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Probing the weak wind phenomenon in massive stars through hydrodynamical simulations

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Probing the weak wind phenomenon in Galactic O-type giants

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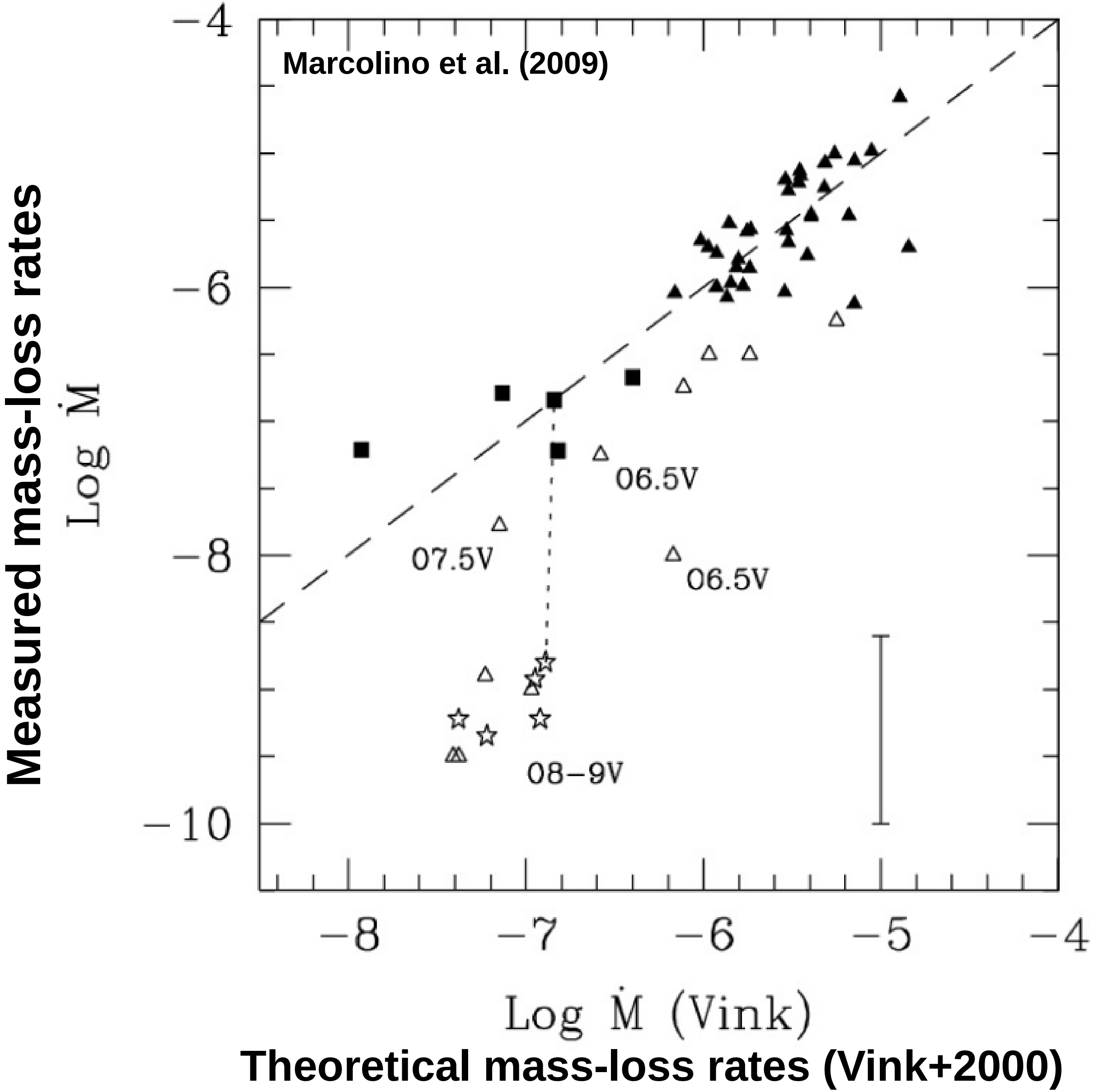
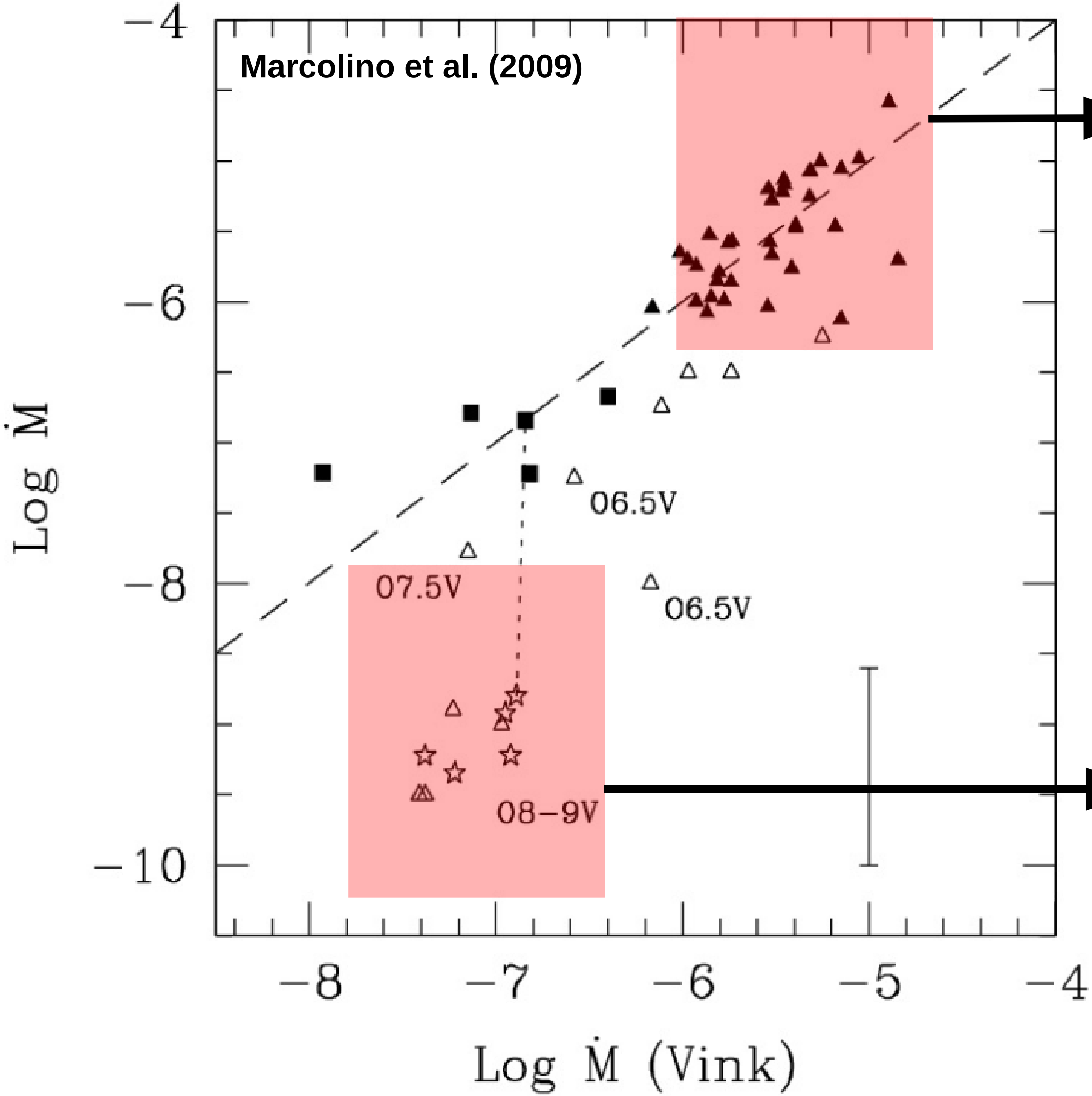

Marcolino et al. (2009)
Measured mass-loss rates
Log Ṁ
Log Ṁ (Vink)
Theoretical mass-loss rates (Vink+2000)
O6.5V
O7.5V
O6.5V
O8−9V
−4
−6
−8
−10
−8
−7
−6
−5
−4

The weak wind phenomenon: introduction

Measured mass-loss rates



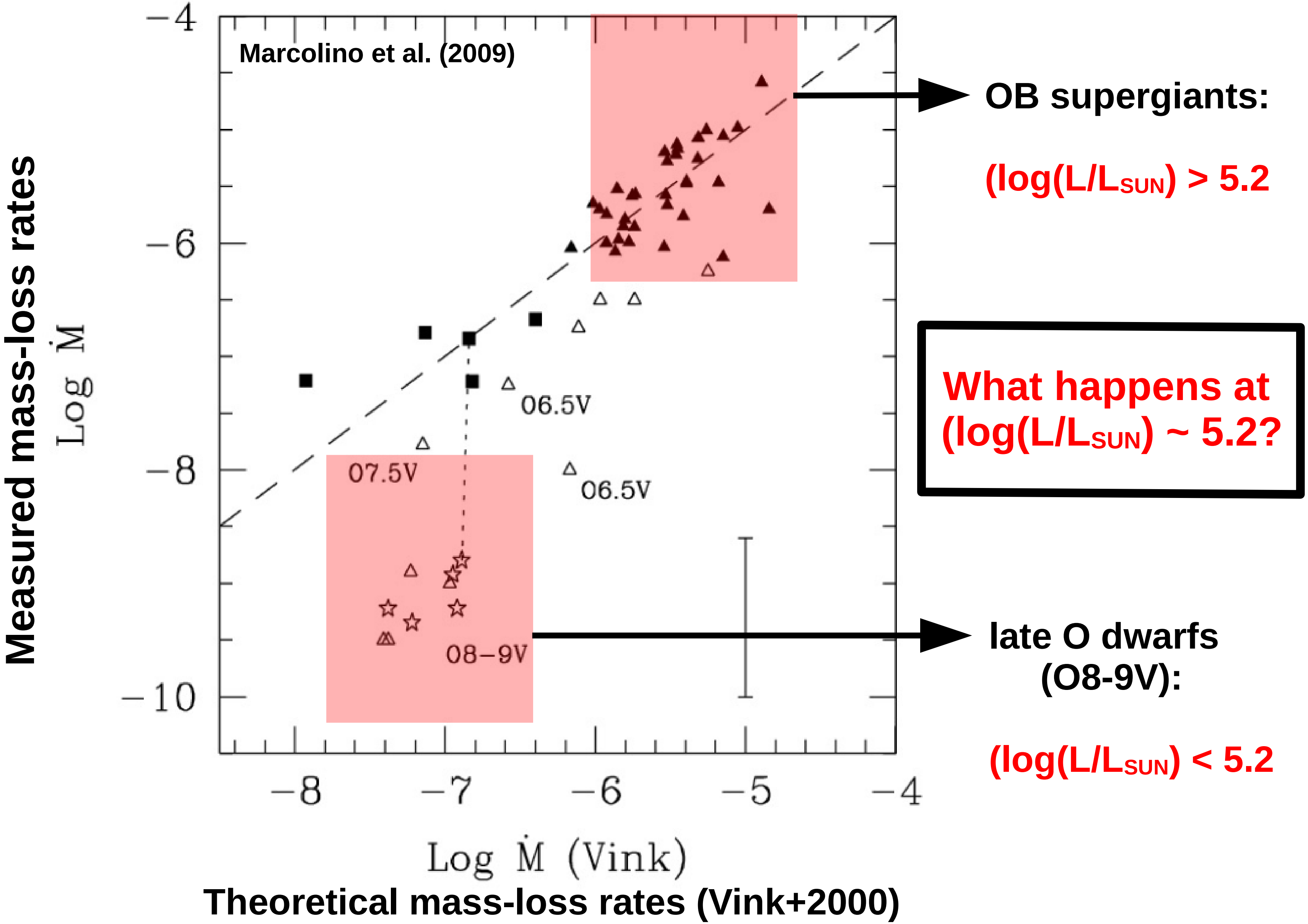
Theoretical mass-loss rates (Vink+2000)

OB supergiants:

(log(L/L$_{SUN}$) > 5.2

late O dwarfs (O8-9V):

(log(L/L$_{SUN}$) < 5.2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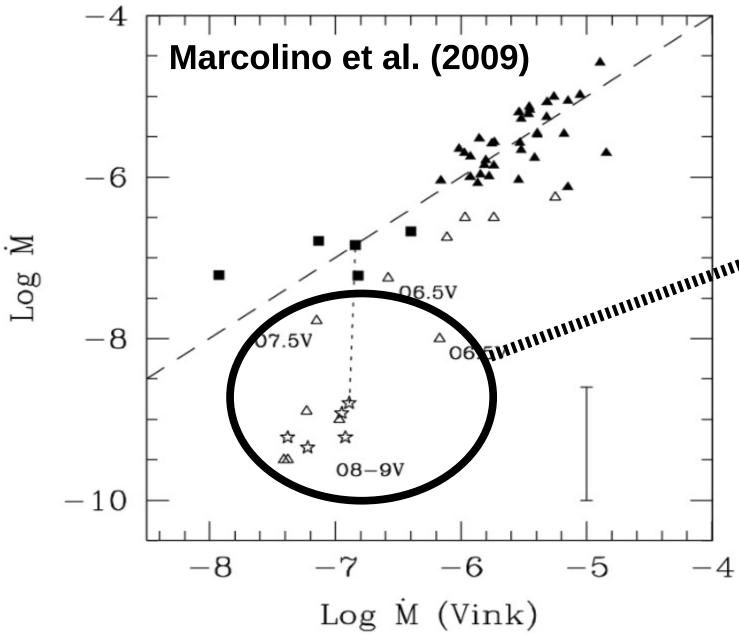
OB supergiants:
(log(L/LSUN) > 5.2
What happens at (log(L/LSUN) ~ 5.2?
late O dwarfs (O8-9V):
(log(L/LSUN) < 5.2



Weak winds are found in **late O dwarfs**:

$$\dot{M}_{\mathrm{spectroscopic}} << \dot{M}_{\mathrm{theoretical}}$$

(e.g., Marcolino+2009) (Vink+2000)

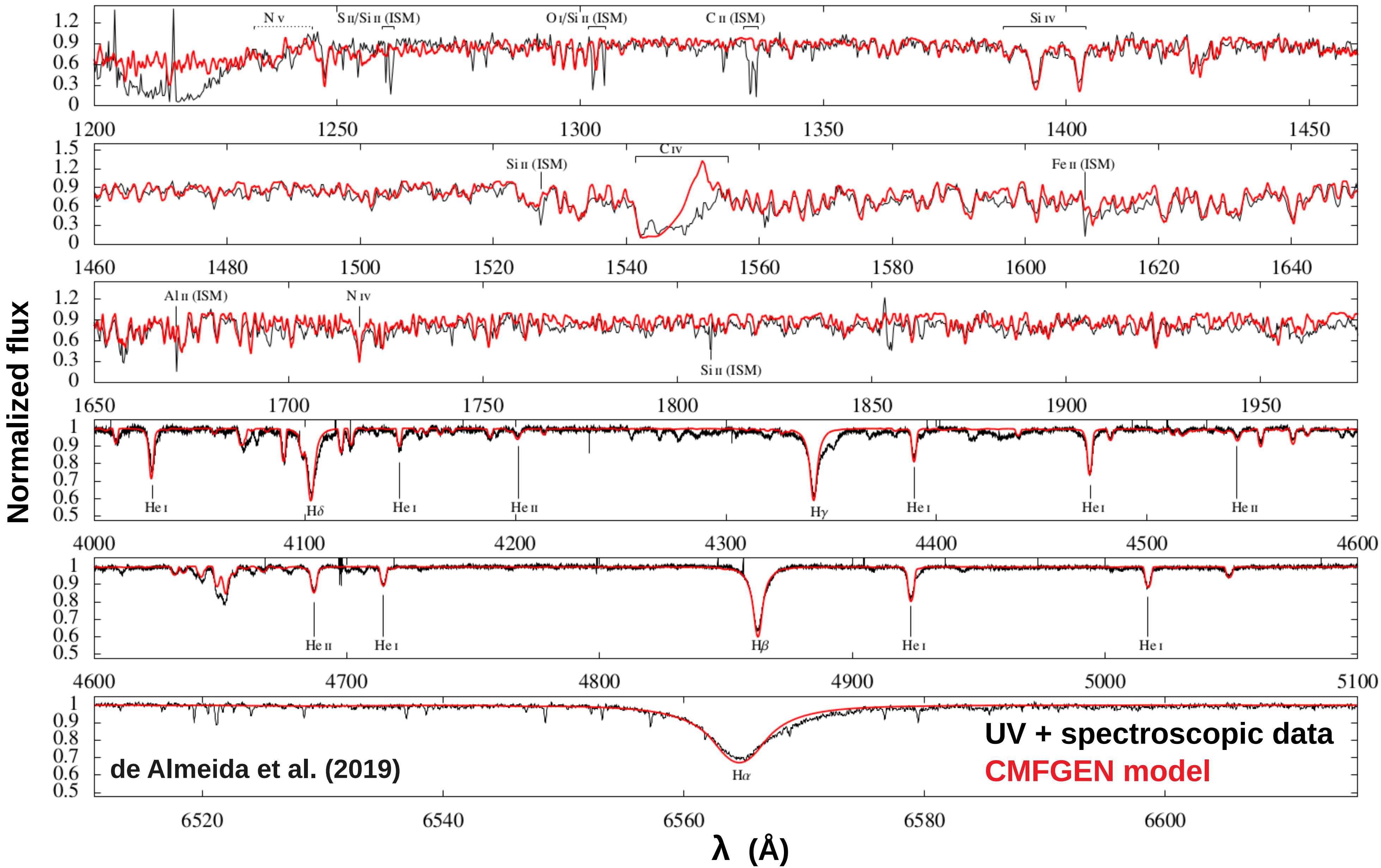
- **UV and visible** spectroscopic analysis of 9 **late O giants** (O8-9.5III stars):

  (log(L/L_{SUN}) ~ 5.2)

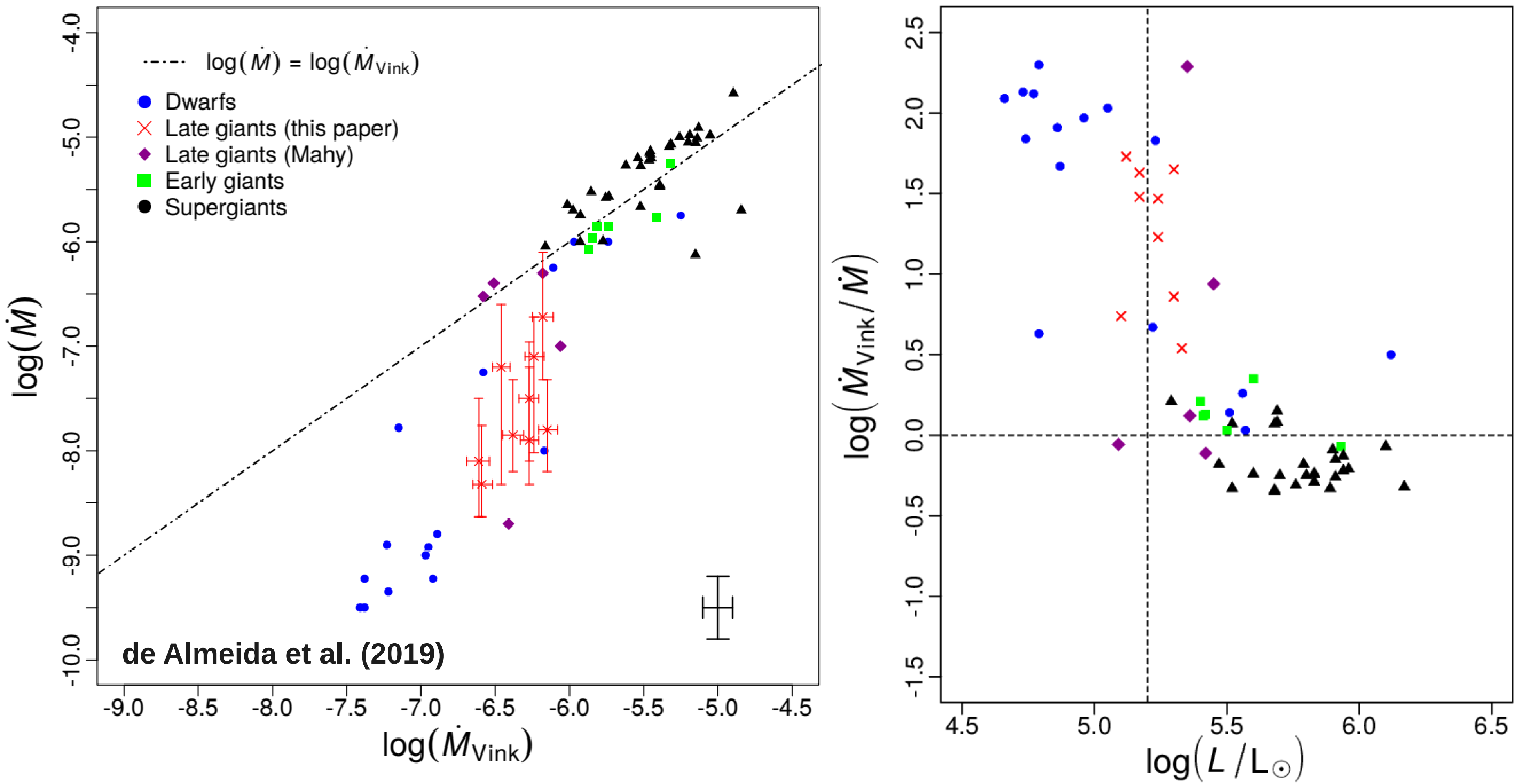
  – Non-LTE radiative transfer code CMFGEN (Hillier & Miller 1998)

- Constraining the stellar and wind parameters: $\mathrm{e.g.,}\ T_{\mathrm{eff}}\ \log(g)\ \dot{M}\ v_{\infty}$

Example of modeling fitting for one star of the sample: HD 156292 (O9.7III)



- Comparison with the mass-loss rates predicted from **Vink+2000:**



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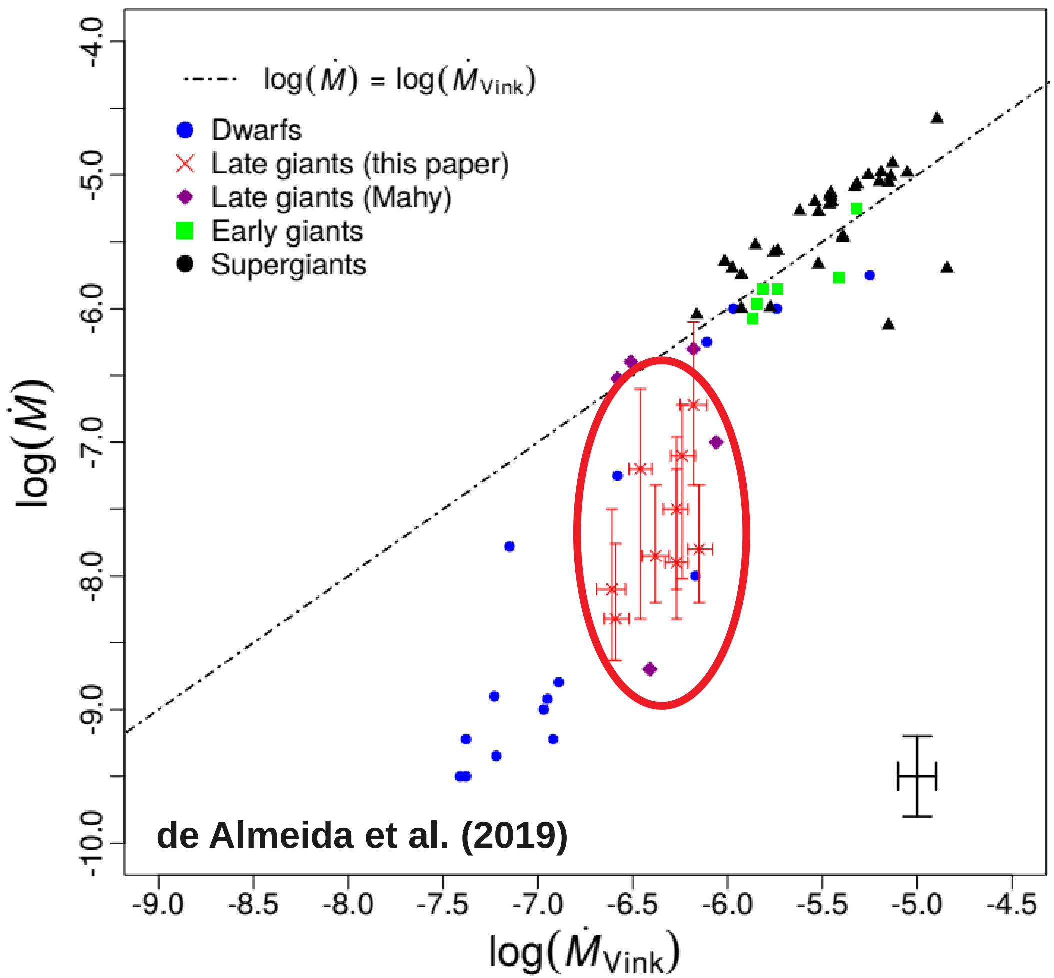
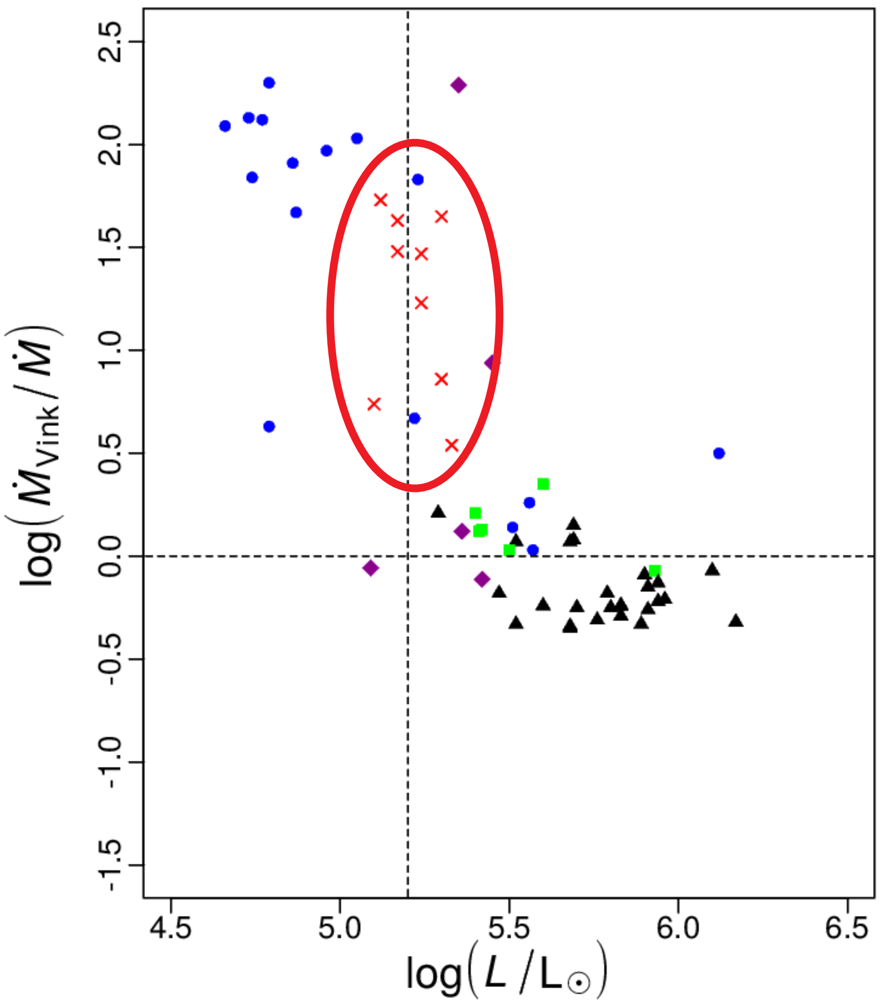
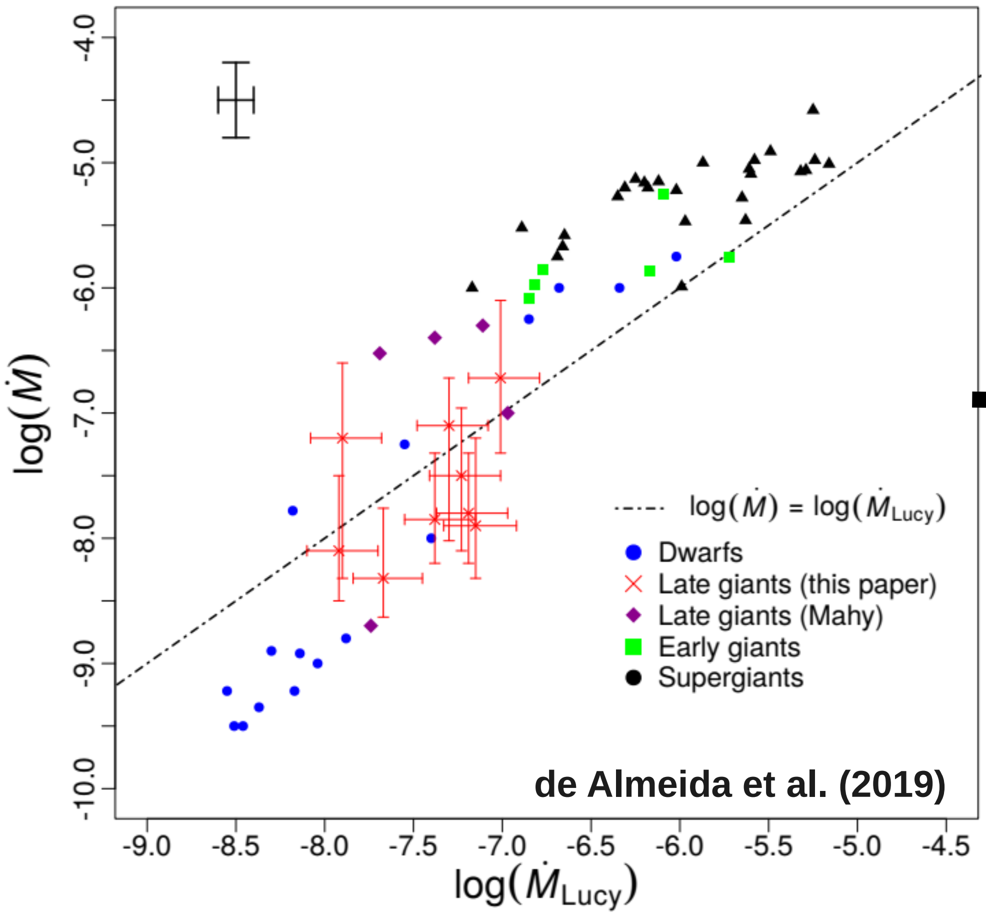
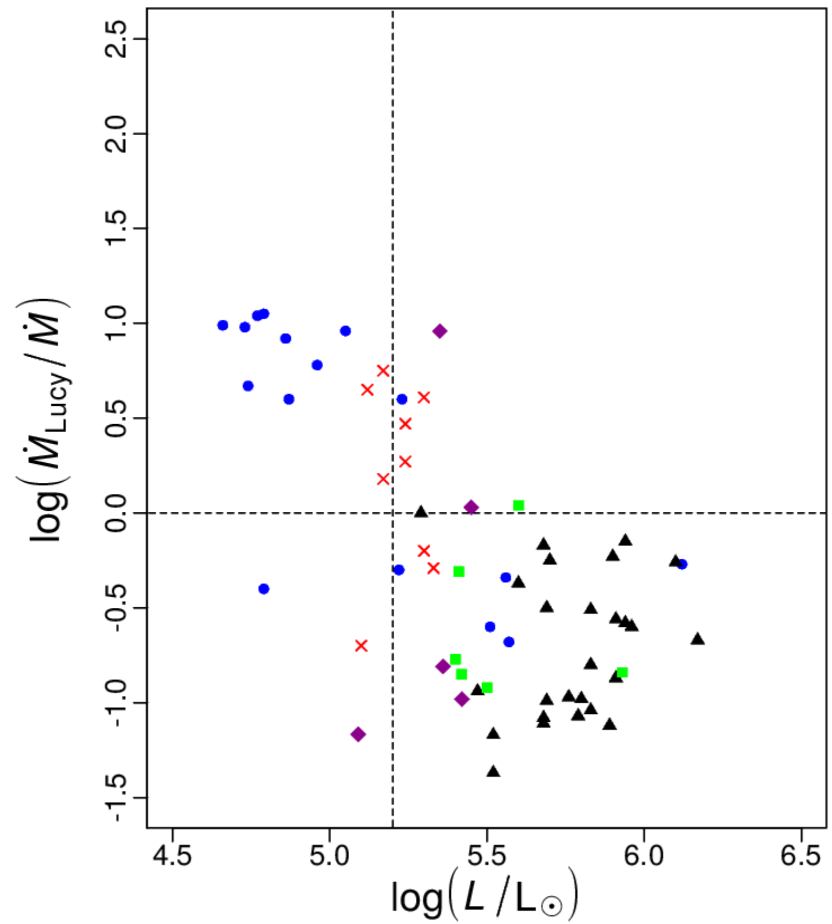




- Weak winds also are found in **late O giants!**

- Comparison with the mass-loss rates predicted from **Lucy 2010:**





- **Better agreement** for low-luminosity O stars (late dwarfs and giants)
- **Mismatch** for OB supergiant

Beyond the UV and visible regions: infrared (L-band)

- de Almeida et al. 2019: **UV + visible**

- Brα: interesting mass loss diagnostic line (Puls el al. 2008; Najarro et al. 2011)

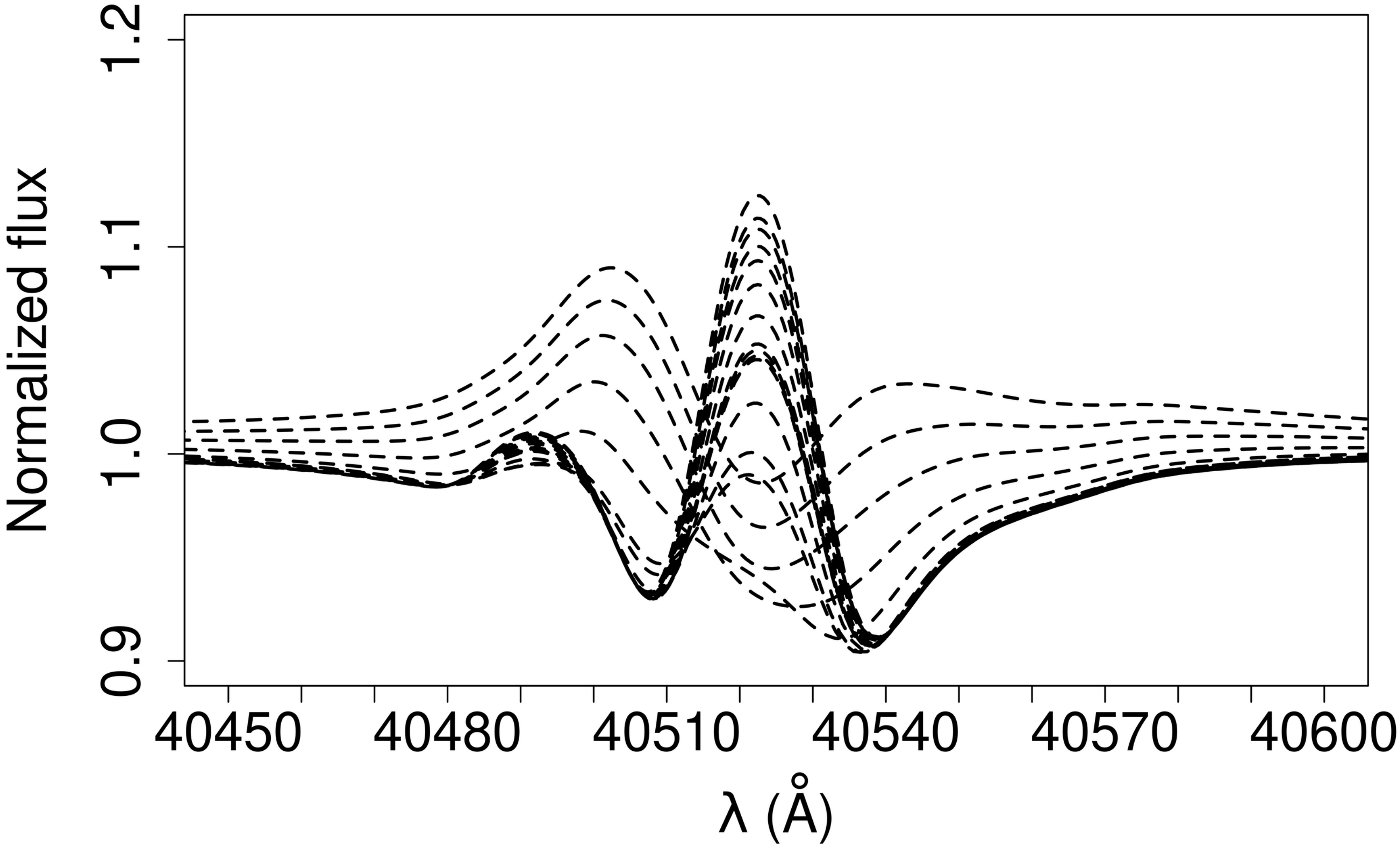
- It lacks a **UV + visible + infrared** analysis of weak winds

- Exploring the weak wind phenomenon in the **infrared region:**

  Observations of late O dwarfs and giants with VLT/CRIRES+ and Gemini North/GNIRS instruments (L-band, Brα)

- Total of 7 late O giants and dwarfs (ESO P112, ESO P113, Gemini 2023B, and Gemini 2024A)

- **Test case:** HD 24431 (O9III)
- Small grid of CMFGEN models varying only the mass-loss rate: 10^{-10} to 10^{-6} $\mathrm{M_\odot/yr}$



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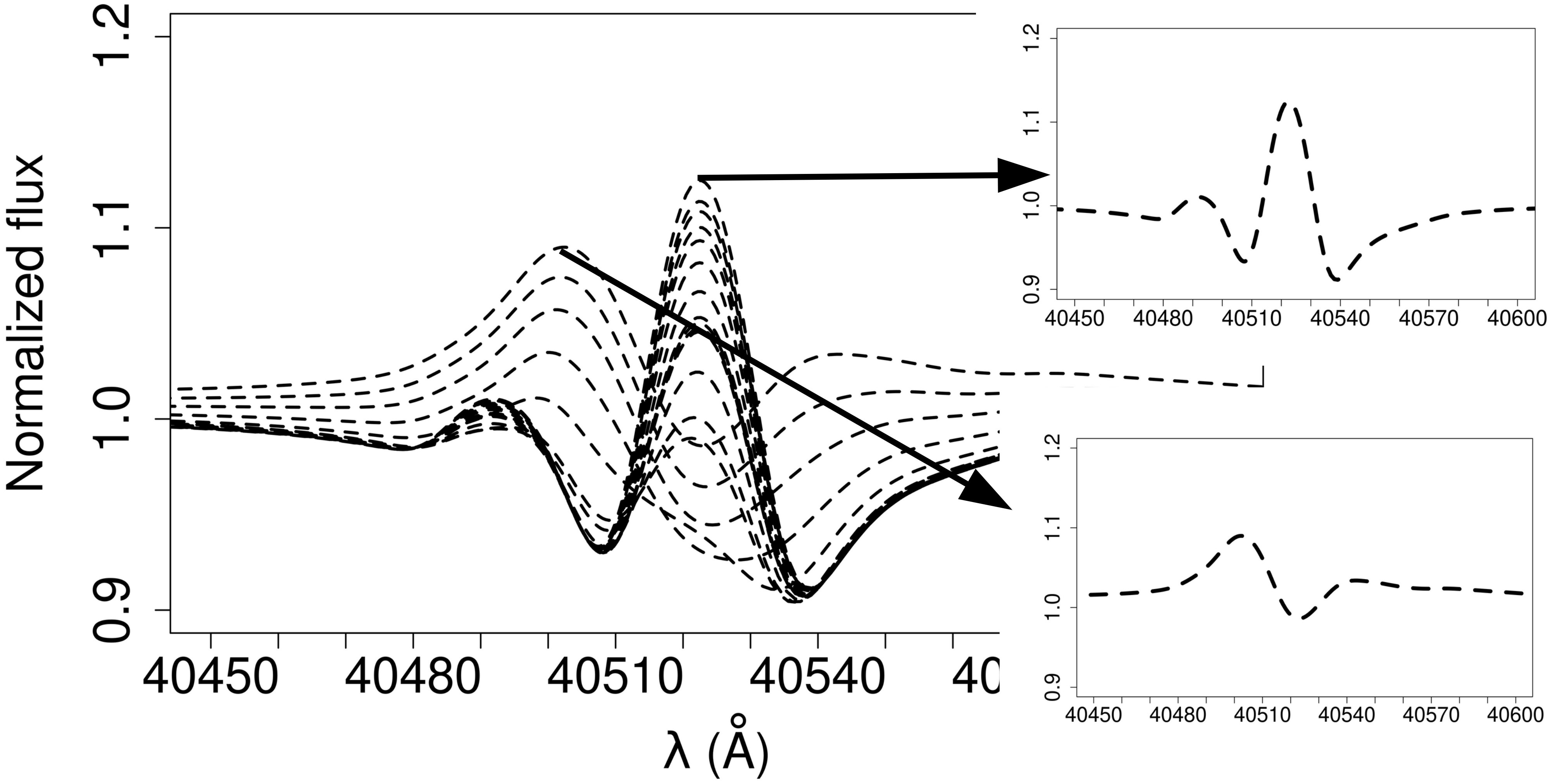

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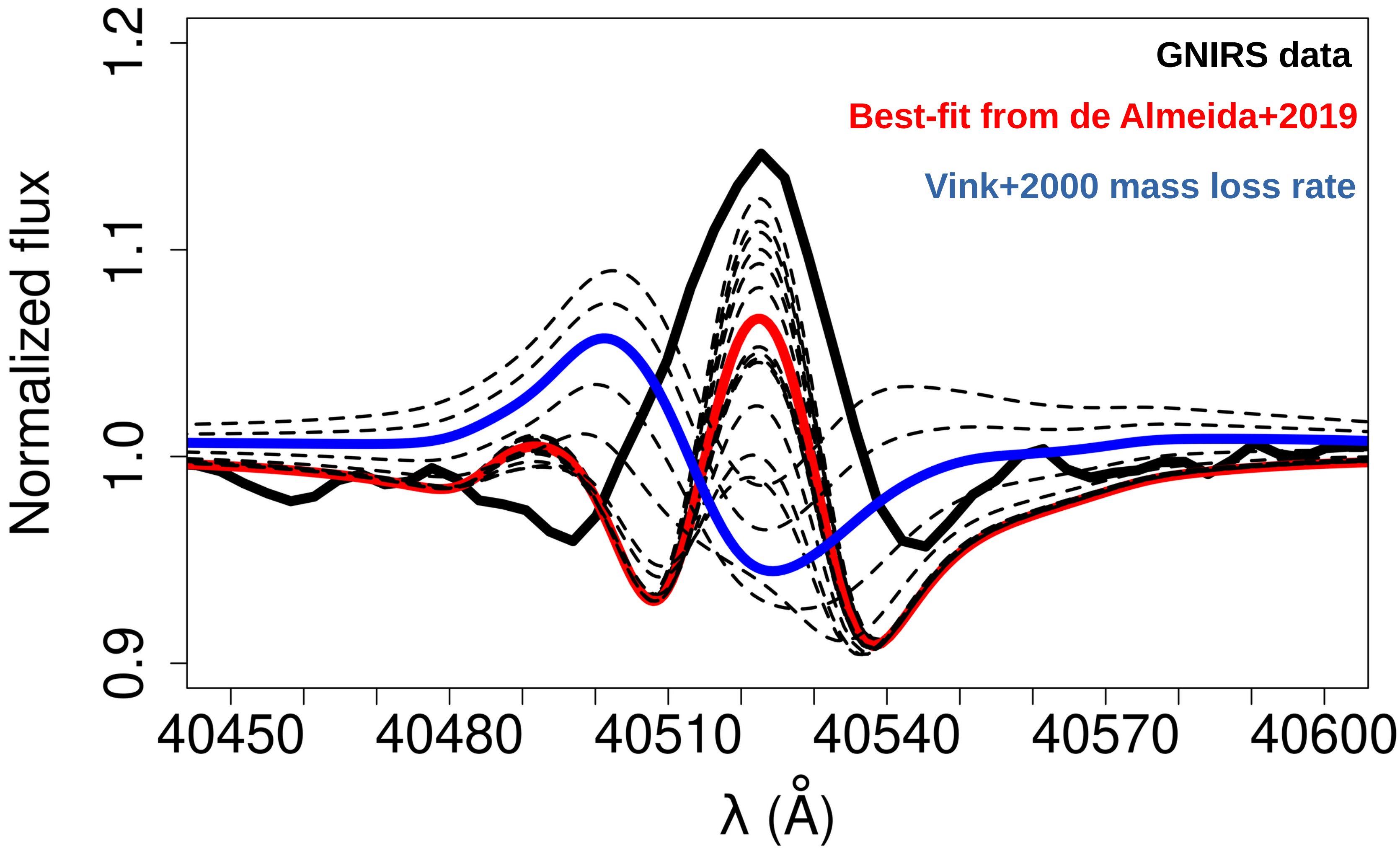

What hydrodynamical simulations can say about weak winds?

- So far, all the results shown here consider an **adopted wind velocity and density:**

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

$$v(r) = v_\infty \left(1 - \frac{R_\star}{r}\right)^\beta$$

} **input parameters** in CMFGEN

Parameterized by the beta-law approximation: $\beta = 1.0$

(typical value for O-type stars)

- But we can ***"play"*** with **β** to **fit the observations!**

– Instead of β ~ 1.0**,** B supergiants require β value as high as 2-3!

- **Code HYDWIND** (Curé 2004; Curé & Rial 2007):

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

(line radiative acceleration)

$$v\frac{\mathrm{d}v}{\mathrm{d}r} = -\frac{1}{\rho}\frac{\mathrm{d}P}{\mathrm{d}r} - \frac{GM_*(1-\Gamma_e)}{r^2} + g_{\mathrm{line}}$$

- **CAK-theory** of line-driven winds (Castor, Abbott & Klein 1975, Pauldrach et al. 1986):
  - Expressing g_{line} as a function of g_e!

$$\frac{g_{\mathrm{line}}}{g_e} = \mathcal{M}(t)$$

line-force multiplier factor: 3 line-force parameters

$$\alpha,\ k,\ and\ \delta$$

- **Code HYDWIND** (Curé 2004; Curé & Rial 2007):

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

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- Input parameters: $T_{\mathrm{eff}},\ \log(g),\ R_\star,\ L_\star,\ M_\star$ **+** $\alpha,\ k,\ and\ \delta$

…from solving the equation of momentum

$\dot{M}\ \ v(r)$ → to used as input parameters in radiative transfer models!

What hydrodynamical simulations can say about weak winds?

- **Code HYDWIND** (Curé 2004; Curé & Rial 2007):
- Initial HYDWIND grid for weak winds: ~13000 models

↓

- Radiative transfer code FASTWIND (Puls et al. 2005)

  ~10-30 minutes

↓ Based on the results from FASTWIND to fit **UV + visible + infrared data**

- To create CMFGEN model grid

  up to ~day to converge one single model!

What hydrodynamical simulations can say about weak winds?

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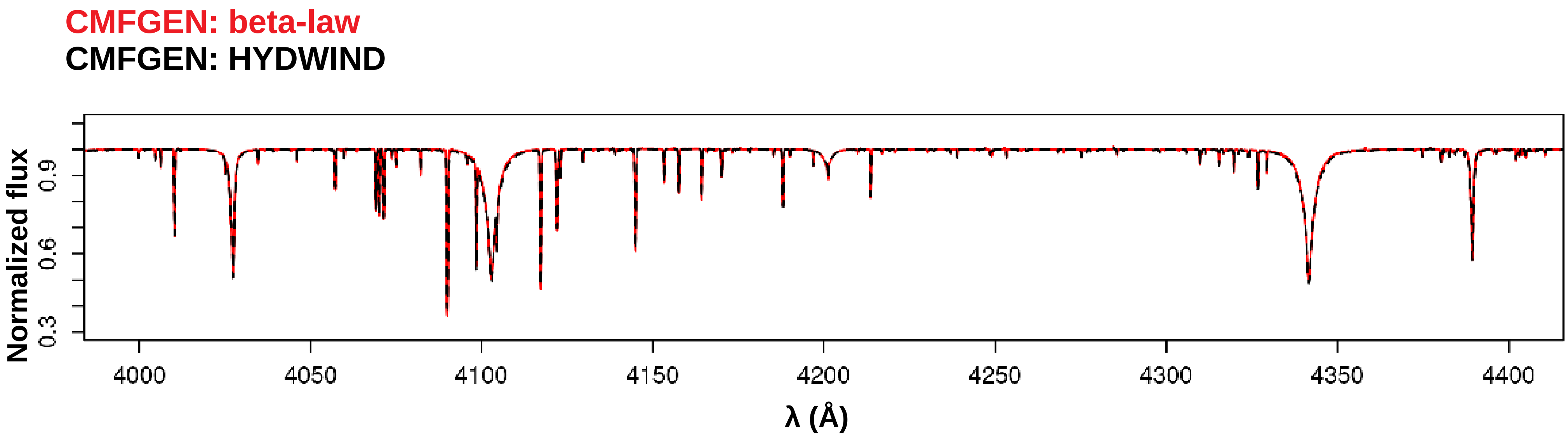

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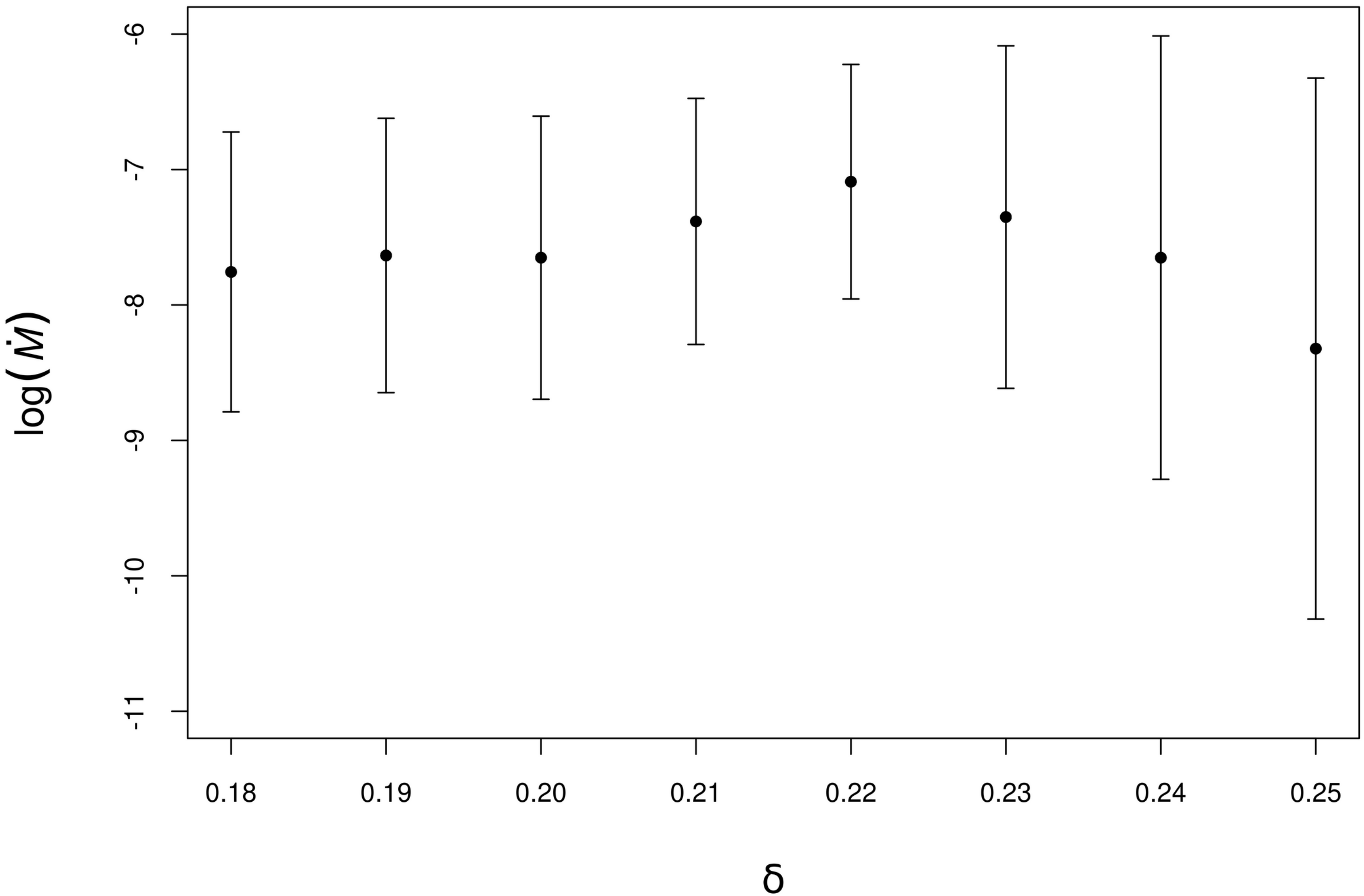

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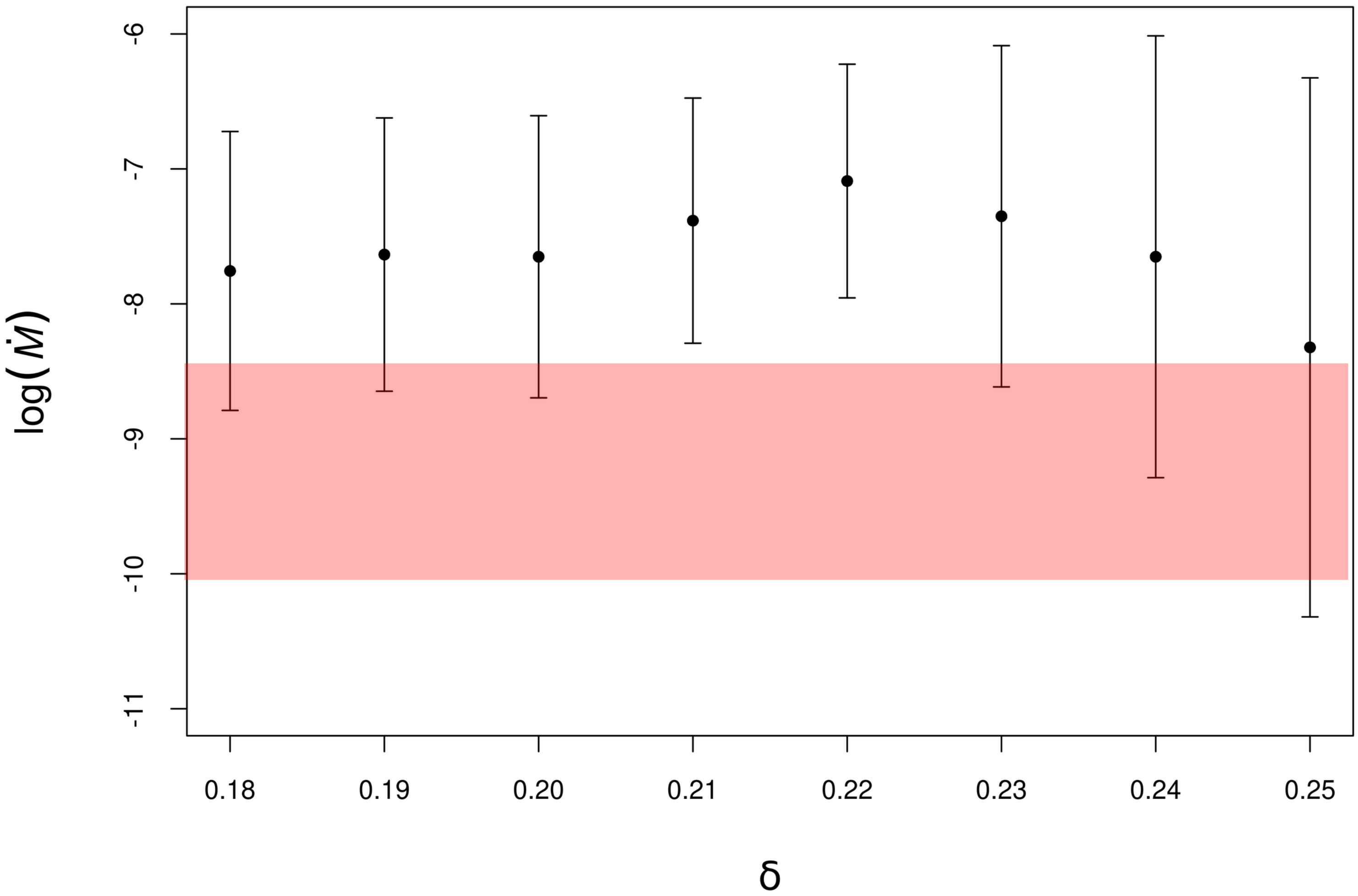

Final remarks and perspectives

- Onset of **weak winds** at **$\log(L/L_{SUN}) \sim 5.2$**

- For the first time, **weak winds** are found in more **evolved O stars (late O giants)**:

  – Weak winds are not highly affected by evolution

  – Weak winds should be found during all the H-burning phase

- One idea to explain weak winds in the framework of the CAK-formalism:

  – Exploring the fast wind regime using **large values of δ**

  – To be tested by fitting UV + visible + **mid-infrared spectroscopy (Brα line)**

- Observations with Gemini North/GNIRS and ESO/CRIRES+ instruments (L-band):

  – total of 7 late O dwarfs and giants

  – test case for HD 24431 (O9III): **weak wind model is favored**

Obrigado! / thank you!

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