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Nucleosynthesis in metal-poor AGB stars

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We present detailed abundance results concerning CEMP (Carbon Enhanced Metal-Poor) stars and the various subclasses. Statistical arguments from radial velocity monitoring show that these stars are all binaries and have mass transferred from a former AGB. Therefore these stars are the direct witnesses of the nucleosynthesis production of the first low and intermediate mass stars. To put CEMP stars in context, our broad approach includes the study of 180 stars of various metallicities (from solar down to [Fe/H]=-4), luminosity classes (dwarfs and giants), and abundance patterns (C-rich and poor, Ba-rich and poor, etc.). With these data, we attempt to isolate the effect of the intrinsic parameters on AGB nucleosynthesis such as metallicity, mass, dilution, mass loss and neutron source. The abundance ratios suggest that the CEMP-s stars were polluted by low-mass AGB stars, while the CEMP-r&s stars were polluted by intermediate-mass AGB stars. At the lowest metallicities, we propose that the s-process in AGB stars is very inefficient, leading to the formation of CEMP-no stars.

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The largest to date, the HK survey and the HES survey, have provided a tremendous wealth of information for the study of the early chemical evolution of our Galaxy [1]. One of the most surprising result from wide-field spectroscopic surveys for metal-poor stars is the large frequency of carbon-enhanced stars ([C/Fe] $>$ 1.0, hereafter CEMP stars) among metal-poor stars. These surveys indicate that they account for 20 to 30% of stars with [Fe/H] $<$ -2.5. The carbon enhancement phenomenon appears in stars that exhibit four different heavy-elements abundance patterns:
(i) The most numerous class is characterized by enrichments of neutron-capture elements compatible with material processed by the s-process in Asymptotic Giant Branch (AGB) stars (hereafter CEMP-s).
(ii) Another class of CEMP stars show high s-process enrichment but also apparent r-process enrichment (hereafter CEMP-r&s).
(iii) Some CEMP stars have been identified with no enhancements in their neutron-capture elements (hereafter CEMP-no). Unfortunately, few of these stars have currently enough radial-velocity measurements to constrain their binary properties. Consequently, a mass-transfer scenario comparable to that operating in CEMP-s (and possibly in CEMP-r&s) stars is not established.

1. CEMP neutron-capture-rich stars (CEMP-s and CEMP-r&s)

Low-metallicity AGB models predict that, the higher is the mass of the AGB star, the more O is dredged up to the surface [2]. Therefore, r- and s-process-rich stars are likely to have a more massive AGB companion than s-process rich stars because they are more O-rich (Fig. 1).

It has been established that ^{13}C$(\alpha,$n$)^{16}$O is the main neutron source in low-mass AGB stars [4]. C is a primary element in AGB stars and does not depend strongly on the initial metallicity. On the other hand, Ba production by neutron capture requires seeds as well (mostly Fe in this metallicity range). Therefore as the [Fe/H] increases, the amount of Ba created will also increase. From the observed increase in [Ba/C] as [Fe/H] increases (Fig. 2), we confirm that CEMP-s stars have accreted material from a low-mass AGB star. ^{22}Ne$(\alpha,$n$)^{25}$Mg is a very efficient neutron source, so that it is expected to lead to to large yields of s-process elements as well as significant quantities of elements usually classified as r-process [5]. Its efficiency also favors 3$^{\text{rd}}$ peak element production (Pb) to 2nd peak element (Ce). ^{22}Ne in AGB stars is produced by ^{14}N$(\alpha,\gamma)^{18}$O$(\alpha,\gamma)^{22}$Ne and ^{22}Ne$(\alpha,$n$)^{25}$Mg become significant for intermediate-mass stars. Thus the correlation between [Pb/Ce] and [N/H] in CEMP r&s-process-rich stars (Fig. 3) seems to indicate that they have an intermediate-mass AGB companion.

2. CEMP neutron-capture-poor stars (CEMP-no stars)

Figure 4 shows that [Mg/Fe] is consistent with the Galactic average in CEMP-s stars and most of CEMP-r&s stars. But some low metallicity CEMP-r&s as well as some of CEMP-no stars show Mg enhancement. In AGB star models, Mg is only enhanced by ^{22}Ne$(\alpha,$n$)^{25}$Mg and ^{22}Ne$(\alpha,\gamma)^{26}$Mg, which are efficient in higher mass AGB stars.

Figure 5 shows that CEMP-no stars appear mostly at extremely low metallicities ([Fe/H] < -3) . We also noticed a lower C enrichment in these stars as well as high O (see Fig. 1) and Mg

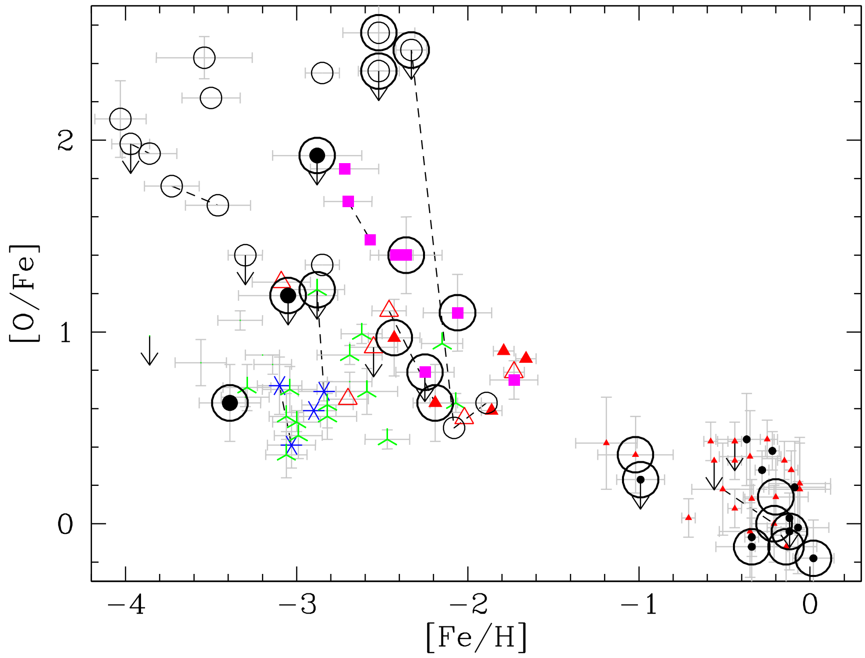

Figure 1: O enhancement in C-rich stars (CEMP-s stars red triangles, CEMP-r&s stars magenta squares and CEMP-no stars black circles) compared to non C-rich stars (blue and green asterisks) gathered from literature (see [3] for references) and from our own study (large circles). The same symbols are also adopted in the other figures.

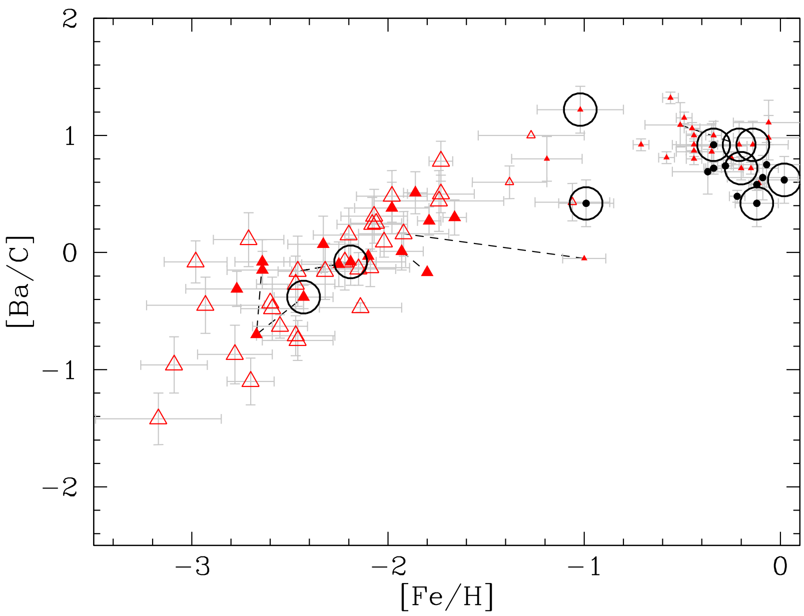

Figure 2: Ba/C ratio as a function of metallicity in CEMP s-process rich stars.

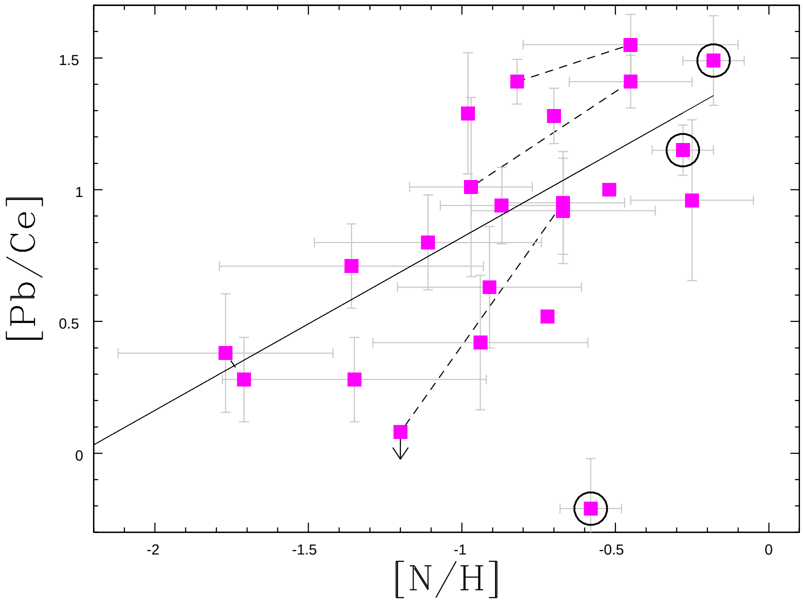

Figure 3: Pb/Ce ratio as a function of N in CEMP-rs stars.

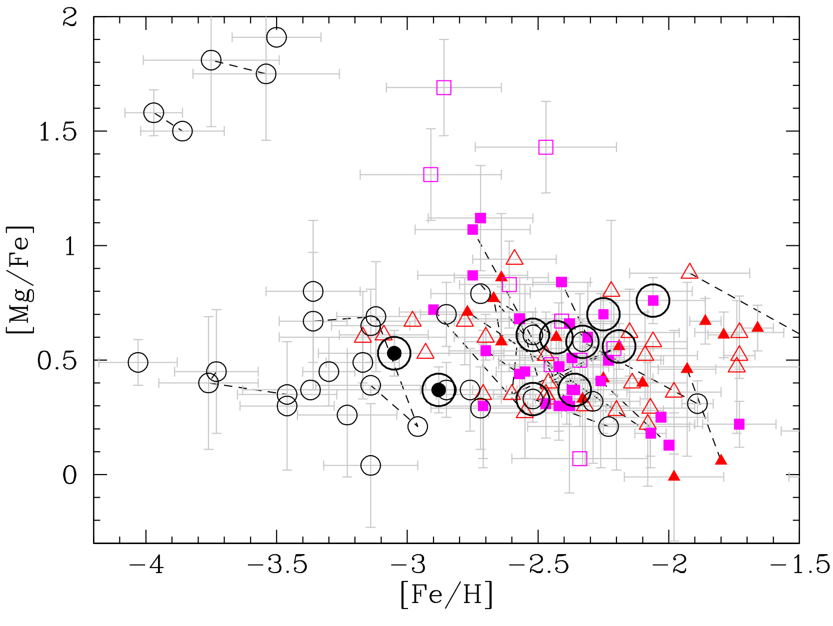

Figure 4: Mg enhancement in CEMP stars.

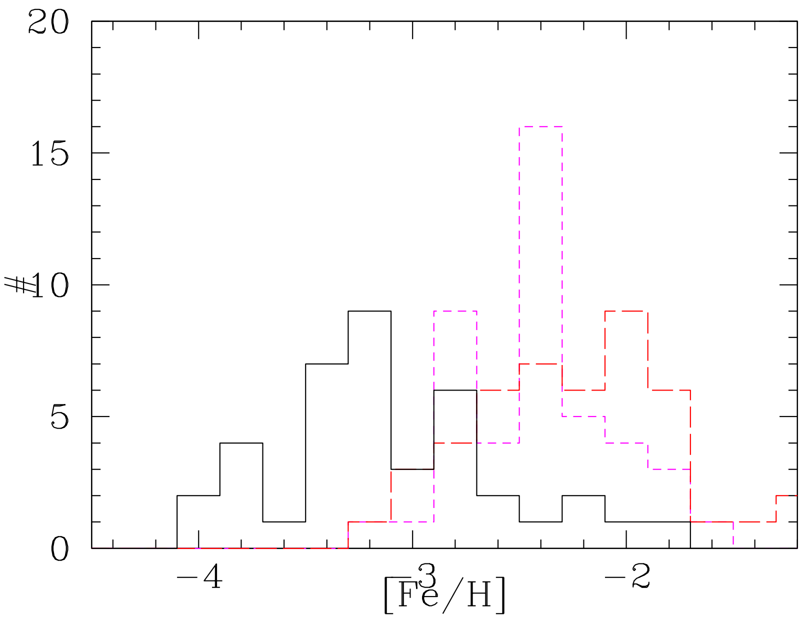

Figure 5: Distribution of CEMP stars as a function of metallicity (CEMP-no stars black solid line, CEMP-s stars red long-dashed line and CEMP-r&s stars short magenta line.

enhancement (see Fig. 4), highlighting metallicity effects on AGB nucleosynthesis compared to s-process C-rich stars.

3. Conclusion

CEMP stars offer a unique opportunity to study low and intermediate mass star formation and evolution. The nucleosynthesis fingerprints left after their extinction on their companions allow us to reconstruct their original characteristics, and in particular their masses and metallicities. Both affect the nucleosynthesis in AGB stars. This explains the different element abundance patterns observed. We are currently determining other elements abundances in CEMP stars such as Li, Na, F, and Rb in order to further constrain nucleosynthesis in low-metallicity AGB stars.

References

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