Exploring the water and carbon monoxide shell around Betelgeuse with VLTI/AMBER*

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* : Based on AMBER observations made with ESO Telescopes at the Paranal Observatory under programmes ID 086.D-0351 and 286.D-5036
This research has made use of the AMBER data reduction package of the Jean-Marie Mariotti Center (Available at http://www.jmmc.fr/amberdrs)

Abstract : We present the results of the analysis of our recent interferometric observations of Betelgeuse, using the AMBER instrument of the VLTI. Using the medium spectral resolution of the instrument (R~1500) we detected the presence of the water vapor and carbon monoxide (CO) molecules in the H and K band. We derived the photospheric angular diameter in the continuum. By analyzing the depth of the molecular lines and the interferometric visibilities, we derived the column densities of the molecules, as well as the temperature and the size of the corresponding regions in the atmosphere of Betelgeuse (the MOLsphere) using a single shell model around the photosphere. Our results confirm the findings by Perrin et al. (2004) and Ohnaka et al. (2011) that the H_2O and CO molecules are distributed around Betelgeuse in a MOLsphere extending to approximately 1.3 times the star's radius.

Data Reduction

The data were reduced using the AMBER data reduction package version 3.0.3 also known as *amdlib*. The reduction package uses the P2VM algorithm described in Tatulli et al. (2007). The algorithm is straightforward but as Betelgeuse has a large apparent diameter, its visibilities are unusually low and the the atmospheric jitter is underestimated . We splitted each data set into five subset to get a better estimation of the error bars. The wavelength calibration was performed using telluric lines in the interferometric calibrator HR-1543 (F6V) flux.

Some datasets were showing unusual low visibilities : this was caused by lock loss from the fringe tracker FINITO. We had to eliminate those files using FINITO keywords in the header of the RAW files as data from the fringe tracker were not yet available (**Fig. 1**) We also observed strong negative squared visibilities (down to -10^{-10}) returned by *amdlib* which was not able to correctly fit the fringes at these wavelengths. By binning our data on the spectral resolution with a seventeen pixels wide box car filter we managed to eliminate this artifact but we also lost all the benefit of the medium resolution of AMBER. We decided to continue on with the initial resolution of the instrument and to keep the default selection criterion on the χ^2 of the fringe fitting.

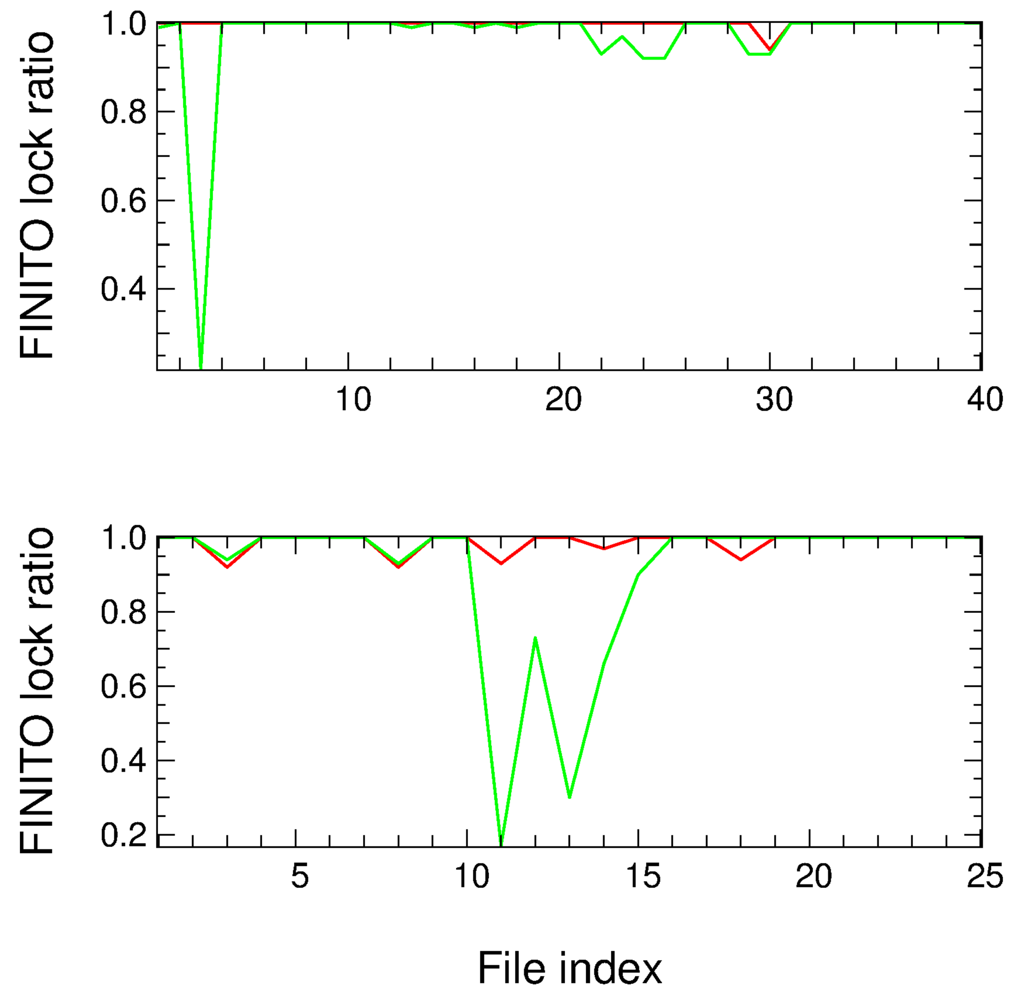


Figure 1 : FINITO lock ratio (channel 1 in red and 2 in green) for Betelgeuse in K band. 2011-01-02 (upper panel) and 2011-01-03 (lower panel)

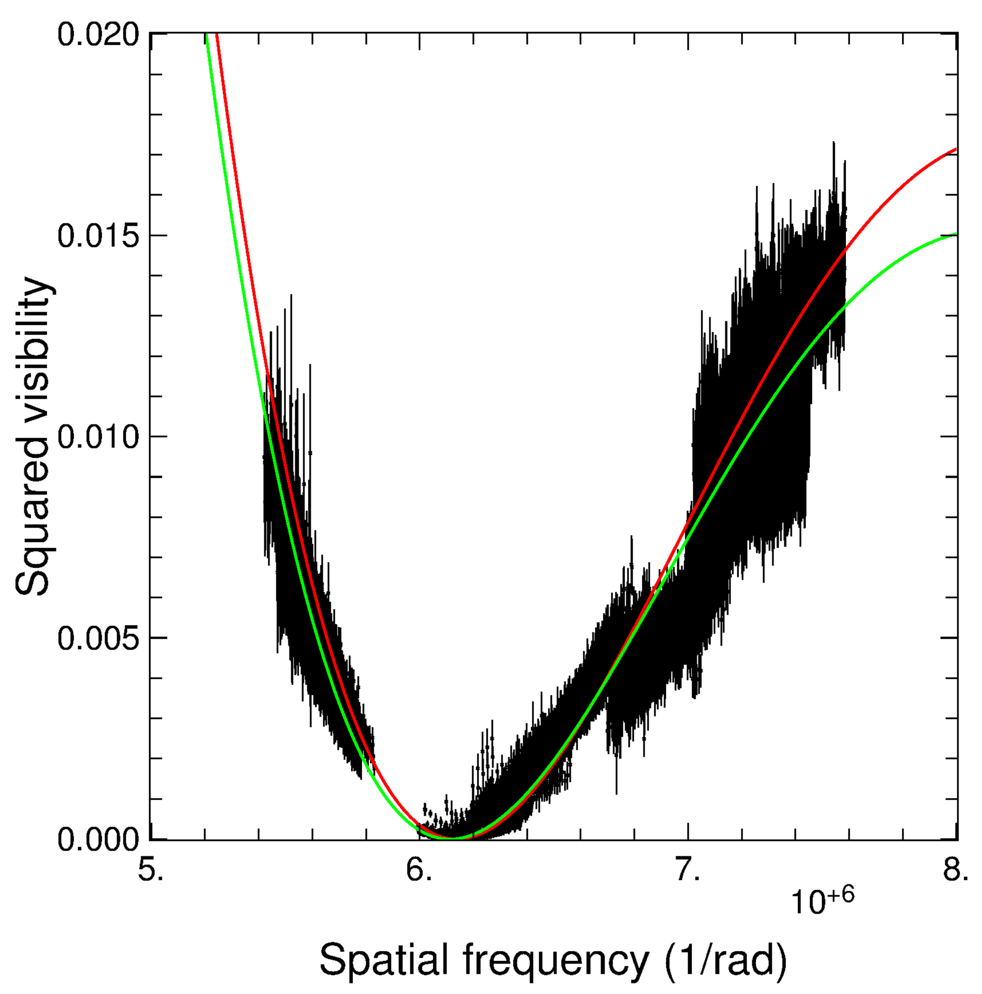


Figure 2 : Fit of the continuum data in the first lobe. Uniform disk (red), LD disk (green)

Continuum analysis

The continuum data (wavelength between 2.1 and 2.24 µm) were fitted using two models : uniform disk and limb darkening disk with a power law (Hestroffer, 1997). We only considered the data up to the top of the second lobe in order to avoid contamination by small structures contribution and therefore reduced our sample from 31577 to *8752 visibility points*. The result of this fit is presented in **Table 1** below and in **Fig. 2**. Our UD value is significantly lower than the previous ones derived by Ohnaka et al. (2009 and 2011) or Perrin et al. (2004). This can be caused by a decrease of the diameter or more probably by a change in the flux repartition on the photosphere of the star. On the other hand, our LDD value fits well with the 42.49+/-0.06 mas of Ohnaka et al. (2011).

UD fit ($I = I_0$)		LDD fit ($I = I_0\mu^\alpha$)	
Diameter (mas)	40.99 ± 0.02	Diameter (mas)	42.31 ± 0.06
		α	0.161 ± 0.008
χ^2	5.28	χ^2	4.91

Table 1 : Result of the continuum fit

Model fitting

To model our data we used a single model layer of the MOLsphere at the Local Thermodynamical Equilibrium (**Fig. 3**) as proposed by Perrin et al. (2004) , we added the line template from Partridge & Schwenke (1997) for CO and H_2O. We first checked the compatibility of the model with our data by computing a spectrum for Betelgeuse (**Fig 4**). We then perform several fit using χ^2 map to locate the best parameter values (**Fig. 5 and 6**). This work was only performed on the first CO overtone band head (*3374 points*) and is now going to be extended to all the band heads.

We obtain similar values for the diameter and temperature of the MOLsphere by fitting the CO or water column densities, the single layer model for both molecules is therefore verified. However, the temperature is a little overestimated and the column densities are underestimated (Perrin et al. 2004 and Ohnaka et al. 2011) : this can be a consequence of the lack of data in the core of the CO band heads caused by the bad fringe fitting at this wavelength by *amdlib*.

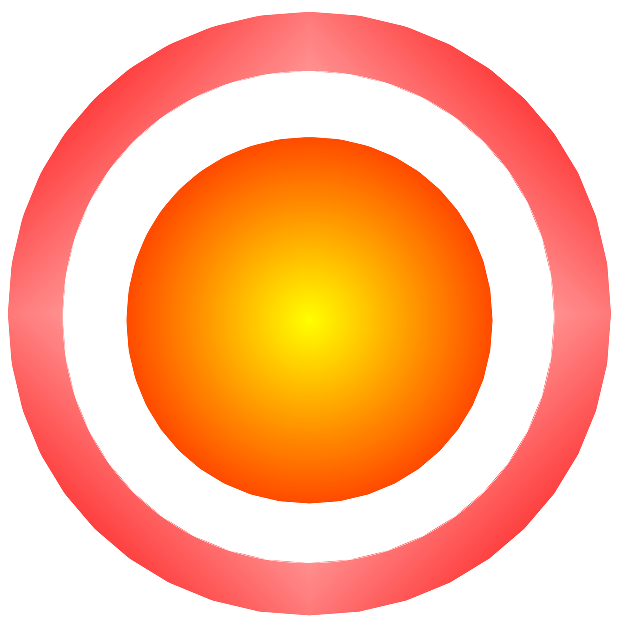


Figure 3 : Representation of the single layer model around a photosphere

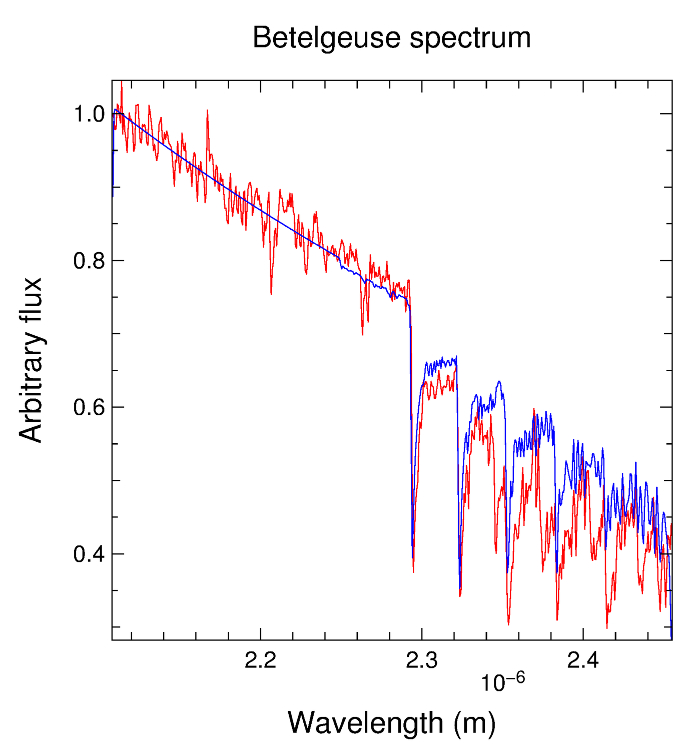
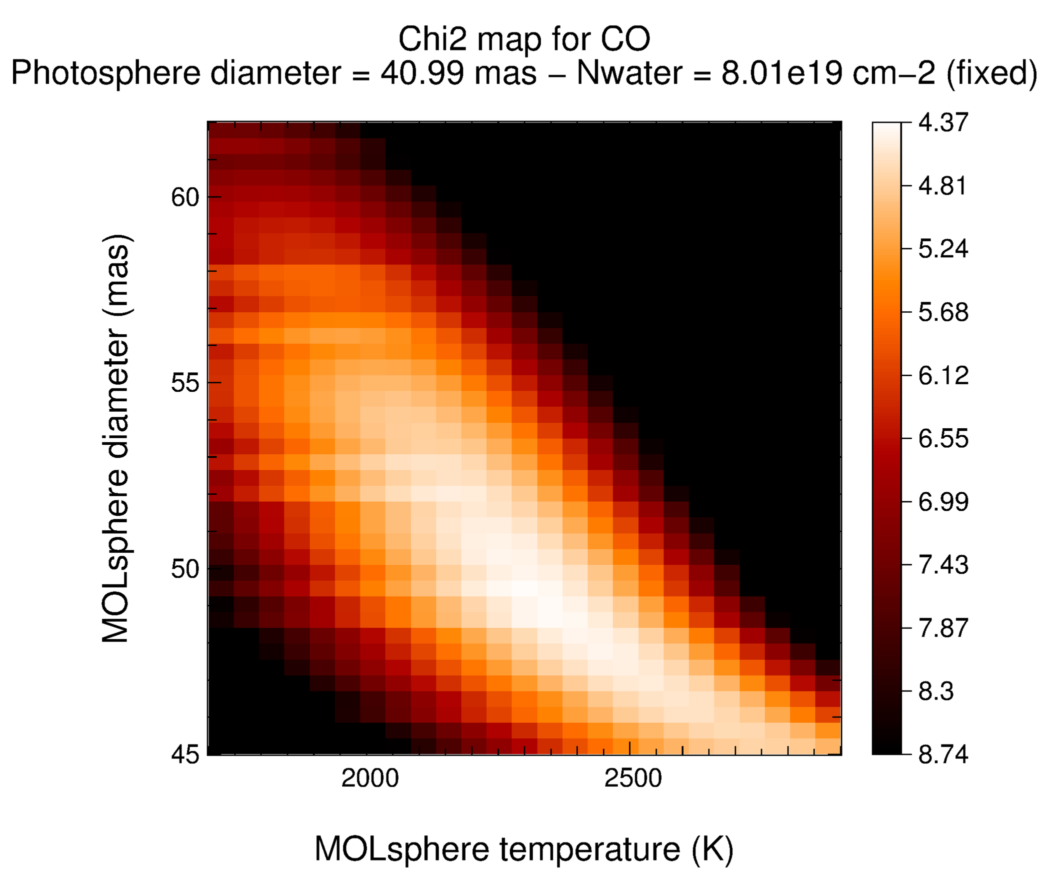


Figure 4 : Spectrum of Betelgeuse in Red – Model in blue for the fitted parameters



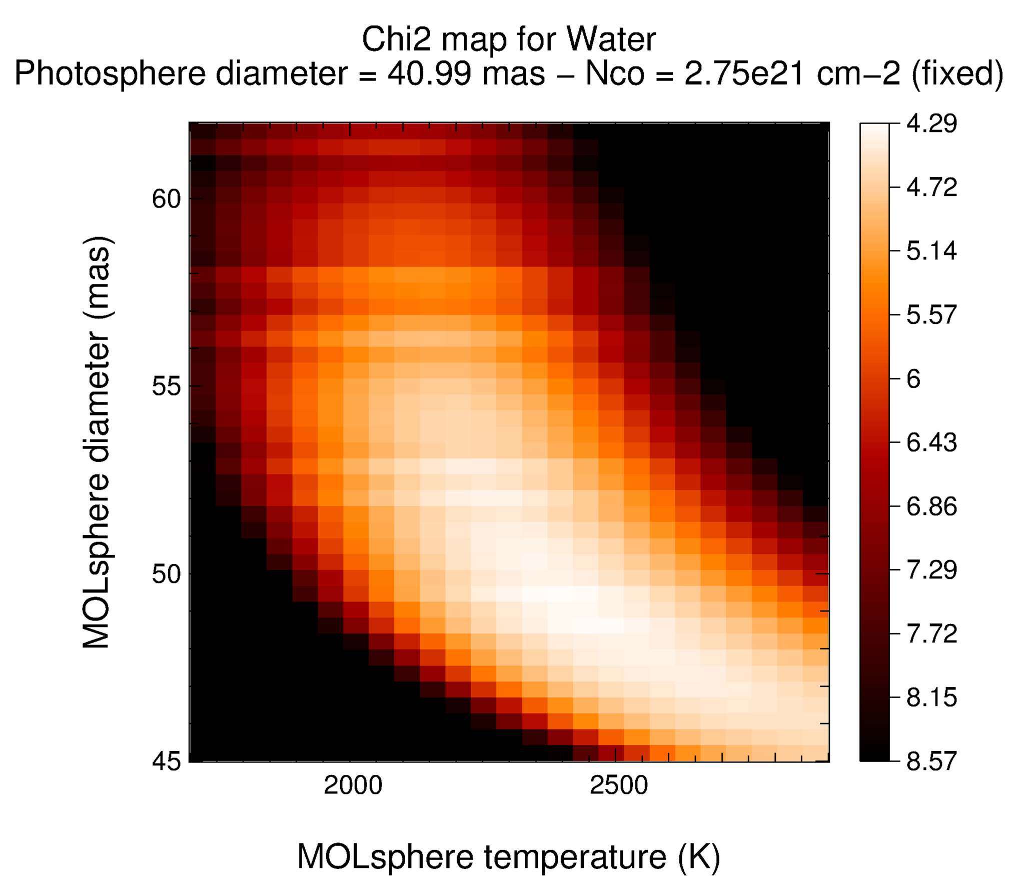


Figure 5 (left) and 6 (right) : χ^2 map obtained by fitting the single layer model to the data. The diameter of the photosphere remains constant. On **figure 5**, the water column density was fixed to 8.01×10^{19} cm^{-2} and the CO column density was fitted on each box of the grid, the minimum occurs for **T = 2300 K, θmol = 49.359 mas and Nco = 2.75×10^{21} cm^{-2}**.On **figure 6**, the water column density was fixed to 2.75×10^{21} cm^{-2} and the water column density was fitted on each box of the grid, the minimum occurs for **T = 2400 K, θmol = 49.359 mas and Nwater = 1.44×10^{20} cm^{-2} .**

Bibliography

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