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Thermohaline mixing and fossil magnetic fields in red giant stars

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Abstract. We discuss the occurence and consequences of thermohaline mixing in RGB stars, as well as the possible inhibition of this process by a fossil magnetic field in Ap star descendants.

Keywords. hydrodynamics - instabilities - stars: abundances- stars: evolution - stars: interiors - stars: rotation

1. Thermohaline mixing in RGB stars

Thermohaline mixing has been recently identified as the dominating process that governs the photospheric composition of low-mass bright red giant stars (Charbonnel & Zahn 2007a). As shown in Fig. 1, thermohaline convection indeed simultaneously accounts for the observed behaviour of the carbon isotopic ratio and of the abundances of Li, C and N in the upper part of the red giant branch. These results have been obtained using the prescription recommended by Ulrich (1982) for the turbulent diffusivity produced by the thermohaline instability in stellar radiation zones, with the shape factor sustained by laboratory experiments (Krishnamurthi 2003). Thermohaline mixing also significantly reduces the ^{3}He production with respect to canonical evolution models as required by measurements of ^{3}He/H in galactic HII regions. This solves the so-called "^{3}He problem", which requires that less than ∼10% of low-mass stars are producing ^{3}He as predicted by the classical stellar theory (Galli *et al.* 1997; Charbonnel 2002).

2. The peculiar case of "thermohaline deviant stars": Ap star descendants?

However a couple of planetary nebulae, namely NGC 3242 and J320, have been found to behave "classically": slightly more massive than the sun, they are returning fresh ^{3}He to the internal medium, in the amount predicted by classical stellar models (Rood *et al.* 1992; Balser *et al.* 1999, 2006).

To reconcile the ^{3}He/H measurements in Galactic HII regions with the high values of ^{3}He in NGC 3242 and J320, we propose that thermohaline mixing is inhibited by a fossil magnetic field in RGB stars that are descendants of Ap stars (Charbonnel & Zahn 2007b). We obtain a threshold for the magnetic field of 10^4–10^5 Gauss, above which it inhibits thermohaline mixing in red giant stars located at or above the L-bump. Fields of that order are expected in the descendants of Ap stars, taking into account the contraction of their core.

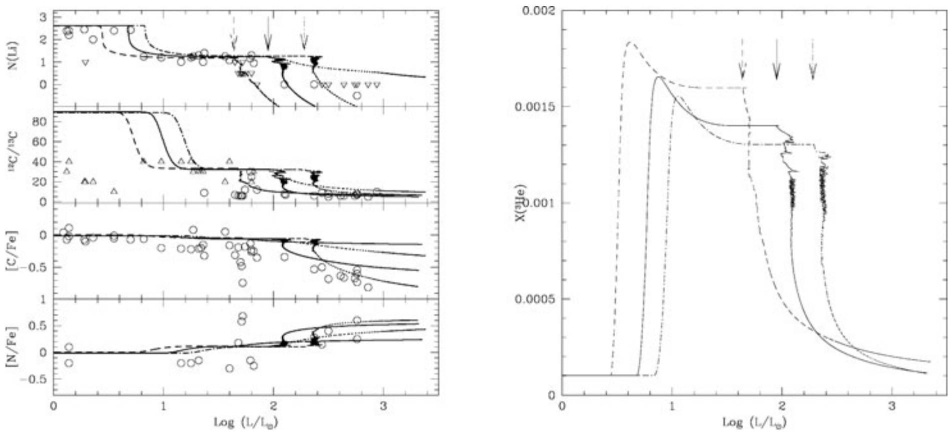

Figure 1. (Left) Evolution of the lithium abundance, of the carbon isotopic ratio, of [C/Fe] and [N/Fe] as a function of the luminosity logarithm for the 0.9M$_\odot$ models with [Fe/H] = −1.8, −1.3 and −0.5 (respectively dashed-dotted blue, full line black, and dashed red) computed with thermohaline mixing. The arrows in the upper panel indicate the location of the bump for the three metallicities. Observational data are from Gratton *et al.* (2000) for field stars in the metallicity range [Fe/H] ∈ [−2;−1]. Blue symbols are for stars with measured [Fe/H] values lower than –1.4, black for stars with −1.4 ⩽[Fe/H]⩽ −1.2, and red for [Fe/H] higher than –1.2. Circles are actual measurements, open upward triangles are *lower* limits and open downward triangles are *upper* limits. The first modification in the surface abundances is due to the classical first dredge-up. When the star reaches the L-bump, thermohaline mixing strongly modifies the surface abundances, in agreement with the observations. (Right) Evolution of the surface abundance of ^{3}He (in mass fraction). The line symbols are as in the left figure. Figures from Charbonnel & Zahn (2007a).

We conclude that in a large fraction of the descendants of Ap stars thermohaline mixing does not occur. As a consequence these objects must produce ^{3}He as predicted by the standard stellar theory and as observed in the planetary nebulae NGC 3242 and J320. The relative number of such stars with respect to non-magnetic objects that undergo thermohaline mixing is consistent with the statistical constraint coming from observations of the carbon isotopic ratio in red giant stars (Charbonnel & Do Nascimento 1998). It satisfies also the Galactic requirements for the evolution of the ^{3}He abundance.

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