The evolution and C, N and O yields of intermediate-mass $Z = 10^{-5}$ stars in isolation and in close binary systems

Gil-Pons, P.[*,†], Doherty, C.L.[†], Suda, T.[†], Campbell, S.W.[†], Lau, H.[**], Guilani, S.M.[‡] and Lattanzio, J.C.[†]

[*]*Poytechnical University of Catalonia, Spain*
[†]*Monash University, Australia*
[**]*Max Plank Institute für Astrophysik, Germany*
[‡]*Polytechnical University of Catalonia, Spain*

Abstract.
We have computed the evolution of $Z = 10^{-5}$ stars of masses between 4 and 9 $M_{\odot}$, from their main sequence till the late TP-(S)AGB phase. We use a recent version of the Mount Stromlo Stellar Evolution code, in which molecular opacities include the effects of variable C/O abundances ratio, [1]. By computing hundreds (or thousands) of thermal pulses, we have been able either to remove the bulk of the stellar envelopes or to obtain stellar cores very close to M_{Ch}. Using [2] prescription for the mass loss rates the computed stars lose their envelopes before their cores reach M_{Ch}. This would forbid the occurrence of SN 1.5 for $Z = 10^{-5}$ stars. Nevertheless the results by [3] suggest that the former prescription might overestimate the mass-loss rates. Therefore we have decreased the rates by [2]. For all the cases we present, even a decrease of one order of magnitude let the stellar cores reach M_{Ch} before the envelope is lost. Therefore the occurrence of SN1.5 at $Z = 10^{-5}$ and their potential contribution to the chemical evolution of the Universe should not be discarded.

We consider the combined effects of the deep/corrosive 2^{nd} dredge-up and Roche Lobe Overflow (RLOF) during the E-AGB to help to constrain the contribution of massive $Z = 10^{-5}$ AGB stars to the CEMPs problem. Our results have implications for the chemical evolution of the Universe and might provide another piece for the puzzle of the CEMPs problem.

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EVOLUTION OF $Z = 10^{-5}$ STAR IN ISOLATION

We present the results of the complete the evolution of $Z = 10^{-5}$ stars of masses between 4 and 9 $M_{\odot}$ till very advanced stages of the TP-(S)AGB phase. Calculations halt when an envelope instability of the type studied by [4] or [5] occurs, leaving envelopes of $0.2M_{\odot}$ for the initially $4M_{\odot}$, and of $1.5M_{\odot}$ for the initially $9M_{\odot}$. This work is an important advance with respect to former calculations in similarly low metallicity regimes, in which main results were somewhat risky extrapolations based on incomplete calculations, [6], [7] . The key factor allowing the present results have been the introduction of the new molecular opacities by [1], in which variable C/O abundance ratios in the surface have been considered.

Apart from the treatment of convection, an important piece of input physics that determines our results is the prescription for the mas-loss rates due to stellar winds.

TABLE 1. Ejected mass of carbon, nitrogen and oxygen due to stellar winds from $Z = 10^{-5}$ stars between 4 and 9 $M_{\odot}$

$M_0/M_{\odot}$	$4M_{\odot}$	$5M_{\odot}$	$6M_{\odot}$	$7M_{\odot}$	$8M_{\odot}$	$9M_{\odot}$
$M_{ej}(C)$	1×10^{-4}	4×10^{-4}	3×10^{-3}	2×10^{-3}	1×10^{-3}	1×10^{-3}
$M_{ej}(N)$	5×10^{-3}	2×10^{-2}	1×10^{-2}	2×10^{-2}	3×10^{-2}	1×10^{-2}
$M_{ej}(O)$	5×10^{-5}	1×10^{-4}	9×10^{-4}	5×10^{-4}	2×10^{-4}	1×10^{-3}

In the case of $Z = 10^{-5}$ stars, the lack of observations limits the reliability of mass-loss rates prescriptions. We have used [2] for our complete calculations but, as concluded by [3], the use of these rates might suppose a significant overestimation. Stars of such low metallicity are not able to drive pulsations strong enough to lift envelope matter up to the low temperature regions of the photosphere. Therefore grains can not form and the mechanism of P_{rad} on them that is supposed to cause winds would be supressed. In order to account for this possibility we have computed the evolution of the envelope mass with mass-loss rates between the values of [2] and down to three orders of magnitude below. For the cases we have studied (between 4 and 9 $M_{\odot}$) one order of magnitude decrease is enough to allow the degenerate cores to grow up to M_{Ch} before significant amounts of envelope masses are ejected. Therefore we conclude that theoretical models for $Z = 10^{-}5$ stars favour the formation of SN1.5. The $9M_{\odot}$ and, probably, the $8M_{\odot}$ initial mass stars are somewhat limit cases, as they reach very high luminosities and the use of [2] rates might be reasonable. The masses of carbon, nitrogen and oxygen ejected due to stellar winds by stars between 4 and 9 $M_{\odot}$ are shown in Table 1.

EVOLUTION OF $Z = 10^{-5}$ STAR IN CLOSE BINARY SYSTEMS

We have considered the evolution of the radii of intermediate-mass $Z = 10^{-5}$ stars and focused on the fact that our models, and specially the most massive ones, present significant increases in their radii during the second dredge-up episode (SDU) and just before the TP-(S)AGB phase. Therefore it is quite reasonable to assume that these phases of the evolution present a high likelyhood for the occurrence of RLOF in the case that our model stars were primary components of close binary systems.

Stars of this metallicity range experience a corrossive/deep SDU episode. The convective envelope does not only reach the H-burning shell, but also regions that have been processed by He-burning. Thus, significant amounts of carbon are mixed in the convective envelope. Mass ejection occuring at this time would be characterised by carbon abundances higher than those of nitrogen and oxygen. Because no third dredge-up episode would have had time to occur, the ejected matter would not present s-process elements. A common envelope is likely to form in the scenario described above. In such case most of the mass lost by the primary star would be lost to the ISM and only a small percentage would be accreted by the secondary star.

The masses of carbon, nitrogen and oxygen ejected by primary stars between 4 and 9 $M_{\odot}$ are shown in Table 2.

TABLE 2. Ejected mass of carbon, nitrogen and oxygen during RLOF from $Z = 10^{-5}$ primary stars between 4 and 9 $M_{\odot}$

$M_0/M_{\odot}$	$4M_{\odot}$	$5M_{\odot}$	$6M_{\odot}$	$7M_{\odot}$	$8M_{\odot}$	$9M_{\odot}$
$M_{ej}(C)$	2×10^{-3}	2×10^{-4}	2×10^{-4}	3×10^{-5}	5×10^{-3}	1×10^{-2}
$M_{ej}(N)$	2×10^{-4}	2×10^{-4}	1×10^{-4}	2×10^{-5}	7×10^{-4}	8×10^{-4}
$M_{ej}(O)$	3×10^{-5}	3×10^{-5}	3×10^{-5}	2×10^{-5}	7×10^{-4}	2×10^{-3}

CONCLUSIONS

1. The evolution of $Z = 10^{-5}$ intermediate-mass has been followed using the new variable C/O molecular opacities, [1] and the mass loss rates by [2].
2. C, N and O yields have been computed up to the occurrence of the late envelope instability. Because [2] is likely to overestimate mass-loss rates, this yields might represent a lower limit to the expected N/C ejected to the ISM. This will be further analysed on a forthcoming publication.
3. We have computed the evolution of the envelope mass versus time using values for the mass-loss rates between one and three orders of magnitude lower than [2]. A reduction of one order of magnitude is enough to allow the formation of SN1.5. Therefore these objects can make an important contribution to the chemical evolution of the Galaxy.
4. Instant mass loss due to RLOF in primary stars hosting deep convective envelopes has been considered. This is likely to occur near the time when surface carbon abundance has reached its maximum value due to the deep SDU process. The proposed scenario might help to explain the frequecy of CEMP-no s stars [8].

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