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 consis-
tent 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

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 interstel-
lar medium. Also, AGB stars contribute significantly to the total flux emitted by galaxies
containing populations of young/intermediate ages. These aspects makes the understand-
ing 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 \( \lambda = [2.9 – 13.0] \) \( \mu m \). 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 \((\lambda = [2.4, 25.0] \mu m, \text{de Graauw et al. 1996})\), IRTF \((\lambda = [0.8, 5.0] \mu m, \text{Rayner et al. 2009})\) and IRAS \((\lambda = [7.0, 23.0] \mu m, \text{IRAS catalogs})\) 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 \((\lambda = [8.0, 13.0] \mu m)\).

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 \(\mu m\), while at 11.4 \(\mu m\) 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 \(\mu m\) 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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