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The solar Lithium problem: is the explanation due solely to mixing or also to the e^--capture decay rate of ^{7}Be?

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Abstract. The nucleosynthesis of ^{7}Li is one of the most crucial problems in nuclear astrophysics, as its observations in several sites are hard to be explained. Concerning the Sun, the most common interpretations of the low Li abundance invoke either burning in early stages or non-convective mixing below the envelope. Here we apply a diffusive mechanism of mixing, together with a recent estimate of the rate for e^--captures on ^{7}Be, to establish whether the solar Li destruction should be attributed to purely pre-Main Sequence (MS) nuclear processes or if the coupling of mixing and nucleosynthesis on the MS can account for it. Our preliminary results indicate that, whether Li survives the pre-MS phase, the changes of the ^{7}Be e^--capture rate do not affect its production/destruction. The low Li abundance should then depend only on diffusion processes from the bottom of the convective envelope to the lowerlying tachocline zone. We suggest that, if diffusive processes occurred over the age of the Sun, they required diffusive mass transfers of a few 10^{-13} $M_\odot$/yr to explain the Li drop. This is a high estimate: future works will tell us if it is realistic or not. In this second case, pre-MS burning would remain the only alternative.

1 Introduction

The ^{7}Li abundance in the solar photosphere is a factor of about 160 lower than in meteorites [1]. This discrepancy ("the solar Li problem") may mean that nuclear processes in pre-MS phases affected strongly the Li abundance, which fact was found to be possible in models where convection is extended as compared to what the Schwarzschild criterion predicts by some forms of overshooting [2]. Models without them fail in destroying Li in pre-MS by more than a factor of around 7 and need that, during the MS itself, Li is exposed to conditions where *p*-captures effectively destroy it. On the MS, the temperature of sub-convective layers remain always rather low, but Li is a fragile nucleus and a weak burning integrated over 4.56 Gyr of life is enough for its consumption. Below the convective envelope, indeed, Li abundances as low as 10^{-15} or less are found [3]. Processes of diffusive mixing below the formal inner border of solar convection are therefore sometimes invoked as an alternative to pre-MS burning [4]. Thanks to helioseismology, we know that the internal solar structure is characterized by two different profiles of rotational velocity: a differential rotation in the convective envelope and a rigid-body one in the innermost regions. The transition region between these two regimes is called *tachocline*: it is the layer where a differential rotation is established and the solar dynamo with

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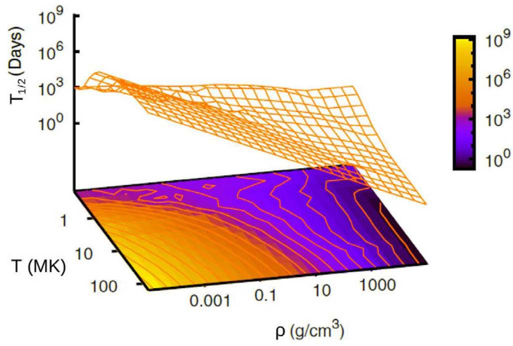

Figure 1. The half-life for ^{7}Be decay through e$^-$-captures, as a function of the plasma temperature T and the plasma density ρ, as derived in [5] and used in the present work in place of the previous one by [6].

all its ensuing buoyancy phenomena have their roots. The tachocline is limited above by the convective border, at $r \simeq 0.70\ R_\odot$, and has a thickness of about $0.04\ R_\odot$ [2]. The limited knowledge we have on the hydrodynamics of matter diffusion through the tachocline is added to our poor understanding of some nuclear reactions for the synthesis of ^{7}Li, in particular of the electron captures on ^{7}Be that directly feed it [5]. For these reasons we have investigated the possible variations due to the use of a new rate. In particular, in this work, we will use the rate for Be decay proposed by [5]. This was previously computed and applied for typical conditions of evolved stars, but we are allowed to use it also for the solar case. In fact, comparing the values of the electron density at the Be nucleus, representing the crucial parameter to calculate the e$^-$-capture rate, produced by this new method and the one from a traditional Debye-Hückel approximation, they differ by less than 1.5% at solar condition (see Table 1 of [5] and references therein).

2 Deep mixing and e$^-$-captures on ^{7}Be

Let us therefore assume a limited Li burning in the pre-MS phases. Using the Schwarzschild criterion, we actually found an initial MS concentration only a factor of 2 below the meteoritic value. Despite the limited masses involved in the tachocline, mixing through its layers would then be required to reduce the Li abundance. The temperature at the base of solar convection is indeed too low for any Li burning and the surface abundance must have been diluted with regions where instead Li consumption occurred, in order to explain its large drop. In this note, we have computed the mixing and nucleosynthesis processes that materials circulating through the inner border of solar convection must undergo. In these calculations, we adopted the rate for Be decay proposed by [5] and the corresponding half-life is shown in Figure 1 as a function of temperature and density. The treatment of the combined occurrence of mixing and burning is the same described in [7]. Namely, a slow circulation is added by imposing transport of envelope material at a mass-flow rate $\dot{M}$ down to some depth corresponding to the base of tachocline zone. Our post process code for deep-mixing calculations was then applied to a solar evolutionary sequence calculated with the FRANEC code [3]. We found that in the Sun, which is characterized by low mixing rate and low temperature, any nuclear effect from ^{3}He+^{4}He and the subsequent ^{7}Be decay is marginal. Therefore Li abundances are affected only by mixing (see panel a of Figure 2). We also found that the same rate for ^{7}Be production is extremely low at the temperatures of the tachocline ($\simeq 2.5\times10^6$ K), so that Be is not produced and hence does not decay to Li in the circulating material, which stays in the tachocline layers for less than 30% of the mixing time.

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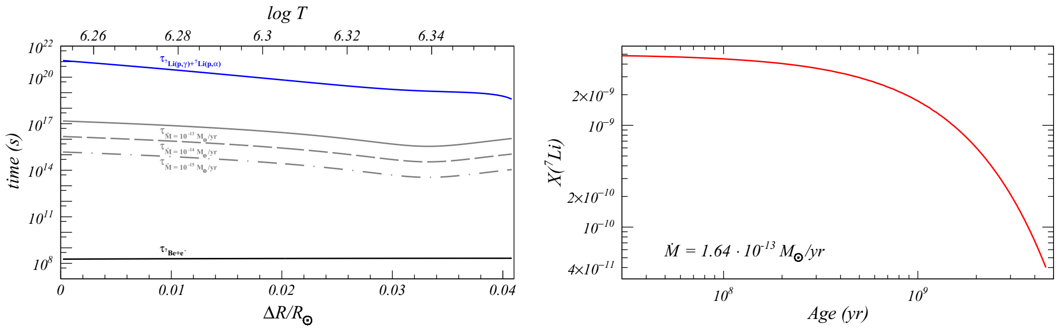

(a) (b)

Figure 2. (a) Comparison between the timescale for Li destruction by *p*-captures, for Li production from e$^-$-captures on ^{7}Be, and the overturn time of mixing, assuming different circulation rates, as indicated. The plot refers to the solar tachocline zone. On the lower abscissa, ΔR represents the distance from the top of the tachocline; the upper abscissa shows the corresponding temperature. Here the competition, unlike the AGB stars cases, is almost negligible, so we cannot obtain enhanced/reduced Li abundances due to nuclear production/destruction. (b) The destruction of Li in a deep-mixing process, during which material is brought from the solar envelope to the *tachocline* and vice versa. The process can be described as a slow circulation with an average mass transfer around 10^{-13} $M_\odot$/yr.

3 A diffusive mixing solution?

The situation is therefore quite different with respect to normal radiative burning on the MS, so that Li is not affected by nuclear processing along the path. The main issue is that the decrease in the sub-convective Li, obtained by solar models without any circulation, derives by the exposition of the local material, for extremely long times, to the same stable conditions. In the matter arriving from the convective envelope, instead, the small extension of the tachocline allows the nuclei to stay in the warmer zones for a very limited time, insufficient to permit any significant burning. These results would indicate that a solution to the solar Li problem (see panel b of Figure 2) can rely only on a pure dilution, where the higher Li concentration of the envelope is decreased by being mixed with the low abundance already present in the inner layers. Such a mixing would require a relatively high circulation rate (a few 10^{-13} $M_\odot$/yr) to reduce the Li abundance to the observed value.

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References

[1] M. Asplund, N. Grevesse, A.J. Sauval et al., ARAA **47**, 481 (2009), 0909.0948
[2] F. Thévenin, A.V. Oreshina, V.A. Baturin et al., A&A **598**, A64 (2017), 1612.01331
[3] L. Piersanti, O. Straniero, S. Cristallo, A&A **462**, 1051 (2007), astro-ph/0611229
[4] J.D. Do Nascimento, J.S. da Costa, J.R. de Medeiros, A&A **519**, A101 (2010), 1006.3861
[5] S. Simonucci, S. Taioli, S. Palmerini, M. Busso, ApJ **764**, 118 (2013), 1212.5737
[6] E.G. Adelberger et al., Reviews of Modern Physics **83**, 195 (2011), 1004.2318
[7] S. Palmerini, S. Cristallo, M. Busso et al., ApJ **741**, 26 (2011), 1107.2844