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The primordial Li abundance derived from giant stars

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Abstract.
In this contribution we discuss the use of the surface Li abundance in lower RGB stars as alternative diagnostic of the primordial Li abundance. These stars are located in the portion of the RGB after the completion of the First Dredge-Up and before the extra-mixing episode occurring at the RGB Bump magnitude level. They are sensitive to the total Li content left at the end of the Main Sequence phase and are significantly less sensitive to the efficiency of atomic diffusion when compared with dwarf stars. We analysed lower RGB stars in the Galactic Halo and in the globular clusters NGC 6397, NGC 6752 and M4. The final estimates of A(Li)$_0$ span a narrow range of values (between 2.28 and 2.46 dex), in good agreement with the *Spite Plateau* and confirming the discrepancy with the values obtained from the standard Big Bang nucleosynthesis calculations.

Key words. Stars:abundances — stars: Population II — globular clusters: individual (NGC 6397) — globular clusters: individual (NGC 6752) — globular clusters: individual (M4)

1. Introduction

The so-called *Lithium problem* is one of the most intriguing and debated astrophysical topics, touching on a number of aspects of cosmology and stellar evolution. Population II dwarf stars hotter than ~5500 K share the same Li abundance regardless of their metallicity and temperature—the so-called *Spite Plateau* (Spite & Spite 1982). This evidence – confirmed by three decades of observations – has been interpreted as the signature of the primordial ^{7}Li abundance produced during the standard Big Bang nucleosynthesis (SBBN). The *Spite Plateau* turns out to be in the range A(Li)= 2.1–2.4 dex (where A(Li) is equal to 12+log(N(Li)/N(H)), depending on the adopted temperature scale. The recent estimate of the cosmological baryon density obtained with the WMAP satellite (Larson et al. 2011) contradicts the classical interpretation of the *Spite Plateau*, providing a primordial abundance A(Li)=2.72±0.06 dex (Cyburt et al. 2008), higher than the *Spite Plateau* by at least a factor of 3.

At present, the discrepancy between the WMAP results and the *Spite Plateau* is still unsolved and different solutions have been advanced: (1) an inadequacy of the SBBN models; (2) Population III stars could have burned some of the pristine Li (Piau et al. 2006); (3) Li may be depleted in the photosphere of Population II dwarf stars by the combined effect of atomic diffusion and some competing turbulent mixing (Richard et al. 2005).

We investigated an alternative route to derive the primordial Li abundance, by using the lower Red Giant Branch (RGB) stars (Mucciarelli et al. 2012). These stars are located after the completion of the First Dredge-Up (FDU) and before the extra-mixing episode occurring at the magnitude level of the RGB Bump.

2. Why lower RGB stars?

The surface Li abundance after the FDU is essentially a consequence of the dilution due to the increased size of the convective envelope after the Main Sequence phase. When a star evolves off the Main Sequence, the surface Li abundance starts to decrease because the deepening convective envelope reaches layers where the Li burning occurs. The depletion ends when the convective envelope reaches its maximum depth and thus the FDU is complete. Thus, the surface Li abundance during the RGB phase remains constant until the onset of the extra-mixing episode occuring at the magnitude level of the RGB Bump, that leads to a further drop of the surface Li abundance.

From an observational point of view, the existence of a Li *Plateau* among the lower RGB stars has been detected in several works, concerning field (Gratton et al. 2000; Spite et al. 2006; Palacios et al. 2006) and globular cluster (Lind et al. 2008; Mucciarelli et al. 2011) stars. However, the use of the RGB Li *Plateau* as empirical diagnostic of the primordial Li abundance has been discussed and investigated only recently by Mucciarelli et al. (2012).

2.1. Theoretical advantages of lower RGB stars

The main advantage of this kind of stars is that the surface Li abundance in lower RGB stars depends mainly on the total Li content left in the star after the Main Sequence phase. Thus, the observed Li abundance in these stars is affected by the total amount of Li (eventually) burned during the Main Sequence (due to the atomic diffusion or other mechanisms invoked to moderate the diffusion). On the other hand, in the analysis of the dwarf stars we need to have a precise description of the physical mechanisms able to transport Li below the convective envelope and eventually into the burning zone.

We investigated the amount of Li depletion Δ(Li) among the lower RGB stars with respect to the initial Li abundance A(Li)$_0$ by using a set of stellar evolution models with different metallicities (from [Fe/H]= –3.62 to [Fe/H]= –1.01 dex) and with different physical assumptions. For all the metallicities the SBBN A(Li) value of 2.72 dex is adopted as initial A(Li).

Fig. 1 shows the evolution of the surface A(Li) as a function of $T_{\rm eff}$ for stellar models with [Fe/H]= –1.01 dex and 0.855 $M_{\odot}$, with (dashed line) and without (solid line) atomic diffusion. The surface Li abundance at the end of the FDU is only 0.07 dex lower when fully efficient atomic diffusion is taken into account. This is in contrast with models for upper Main Sequence stars, where the effect of diffusion on the surface abundances can reach several tenths of dex (see e.g. Fig. 3 in Mucciarelli et al. 2011).

Also, the lower RGB stars are very weakly sensitive to other stellar parameters, as the mixing length calibration, the precise stellar age, the initial He abundance and the overshooting extension below the Schwarzschild boundary of the convective envelope.

Hence, the study of the Li abundance in the lower RGB stars can provide not only an independent diagnostic of the primordial Li abundance – if we consider the discrepancy between the Spite Plateau and WMAP results as unsolved – but also a further strong constraint on the efficiency of the additional turbulent mixing, when it is invoked to reconcile Spite Plateau with WMAP results.

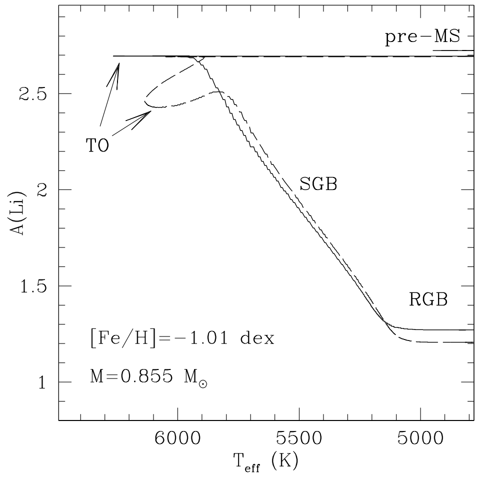

Fig. 1. Evolution of the surface A(Li) as a function of T_{eff} for [Fe/H]= −1.01 dex and 0.855 $M_{\odot}$ stellar models with (dashed line) and without (solid line) atomic diffusion.

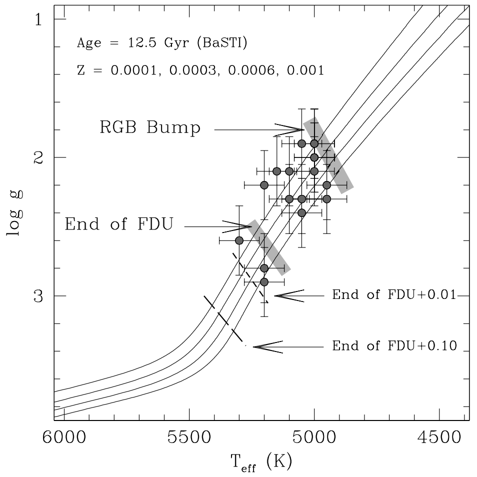

Fig. 2. Position of the targets in the T_{eff}–log g diagram. A set of theoretical isochrones at different metallicities from the BaSTI database is shown for reference. The location of the RGB Bump is marked as a grey shaded region. The fainter shaded region marks the boundary beyond which surface A(Li) stops decreasing. The short-dashed and long-dashed lines correspond to A(Li) increased by 0.01 and 0.1 dex, respectively.

3. Primordial Li abundance from lower RGB stars

3.1. Halo field stars

We have selected a sample of 17 metal-poor (with [Fe/H] between ∼−3.4 and ∼−1.4 dex) Halo stars located in the lower RGB. The position of the targets in the T_{eff}–log g diagram is shown in Fig. 2. All the stars are located below the RGB Bump level (thus before the onset of the extra-mixing episode), as confirmed also by the measurement of the $^{12}C/^{13}C$ ratio (higher than ∼15–20).

High resolution (R>40000) spectra were retrieved from the ESO [1] and ELODIE [2] archives. The analysis was performed by employing three different temperature scales, namely *(i)* the photometric scale by Alonso et al. (1998) (A99), *(ii)* the photometric scale by Gonzalez Hernandez & Bonifacio (2009) (GHB09), and *(iii)* the spectroscopic scale based on the excitation equilibrium. Basically, photometric and spectroscopic scales well agree with each other, regardless of the metallicity.

Li abundances have been determined from the Li line at 6707.7 Å through the comparison with synthetic spectra and applying suitable corrections for the departures from LTE. Fig. 3 shows the behaviour of the surface A(Li) as a function of the iron content (lower panel) and of the spectroscopic T_{eff} (upper panel). The average Li abundance is A(Li)= 0.97 dex (σ= 0.06 dex), when the spectroscopic effective temperatures are adopted, and A(Li)= 0.97 dex (σ= 0.07 dex) and 1.07 dex (σ= 0.07 dex) by adopting A99 and GHB09 scales, respectively.

Table 1 summarises the estimates of the initial Li abundance $A(Li)_0$ in our sample of lower RGB stars and considering three sets of stellar evolution models (without and with atomic diffusion but without overshooting and without diffusion but including overshooting) and the three adopted T_{eff} scales. The derived $A(Li)_0$ span a narrow range of values and our

[1] `http://archive.eso.org/eso/eso_archive_main.html`

[2] `http://atlas.obs-hp.fr/elodie/`

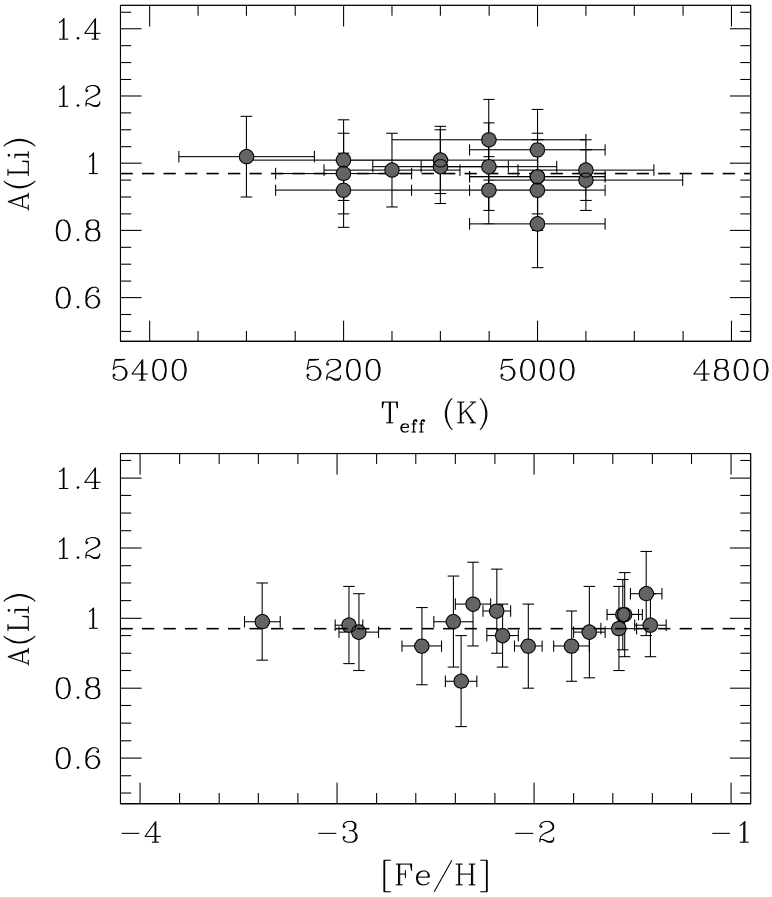

Fig. 3. Behaviour of the Li abundance as a function of the temperature (upper panel) and of the iron abundance (lower panel). The dashed lines represent the average $A(Li)_0$ of the field stars of the sample.

results well match the typical values of the *Spite Plateau.* Models including atomic diffusion (without overshooting) lead to $A(Li)_0$ larger by 0.07 dex with respect to models without diffusion. Models including overshooting predict Li abundances larger by only 0.01 dex with respect to the standard case.

3.2. Globular clusters stars

In order to strengthen our results, we derived Li abundances in lower RGB stars in three Galactic globular clusters, namely NGC 6397, NGC 6752 and M4.

3.2.1. NGC 6397

— We have analysed 45 lower RGB stars in NGC 6397, retrieved from the dataset of GIRAFFE/FLAMES spectra already discussed by Lind et al. (2008). We derived initial Li abundances $A(Li)_0$= 2.33-2.42 dex with the model without atomic diffusion (A99 and GHB09, respectively), and 2.40-2.49 dex when the model with atomic diffusion is employed.

3.2.2. NGC 6752

— We have analysed 21 lower RGB stars retrieved from the UVES archive. The mod-

Table 1. Estimates of the initial Li abundance $A(Li)_0$ in our sample of lower RGB field stars.

Models	$A(Li)_0$(A99)	$A(Li)_0$(GHB09)	$A(Li)_0$(spect)
Standard	2.28	2.39	2.30
Diffusion	2.35	2.46	2.37
Overshooting	2.29	2.40	2.31

els without and with the inclusion of the atomic diffusion provide initial Li abundances $A(Li)_0$= 2.29-2.35 (GHB09 scale), 2.18-2.24 (A99 scale) and 2.19-2.25 dex (spectroscopic scale).

3.2.3. M4

— The evolution of the surface A(Li) in M4 from the turn-off stars to the RGB Bump magnitude level has been discussed in Mucciarelli et al. (2011). The derived Li abundance in lower RGB stars is A(Li)= 0.92 dex that leads to a primordial Li abundance $A(Li)_0$= 2.35 dex (without atomic diffusion) and 2.40 dex (with atomic diffusion).

4. Conclusions

In this contribution we have discussed the use of the lower RGB stars as alternative route to derive the primordial Li abundance (Mucciarelli et al. 2012). These stars are sensitive to the total Li content left at the end of the Main Sequence phase and are significantly less sensitive to the efficiency of atomic diffusion (if compared with the dwarf stars).

The values of $A(Li)_0$ inferred from our sample range from 2.28 (obtained with the A99 T_{eff} scale and without the inclusion of atomic diffusion) to 2.46 (obtained with the GHB09 T_{eff} scale and including atomic diffusion). When a given T_{eff} scale is adopted, the effect of fully efficient atomic diffusion on the derived $A(Li)_0$ is by at most 0.07 dex. The analysis performed on lower RGB stars in three Galactic globular clusters (namely, NGC 6397, NGC 6752 and M4) confirms these values of $A(Li)_0$.

These values well agree with those usually obtained by analysing the dwarf stars of the *Spite Plateau*. Our results provide an independent estimate of the primordial Li abundance, confirming the discrepancy occuring with the WMAP+SBBN calculations.

Summarising, the lower RGB stars represent an empirical diagnostic of the primordial Li abundance:

- alternative to the *Spite Plateau*, allowing also estimates of the Li content in stellar systems more distant than those usually observed to investigate the dwarf stars. Thus, the use of these stars will allow to enlarge the sample of field stars and globular clusters to study the primordial $A(Li)_0$ abundance within the Galaxy but also to assess whether the Li problem exists in extragalactic systems (see e.g. Monaco et al. 2010, for the study of the initial Li in ωCen).
- complementary to the *Spite Plateau*. In fact, the combination of the information arising from the two *Plateau* sets robust constraint for the physical processes invoked to resolve the Li discrepancy (in particular the efficiency of the turbulent mixing).

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