Why Galaxies Care About AGB Stars: A Continuing Challenge through Cosmic Time
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Abundances of C, N, and O in AGB Giants and Model Atmospheres

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Abstract. Based on hydrostatic models we discuss the effects of molecular opacities and abundance changes concerning C, N or O on the atmospheric structures, spectra and photometric properties of C/M AGB giants.

Keywords. stars: atmospheres, stars: abundances, stars: carbon, stars: AGB and post-AGB

1. Model Atmospheres and Opacities

In this discussion we focus on the warmer AGB stars with effective temperatures above about 2800 to 2900 K showing weak or no pulsation. Their observable properties may be simulated by classical hydrostatic models (e.g. Aringer *et al.* 2009, Aringer *et al.* 2016), while cooler objects with stronger pulsation are dominated by shock waves, dust formation and mass loss plus deviations from spherical symmetry as well as from chemical and local thermodynamic equilibrium. Due to the uncertainties related to the combination of all these complicated phenomena, which are discussed in several contributions presented in this symposium (e.g. Bladh *et al.*, Eriksson *et al.*, Gobrecht *et al.*, Freytag *et al.*, this volume), it remains very difficult or impossible to study abundance effects in the AGB giants with low temperatures and large amplitudes.

In the hydrostatic case the model structures and spectra are mainly determined by a huge number (10^8 to 10^9) of molecular and atomic transitions absorbing a large fraction of the stellar radiation. In Fig. 1 we demonstrate the situation for a typical cool M giant, where TiO and water are the dominant species. Due to the strong influence of the opacities on the atmospheres it is essential to treat the corresponding input data and chemical abundances for the calculation of models and observable properties in a consistent way. Thus, one needs line lists, which are complete enough to derive realistic temperature-pressure structures and accurate enough to get good medium and high resolution spectra. Unfortunately, such data are not always available (especially for carbon stars).

An example for the problems with the molecular opacities in carbon giants can be seen in Fig. 2, where we present C_2H_2 spectra based on various available sources. In addition to the HITRAN 2008 list, which contains only a limited number of measured lines, the plot includes the old SCAN data (Jørgensen *et al.* 1989) still used in our standard C star models and the more recent ASD1000 data (Lyulin & Perevalov 2017). The latter are expected to be more accurate, but above 1000 K they may not be complete. We find a large difference between SCAN and ASD1000, which has also a huge impact on the atmospheric structures. This becomes obvious, when we compare the result of a

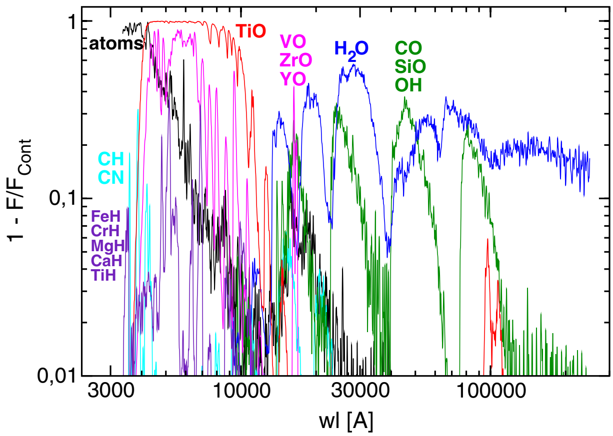

Figure 1. Low resolution $R = 200$ spectra for various species computed from a COMARCS M star model with $T_{\rm eff} = 2800$ K, $\log(g\ [{\rm cm/s^2}]) = 0.0$, solar mass and abundances. The data are subtracted from a calculation without line opacities.

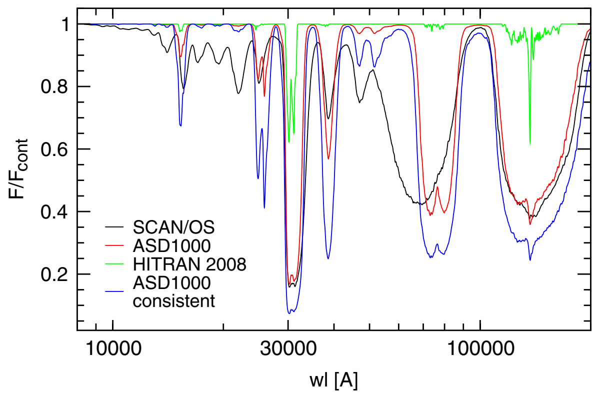

Figure 2. Low resolution R = 200 C_2H_2 spectra computed from a COMARCS carbon star model with $T_{\rm eff} = 2800$ K, $\log(g\ [{\rm cm/s^2}]) = 0.0$, C/O = 1.4, solar mass and metallicity using different opacity data (see text). The spectra are normalised relative to a calculation without lines.

consistent calculation with ASD1000 to one, where the new list was only taken for the spectral synthesis. Thus, we must conclude that there is still a considerable uncertainty affecting the models of cool C giants.

2. Models with an Enhancement of C, N & O

The study presented here is based on the COMARCS grid of hydrostatic spherical model atmospheres for K, M, S and C stars (Aringer *et al.* 2016). It covers effective temperatures between 2500/2600 and 4500/5000 K, $\log(g\ [{\rm cm/s^2}])$ values from $-1/0$ to 5 and metallicities in the range $-2 \leqslant [{\rm Z/H}] \leqslant +1$. C/O ratios between 0.3/0.55 and 2/29 have been considered. In addition, sequences of C and M giant models with deviating oxygen and nitrogen abundances are available in order to derive correction terms, which can be applied to the standard grid, when colours or spectra in synthetic stellar populations are predicted. All spectra and photometric data may be found at http://starkey.astro.unipd.it/atm.

An example for the photometric results can be seen in Fig. 3, where we plot $(J-K)$ as a function of the carbon excess [C$-$O] for C giant models having 2800 and 3300 K. If

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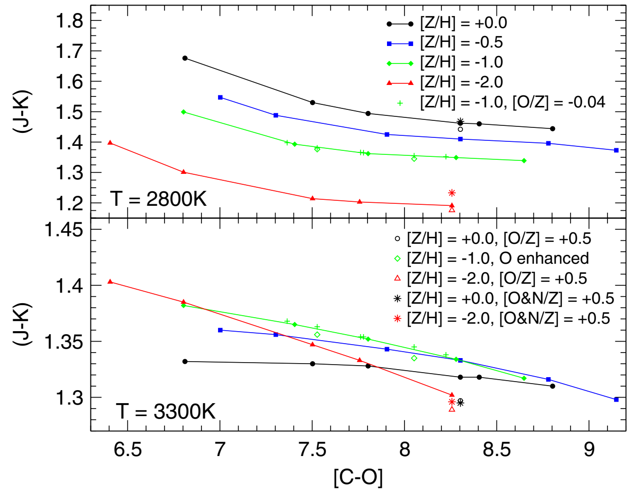

Figure 3. The $(J-K)$ colour as a function of [C$-$O] for COMARCS carbon star models with $\log(g\ [\mathrm{cm/s^2}]) = 0.0$ and one solar mass having $T_{\mathrm{eff}} = 2800$ K and 3300 K. The colours in the plot correspond to different metallicities [Z/H]. Filled symbols connected by lines represent the sequences with standard composition where [O/Z] and [N/Z] remain 0.0. Crosses and open symbols mark results for a deviating oxygen abundance. Asterisks stand for an enrichment of O plus N.

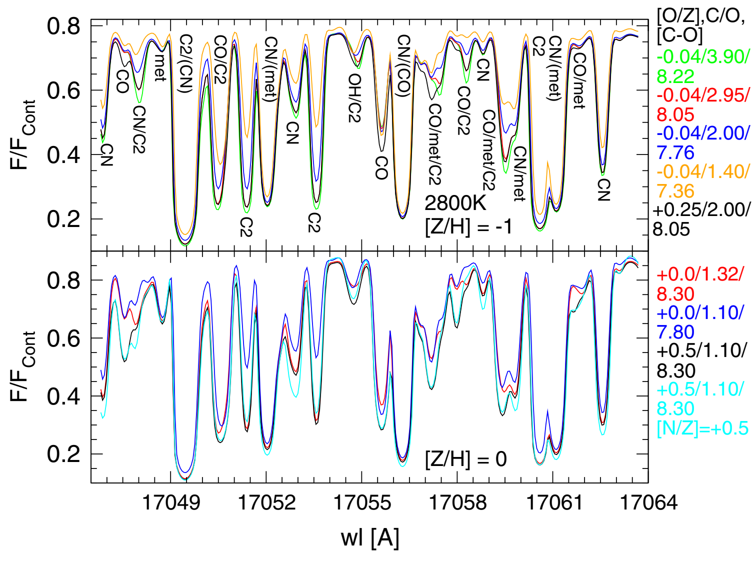

Figure 4. High resolution R = 300 000 spectra based on COMARCS carbon star models with $\log(g\ [\mathrm{cm/s^2}]) = 0.0$ and one solar mass having $T_{\mathrm{eff}} = 2800$ K and [Z/H] = 0 or -1. The data are normalised relative to a calculation without line opacities. The included combinations of [C$-$O], [O/Z] and [N/Z] are shown with different colours. The absorption features have been marked with the species creating them ("met" = metals). If a component of a blend is much weaker than the rest, it was put in brackets.

the amount of oxygen changes, predictions concerning spectra and colours derived from the stellar parameters, metallicity and [C$-$O] are much better than those involving C/O, since [C$-$O] determines the abundances of many important molecules.

Quantities like [C$-$O], [O/Z] or [N/Z] cannot be determined from low resolution spectra and photometric data alone. As we show in Fig. 4, this is in principle possible using high resolution spectra. For C giants [C$-$O] has again a strong effect on many of the lines,

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which exceeds for the models presented in the plot changes caused by a moderate variation of $T_{\rm eff}$ (100 K) or $\log(g)$ (0.5 dex) and the influence of a thin dust shell. Only the CO transitions depend mainly on the oxygen abundance.

Acknowledgements

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Discussion

Andersen: Could you clarify, if you really meant that it is basically impossible to get abundances for AGB stars, or did you just mean "the naughty" ones?

Aringer: We can get abundances for the more hydrostatic stars, if we have good opacities. For the cool pulsating (naughty) objects it will take much longer, since shocks, dust, mass loss, non-LTE, deviations from spherical symmetry and chemical equilibrium come together. It is hard to include everything at the same time in one model!

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