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New AGB models to explore the spread of abundances in Globular Clusters

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Abstract. Following the line of thought that the inhomogeneities in composition of GC stars are due to contamination from the ejecta of the massive AGBs which evolved in the first 100-200Myr, we must study in detail the production of elements during the AGB evolution. The study requires computation of complete stellar models including nuclear processing by Hot Bottom Burning, coupled with non- instantaneous mixing for as many elements as possible. These models are still subject to many uncertainties, so that the additional hypothesis that the spreads in abundances are not random, but can be attributed to the existence of several different generation of stars directly formed from AGB ejecta, provides a powerful tool to constrain the efficiency of Hot Bottom Burning and the role of the third dredge up. We show that many difficulties are still present in this scenario, in particular our recent models confirm that the anticorrelation Na–O is not well explained. If the spreads are indeed due to different stellar generations, however, we can use the abundance anomalies to understand better the AGB models.

Key words. Abundances in Globular Cluster stars – AGB models – self–pollution

1. Introduction

We summarize the results of our previous work on AGB evolution in Population II stars (Ventura et al. 2001; Ventura, D'Antona, & Mazzitelli 2002), and show the preliminary results of new computations, in which we follow the nuclear evolution, coupled with the diffusive mixing, for 30 isotopes. Our preliminary results indicate that these models do not provide a direct Na- O anticorrelation, so that some escape from this problem must be found if we wish to preserve the view that the stars showing reduced Oxygen and increased Sodium are born directly from the ejecta of massive AGs.

2. The proposed scenario

If selfpollution is simply successive stellar generations formed from ejecta of massive AGBs, as proposed recently by D'Antona et al. (2002), the patterns of inhomogeneities have a simple key interpretation: the mass evolving in the first epoch is a simple function of the time and the newborn stars have the chemistry of the ejected AGB envelopes, which de-

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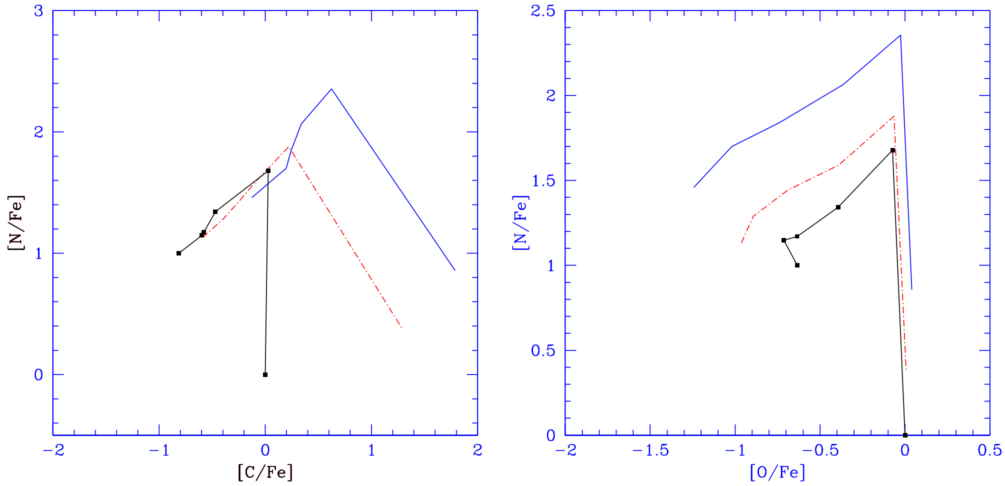

Fig. 1. The Nitrogen vs. Carbon and Nitrogen vs. Oxygen average abundance in the ejecta from AGB stars of different mass and metallicity (Z=2×10^{-4} (blue, solid), 6×10^{-4} red, dot-dashed) and $\times10^{-3}$ (black with dots) from top to bottom curves). The masses are from 3 to 5.5$M_\odot$ from right to left. In fact, the lower the mass, the more Carbon is dredged up, and it is cycled to Nitrogen in the masses for which Hot Bottom Burning is relevant. The AGBs whose winds are expected to form second generation stars are the most massive. In fact, Oxygen is reduced in these stars, but Nitrogen should be increasing, contrary to what happens in these models.

pends on the initial mass. Therefore, the dispersion in the composition of GC stars *is not* random: it must resemble the distribution of the yields as function of the total mass. As AGB models are subject to severe uncertainties, we can use the observed spreads to validate (or falsify) the models. The first difficulties with this scenario are already present in the Ventura, D'Antona, & Mazzitelli (2002) data. We show in the left part of Figure 1 the correlation between the Carbon and Nitrogen abundances in the ejecta of AGB stars of different masses (the mass increases as Carbon decreases). The right part of Figure 1 shows the same Nitrogen abundance versus the corresponding abundance of Oxygen. It is evident that the points with relatively low Nitrogen and very high Carbon (up to [C/Fe]~2) are the ejecta of Carbon stars (relatively small masses $\sim 3M_\odot$), while larger masses cycle more and more Carbon to Nitrogen. In the most massive stars, however, Carbon is actually depleted, and Nitrogen becomes less overabundant. While we can easily infer from the huge Carbon abundances that there is no longer star formation at the epoch of Carbon stars, the masses in which Nitrogen decreases are actually those in which also ON cycling takes place, so that the Oxygen decrease should imply also a *decrease* in Nitrogen. But this *is not* what occurs among GC stars: the most Oxygen poor stars have the largest Nitrogen! This means that our models make a good prediction (Oxygen reduction) but also a bad one (Nitrogen is not anticorrelated with Oxygen).

Why do our models have huge Nitrogen abundances at masses $\sim 4M_\odot$? It is easy to understand that this is due to the third dredge up, which does not lead to Carbon star features in these objects, as Hot Bottom Burning cycles the dredged up Carbon into Nitrogen. Consequently, if we wish to maintain the model of successive stellar generations, we must conclude that *dredge up must be less efficient* than what occurs in our models!

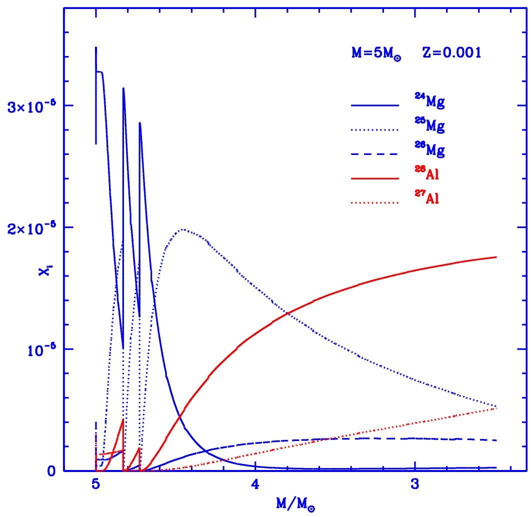

Fig. 3. The three Magnesium and two Aluminum isotopes during the same evolution. The spikes are probably due to numerical artifacts.

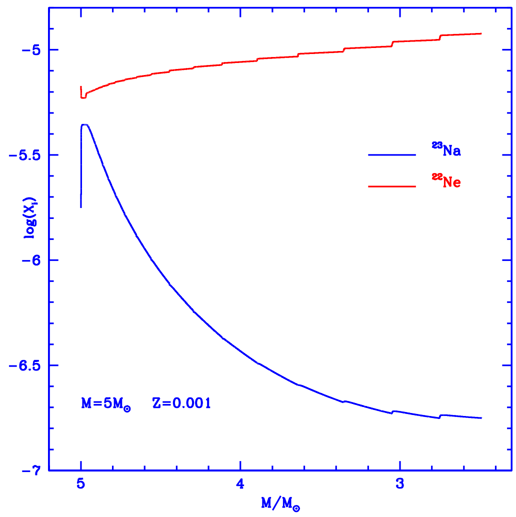

Fig. 4. The Sodium and Neon 22 evolution for the same star. It is clear that ^{23}Na decreases, as well as Oxygen decreases (see Figure 2). The Sodium Oxygen anticorrelation is not reproduced by these models.

3. The total CNO abundance

In fact, the sum of CNO elements in the polluted stars seems to be not very different from that in the stars with normal abundances. Does this mean that the third dredge up has not a long time to be efficient in these stars? Figure 2 shows the run of abundances of CNO and

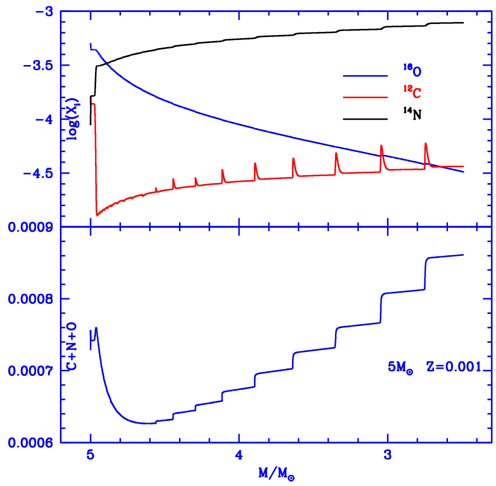

Fig. 2. Nitrogen (top curve), Carbon (lowest) and Oxygen (middle) in the envelope during the evolution of a $5M_{\odot}$ star of Z=10^{-3}. The total mass of the star, which decreases due to wind mass loss, is chosen as abscissa. The bottom figure shows the total CNO abundance.

of their sum along the evolution of a $5M_{\odot}$: the total CNO increases, but not sensibly, during the evolution. If the envelope is lost before there will be many more thermal pulses, the total CNO abundance in the ejecta will be similar. For stars of smaller masses, the evolution is longer, and mass loss is less efficient. Therefore, there are many more thermal pulses, more dredge up, and finally a larger total CNO. The observations seem then to indicate that mass loss must be more efficient, to reduce the effect of the dredge up.

4. New models

Figures 3 and 4 show the behaviour of other elements in the same evolution of $5M_{\odot}$. These are preliminary results of new computations, including the nuclear evolution of many more elements with respect to Ventura, D'Antona, & Mazzitelli (2002). We show the evolution of Magnesium and Aluminum, which can be consistent with the anticorrelation found in the GC stars, but Figure 4 shows that Sodium first increases but, at a later stage, it is destroyed. Consequently, these models *are not consistent with the Oxygen – Sodium anticorrelation*. Denissenkov & Weiss (2001) had suggested this difficulty, and similar models have been reported by Denissenkov & Herwig (2003). It is probably too early to derive strong conclusions, but it is clear that several pieces of the puzzle are not yet at the right place.

5. Conclusions

A lot of work remains to be done to understand both the chemical abundances in GCs and the AGB models. Nevertheless, we have now models and observations at a stage which can allow fruitful comparisons and, hopefully, a final global understanding.

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