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Nucleosynthesis in very metal poor AGB stars

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Abstract. High resolution spectroscopy of very metal poor C- and s-rich stars provides a fossil record of the nucleosynthesis that occurred several Gyr ago in halo AGB stars. They are dwarfs or giants, whose surface composition was polluted by the wind of an AGB companion. Then, the C and s-element enhancements are ashes of the nucleosynthesis occurred in the He-rich inter-shell of a low metallicity AGB star. We present a calculation of a $Z=5\times10^{-5}$ low mass ($M=1.5\ M_\odot$) AGB stellar model. A full network including all the relevant isotopes up to the end point of the s-process path has been used. After a few weak thermal pulses, the convective region generated by the He burning engulfs protons from the overlying H-rich envelope into the hot He-rich region. This occurrence induces a violent H-flash, followed by a quiescent double shell burning and, later on, by a deep dredge up. During the H-flash the density of the neutrons released by the $^{13}C(\alpha,n)^{16}O$ becomes quite large ($>10^{13}$ cm^{-3}), but only for a few days. Then, after the deep dredge up episode, the envelope composition is strongly enhanced in C and N, but not in s-elements. At that time, the mass fraction of CNO in the envelope is as large as 10^{-3} and the subsequent evolution becomes similar to that of more metal-rich AGBs. Then, each thermal pulse is regularly followed by a third dredge up episode. Near to the region of the maximum penetration of the convective envelope, a ^{13}C-pocket forms, whose burning produces neutrons and allows the s-process nucleosynthesis. A secondary burst of s-process, resulting from the activation of the $^{22}Ne(\alpha,n)^{25}Mg$ reaction, takes place within the convective zone generated by the thermal pulse. The evolution of the surface composition is presented in some details.

Key words. AGB stars – nucleosynthesis – *s*-process

1. Introduction

The typical mass of halo AGB stars is about 0.6 $M_\odot$. This is, for example, the average mass of HB stars in galactic globular clusters, the phase that precedes the asymptotic giant branch (AGB). Such a low mass is compatible with the old age of the halo (13-14 Gyr), which corresponds to the lifetime of stars with initial mass of about 0.8-0.9 $M_\odot$. The envelope of these AGBs is so small that the third dredge up does not take place. Thus no C and s-element enhancements can be seen at the surface. Nevertheless, several C and s-rich stars

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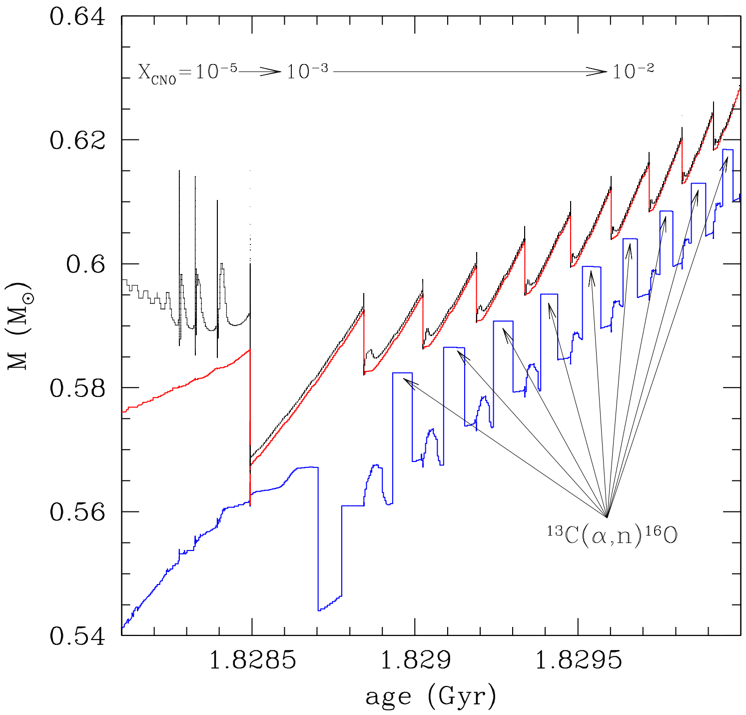

Fig. 1. Thermally Pulsing AGB: initial mass M=1.5 M$_\odot$, Z=5 10^{-5}. The 3 lines represent (top to bottom): the inner border of the convective envelope, the location of the maximum nuclear energy production within the H-rich layer, the location of the maximum nuclear energy production within the He-rich layer.

are commonly observed in the galactic halo. At variance with the C(N) stars commonly observed in the galactic disk, the halo C-rich stars are usually also N-rich. They are dwarfs or giants, but not AGBs. Their composition is probably due to a mass transfer process from an AGB companion. Many of these stars show evidences of radial velocity variations attributed to an orbital motion with period of a few years (see e.g. the contribution by Tsangarides et al. in these Proceedings). In this case, when the more massive component of the binary system becomes an AGB, the secondary (unevolved) star may be polluted by the wind produced by the primary. What we presently see is the secondary polluted star, while the primary has evolved into a cool (undetected) WD. In the present paper, we discuss the properties of a probable primary component of this kind of system, when it was an AGB star. The evolution and the nucleosynthesis of a thermally pulsing AGB star with Z=5 $\times$ 10^{-5} and M=1.5 M$_\odot$ is presented. This calculation has been performed by means of the FRANEC code Chieffi, Limongi & Straniero (1998). A network including about 500 isotopes and 800 nuclear process (strong and weak interactions) has been adopted. Some details of the code are illustrated in the contribution by Cristallo et al. in these Proceedings.

2. The model

Figure 1 shows the evolution of the region of the star between the top of the CO core and the base of the convective envelope. After few weak thermal pulses an evident dredge up episode takes place. This occurs after the con-

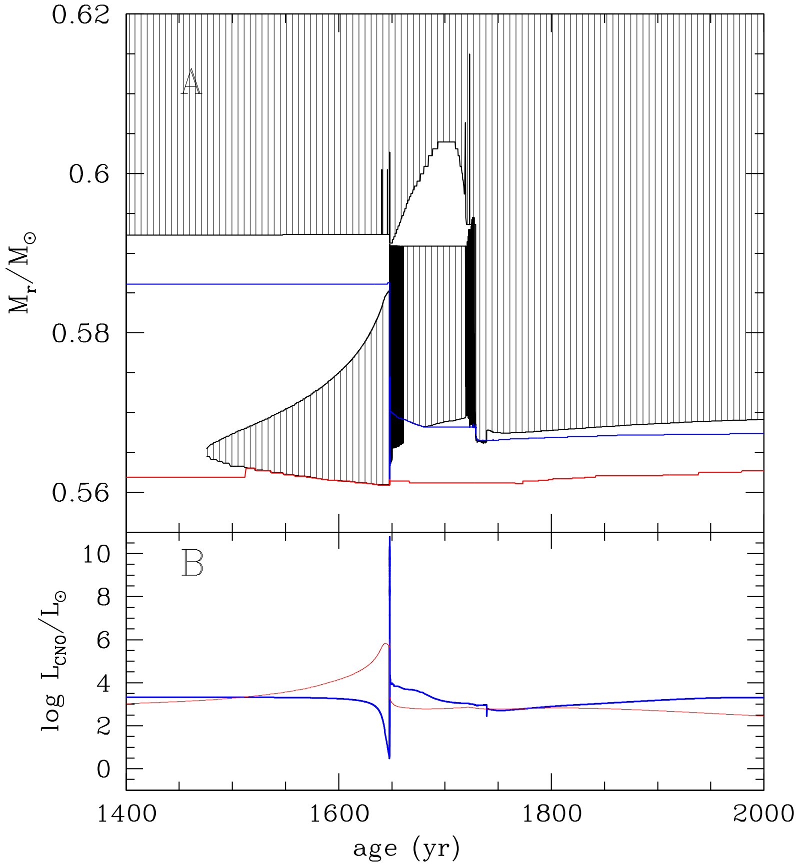

Fig. 2. Panel A: Zoom of Fig. 1 at the epoch of the H-engulfment episode (~ 1.8285 Gyr) Panel B: Luminosity of the H-burning (heavy solid) and luminosity of the 3α burning (light solid). The convective regions are highlighted (shaded areas).

vective zone generated by the pulse engulfs protons from the overlying H-rich envelope. The consequences of the ingestion are shown in Figure 2. H is brought into the intershell, at temperatures as large as 10^8 K, where the large C abundance allows violent CNO burning. A peak luminosity of 10^{11} $L_\odot$ is reached. The flash elapses for about 9 days. Then a quiescent H-burning takes places for about 80 years. Huge amounts of ^{13}C and ^{14}N are produced within the convective zone powered by the H-flash. The high temperature favors neutron production via the ^{13}C(α,n)^{16}O reaction, but in spite of a neutron density as large as 10^{12} cm^{-3}, owing to the short duration of the flash and the huge amount of ^{14}N (which is a powerful poison), the resulting neutron capture nucleosynthesis is negligible. After the dredge up, the [C/Fe] and the [N/Fe] in the envelope are 2.6 and 2.1, respectively. A smaller enhancement of the O is also obtained ([O/Fe]=0.67, starting from a scaled solar composition). The heavier elements remain, practically, untouched. The envelope mass fraction of CNO raises up to 2 10^{-3} and the subsequent evolution becomes qualitatively similar to that of a metal rich (disk) AGB. Ten thermal pulses followed by third dredge up (TDU) episodes have been obtained. After each TDU, the receding convective envelope leaves a proton tail where, later on, a ^{13}C-pocket forms. The most striking features of the resulting neutron capture nucle-

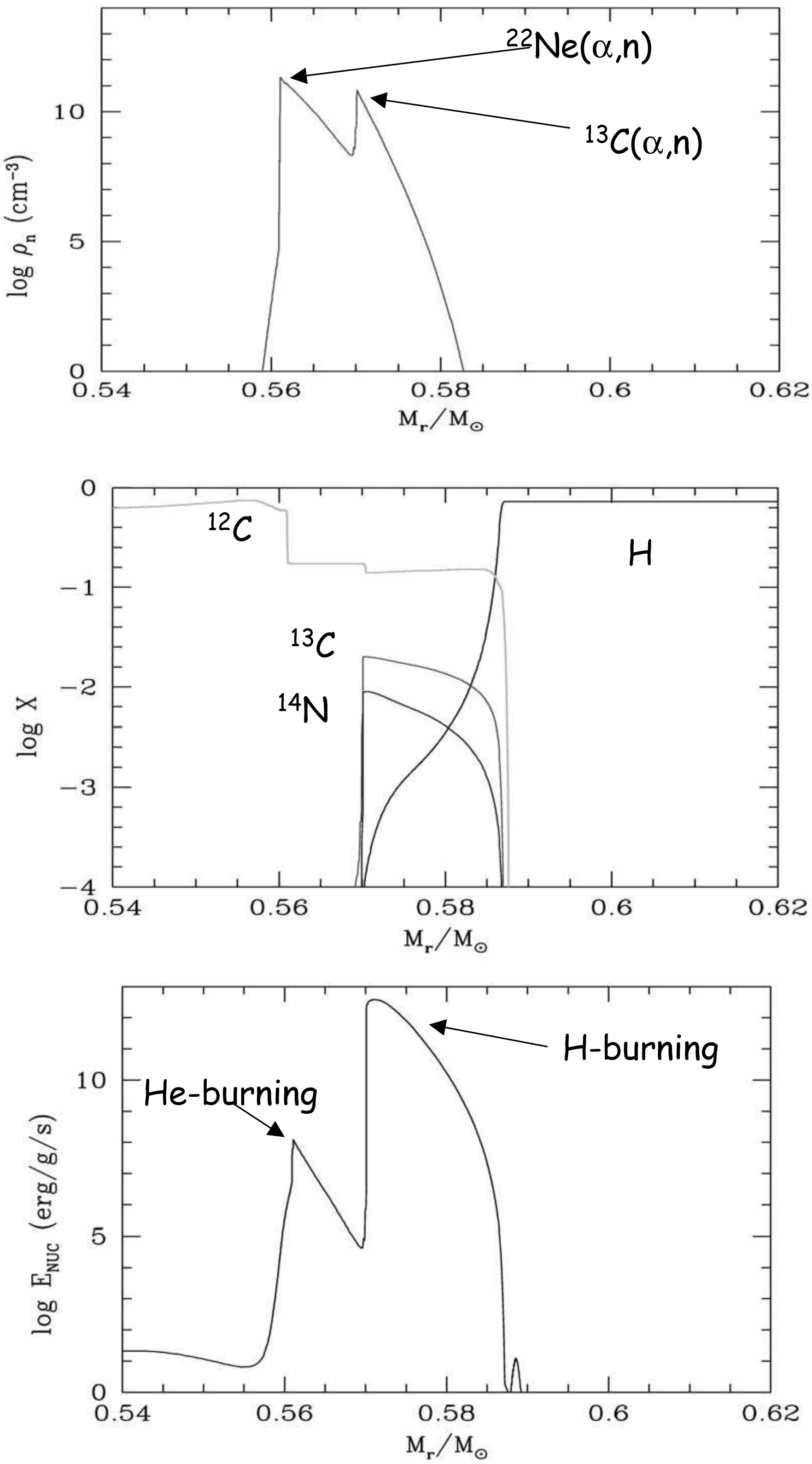

Fig. 3. Properties of the He-rich intershell at the time of the H-engulfment: neutron density (upper panel), chemical composition profile (central panel) and nuclear energy per unit mass and time (lower panel).

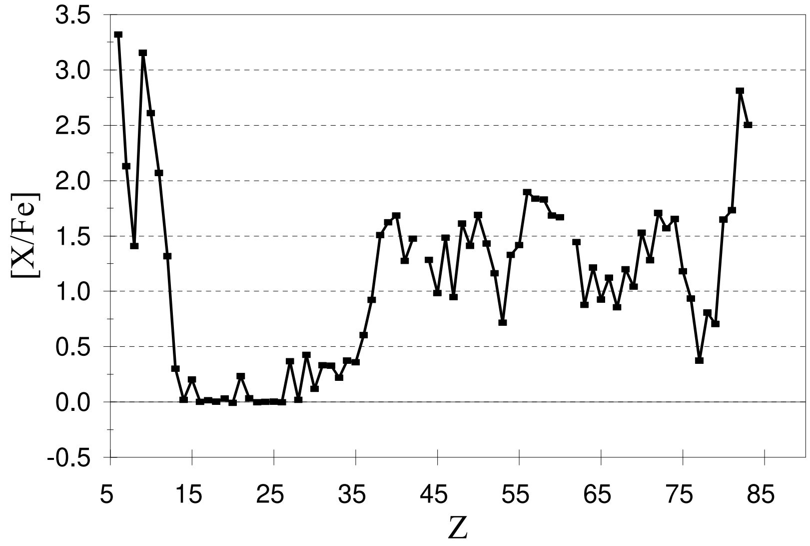

Fig. 4. Final surface composition

osynthesis are: a) the huge production of lead: [Pb/Fe]=2.8 in the envelope at the last computed model;

b) [Pb/Ba]=0.9 and [hs/ls]=0.2 (the contribution by Delaude et al. in these Proceedings discusses the importance of these intrinsic indicators of the s-process nucleosynthesis).

c) the final amount of fluorine is [F/Fe]=3.15:

Note that the fluorine is produced in the convective zone generated by the thermal pulse via the $^{15}N(\alpha,\gamma)^{19}F$ reaction and ^{15}N is accumulated in the ^{13}C-pocket mainly through the chain $^{14}N(n,p)^{14}C(\alpha,p)^{18}O(p,\alpha)^{15}N$ (see also the contribution by Lugaro et al. in these Proceedings).

As a consequence of the 10 dredge up episodes the final amount of C is further increased ([C/Fe]=3.32 in the last computed model), while N remains unchanged. O increases up to [O/Fe]=1.4. A large amount of ^{22}Ne is also produced ([Ne/Fe]=2.6). Significant productions of Na and Mg are also noticeable. The final envelope composition is reported in Fig 3.

Let us finally mention the s-process production of Eu, an element usually ascribed to the r-process. The final overabundance is [Eu/Fe]=0.9, with the isotopic ratio $f = \frac{^{151}Eu}{^{151}Eu+^{153}Eu} = 0.57$. This last result, in particular, is in excellent agreement with the value recently measured in metal poor C- and s-rich stars Aoki et al. (2003). This result has been obtained by using the rate published by Best et al. (2001) for the neutron captures on ^{151}Sm, ^{151}Eu and ^{153}Eu. Note that a recent work based on nTOF measurements Marrone et al. (2004) suggests a significant larger value (about a factor 2) for the $^{151}Sm(n,\gamma)$ and, in turn, it would imply a lower Europium isotopic ratio.

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