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Rotation and Nitrogen Enhancements in Blue Supergiants

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Abstract. Rotation brings significant surface He– and N–enhancements. The excesses are higher for higher masses and rotation. Rotating stellar models may account for the nitrogen enhancements observed at the surface of blue supergiants.

Far from being a small refinement in the physics of stellar interior, rotation affects all the outputs of massive star models (see e.g. Maeder & Meynet 2000 and references therein; Meynet & Maeder 2000; Heger et al. 2000). In particular rotation modifies deeply the evolution of the surface abundances.

Fig. 1 compares predicted and observed values of nitrogen to carbon (N/C) ratios at the surface of supergiants. Let us recall that for non–rotating stars, the surface enrichment in nitrogen only occurs when the star reaches the red supergiant phase (see e.g. Fig. 17 in Meynet & Maeder 2000). There, CNO elements are dredged–up (Dup) by deep convection. This means, that in the plane $\Delta \log \mathrm{N/C}$ versus $\log L/L_\odot$ (see Fig. 1), these models predict that stars are either on the horizontal line defined by $\Delta \log \mathrm{N/C} = 0$ or along the line labelled "1^{st} Dup, $v = 0$ km/s", no stars are predicted outside these two regions. For rotating stars, N–excesses already occur during the main sequence (MS) phase. For solar metallicity stars, the N–excesses remain nearly constant during the crossing of the Hertzsprung–Russell diagram and continue to increase when the star becomes a red supergiant as a consequence of the dredge-up episode. One sees also from Fig. 1 that the enhancements are larger for higher rotation and initial stellar masses. Due to the initial distribution of masses and rotational velocities, the rotating models predict that the observed points in the plane $\Delta \log \mathrm{N/C}$ versus $\log L/L_\odot$ can be distributed everywhere between the horizontal line "$\Delta \log \mathrm{N/C} = 0$" and a line corresponding to the maximum enrichment allowed by the highest initial rotational velocities.

The points in Fig. 1 correspond to observations of supergiants performed by Venn (1995), Gies and Lambert (1992), Lennon (1994), Vrancken et al. (2000), McErlean et al. (1999) and Carr et al. (2000). We note that :

- The observed points are not concentrated along the horizontal line $\Delta \log \mathrm{N/C} = 0$ and along the line labelled "1^{st} Dup, $v = 0$ km/s" as is predicted by non–rotating models.
- Some of the observed supergiants show nitrogen enhancements well below the values predicted by the first dredge–up of non–rotating models. These stars cannot be on a blue loop. Instead, Venn (1995) suggested that they are on their way from the MS to the red giant branch and have undergone some mixing in the early stage of their evolution. Rotating models support this view. Indeed

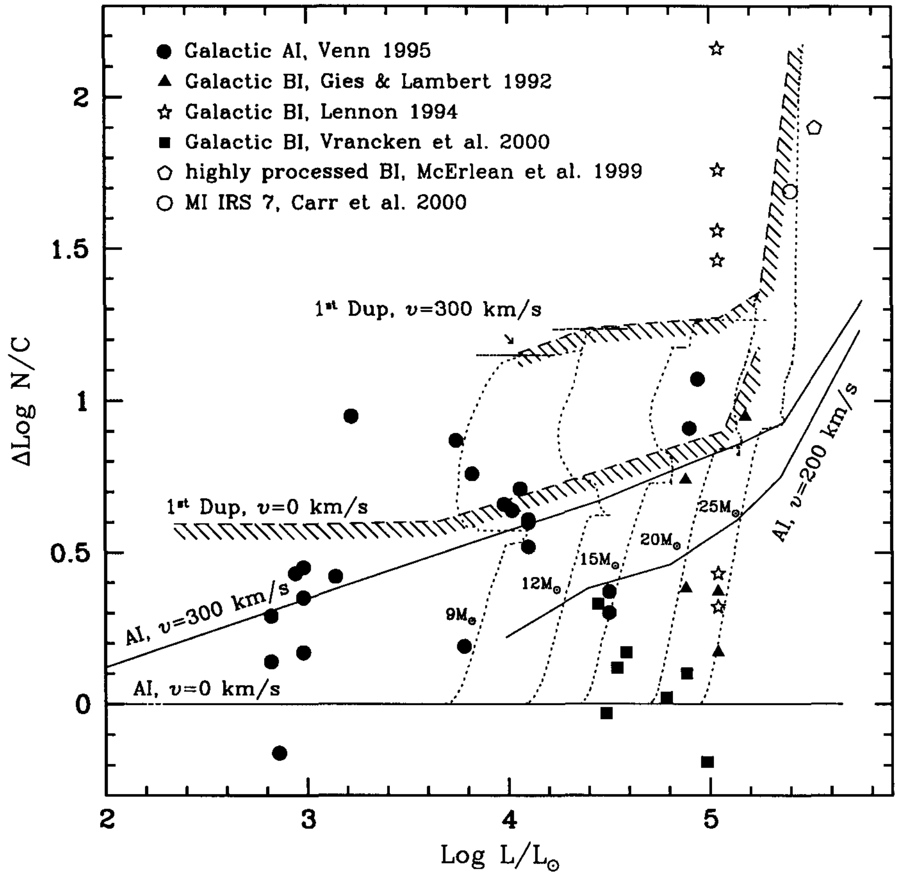

Figure 1. Nitrogen to carbon ratios as a function of the luminosity. The quantity $\Delta \log(\mathrm{N/C})$ is equal to $\log(\mathrm{N/C}) - \log(\mathrm{N/C})_i$, where N and C are the surface abundances (in number) of nitrogen and carbon respectively and the index i indicates initial values. The dotted lines represent evolutionary tracks for rotating models with initial velocity of 300 km s^{-1}. The continuous lines indicate the $\Delta \log(\mathrm{N/C})$ versus $\log L/L_\odot$ relation obtained from non-rotating and rotating models when the star is an A-type supergiant (AI). The hatched lines show the same relation but after the star has undergone the first dredge-up (1^{st} Dup). The points represent the observed values (see text).

the rotating models, with various initial velocities, can naturally reproduce the abundances observed at the surface of these stars as can be seen from Fig. 1.

- A-type supergiants observed by Venn (1995) are also observed well above the line corresponding to the first dredge–up of non–rotating models. Again, this is an indication of an extra–mixing process active in massive stars. According to the present models these stars could originate from stars with initial equatorial velocities superior to 300 km $\sec^{-1}$.
- Very interestingly, B–type supergiants present very high N/C ratios (see the points from Lennon 1994 and McErlean et al. 1999). These stars are likely on a blue loop after a red supergiant phase. Presently, the models predict no blue loops at such high initial masses. Maybe this is an indication that the mass loss rates during the red supergiant phase are much higher than accounted for in the models, because high mass loss rates at this stage might bring the star back to the blue.
- We have indicated also the position in this diagram of the red supergiant observed at the center of our Galaxy (IRS 7). This star shows a nitrogen enhancement well above what is predicted by standard models. According to Carr et al. (2000 and references therein) the metallicity at the galactic center is near solar. On the basis of this strong enrichment, these authors suggest that this star might have been a rapid rotator. The present models show that indeed rotating models can account for the enrichments observed at the surface of this star.
- As noted above, theory predicts larger excesses for higher masses and thus for higher luminosities, however the superpositions of stars with different initial velocities tends to blur this simple picture. In Fig. 1, one observes however that the most enriched stars are the most luminous ones. However more observations are needed to confirm such a view.
- Finally, let us add that rotation affects in an important manner the evolution of the most massive stars into the Wolf-Rayet (WR) stage. Rotation increases the duration of the WR phase and the minimum initial mass for stars going through a WR phase is decreased by rotation (see Maeder & Meynet 2000 and references therein).

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