Massive Stars Near and Far
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Nitrogen production in population III stars

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Abstract. The first stars in the Universe have inherited their composition from primordial nucleosynthesis, so they have no metal. These stars, which are also named population III (pop III) stars, began the process of reionization in the Universe and contributed to the metal enrichment with heavy elements. Previous studies showed that they should have been rotating fast due to small or no angular momentum loss, reaching easily the critical velocity since they are massive and have very low stellar winds, thus their mass loss is very low or zero. Our aim is to study how the production of primary nitrogen is affected due to high rotation in the pop III stars. So, we compared grids of pop III stars with zero, average, and high rotation. All these models have been computed using Geneva code (GENEC) in the mass range of $9M_{\odot} \leqslant M_{ini} \leqslant 120M_{\odot}$. Due to the rotational mixing, the carbon produced in the He-burning core is diffused towards the H-burning shell, triggering the CNO cycle and producing primary nitrogen. In some models the transition of the shell from a pp-chain H-burning to a CNO H-burning induces a strong energy release and a complete change of the stellar structure and the nucleosynthesis. The production of nitrogen is boosted for the high rotation models.

Keywords. stars: rotation, stars: interiors, stars: population III, stars: evolution

1. Stellar models

We computed a grid with fast rotating stellar models, $u_{ini} = 0.7u_{crit}$, using GENEC. Then, we compared grids of stellar models with different initial rotational velocities, zero, average ($u_{ini} = 0.4u_{crit}$) (Murphy et al. 2021), and high rotation. All the models have been computed with consistency to the papers of Murphy et al. (2021), Ekström et al. (2012), Georgy et al. (2013), and Groh et al. (2019) but with different initial rotations and metallicities. The u_{crit} is the critical limit of rotation and it is defined by $u_{crit} = \sqrt{\frac{2}{3}\frac{GM}{R_p}}$, where R_p is the polar radius at break-up limit. The critical velocity is reached when the gravitational acceleration is counterbalanced by the centrifugal force. Rotational mixing of the chemical elements is mainly due to shear turbulence.

2. Production of nitrogen

1. Shear turbulence at the border of the He-burning core is a key process to bring C into the H-burning shell and produce primary N, left panel of figure 1.
2. The contraction is in part the cause of the Ω gradient that drives the shear turbulence that brings carbon into the H-shell and produce the primary nitrogen.
3. In pop III stars the contraction is less strong than on models with even a small initial content of heavy elements.
4. This is because in pop III stars H-burning occurs at higher temperatures which are near the temperatures that are needed for the 3α-process, right panel in figure 1.
5. Therefore we would expect much less production of primary N in the pop III models than in models with higher metallicities.

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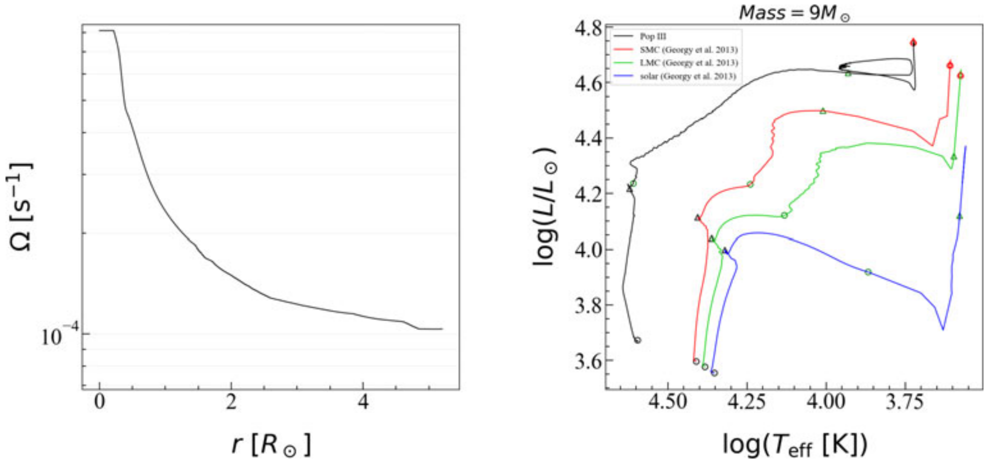

Figure 1. Left panel: The evolution of the angular velocity $\Omega(r)$ at the end of He-burning phase for the $20M_{\odot}$ model. Right panel: HR diagram for $9M_{\odot}$ models with different metallicities (Georgy et al. 2013).

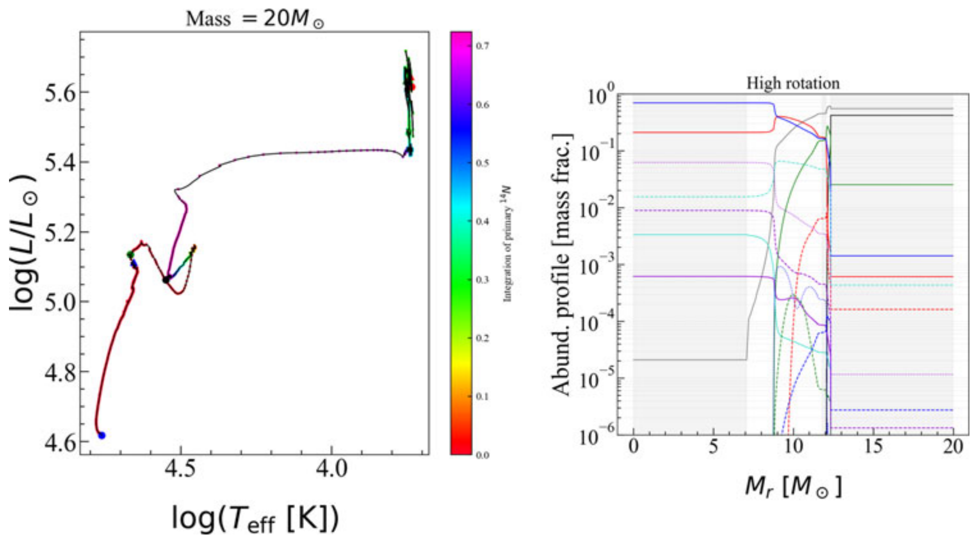

Figure 2. Left panel: HR diagram with the integrated amount of N during its evolution. Right panel: The chemical structure of the $20M_{\odot}$ model with high rotation at the end of He-burning phase from the core to the surface. The grey shaded areas are the convective regions of the star. The green line corresponds to N.

6. However, in the case that the pop III stars are fast rotating models, they may produce a significant amount of primary N as seen in right panel of figure 2.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1743921322003076.

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