Using interferometry to model the winds of red supergiants

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1 Abstract

We propose a semi-empirical model that extends the atmosphere of red supergiants (RSGs) up to several stellar radii, being the first model that shows extension for this type of massive stars up to date. We match the visibilities to compare our results with observations of VLTI/GRAVITY, MATISSE and AMBER.

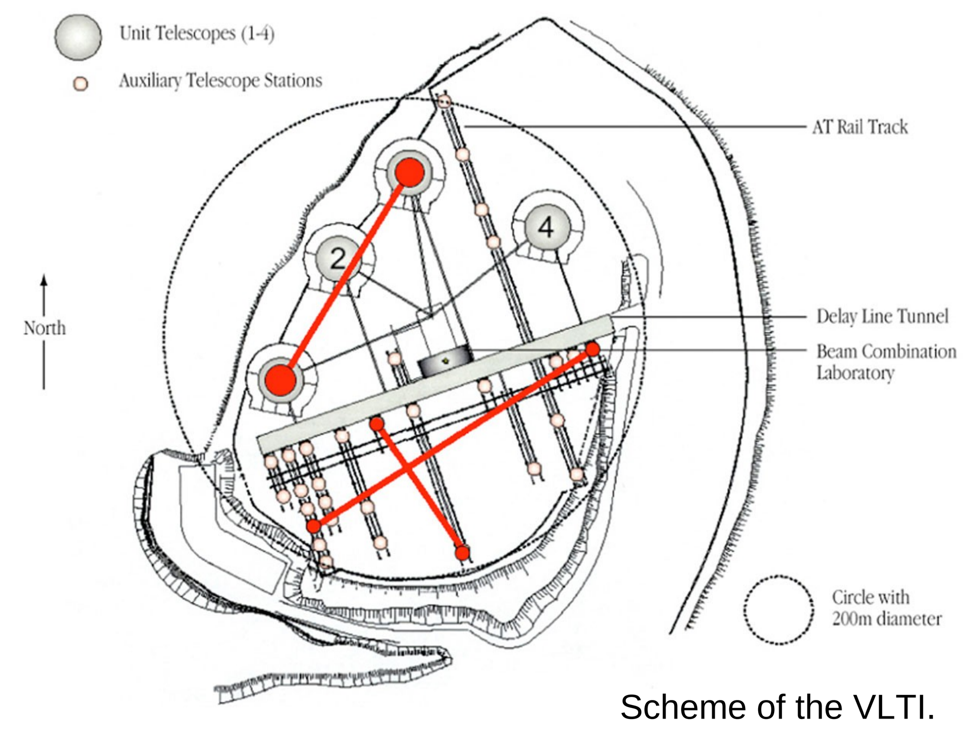
2 Introduction

Red supergiants (RSGs): Evolved massive stars in a stage Preceding core-collapse supernova. Mass loss events occur in their extended atmospheres up to several stellar radii.
Further from that, they have a dust shell.

A RSG representation.

Interferometry

- Based on: $\Delta\theta \approx \frac{\lambda}{D}$ λ = wavelength of light, D = diameter of lens → For large wavelengths, the bigger the telescope the better: use an array!
- We observe the "Visibility" → Fourier transform of the intensity.



Scheme of the VLTI.

The VLTI in Paranal, Chile.

3 Model

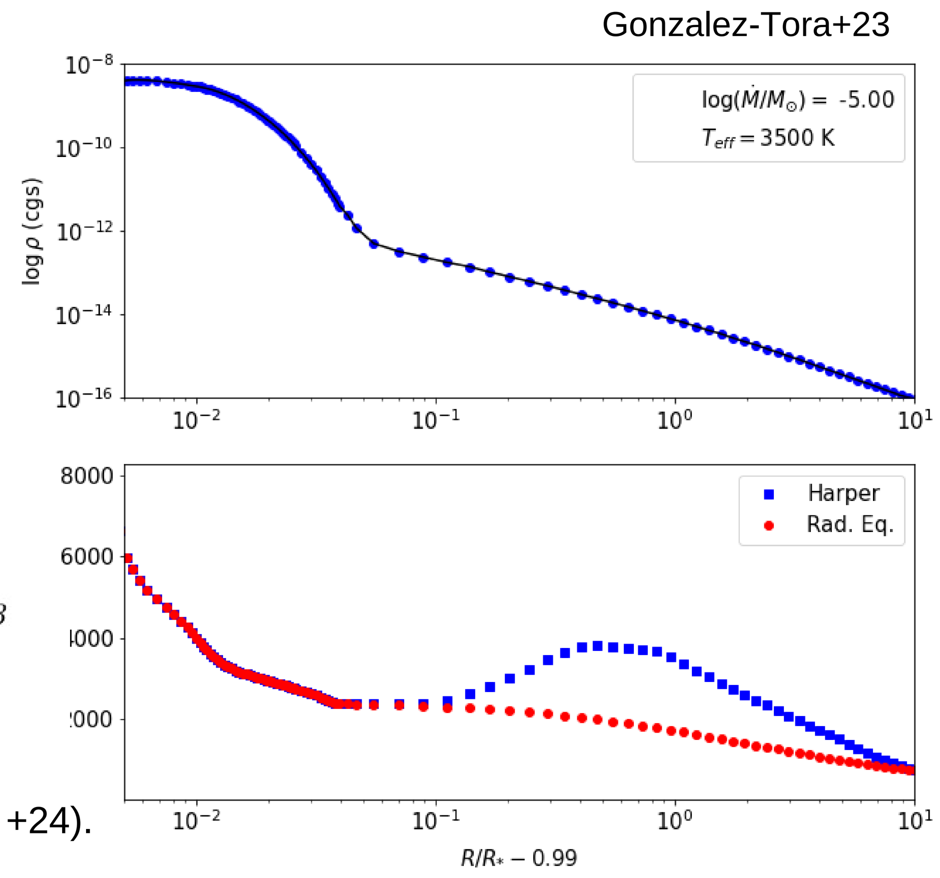
- Based on Davies&Plez+21.
- Start with a simple MARCS model (Gustafsson+08)and extend it up to ~8Rstar (or > 800 K).
- Using a constant mass-loss rate, Ṁ, and the mass continuity expression:

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

- The density profile:

$$\rho_{\rm wind} = \frac{\rho_{\rm phot.}}{(R_{\rm max}/R\star)^2}\left(1-\left(\frac{0.998}{(R_{\rm max}/R_\star)}\right)^{\gamma}\right)^{\beta}$$

with β=-1.60 and γ=0.05 (Gonzalez-Tora+23, +24).



- The temperature profile: based on Harper+01 (blue) or simple radiative equilibrium (red).
- The velocity profile: we assume a limit velocity v_{wind}=25±5 km/s (Richards&Yates+98).

Computation of intensities, spectra and visibilites:

- We use the software *TURBOSPECTRUM* (Plez+12) for the intensity and SEDs.
- For the visibilities:

$$V_{\rm Model}(\lambda) = \int_0^1 S_\lambda I_\lambda^\mu J_0[\pi\theta_{\rm Model}(B/\lambda)(1-\mu^2)^{1/2}]\mu d\mu$$

4 Case study

- Compare the model with AMBER data from Arroyo-Torres+15 of HD95687 and new VLTI/GRAVITY and MATISSE data of AH Sco, KW Sgr, V602 Car, CK Car and V460 Car.
- K, L and M bands: 1.8 – 5.0 µm.
- Parameters for our model:

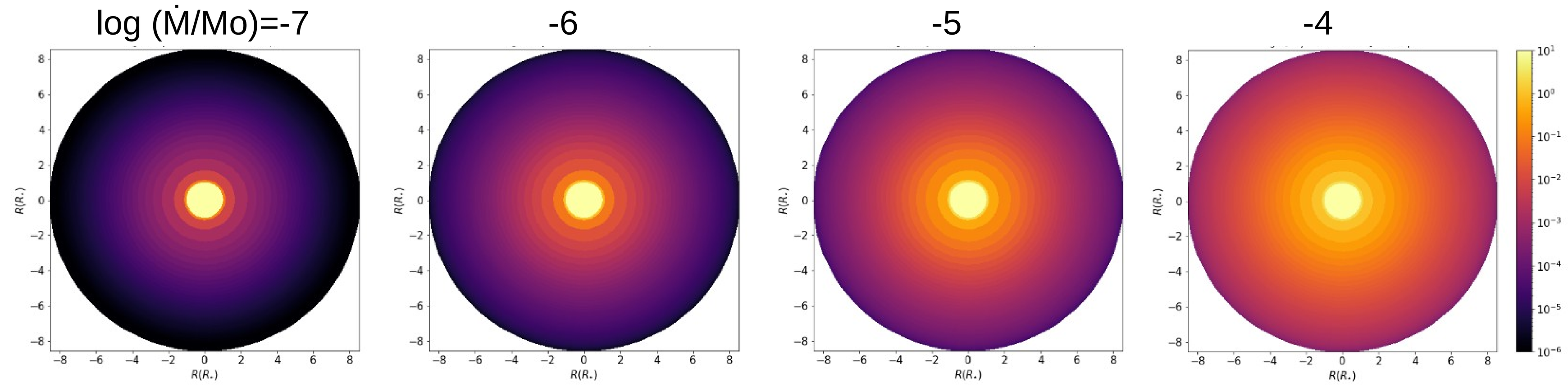
RSG	log L/L☉	$T_{\rm eff}$ (K)	log g	[Z]	ξ (km/s)	M/M☉	$R_\star/R_\odot$	log $\dot{M}$/M☉yr^{-1}
AH Sco	5.52	3600	-0.5	0	5	20	1411	-4.0 ± 0.50
KW Sgr	5.24	3700	0.0	0	5	20	1009	-4.5 ± 0.50
V602 Car	5.1	3400	-0.5	0	5	20	1015	-5.0 ± 0.50
CK Car	4.86	3500	0.0	0	5	15	690	-5.0 ± 0.50
V460 Car	4.46	3600	-0.5	0	5	15	539	-6.5 ± 0.50

Gonzalez-Tora+24

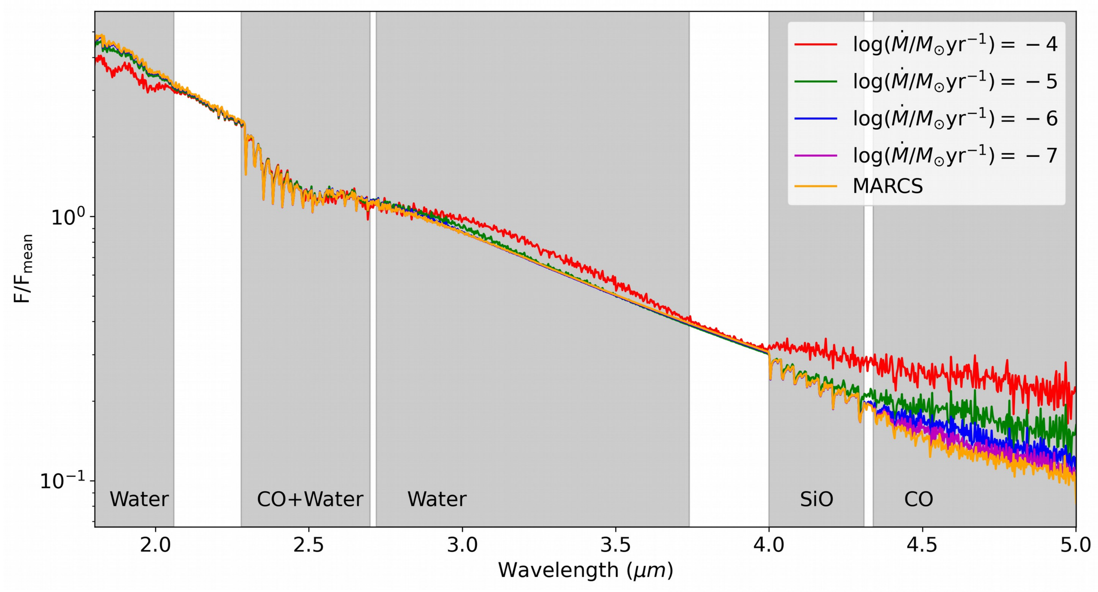
- We use a mass-loss rate grid of -7 < log (Ṁ/Mo) < -4 with a step of δlog (Ṁ/Mo)=0.25. We also compare with the case of no extension (MARCS).

5 Results and discussion

Intensities:



Spectra:

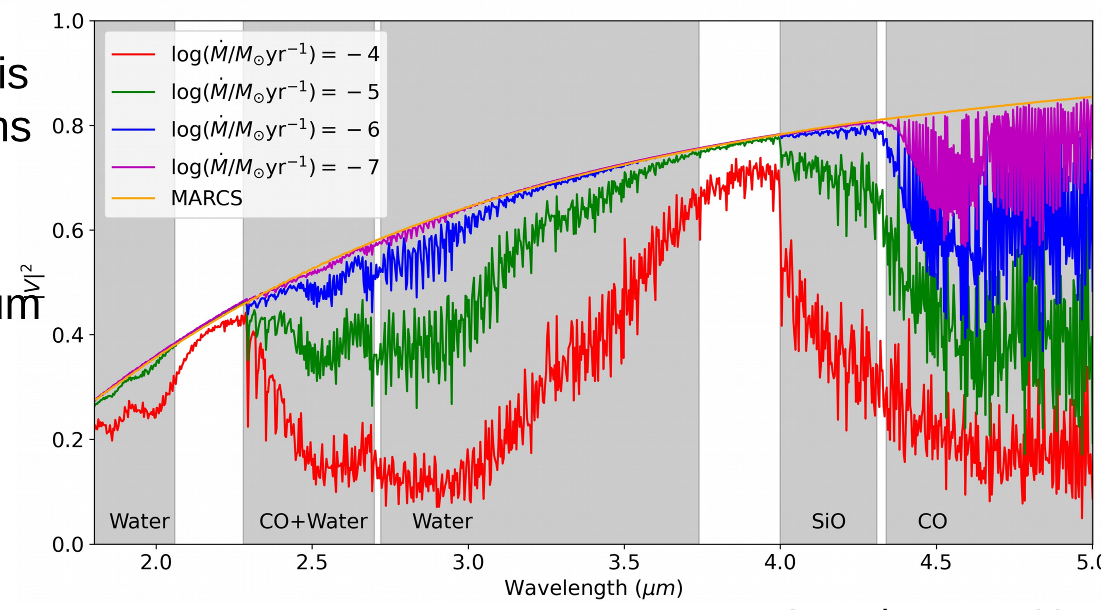


- We see extension for > 1Rstar (not seen with previous models).
- We can reproduce the water, CO and SiO extensions.

Visibilities:

-The mass-loss rate we obtain is higher than previous predictions (e.g., Beasor+20).

- The simple radiative equilibrium T(r) fits better both SED and visibilities.



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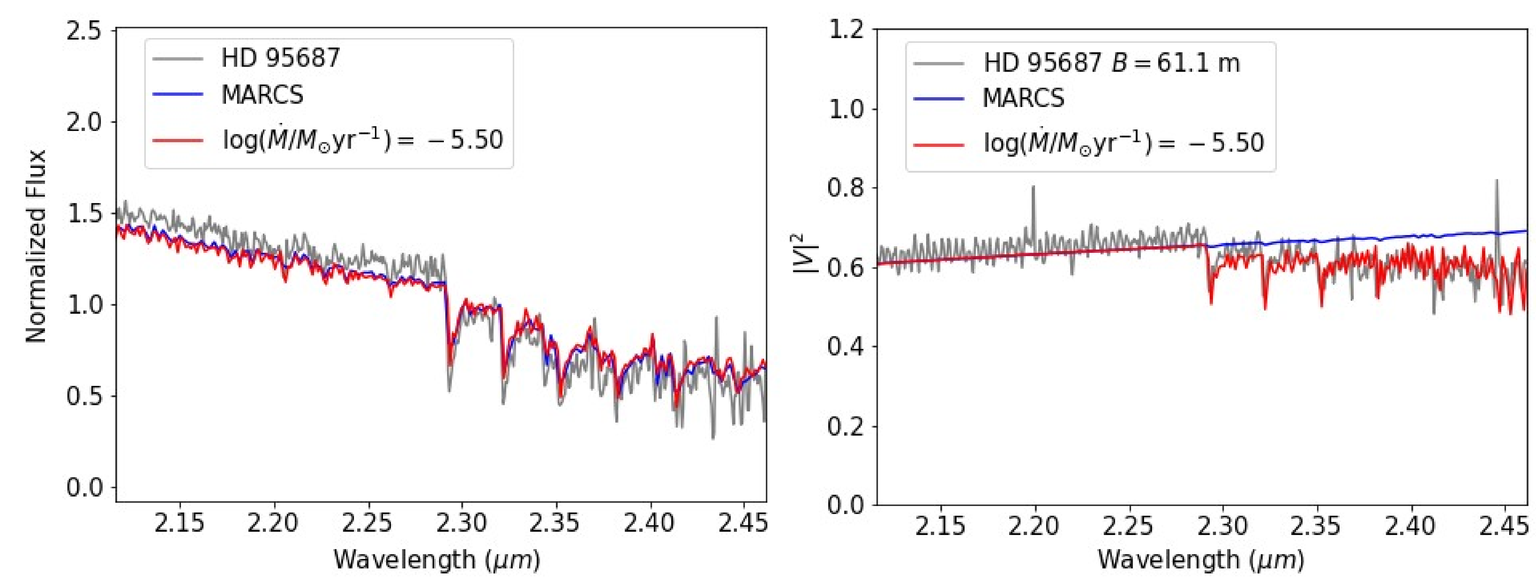
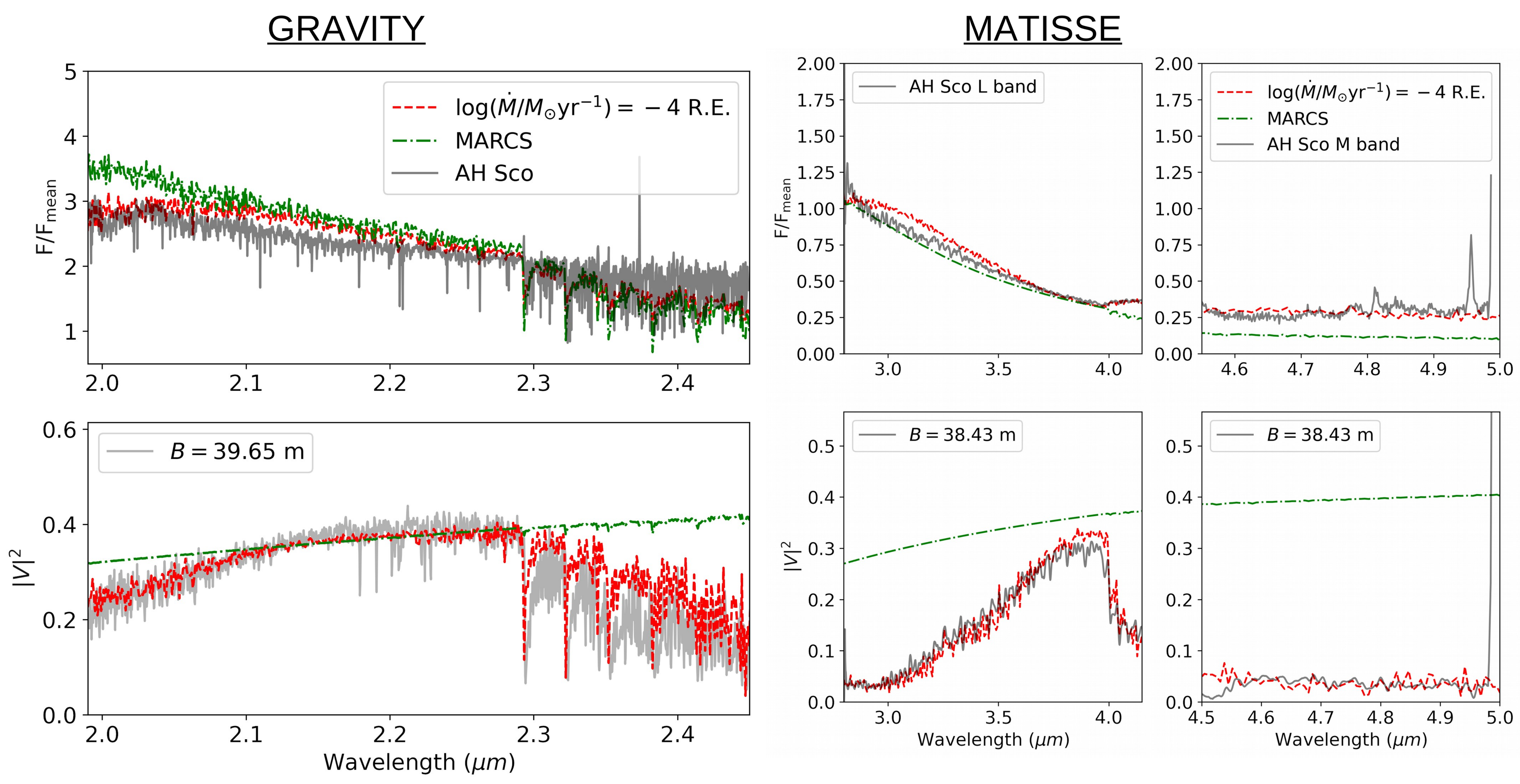
Results for the observations:





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Reconciling the best Ṁ fit:

- A different density profile, by changing the β and γ parameters in the density profile.
- Localized mass-loss events (Humphreys&Jones+22).
- Need to include the dust component at < 800 K.

6 Conclusions

This is the first extended model that can reproduce the SED and visibilities for the K, L and M bands. The method can be extended to different wavelength bands for both spectroscopic and interferometric observations. This could help develop a accurate dynamic models to understand extended atmospheres of cool massive stars.

References

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