From Lithium to Uranium: Elemental Tracers of Early Cosmic Evolution
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Tachocline mixing and light elements in halo stars

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Abstract. We have computed updated models of population II stars on the Spite plateau. We focus here on the light elements abundance predictions when the new tachocline mixing process is accounted for.

Keywords. Stars: interiors, stars: abundances, stars: rotation

1. The light elements in population II stars

Predictions on lithium and beryllium abundances in the oldest stars of the Galaxy are interesting in several respects. The Big Bang nucleosynthesis should produce an observable ^{7}Li fraction so that the ^{7}Li measurements in the population II stars constrain cosmology. ^{6}Li and ^{9}Be are chiefly produced by fusion and spallation in the interstellar medium. Using models of the interstellar medium ^{9}Be production allows to constrain the age of the first stars (Pasquini *et al.* (2004)) and the early Galaxy evolution.

Using stellar models we relate here the observed and the initial light elements abundances in population II stars (having [Fe/H] $= -2$ dex) on the [6500, 5000] K $T_{\rm eff}$ range. The models are evolved from the pre-main sequence to 13 Gyrs. Light elements are destroyed at low temperature in stellar interiors and any mixing process could significantly change their surface fractions. They enable us to constrain the dynamical processes inside the stars. We investigate the light elements history as predicted from models including the most recent physics in terms of opacities and equation of state (OPAL), atmospheres (NextGen), nuclear reactions (NACRE). We moreover take into account the impact of microscopic diffusion coupled to a turbulent diffusion process related to the rotation : the tachocline mixing (Spiegel & Zahn (1992)).

2. From the microscopic diffusion to the tachocline mixing

The microscopic diffusion lowers the light elements abundances during main sequence. For ^{7}Li we find a depletion factor varying from 0.2 dex below $T_{\rm eff} = 5500$ K to 0.4 dex at 6400 K in agreement with Richard *et al.* (2005). This decreases the discrepancy between the observations in oldest stars and the recent predictions on Big Bang nucleosynthesis (Coc *et al.* (2004)). For atomic diffusion models however: i) a 0.2 dex difference between predictions and observations remains; ii) there is no observational evidence of an increase in ^{7}Li or ^{6}Li abundances when the temperature varies from 6500 to 5500 K as predicted; iii) the strong decrease observed in ^{7}Li abundance below 5500 K is not predicted.

The tachocline mixing has been successfully included in the population I stellar models where it explains ^{7}Li and ^{9}Be history and improves the agreement between the helioseismic predictions and observations (Brun *et al.* (1999), Piau *et al.* (2003)). The tachocline mixing occurs just below the outer convection zone and is directly related to the rotation. However it is compatible with a nearly solid body rotation (which has been suggested by

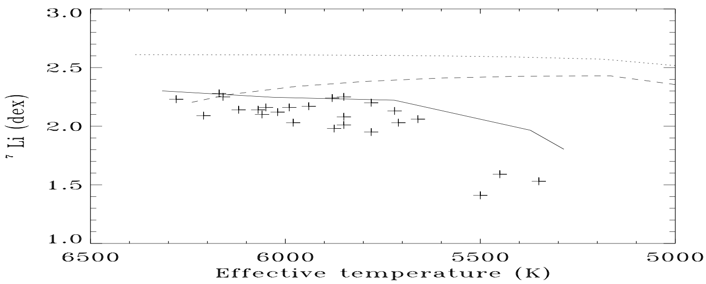

Figure 1. ^{7}Li abundances in non diffusive models (dotted line) microscopic diffusion models (dashed line) and microscopic + tachocline diffusion models (solid line). Initial ^{7}Li abundance is 2.6 dex as deduced from BBN Coc *et al.* (2004) calculations. The observationnal data are from Ryan *et al.* (1996) and Ryan & Deliyannis (1998).

Talon and Charbonnel (2003)) and is not related to angular momentum loss. We modeled the rotation history in the solid body assumption using a similar wind braking prescription as used for the population I objects (Kawaler (1988)). The rotation goes below 10 km/s after 0.1 Gyr and decreases further as age$^{-1/2}$. The effect of the tachocline diffusion is tuned by the tachocline breadth that we assume similar as in the present Sun (0.05 $R_\star$). It is also tuned by the buoyancy frequency in this region that lies between 1 and 100 μHz.

The tachocline diffusion brakes ^{7}Li and ^{9}Be microscopic diffusion above $T_{\rm eff} = 5500$ K. This improves the $^7\mathrm{Li} - T_{\rm eff}$ relation agreement to the observations on the Spite plateau as shown in figure 1. The 0.2 dex increase in ^{9}Be at the turnoff also changes the age estimate of these stars based on the ^{9}Be fraction.

^{6}Li nuclear burning region lies slightly below the base of the outer convection zones. The tachocline models therefore predict a significant ^{6}Li depletion : 0.4 dex at $T_{\rm eff} =$ 6500K. The destruction moreover increases with decreasing $T_{\rm eff}$ below 6500 K at variance with the microscopic diffusion models. To date ^{6}Li has not been detected below 5900 K.

3. Conclusion

In population II stars the tachocline mixing process improves the agreement between models and observations for the ^{7}Li abundances. It moreover makes clear predictions on the less observed ^{6}Li and ^{9}Be isotopes that will have to be compared with new observations in the near future.

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