Structure and shaping processes of the extended atmospheres of AGB stars

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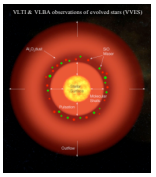


Summary

We present recent studies using the near-infrared instrument **AMBER** of the VLT Interferometer (VLTI) to investigate the structure of the **extended atmospheres of AGB stars**. These studies are mostly a part of our project of concurrent VLTI and VLBA observations, see the poster by Wittkowski, Boboltz, and Karovicova for a project overview.

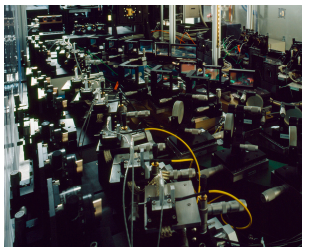
Spectrally resolved near-infrared AMBER observations of the Mira variable S Orionis have revealed **wavelength-dependent angular radii**. These data were successfully **compared to dynamic model atmospheres**, which predict wavelength-dependent radii because of geometrically extended **molecular layers**. In the near-infrared, H_2O is most important across the AMBER bandwidth, CO and other molecules are noticeable at relevant wavelength. The characteristic shape of the visibility function, mostly due to the **H_2O layer**, has subsequently also been seen for other oxygen-rich evolved stars.

The **AMBER** instrument with its capability to provide spectrally resolved visibility functions has thereby proven to be a valuable instrument to study both the **photospheric layer** at spectral channels that are little contaminated by molecular emission, **and molecular layers** (H_2O and CO) at relevant spectral channels.

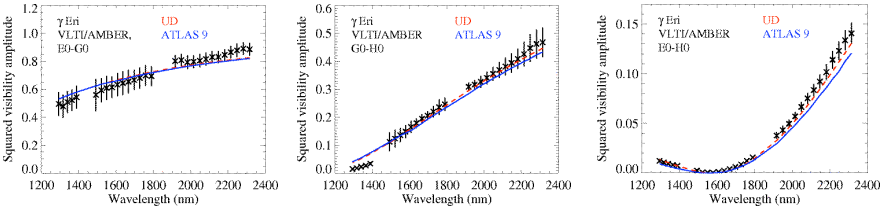
Most recently, **closure phases** measured with AMBER **also show wavelength-dependent variations**. This might indicate a **complex non-spherical stratification of the atmosphere**, and may reveal whether observed asymmetries are located near the photosphere or in the outer molecular layers.

SiO maser images provide additional information on the **morphology and kinematics** of the maser shell **at similar distances from the photosphere**.

These observations promise to give important new insights into the **shaping processes** at work during the AGB phase.

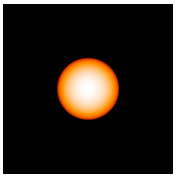


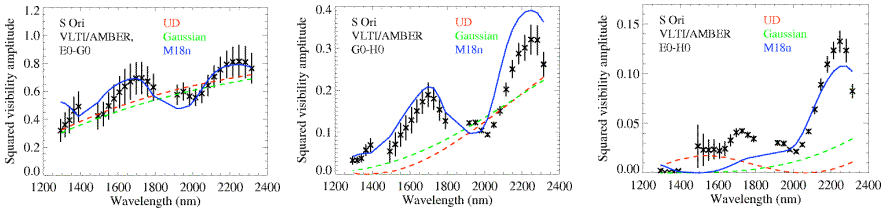
AMBER spectro-interferometry of the Mira variable S Orionis (Wittkowski et al. 2008, A&A, 479, L21):



Regular M giant (γ Sge, M0.5 III):

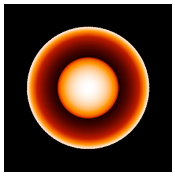
- Smooth shape of the visibility function across the J, H, K bands.
- Well consistent with a uniform disk (UD) or a standard static atmospheric model (ATLAS 9).





Mira variable (S Ori, M6.5e-M9.5e, P=430d):

- "Bumpy" shape of the visibility function across the J, H, K bands.
- Not consistent with a uniform disk (UD) or a standard static atmospheric model
- Indicates variations of the apparent radius as a function of wavelength.
- Consistent with dynamic model atmospheres (M series) that include geometrically extended molecular layers with wavelength-dependent opacity (across the J, H, K bands in low resolution mode most importantly H_2O).

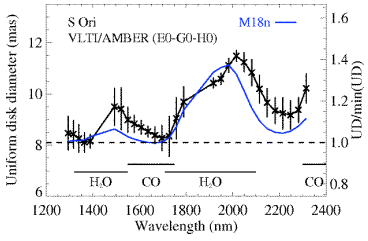


Model reference (M series): Ireland et al. 2004, MNRAS, 352, 318 & 344, 444

The *bumpy* visibility curve obtained with VLTI-AMBER in low resolution mode is a signature of (mostly) a H_2O layer lying above the continuum-forming photosphere.

This characteristic shape of the visibility curve has subsequently also been seen for other oxygen-rich evolved stars, such as the supergiant VX Sgr (Chiavassa et al, A&A, in press), or the OH/IR star IRAS 17020-5254 (Ruiz Velasco et al., poster presentation).

AMBER observations are well suited to probe the continuum-forming photosphere at spectral channels that are little contaminated by molecular emsision (e.g., 1.7 μm, 2.25 μm), as well as to probe molecular layers at spectral channels where the molecular opacity is large (e.g., H_2O opacity at 2.3-2.5μm).



S Ori UD diameter values as a function of wavelength compared to the prediction by the M18n model atmosphere.

Asymmetric shapes and shaping processes

Most recently, closure phases measured with AMBER also revealed wavelength-dependent variations (Figure to the left, work in preparation). This might indicate a complex non-spherical stratification of the atmosphere, and may reveal whether observed asymmetries are located near the photosphere or in the outer molecular layers.

SiO maser images provide additional information on the morphology and kinematics of the maser shell at similar distances from the photosphere. For some targets, these images indicate an elongated maser shell, such as for RR Aql (image to the right, work in preparation), or the maser kinematics indicate a rotation of the shell (IK Tau, Boboltz & Diamond 2005, ApJ, 625, 978; GX Mon, Boboltz et al., in preparation).

These observations promise to give important new insights into the shaping processes at work during the AGB phase. Shaping processes may include large-scale photospheric convection, external torques of a close or merging binary companion, episodic dust formation, the mergence of magnetic fields, or the interaction of slow and fast winds, with different expected effects on the different layers of the atmosphere and circumstellar environment (photosphere, molecular layer, dust shell, wind region).