LIGHT ELEMENT ISOTOPIC COMPOSITION IN THE WIND OF A TYPICAL AGB STAR. Maurizio Busso[3], Roberto Gallino[1,2,3], Claudia M. Raiteri[3], and G. J. Wasserburg[1]. [1]Lunatic Asylum, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, [2]Istituto di Fisica Generale, Università di Torino, Via P. Giuria 1, 10125, Torino, Italy, [3]Osservatorio Astronomico di Torino, Strada Osservatorio 20, 10025 Pino Torinese, Italy

Interstellar grains very likely condense in the extended mass-losing cool atmospheres of low mass red giants ($M < 3M_\odot$) during the time when they are ascending the Asymptotic Giant Branch (AGB). These stars are enshrouded by circumstellar envelopes, being among the most important galactic IR sources. The AGB stars are expected to show a strongly anomalous isotopic composition of the CNO elements and of many other light elements with respect to the solar system. This is due to the occurrence of different mixing episodes that bring to the surface newly synthesized matter from the inner stellar zones. Both the oxygen-rich and the carbon-rich AGB stars should have large isotopic anomalies in light elements as C, N, O, He, Ne, Mg.

All red giant stars suffer for a major I dredge-up episode during their early stages (M stars). A deep convective envelope sets in, penetrating into the partially H-burning inner zones and homogenizing the whole outer structure. Standard evolutionary theory [1] predicts that the stellar atmospheric ^{12}C is reduced by about 1/3 of its initial value, ^{14}N is increased by a factor 2 - 3, ^{15}N is reduced by about 30% and ^{13}C is increased by a factor 2. Thus the carbon isotopic ratio is expected to be considerably lower than solar, in the range $^{12}C/^{13}C = 20 - 30$. A ratio close to $^{14}N/^{15}N = 1200$ is expected. Spectroscopic observations of M stars [2, 3] partly agree with these expectations, for star of $M > 2\ M_\odot$. But the lower mass M stars with $M < 2\ M_\odot$ show much lower values of $^{12}C/^{13}C$, that roughly scale with stellar mass. It is then necessary to postulate some sort of extra mixing [4] to further reduce the $^{12}C/^{13}C$ ratio to 10 - 20. The same process would also affect nitrogen isotopes, with a resulting increase of the $^{14}N/^{15}N$ to about 4,000. In addition, the oxygen abundances are affected by the I dredge-up. While ^{16}O remains essentially unchanged, the envelope convection reaches the inner zones close to the H-shell where a large production of ^{17}O occurs. This causes the surface $^{16}O/^{17}O$ ratio to substantially decrease. This ratio is in principle a very sensitive function of the maximum depth reached by the outer convection and of the still highly uncertain reaction rate of $^{17}O(p,\alpha)^{14}N$. From a comparative analysis of theory and spectroscopic observations, which is biased by the poor knowledge of the mass of the sample stars [5,6], one can infer that $^{16}O/^{17}O$ decreases about exponentially with the initial mass of the star, from its initial value for stars of about 1 $M_\odot$, down to a factor 20 for stars of 2 $M_\odot$, and then it increases back, up to about 1/3 the initial $^{16}O/^{17}O$ for stars of about 20 $M_\odot$. Concerning He, all red giants are slightly enriched in ^4He, but a large enrichment is predicted for ^3He for the lower masses [1].

Finally, when the star is on the AGB, its intermediate layers (outside the degenerate C-O core which is the parent of a future white dwarf) are periodically swept by recurrent episodes of convective He-shell burning (the thermal pulses). This is followed by the partial penetration of the external convective envelope which mixes to the surface material enriched in He-burning ashes, mainly ^{12}C. During this process, ashes of the (now inactive) H-shell, containing CNO nuclei in equilibrium abundances are taken to the surface. We note that AGB stars more massive than 4-5 $M_\odot$, though rare, can give rise to further hydrogen processing, occurring at the base of the convective envelope. Such stars are now recognized to produce abundantly ^7Li, ^{14}N, ^{13}C and ^{26}Al. During AGB evolution the envelope is progressively peeled off by mass loss. This is treated by extensive parametric modeling but understanding is poor. The most widely used simplified treatment [7] involves a free parameter (η); by tuning it to a common value (0.4) it is possible to account very well for the mass loss rates observed in MS, S and C-stars (see observations by [8]; models by [9]). As for the mixing expected after each pulse, (the third dredge-up), we follow the model for this mixing from recent results on AGB evolution [10]. Some typical results concerning the mass loss rate, the C/O ratio and the $^{12}C/^{13}C$ ratio versus pulse number are illustrated in Figs. 1 and 2. While C becomes more and more enriched in ^{12}C during the III dredge-up episodes, no appreciable O composition variation is expected to occur in the envelope of low mass AGB star. As for nitrogen, the ^{14}N produced in the H-burning shell is also mixed with the envelope when the convection zone penetrates below the temporarily inactivated H-shell. We recall that the most important signature of the third dredge-up consists in a strong increase of the heavy s-elements that were built through neutron captures during each convective He-burning instability (thermal pulse). The neutron source in carbon stars is provided by the $^{13}C(\alpha,n)^{16}O$ reaction, whereas the temperature of the He shell never becomes sufficiently high to allow ^{22}Ne to be consumed. Consequently, a major consequence of the III dredge-up is to carry essentially pure ^{22}Ne matter into the envelope. Among interstellar dust grains produced in the reducing conditions of carbon rich atmosphere are the SiC grains. The mainstream population of SiC grain shows a $^{12}C/^{13}C$ distribution [11,12], that compares nicely [13] with the observed distribution in carbon stars [2]. A debated problem is the interpretation of the isotopic anomaly of Si, however, which shows a linear correlation of $^{29}Si/^{28}Si$ versus $^{30}Si/^{28}Si$ on a steeper slope (n = 1.4) than that predicted by the s-process analysis on the basis of an assumed S/Si initial composition by [14]. We have found that it is possible to match the observed slope using a lower initial S/Si value, a factor of 3 lower than that currently adopted. While the dominant mass loss rate over the whole stellar evolution of AGB stars occurs with C/O > 1 , thus providing a source for C, SiC, TiC grains, it should be noted that about 10% of the mass lost is in the region where C/O < 1 and where $^{16}O/^{17}O$ was increased in the envelope by the I dredge-up. This could permit oxide grains to form. In particular, the rare Al_2O_3 grains could be produced during the early stage of AGB evolution when C/O <1.

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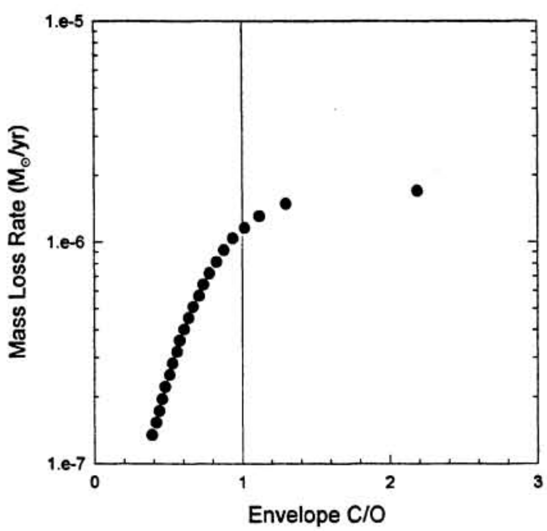

Figure 1. Mass loss rate versus C/O in the envelope for a 1.6 $M_\odot$ star during the thermal pulses (filled circles) along the AGB track.

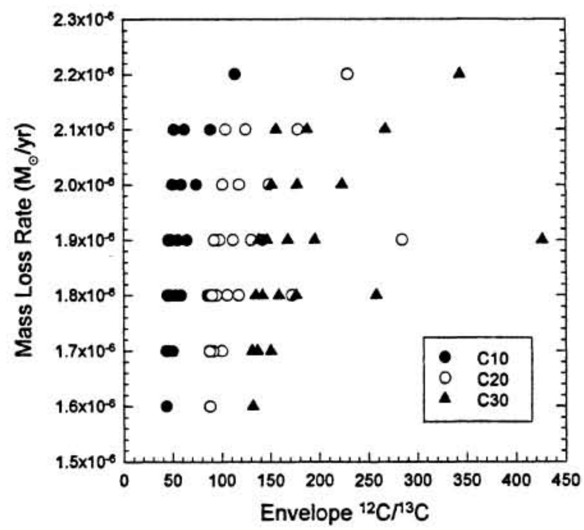

Figure 2. Mass loss rates versus envelope $^{12}C/^{13}C$ for AGB stars of twenty initial masses and three $(^{12}C/^{13}C)_0$ = 10, 20, and 30 at the last pulse before the star leaves the AGB.