VLTI/AMBER studies of the extended atmospheres of AGB and RSG stars

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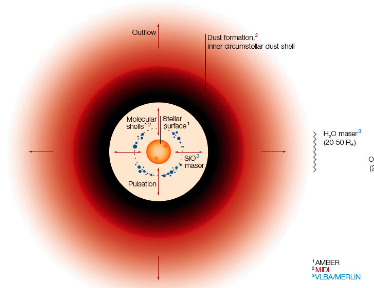
We present a series of VLTI/AMBER studies of the extended molecular atmosphere of Asymptotic Giant Branch (AGB) and Red Supergiant (RSG) stars with the following conclusions:

- Observationally, both types of stars show similar atmospheric extensions
- Theoretically, the mechanisms that elevate the atmosphere are likely different

- Comparisons to theoretical pulsating model atmospheres and 3D convection simulations show that both types of models can explain the extensions of Mira variable AGB stars
- Neither of them can currently explain the extensions of RSG stars
- A correlation of atmospheric extension with luminosity is observed for RSG stars but not for AGB stars, possibly pointing to different dominating mechanisms to elevate the atmosphere: Shock fronts for Mira stars; Radiative pressure on molecular lines for RSG stars

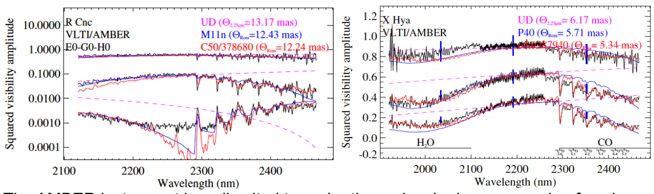
- Other mechanisms to look at:
  Magnetic fields, the effect of dominating surface spots, (very) small inner dust radii, etc.



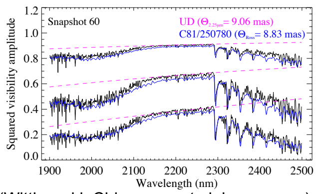
Introduction

AGB (low-to-intermediate mass) and RSG (massive) stars are cool evolved stars with low effective temperatures between about 2500 K and 4000 K, and together spanning a large range of luminosities. They experience a mass loss rate of up to about 10^{-5} to 10^{-4} M_{sun}/year, precipitating the return of material to the interstellar medium. The mass-loss process is thought to be triggered by a levitation of the atmosphere to radii where dust can form, and radiative acceleration on dust grains dragging along the gas. However, the details of this process are surprisingly little understood, in particular for large-amplitude long-period pulsating oxygen-rich AGB stars (O-rich Miras), low amplitude (semi-regular) pulsating AGB stars, and for red supergiants. The mass-loss is initiated within the extended atmospheres located on top of the photosphere up to radii where dust can form, a crucial region that we study here by near-infrared spetro-interferometry (see sketch above).

Extended atmospheres of Mira-variable AGB stars



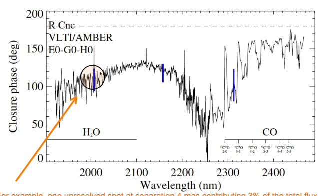
The AMBER instrument is well suited to probe the molecular layer scenario of cool evolved stars. The visibility as a function of wavelength decreases in bands of H_2O and CO, indicting a larger extension in molecular layers compared to the continuum forming layers. These visibility features can be well explained by 1-D self-excited dynamic model atmospheres (Ireland et al. 2008, 2011), where shock fronts enter the extended atmosphere and levitate it to a few photospheric radii. More details and more examples are available in Wittkowski et al. (2011).



3-D simulations of AGB stars by Freytag & Höfner (2008) show large convection cells and pulsations that give rise to roughly spherically expanding shock waves, comparable to stellar pulsations in the 1-D models. Indeed, visibility predictions of the 1-D dynamic model atmospheres above and the 3D simulations are very similar (Wittkowski, Chiavassa, et al. in progress).

In both cases, 1-D pulsating and 3-D convection models, (roughly) spherically expanding shock waves enter the extended atmosphere and levitate the material to radii where dust can form.

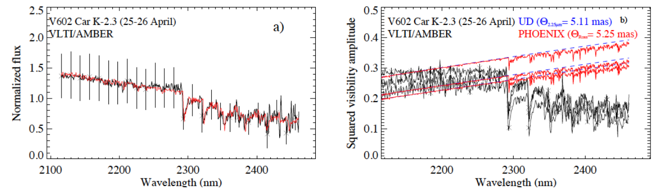
Effects of surface inhomogeneities



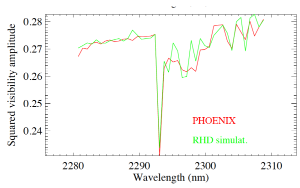
For example, one unresolved spot at separation 4 mas contributing 3% of the total flux

Wavelength-dependent closure phases indicate deviations from point symmetry at all wavelengths and thus a complex non-spherical stratification of the atmosphere. In particular, the strong closure phase signal in the water vapor and CO bandpasses is interpreted as a signature of large-scale inhomogeneities/clumps of molecular layers caused by pulsation- and shock-induced chaotic motion in the extended atmosphere (cf. Wittkowski et al. 2011). These clumps of possibly more extreme conditions compared to the averaged stellar disk may facilitate the mass-loss process.

Extended atmospheres of RSG stars

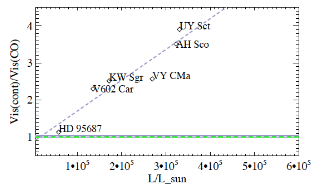


VLTI/AMBER observations with VLTI/AMBER of RSG stars show a similar shape of the visibility function versus wavelength, indicating extended molecular layers similar to AGB stars. A comparison to hydrostatic PHOENIX model atmospheres shows that the AMBER spectra can be well reproduced but that the drops of the visibility in the CO bands cannot be reproduced, indicating that the opacities are well included in the models, but that the extension of the CO layers is much too compact in the models compared to observations. More details and more examples are available in Arroyo-Torres (2015, PhD thesis ,Univ. of Valencia), and Arroyo-Torres et al. (2013, 2015)



n the case of RSG stars, 3D simulations of RSG stars lead to atmospheres as compact as hydrostatic PHOENIX models, at least at the spectral resolution of AMBER . The same has been shown for 1-D pulsation models with parameters of RSG stars instead of AGB stars. Shock fronts do not enter the atmosphere in any of these models with parameters of RSG stars. Details in Arroyo-Torres et al. (2015).

The atmospheric extension of RSG stars is observed to correlate with the luminosity, unlik for AGB stars (Arroyo-Torres et al. 2015). This points to a process of radiative acceleratic on Doppler-shifted molecular lines that levitate the material for RSG stars, as suggested by Josselin & Plez (2007).



References

Arroyo-Torres, B. 2015, PhD thesis, Univ. of Valencia, Spain
Arroyo-Torres, B., Wittkowski, M., Marcaide, J., & Hauschildt, P. J. 2013, A&A, 554, 76
Arroyo-Torres, B., Wittkowski, M., Chiavassa, A., et al. 2015, A&A, 575, A50
Freytag, B, Höfner, S. 2008, A&A, 483, 571
Ireland, M. J., Scholz, M., Wood, P. R. 2008, MNRAS 391, 1994 & 2011, MNRAS, 418, 114
Josselin, E., & Plez, B., 2007, A&A, 469, 671
Wittkowski, M., Boboltz, D. A., Ireland, M., et al. 2011, A&A, 532, L7