Image credit: Instituto de Astrofísica de Canarias

Asymmetries of the Wind from Giants *in S-type Symbiotic Binaries* from UV and Optical Observations

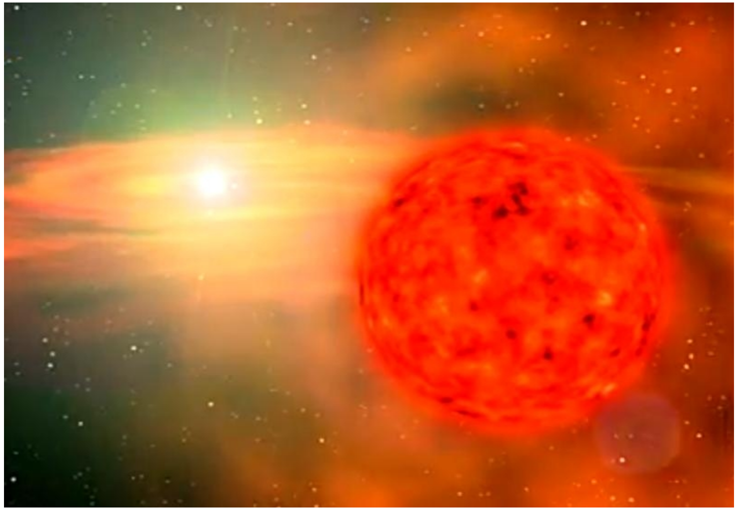
N. Shagatova and A. Skopal

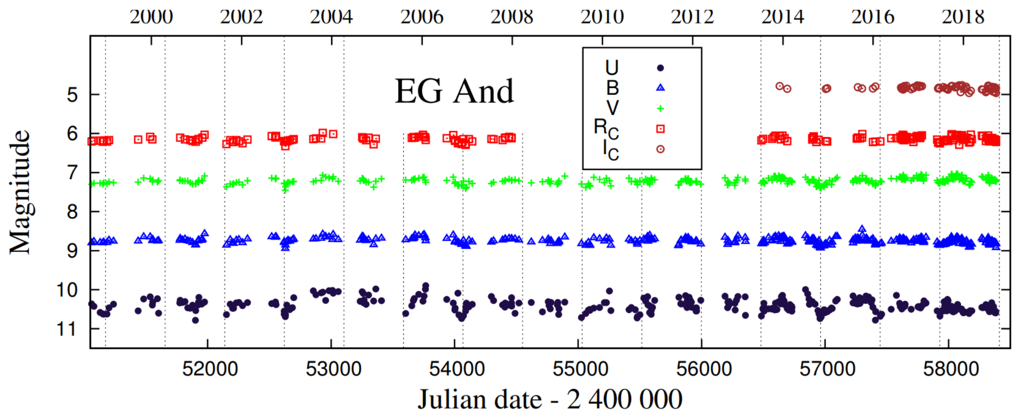
Astronomical Institute, Slovak Academy of Sciences, Tatranská Lomnica, Slovakia

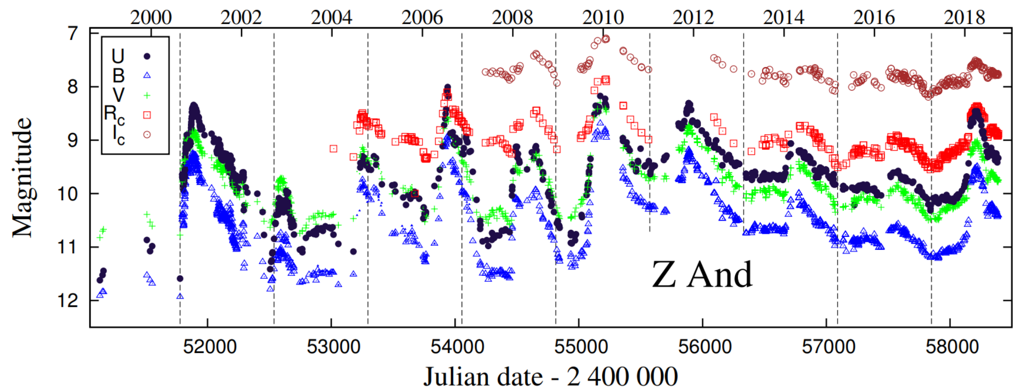
Supported by VEGA 2/0030/21 and APVV-20-0148 grants.

S-type symbiotic stars

- wide interacting binary stars (P ≈ few years)
- white dwarf + red giant (RGB)
- mass transfer via stellar wind
- neutral and ionized wind
- quiescent and active phases

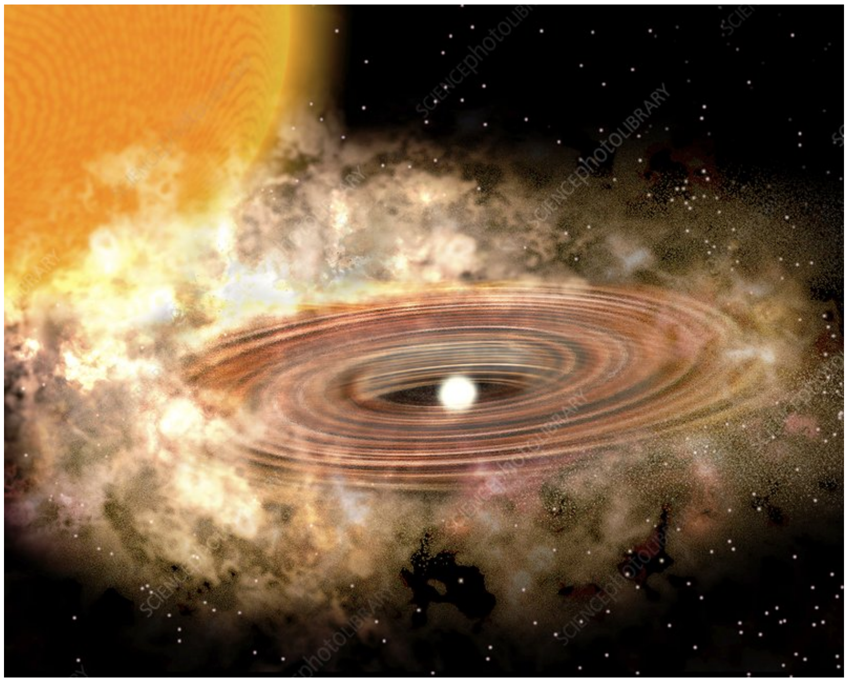






The luminosity problem

- accretion heats up the white dwarf up to T ~ 100 000 K and $L \sim 1000\ L_{Sun}$



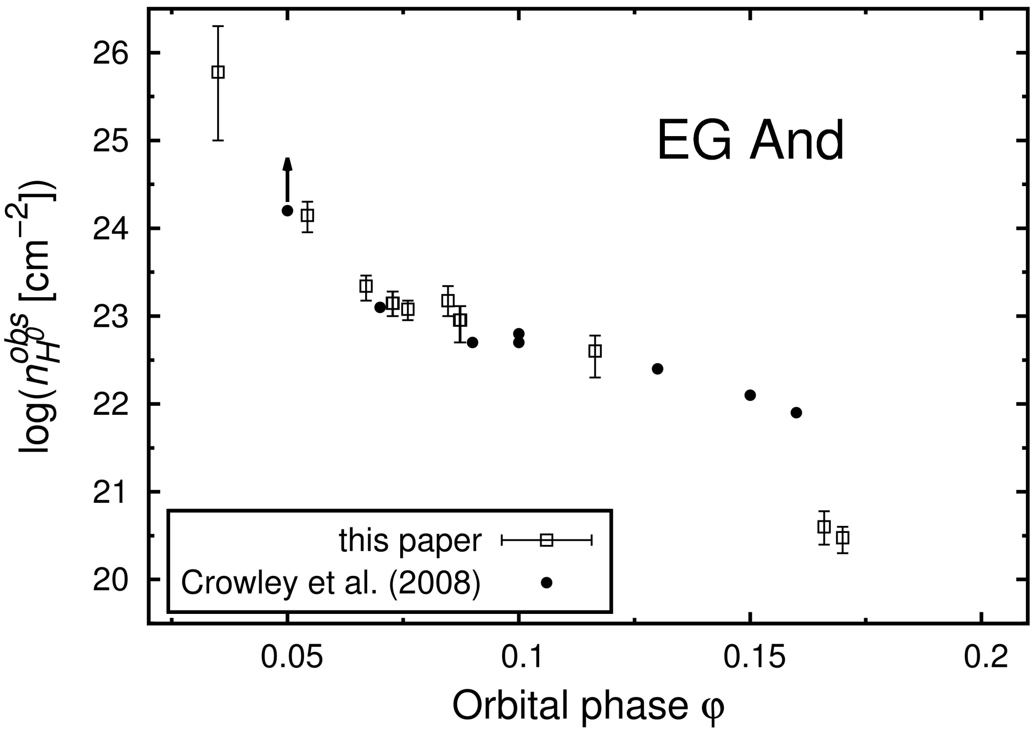
Required **accretion rate** :
$10^{-8} - 10^{-7}\ M_{Sun}$ / year

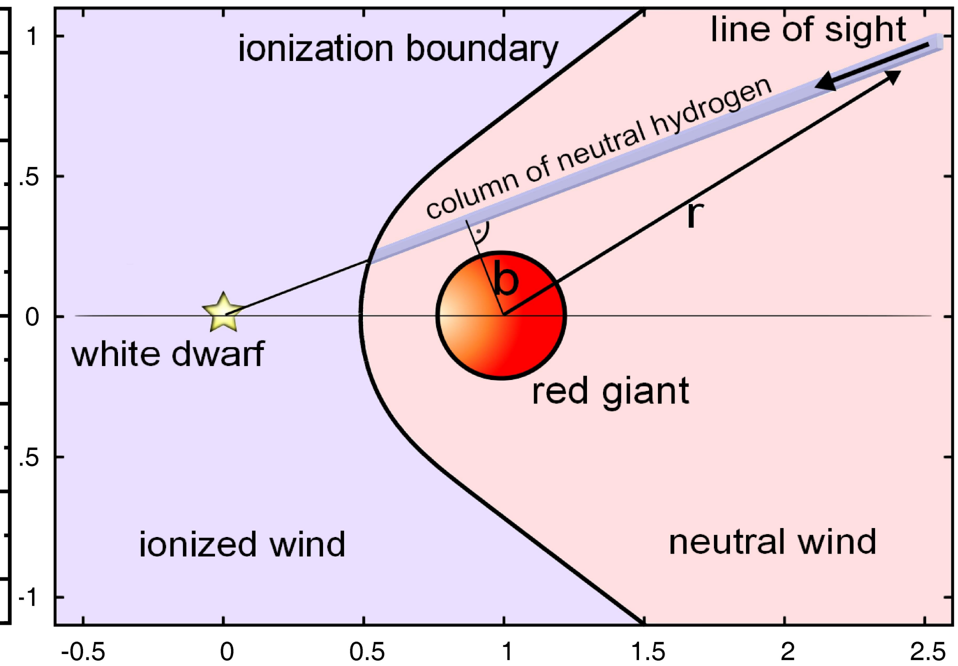
Measured **mass-loss rate** :
$\sim 10^{-7}\ M_{Sun}$ / year

- binary stars: **mass accretion rate ~ few % of the mass loss rate**

H^0 column density during quiescent phases

- no outbursts on the white dwarf
- conical neutral wind area around the red giant
- fraction of the red giant wind ionized by the white dwarf

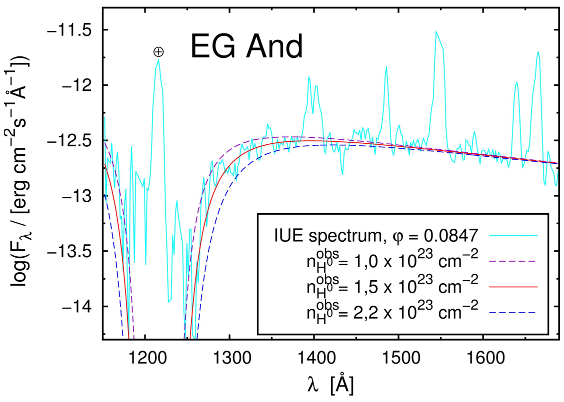




H^0 column densities from Rayleigh scattering

- for **EG And** and **SY Mus**
- *IUE* and *HST* spectra

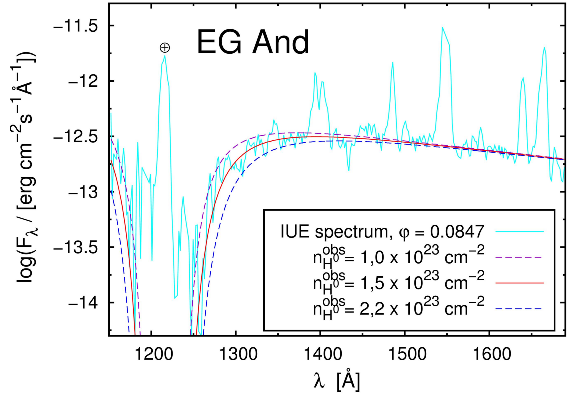
  + adopted values from literature

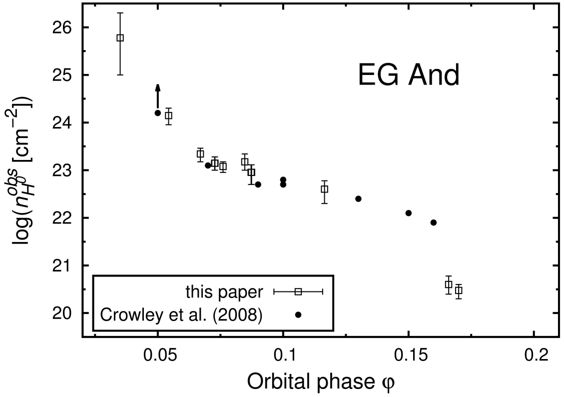


H^0 column densities from Rayleigh scattering

- for **EG And** and **SY Mus**
- *IUE* and *HST* spectra

  + adopted values from literature

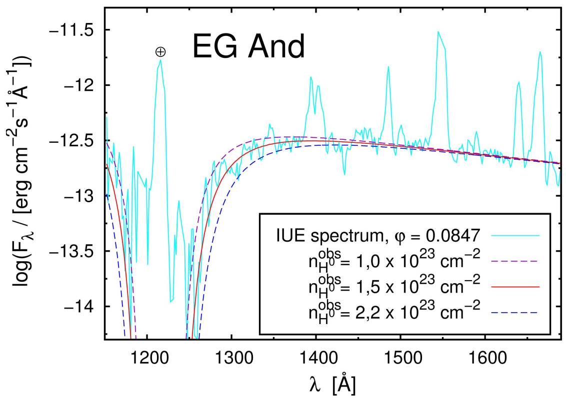


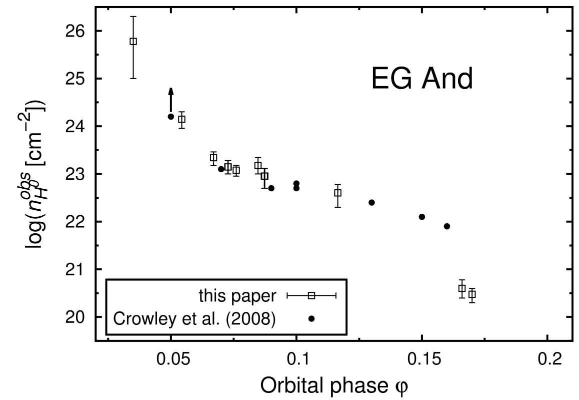


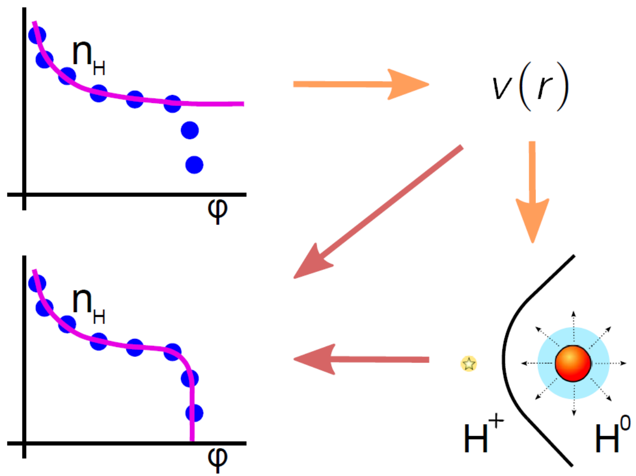
H^0 column densities from Rayleigh scattering

- for **EG And** and **SY Mus**
- *IUE* and *HST* spectra

  + adopted values from literature



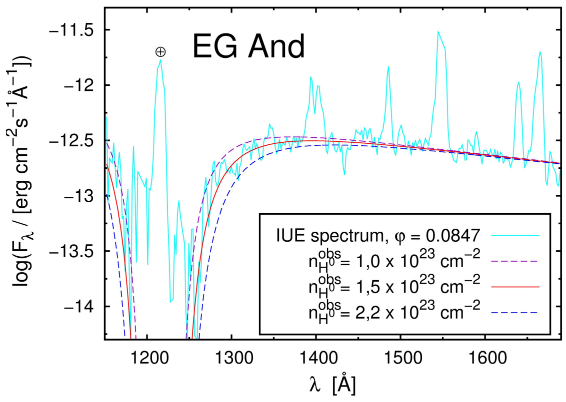


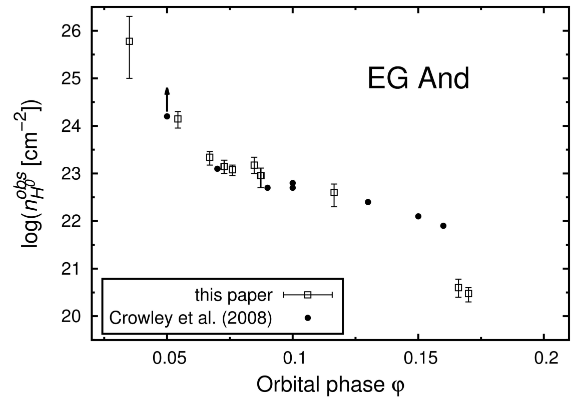


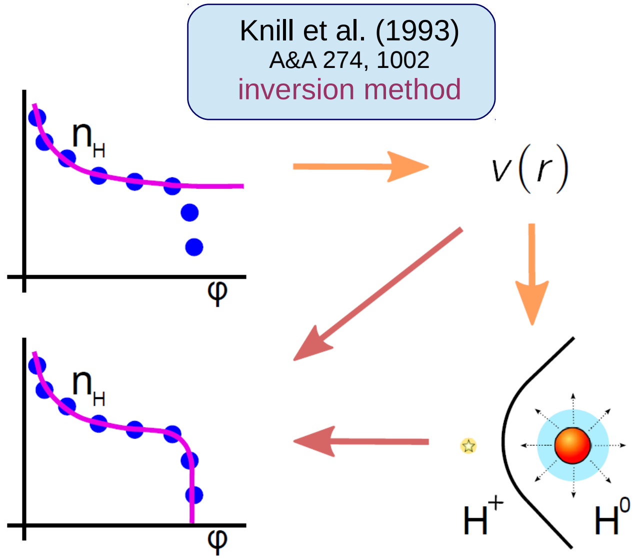
H^0 column densities from Rayleigh scattering

- for **EG And** and **SY Mus**
- *IUE* and *HST* spectra

+ adopted values from literature



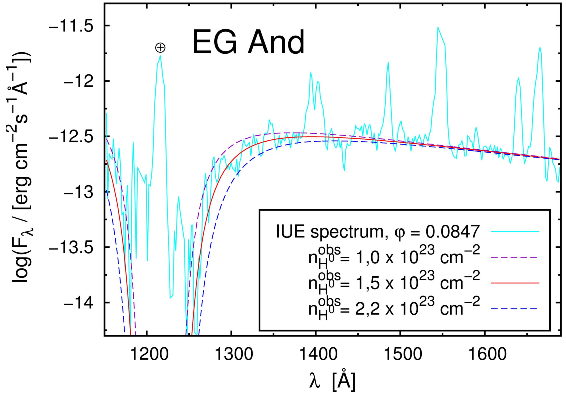


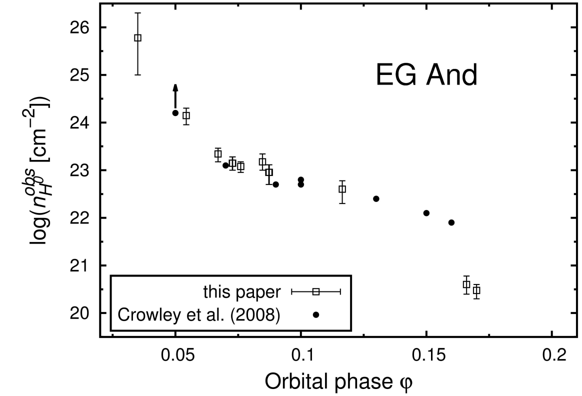


H^0 column densities from Rayleigh scattering

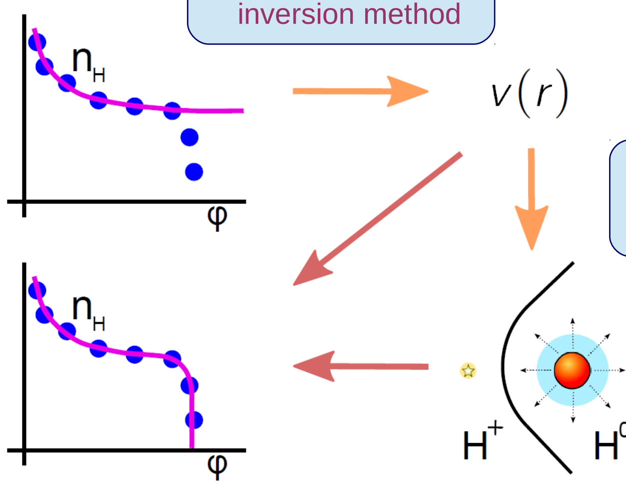
- for **EG And** and **SY Mus**
- *IUE* and *HST* spectra

+ adopted values from literature



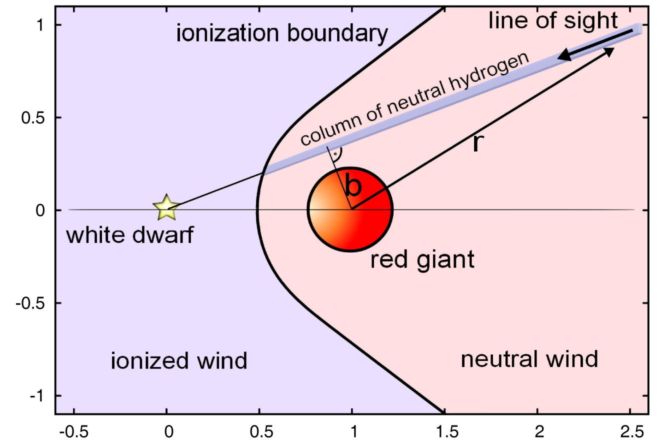


Knill et al. (1993)
A&A 274, 1002
inversion method



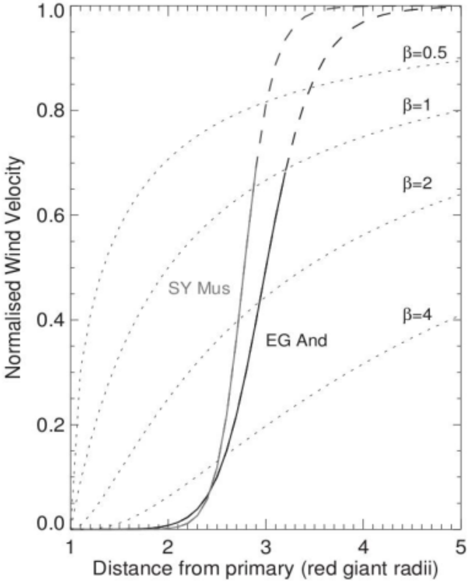
Seaquist et al. (1984)
ApJ 284, 202
ionization boundary

- including **ionization** of the wind



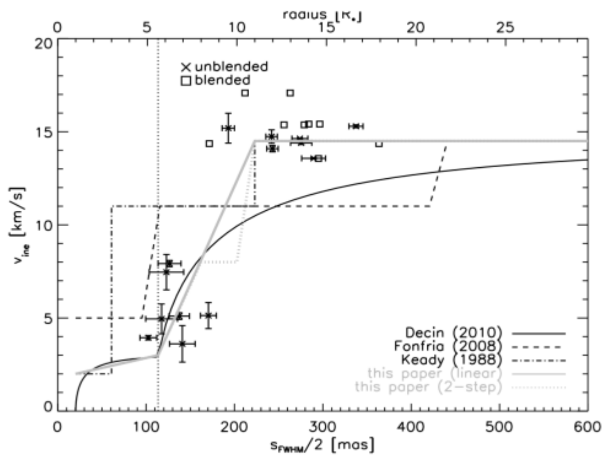
Velocity profile

- canonical β-*law* $v(r) = v_\infty \left(1 - \frac{R}{r}\right)^\beta$



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

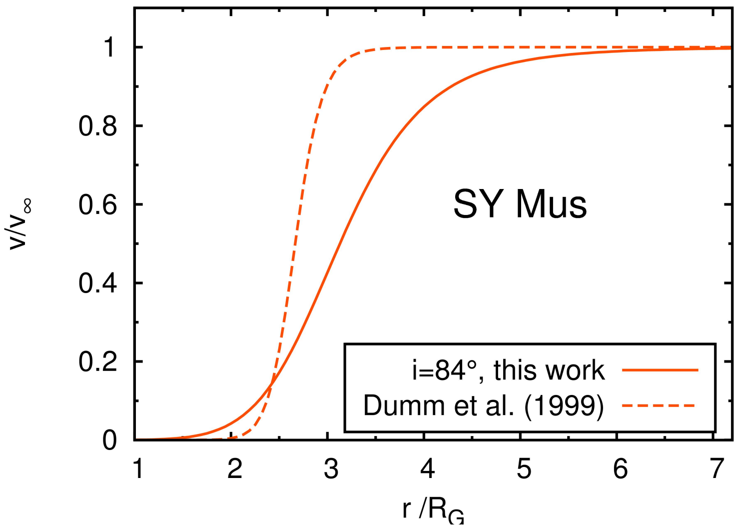
- *steeper v(r) for cooler stars*



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

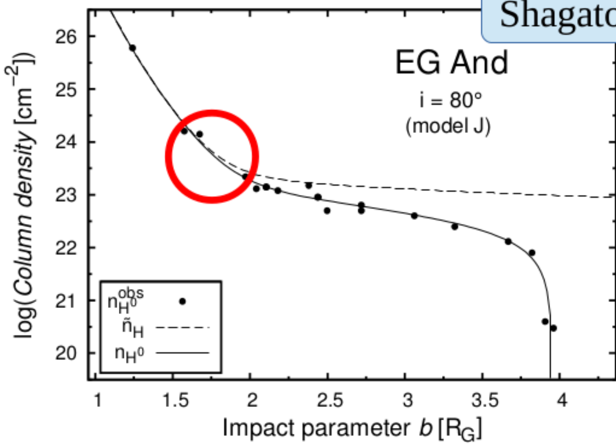
- simple analytic formula:

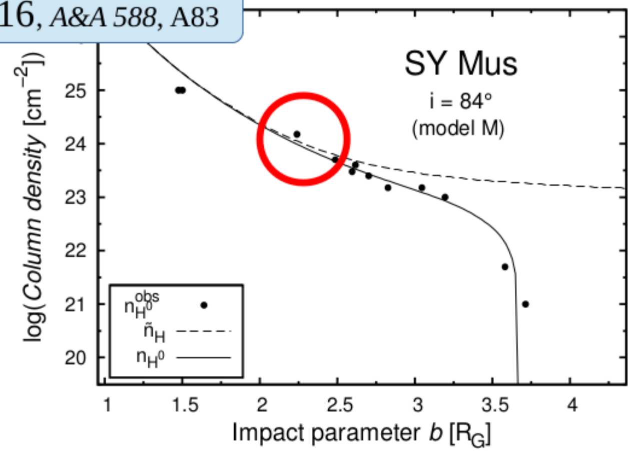
$$v(r) = \frac{v_\infty}{1 + \xi r^{1-K}}$$



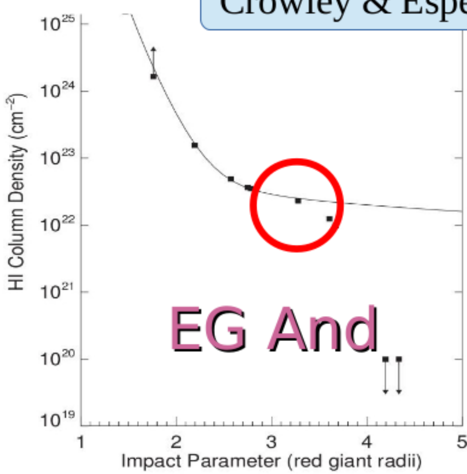
Column density models - comparison

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

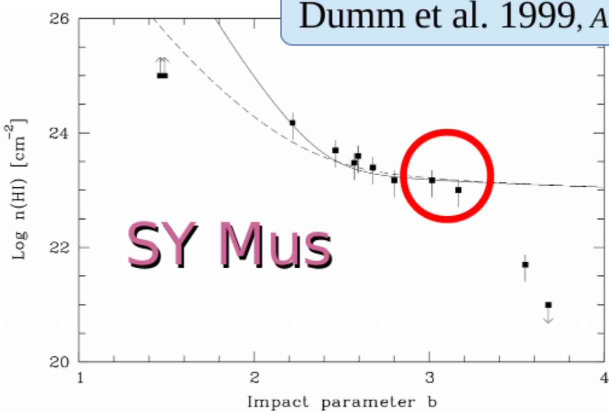




Crowley & Espey 2010, ASP Conf. Ser. 425, 191



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



Wind enhancement in the orbital-plane area

Object	i	$\dot{M}_{sp}$ [$M_{\odot}$ yr^{-1}]	model
EG And	70°	1.06×10^{-6}	I
	80°	9.00×10^{-7}	J
	90°	7.91×10^{-7}	K
SY Mus	80°	2.13×10^{-6}	L
	84°	1.65×10^{-6}	M
	90°	1.62×10^{-6}	N
	84°	6.51×10^{-7}	O

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

Wind enhancement in the orbital-plane area

Object	i	$\dot{M}_{sp}$ [$M_\odot$ yr^{-1}]	model
EG And	70°	1.06×10^{-6}	I
	80°	9.00×10^{-7}	J
	90°	7.91×10^{-7}	K
SY Mus	80°	2.13×10^{-6}	L
	84°	1.65×10^{-6}	M
	90°	1.62×10^{-6}	N
	84°	6.51×10^{-7}	O

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

Mass-loss rate for giants in S-type symbiotic systems from **line-of-sight independent** methods ≈ **10^{-7}** $M_\odot$/year

(from nebular emission in radio and optical wavelengths)

Seaquist et al. 1993, ApJ 410, 260
Mikołajewska et al. 2002, Adv. Space Res. 30, 2045
Skopal 2005, A&A 440, 995

Wind enhancement in the orbital-plane area

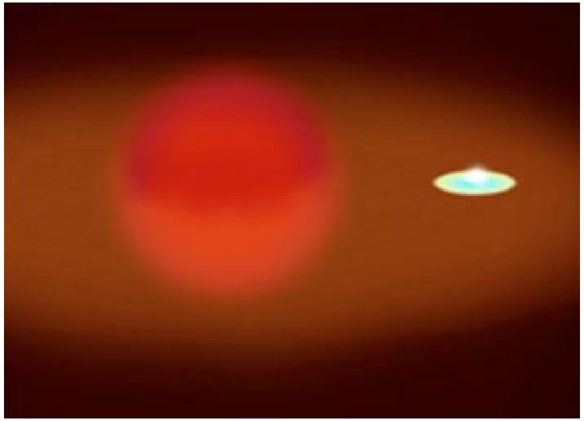
Object	i	$\dot{M}_{sp}$ [$M_{\odot}$ yr^{-1}]	model
EG And	70°	1.06×10^{-6}	I
	80°	9.00×10^{-7}	J
	90°	7.91×10^{-7}	K
SY Mus	80°	2.13×10^{-6}	L
	84°	1.65×10^{-6}	M
	90°	1.62×10^{-6}	N
	84°	6.51×10^{-7}	O

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

Mass-loss rate for giants in S-type symbiotic systems from **line-of-sight independent** methods ≈ **10^{-7}** $M_{\odot}$/year

(from nebular emission in radio and optical wavelengths)

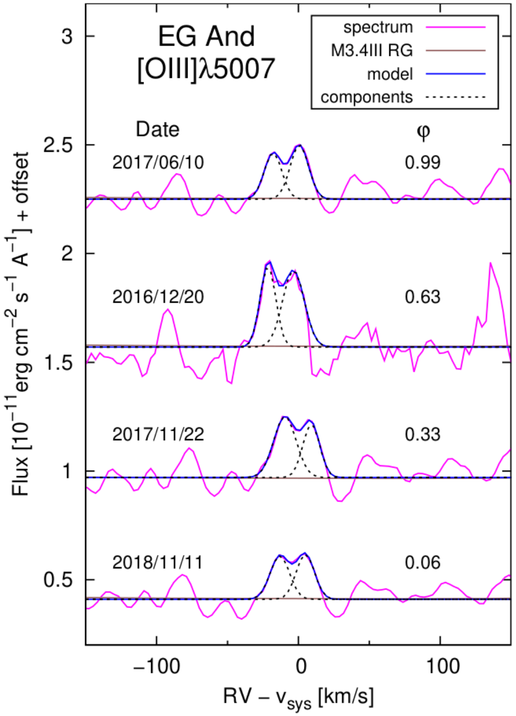
Seaquist et al. 1993, ApJ 410, 260
Mikołajewska et al. 2002, Adv. Space Res. 30, 2045
Skopal 2005, A&A 440, 995

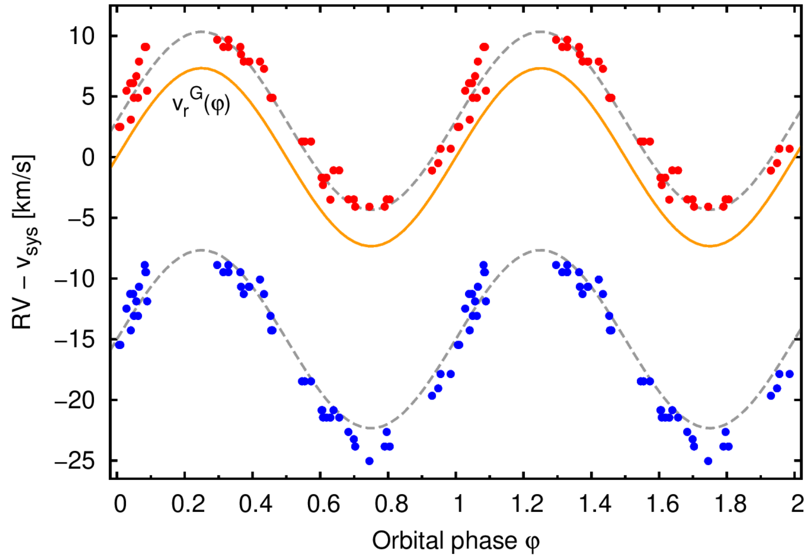


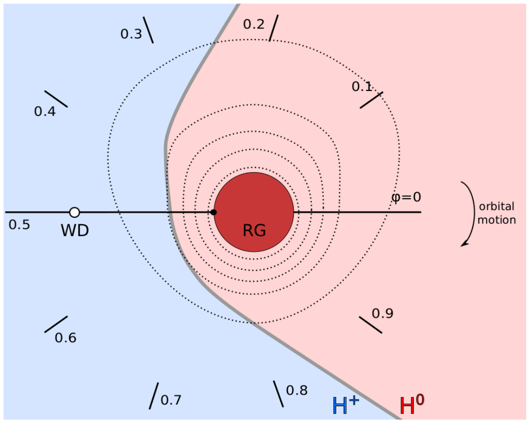
Inconsistent with spherically symmetric wind.

Location of [OIII] λ5007 line regions

- optical spectra from 1.3m telescope at Skalnaté Pleso, R = 30000, λ = 4200 – 7300 Å



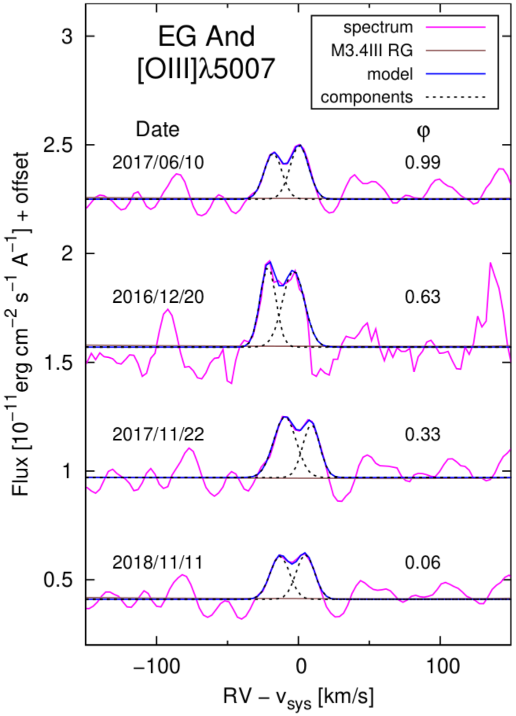


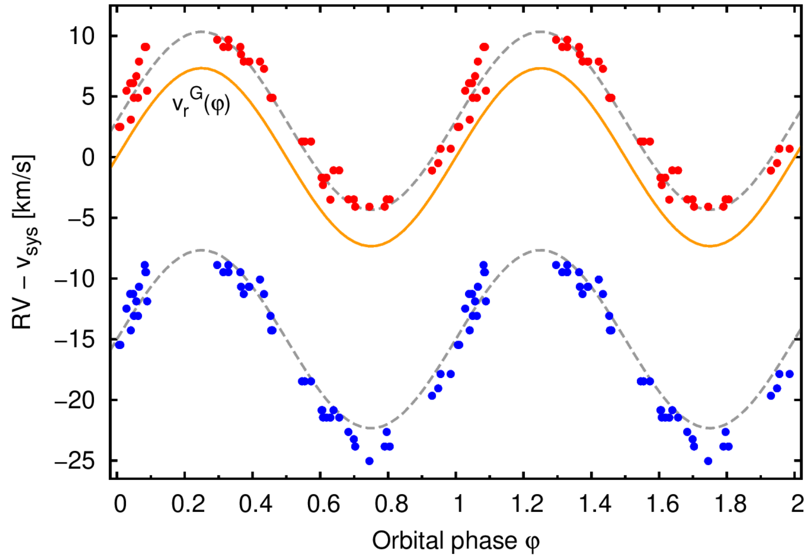


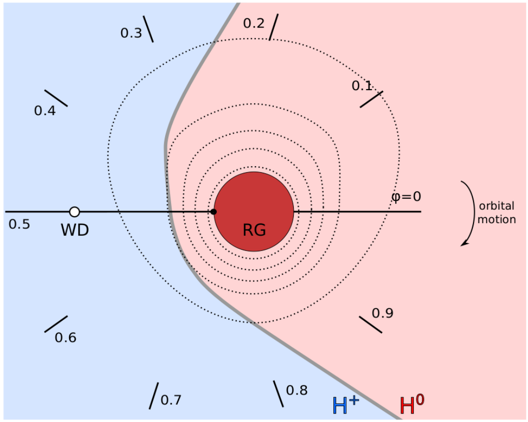
- adapted from Shagatova 2017

Location of [OIII] λ5007 line regions

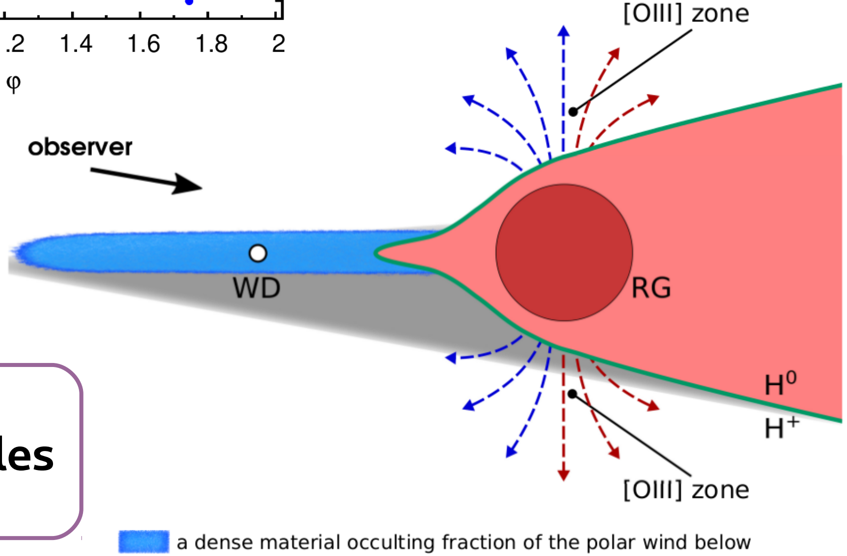
- optical spectra from 1.3m telescope at Skalnaté Pleso, R = 30000, λ = 4200 – 7300 Å







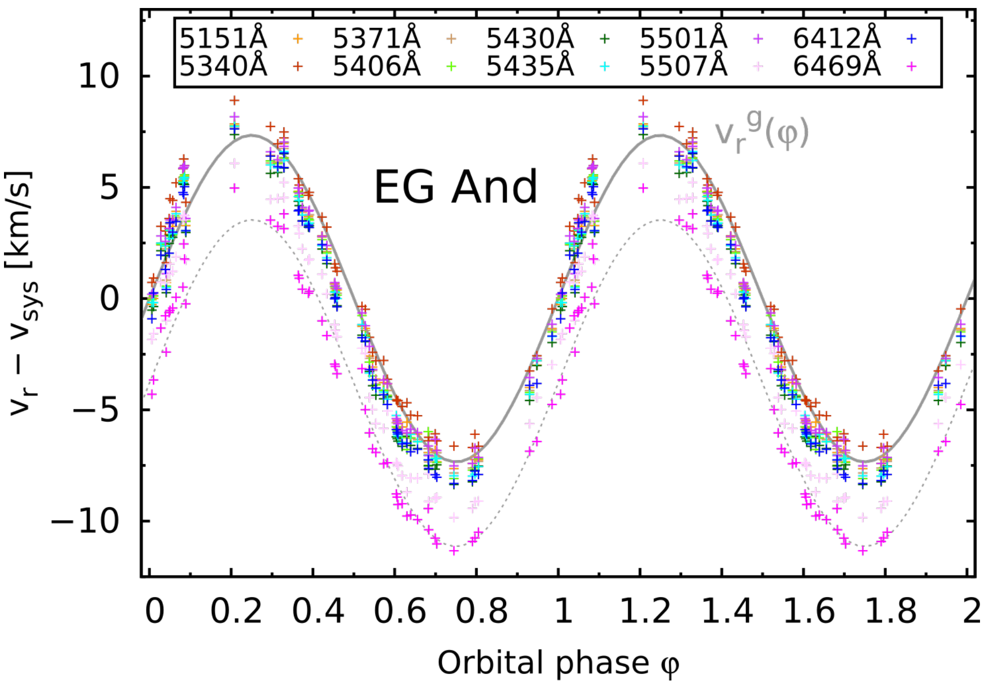
- adapted from Shagatova 2017

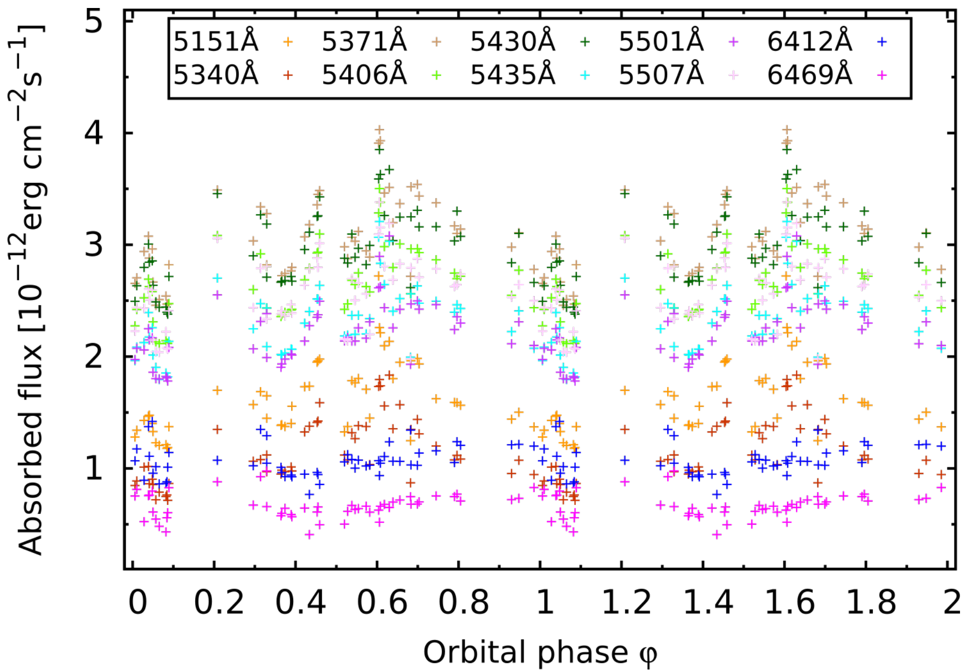


- [OIII] lines originate in regions with $\mathbf{n_e \sim 3 \times 10^7\ cm^{-3}}$ (Skopal et al. 2001)

--→ ionised **diluted wind** close to the **red giant poles**

Orbital variability of the Fe I absorption lines





- **slow outflow** up to -5 km/s
- **inflow** values around φ = 0.1

$v_r^G(\varphi)$ – radial velocity of the red giant

v_{sys} = -94.88 kms^{-1} (Kenyon & Garcia 2016)

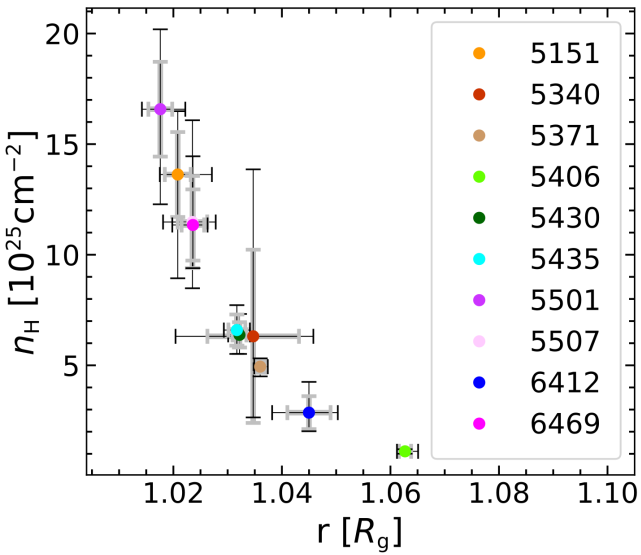
- Gaussian fits using Fityk (Wojdyr 2010)

- absorbed fluxes: maxima at φ ~ **0.6**

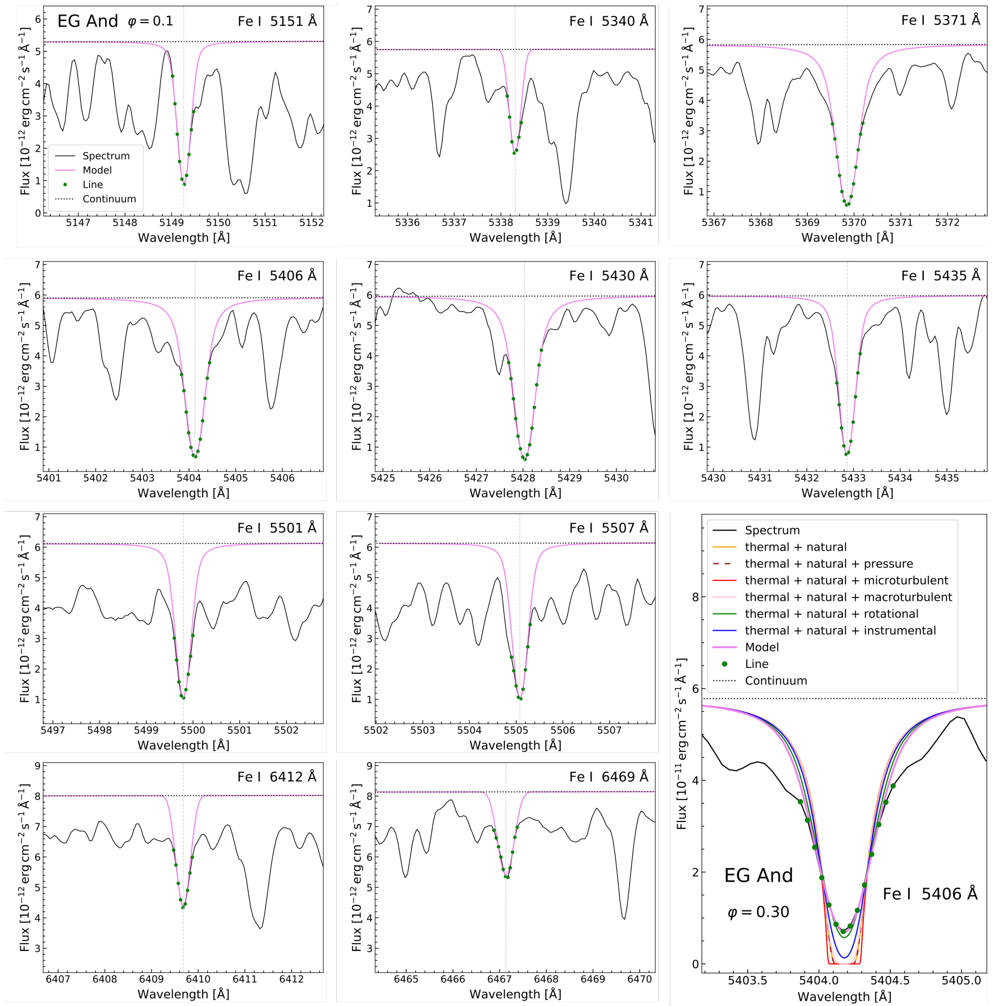
--> asymmetry of the circumstellar matter distribution

Modelling line profiles of Fe I absorption lines

- 10 Fe I absorption lines (5151 – 6469 Å)
- 10 orbital phases
- MARCS model + extension up to 150 R_g
- all relevant broadening mechanisms included
- atmosphere layer / **distance from center** and **radial velocity** as free parameters

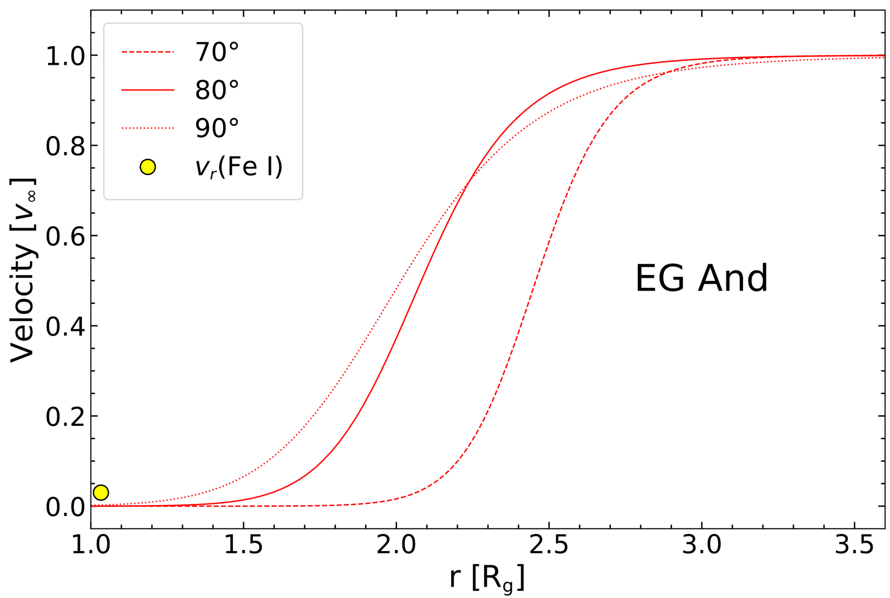


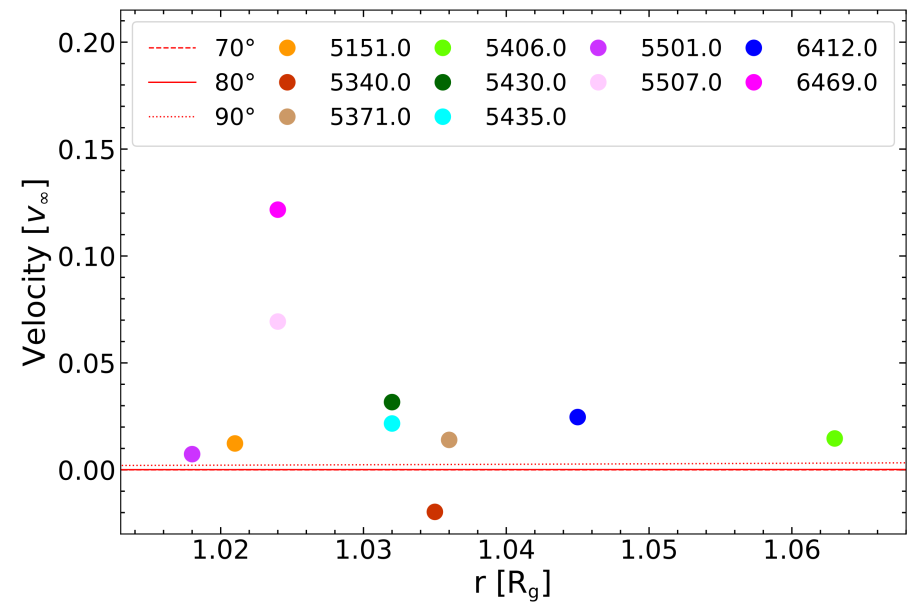
- **r** = deepest layer of origin of the spectral line
- heights **≈ 0.02 to ≈ 0.06 R_g** above the RG photosphere



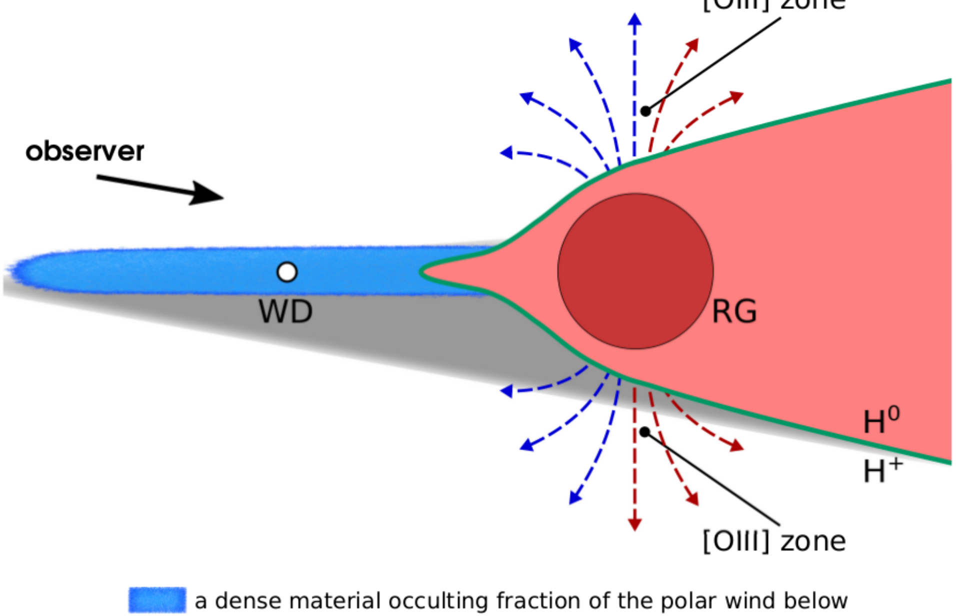
Comparison with velocity profiles

derived from measured near-orbital H^0 column densities





Implications for wind focusing towards the orbital plane



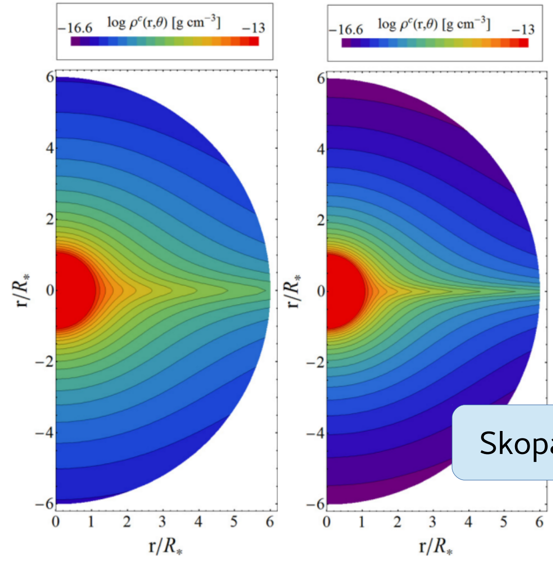
- **focusing by rotation**

- average over 200 modelled line profiles
- for i = 80° ± 10° :

v_{rot} = **11.1** $_{-2.2/+2.6}$ km/s

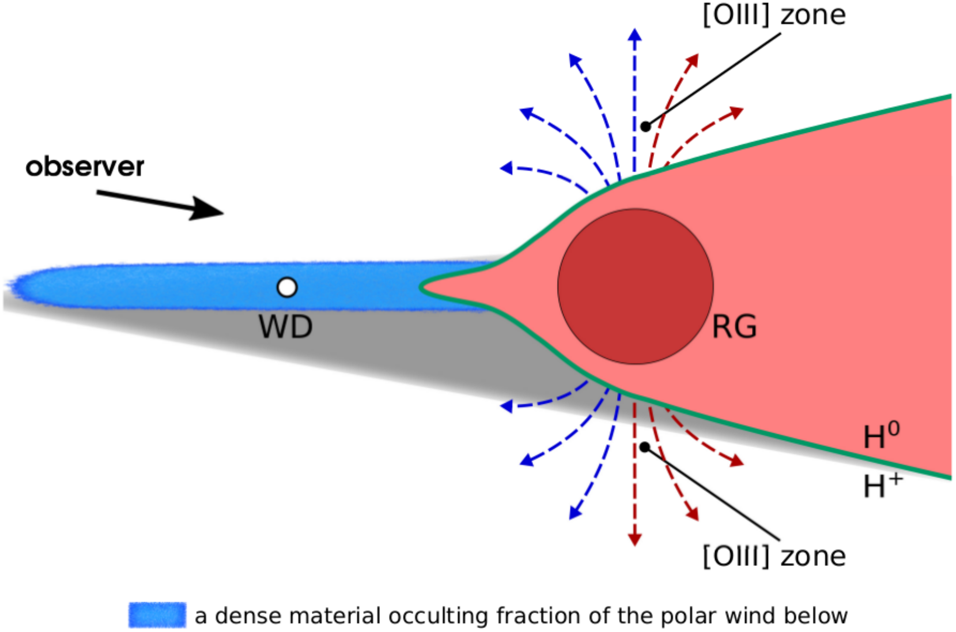
Shagatova et al. 2023

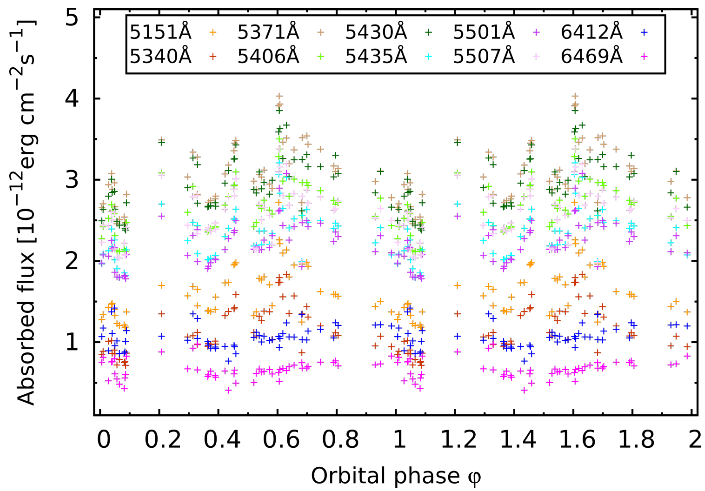
S-type systems

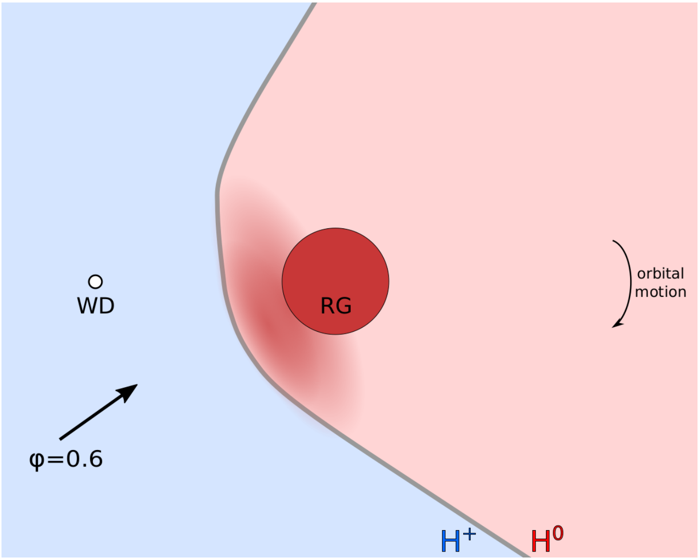


Skopal & Cariková 2015

Implications for wind focusing towards the orbital plane

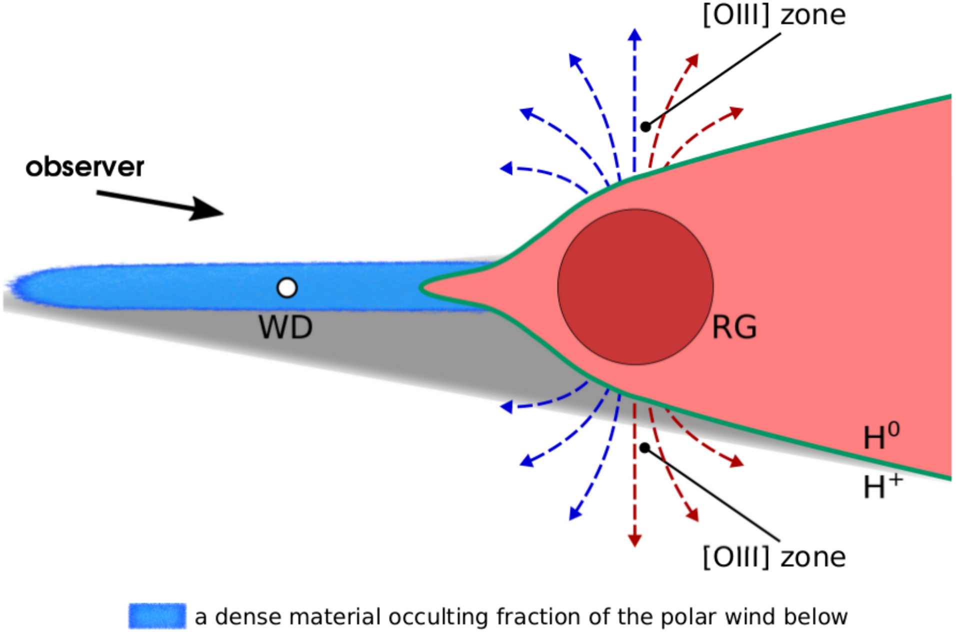




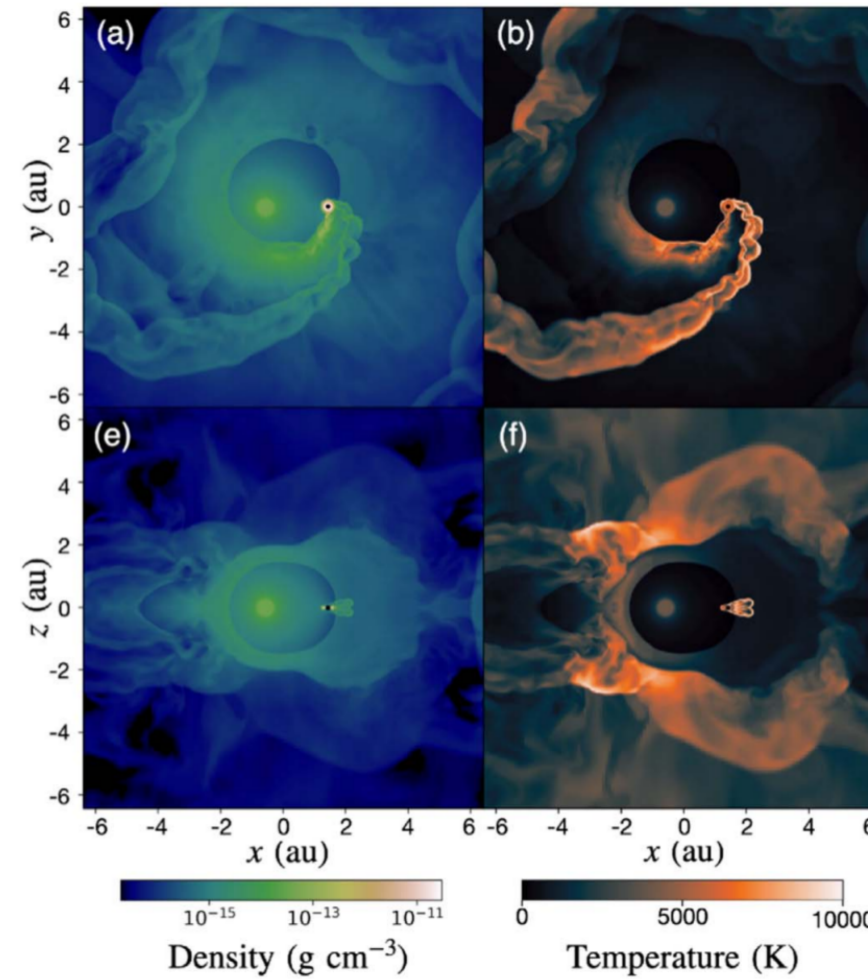


- **gravitational focusing**

Implications for wind focusing towards the orbital plane

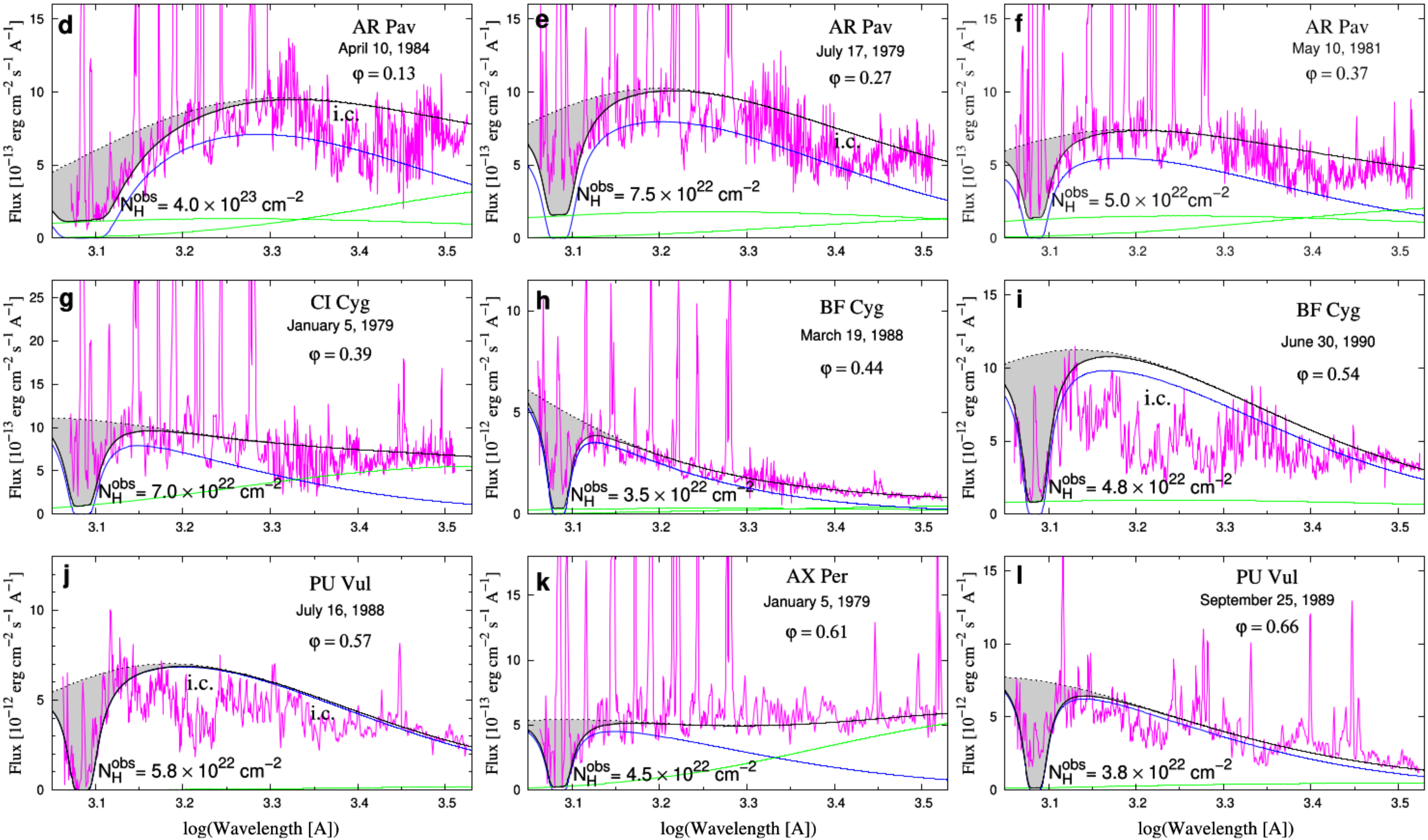


- **gravitational focusing**

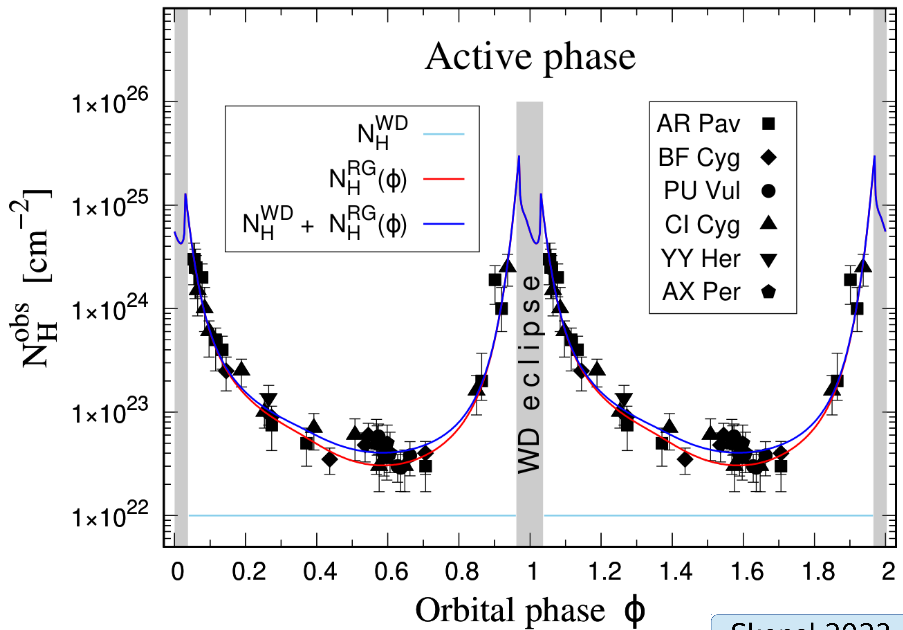


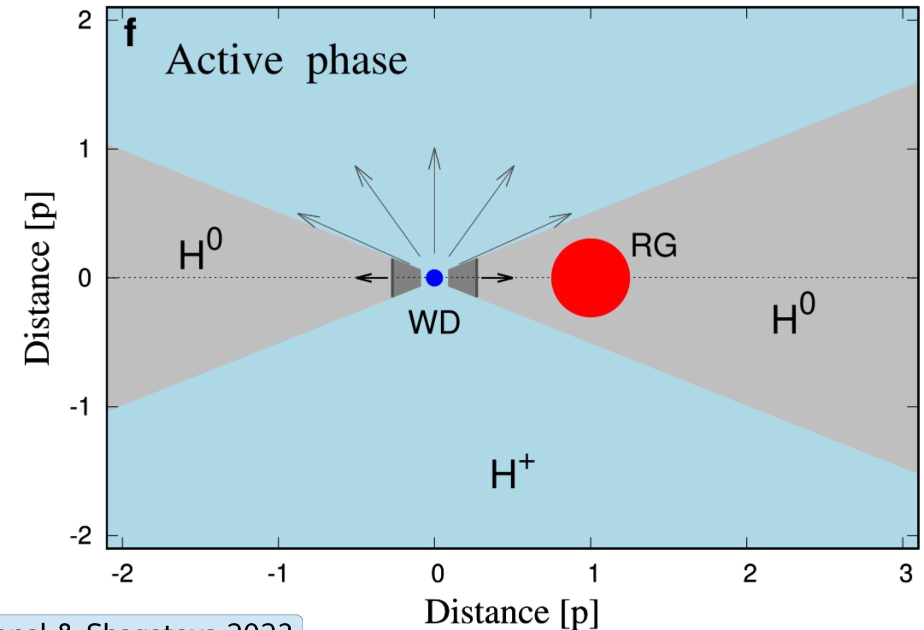
Lee et al. 2022, ApJ 931, 142

H^0 column density during active phases



Geometry of the neutral region and mass-loss rate



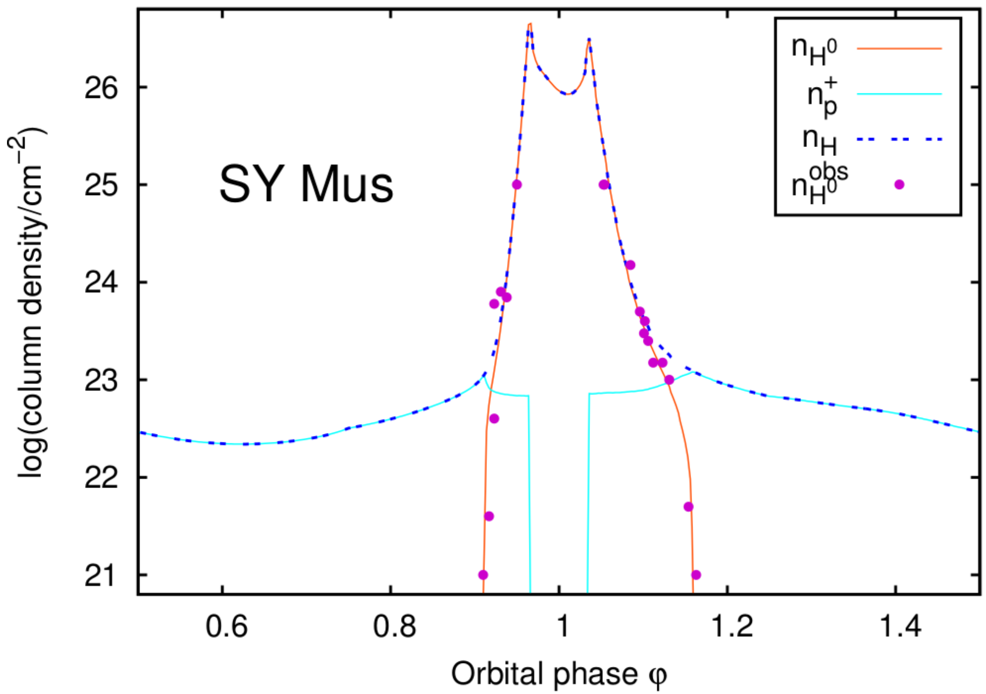


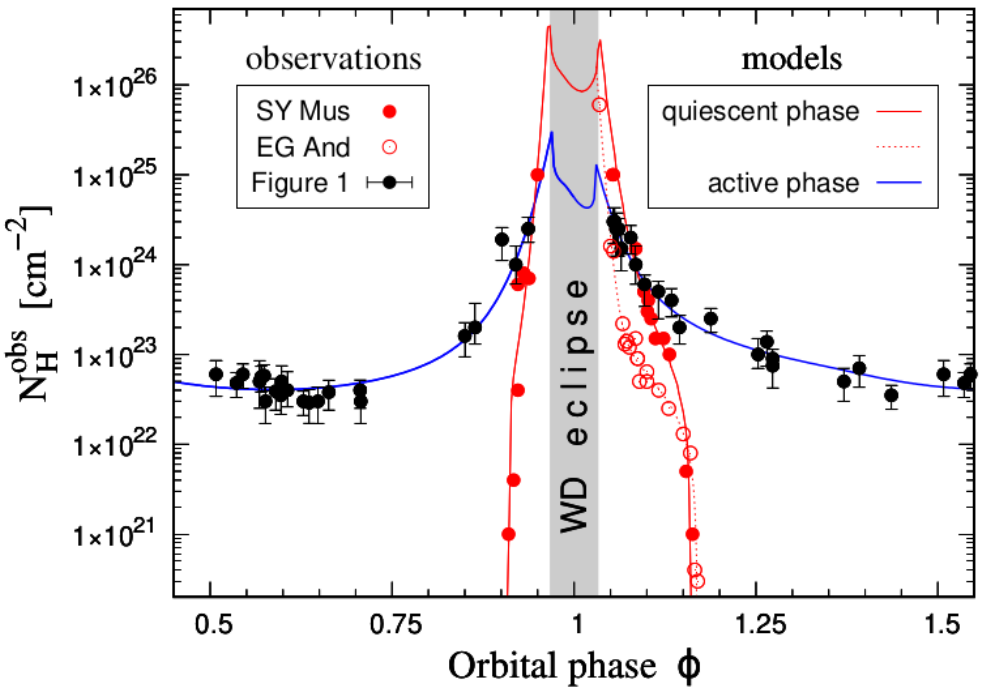
Skopal 2023, Skopal & Shagatova 2023

- transient emergence of a **neutral disk-like** structure in the orbital plane during active phases
- **dominant** contribution to n_H is from **red giant's wind**
- high spherical equivalent of the mass-loss rate ⇨ **wind focusing** ⇨ **effective mass transfer** onto the white dwarf companion

i	$E/I^{(a)}$	$\dot{M}_{sp}^{(b)}$
70°	E	$2.84^{+0.99}_{-1.14} \times 10^{-6}$
	I	$6.80^{+4.76}_{-3.40} \times 10^{-7}$
80°	E	$2.24^{+1.34}_{-0.78} \times 10^{-6}$
	I	$6.33^{+7.29}_{-3.65} \times 10^{-7}$
90°	E	$1.19^{+1.43}_{-0.83} \times 10^{-6}$
	I	$5.53^{+7.19}_{-4.24} \times 10^{-7}$

Wind column densities during quiescent and active phases





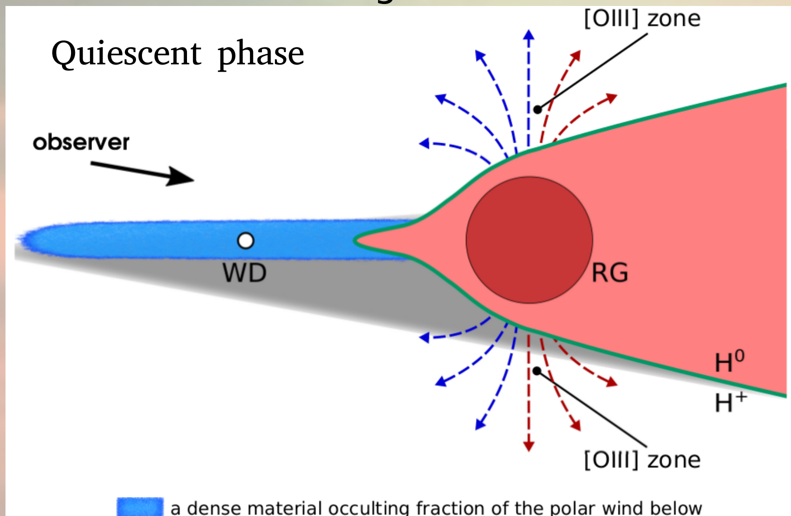
- **asymmetric distribution** of the giant's wind in the orbital plane during quiescent and active phases

- **wind focusing** towards orbital plane - **a common property** of winds from giants in S-type symbiotic stars ➡ <u>high luminosities of the accretors</u>

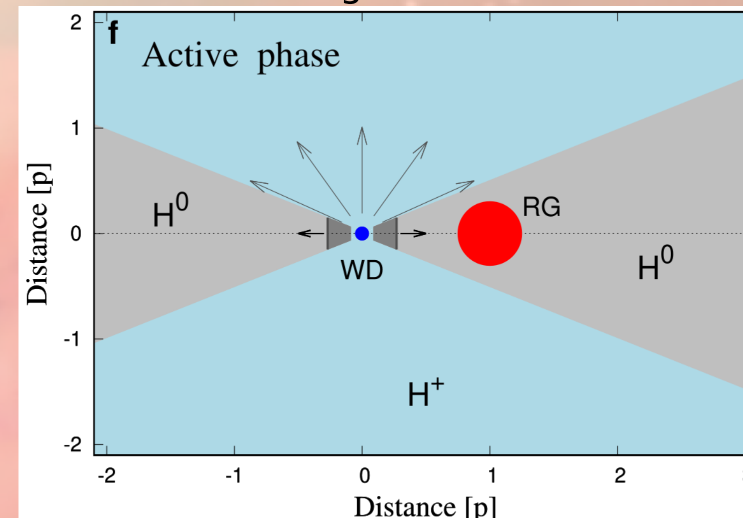
Conclusions

Wind asymmetries in S-type symbiotic stars

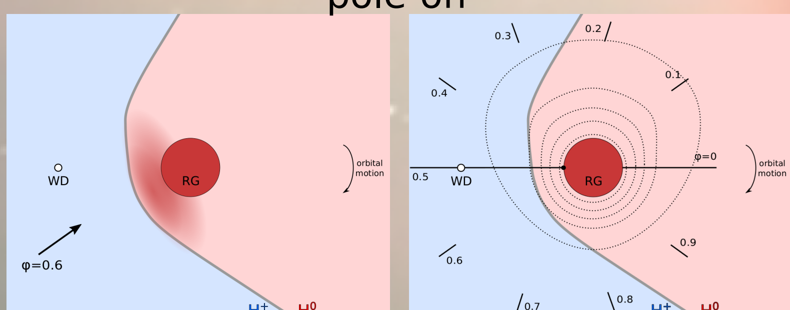
edge-on



edge-on



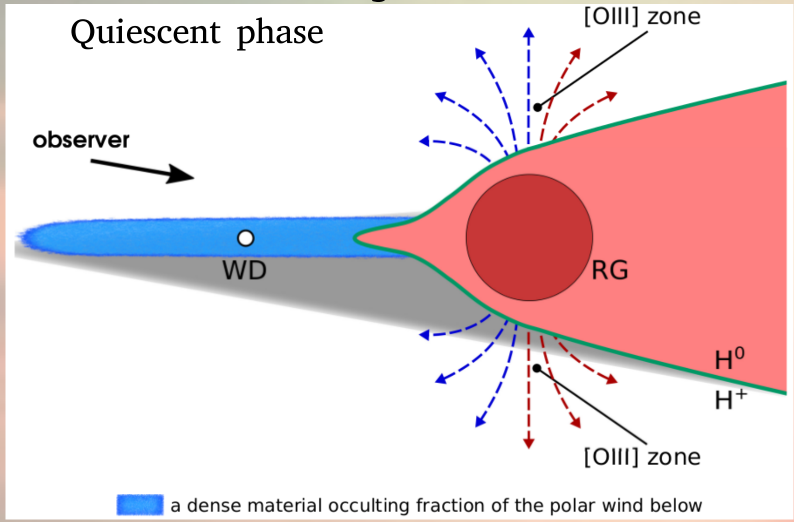
pole-on



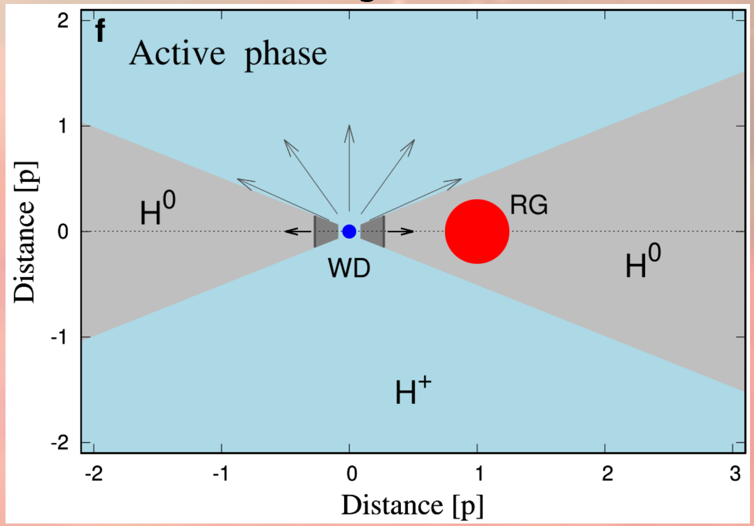
Conclusions

Wind asymmetries in S-type symbiotic stars

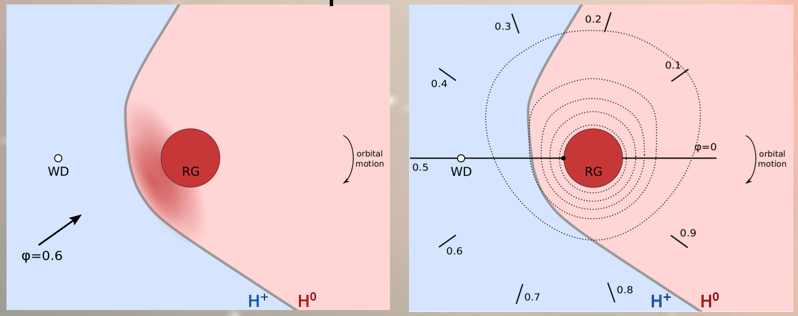
edge-on



edge-on



pole-on



Thank you for your attention!