Wind properties in the vicinity of the red giant in symbiotic binary EG Andromedae

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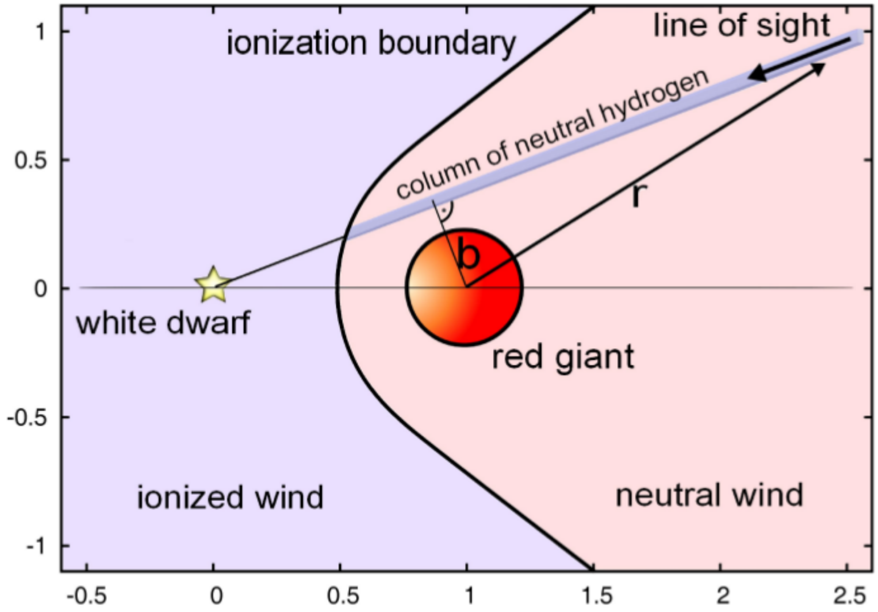
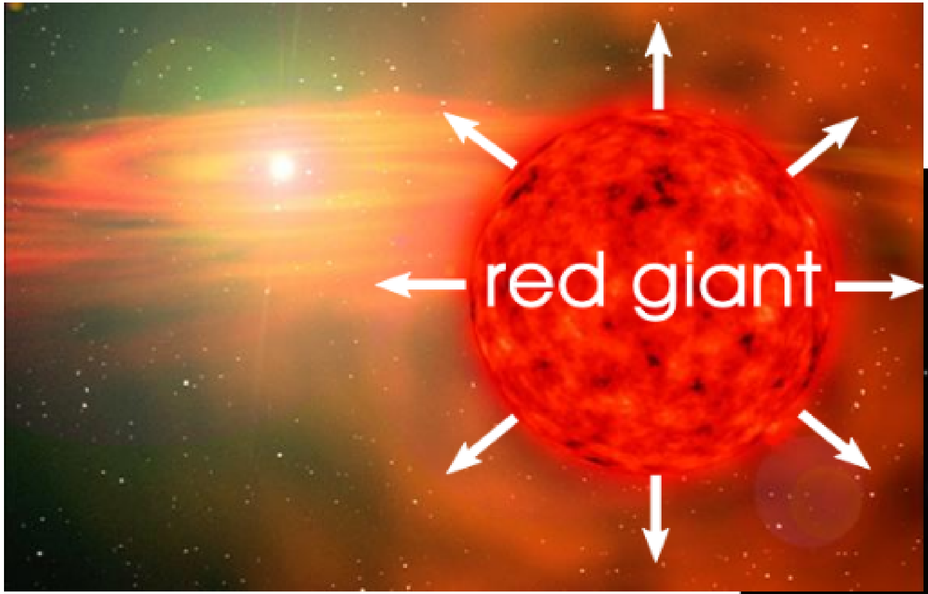
Symbiotic stars

- widest interacting binary stars (P≈few years)
- white dwarf + red giant
- neutral and ionized wind
- quiescent and active phases

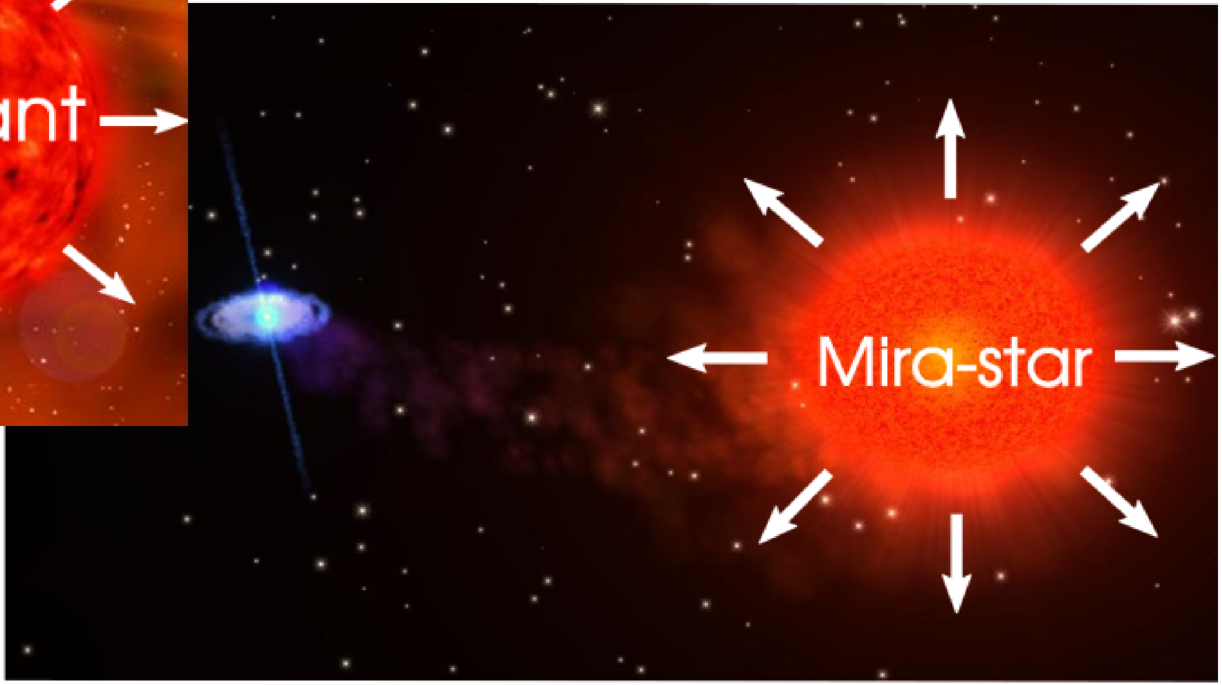


Mechanism of the mass loss from cool companions

S-type systems



D-type systems



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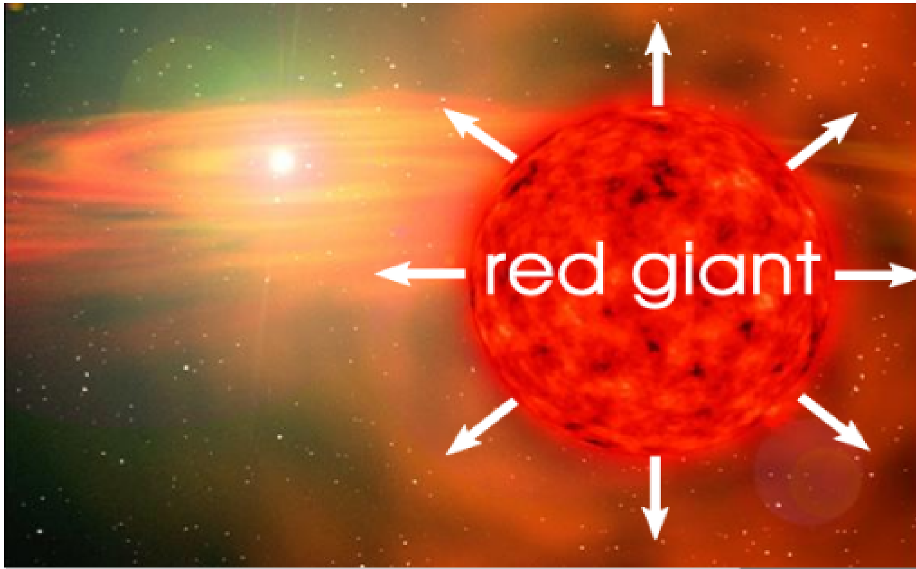

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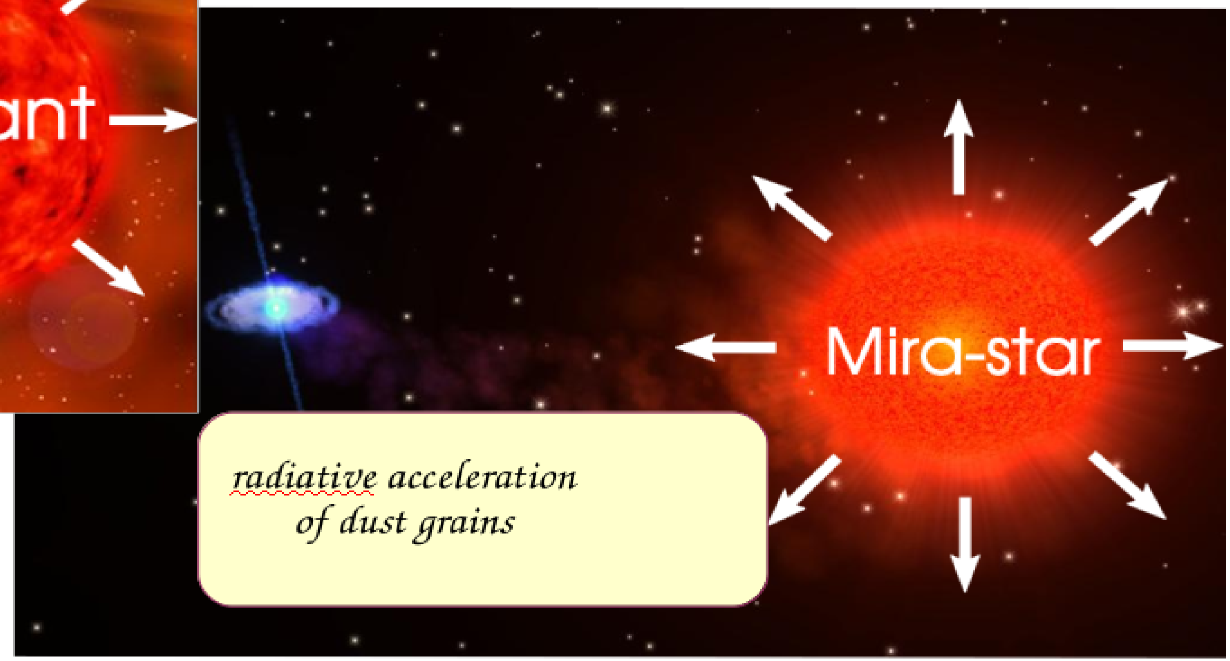

Höfner 2015, ASP Conf. Ser. 497, 333

Mechanism of the mass loss from cool companions

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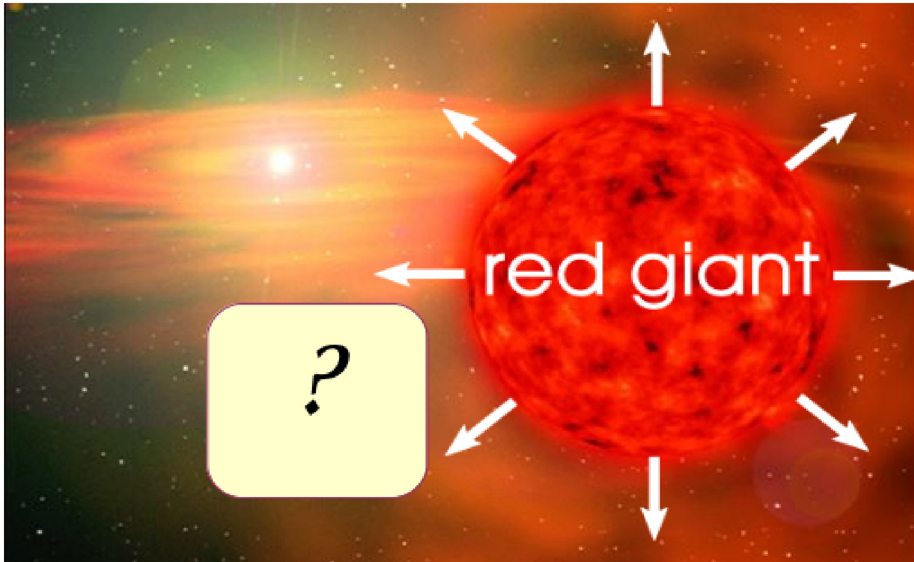

O'Gorman et al. 2013, AJ 146, 98

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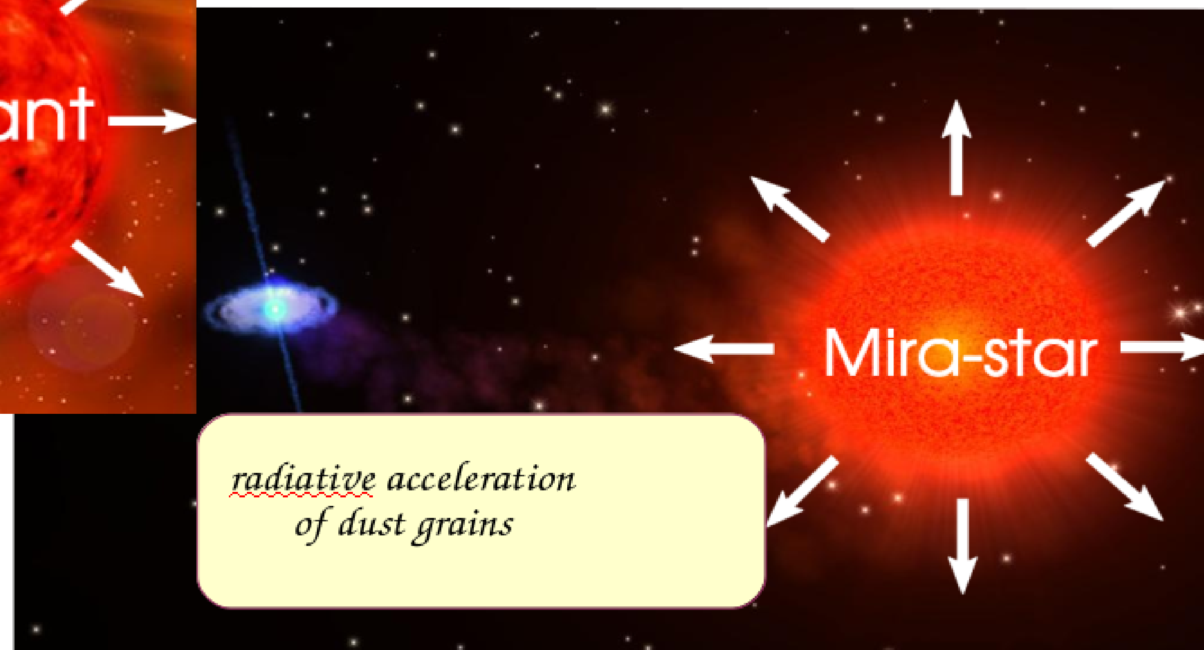
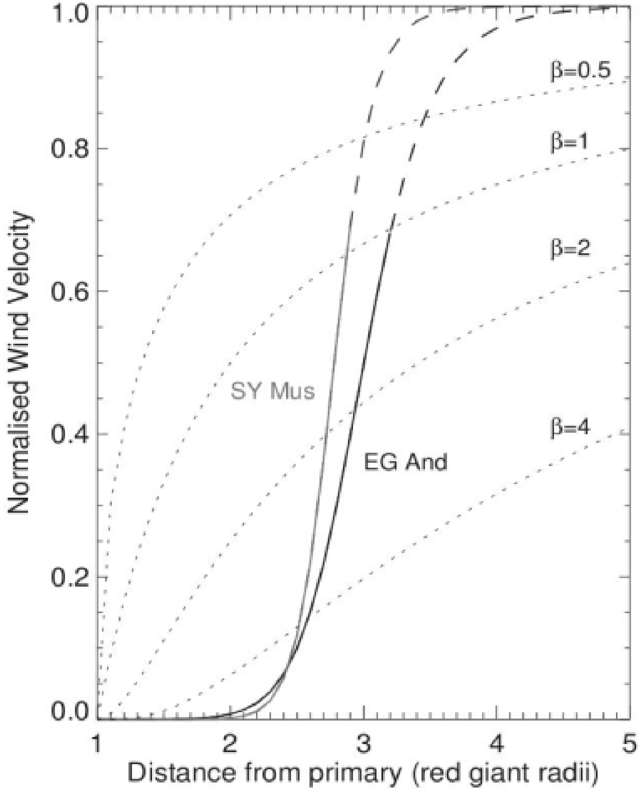


Höfner 2015, ASP Conf. Ser. 497, 333

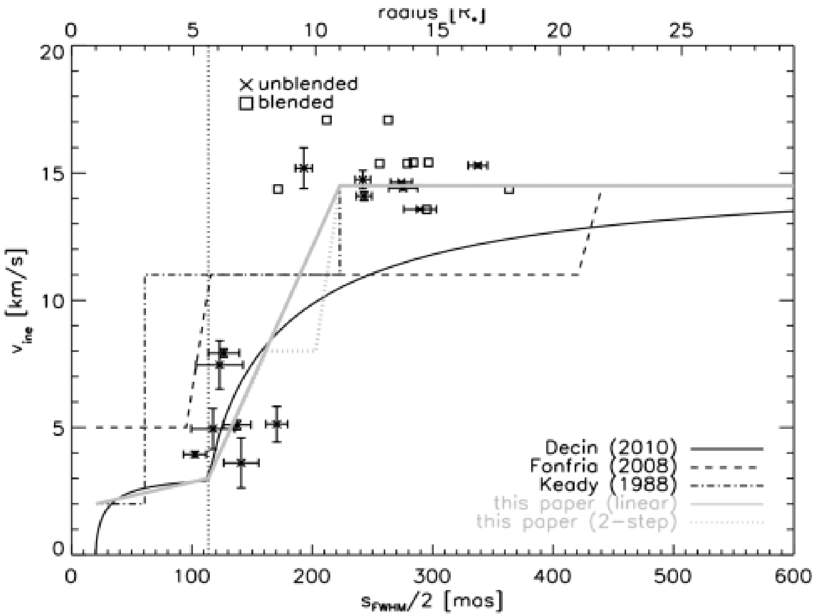
Mechanism of the mass loss from cool companions

- 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

EG Andromedae

- quiet symbiotic star (no recorded outburst)

- white dwarf (WD) + red giant (RG)

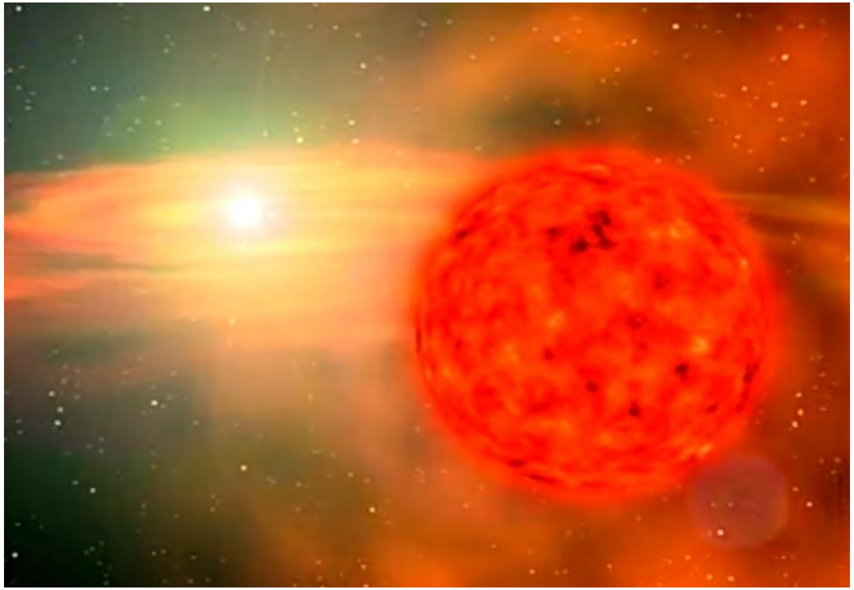
- P = 483 days, i ≈ 80°

- RG: $R = 75 \pm 10\, R_{Sun}$, $L \approx (1 - 2) \times 10^{3}\, L_{Sun}$

- mass transfer via stellar wind

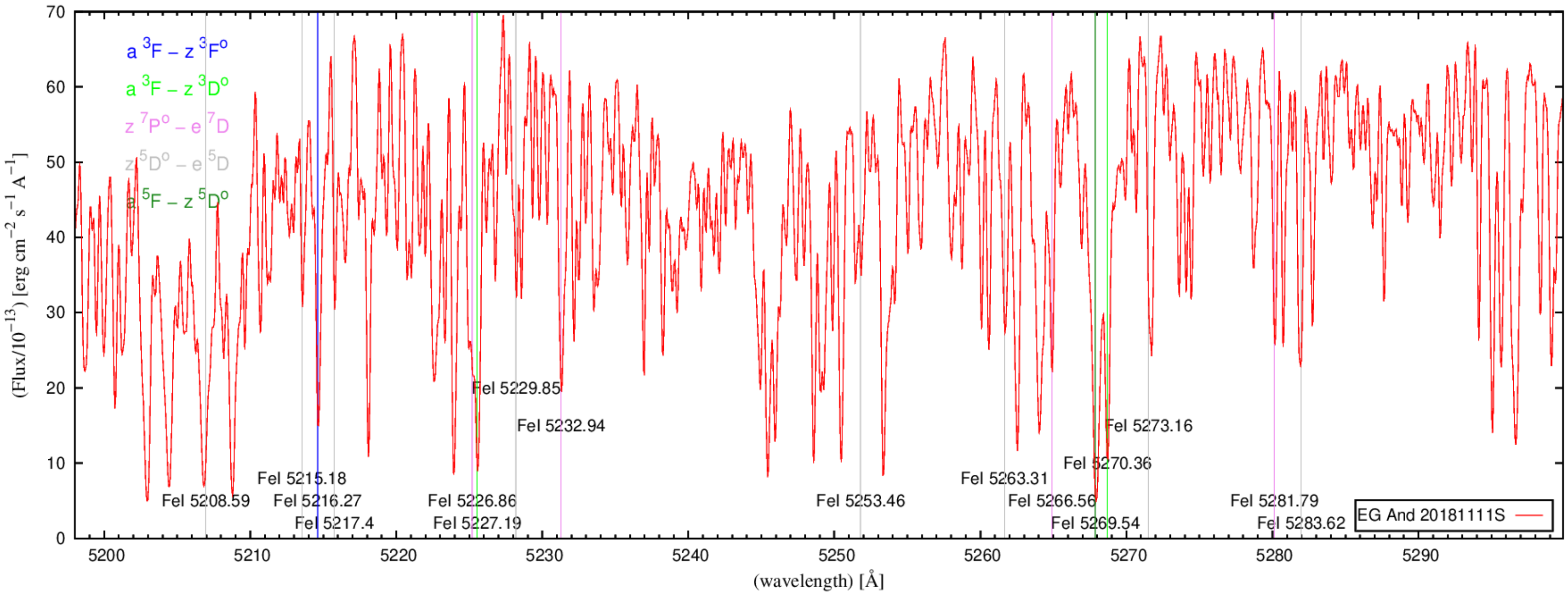
- RG wind terminal velocity of ~ 30 km/s

- many absorption lines of molecules and atoms originating in the cool giant's wind

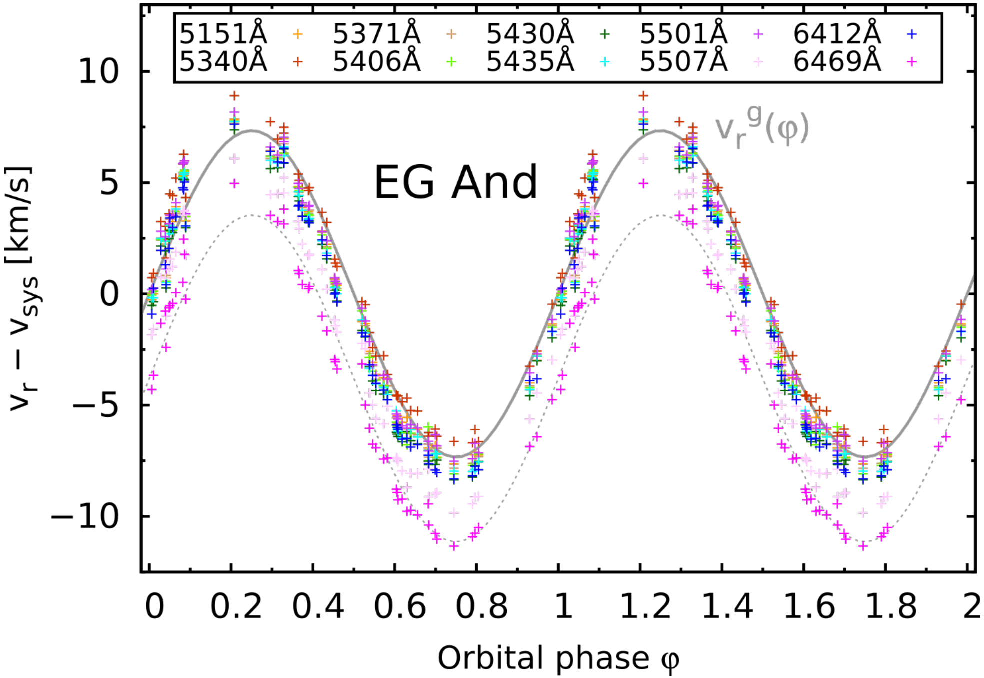


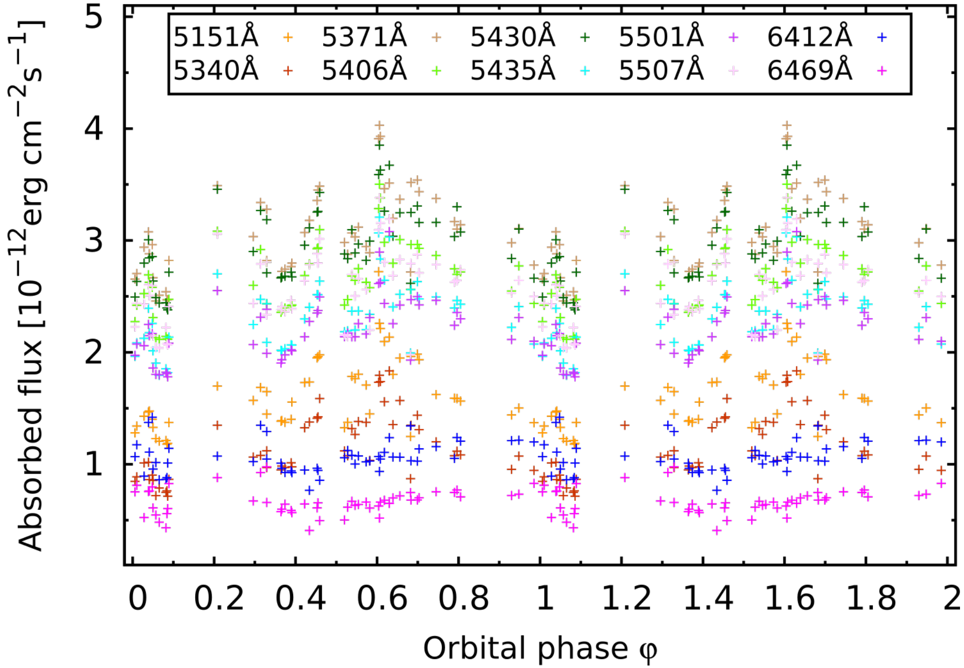
Observations

- 53 optical spectra from years 2016 -2023
    - 1.3m telescope at Skalnaté Pleso, R = 30000, λ = 4200 – 7300 Å
    - $UBVR_C$ photometry for flux calibration (Sekeráš et al. 2019, G2, AAVSO)
    - typical systematic error of radial velocity 0,2 – 0,6 km/s



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)

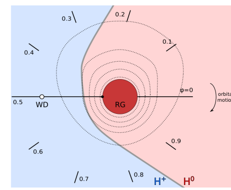
- absorbed fluxes: maxima at φ ~ **0.6**

--> asymmetry of the circumstellar matter distribution

Model atmosphere

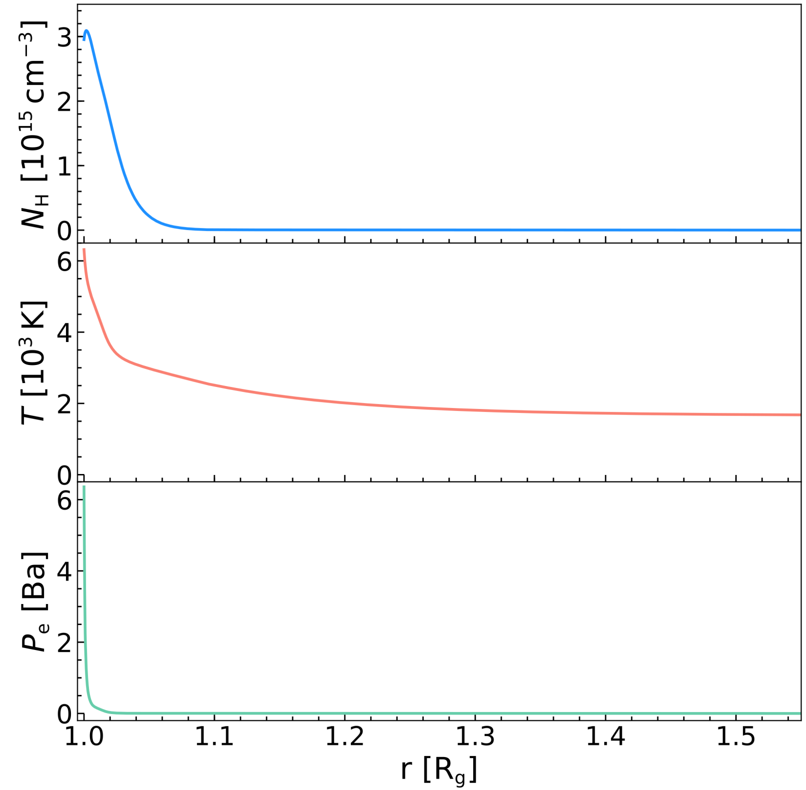
- to model spectral profiles:
  - 10 Fe I absorption lines (5151 – 6469 Å)
  - 10 orbital phases

- MARCS model (1 – 1.1 R_g):



  - Gustafsson et al. 2008
  - spherical geometry, T_{eff} = 3700 K, M = 1.0 M_{Sun}, [Fe/H] = 0

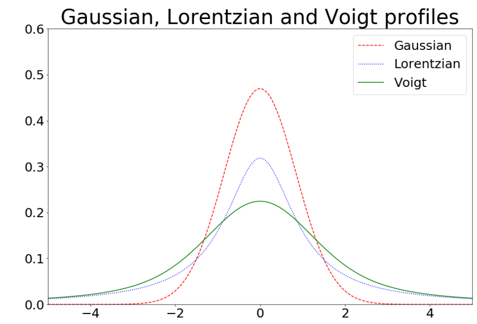
- simplified extension (1.1 – 150 R_g):
  - N_H and T at 150 R_g estimated from hydrodynamical simulation of M-giant wind (Wood et al. 2016)
  - asymmetric conical shape of the neutral zone taken into account



$$N_H(r) = \frac{n_1}{2\lambda_1 R_g}\frac{1+\xi r^{1-K}}{r^2}$$

r [R_g]	1 - 1.1	1.1 - 150	150
N_H	MARCS	interpolation by function from Shagatova et al. (2016) [a]	10^4 cm^{-3} (Wood et al. 2016)
T	MARCS	interpolation by exponential + linear function	30 K (Wood et al. 2016)
P_e	MARCS	interpolation by exponential function	10^{-17} dyne/cm^2 (dense ISM clouds) [b]

Line profile of Fe I absorption lines



- atmosphere layer / **distance from center** and **radial velocity** as free parameters

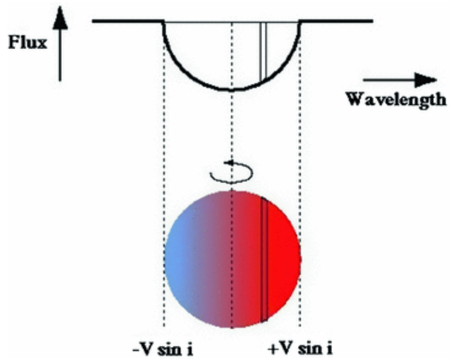
- <u>several broadening mechanisms included</u>:

- natural, pressure, thermal and microturbulence

- Gray 2005, Halenka & Madej (2002), NIST and VALD databases
- **pressure** broadening was treated as originating **from the collisions with neutral hydrogen**

- rotational

- $\boldsymbol{v_{rot}}$**sin(i)** as a free parameter
- Python function *rotBroad* (PyAstronomy.pyasl library)



- macroturbulence

- typical value for RGs is v_{mac} = 3 km/s
- to obtain lower and upper limits of v_{rot}sin(i) – two isotropic Gaussian macroturbulence models with $\boldsymbol{v_{mac}}$ **= 0 and 3 km/s**

- instrumental

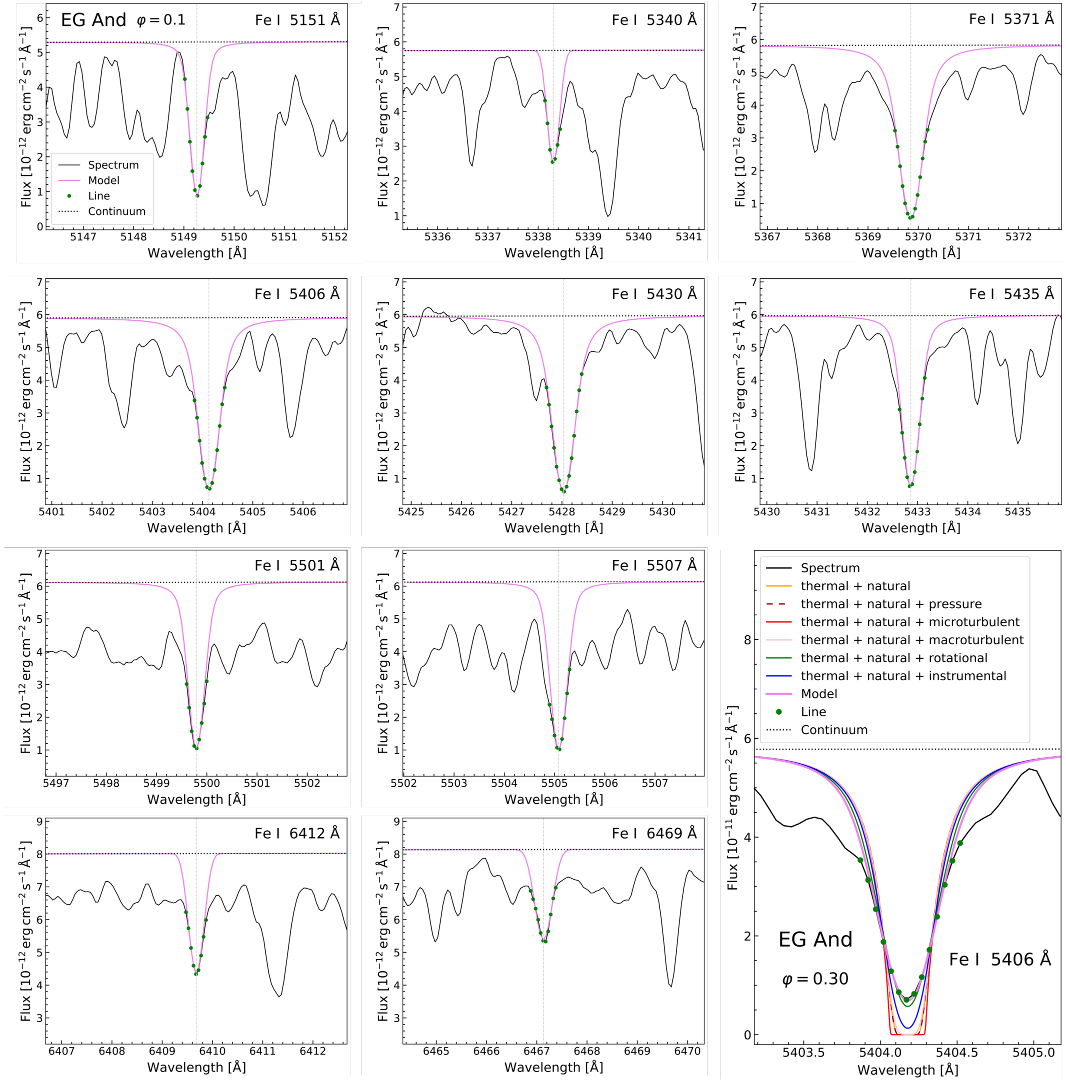
- *broadGaussFast* function (PyAstronomy.pyasl library)
- at 5151 – 6469 Å, the spectral resolution of our spectra goes from ≈ 39100 to 24000

Line profile of Fe I absorption lines

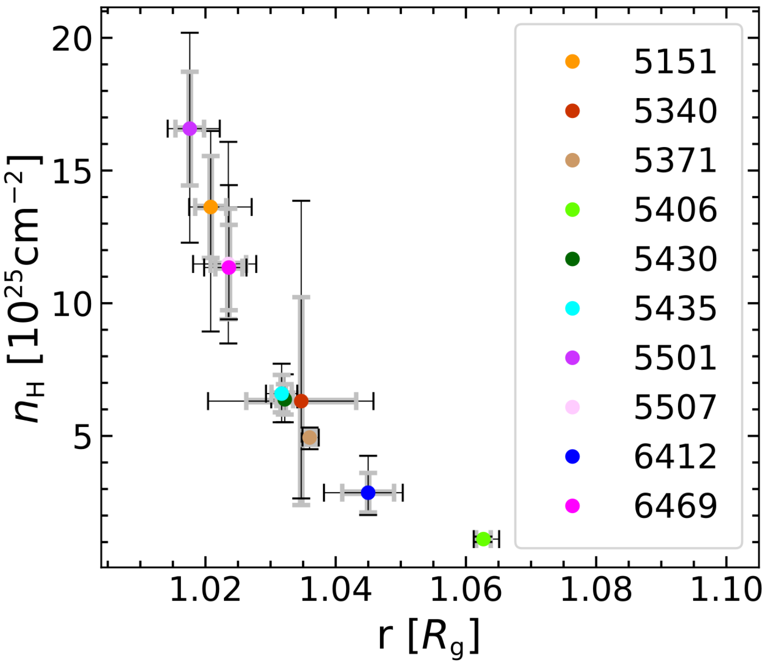
- models <u>with and without macroturbulence</u>:
  --→ negligible effect on resulting depths in the atmosphere

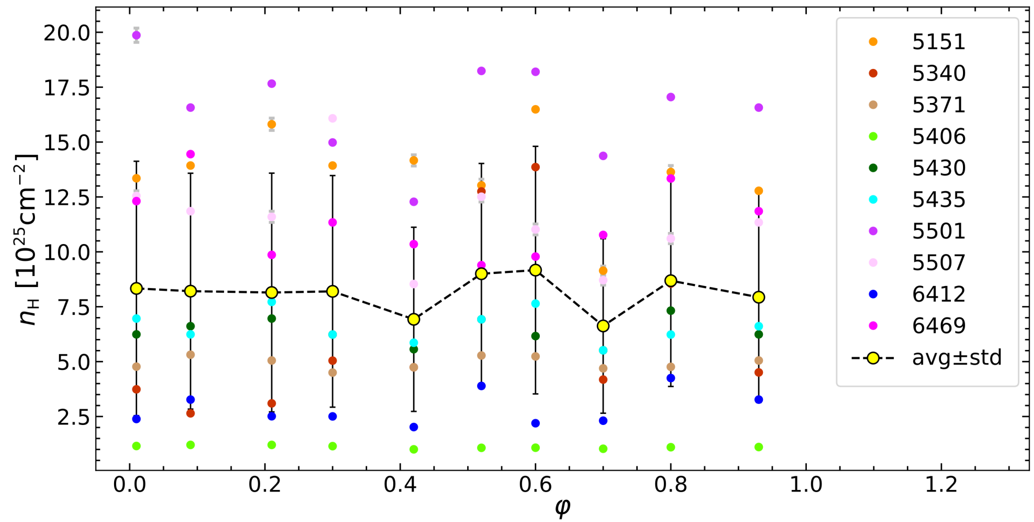
- v_{rot}**sin(i)** values <u>can be affected</u>:
  --→ by potential blending of the spectral line
  --→ by comparable strength of instrumental broadening

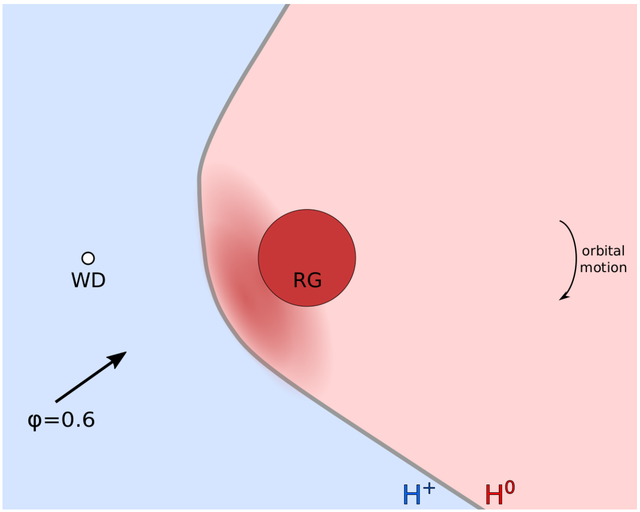
- <u>other limits</u>:
  --→ while neutral area shape is asymmetric, the distribution of physical quantities is symmetric



Height in the atmosphere / column density

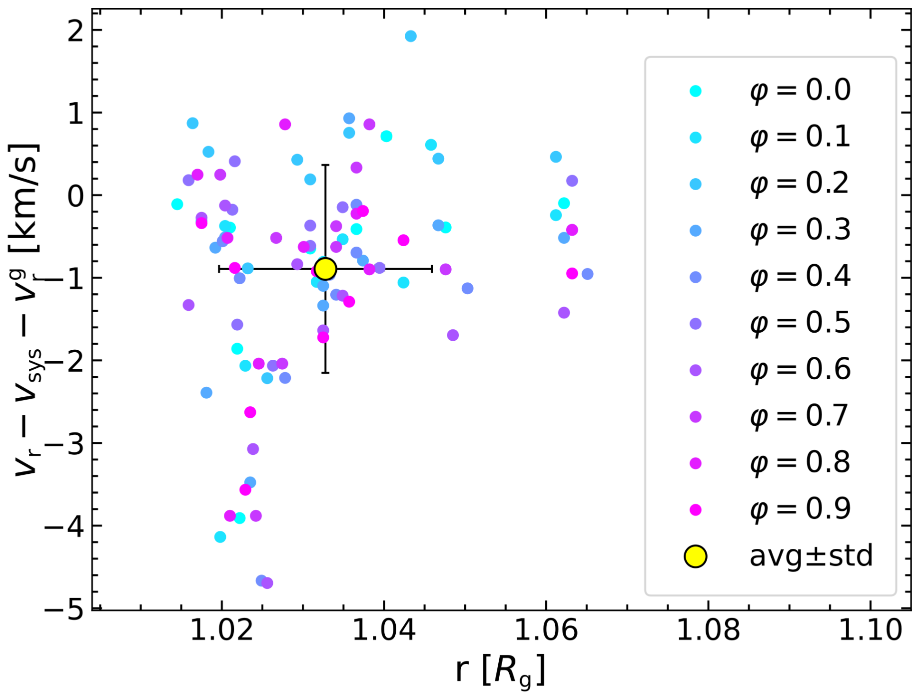


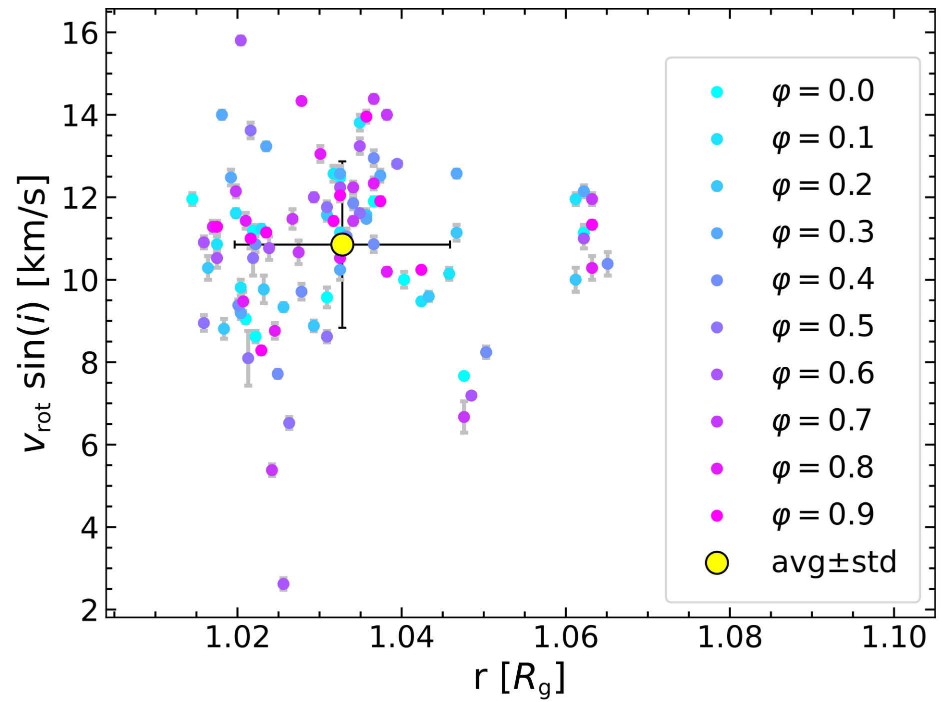




- **r** represents the maximal depth at which the integration of the line-profile stops, and corresponds to the **deepest layer of origin of the spectral line**
- heights are within **≈ 0.02 to ≈ 0.06 R_g** above the RG photosphere
- **higher column density** in the neutral zone **between the apex** of its cone **and the RG**

Radial and rotational velocities



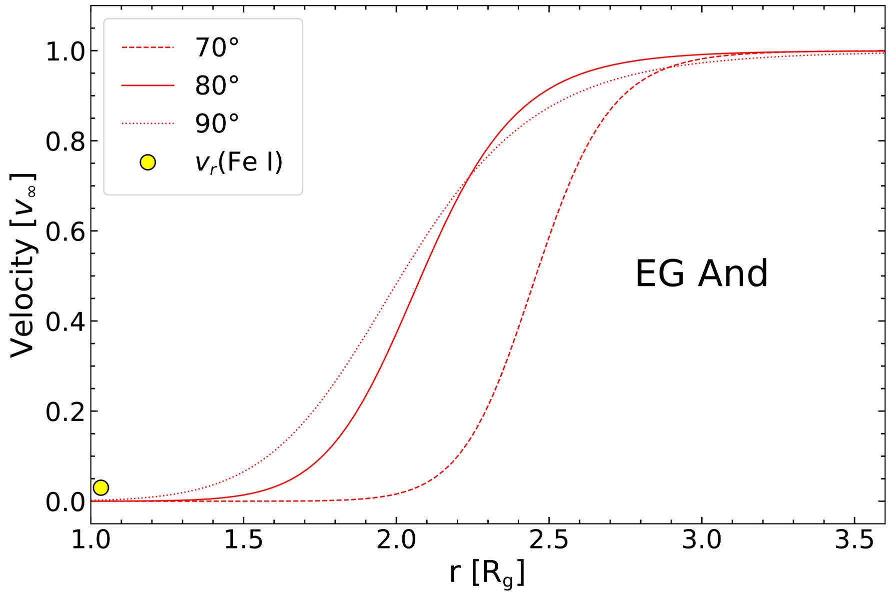


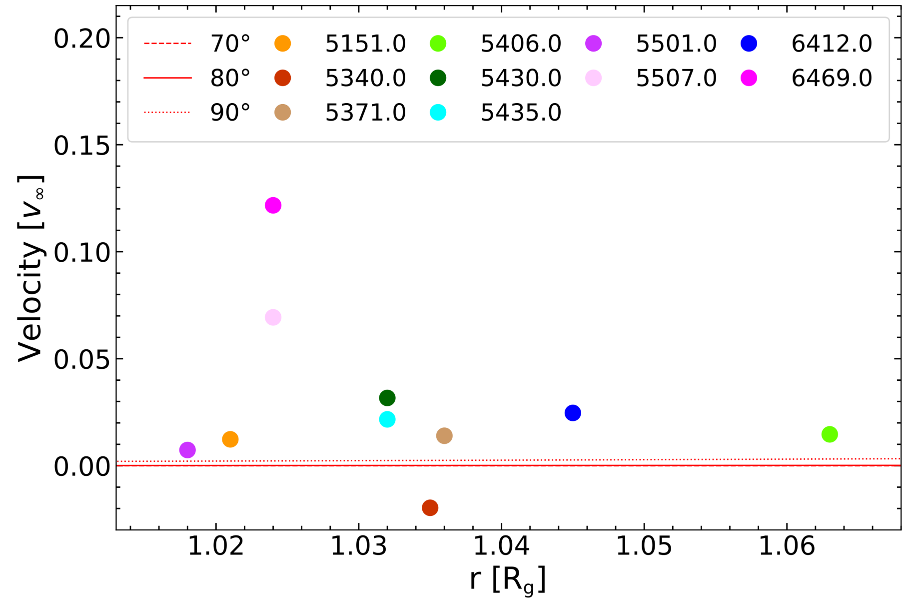
- total <u>averages ± std</u>: v_r = - 0.9 ± 1.3 km/s

at r = 1.03 ± 0.01 R_g

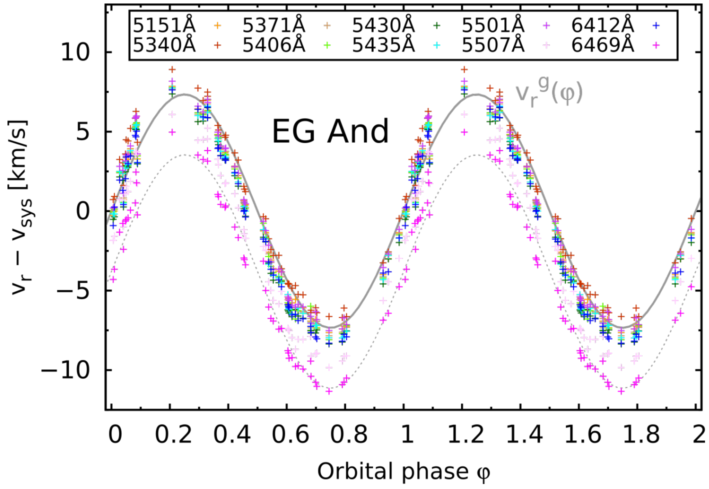
v_{rot}sin(i) = 10.9 ± 2.0 km/s

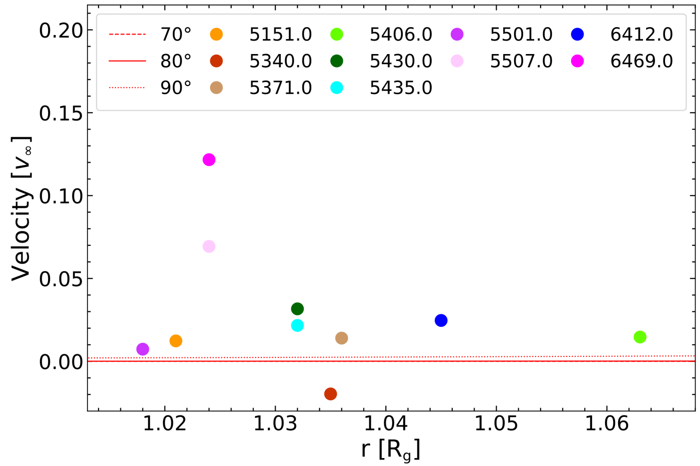
Comparison with velocity profiles
derived from measured H^0 column densities

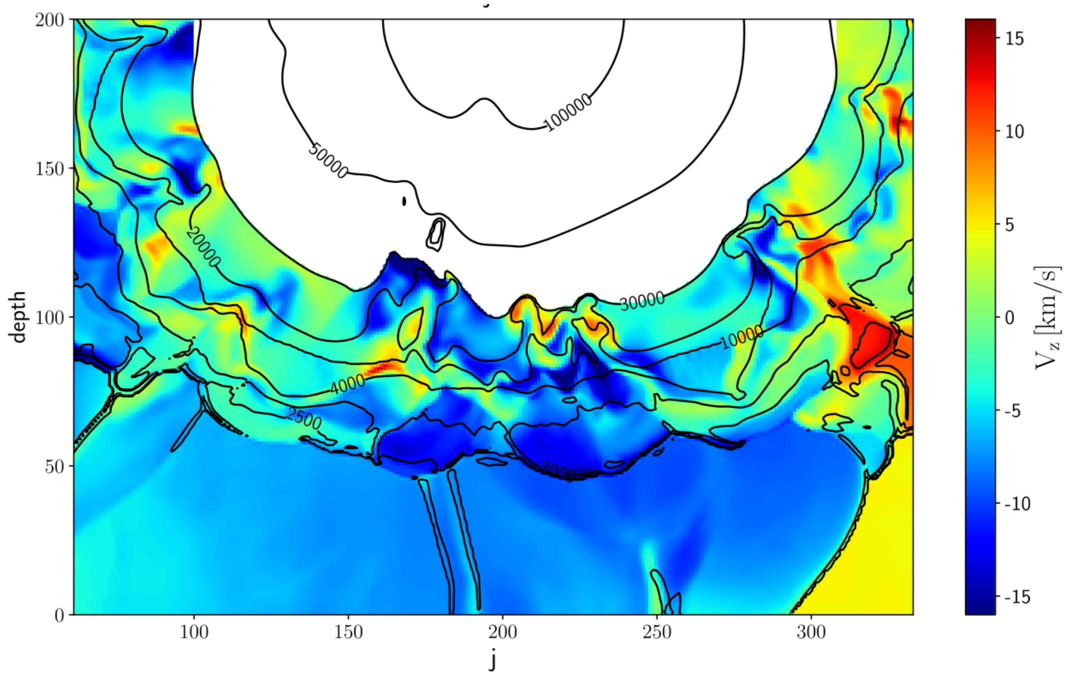




Implications from measured radial velocities

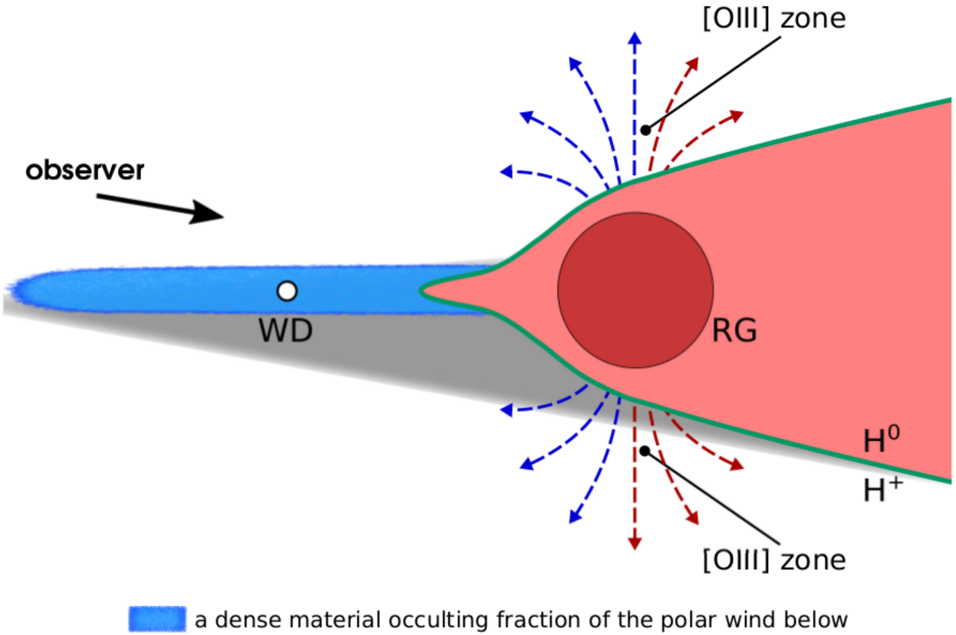






Kravchenko et al. 2018

Implications for wind focusing towards the orbital plane



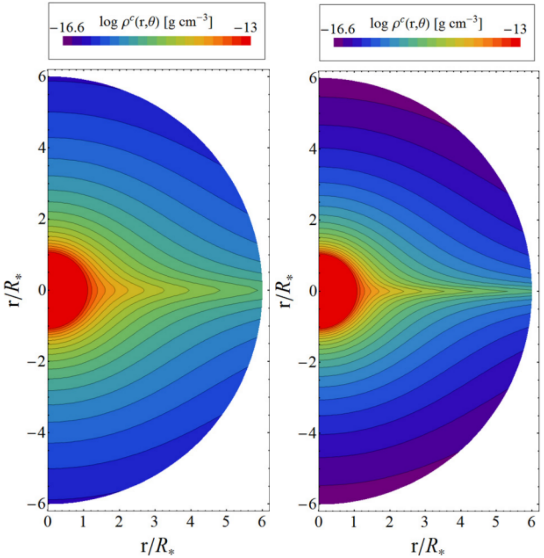
Seaquist et al. 1993; Shagatova et al. 2016, 2021

- focusing by rotation

- for i = 80° ± 10° :

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

S-type systems



Skopal & Cariková 2015

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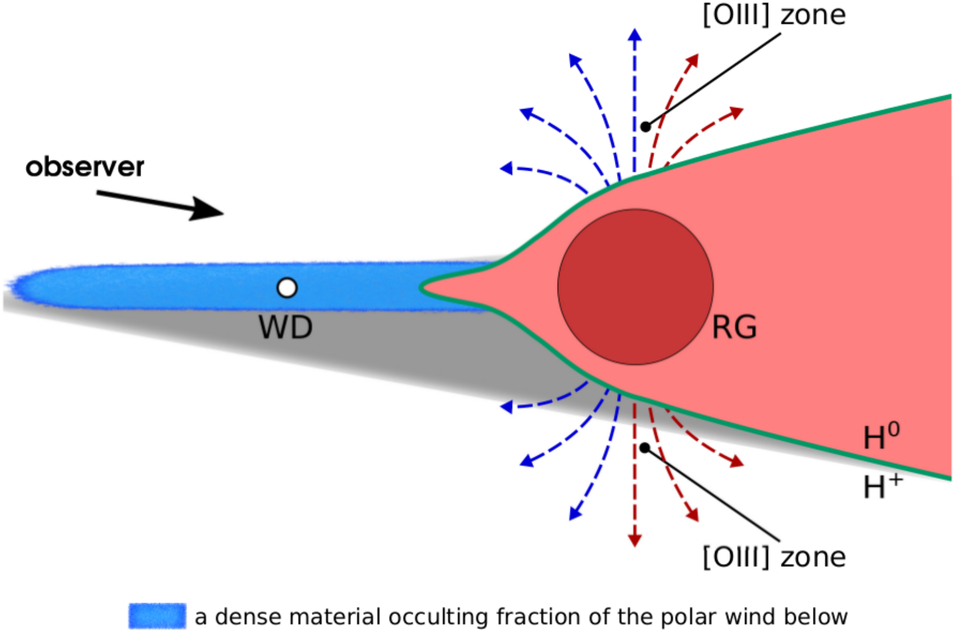

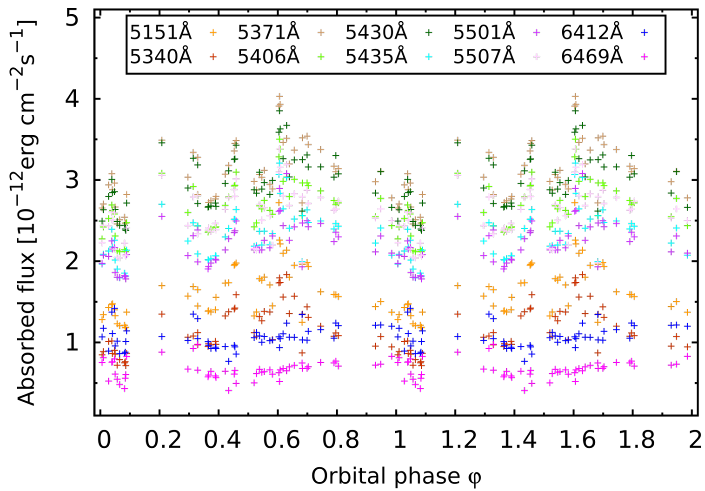

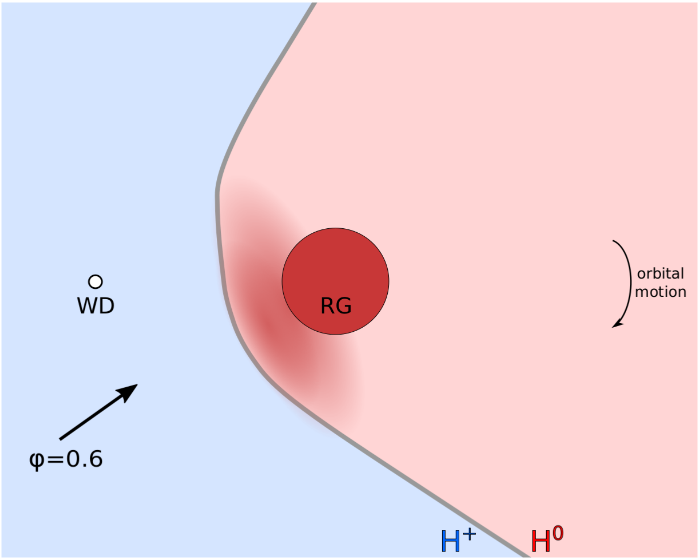

- gravitational focusing

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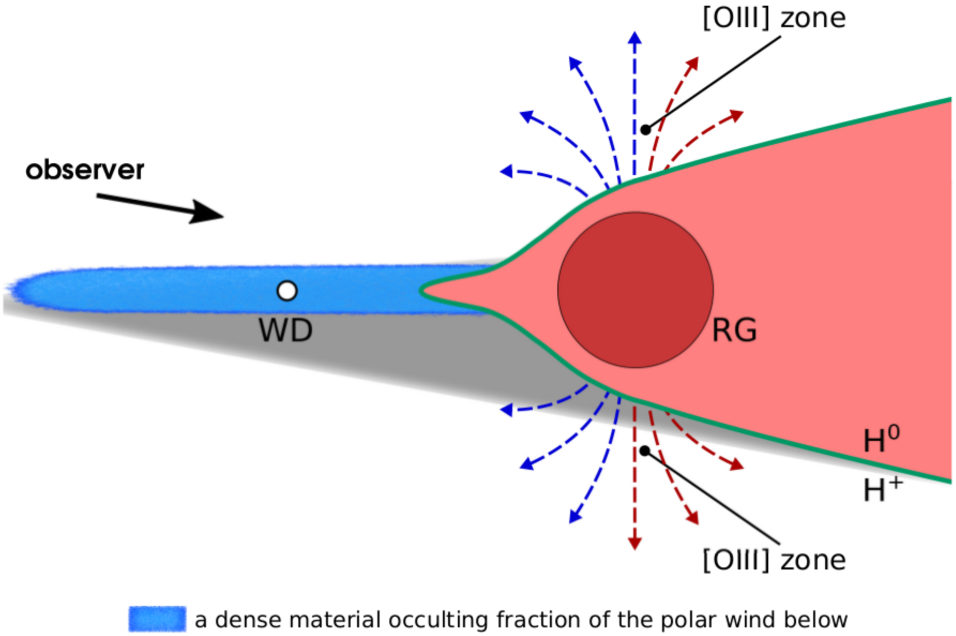

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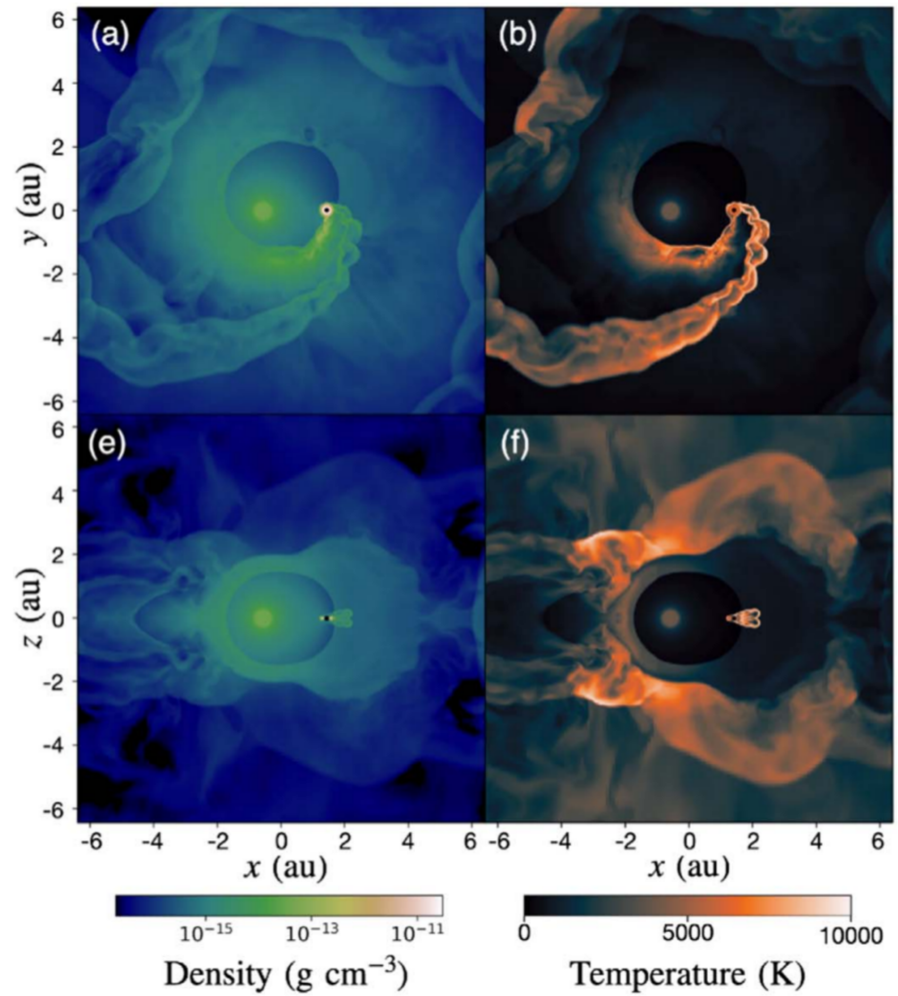

Lee et al. 2022

Conclusions

- radial velocities of Fe I absorption lines indicate **slow wind outflow** of up to 13% of terminal velocity, inflow values were also measured

- **typical outflow velocity at** the distance of **~ 0.03 R_g** above the giant's surface **is ~ 1 km/s**

- the dispersion of radial velocity values of several km/s may be a sign of the **complex nature** of the near-surface mass flows in the RG atmosphere

- **rotational velocity** of the RG of **~ 11 km/s**

- support for both **rotationally and gravitationally induced focusing of the wind** as possible acting mechanism

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Thank you for your attention!