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Evolution of AGB stars at varying surface C/O ratio: the crucial effect of molecular opacities

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Abstract. We investigate the effects of molecular opacities on the evolution of TP-AGB stars that experience the third dredge-up, i.e. with surface abundances of carbon and oxygen, hence surface C/O ratio, varying with time. It turns out that in order to correctly model the properties of carbon stars (with C/O>1) the use of solar-scaled opacities – the standard choice in present stellar evolution models – should be relaxed and replaced with that of opacities properly coupled to the actual surface abundances. Only in this way we could be able to reproduce basic observables of carbon stars, like their effective temperatures, C/O ratios, and near-infrared colours.

Key words. stars: AGB and post-AGB – stars: evolution – stars: carbon – stars: fundamental parameters – stars: mass loss

1. Introduction

In most stellar evolution models of AGB stars the description of low-temperature opacities is still inadequate. In fact, the usually adopted opacity tables (e.g. Alexander & Ferguson 1994) are strictly valid for solar-scaled abundances of elements heavier than helium, hence implying C/O~ 0.48.

The inadequacy of this choice is particularly evident for carbon stars, commonly interpreted as stars with the surface C/O ratio larger than one as a consequence of recurrent third dredge-up during the AGB evolution.

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This issue is analysed in the present study by comparing the results of envelope integrations for TP-AGB stars, obtained either with solar-scaled or variable opacities.

2. Solar scaled vs. variable molecular opacities

A routine is constructed to derive the molecular concentrations through dissociation equilibrium calculations, and estimate the opacities due to H_2, H_2O, OH, C_2, CN, and CO for any given density, temperature and chemical composition of the gas (Marigo 2002).

Synthetic TP-AGB models with dredge-up (based on envelope integrations) are calculated by either adopting the newly developed routine, or interpolating between

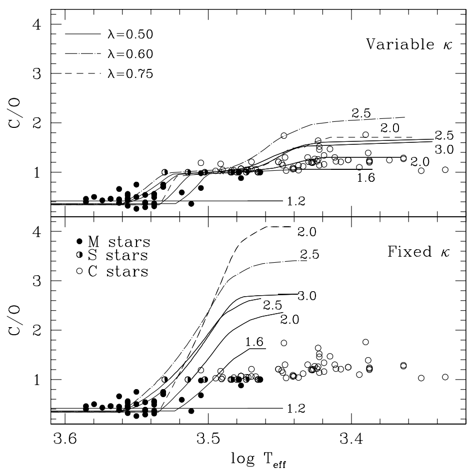

Fig. 1. Effective temperatures as a function of the C/O ratio in Galactic giants. Abundance determinations are taken from: Smith & Lambert (1990) for M stars (C/O< 1); Ohnaka & Tsuji (1996) for S stars (C/O∼ 1); Lambert et al. (1986), Ohnaka et al. (2000) for C stars (C/O> 1). Effective temperatures are taken from the same quoted works, except the C-star group for which we refer to Bergeat et al. (2001). Observed data (circles) are compared to predictions of synthetic TP-AGB models with dredge-up (lines), adopting either fixed solar-scaled opacities (bottom panel), or 'chemically-variable' opacities (top panel).

fixed opacity tables for solar chemical composition (with C/O∼ 0.48).

The comparison between the two cases, presented in Fig. 1, shows that the change in the dominant opacity sources, as the C/O ratio grows from < 1 to > 1, causes a notable cooling of the carbon-rich models (with C/O> 1). This predicted behaviour is fully supported by observations, as TP-AGB models with variable molecular opacities are able to reproduce the observed range of effective temperatures of C-type giants in the solar neighbourhood, otherwise failed if assuming fixed molecular opacities for solar-scaled mixtures. We mention other possibly important evolutionary and observational effects that result from the adoption of the variable opacities, such as:

- significant shortening of the C-star phase due to the earlier onset of the super-wind;
- consequent reduction of the AGB-tip luminosities; lower final masses; lower carbon yields;
- reproduction of the observed range of near-infrared colours of C-stars.

3. Conclusions and future aims

We stress the importance of consistently coupling molecular opacities with current envelope chemical composition in TP-AGB evolution models.
This is a necessary step in view of realistically modelling carbon star populations, that are now resolved in many galaxies of the Local Group. Construction of new calibrated TP-AGB models and related isochrones is under way (Marigo, Girardi & Chiosi 2003, in preparation).

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