Probing the mass-loss process in O-rich AGB stars
The wind of RT Virginis

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Mass loss is a fundamental, observationally well-established feature of AGB stars but many aspects of this process still remain to be understood. To date, self-consistent dynamical models of dust-driven winds reproducing the observed mass-loss rates for M-type stars seem to require that iron-free dust grains in the close circumstellar environment grow to larger sizes than previously assumed. In order to study the chemistry and grain-size in regions where the mass loss is initiated, high spatial resolution interferometric observations are necessary. We have observed the M-type star RT Vir using the VLTI/MIDI instrument to constrain the innermost mineralogy through modeling the 10-micron silicate feature.

Spectro-Interferometric observations

The Very Large Telescope Interferometer (VLTI) of ESO's Paranal Observatory was used with MIDI, the mid-infrared (λ=8.0-13 μm) interferometric recombiner. MIDI combines the light of two telescopes and provides single-dish acquisition images, flux-calibrated spectra and visibilities in the N band atmospheric window. The GRISM mode providing a spectral resolution of about 230 was used. Observations of RT Vir were conducted in 2009 and 2011 with the VLT auxiliary telescopes (ATs) G0-H0, D0-H0, A0-G1, and A0-K0. This provides projected baselines in the range of 30 to 128 m probing spatial scales going from the stellar photosphere to regions located above the dust condensation zone ($\sim$5 stellar radii). The data reduction software package MIA+EWS was used to calibrate the spectra and visibilities.

The correlated flux

The strategy aims at constraining the dust contribution in the very inner part of the circumstellar environment. For that measurements are interpreted in terms of correlated flux (see Fig. 1). The definition of the correlated flux for an AGB star is the following

$$CF = F_\star \times V_\star + F_{\rm mol} \times V_{\rm mol} + F_{\rm dust} \times V_{\rm dust} \qquad (1)$$

where $F_\star$, $F_{\rm mol}$ and $F_{\rm dust}$ are the flux contributions of the central star, the molecular layer and the dusty environment to the total flux expressed as $F^{\rm tot} = F_\star + F_{\rm mol} + F_{\rm dust}$, while $V_\star$, $V_{\rm mol}$ and $V_{\rm dust}$ are the corresponding contributions to the visibility.

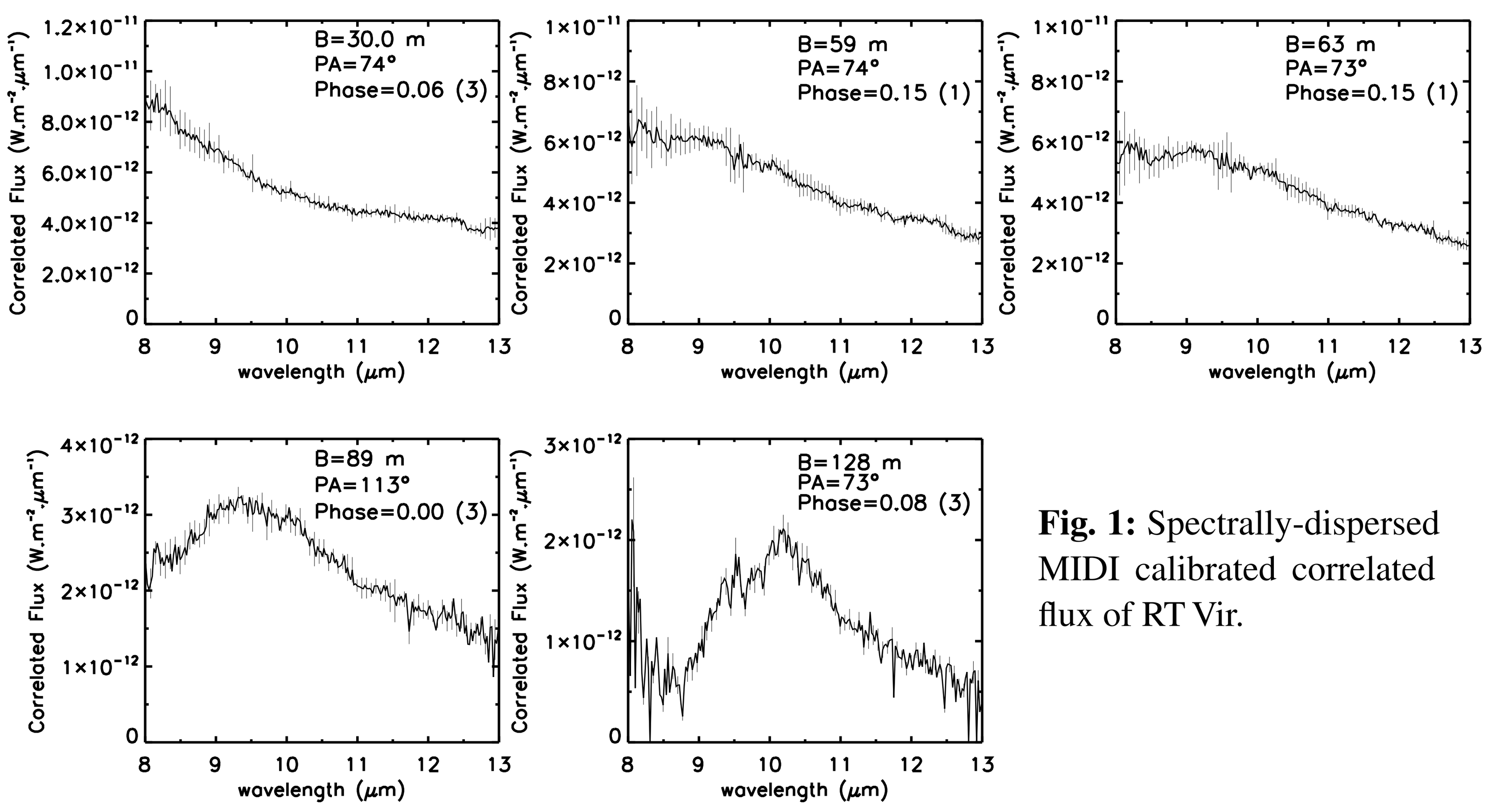

Fig. 1: Spectrally-dispersed MIDI calibrated correlated flux of RT Vir.

Considering a dust envelope extending from 4 stellar radii (dust formation zone), the contribution of the dusty environment of RT Vir to the visibility is negligible for baselines larger than 80 m and Eq. 1 becomes $CF(B_p > 80\,m) = F_\star \times V_\star + F_{\rm mol} \times V_{\rm mol}$.
By modeling the large baselines CF measurements of RT Vir, we can then predict the contribution of the central star plus molecular environment to the small baselines correlated flux. Finally, by subtracting this last contribution from the correlated flux measurements at small baselines, we can retrieve the contribution of the inner dusty environment to the correlated flux as follows

$$CF_{\rm dust} = CF(B_p < 80\,m) - CF^{\rm model}_{\star+{\rm mol}}(B_p < 80\,m) \qquad (2)$$

Stellar photosphere and molecular environment

The first step of the study aims at reproducing the large baselines (128 and 89 m) correlated flux measurements probing the photosphere and the extended molecular environment ($\sim$2 stellar radii).
The determination of the stellar parameters is done by comparing hydrostatic stellar atmospheric models to the spectrophotometric data of RT Vir up to 5 μm. A least-square fitting minimization was completed from a grid of MARCS models (Gustafsson et al., 2008, A&A 486, 951).
The extended molecular environment (MOLsphere) is then added to the best-fitting MARCS model photosphere. Opacities of H_2O and SiO molecular gas in local thermodynamical equilibrium were derived varying the gas temperature and the column densities in the radial direction (Ohnaka, 2005, A&A 429, 1057).
The corresponding correlated flux obtained by Hankel transform of the MARCS+MOLsphere intensity distribution are then fitted to the 89 and 128 m baselines correlated flux measurements (see Fig. 2). As expressed in Eq. 2, the subtraction of the synthetic correlated flux of the central star plus molecular environment from the correlated flux measurements at small baselines allows to predict the contribution of the inner dusty environment to the correlated flux (see Fig. 3).

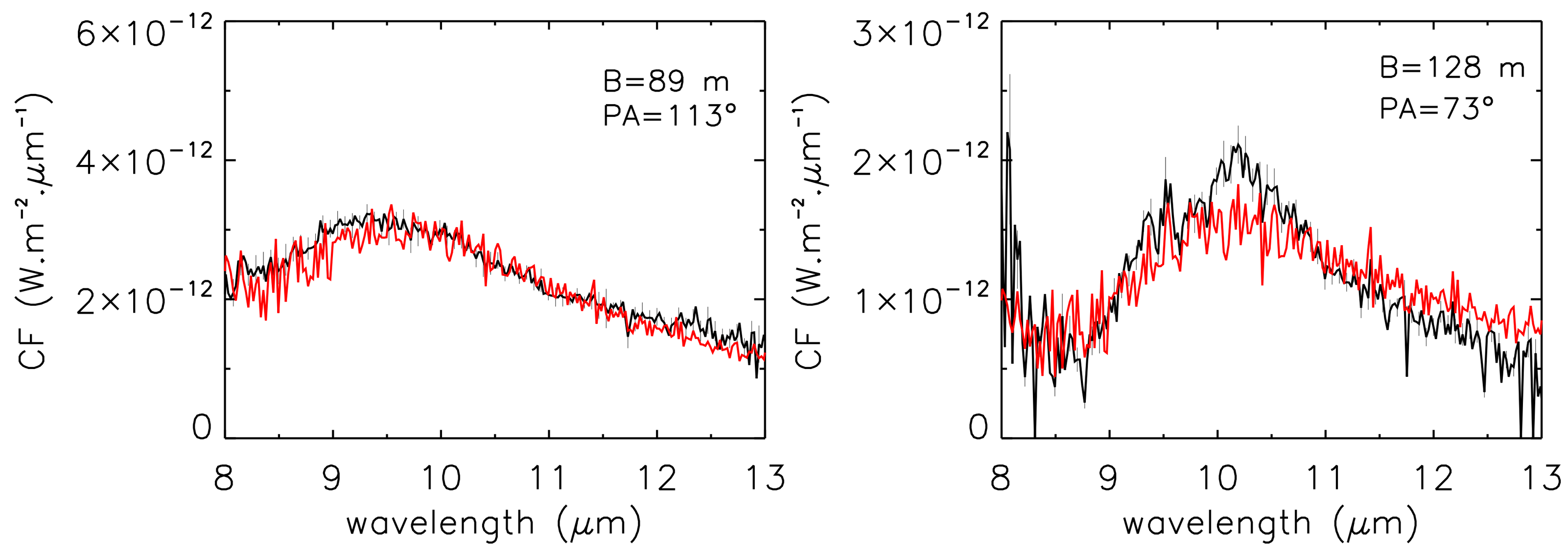

Fig. 2 Best fitting MARCS+MOLsphere model (red solid line) to the 89 (left panel) and 128m (right panel) correlated flux measurements (black solid line + error bars).

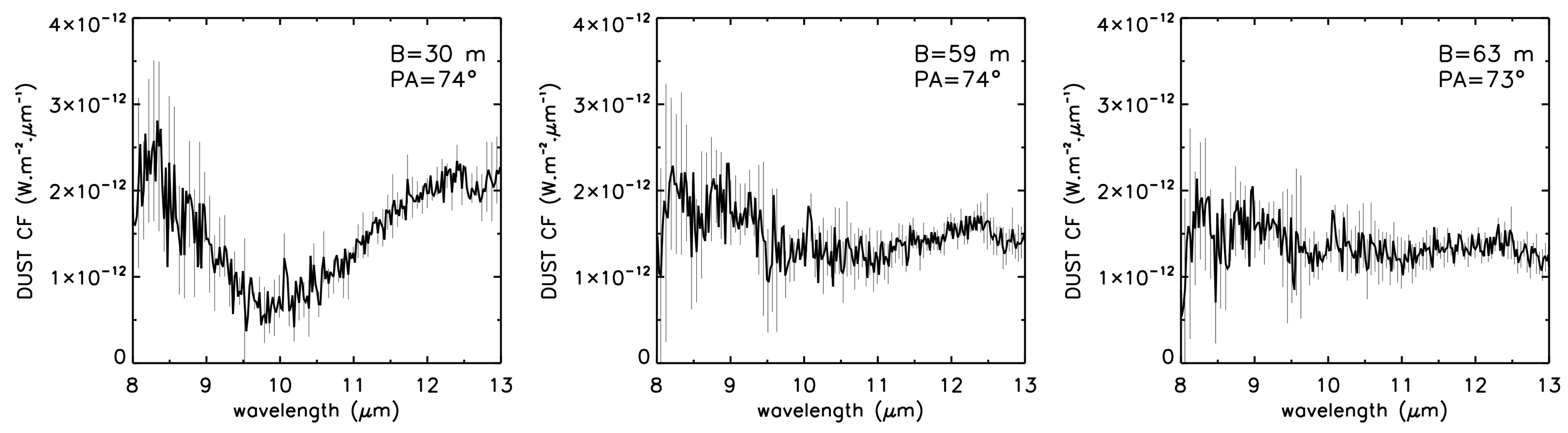

Fig. 3 Inner dust contribution to the 30, 59 and 63 m baselines correlated flux.

The innermost mineralogy

The second step of the study aims at modeling the inner dust contribution to the correlated flux (see Fig. 3) to constrain the innermost mineralogy of RT Vir.
The DUSTY code (Ivezić & Elitzur, 1997, MNRAS 287, 799) solves the problem of radiation transport in a circumstellar dusty environment by calculating the radiative transfer equation in plane-parallel or spherical geometry. The inner dust contribution to the 30 and 60 m baselines correlated flux (see Fig. 3) are fitted independently with DUSTY. The reason for that comes from theoretical predictions and laboratory experiments showing that the mineralogy depends on the temperature and density condition of the environment. In order to account for the different spatial scale mineralogies, 3 different dust compounds were considered in the modeling (i) Amorphous aluminium oxide (Al_2O_3: Begemann et al., 1997, ApJ 476, 199), (ii) Spinel ($MgAl_2O_4$: Fabian et al., 2001, A&A 373, 1125) and (iii) Amorphous forsterite (Mg_2SiO_4 : Jäger et al., 2003, A&A 408, 193). Those species were chosen knowing that they are stable to the temperature and pressure conditions of the closest regions ($\sim$3 to 5 stellar radii) probed by the 30 and 60 m baselines measurements. Pure grains and grain mixture compositions are considered. In the case of grain mixtures, 3 combinations involving fractional abundances of 35, 50 and 65% of forsterite in addition to 60, 45 and 30% of alumina were considered. Fractional abundance of spinel is usually very small compared to the other components and was fixed to 5% for all involved mixtures. Grids of models were computed based on the different chemical compositions and free parameters of grain size and optical depth. The best fit of the 30 m baseline probing regions around 5 stellar radii reveals a pure composition of big ($\sim$1.5 μm) forsterite grains. The best fit of the 60 m baseline probing regions around 3 stellar radii reveals a grain mixture of 65% Mg_2SiO_4 + 30% Al_2O_3 + 5% $MgAl_2O_4$. Fig. 4 presents the best fits of the inner dust contribution to the correlated flux.

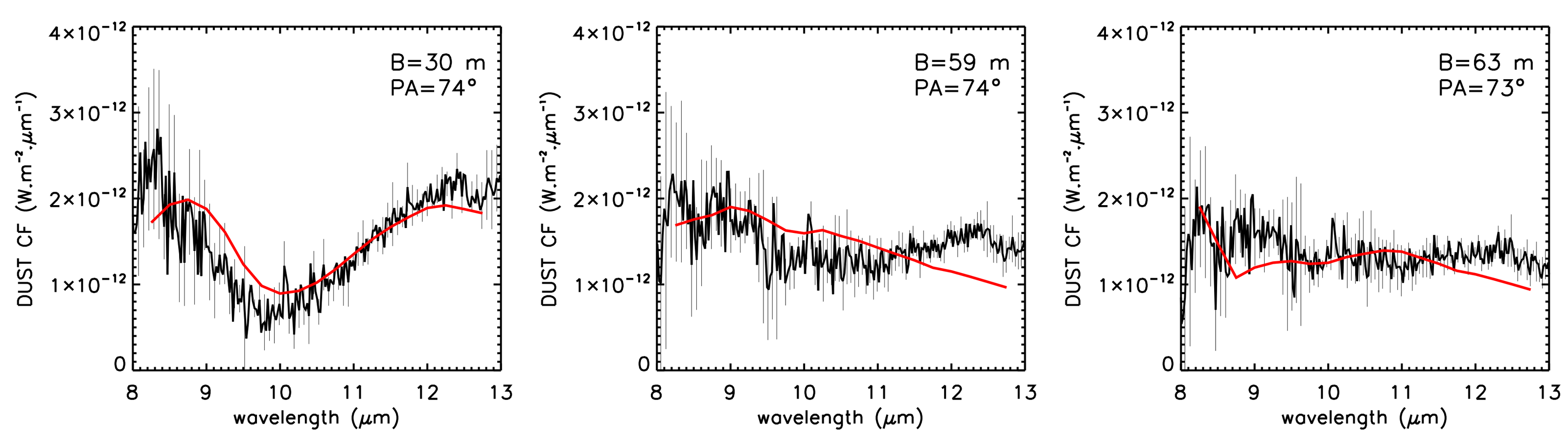

Fig. 4 Best fits of the inner dust contribution to the correlated flux from 3 (60 m baselines) to 5 (30 m baseline) stellar radii.

Conclusions

The inner dust contribution to the correlated flux of RT Vir shows a large change in the spectral appearance from 3 to 5 stellar radii. The 3 stellar radii region reveals a mixture of alumina, forsterite and spinel in good agreement with the dust condensation scenario. Around 5 stellar radii, only a pure chemistry composed of micrometer-size forsterite grains is able to reproduce the data. This last chemistry is in good agreement with the scattering scenario proposed by S. Höfner (2008, A&A 491, 1) explaining the mass-loss process of O-rich stars.