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Lithium evolution from Pre-Main Sequence to the Spite plateau: an environmental solution to the cosmological lithium problem

Xiaoting Fu[1], **Alessandro Bressan**[1], **Paolo Molaro**[2], **Paola Marigo**[3]

[1]SISSA - International School for Advanced Studies,
via Bonomea 265, 34136 Trieste, Italy
email: `xtfu@sissa.it, sbressan@sissa.it`

[2]INAF - Osservatorio Astronomico di Trieste,
via G. B. Tiepolo 11, 34143 Trieste, Italy
email: `molaro@oats.inaf.it`

[3]Dipartimento di Fisica e Astronomia, Università di Padova,
Vicolo dell'Osservatorio 2, I-35122 Padova, Italy
email: `paola.marigo@unipd.it`

Abstract. Lithium abundance derived in metal-poor main sequence stars is about three times lower than the primordial value of the standard Big Bang nucleosynthesis prediction. This disagreement is referred to as the lithium problem. We reconsider the stellar Li evolution from the pre-main sequence to the end of main sequence phase by introducing the effects of overshooting and residual mass accretion. We show that ^{7}Li could be significantly depleted by convective overshooting in the pre-main sequence phase and then partially restored in the stellar atmosphere by residual accretion which follows the Li depletion phase and could be regulated by EUV photo-evaporation. By considering the conventional nuclear burning and diffusion along the main sequence we can reproduce the Spite plateau for stars with initial mass $m_0 = 0.62 - 0.80\ M_\odot$, and the Li declining branch for lower mass dwarfs, e.g, $m_0 = 0.57 - 0.60\ M_\odot$, for a wide range of metallicities (Z=0.00001 to Z=0.0005), starting from an initial Li abundance $A(\mathrm{Li}) = 2.72$.

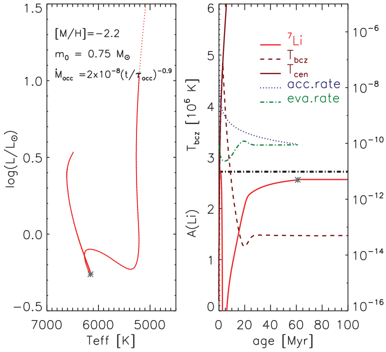
Keywords. stars: abundances, stars: pre–main-sequence, stars: Population II

1. Model

Envelope overshooting. Overshooting (OV) may occur at the borders of any convectively unstable region. As the star moves toward the zero age main sequence (ZAMS), we vary the overshoot efficiency proportionally to the mass size of the outer unstable convective region (f_{cz}), until the value estimated for the Sun $\Lambda_e = 0.3H_p$ (Christensen-Dalsgaard *et al.* 2011) is reached: $\Lambda_e = 0.3 + (1.5 - 0.3) * f_{cz}$.

Residual accretion. After the main accretion during the proto-stellar phase, the star leaves the stellar birth-line, while a residual accretion keeps going on. We assume that the residual accretion begins at τ_{acc} when deuterium burning ends. The accretion rate $\dot{M}_{acc} = 2 \times 10^{-8}(t/\tau_{acc})^{-0.9}$ $[M_\odot/\mathrm{yr}]$ is applied to recover most of the observed residual accretion rates. Fig. 1 illustrates the effect of late accretion on the Li evolution for a $m_0 = 0.75M_\odot$ star. The accretion material falling onto the star contains initial ^{7}Li. Even if accretion is very small, it restores the surface ^{7}Li towards the initial value.

EUV-photoevaporation. Late accretion will last until the remaining gas reservoir is consumed or some feedback mechanism from the star itself is able to clean the nearby disk. Extremely UV (EUV) photons have energy high enough to heat the disk surface gas and flow it away. The disk mass loss is given by Dullemond *et al.* (2007): $\dot{M}_{EUV} \sim$



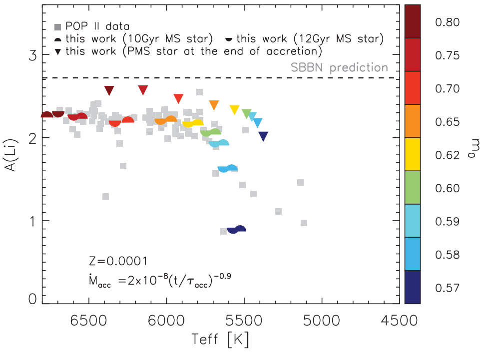


Figure 1. PMS evolution for a $m_0 = 0.75 M_\odot$, [M/H]=-2.2 star. Left panel: H-R diagram of the evolutionary track. The solid line starts when deuterium burning ends. The asterisk marks the end of the residual accretion. Right panel: Li evolution starting from A(Li)=2.72 (horizontal line). The temperatures at the center (T_{cen}, dark red dot dot dashed line) and at the base of the convection zone (T_{bcz}, dark red dashed line) are also shown. The accretion rate is the dark blue dotted line while the EUV photo-evaporation is the dark green dot dashed line.

Figure 2. Our results in comparison with the lithium abundance measurements in Pop II stars. The grey filled squares are Pop II data from Molaro *et al.*(2012). Our predictions are shown for stars at the end of the late accretion phase (filled triangles), and on the main sequence at 10 Gyr (filled upper circle) and 12 Gyr (filled lower circle). Symbols are color-coded according to the initial stellar mass (legend on the right). The black dashed line marks the primordial Li abundance according to the SBBN.

$4 \times 10^{-10}(\Phi_{EUV}/(10^{41}s^{-1}))^{0.5}(M_*/M_\odot)^{0.5}$ $[M_\odot/\mathrm{yr}]$, where Φ_{EUV} is the EUV photon luminosity produced by the central star as a black body. When the evaporation rate is larger than the accretion rate, the Li restore together with the accretion effectively stops.

Main sequence diffusion and Li burning. During the MS phase Li could be burned at the convective zone base. For masses larger than $m_0 = 0.60$ M$_\odot$, Li burning is insignificant. Another effect, microscopic diffusion, leads to a depletion of the surface elements.

2. Results

By considering the PMS and MS Li evolution, at the age of the Pop II stars (10-12 Gyr), $m_0 = 0.62$ M$_\odot$ - 0.80 M$_\odot$ stars nicely populate the Spite plateau (Fig.2). The Li declining branch is also reproduced by stars with $m_0 = 0.57$ M$_\odot$ - 0.60 M$_\odot$. Both PMS Li depletion and MS diffusion/burning contribute to the total A(Li) decrease, with the former process playing the main role. With the same parameters, we can reproduce the plateau and the Li declining branch, over a wide range of metallicities (from Z=0.00001 to Z=0.0005, which is from [M/H]=-3.2 to [M/H]=-1.5). This environmental Li evolution model (Fu *et al.* 2015) also offers the possibility to interpret the decrease of Li abundance in extremely metal-poor stars, the Li disparities in spectroscopic binaries and the low Li abundance in planet hosting stars.

References

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