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NUCLEOSYNTHESIS IN POPULATION III AGB STARS

Lionel Siess and Stéphane Goriely[1]

Abstract. We briefly describe the nucleosynthesis taking place in primordial AGB stars, focusing on the production of s-elements and confronting these results with recent observations.

1 Main sequence evolution

Soon after the Big Bang, the first stars formed in the universe from the fragmentation of primordial gas condensations. Their chemical composition, inherited from the Big Bang nucleosynthesis, is characterized by the absence of metals. The lack of CNO nuclei forces stars more massive than $\sim 1\ M_\odot$, which traditionally sustain their energy production by the CN cycle, to develop a higher central temperature in order for the 3α reactions to ignite already during the main sequence. The induced carbon production activates the CN cycle which rapidly becomes the dominant nuclear energy source, as in more metal rich stars. Thus population III stars are globally hotter.

2 Nucleosynthesis during the AGB phase

In intermediate mass stars, the development of thermal pulses is conditioned by the fact that the CN cycle operates in the H burning shell (Fujimoto *et al.* 1984). The absence of CNO catalysts in primordial stars should thus prevent the occurrence of instabilities in the He burning shell. However the development of mixing episodes at the end of the early AGB phase (Chieffi *et al.* 2001, Siess *et al.* 2002) allows the carbon produced in the He burning shell to mix with the envelope. The pollution of the H-rich regions in CNO catalysts then allows the CN cycle to operate in the H burning shell and the thermal pulses to occur (see also Siess 2001).

The major neutron sources for the s-process are the $^{13}\mathrm{C}\,(\alpha\,,\mathrm{n})\,^{16}\mathrm{O}$ at low temperature and $^{22}\mathrm{Ne}\,(\alpha\,,\mathrm{n})\,^{25}\mathrm{Mg}$ above $T \gtrsim 3\times10^8$K. For ^{13}C to form, protons from the envelope must mix with C-rich layers. In the partial mixing (PM) paradigm, this can be achieved by the diffusion of protons at the time of the third dredge-up

[1] Institut d'Astronomie et d'Astrophysique, ULB, CP 226, B-1050 Brussels, Belgium.

when the convective envelope penetrates the region previously occupied by the thermal pulse. Imposing an artificial proton profile below the envelope over an extension of 5% of the radial pulse extension and using realistic stellar models, we computed the full nucleosynthesis taking place in the region of PM (Goriely & Siess 2001). The simulations indicate that, because of the absence of metals in primordial stars, neutrons are mainly captured by the abundant CNOF and Ne isotopes. Heavier elements with higher neutron capture cross sections are synthesized and contribute to the propagation of the neutron flow. However, the flow is partially halted by the recycling reaction $^{33}\mathrm{S}\,(\mathrm{n}\,,\alpha)\,^{30}\mathrm{Si}$. When this bottle-neck is passed, the s-process resumes and after the first interpulse irradiation ($\sim 10^5$ yr), all the s-elements and mostly Pb and Bi are synthesized. The high temperatures achieved at the base of the thermal pulses ($T \gtrsim 4 \times 10^8$K) activates the second neutron source $^{22}\mathrm{Ne}\,(\alpha\,,\mathrm{n})\,^{25}\mathrm{Mg}$ and this short (~ 10 yr) neutron exposure leads to some (minor) rearrangements of the distribution of specific s-only elements. In the PM zone, ^{14}C, ^{18}O and ^{15}N are also produced by $^{14}\mathrm{N}\,(\mathrm{n}\,,\mathrm{p})\,^{14}\mathrm{C}$ and $^{14}\mathrm{C}(\alpha,\gamma)^{18}\mathrm{O}(\mathrm{p},\alpha)^{15}\mathrm{N}$. In the pulse ^{15}N then convected into ^{19}F by α captures. In addition, primordial stars are subject to hot bottom burning, i.e. nuclear burning at the base of the convective envelope. The major impact is a surface increase in ^{14}N (from the operation of the CN cycle) and ^{23}Na by proton captures on ^{22}Ne. As a consequence, primordial stars should exhibit enhanced ^{14}N, ^{23}Na and s-elements surface abundances characterized by strong Pb and Bi signatures.

3 Conclusion

Provided PM of protons is at work in primordial stars, an efficient s-process nucleosynthesis takes place, characterized by a large overabundance of Pb and Bi. The recent discovery of "Pb-stars" support these results (Van Eck *et al.* 2001) but the concomitant observations of s-process enriched stars with no overabundance of Pb and Bi is puzzling. At present time, the PM scenario cannot account for these peculiar abundances and one has to invoke new processes. Among those, the possible massive injection of protons during the thermal pulses of very-low metallicity stars (Iwamoto *et al.* 2002) or the effects of rotationally induced mixing (Langer & Herwig 2001) are the most promising solutions, but consistent simulations remain to be performed.

References

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