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# STELLAR EVOLUTION ON THE ASYMPTOTIC GIANT BRANCH: SOME ACTUALITIES

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**Abstract.** The introduction reviews the main aspects of the asymptotic giant branch phase of stellar evolution. Then some important aspects of the investigations of this stage are considered, namely, the initial mass of carbon stars in our Galaxy and the nature of S-type stars. Characteristic examples of the mistakes in the identification of evolution stage of a star are discussed.

**Key words:** stars: asymptotic giant branch – stars: evolution

## 1. Introduction

Following the exhaustion of helium at the center, low and intermediate mass stars develop an electron-degenerate carbon-oxygen core and settle onto the so-called asymptotic giant branch (AGB) in the Hertzsprung-Russel (HR) diagram, with substantial rise in luminosity and small change in effective temperature. While on the AGB, a star passes through two evolutionary phases: an early stage (E–AGB), when the hydrogen shell source is inactive and most of the energy is generated in the helium shell source, and thermally pulsating AGB (TP–AGB), when nuclear burning in the helium shell occurs in the form of thermal flashes, during which a convection zone develops between the hydrogen and helium shells. Elements freshly synthesized in this shell are carried to the surface by a process of convective dredging, and these elements should thus be observable at the surface and, subsequently (as a result of mass loss from the stellar surface), could contribute to some elements of the interstellar medium. These two phases of the AGB are described in detail by Iben and Renzini (1983).

The structure of the typical star on this stage is very exotic. While the size of the carbon-oxygen core reaches $\sim 10^{-2} R_\odot$, the size of the whole star is $10^3 R_\odot$; the difference is about five orders, but masses of the core and the envelope are comparable. Although the mass of the helium shell is only $10^{-4} - 10^{-7} M_\odot$, the luminosity and surface temperature reach $10^7 L_\odot$ and $300 \cdot 10^6$K, respectively.

The process of mass loss is of unquestionable importance for the evolution of AGB stars and for a star's ultimate fate. In the HR diagram the remnant carbon-oxygen core shifts a star into the region occupied by the nuclei of planetary nebulae and white dwarfs. If, however, the core succeeds in reaching the Chandrasekhar limit of 1.4 $M_\odot$ before ejecting the envelope, a supernova explosion should ensue. These stars lose mass through stellar winds: some may eventually eject most of their residual hydrogen-rich envelope by rapid mass-loss responsible for the formation of planetary nebulae. Reimers (1975) has proposed an empirical expression relating mass loss rate with basic stellar parameters, but this expression has been derived from a sample of stars which does not include large amplitude red variables. Many observations, however, suggest that apart from the conventional wind, some other mechanism also ought to operate during the AGB phase, substantially raising the mass loss rate. Without allowing for a very intensive mass loss during the AGB stage one can explain neither the luminosity distribution of carbon stars in the Magellanic Clouds nor the mass distribution of white dwarfs in the solar neighbourhood (Frantsman 1986a,c). Although there is no consensus as to the origin of this rapid mass loss, Renzini (1981) has suggested that at late stages of its evolution a star will generate a "superwind" which will detach the rest of the envelope and form a planetary nebula. But even this idea fails to solve the discrepancies between theory and observations mentioned above. The agreement of theoretically calculated parameters of AGB stars with observations is rather satisfactory if an abrupt tenfold jump in the mass-loss rate for these stars reaching a certain luminosity during the evolution is assumed (Frantsman 1986a,b, 1989).

Since carbon is the main product of helium reactions, its and s-process elements abundance in the envelope of an AGB star should increase with time. According to current evolution theory, during the AGB stage the carbon to oxygen ratio (C/O) in the envelope of a star gradually rises. The star will successively pass through the stages M–MS–S–SN–N, turning into a carbon star when C/O>1. But AGB star abundance peculiarity (carbon and s-process overabundances) is not limited to the stars which now are on the AGB. The s-process element abundance syndrome occurs in stars of nearly all types, from main-sequence stars of near-solar luminosity (Kollatschny 1980, Warren et al. 1993) to stars at all levels along the giant branch, the so-called barium stars (Frantsman 1992 and references therein). In recent years the origin of these stars has often been attributed to some phenomenon which can occur in close binaries. It is assumed that during the TP–AGB phase, the primary component presumably generated s-process elements in its helium burning shell, dredged this material to its surface and transferred the enriched material by Roche-lobe overflow to the secondary component which is now a star enriched by s-process elements.

This has been a very brief description of the AGB stage of stellar evolution. For more details see, for instance, the reviews of Iben (1981), Iben and Renzini (1983), Weidemann and Schönberner (1990), Frantsman (1992). In the present paper, the emphasis will be put on some specific questions concerning the AGB phase of evolution.

## 2. The initial mass of the galactic carbon stars

In the Galaxy not all low and intermediate-mass stars become carbon stars during the evolution on the AGB. Many factors play an important role in this process. The initial chemical composition is one of the most important factors because for greater heavy element abundances more carbon must be dredged into the envelope in order to achieve the state when C/O>1. But the initial abundance of heavy elements in our Galaxy depends on the age, being much smaller in early stages of its evolution. According to Twarog (1980) and Scalo and Miller (1981), the initial abundance of heavy elements by mass for a 1 $M_\odot$ star is 0.006, while for a 1.5 $M_\odot$ star it is 0.021.

Fig. 1 shows the maximum C/O as a function of the initial mass $M$ for different assumptions about the mass loss by stars on the AGB. The important result of our calculations is that N-type stars in the Galaxy may be formed only from the stars with the initial mass $< 1.5$ $M_\odot$, due to their having a relatively small initial heavy element abundance. This appears to be the main reason why carbon stars are not observed in open clusters of the Galaxy.

It is interesting to note that in some cases (if mass loss intensity is not too high) N-type stars may be formed from the stars with rather high initial mass. The great number of helium shell flashes

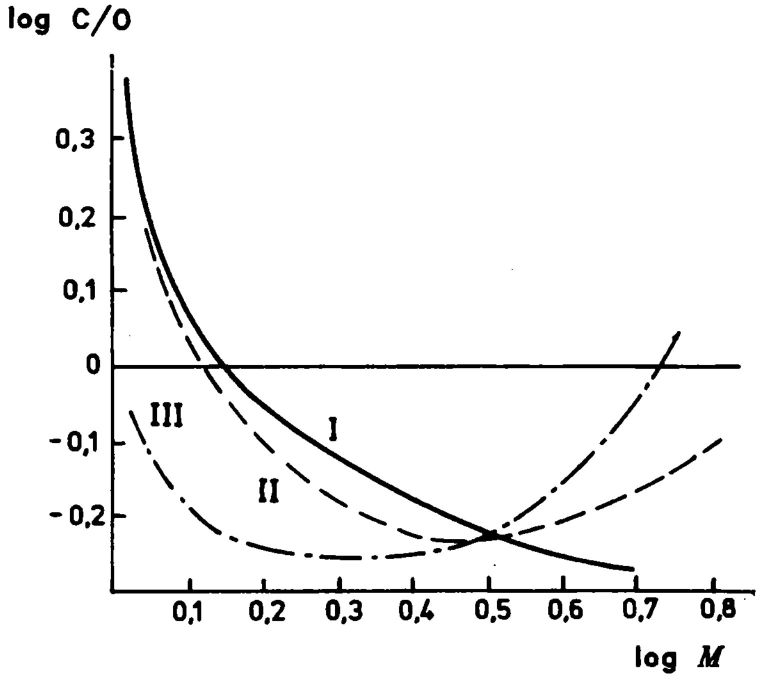


**Fig. 1.** The maximum C/O ratio plotted against the initial mass ($M$) for different values of the Reimers mass-loss coefficient $\alpha$: (I) $\alpha = \alpha_0 + \alpha_1 \exp M_c$, where $M_c$ is the mass of a carbon-oxygen core and the coefficients $\alpha_0$, $\alpha_1$ are chosen so that $\alpha = 0.33$ if $M_c = 0.5\ M_\odot$ and $\alpha = 10$ if $M_c = 1.0\ M_\odot$; (II) $\alpha = 1$ if $\log(L/L_\odot) \leq 4.1$ and $\alpha = 10$ (a tenfold jump of mass loss intensity) if $\log(L/L_\odot) \geq 4.1$; (III) $\alpha = 3$.

available in these stars plays an important role in the appearance of carbon star peculiarities. So, if the initial mass $M_{in} = 1 M_\odot$, only 10 shell flashes have enough time to take place, but if $M_{in} = 8 M_\odot$, as much as 6000 flashes may then occur.

## 3. S-type stars in the Magellanic Clouds

So far a simple stellar evolutionary scheme M–MS–S–SN–N, as a result of dredge-up process on the AGB, remains under discussion. There are serious observational arguments that at least in some S-type stars the dredge-up process does not take place.

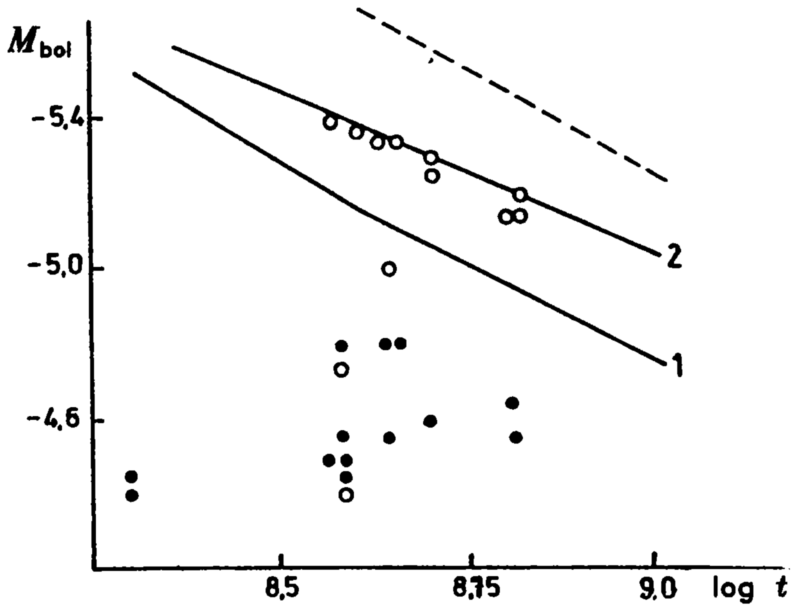


**Fig. 2.** The bolometric magnitude $M_{bol}$ for N and S stars in LMC clusters versus age $t$. Open circles are N stars and filled circles are S stars. Solid line 1 shows the beginning of helium shell flash stage (TP–AGB), solid line 2 is the end of this stage assuming that the coefficient $\alpha$ in the Reimers mass-loss formula is chosen as in case I (see the caption for Fig. 1). The dashed curve shows the end of the TP–AGB stage if $\alpha$=1.

In Fig. 2, the absolute bolometric magnitude is plotted versus age for S and N stars in the LMC clusters. The ages of the clusters were obtained from the relationship between the age and the maximum luminosity on the AGB, comparing the observed and theoretical luminosities of the AGB cluster members (Frantsman 1988). The stars in the TP–AGB phase of evolution must be located between solid lines 1 and 2, or, if the mass loss intensity would be lower, between line 1 and the dashed one. According to Fig. 2, the majority of N stars are at the TP–AGB stage of evolution, but the luminosity of S stars is much lower and it is possible that most of them are at the E–AGB stage where hydrogen burning is extinct and helium burning in the narrowing shell provides most of the energy reaching the surface. The E–AGB stage of S stars in the Magellanic Clouds is confirmed by the comparison of effective temperature distributions of S and N stars and theoretical distributions of stars in E–AGB and TP–AGB stages (Frantsman 1986c, 1988). The presence of some N stars below line 1 may be explained by a luminosity dip after helium ignition in the shell (see, for example, Boothroud and Sackmann 1988, Olofsson et al. 1990). Now it is believed that the most common evolutionary scenario for S stars without technetium in our Galaxy and for major part of S stars in the Magellanic Clouds is related to the peculiarities of the evolution of close binaries. Here, a mass enriched by carbon and s-process elements is transferred from the AGB star through Roche lobe overflow to its companion which then becomes an S-type star.

## 4. Consequences of mistakes in the identification of evolutionary stage

### *4.1. The ages of the Magellanic Cloud clusters*

Before using the luminosity of the AGB stars for the age determination of a cluster, it is necessary to distinguish their phases. It seems, however, that Mould and Aaronson (1982) have used the E–AGB stars for age determination of several clusters, considering that these stars are in the TP–AGB stage. Consequently, the ages of these clusters are incorrect. In some cases the errors can reach an order of a magnitude or even more. Some extreme cases of these mistakes are presented in the following table:

| Cluster | $t(10^9 yr)$ | $t[MA](10^9 yr)$ |
|---|---|---|
| NGC 416 | 0.25 | 8 |
| NGC 1872 | 0.1 | 5 |
| NGC 2162 | 0.2 | 11 |

Column (2) gives the correct ages obtained by considering the AGB stars to be in the E–AGB stage, and column (3) gives the ages by Mould and Aaronson (1982) determined by assuming incorrectly that the most luminous stars are on the TP–AGB stage.

### 4.2. *The evolution of the LMC*

Let us discuss the results by Frogel and Blanco (1983), Frogel (1984), Chiosi et al. (1988) and Alongi and Chiosi (1991) on the nature of the bimodality in the colour-magnitude diagram for the field and cluster AGB stars in the LMC. Two well-defined AGBs for these stars have been found and the authors came to the conclusion that this division is associated with two star formation epochs, one a few Gyrs ago and the other about $10^8$ yr ago. We have explained these two regions of star concentration in the colour-magnitude diagram in a quite different manner, taking into account two phases of AGB (E–AGB and TP–AGB).

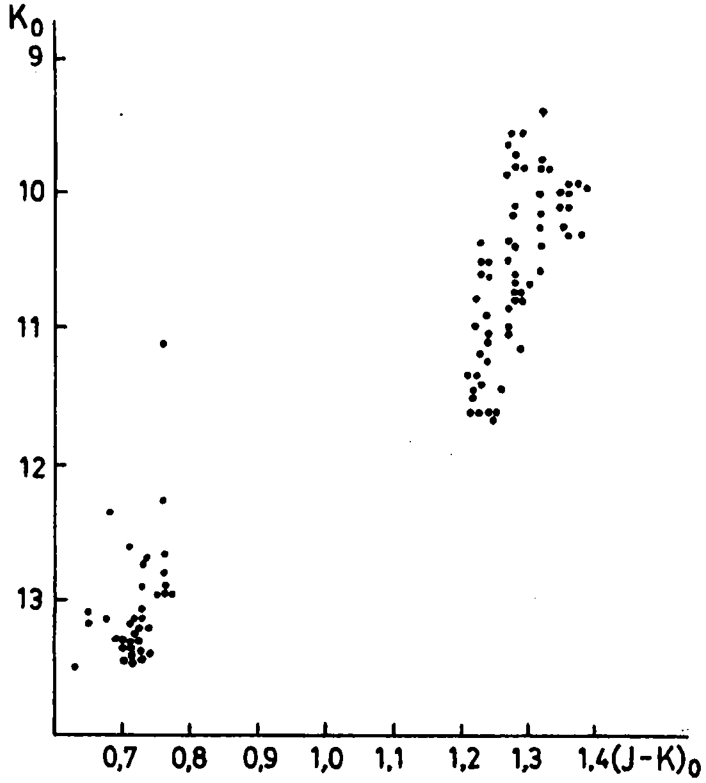


**Fig. 3.** A theoretical infrared colour-magnitude diagram for the AGB stars with $M_{\rm bol} < -3.0$ mag.

The theoretical population of AGB stars for the Salpeter initial mass function and constant stellar birth-rate was calculated. The method of computation has been explained in Frantsman (1986a). In Fig. 3, the theoretical colour-magnitude diagram is presented. It is apparent that there is a complete separation of all calculated stars into two groups. Stars with bluer $J$–$K$ colours and lower luminosities are at the E–AGB stage, whereas those with redder $J$–$K$ and higher luminosities are at the TP–AGB stage. These data qualitatively fit the observations without an assumption of two epochs of star formation.

Both these cases show that it is necessary to be very careful identifying the evolution stage of a particular star and trying to use the theoretical results for interpretation of observations.

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