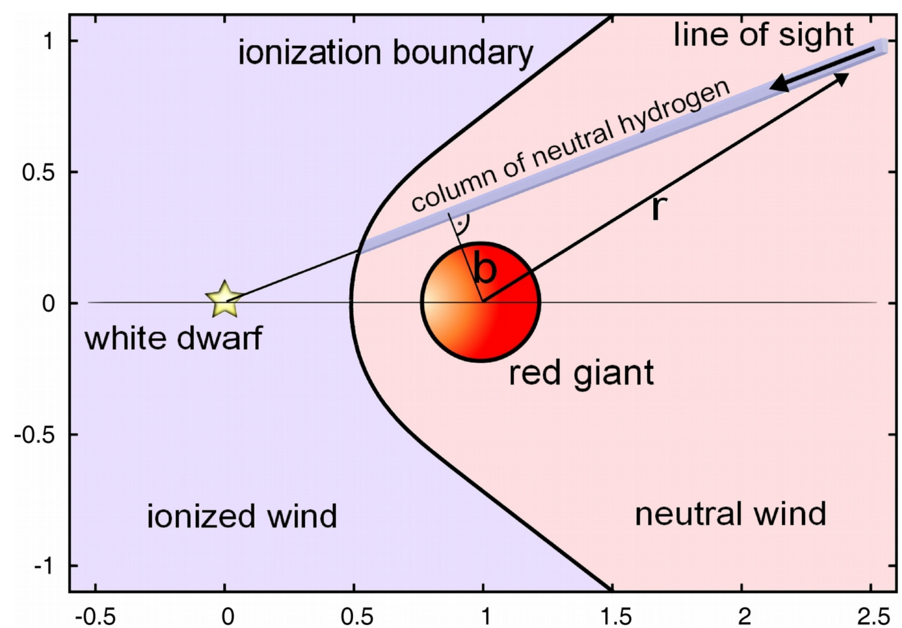
v(r) for red giants in symbiotic binaries

Crowley & Espey 2010, ASP Conf. Ser. 425, 191



Dumm et al. 1999, *A&A 349*, 169

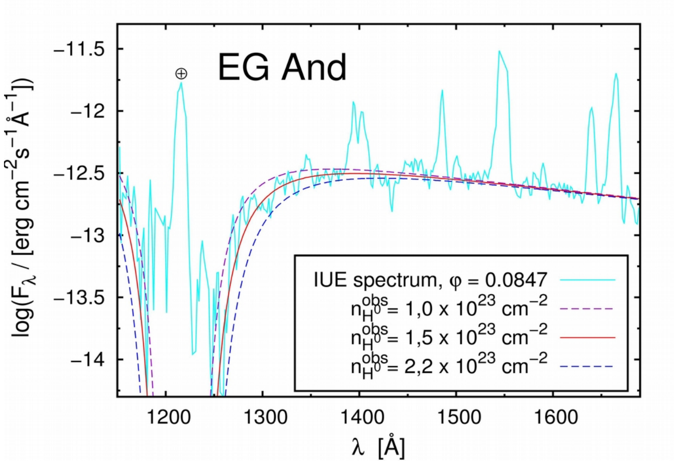




- **estimated** the effect of the **ionization** of the wind on n_{H0} column density

- obtaining H^0 column densities from **Rayleigh scattering**

for **EG And** and **SY Mus** using *IUE* and *HST* spectra + adopted values from literature



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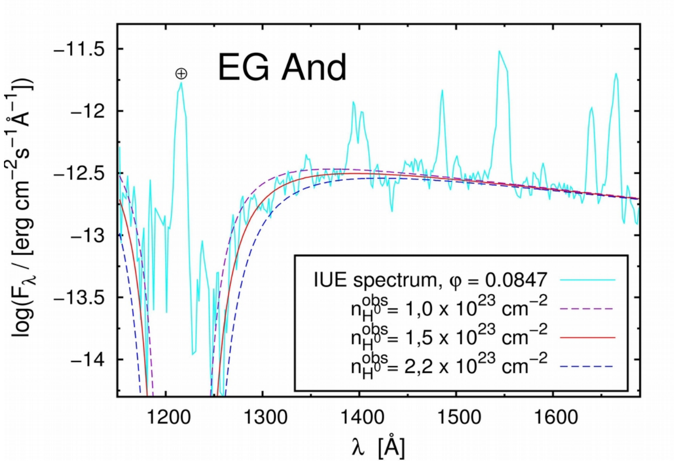

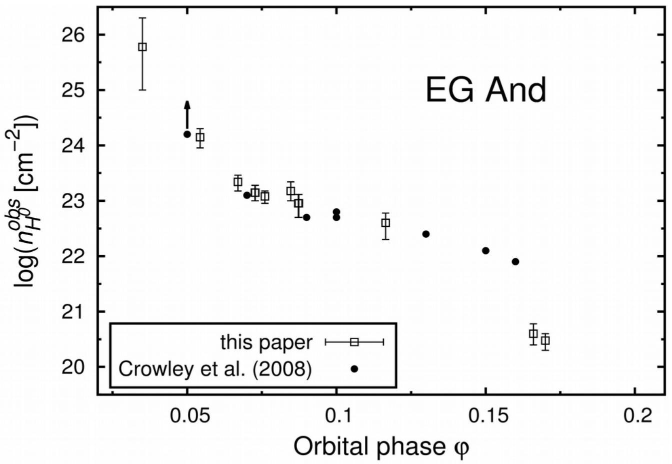

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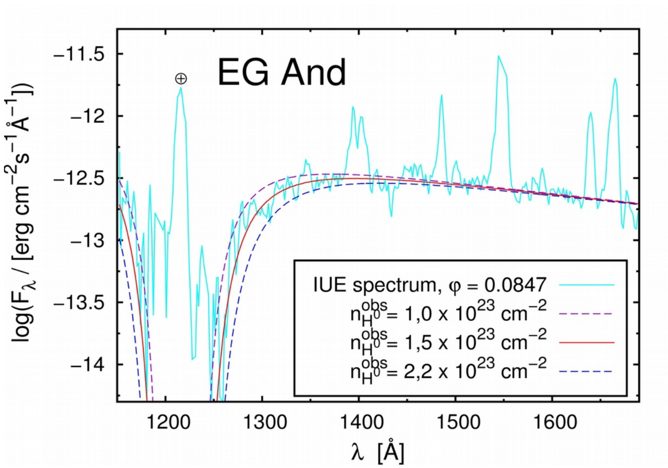
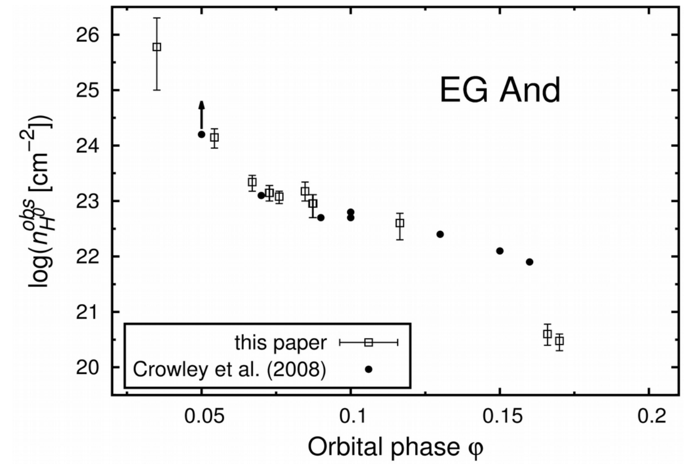
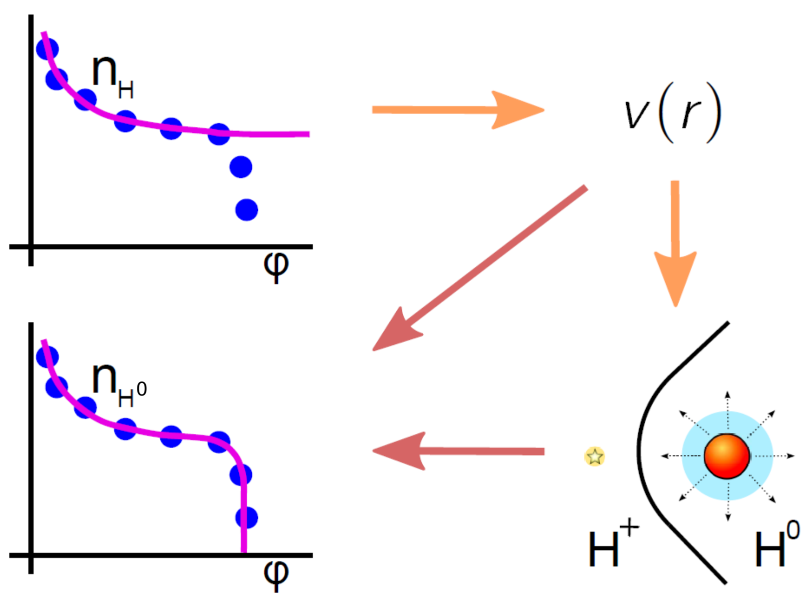




- including **ionization** of the wind



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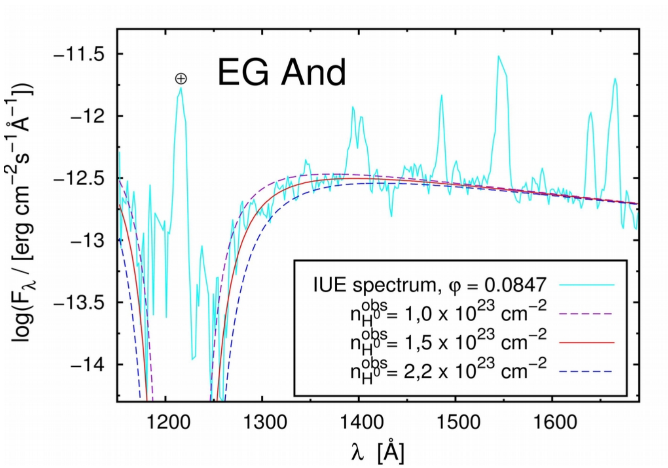
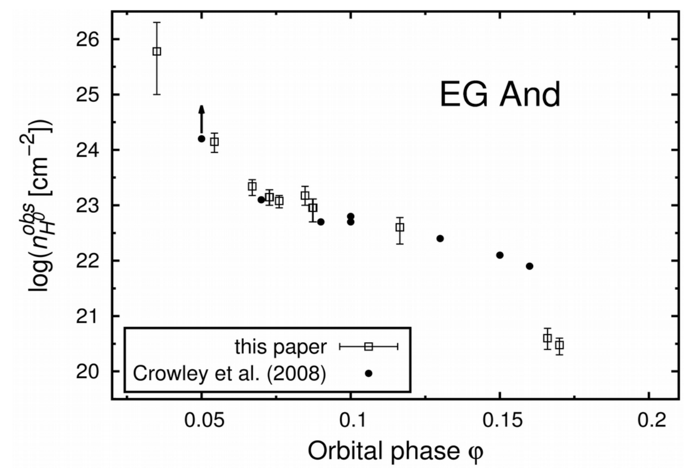
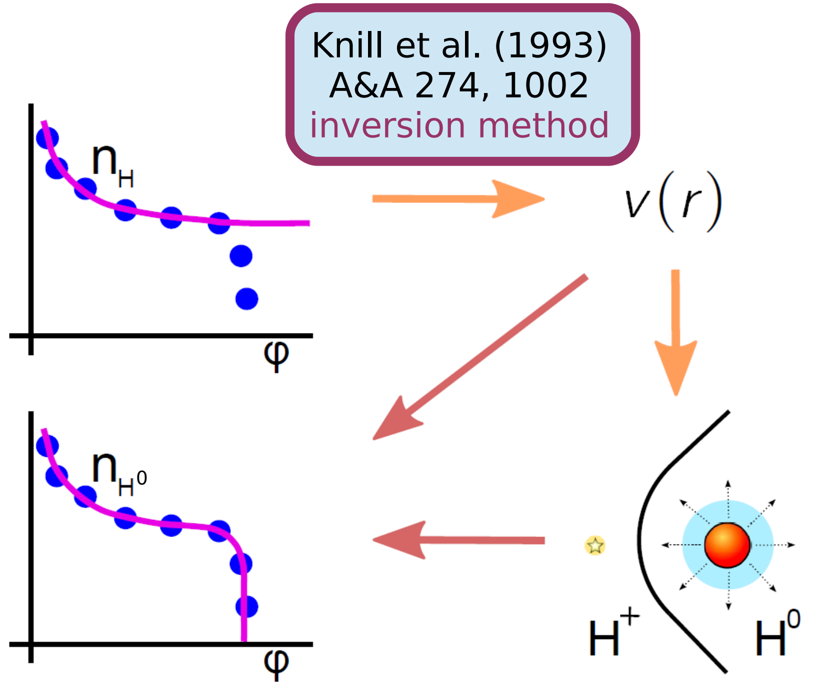




- including **ionization** of the wind



- obtaining H⁰ column densities from **Rayleigh scattering**

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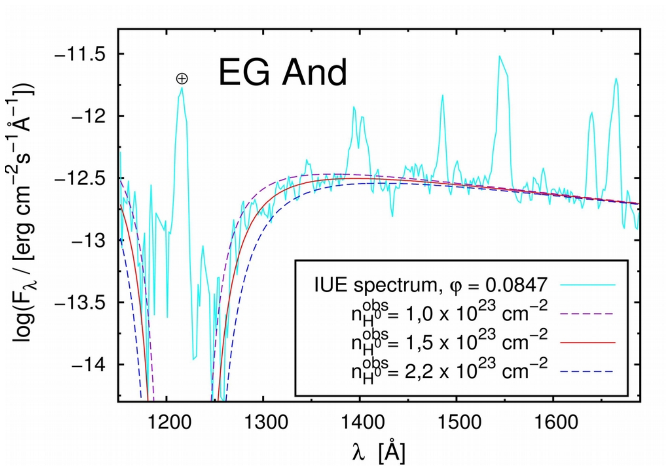
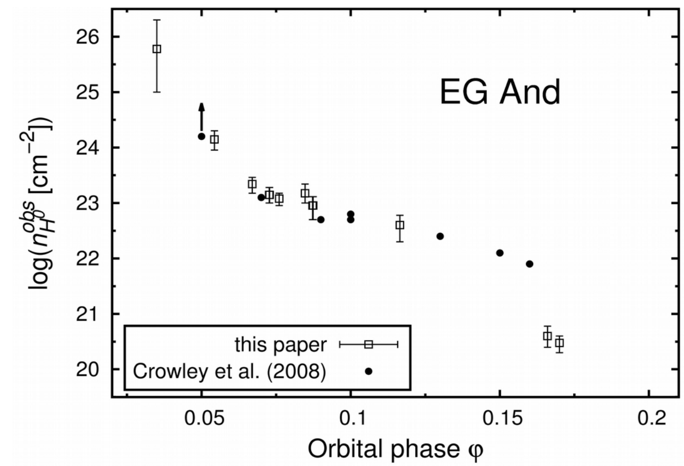
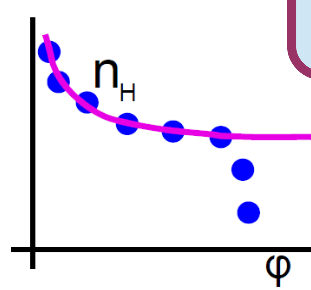




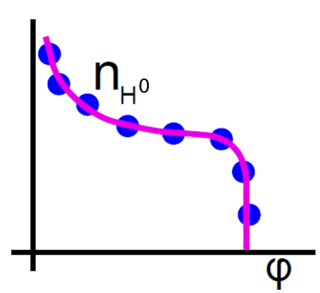
Knill et al. (1993)
A&A 274, 1002
inversion method

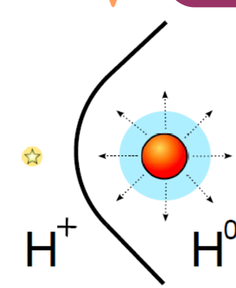


$v(r)$

Seaquist et al. (1984)
ApJ 284, 202
ionization boundary

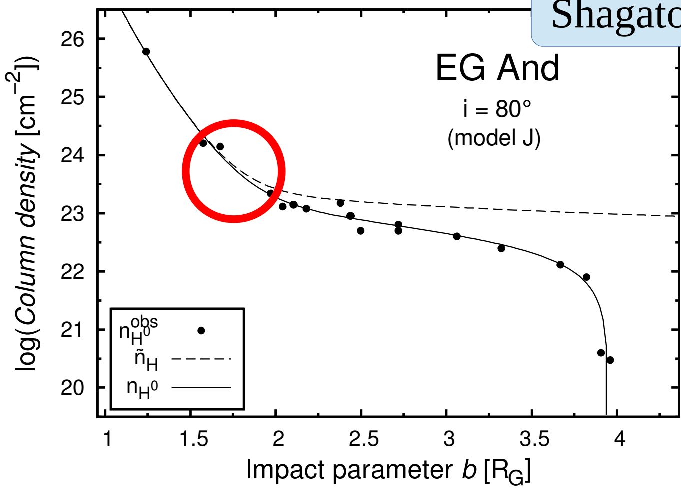
- including **ionization** of the wind

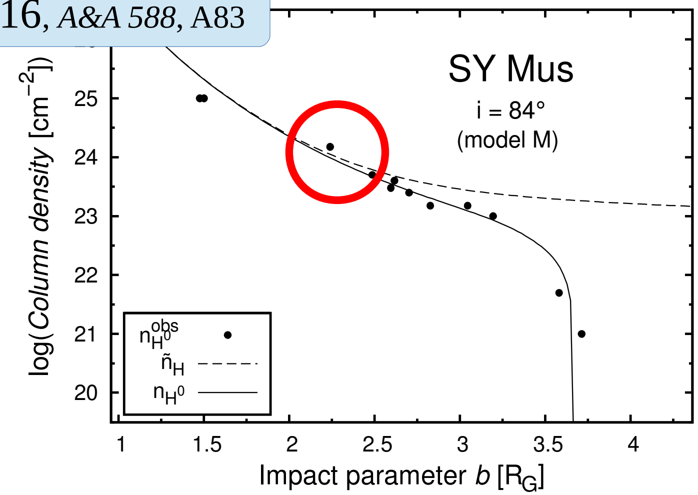




Comparison of resulting models

Shagatova et al. 2016, *A&A 588*, A83





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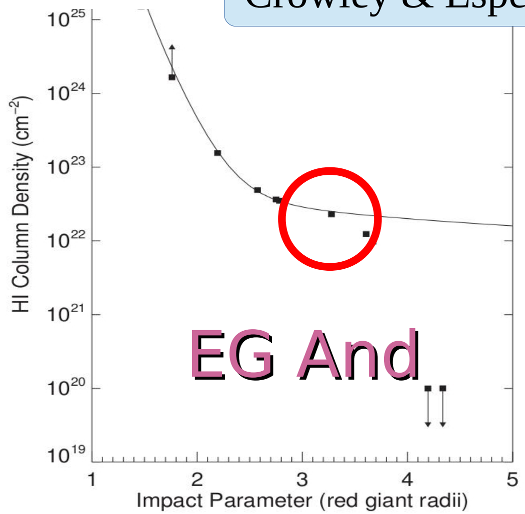

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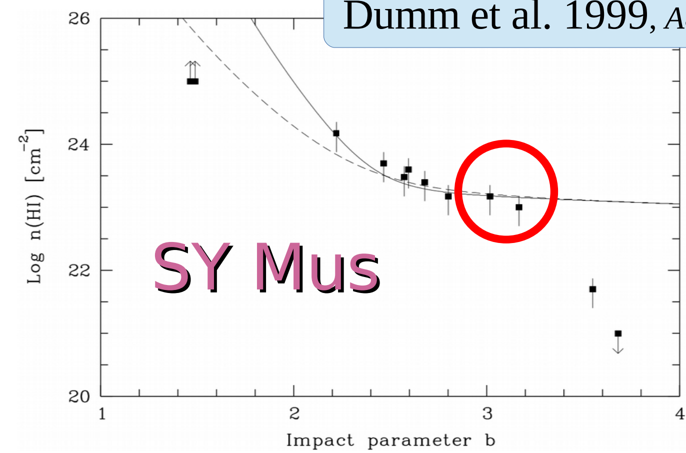
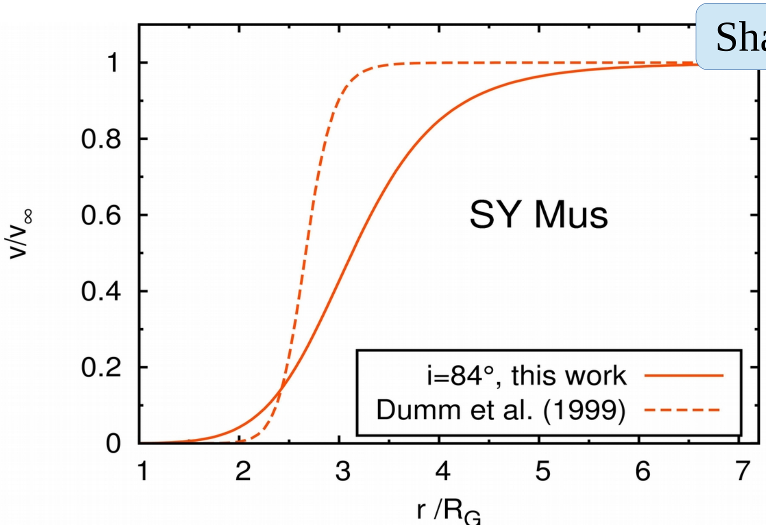


- more precise velocity profiles of the wind

Shagatova et al. 2016, *A&A 588*, A83



- simple analytic formula:

$$v(r) = \frac{v_\infty}{1 + \xi r^{1-K}}$$

$$\tilde{n}_{\rm H}(b) = \frac{n_1}{b} + \frac{n_K}{b^K}$$

- formula for the total hydrogen column density

object	i	E/I[1)]	$n_1[10^{23}]$	$n_{\rm K}$	K	ξ	$X^{\rm H+}$	$\chi^2_{\rm red}$	model
EG And	70°	E	4.54	5.12×10^{30}	21	6.40×10^{7}	1.75	1.67	I
	80°	E	3.87	1.15×10^{27}	14	1.38×10^{4}	1.85	1.60	J
	90°	E	3.40	4.83×10^{25}	10	5.49×10^{2}	1.88	1.63	K
SY Mus	80°	E	8.00	1.50×10^{27}	9	8.94×10^{3}	2.30	1.02	L
	84°	E	6.20	5.30×10^{26}	8	2.94×10^{3}	2.50	0.94	M
	90°	E	6.10	5.00×10^{26}	8	2.82×10^{3}	2.53	1.39	N
	84°	I	2.45	1.00×10^{27}	13	1.81×10^{4}	16.0	2.33	O

Notes: [1)] E – egress data, I – ingress data

- higher mass-loss rates!

Object	i	$\dot{M}_{sp}$ [$M_{\odot}$ yr^{-1}]	model
EG And	70°	2.11×10^{-6}	I
	80°	1.80×10^{-6}	J
	90°	1.58×10^{-6}	K
SY Mus	80°	4.26×10^{-6}	L
	84°	3.30×10^{-6}	M
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Mass-loss rate for giants in S-type symbiotic systems from line-of-sight independent methods ≈ **10^{-7}** $M_\odot$/year

Seaquist et al. 1993, *ApJ 410*, 260
Mikołajewska et al. 2002, Adv. Space Res. *30*, 2045
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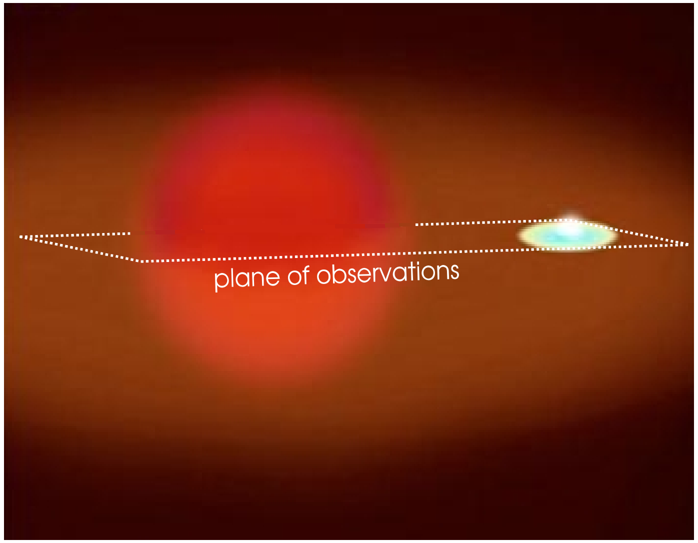

plane of observations ≈ orbital plane
for eclipsing binary systems

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⟺

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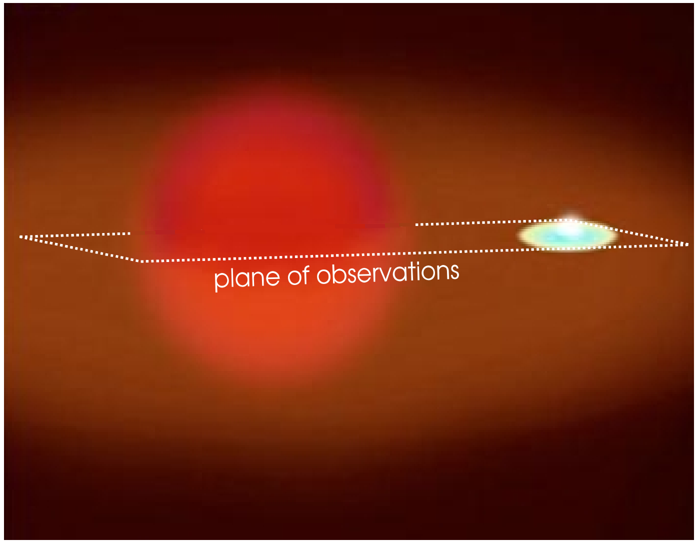

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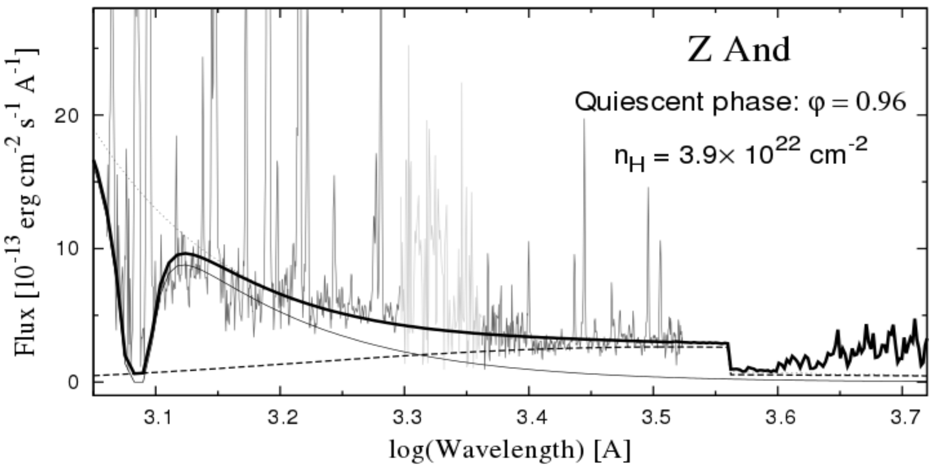
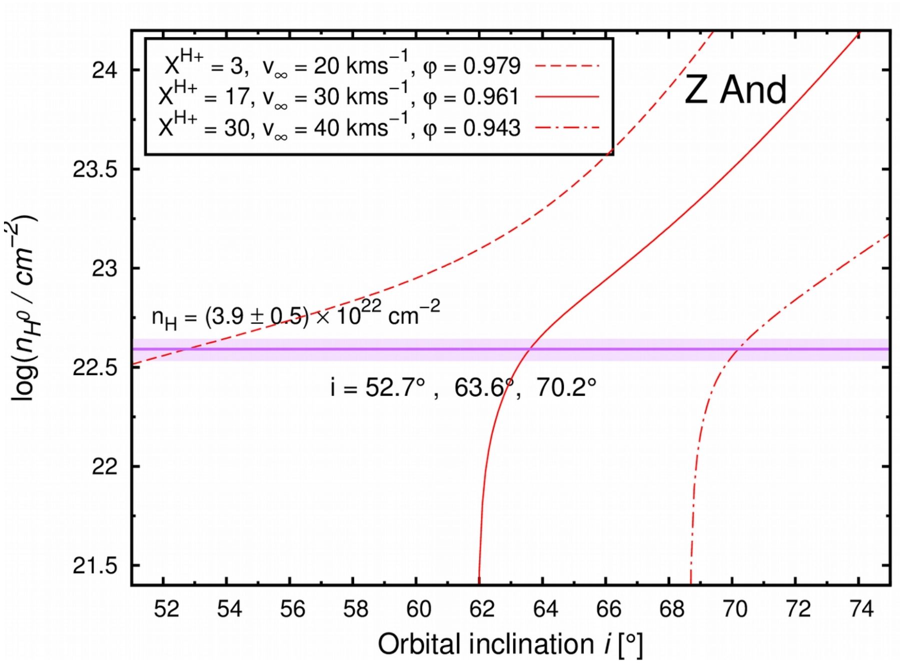
Indication of the wind focusing towards orbital plane

Orbital inclination of Z Andromedae



- orbital inclination of Z And in literature ≈ **41° - 76°**

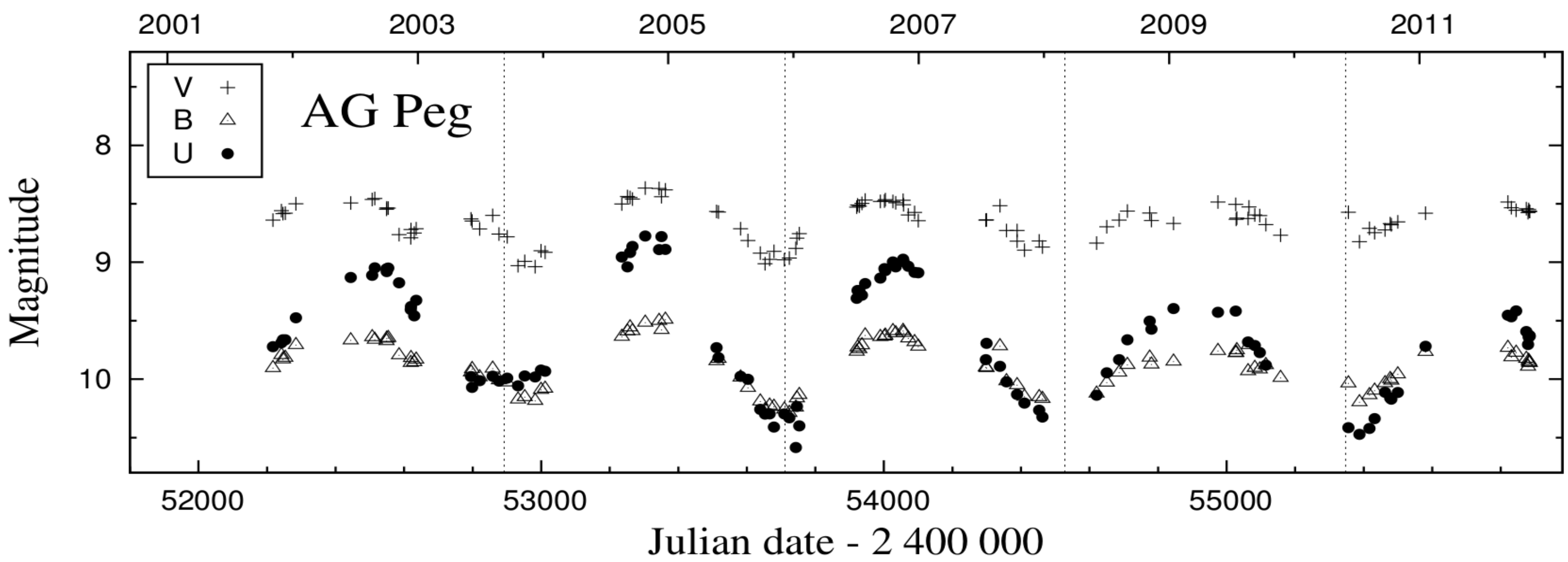


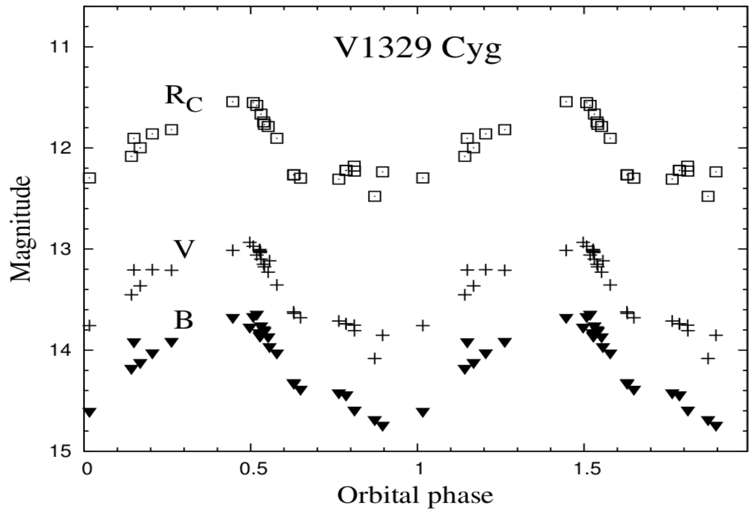
Determination of orbital inclination by column density modelling.

i = 63.6° - 12.2°/ + 6.9°

Method: Shagatova & Skopal 2012, *A&A 547*, A45
Updated results: Shagatova 2015, Dissertation Thesis

Asymmetric light curves of symbiotic stars

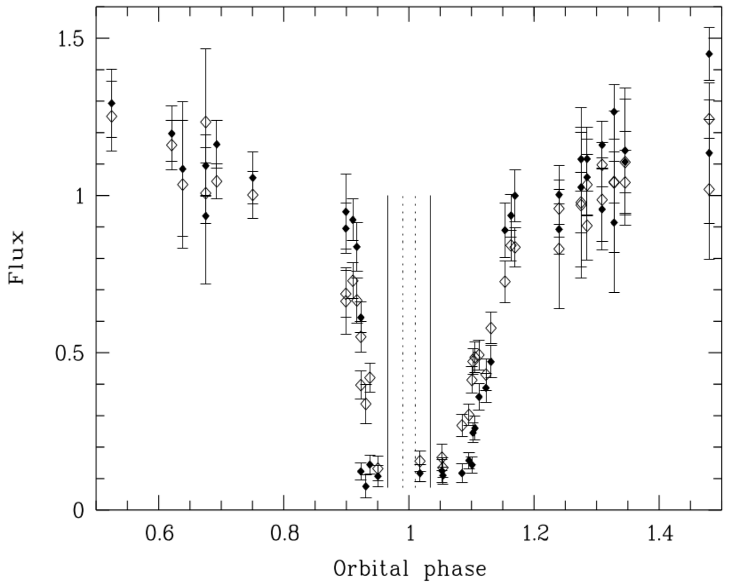




Skopal et al. (2012)
AN 333, No. 3, 242

SY Muscae

- i = 84°
- white dwarf + red giant
- asymmetry in UV light curves



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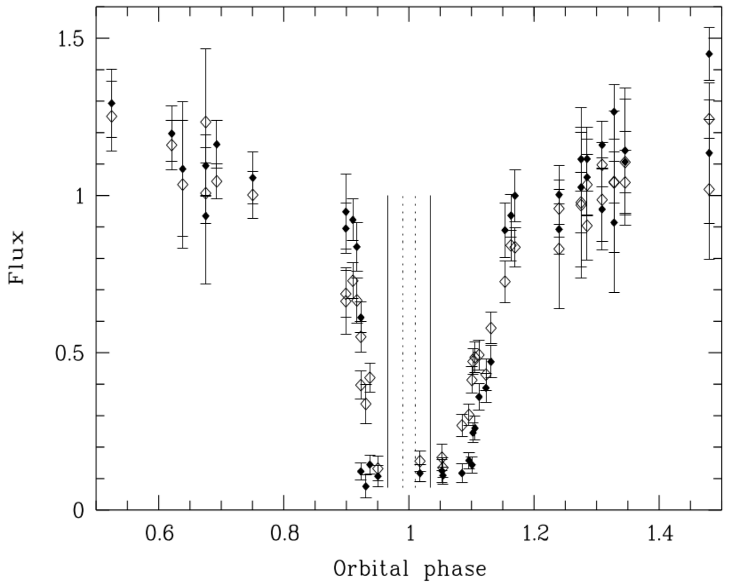

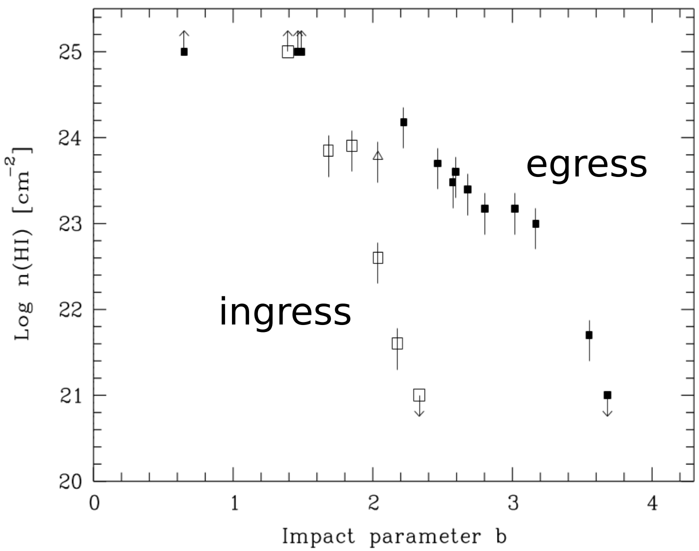

Dumm et al. (1999), A&A 349, 169:

asymmetric wind distribution

- possible cause of the asymmetry in LCs

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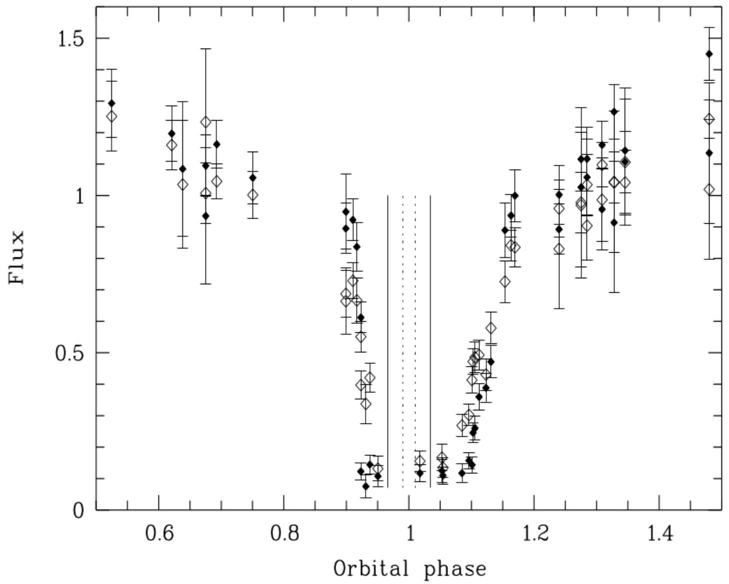

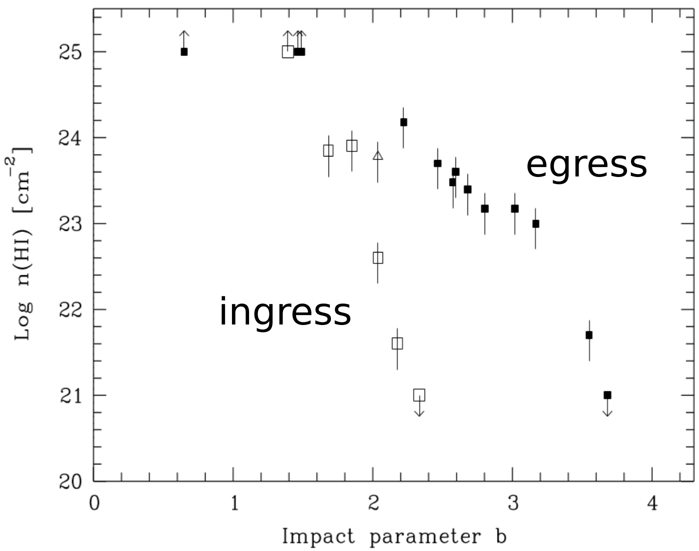

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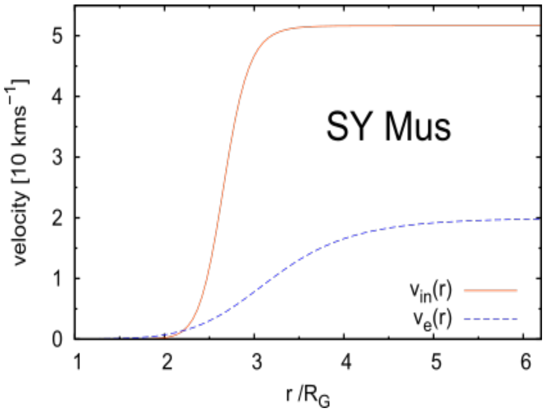
Can we justify it in a quantitative way?

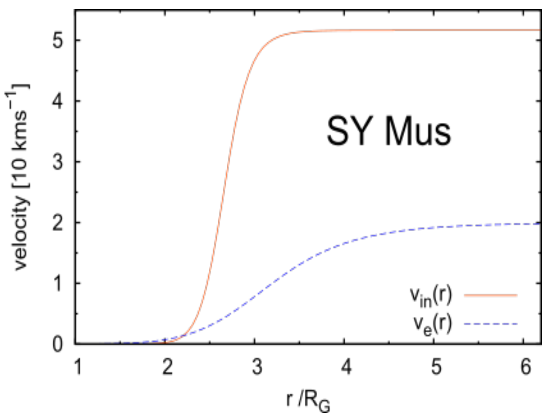
Model with unified velocity profile



Assumption: gradual change of the velocity profile from $v_e(r)$ to $v_{in}(r)$.

- interconnection by a smooth function

Model with unified velocity profile



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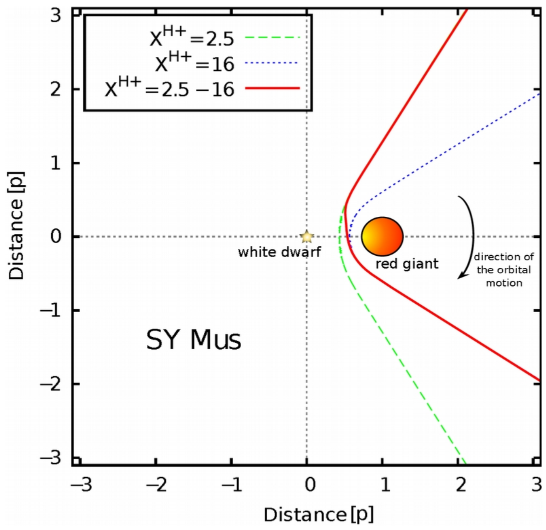
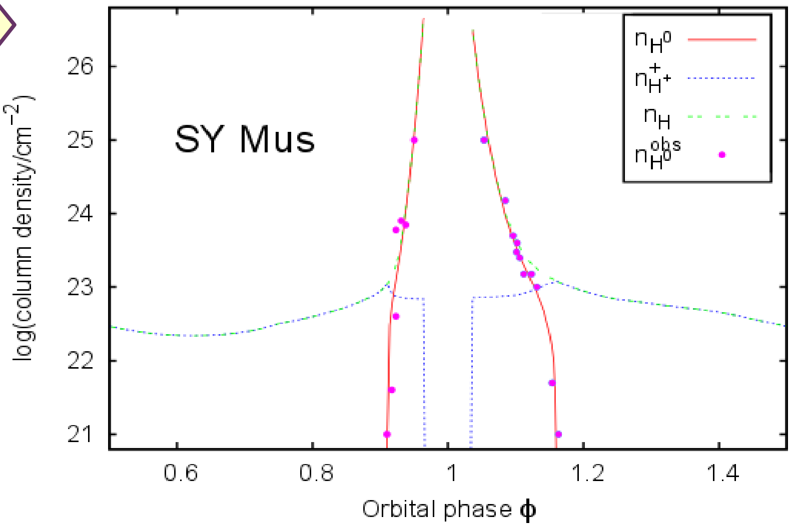


- ionization structure



- column density distribution of neutral and ionized hydrogen

UV continuum light curves modelling

Sources of radiation:

$$F_\lambda(\varphi) = F_\lambda^{\mathrm{h}}(\varphi) + F_\lambda^{\mathrm{n}}(\varphi)$$

WHITE DWARF

$$F_\lambda^{\mathrm{h}}(\varphi) = \pi B_\lambda(T_{\mathrm{h}}) e^{-\tau_\lambda(\varphi)}$$

NEBULA

$$F_\lambda^{\mathrm{n}}(\varphi) = \alpha_\lambda \sin[2\pi(\varphi - 0.25)] + \beta_\lambda$$

- geometrical attenuation of nebular radiation modelled by a sine wave

RED GIANT

- negtectable contribution in UV

Attenuation:

$$\tau_\lambda(\varphi) = \tau_\lambda^0(\varphi) + \tau_\lambda^+(\varphi)$$

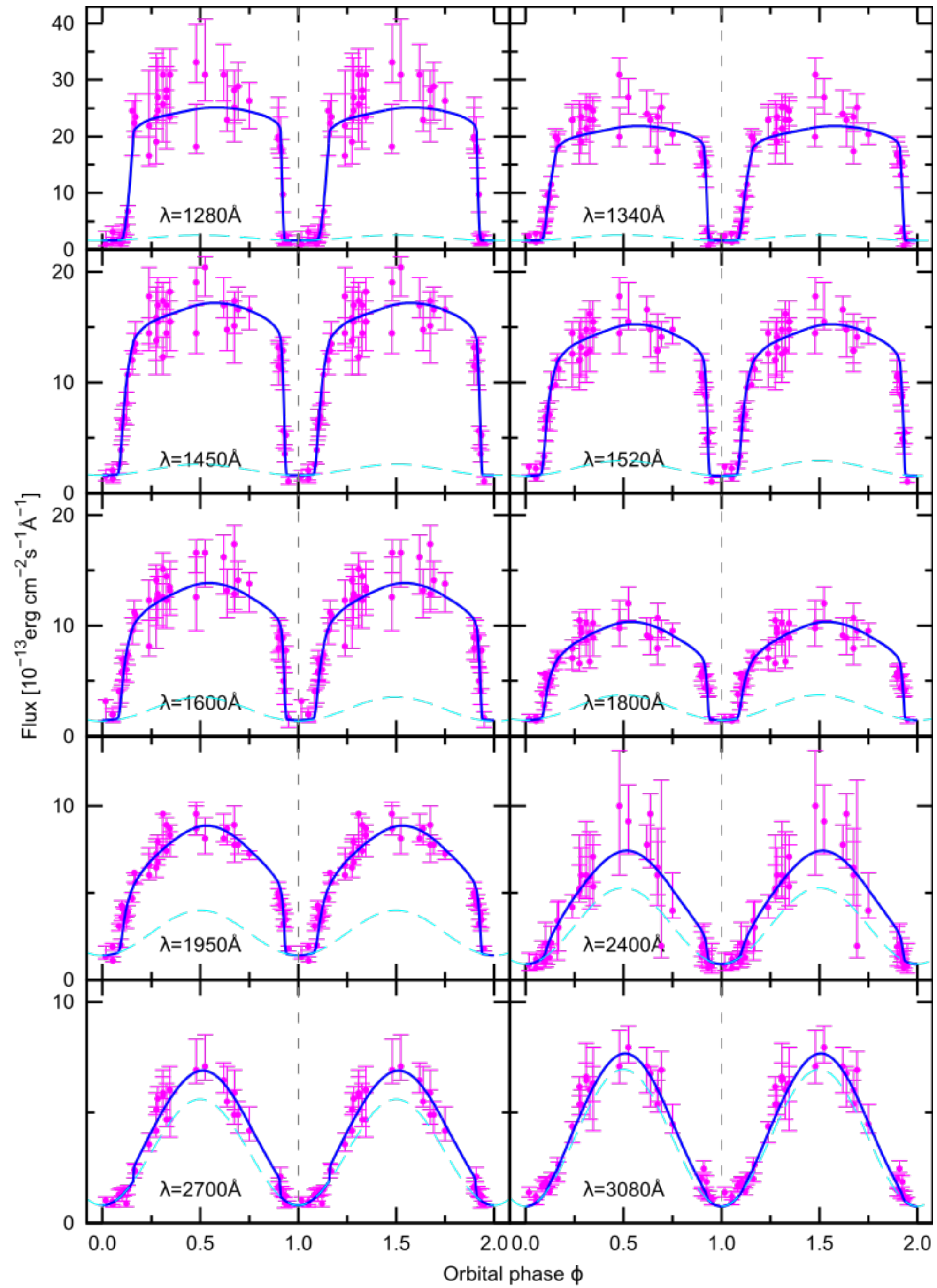
$$\tau_\lambda^0(\varphi) = \sigma_{\mathrm{Ray}}(\lambda) n_{\mathrm{H}^0}(\varphi) + \kappa_{\mathrm{H}^-}(\lambda) n_{\mathrm{H}^-}(\varphi)$$

$$\tau_\lambda^+(\varphi) = \sigma_{\mathrm{e}^-}^+ n_{\mathrm{e}^-}^+(\varphi) + \sigma_{\mathrm{H}^0}^+(\lambda, \mathrm{T_e}) \mathrm{n}_{\mathrm{H}^0}^+(\varphi)$$

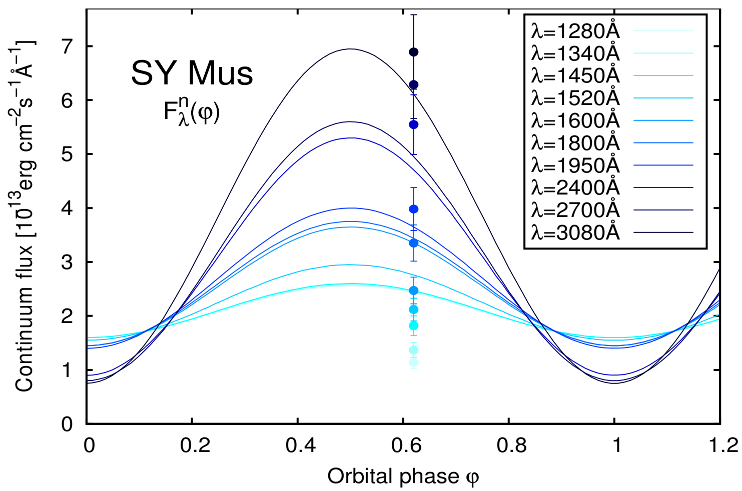
$$n_{\mathrm{e}^-}^+(\varphi) = 1.2\, n_{\mathrm{H}^+}^+(\varphi)$$

Observations

UV continuum light curves
at 10 wavelengths from 1280 to 3080Å
from 44 IUE SWP, LWP/LWR spectra



Model



$$n_{\mathrm{H}^-}(\varphi) = 5.0\times10^{-7} n_{\mathrm{H}^0}(\varphi)$$
$$n^+_{\mathrm{H}^0}(\varphi) = 1.5\times10^{-4} n^+_{\mathrm{H}^+}(\varphi)$$

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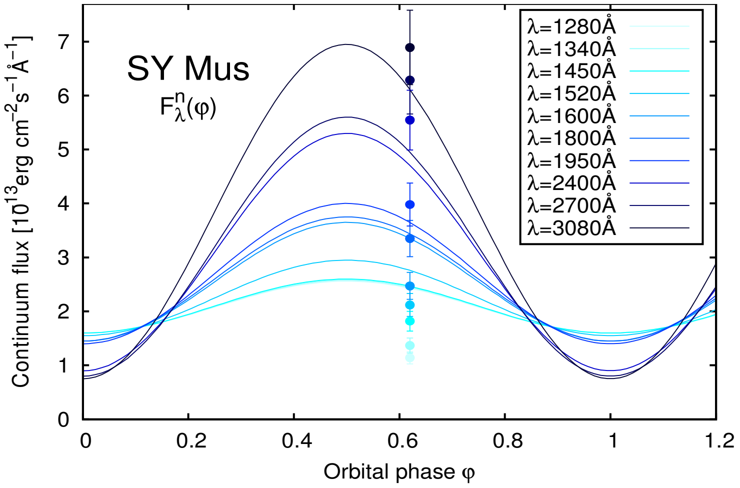

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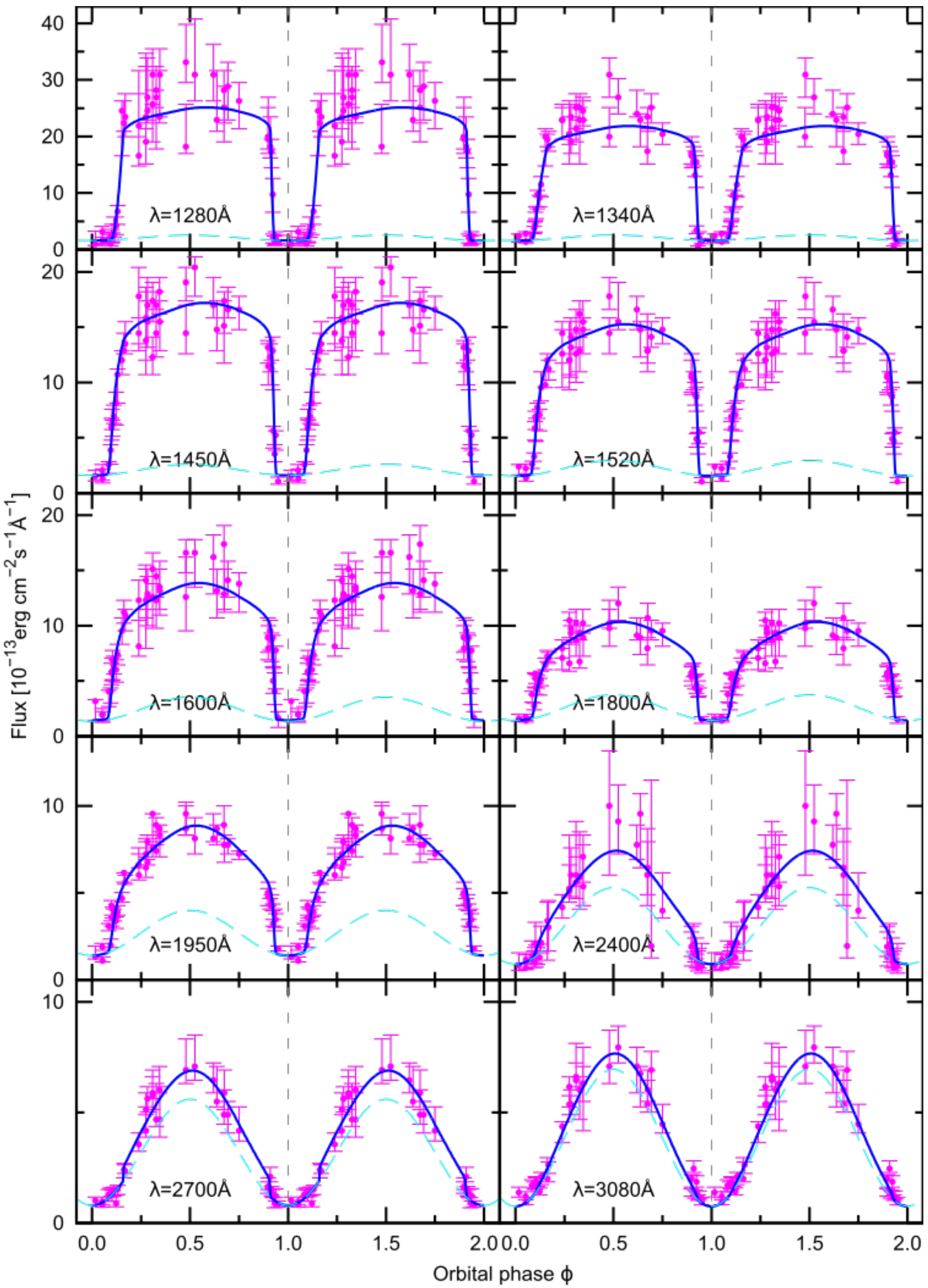
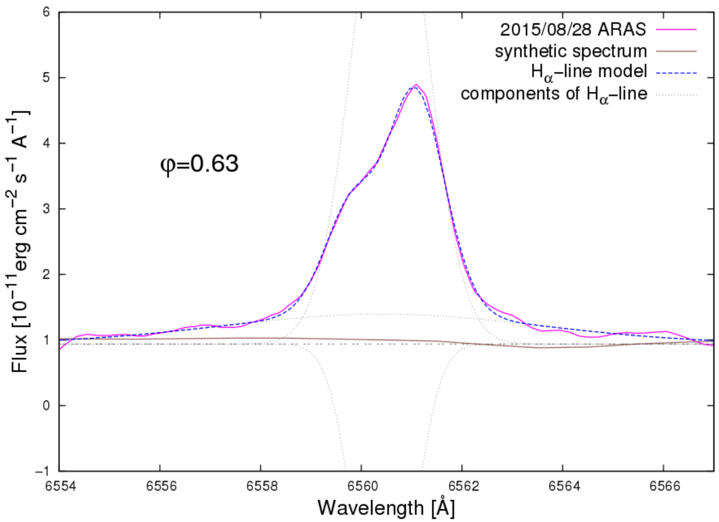
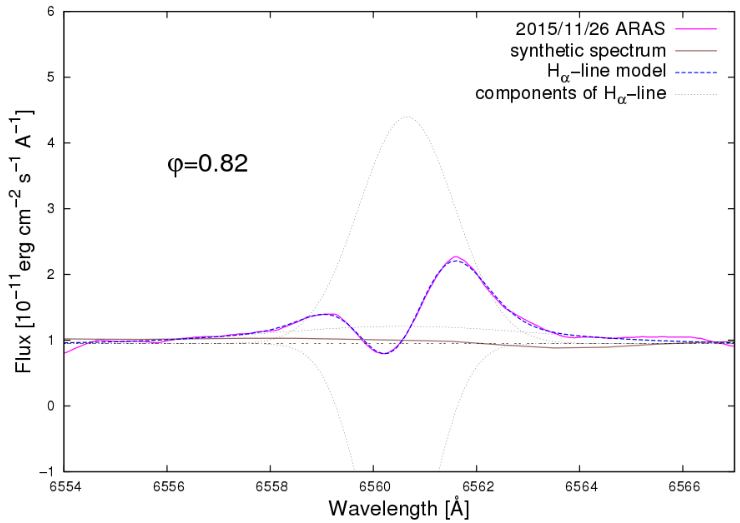
LC asymmetry is caused by the asymmetric distribution of the wind from RG.



Future plans

- to model the Hα-line profile for symbiotic system EG And





- the Hα-line profile shows variability with orbital motion

- available spectra from Stará Lesná Observatory and ARAS database

- our velocity profiles can be used to model the absorption component

Conclusions

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Thank you for attention!