Clues on the first stars from CEMP-no stars

Arthur Choplin\(^1\), Georges Meynet\(^1\), André Maeder\(^1\), Raphael Hirschi\(^2\), Sylvia Ekström\(^1\) and Cristina Chiappini\(^3\)

\(^1\)Geneva Observatory, Geneva University, CH–1290 Sauverny, Switzerland
email: arthur.choplin@unige.ch
\(^2\)Astrophysics group, Keele University, Lennard-Jones Lab., Keele, ST5 5BG, UK
\(^3\)Leibniz-Institut fuer Astrophysik, An der Sternwarte 16, 14482 Potsdam, Germany

Abstract. The material used to form the CEMP-no stars presents signatures of processing by the CNO cycle and by He-burning from a previous stellar generation called spinstars. We compare the composition of the ejecta (wind + supernova) of a spinstar model to observed abundances of CEMP-no stars. We show that observed abundances as well as the isotope ratio \(^{12}\)C/\(^{13}\)C may be reproduced by the spinstar ejecta if we assume different mass cuts when adding the supernova material to the wind ejecta.

Keywords. stars: evolution, rotation, massive, abundances, nucleosynthesis, chemically peculiar

1. Introduction

CEMP-no stars (Carbon Enhanced Metal Poor stars with no signature of s or r processes) are chemically peculiar objects that dominate the stellar populations at \([\text{Fe/H}] < -3\) (Aoki et al. 2010, Norris et al. 2013). The "spinstar scenario" (Meynet et al. 2010), suggests that CEMP-no stars formed in a region previously enriched by a fast rotating, low metallicity, massive star, experiencing mixing, mass loss and eventually a supernova at the end of its life.

We discuss a 32 \(M_\odot\) spinstar model computed with the Geneva code. Absolute amounts of C, N, O, F, Ne, Na, Mg, Al as well as isotope ratios \(^{12}\)C/\(^{13}\)C, \(^{24}\)Mg/\(^{25}\)Mg and \(^{24}\)Mg/\(^{26}\)Mg in the ejecta are compared to observed CEMP-no abundances.

2. Results

Fig.1 shows the \([\text{X/H}]\) ratios (left panel) and 3 isotope ratios (right panel). The grey line is the initial composition of the model which is a modified \(\alpha\)-enhanced mixture (\(\alpha\)-mod) : initial abundances of \(\alpha\)-elements are enhanced and \([\text{C/N}], [\text{O/N}]\) and \(^{12}\)C/\(^{13}\)C ratios are set to 2, 1.6 and 30, according to suggestions of Maeder et al. (2014) for \([\text{C/N}]\) and \([\text{O/N}]\) and to prediction of galactic chemical evolution models at low metallicity of Chiappini et al. (2008) for \(^{12}\)C/\(^{13}\)C. The black lines are patterns in the ejecta when considering either the wind only, or the wind plus supernova obtained for various \(M_{\text{cut}}\), \(M_{\text{cut}}\) being the mass coordinate inside the star delimiting the expelled part from the part which is kept into the remnant.

The effects of the CNO cycle and the Ne-Na Mg-Al chains are visible in every pattern (except in the \(M_{\text{cut}} = 10M_\odot\) one). When the CNO cycle operates, \(^{12}\)C and \(^{16}\)O are transformed into \(^{14}\)N and \(^{13}\)C during the evolution, explaining the higher \([\text{N/H}]\) ratios compared to \([\text{C/H}]\) and \([\text{O/H}]\). \(^{12}\)C/\(^{13}\)C ratios are close to the CNO equilibrium value
(log\(\frac{^{12}C}{^{13}C}\) \sim 0.7), showing also that the major part of those ejecta was processed by the CNO cycle. Also some Ne and Mg were transformed into \(^{23}\)Na and \(^{27}\)Al owing to the Ne-Na Mg-Al chains so that \([\text{Na}/\text{H}] > [\text{Ne}/\text{H}]\) and \([\text{Al}/\text{H}] > [\text{Mg}/\text{H}]\) in the final ejecta.

About 2 \(M_\odot\) of the He-burning shell was ejected in the fourth case (\(M_{\text{cut}} = 10 M_\odot\)). The associated pattern bears indeed the signature of He-burning: \([\text{C}/\text{H}], [\text{O}/\text{H}]\) and \(\frac{^{12}C}{^{13}C}\) are several dex higher than previous patterns. It is worthwhile to remark that \(\frac{^{12}C}{^{13}C}\) is a relevant isotope ratio to constrain \(M_{\text{cut}}\): if too deep layers are expelled, part of the He-burning region is expelled and \(\frac{^{12}C}{^{13}C}\) increases a lot, lying clearly outside of the observed values. Interesting also is the \([\text{Ne}/\text{H}]\) ratio which have raised by \sim 2\) dex. This is due to the reaction \(^{16}\)O(\(\alpha,\gamma\))\(^{20}\)Ne and to the destruction of \(^{14}\)N in the He-core through \(^{14}\)N(\(\alpha,\gamma\))\(^{18}\)F(\(e^+,\nu_e\))\(^{18}\)O(\(\alpha,\gamma\))\(^{22}\)Ne. Isotopes ratios \(^{21}\)Mg/\(^{25}\)Mg and \(^{24}\)Mg/\(^{26}\)Mg are lowered by \sim 1\) dex in this case because of the synthesis of \(^{25}\)Mg and \(^{26}\)Mg through \(^{22}\)Ne(\(\alpha,n\))\(^{25}\)Mg and \(^{22}\)Ne(\(\alpha,\gamma\))\(^{26}\)Mg in the He-core.

The models can explain large parts of the observed scatter in \([\text{X}/\text{H}]\) and \(\frac{^{12}C}{^{13}C}\) ratios, except for \([\text{Al}/\text{H}]\), which is always overestimated by at least 1\) dex. Since \([\text{Al}/\text{H}]\) \sim -3.8 in the ISM, dilution of the ejecta with the initial ISM would allow \([\text{Al}/\text{H}]\) values of -3.8 at best, but not lower, where more than half of the observed CEMP-no are lying. Aluminum surproduction is the biggest discrepancy between models and observations and should be investigated in a future work.

References

Aoki, W. 2010, Carbon-Enhanced Metal-Poor (CEMP) stars, Proc. IAU Symposium No. 265, p. 111


