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Lithium isotopes in halo dwarfs

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Abstract. We present calculations of ^{7}Li evolution in halo dwarfs during pre-MS and MS. The combination of tachocline mixing, nuclear destruction and microscopic diffusion is investigated. We briefly touch on the question of ^{6}Li.

Keywords. Stars: abundances, stars: evolution

1. General inputs

We exploit the CESAM stellar evolution code (Morel 1997) with the following inputs:

- OPAL equation of state and opacities for a Population II mixture: $[\alpha/\mathrm{Fe}] = 0.3$.
- Nuclear reactions from NACRE (Angulo *et al.* 1999) and microscopic diffusion of Michaud & Proffitt (1993).

The initial composition is Y = 0.2479, [Fe/H] = −2 & [^{7}Li] = 2.6 (Coc *et al.* 2004), [^{6}Li] = 1.1. We assume that the rotation history is similar to Population I solar analogs. The angular momentum (J) loss through magnetized wind and the rotation (Ω) rely on the Kawaler (1988) prescription: $\frac{dJ}{dt} = -K\Omega 3(\frac{R}{R_\odot})^{1/2}(\frac{M}{M_\odot})^{-1/2}$

K is a constant calibrated to reach the solar rotation in solar models. Rotation induces mixing in the upper radiation zone, just below the base of the convection zone : the tachocline mixing (Spiegel & Zahn 1992). The analytical developments provide the rotationally induced turbulence coefficient: $D_T(r) \sim \nu_H \left(\frac{d}{r_{bcz}}\right) 2\,(\tilde{\Omega}/\Omega)2\exp(-2\zeta)\cos 2(\zeta)$ with ν_{H} the horizontal viscosity, $\tilde{\Omega}$ the differential rotation. $\zeta = 4.933(\mathrm{r_{bzc}} - \mathrm{r})/\mathrm{d}$, $\mathrm{d} = \mathrm{r_{bzc}}(2\Omega/\mathrm{N})^{1/2}(4\mathrm{K}/\nu_{\mathrm{H}})^{1/4}$ the width of the tachocline. $\mathrm{r_{bcz}}$ is the radius of the convection zone, $\mathrm{N2} = \mathrm{g}[1/\Gamma_1 \mathrm{d}\ln\mathrm{p}/\mathrm{dr} - \mathrm{d}\ln\rho/\mathrm{dr}]$ is the squared buoyancy frequency, $\mathrm{K} = \chi/\rho\mathrm{c_p}$ is the radiative diffusivity.

The stars are evolved to 200 Myr (end of pre-MS) and then 13 Gyr (present age). calculations as they need ∼1 Gyr to have a significant impact.

2. Lithium evolution

Above $\mathrm{T_{eff}} = 5200$K no ^{7}Li pre-MS depletion is computed. Below this temperature the slope of the ^{7}Li-$\mathrm{T_{eff}}$ relation does not match the observations. Thus ^{7}Li surface abundances are presumably determined during the MS.

Provided both microscopic and tachocline diffusion are accounted for, ^{7}Li abundances at 13 Gyr fit the observations below $\mathrm{T_{eff}} = 5500$ K. A plateau is also reproduced above that temperature but it lies ∼0.2 dex above the current observations (figure 1). Despite their fast rotation (5–10 km.s^{-1}) and thus reinforced deep mixing, the warm ^{7}Li poor stars can't be explained in the framework of our calculations. Three out of four of these objects are confirmed spectroscopic binaries (Ryan *et al.* 2002) the companion being most likely a compact object. Given the shallow convection zones of the ^{7}Li poor stars, a mass transfer of 1 to 3.10^{-2}M$_\odot$ of ^{7}Li free matter as the companion was on the giant stage could explain the observed abundances: [^{7}Li] < 1.7.

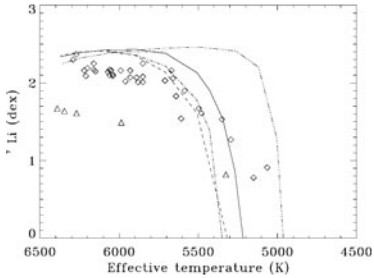

Figure 1. $T_{\rm eff}-{}^{7}$Li MS relation at 13 Gyr in tachocline models for buoyancy frequency 10 μHz (solid line) and 2 μHz (dashed line) in the tachocline region. The buoyancy frequency varies rapidly with depth near the upper limit of the radiation zone, thus it is a free parameter of the tachocline mixing. The depletion pattern is also provided for five time faster rotation history and buoyancy frequency of 10 μHz (dot-dashed line) and pure microscopic diffusion models (dash-three dotted line). Observations (diamonds) and upper limits (triangles) are from Ryan & Deliyannis (1998), Ryan *et al.* (1999) and Ryan *et al.* (2001).

^{6}Li is destroyed by proton capture at lower temperature than ^{7}Li. Any object now having $T_{\rm eff} < 6200$K should have experienced a strong pre-MS depletion. For the models with tachocline mixing exhibiting $T_{\rm eff} = 6000$K at 13 Gyr we predict a $\sim$1 dex depletion.

3. Conclusion

$\Longrightarrow$ The ^{7}Li abundances mostly result from the MS evolution. Below $T_{\rm eff} = 5500$ K our predictions on ^{7}Li match the observations. A flat plateau is calculated above this temperature but still lies $\sim$0.2 dex above the current observations if we start the models with the standard BBN abundance $[{}^{7}\mathrm{Li}] = 2.6$. This assumption could be reconsidered however (e.g. Piau *et al.* 2006). A mass transfer of a few percent of solar masses of ^{7}Li free matter could explain the warm ($T_{\rm eff} > 6000$ K) lithium poor halo dwarfs.

$\Longrightarrow$ We predict a very strong pre-MS and MS ^{6}Li depletion below $T_{\rm eff} = 6200$ K. This hardly is compatible with the recent $[{}^{6}\mathrm{Li}]\sim 1$ measurements in the halo unless the isotope was massively produced before/during the Galactic halo formation. Observationally the ^{6}Li measurements need confirmation (Cayrel *et al.* 2007).

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