CARBON STARS IN THE EARLY–AGB STAGE OF EVOLUTION

JU. L. FRANTSMAN*
Radioastrophysical Observatory
Latvian Academy of Sciences
Riga, LV-1527, Latvia

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Abstract. The assumption that faint carbon stars, as well as high-luminosity carbon stars whose effective temperatures are well above those of ordinary N–type stars in the Magellanic Clouds, are in the early asymptotic giant branch (E–AGB) evolutionary stage, is examined using population simulation techniques.

1. Introduction

The cool N–type carbon stars are generally associated with the thermally-pulsing asymptotic giant branch (TP–AGB) stage of evolution. But there are two groups of carbon stars whose luminosities and effective temperatures indicate that they are not in this stage:

1. Both theory and observation show that the minimum luminosity of carbon stars in the TP–AGB stage is about $M_{\rm bol} = -3.0$ mag (see, for example, Vassiliadis & Wood 1993; Groenewegen & de Jong 1993, 1994). Nevertheless, according to *JHK* photometry (Westerlund et al. 1992, 1995) and a low-dispersion spectroscopic survey (Rebeirot et al. 1993) of carbon stars in the Small Magellanic Cloud, there are N–type stars fainter than $M_{\rm bol} = -3.0$ mag, the least luminous having $M_{\rm bol} = -1.8$ mag.

2. Suntzeff et al. (1993) have presented the results of photometry of carbon stars in the Large Magellanic Cloud which had been classified as CH stars (Hartwick & Cowley 1988; Cowley & Hartwick 1991). These carbon stars are significantly bluer than ordinary carbon stars in the LMC. Their mean bolometric magnitude is $M_{\rm bol} = -5.3$ mag while the brightest members reach $M_{\rm bol} = -6.2$ mag.

The main idea is that these stars are in the E–AGB evolutionary phase. This phase is the first part of the AGB evolution, when the hydrogen-

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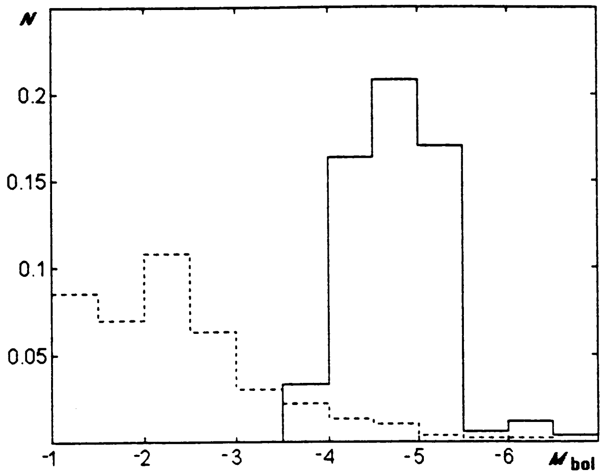

Figure 1. Theoretical luminosity functions of carbon stars with Z = 0.002. *Solid line*: TP–AGB stars; *dashed line*: E–AGB stars (the result of the evolution of close binaries).

burning shell is extinguished and helium burns steadily in a thin shell, providing most of the energy reaching the stellar surface. Towards the end of the E–AGB phase, H is re-ignited in a thin shell, and He burning continues in the form of the periodic thermal pulses. The TP–AGB stage then begins.

2. Simulation of Carbon Star Populations

The theory of two AGB stages (E–AGB and TP–AGB) was developed more than decade ago, but some investigators still do not take into account the E–AGB phase in spite of the fact that for some stars it lasts considerably longer than the TP–AGB stage.

Our scenario assumes that the above-mentioned two groups of stars are components of close binary systems. Mass was transferred from a TP–AGB carbon star by Roche lobe overflow to its companion which, as a result, becomes a carbon-enriched star. During its subsequent evolution, this star passes through all the later stages, including the E–AGB stage.

The results of a simulation of carbon star populations are plotted in Figures 1 and 2.

The luminosity functions are presented in Figure 1. The most significant result is a substantial extension of the carbon star luminosities towards fainter luminosities in comparison with TP–AGB carbon stars. Notice that a few high luminosity E–AGB carbon stars ($M_{\rm bol} < -5$ mag) exist.

A comparison between the theoretical luminosity function for E–AGB carbon stars and the observational one for faint carbon stars in the SMC

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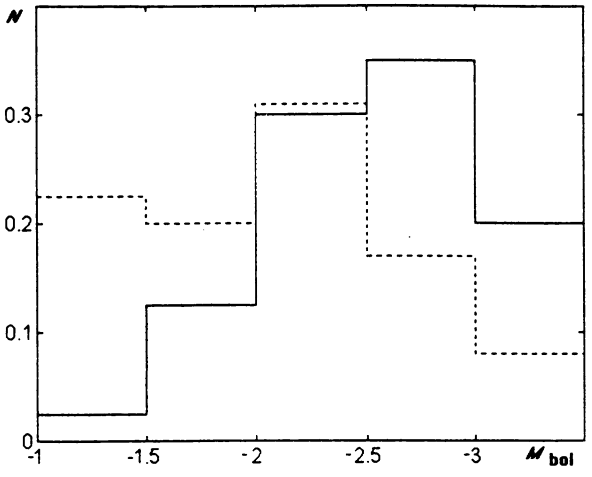

Figure 2. Luminosity functions of faint ($M_{\mathrm{bol}} > -3.5$ mag) carbon stars. *Solid line*: the results of observations (Westerlund et al. 1995); *dashed line*: the results of calculations.

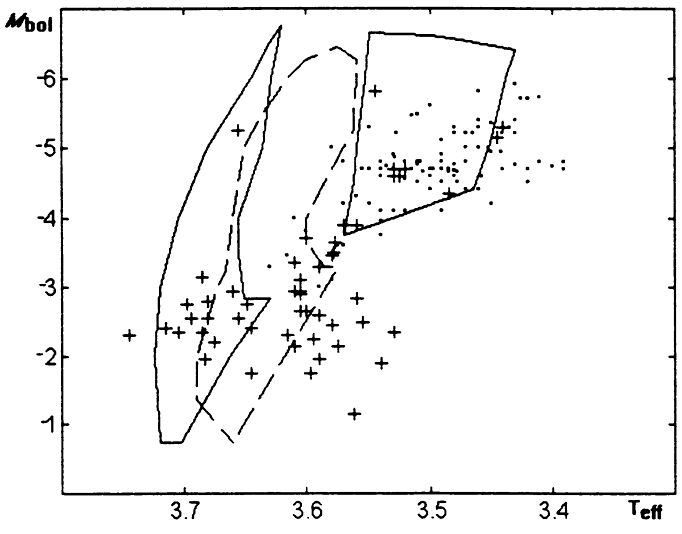

Figure 3. The positions of SMC carbon stars on the HR diagram. *Dots*: data from Westerlund et al. (1991); *crosses*: from Westerlund et al. (1995). The solid line contours outline the regions occupied by the E–AGB stars (left region) and by the TP–AGB stars (right region). The dashed line contour denotes the E–AGB region according to Fagotto et al. (1994).

(Westerlund et al. 1995) is presented in Figure 2. The two luminosity distributions are in qualitative agreement.

Figure 3 presents the HR diagram for SMC carbon stars, also showing the theoretically-calculated borders of regions occupied by the E–AGB and

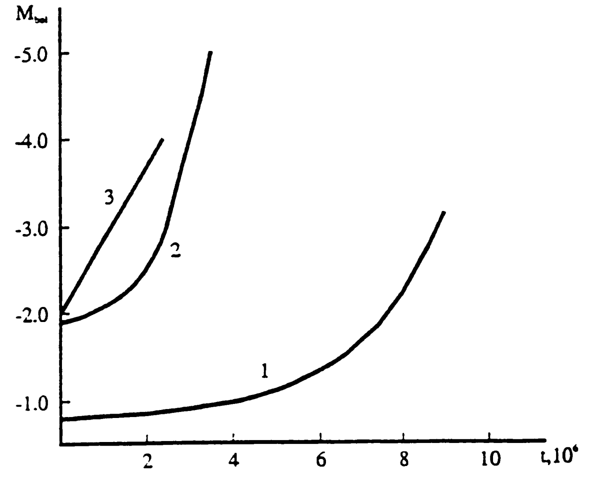

Figure 4. The dependence of the luminosity of a 3 $M_\odot$ E–AGB star on time, in units of 10^6 yr.: (1) Z = 0.02; (2) Z = 0.001 (Lattanzio 1991); (3) our calculations for Z = 0.001, using the formulas of Iben & Renzini (1984).

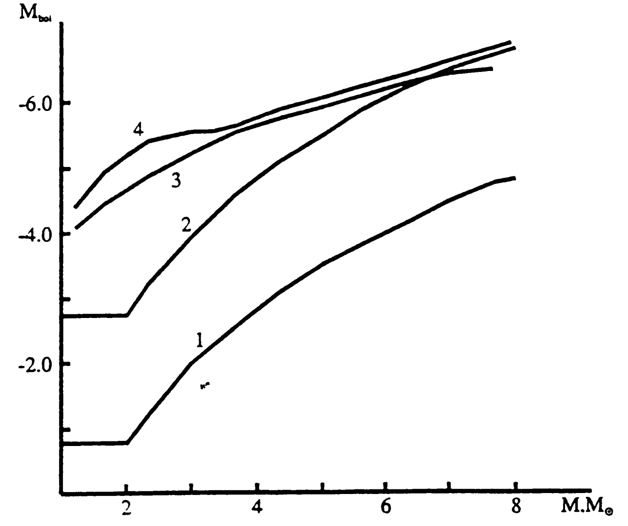

Figure 5. The dependence of luminosity on the initial mass for different stages of evolution: (1) the beginning of the E–AGB; (2) the end of the E–AGB; (3) the beginning of the TP–AGB; (4) the end of the TP–AGB.

TP–AGB models. All stars under consideration can be divided into two groups: (1) more luminous stars, with lower effective temperatures, and (2) fainter stars with higher temperatures. The former correspond closely to the TP–AGB model region, and the latter to the E–AGB region.

The dependence of the luminosity of a 3 $M_\odot$ E–AGB star on the time

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of evolution is presented in Figure 4. It is interesting to note that E–AGB stars can reach high luminosities only if the heavy-element abundance is low (typical for the Magellanic Clouds, but not for the Galaxy).

In Figure 5, the dependence of the luminosity of a theoretical model ($Z = 0.002$) on the initial mass is shown for different stages of evolution. Only massive stars reach a high luminosity, comparable to the TP–AGB star luminosity.

3. Conclusion

The main conclusion of this study is that the N–type carbon star population is not homogeneous but consists of objects which belong to two different stages of the evolution, the TP–AGB and the E–AGB.

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