Looking for the onset of the RSG mass loss : VLTI imaging of Antares (alpha Sco)

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1. Introduction

The mass loss of evolved massive stars

Red supergiant stars (RSGs) are evolved, cool, and extended stars, known to be progenitors of Type II supernovae. Their surfaces show vigorous **convection** and they are surrounded by complex **circumstellar environments** shaped by inhomogeneous **mass loss**. The physical driving mechanism of ejected material is still not understood, i.e., it is not reproduced by ab initio 3D hydrodynamical simulations (Figure 1).

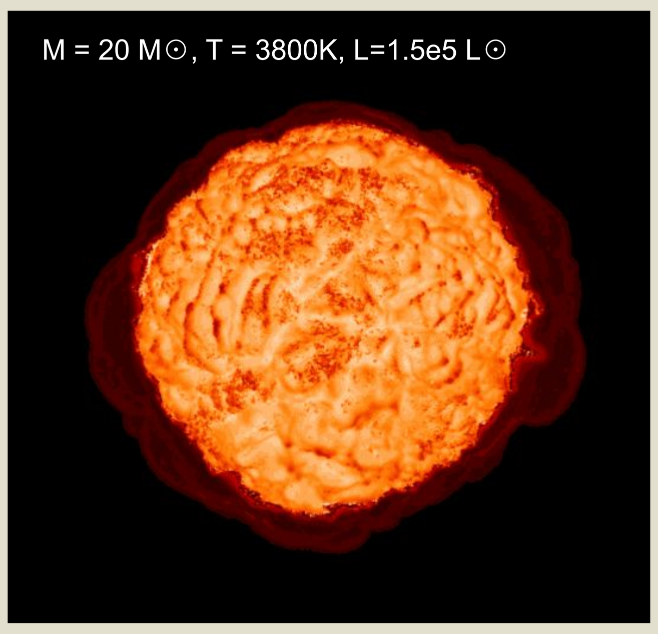


Figure 1 : Temporal sequence of RSG model. **AREPO** 3D RHD snapshots (Ma et al. 2025) were post-processed with **Optim3D** (Chiavassa 2009) to produce intensity maps in the GRAVITY K-band continuum.

Antares, one of the closest RSG

Antares is a close-by RSG star at 170 pc (van Leeuwen 2007). It has an effective temperature of 3600K (Ohnaka 2013) and its radius has been measured around 700 $R_\odot$ (Ohnaka 2017). GRAVITY/VLTI observations obtained in the summer of 2023 provide high angular resolution K-band interferometric data, reaching a resolution of 1.66 mas, or ~4.5% of the stellar apparent stellar diameter.

2. Motivations

To constrain the mass-loss mechanism in Antares, we probe the stellar convective photosphere together with the extended atmospheric regions where molecules form. The K-band spectrum of Antares is shown in Figure 2. This poster presents the first step of the study, focusing on the **continuum** (i.e., the region of relatively low line density) emission of the star, indicated by the blue band in the figure below.

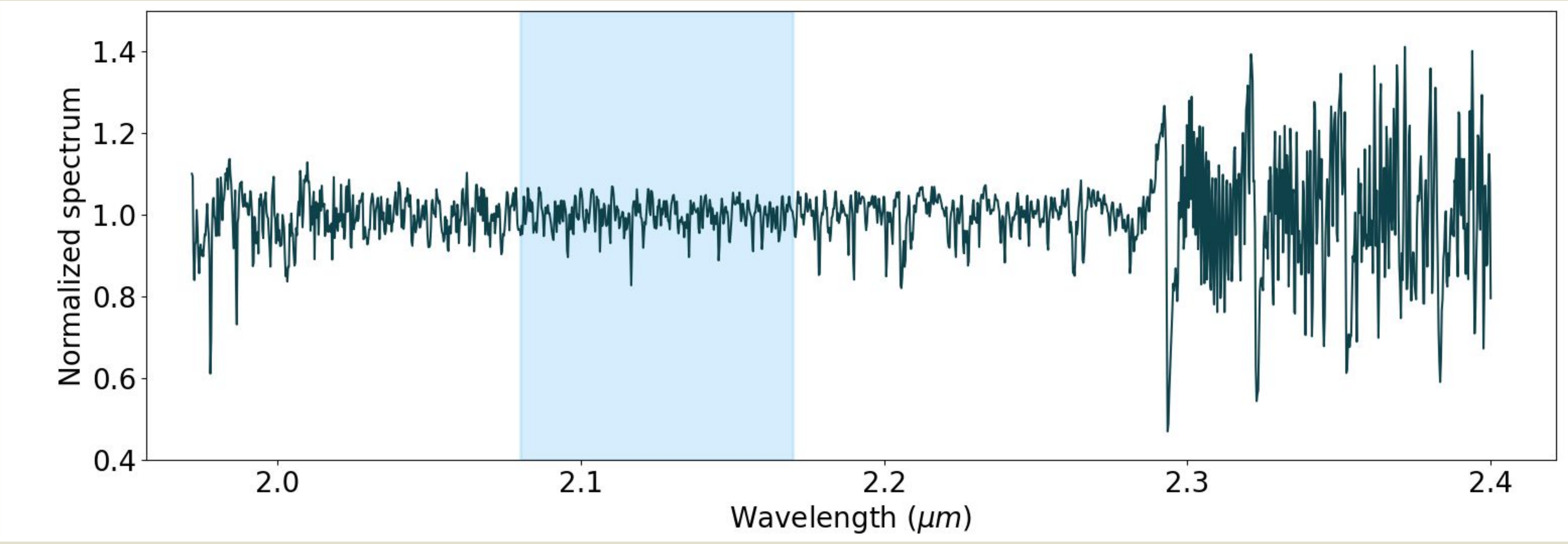


Figure 2 : K-band spectrum of Antares taken with GRAVITY/VLTI. The blue band indicates the continuum region used for this study.

3. Methods

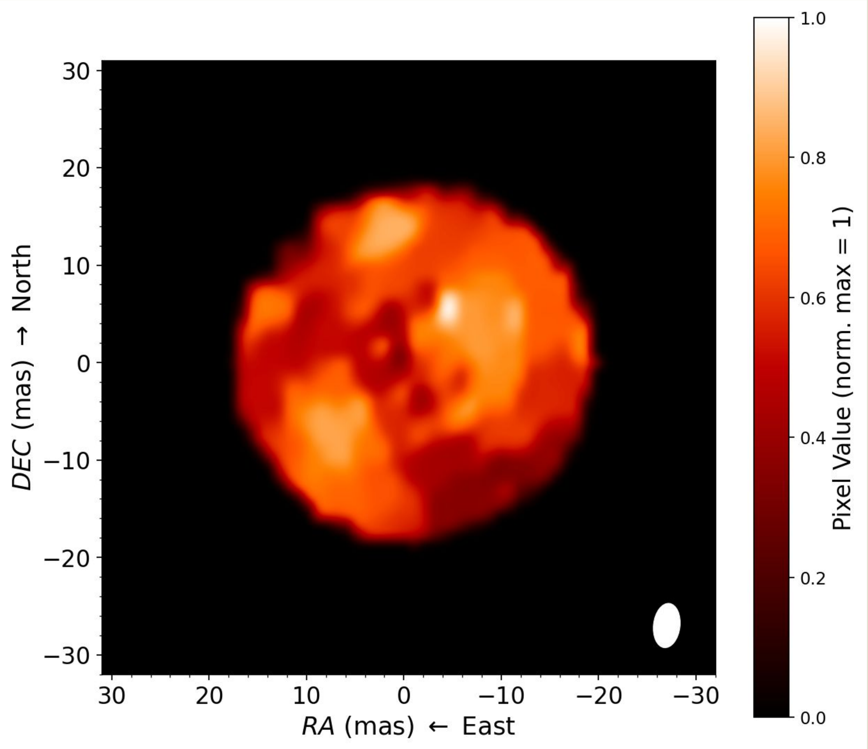


Figure 3: **OITOOLS** reconstructed image. The white circle is the synthesized interferometric beam.

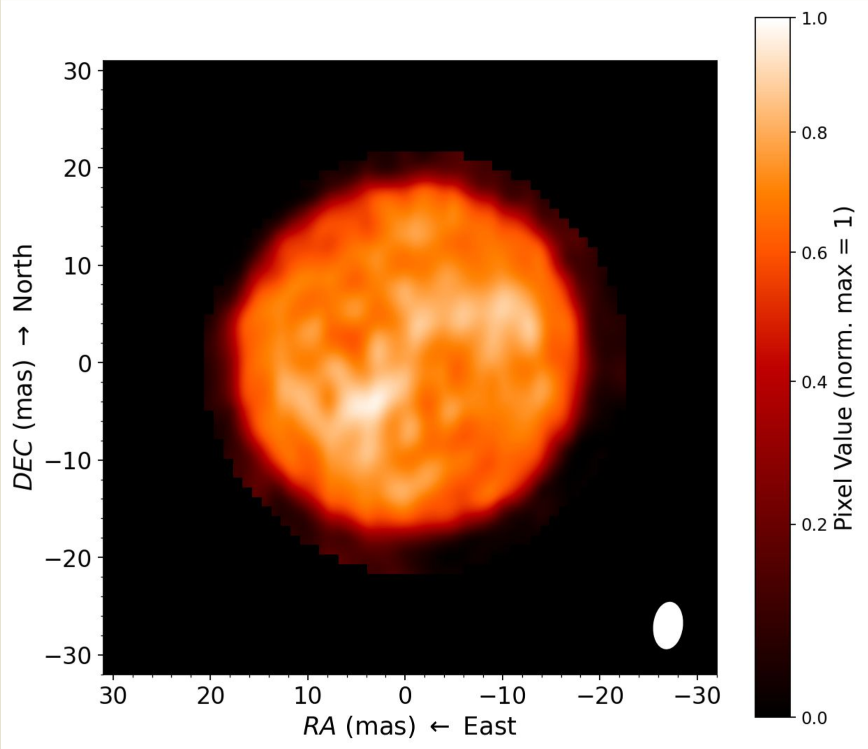


Figure 4: **MiRA** (through **PYRA**) reconstructed image. The white circle is the synthesized interferometric beam.

We use the interferometric observables sampled in the Fourier plane to perform **image reconstruction**. This provides an image of the surface of Antares.

Both reconstructions reveal bright and dark features at corresponding locations on the stellar disk, indicating that the detected structures are astrophysical signatures of convection. Remaining difference can be related to the chosen regularization, which imposes assumptions on the brightness distribution during the reconstruction, or from software difference.

From this point onward, only the OITOOLS image will be considered for the analysis.

OITOOLS : https://github.com/fabienbaron/OITOOLS.jl
MiRA: https://github.com/emmt/MiRA // PYRA : https://github.com/jdrevon/PYRA

4. Analysing the surface

To study convection on the stellar surface, we first need to isolate the surface structures from the global stellar limb. We therefore model the limb-darkened stellar disk and subtract it from the reconstructed image.

Then, the residual map reveals the convective spots more clearly (Figure 5). From the detected regions, we measure the spot areas and derive their characteristic sizes, presented in Figure 5.

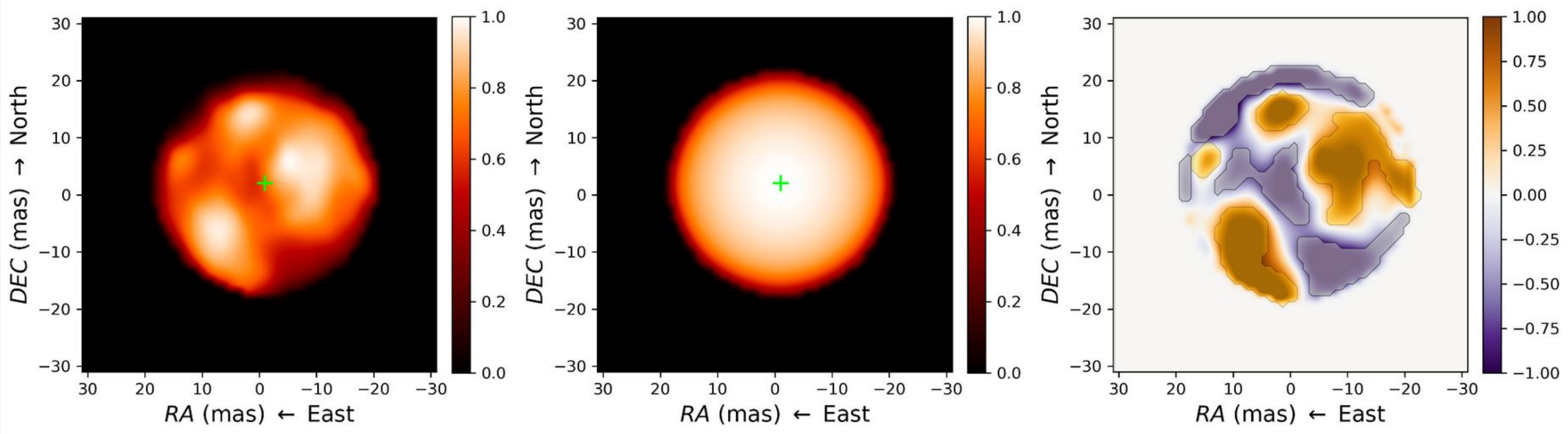
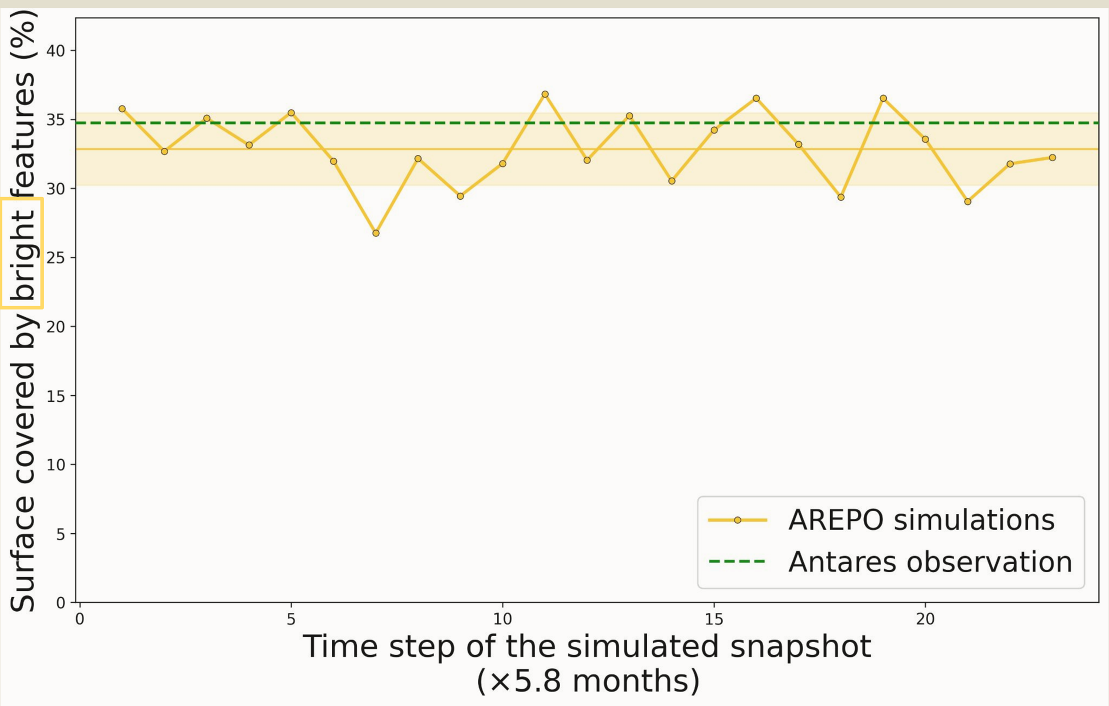


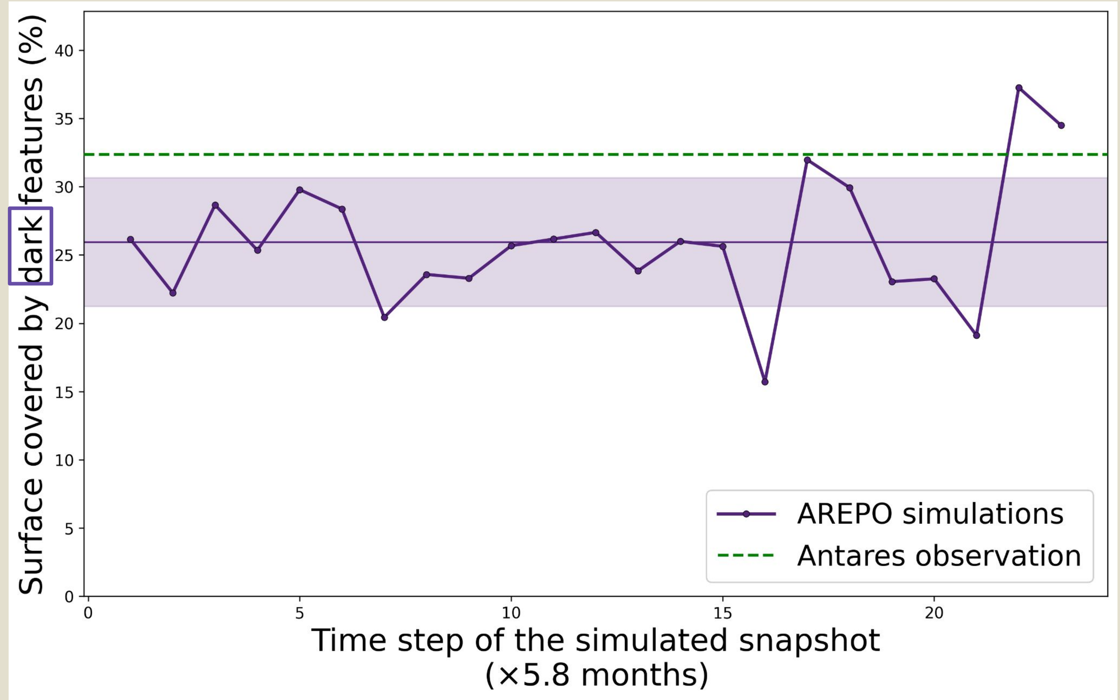
Figure 5 : [Left] Convolved reconstructed image normalized at 1. [Middle] Fitted limb darkening model. [Right] Subtraction of the middle image from the left one image and cells detection.

5. Comparing with simulations

We use 22 snapshots from the AREPO simulation code shown in Figure 1 (Ma et al 2025). Each snapshot is treated as an independent realization of the convective pattern of the photosphere and used to generate synthetic interferometric observables with the same (u,v) coverage as the dataset of Antares. An image is then reconstructed for each simulated snapshot. We apply the same spot-detection procedure as previously described.

The bright-feature surface coverage recovered in the reconstructed image agrees well with the simulations.However, the dark-feature coverage appears slightly larger in the reconstruction than in the simulated snapshots.





6. Conclusion

Take home message

- We have produced a robust image of the surface of Antares, at a resolution of 1.66 mas using GRAVITY/VLTI
- Comparing empirically derived horizontal sizes of rising and sinking convective cells with 3D models of convective energy transport provides insight into surface activity. This helps assess its possible contribution to the initiation of mass loss and the formation of wind structures.

Forward look

- This study will be expanded through detailed analysis of the molecular lines to further constrain the mass loss.
- The study emphasizes the need for a monthly cadence observations to monitor the evolution of the stellar surface.