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The Carbon Stars Adventure
Modelling C-star atmospheres†

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Abstract. We compare in a systematic way spectrometric, photometric and mid-infrared (VLTI/MIDI) interferometric measurements with different types of model atmospheres. Self-consistent dynamic model atmospheres in particular were used to interpret in a consistent way the dynamic behavior of gas and dust. The results underline how the joint use of different kind of observations, as photometry, spectroscopy and interferometry, is essential to understand the atmospheres of pulsating C-rich AGB stars. The sample of C-rich stars discussed in this work provides crucial constraints for the atmospheric structure.

Keywords. instrumentation: high angular resolution – techniques: interferometric – stars: AGB and post-AGB – stars: atmospheres – stars: circumstellar matter – stars: fundamental parameters

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1. Introduction

In the atmospheres of Asymptotic Giant Branch stars, molecules and dust form, in combination with stellar pulsations a stellar wind is triggered. All the physical processes happening there, as pulsation, convection or transport of nucleosynthesis products, cause the atmospheres to be the crucial interface between the stellar interior and the interstellar medium. Also, AGB stars contribute significantly to the total flux emitted by galaxies containing populations of young/intermediate ages. These aspects makes the understanding of C-rich AGB star atmospheres indispensable in the context of stellar evolution and models of galaxies.

The first target of our study was RU Vir, for which the dynamic model atmospheres fit well the ISO/SWS spectra in the wavelength range $\lambda = [2.9 - 13.0]$ μm. However, the object turned out to be "peculiar" (Rau *et al.* 2015). Thus further targets are included in this work and will be presented in Rau *et al.* (in prep.).

2. Observations and methods

Our aim is to constrain the model atmospheres with different kind of observations in a consistent way.

It has been demonstrated by Aringer *et al.* (2009) that hydrostatic models can reproduce the C-rich atmospheres if the pulsation is not pronounced, and also the work on RU Vir shows this (Rau *et al.* 2015). For strongly pulsating stars, the necessity of dynamic models

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becomes evident: the evolution of the star leads to the expansion of the atmosphere and shock waves propagating through it. The dynamics then *need* to be considered through proper modelling. Therefore, we used in this work dynamic model atmospheres (DMA) from Mattsson *et al.* (2010) and model spectra from Eriksson *et al.* (2014). The system of equations for hydrodynamics, frequency-dependent and spherically symmetric radiative transfer have been solved in those models, plus they include a description of the time-dependent dust grain formation, growth, and evaporation with a set of equations.
Photometric, spectroscopic and interferometric data have been used. Spectra of ISO ($\lambda = [2.4, 25.0]$ μm, de Graauw *et al.* 1996), IRTF ($\lambda = [0.8, 5.0]$ μm, Rayner *et al.* 2009 and IRAS ($\lambda = [7.0, 23.0]$ μm, IRAS catalogs) were available for the chosen sample of carbon-rich Miras. Photometric data were available in B, V, R, I, J, H, K and additionally L, M, $IRAS12$, $N1$, $N2$, $N3$ data, if available. Interferometry is the optimal tool to study the stratification, and in particular we worked with MIDI data at the ESO/VLTI. MIDI (Leinert *et al.* 2003) provides spectrally dispersed visibilities, photometry, and differential phases in the N band ($\lambda = [8.0, 13.0]$ μm).

3. Results and conclusions

The sample of C-rich Mira stars discussed in this work includes: RU Vir, R Lep and R For. A general trend of the results is that the DMA fit the spectra and photometry rather well, except for the visible part of the spectrum of RU Vir. With regard to the interferometric observations, there is a good agreement between models and observations at 8.5 μm, while at 11.4 μm the shape of the visibility curves are not reproduced well by the models. Indeed, the data at the two wavelengths are of similar shape, but the visibility levels are different due to a different contribution from dust shells at longer wavelengths. We suspect that the overall distribution of the dust emitting beyond 10 μm is not correct in the models. A detailed description of the results will be presented in Rau *et al.* (in prep.), together with an extensive comparison between DMA and a larger sample of C-rich Mira observations.
Overall, the increased sample of C-rich stars of this work provides further constraints for the atmospheric structure. Eventually, the second generation VLTI instrument MATISSE, the VLT instrument CRIRES and the E-ELT instrument METIS, all working in the L-, M- and N-bands, will be perfect tools to detect and study asymmetries and the global distribution of molecules and dust: MATISSE will allow imaging at the highest angular resolution while CRIRES and METIS will give information on the kinematics.

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