# *Interferometric detection of amorphous alumina grains in Betelgeuse*

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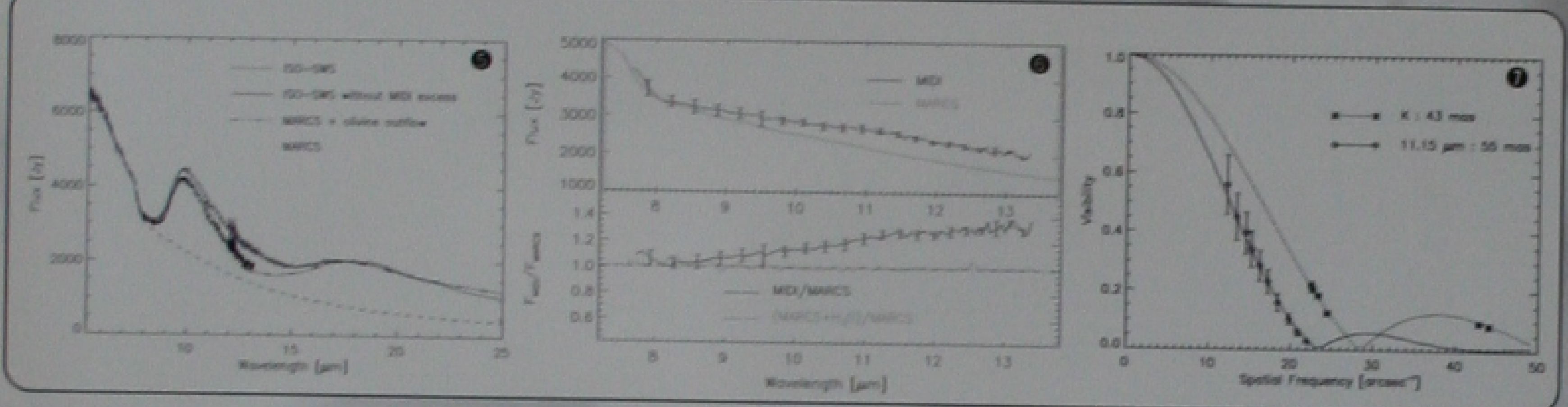
Based on Verhoelst et al. 2006, Astronomy and Astrophysics, v.447, p.311

## 1. Introduction

Evolved red supergiants such as Betelgeuse, like their less massive AGB counter-parts, are also embedded in a circumstellar environment (CSE) of molecular layers, gaseous outflow and dust. What sets them apart, however, are the low amplitude pulsations, relatively high effective temperatures and sometimes the presence of a chromosphere. It is therefore questionable whether the mechanism driving their mass-loss is similar to that of AGB stars, i.e. a complex interplay between pulsations, shock waves, molecular opacity and dust condensation ([1], [2] and references therein).
Its proximity and size make Betelgeuse a prime target for a spectral and spatial study of the close CSE. [3] already performed such a study for the gas fraction of the CSE. We present here in short our analysis of the molecular and dusty environment around Betelgeuse using IR spectroscopy and interferometry. For a more detailed report on these results, we refer to [6].

## 3. The mid-IR



In the mid-IR,the silicate emission evident in the ISO-SWS spectrum (Fig. 5) does not enter the narrow-slit N-band spectroscopy (MIDI single UT photometry, Fig. 6) clearly demonstrating that the silicates are located at least 0.5" (20 $R_\star$) from the central star. An optically thick, non-silicate excess is detected 0.5 stellar radii above the photosphere, as shown by the narrow-slit spectrum and by the ISI 11 micron interferometry ([8], Fig. 7).

## 5. Discussion and Conclusions

We find that the IR spectroscopic and interferometric data are best explained with a model consisting of a typical red supergiant photosphere, above which sits, at about 0.5 stellar radii, a stationary(?) layer containing an optically thin amount of hot water vapour and a mid-IR optically thick column of amorphous alumina grains. Much further out, starting at several tens of stellar radii, amorphous olivine dust grains emit in the 9.7 and 18 µm silicate bands.

We prefer the thin layer of water to the altered photospheric temperature distribution because water lines have been observed in high-resolution mir-IR spectra. This can only be understood if the water is not located behind the optically thick alumina layer, i.e. if it's not photospheric. The next step concerning the molecular environment should be the modelling of such a layer in chemical equilibrium: the inclusion of CO, SiO and TiO should introduce observable effects in the spectrum, and will possibly influence the photospheric abundance determination (now taken from [11]).

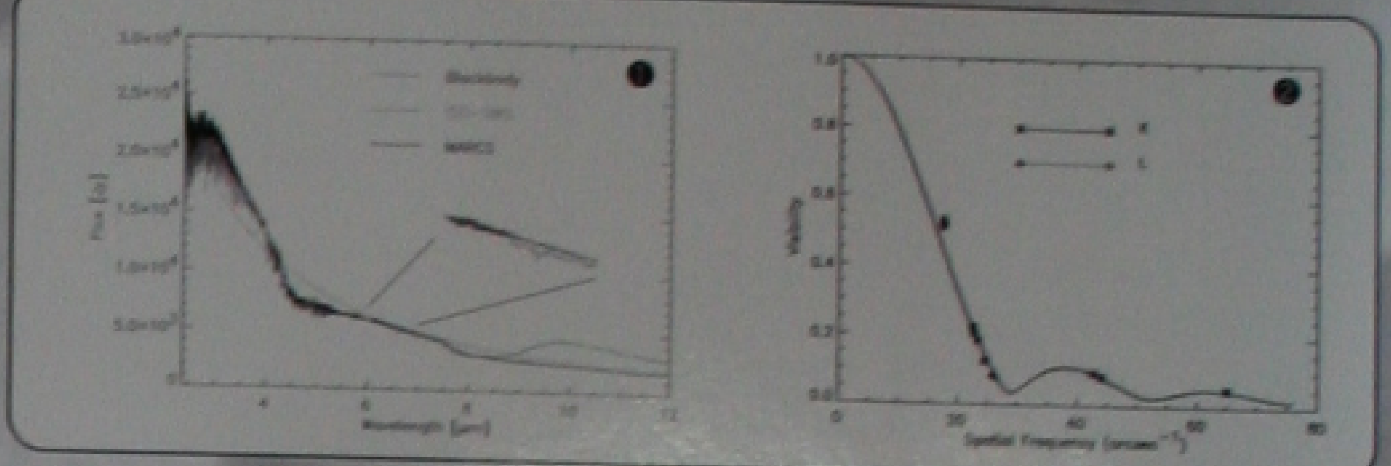
Hitherto, the dust shell around Betelgeuse was believed to contain only silicates and these were found to be located far from the central star. The fact that we find alumina much closer to the photosphere is consistent with its higher stability temperature and suggests that dust nucleation is still taking place. Fully consistent oxygen-based dust wind models for late-type stars do predict such a region of high alumina density at this location. However, in these models, alumina is not the first species to nucleate ($TiO_2$ is), and moreover, it doesn't have the required opacity at shorter wavelenghts to experience siginificant radiative acceleration (Woitke, priv. discussion). It is therefore still unclear how this inner region with alumina grains relates to the outer silicate shell.

Another open question is how this medium temperature layer can co-exist with the hot chromospheric component. Inhomogeneities must be the answer here, but so far the mid-IR interferometric data do not show large scale asymmetries. Note that large hot spots have been observed at shorter wavelengths.

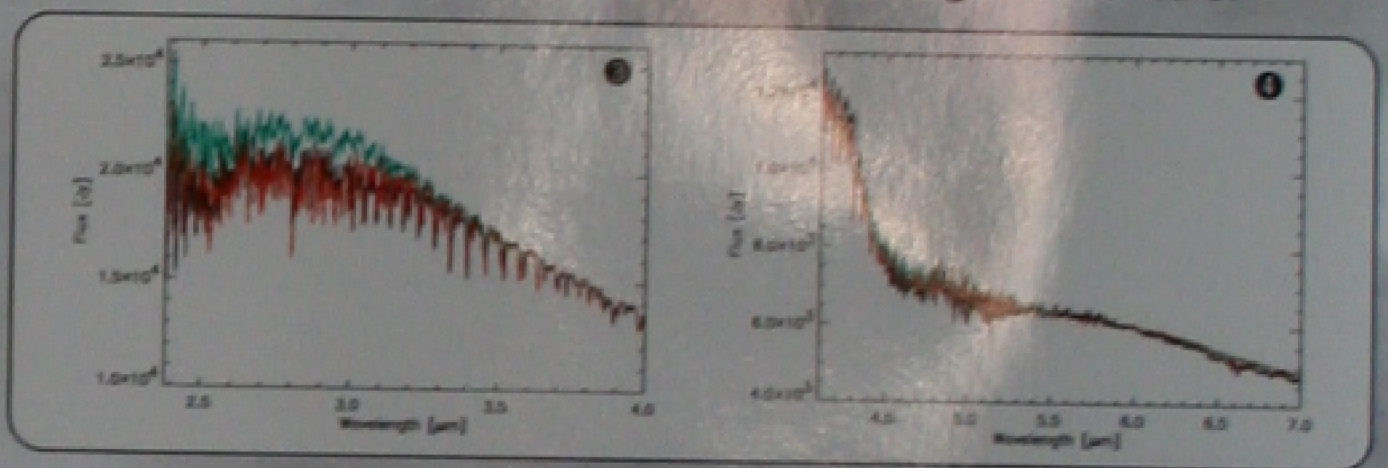
We conclude that, although we are far from understanding mass loss in oxygen-rich environments, dust nucleation and condensation appear to take place close to the photosphere, and that red supergiants are interesting targets for the study of mass loss mechanisms.

Background: fracture surface of an alumina ceramic

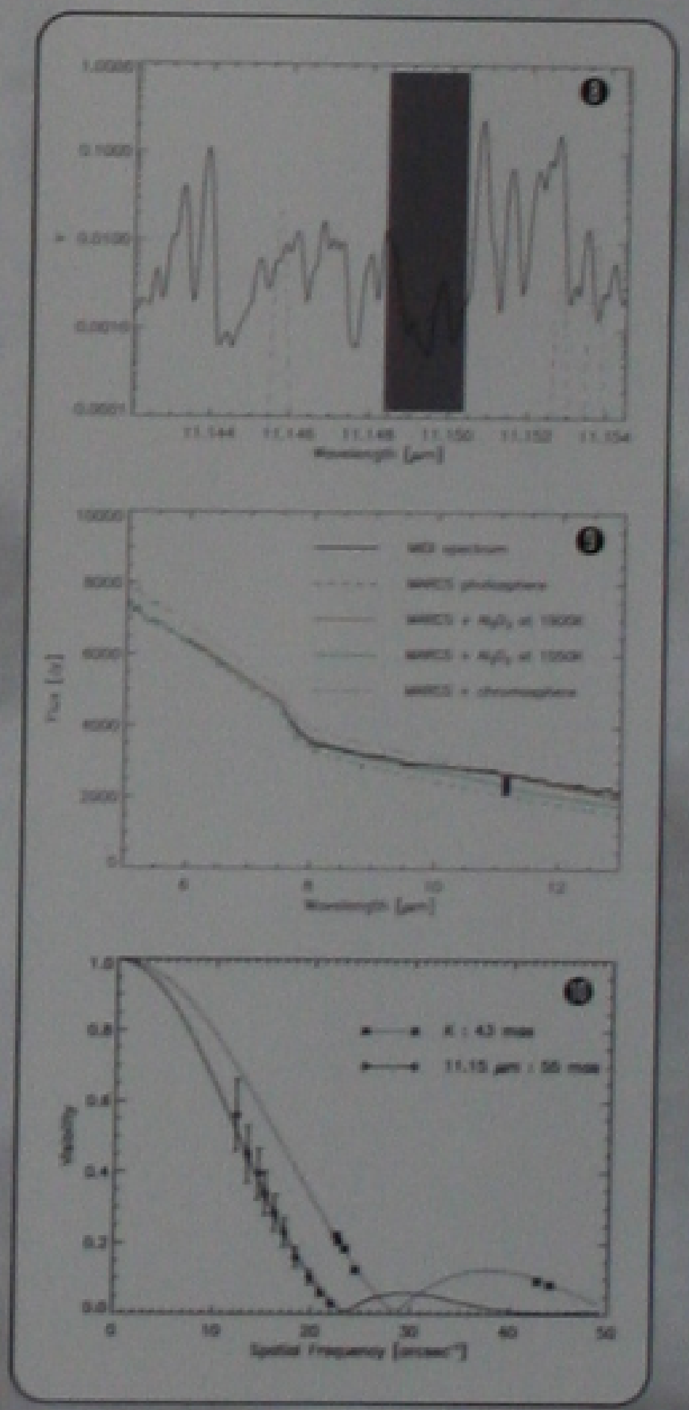
## 2. The near-IR



The ISO-SWS spectrum (Fig. 1) reveals some water absorption lines which are not present in a dedicated MARCS model atmosphere. They are too weak to influence the broad-band near-IR interferometry with FLUOR (K, [4]) and TISIS (L, [5]) on IOTA: these data are consistent with photometric diameter estimates and the limb-darkening is fully reproduced by the MARCS model (Fig. 2). The additional water lines can be included in the model by either (1) an optically thin water layer around the photosphere ([6], Fig. 3 and 4, black is ISO, green MARCS and red MARCS + water layer) or (2) a lowered temperature profile in the outermost layers of the model ([7]). Neither alteration can be detected in the broad-band interferometry but it will be easy to decide upon this issue using AMBER on the VLT-I. Moreover, strong evidence for the former option is given in Sect. 5.



## 4. Molecular, Chromospheric or Dusty?



What is the origin of this excess emission?

It is unlikely to be molecular because only SiO and water have significant lines within the ISI bandpass (Fig. 8) but these cannot be optically thick because that would show in the near-IR, where we found only evidence for an optically thin water layer (Sect. 2)

Betelgeuse is know to have a hot chromospheric component and an ionised wind, but both the amount and shape of the excess seen in the N-band are incompatible with the high temperatures in a chromosphere and with the wavelength dependence of its opacity (See Fig. 9 for an optically thin chromospheric component).

The last and most promising candidate is dust: we find that we can reproduce both the ISI visibilities (Fig. 10) and the MIDI (Fig. 9) and ISO (Fig. 5) spectra with the addition of amorphous alumina grains in the layer already containing the water found in the near-IR.

References:

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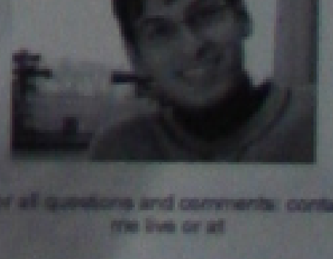

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