The primordial lithium abundance

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ABSTRACT
Lithium abundances in a selected sample of halo stars have been revised by using the new accurate IRFM effective temperatures by Alonso, Arribas & Martínez-Roger (1996a). From 41 plateau stars (T\textsubscript{eff} > 5700 K and [Fe/H] \leq -1.5) we found no evidence for intrinsic dispersion, a tiny trend with T\textsubscript{eff} and no trend with [Fe/H]. The trend with the T\textsubscript{eff} is fully consistent with the standard Li isochrones of Deliyannis, Demarque & Kawaler (1990) implying a primordial value for Li of A(Li)= 2.238 \pm 0.012\sigma \pm 0.05_{\text{sys}}. The present results argue against any kind of depletion predicted by diffusion, rotational mixing or stellar winds. Therefore the Li observed in Pop II stars provides a direct and reliable estimate of the baryonic density that can rival other baryonic indicators such as the deuterium in high redshift systems. The present upwards revision of primordial Li in the framework of SBBN gives at 1\sigma two solutions for the baryonic density: \Omega_B h^2 = 0.0062^{+0.0018}_{-0.0011} or \Omega_B h^2 = 0.0146^{+0.0029}_{-0.0033}.

Key words: Stars: abundances – Stars: Population II – Stars: fundamental parameters – Galaxy: halo – Cosmology: observations

1 INTRODUCTION
In a seminal paper Spite & Spite (1982) found that the warm Pop II dwarfs (T\textsubscript{eff} > 5700 K) share a unique Li abundance, at variance with their Pop I counterparts, where a large spread in Li abundances is observed. Since no sign of stellar depletion was evident on the first dozen stars the Spite plateau was readily interpreted as a signature of pristine Li abundance directly related to primordial nucleosynthesis. The original finding has been later confirmed by a number of investigations (Spite, Maillard & Spite 1984, Spite & Spite 1986, Hobbs & Duncan 1987, Rebolo, Molaro & Beckmann 1988). The tight connection between Pop II Li abundance and BBN is of far reaching cosmological importance since in the standard BBN the primordial Li abundance is a function of $\eta \equiv n_\text{p}/n_\gamma$, the baryon to photon ratio, which is the only free parameter now left in the standard model. The information provided by Li is especially interesting in view of the recently conflicting observations of deuterium in high redshift absorption systems (Songaila et al. 1994, Carswell et al. 1996, Wampler et al. 1996, Rugers & Hogan 1996, Tytler, Fan & Burles 1996, Burles & Tytler 1996).

In the recent years the existence of a true plateau in the Li abundances of the warm halo dwarfs has been debated. Deliyannis, Pinsonneault & Duncan (1993) claimed the existence of a rather small dispersion of 10%, at 1 \sigma level, in Li abundances on the Spite plateau. Thorburn (1994) found an even larger dispersion of Li abundance on the plateau and found a trend both with T\textsubscript{eff} and [Fe/H]. Norris, Ryan & Stringfellow (1994) and Ryan et al. (1996) also support the existence of a trend of Li abundance with both T\textsubscript{eff} and [Fe/H]. The existence of dispersion and trends on the plateau could argue in favour of depletion and/or Galactic enrichment in halo dwarfs. In particular, stellar models have been proposed where Li is considerably depleted by rotational mixing, diffusion or stellar winds (Vauclair & Charbonnel 1995). If this is the case then the abundance of Li in warm Pop II dwarfs does not reflect the primordial Li abundance.

On the other hand the existence of the Spite plateau has been reasserted by Molaro, Primas & Bonifacio (1995a) from the analysis of a subsample of stars with uniform T\textsubscript{eff} derived from Balmer line profiles by Fuhrmann, Axer & Gehren (1994). Their result was that there is no dispersion on the plateau above what is expected by observational errors and that there is no slope in either T\textsubscript{eff} or [Fe/H]. Spite et al. (1996) tackled the problem in a similar fashion using three samples of stars for which T\textsubscript{eff} was determined from either excitation equilibria, Balmer line profiles, or $b - y$, and concluded that there is no evidence of dispersion or trends. So it appears that the existence of the Spite plateau is real when small samples of stars with homogeneous T\textsubscript{eff} are examined, but it is blurred when the whole set of stars is considered.

In this paper we use a new T\textsubscript{eff} scale based on the semi-direct Infrared Flux Method (IRFM, Blackwell et al. 1990) applied to a large sample of stars by Alonso et al. (1996a), to investigate the distribution of Li abundance with [Fe/H] and T\textsubscript{eff} for a statistically significant fraction of the stars with Li measured. Preliminary results have been already presented by Bonifacio & Molaro (1996).
2 A NEW SAMPLE FOR Li

Li is present mainly in the form of the singly ionized ion in the atmospheres of cool dwarfs and a large ionization correction is required when deriving the Li abundance from the Li I 6707 Å resonance doublet. This correction is strongly dependent on the adopted \( T_{\text{eff}} \) making the determination of \( T_{\text{eff}} \) crucial for the discussion of possible trends and/or dispersion on the Spite plateau. Other stellar parameters such as surface gravity, metallicity or microturbulence are much less important for the Li abundance. In this paper we consider a new sample of stars with Li observations available and with accurate and internally coherent \( T_{\text{eff}} \)’s.

Effective temperatures are usually determined either from the continuum spectrum (colours, flux distribution) or from the line spectrum (Balmer line profiles, excitation equilibria). These methods are calibrated on the few stars for which the direct measure of \( T_{\text{eff}} \) is obtained from the bolometric fluxes and angular diameter measurements. The Sun is the only star cooler than F5V for which the angular diameter is known determining an intrinsic uncertainty in the scale of effective temperatures in the low main sequence. In particular, for Pop II stars there are no stars with measured angular diameter which can be used as primary calibrators; therefore, one is forced to rely on theoretical models to derive the metallicity dependence of his favourite \( T_{\text{eff}} \) indicator.

In the impossibility of obtaining a direct measure of \( T_{\text{eff}} \), the semi–direct Infrared Flux Method (IRFM, Blackwell et al. 1990) is the best alternative to derive the temperature of F and G stars. The IRFM relies only weakly on theoretical models and its main uncertainty is related to the absolute flux calibrations of the infrared magnitudes. It has been extensively applied to different samples of Pop I stars (Saxner & Hammarback 1985, Blackwell et al. 1990). The works of Magain (1987) and Arribas & Martínez-Roger (1989) applied the IRFM to limited samples of metal poor stars. Alonso et al. (1996a) have recently determined IRFM temperatures for an enlarged sample of 475 dwarfs of spectral types from F5 to K0, with a wide range of metallicities. The effective temperatures are reddening corrected. Alonso et al. (1996a) derived three effective temperatures for the J, H and K fluxes showing a good internal consistency. They provided a final \( T_{\text{eff}} \) as the mean of the three, weighted with the inverse of their errors. The zero point of the IRFM \( T_{\text{eff}} \) by Alonso et al. (1996a) differ by 112, 0 and -56 K from the zero point of the IRFM \( T_{\text{eff}} \) derived by Magain (1987), Saxner & Hammarback (1985) and Bell & Gustafsson (1989) respectively, which may be explained by several improvements in the Alonso et al. (1996a) analysis. The mean accuracy of the \( T_{\text{eff}} \) estimated by Alonso et al. (1996a) is about 1.5 %, which includes both systematic and random errors.

Out of the sample of Alonso et al. (1996a), 64 stars have been observed for Li, and they form our sample for the study of the Spite plateau. The star names together with the stellar parameters and Li equivalent widths are reported in Table 1. The Li EWs for the 64 stars have been taken from the literature. For multiple measurements we adopted the weighted average. The errors in the EW have been taken from the original papers, when available, or from Ryan et al. (1996), which estimated the errors according to the Cayrel (1988) prescriptions. Following Ryan et al. (1996) we kept a 1 mÅ as the highest precision claimed in the observations, with the only exception of the few stars observed by Deliyannis, Boesgaard & King (1995) with the Keck telescope, at very high S/N. Multiple observations are in general in excellent agreement and an accurate statistical analysis of the errors for multiple observations of the same stars has been performed by Ryan et al. (1996) confirming that in the majority of cases the scatter between multiple observations is consistent with the stated errors. The measurement of EWs may be occasionally affected by non gaussian noise, such as that arising from cosmic rays hits or scattered light in the spectrograph. This event is rare but has to be considered in case of claims of intrinsic dispersion of isolated stars for which only single observations are available.

The frequency of binarity among halo dwarfs is not well established but it may be between 20-30% up to 50% as it is for Pop I stars. An investigation on the impact of binarity was done by Molaro (1991) showing that known binaries were not significantly different from other stars. However, the influence of binaries may be important in assessing the presence of a small dispersion. In Molaro et al. (1995a) the A(Li) in three stars was consistent with the mean value only considering the full error. One of these, HD 116064, has been later found to be a spectroscopic binary by Spite et al. (1996) and the compensation for the veiling, which is of 20 % in the EW, move the A(Li) closer to the mean value. This is a clear example of how binarity may affect the dispersion analysis on the plateau. Another example is G020-008 found to be double by Fouts (1987), which, in the small sample of stars considered by Spite et al. (1996), contributes to increase the dispersion.

Several binaries are present in our sample: HD 219617, BD+20 3603, HD 3567, HD 16031, BD+01 2341p, HD 84937, HD 132475, G206-034, HD 188510, BD+38 4955 have been identified as binaries or suspected radial velocity variables by Carney (1983). By means of spectroscopic analysis over a four-year temporal baseline, Stryker et al. (1985) classified as certain binaries: HD 84937, HD 94028, HD 201891 BD+26 2606, G090-025, HD 188510; as possible binaries: BD+28 2137, BD+34 2476, BD+13 3683, BD+26 3578; near significance criterion: BD+01 2341p, BD+29 2091, BD+38 4955, BD+21 607, HD 108177, G090-003. Lu et al. (1987) by means of the speckle technique identified: BD+17 4708. G020-008, G020-024, HD 16031 have been found to be binaries by Fouts (1987). Thus in total there are 25 known or suspected binaries out of 64 stars, which gives a binarity fraction of at least 39% in our sample.
3 MODEL ATMOSPHERES AND Li ABUNDANCES

The different atmospheric models adopted by different authors to derive lithium abundances are known to be generally consistent with one another, but in some cases they may be responsible for systematic differences in lithium abundances. As shown by Molaro et al. (1995a) and Molaro, Bonifacio & Primas (1995b), the Kurucz (1993) models which include overshooting are hotter than the Bell & Gustafsson models in the Li doublet forming region. As a consequence, the Thorburn (1994) Li abundances, derived by using Kurucz models with overshooting, are systematically \approx 0.1 dex higher than those of other researchers. On the other hand the Kurucz (1993) models with the overshooting switched off are in good agreement with the others. Castelli, Gratton & Kurucz (1996) have shown that for all F and G stars, except the Sun, the Kurucz models computed without overshooting are more consistent with the observations than models with overshooting. Consistently with these findings, in this investigation we use model atmospheres computed with the ATLAS9 code (Kurucz 1993) with the overshooting option switched off.

For the opacities we used the ODFs with enhanced $\alpha$ elements, which provide a more realistic chemical composition for Pop II stars than the solar scaled ODFs. The microturbulent velocity was assumed to be 1 kms$^{-1}$. However, the precise value of the microturbulent velocity is relatively unimportant for the Li abundance in halo stars, since 0.5 kms$^{-1}$ change in the microturbulent velocity induce a change of 0.005 dex in Li.

We checked our models with those used in Ryan et al. (1996) by comparing our curve of growth for a model with $T_{\text{eff}} = 6500$, log $g = 4.0$, [Fe/H] -2.0 and microturbulence of 1 kms$^{-1}$ with the corresponding curve of growth, based on Bell-Gustafsson models, published by Ryan et al. (1996). The difference in Li abundance is zero for an equivalent width of 14 mÅ (A(Li)$\approx 2.1$) and 0.008 dex for an equivalent width of 24 mÅ (A(Li)$\approx 2.4$), with our models giving abundances higher than the Bell-Gustafsson ones.

Surface gravities have been redetermined for each star to identify possible subgiants. As already mentioned, the Li doublet equivalent width depends little on surface gravity with a 0.02 dex change in Li abundance for a 0.7 dex change in log $g$, but the identification of subgiants in the sample is important because their Li abundance is expected to be lower due to dilution (Deliyannis et al. 1990). As a gravity indicator we used the c0 index of Strömgren photometry, which measures the Balmer discontinuity. We derived surface gravities from c0 in the same way as described in Molaro et al. (1996). For all our stars, except G201-005, we took the photometry from the General Catalogue of Photometric Data (Mermillod, Hauck & Mermillod 1996), this was dereddened using the Schuster & Nissen (1989) intrinsic colour calibration. For BD +71 31, for which there is no $\beta$ available, we assumed a zero reddening. For some stars we could not find any solution; this happened if the observed c0 value was smaller than any of the theoretical values for the given temperature and metallicity. This was the case for G246-038, HD25329, G090-025 and G190-015. For these stars, as well as for G201-005, we have taken the surface gravity given by Alonso et al. (1996a). From our model grid, described in Molaro et al. (1996), we computed fluxes and both Johnson and Strömgren photometry. In Fig. 1 the c1, (b − y) and c0, (b − y)$_0$ diagrams for our sample of Pop II stars are shown. The solid line represents the locus of points with log $g = 3.5$ for [Fe/H] =-1.5, from our synthetic Strömgren photometry, and the dashed line is the same but for [Fe/H] =-3.0. The region above these lines is populated by subgiants and giants. In our sample of 41 plateau stars only 3 have a surface gravity less than or equal to 3.6, namely G090-003, G126-062 and BD+71 31, with log $g$ 3.55, 3.58 and 3.58, respectively.

Figure 1. a) c1, (b − y) diagram for our sample of Pop II stars; b) c0, (b − y)$_0$ diagram. The solid line represents the locus of points with log $g = 3.5$ for [Fe/H] =-1.5. The dashed line is the same but for [Fe/H] =-3.0. The region above these lines is populated by subgiants and giants. The crosses are the stars with [Fe/H] > -1.5 while the × symbols are stars with [Fe/H] \leq -1.5.
Figure 2. The A(Li) – [Fe/H] diagram for our sample of stars. The circles are stars with $T_{\text{eff}} > 5700$ K, while the squares are those with $T_{\text{eff}} \leq 5700$ K. Subgiants are shown with crossed symbols. Three upper limits are shown as vertical downward arrows.

A model atmosphere was computed for each star with the appropriate gravity and metallicity. We then computed a synthetic profile of the Li doublet with the SYNTHE code (Kurucz 1993) and obtained the equivalent width of the doublet by integrating this profile. The process was iterated, changing the Li abundance, until the computed equivalent width matched the observed one. This approach is different from that used by Thorburn (1994), Molaro et al. (1995a) and Spite et al. (1996), who treated the doublet as a single line. The differences are very small, because for our stars the stronger Li line is never saturated, however the explicit computation of the doublet is physically more realistic.

The present analysis is carried out strictly under the LTE assumption. NLTE effects have been studied by Carlsson et al. (1994) and Pavlenko & Magazzù (1996) and were shown to be minimal for halo dwarfs. The corrections provided by Carlsson et al. (1994) have been applied to the LTE abundances and considered in the discussion of the results.

The errors reported in Table 1 are those following from the error in EW and in $T_{\text{eff}}$. The two errors are summed under quadrature as it is generally done. The errors given do not consider a possible error originated by uncertainties in the gravity and in the microturbulence which are of the order of 0.01 dex each. These are also independent sources of errors and should be added to the above quoted errors. We found that ignoring their contribution to the total error does not affect our results.

4 RESULTS

4.1 Li – $T_{\text{eff}}$, [Fe/H] correlations

The derived Li abundances are given in Table 1 (where $A(\text{Li}) = \log(N_{\text{Li}}/N_{\text{H}}) + 12$). The corresponding $A(\text{Li}) – T_{\text{eff}}$ and $A(\text{Li}) – [\text{Fe/H}]$ diagrams are given in figures 2 and 3. We considered plateau stars those with $T_{\text{eff}} > 5700$ and with $[\text{Fe/H}] \leq -1.5$; this extracts a sample of 41 stars.

To investigate the existence of trends in the $A(\text{Li}) – T_{\text{eff}}$ and $A(\text{Li}) – [\text{Fe/H}]$ planes, we first performed univariate fits by means of four different estimators: (i) the Bivariate Correlated Errors and intrinsic Scatter (BCES) of Akritas & Bershady (1996); (ii) BCES simulations bootstrap based on 10000 samples; (iii) least squares with errors in the independent variable only (as implemented in the routine fitxy of Press et al. (1992)); (iv) least squares with errors in both variables (as implemented in the routine fitexy of Press et al. (1992)). In addition, the presence of a slope was searched by means of a rank correlation analysis using Kendall’s $\tau$. As a second step we performed bivariate fits using both $T_{\text{eff}}$ and $[\text{Fe/H}]$ as independent variables. The need for such bivariate fits follow from the known trend of $T_{\text{eff}}$ with $[\text{Fe/H}]$, which is an observational bias, due to the fact that the more metal–poor stars are, on average, the more distant and therefore also the more luminous and hotter members of the class. So one could suspect that if there is, indeed, a trend of $A(\text{Li})$ with $T_{\text{eff}}$ and $[\text{Fe/H}]$, the trend of $T_{\text{eff}}$ with $[\text{Fe/H}]$ could be exactly tuned so as to suppress the trends when performing univariate fits. For the bivariate fits we used an ordinary least squares method taking into account only errors in the independent variable.

The results of the statistical analysis are reported in Tables 2 – 4. Inspection of Table 2 shows that a small slope of the order 0.02 (± 0.01)/100 K is marginally detected using BCES and fitxy, but not using fitexy. We used Kendall’s $\tau$ to check the detection of the slope and we found a $\tau = 0.2112$ with a two-sided significance level of 0.05, consistent with a positive detection of the slope. Note that the slope found is about one half of those found by Thorburn (1994) of 0.034 (± 0.006)/100 K and Ryan et al. (1996) of 0.0408 (± 0.0052)/100K. One may also note that the goodness-of-fit implied by fitxy is quite small, i.e. of the order of 0.035. This value means that the fit may be believable if the errors are nonnormal or if they have been
Table 1. The primordial lithium abundance

| BD    | HD     | G #  | $T_{eff}$ | $\sigma_{T_{eff}}$ | log $g$ | EW | A(Li) | A(Li)$_1$ | A(Li)$_2$ | A(Li)$_3$ | $\sigma_T$ | $\sigma_{EW}$ | $\sigma_{\sigma_T}$ | $\sigma_{\sigma_{EW}}$ |
|-------|--------|------|-----------|-------------------|--------|----|-------|-----------|-----------|-----------|-----------|----------------|-----------------|-----------------|-----------------|
| BD + 09 122$^b$ | HD 3567 | G270-023 | 5858 | 63 | 3.70 | -1.34 | 45.0 | 6.0 | 2.28 | 2.30 | 2.32 | 2.33 | 0.05 | 0.08 | 0.10 |
| BD + 15 3451 | HD 132475 | G020-024 | 5858 | 63 | 3.85 | -2.15 | 10.0 | 7.8 | 1.09 | 1.11 | 1.17 | 1.76 | 0.08 | 0.65 | 0.66 |
| BD + 04 2660 | HD 201891 | G019-015 | 5858 | 63 | 3.93 | -2.33 | 23.0 | 1.7 | 2.22 | 2.23 | 2.25 | 2.26 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
| BD + 04 4551 | HD 345957 | G119-033 | 5858 | 63 | 3.93 | -2.15 | 44.3 | 1.7 | 2.29 | 2.31 | 2.33 | 2.84 | 0.07 | 0.08 | 0.09 |
### Table 1. Li data (continued)

| BD   | HD        | G # | $T_{\text{eff}}$ | $\sigma T_{\text{eff}}$ | log g | $[\text{Fe/H}]$ | EW   | $\sigma$EW | A(Li) | A(Li)$_1$ | A(Li)$_2$ | A(Li)$_3$ | $\sigma$T | $\sigma$EW | $\sigma_{\text{tot}}$ |
|------|-----------|-----|------------------|--------------------------|-------|-----------------|------|------------|--------|----------|----------|----------|----------|----------|-----------------------|
| BD + 02 4651 | G029-023 | 6102 | 90               | 3.80                     | -2.02 | 27.0             | 2.2  | 2.18       | 2.19   | 2.19     | 2.21     | 0.07     | 0.05     | 0.09     |
| BD + 59 2723  | G217-008  | 6134 | 70               | 4.25                     | -1.91 | 29.0             | 2.1  | 2.23       | 2.24   | 2.24     | 2.25     | 0.05     | 0.04     | 0.06     |

A(Li)$_1$ is the NLTE corrected value according to Carlsson et al. (1995) A(Li)$_2$ is the value corrected for the depletion predicted by the standard Li isochrones of Deliyannis et al. (1990) A(Li)$_3$ is the value corrected both for NLTE and standard depletion

$^*$ the sum under quadrature has been made taking into account three significant figures and then rounded off.

$^b$ binaries

1 this star is LP 608-62=Ross 889, it is indicated as HD 83769C by Olsen (1993)

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**Figure 3.** The A(Li) – $T_{\text{eff}}$ diagram for our sample of stars. The circles are stars with $[\text{Fe/H}] \leq -1.5$, while the squares are those with $[\text{Fe/H}] > -1.5$. Subgiants are shown with crossed symbols. Three upper limits are shown with vertical arrows pointing downwards.

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slightly underestimated (Press et al. 1992). To check this interpretation we performed the same fits, but using the slightly larger errors which you obtain by summing linearly, rather than under quadrature, the errors due to $T_{\text{eff}}$ and EW. While the value of the fitting parameters are little sensitive to this assumption, the goodness-of-fit boosts up to values of the order of 0.7. This comment applies also to the results of Table 3, obtained from fitxy, and to those of Table 4.

Table 3 shows the results of the investigations of trends of A(Li) with $[\text{Fe/H}]$. Irrespective of the method used the slope is not detected, Kendall's $\tau$ is -0.857 with a two–sided significance level of 0.43, i.e. no slope. Note that in almost all cases the slope with $[\text{Fe/H}]$ is negative, contrary to the findings of Thorburn (1994) and Ryan et al. (1996). A negative slope is physically plausible since it could be present if astration is important. An increase of Li with the metallicity is expected when Li synthesis by GCR begins to become significant. Using $^9\text{Be}$ as an indirect indicator, from the $^9\text{Be}$-metallicity correlation found by Molaro et al. (1996), the contribution to Li by energetic galactic cosmic rays is of only 0.03 dex at $[\text{Fe/H}]=-1.5$ and of 0.1 dex at $[\text{Fe/H}]=-1.0$, which is below our detectability threshold.

Table 4 displays the results for the bivariate fits, which show that the values of the slopes found by performing bivariate fits are not significantly different from the values found performing univariate fits.

According to the Deliyannis et al. (1990) standard ZAMS Li isochrones, a very little depletion is indeed expected in the $T_{\text{eff}}$ range between 5700 K and 6400 K. In Fig. 4 one can see the Li isochrones of Deliyannis et al. (1990) corresponding to $[\text{Fe/H}]=-2.3$ and $[\text{Fe/H}]=-1.3$, and an age of 16 Gyr, which have been shifted upwards by 0.1 dex to better match the observations. Using these isochrones we corrected the observed Li abundances so that each star was assigned the A(Li) it should have if its temperature were 6400 K and its metallicity -2.3. In Fig. 5 we show the corrected data and no trend is evident. In fact the formal statistical analysis of this corrected data shows no detectable trend irrespective of the estimators used. Kendall’s $\tau$ is 0.0804 with a two–sided significance level of 0.458, consistent with a non–detection of the slope. Thus the small slope with $T_{\text{eff}}$, which is marginally detected using our sample, is consistent with a constant Li abundance on the plateau with minimal depletion predicted by the standard Li isochrones of Deliyannis et al. (1990). Also for the case of bivariate fits the small slope, marginally detected using the uncorrected Li, disappears after accounting for the Li depletion predicted by standard isochrones.

NLTE correction are even smaller, but again they act in the sense of decreasing the slope. Thus when both corrections
Table 2. Univariate fits in the A(Li)–T\textsubscript{eff} plane.

| Method                  | A(Li)                                      | T\textsubscript{eff}                                      |
|-------------------------|--------------------------------------------|---------------------------------------------------------|
|                         | A(Li) = 0.766(±0.635) + 0.0235(±0.0104) × (T\textsubscript{eff}/100) | BCES                                                     |
|                         | A(Li) = 0.774(±0.644) + 0.0233(±0.0106) × (T\textsubscript{eff}/100) | BCES bootstrap                                           |
|                         | A(Li) = 1.346(±0.353) + 0.0140(±0.0058) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 56.59 \); P = 0.034                   |
|                         | A(Li) = 1.153(±4.056) + 0.0171(±0.0511) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 0.4291 \); P = 1.000                   |

after the theoretical correction for the standard depletion

| Method                  | A(Li)                                      | T\textsubscript{eff}                                      |
|-------------------------|--------------------------------------------|---------------------------------------------------------|
|                         | A(Li) = 1.63 (±0.637) + 0.0097(±0.0104) × (T\textsubscript{eff}/100) | BCES                                                     |
|                         | A(Li) = 1.64 (±0.646) + 0.0095(±0.0106) × (T\textsubscript{eff}/100) | BCES bootstrap                                           |
|                         | A(Li) = 2.009(±0.353) + 0.0035(±0.0058) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 56.47 \); P = 0.035                   |
|                         | A(Li) = 1.827(±4.053) + 0.0064(±0.0444) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 0.4250 \); P = 1.000                   |

after the theoretical correction for the NLTE effect

| Method                  | A(Li)                                      | T\textsubscript{eff}                                      |
|-------------------------|--------------------------------------------|---------------------------------------------------------|
|                         | A(Li) = 0.858(±0.635) + 0.0222(±0.0104) × (T\textsubscript{eff}/100) | BCES                                                     |
|                         | A(Li) = 0.866(±0.644) + 0.0220(±0.0106) × (T\textsubscript{eff}/100) | BCES bootstrap                                           |
|                         | A(Li) = 1.421(±0.353) + 0.0130(±0.0058) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 56.59 \); P = 0.034                   |
|                         | A(Li) = 1.230(±4.056) + 0.0160(±0.0503) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 0.4291 \); P = 1.000                   |

after the theoretical corrections for the standard depletion and NLTE

| Method                  | A(Li)                                      | T\textsubscript{eff}                                      |
|-------------------------|--------------------------------------------|---------------------------------------------------------|
|                         | A(Li) = 1.72 (±0.637) + 0.0084(±0.0105) × (T\textsubscript{eff}/100) | BCES                                                     |
|                         | A(Li) = 1.73 (±0.646) + 0.0083(±0.0106) × (T\textsubscript{eff}/100) | BCES bootstrap                                           |
|                         | A(Li) = 2.084(±0.353) + 0.0025(±0.0058) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 56.47 \); P = 0.035                   |
|                         | A(Li) = 1.902(±4.053) + 0.0054(±0.0441) × (T\textsubscript{eff}/100) | fitxy \(\chi^2 = 0.4250 \); P = 1.000                   |

Figure 4. Zoom of the A(Li)–T\textsubscript{eff} diagram for our sample of stars. The solid line is the ZAMS isochrone of Deliyannis et al. (1990) corresponding to [Fe/H] = −1.3 and an age of 16 Gyrs, the dashed line is the same but for [Fe/H] = −2.3. Both isochrones have been shifted upwards by 0.1 dex to better match the observations.

are applied no slope is detected.

As far as the slope is concerned, a possible explanation of the different results may lie in the different T\textsubscript{eff} adopted. Thorburn (1994) derived a common photometric temperature scale by adapting the temperature calibrations between T\textsubscript{eff} - (V-K); (b-y) of Carney (1983) and Carney et al. (1987) into a T\textsubscript{eff} - (B-V) scale, which is assumed to be valid for all metal poor stars. There are 24 stars in common with Thorburn (1994) and in Fig. 6a the temperature difference between Alonso et al. (1996a) and Thorburn (1994) shows a systematic trend with T\textsubscript{eff}, with the T\textsubscript{eff} of Alonso et al. (1996a) higher at the hot edge of the plateau and lower at the cool edge. This systematic difference in the T\textsubscript{eff} produces the slope in Li versus T\textsubscript{eff} which is observable in Fig. 6b, where the differences between our A(Li) values and those of Thorburn (1994) are shown as a function of T\textsubscript{eff}. In addition to the trend one may notice an offset, which is due to the inclusion of overshooting in the ATLAS9 models used by Thorburn. All our stars, but one, are in common with the sample of Ryan et al. (1996) and in Fig. 6c and 6d we compare our results with those of Ryan et al. (1996) in the same way we did for the Thorburn data. Ryan
Table 3. Univariate fits in the A(Li)–[Fe/H] plane.

| Method                  | A(Li) = 2.09(±0.09) – 0.05(±0.04) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
|-------------------------|-------------------------------------------|----------------------------------|
| BCES bootstrap          | A(Li) = 2.10(±0.09) – 0.04(±0.04) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 61.49$; P = 0.012 | A(Li) = 2.15(±0.06) – 0.02(±0.03) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 5.50$; P = 1.000 | A(Li) = 2.11(±0.15) – 0.04(±0.06) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |

After the theoretical correction for the standard depletion:

| Method                  | A(Li) = 2.17(±0.08) – 0.02(±0.04) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
|-------------------------|-------------------------------------------|----------------------------------|
| BCES bootstrap          | A(Li) = 2.18(±0.08) – 0.02(±0.03) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 56.84$; P = 0.032 | A(Li) = 2.22(±0.06) – 0.00(±0.03) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 7.67$; P = 1.000 | A(Li) = 2.18(±0.15) – 0.02(±0.06) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |

After the theoretical correction for the NLTE effect:

| Method                  | A(Li) = 2.11(±0.09) – 0.04(±0.04) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
|-------------------------|-------------------------------------------|----------------------------------|
| BCES bootstrap          | A(Li) = 2.12(±0.08) – 0.02(±0.03) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 60.90$; P = 0.014 | A(Li) = 2.17(±0.06) – 0.02(±0.02) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 8.41$; P = 1.000 | A(Li) = 2.13(±0.15) – 0.03(±0.06) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |

After the theoretical corrections for the standard depletion and NLTE:

| Method                  | A(Li) = 2.19(±0.08) – 0.02(±0.04) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
|-------------------------|-------------------------------------------|----------------------------------|
| BCES bootstrap          | A(Li) = 2.20(±0.08) – 0.02(±0.03) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 56.66$; P = 0.033 | A(Li) = 2.24(±0.06) – 0.00(±0.02) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |
| fitxy $\chi^2 = 7.64$; P = 1.000 | A(Li) = 2.20(±0.15) – 0.01(±0.06) × [Fe/H] | B(Fe/H) = 0.90(±0.04) × [Fe/H] |

Table 4. Bivariate fits

| $\chi^2$ | P   | Li correction                      |
|----------|-----|------------------------------------|
| 1.0(±0.43) + 0.034(±0.034) × [Fe/H] + 0.019(±0.008) × ($T_{eff}$/100) | 60.21 | 0.012 | none |
| 1.88(±0.43) + 0.018(±0.034) × [Fe/H] + 0.006(±0.008) × ($T_{eff}$/100) | 61.03 | 0.010 | standard depletion |
| 1.17(±0.43) + 0.034(±0.034) × [Fe/H] + 0.018(±0.008) × ($T_{eff}$/100) | 60.57 | 0.011 | NLTE |
| 1.95(±0.43) + 0.018(±0.034) × [Fe/H] + 0.005(±0.008) × ($T_{eff}$/100) | 61.14 | 0.010 | standard depletion and NLTE |

et al. (1996) adopted the average of the ($b$-$y$)–$T_{eff}$ from Magain (1987), the (R-I)–$T_{eff}$ from Buser & Kurucz (1992) and a (B-V)–$T_{eff}$ worked out by interpolation from a grid obtained from the literature. Also in this case, as can be seen in Fig. 6d, a temperature scale difference, which is responsible for the differences in the slope A(Li)–$T_{eff}$ found in the two analyses, is clear. Although the $T_{eff}$ scales used by Thorburn (1994) and Ryan et al. (1996) may be sufficient for a general abundance analysis, they may be not adequate to discuss dispersion and/or trends at the levels claimed, since the indices used ($b - y$, $B - V$ and
R - I) are all metallicity dependent and the first two depend also on gravity. To illustrate the effect of metallicity we divided the 40 stars in common with Ryan et al. (1996) in four metallicity bins (−2.0 < [Fe/H] < −1.5, −2.5 < [Fe/H] < −2.0, −3.0 < [Fe/H] < −2.5 and [Fe/H] < −3.0), the bins have 16, 13, 8 and 3 stars respectively. For each bin we compute the mean of $T_{\text{Alonso}} - T_{\text{Ryan}}$, the results (rounded to the nearest degree) are: +10 K, +50 K, +96 K and +132 K.

The same analysis with the 16 stars we have in common with Molaro et al. (1995a) shows a considerable scatter, but no obvious trend. They used the $T_{\text{eff}}$ obtained by Fuhrmann et al. (1994) by fits of the Balmer lines, i.e. with a totally different approach. Balmer line temperatures have the considerable advantage that they are reckoning independent. A trend with temperature cannot be excluded, but the number is too small to draw any firm conclusion. Ryan et al. (1996), reanalysed the Molaro et al. (1995a) sample, after excluding the two subgiants and outliers, and found a trend of $\approx 0.04/100$ K. However, no trends are found using the whole original sample.

We thus conclude that the presence or absence of trends of lithium abundance with $T_{\text{eff}}$ appears to be strongly dependent on the temperature scale adopted.

### 4.2 Dispersion on the plateau?

The straight average value of A(Li) for the selected stars is A(Li) = 2.19 with a dispersion around the mean value of ±0.094. This dispersion is compatible with the root mean square of the estimated observational errors (0.083 dex) showing no clear evidence for intrinsic dispersion. In fact 29 stars ($\approx 71\%$) are within 1 $\sigma$ of the mean A(Li), which is compatible with a normal distribution, such as would be expected for observational errors. The dispersion around the mean value further decreases down to 0.088 if the Li abundances corrected for the theoretical depletion and the NLTE effects are considered. In Fig. 5 the corrected Li abundances on the plateau are zoomed illustrating that the data are consistent with a unique Li abundance within the errors. The absence of intrinsic scatter is remarkable in the light of the high percentage of binaries or suspected binaries in our sample.

Thorburn (1994) analysed the presence of scatter in the equivalent width - $T_{\text{eff}}$ plane, claiming that the null hypothesis of no intrinsic dispersion is rejected at the 6 $\sigma$ confidence level. In Fig. 8a we show such a diagram for our plateau sample, together with the theoretical equivalent width - $T_{\text{eff}}$ locus obtained from our curves of growth corresponding to three Li abundances ($2.20 \pm 0.10$ dex) for a metallicity of [Fe/H] = −2.0. Note that this locus is not a straight line as assumed both by Thorburn (1994) and Deliyannis et al. (1993), but is better approximated by an exponential, as can be seen by the linear relation displayed in the log($EW$) -$T_{\text{eff}}$ diagram shown in Fig. 8b. The slope of the theoretical lines is $\approx -0.0623$ log(mA) / 100 K. Performing a simple least squares fit with a straight line of this slope (i.e. fitting only one free parameter) we find the dotted line shown in Fig 8b. The fit has a $\chi^2 = 0.393$, corresponding to a goodness-of-fit of practically 1.00, and an R.M.S = 0.066 log(mA). The fitting line almost coincides with the theoretical line corresponding to A(Li) = 2.20. This shows that, even neglecting the metallicity effects on the curve of growth, the data are consistent with the hypothesis of a constant Li, around 2.20, and a scatter due to observational errors only.

The disagreement with Thorburn (1994) on this point can be explained by the fact that she fits an exponential with a straight line. She attributes the very low goodness of fit ($\approx 10^{-10}$) to either an intrinsic scatter in the Li abundances or to an underestimation of the errors by about 50 %, while this can be explained by the use of an incorrect fitting function. In addition, as pointed out by Spite et al. (1996), the temperature errors of Thorburn (1994) appear to be somewhat underestimated.

Deliyannis et al. (1993) discussed the dispersion on the Spite plateau in the $W_\lambda - (b - y)_{0}$ plane which is strictly observational and avoided the problems implied in the determination of $T_{\text{eff}}$. Note, however, that like Thorburn (1994) they also assumed a linear relation between $W_\lambda$ and $(b - y)_{0}$ to look for dispersion. Moreover, there is not a one-to-one mapping from $(b - y)_{0}$ to $T_{\text{eff}}$ since this index depends both on gravity and metallicity. A sample of halo stars with different gravities and metallicities will show a scatter in the $W_\lambda - (b - y)_{0}$ plane even if there is no scatter in the Li abundances, simply because when comparing stars of the same $(b - y)_{0}$ we compare stars with different $T_{\text{eff}}$.

Ryan et al. (1996) identified a triplet of stars (G064-012, G064-037, and CD -33 1173) with similar metallicity and $T_{\text{eff}}$ when comparing stars of the same $(b - y)_{0}$. The results (rounded to the nearest degree) are: +10 K, +50 K, +96 K and +132 K.

The absence of intrinsic dispersion found by us is in agreement with the results of Molaro et al. (1995a) and Spite et al. (1996). The latter authors have considered three small samples of stars with accurate $T_{\text{eff}}$ derived either from excitation
Figure 6. Temperature and A(Li) differences between the present paper and those of Thorburn (1994)(panels a and b), Ryan et al. (1996) (panels c and d) and Molaro et al. (1995a) (panels e and f), for the stars in common.
**Figure 7.** The temperatures of Thorburn (1994), panel a), Ryan et al. (1996), panel b), and Fuhrmann et al. (1994), panel c), are plotted as a function of the temperatures of Alonso et al. (1996). The bisector is shown as a solid line.

**Figure 8.** Equivalent widths as a function of effective temperature. The solid lines are the theoretical loci for A(Li)=2.20 and [Fe/H] = $-2.00$; the dashed lines are the same but for A(Li)=$2.20 \pm 0.1$. The dotted line in panel b) is the fit to the data of a line of slope $-0.0623 \log(\text{m} \AA)/100 ~\text{K}$, which is the slope of the theoretical lines in the same panel.

It is interesting that the presence of the binary G020-008, with a A(Li) lower than the average, is found to contribute considerably to the scatter.

The absence of dispersion on the plateau is remarkable considering the number of processes that might produce it, such as localized Galactic enrichment, chromospheric Li enrichment, different amounts of accretion or astration, binarity, anomalous reddening, mistaken subgiants, pre main-sequence depletion and others. This implies that such possibilities are either intrinsically or statistically irrelevant.

5 DISCUSSION

5.1 Li depletion?

We have found that in our sample of 41 stars on the plateau with the IRFM $T_{\text{eff}}$ derived by Alonso et al. (1996a) there is no evidence for intrinsic dispersion in excess of what can be expected from the measurement uncertainties. In addition, there is no evidence of trends with the metallicity, although our stars span more than two orders of magnitude in [Fe/H]. The tiny trend with $T_{\text{eff}}$, which has been detected, can be entirely explained by the standard Li isochrones of Deliyannis et al. (1990).
The view that the Li abundance on the Spite plateau is the primordial abundance requires that Li has not been destroyed, in appreciable amounts, in the atmospheres of halo dwarfs. Simple models of Li evolution, referred to as standard models, predict little or no depletion of Li on the MS, thus supporting the primordial nature of Li in halo dwarfs. However, it has been suggested that three different mechanisms are able to deplete Li in halo dwarfs in significant amounts. They are diffusion (Michaud, Fontaine & Beaudet 1984), rotational mixing (Pinsonneault, Deliyannis & Demarque 1992) and stellar winds (Vauclair & Charbonnel 1995). More elaborate scenarios with some combination of the three have been also considered. To reproduce the observations such depletion models must be able to deplete Li uniformly in a way which is independent from the metallicity and from the mass (and therefore $T_{\text{eff}}$) of the star. The detection of sizeable dispersion on the plateau would be a strong evidence in favour of some Li depletion during the life of halo stars.

Diffusion has been proposed to be responsible for abundance anomalies in Ap and Am stars which are somewhat hotter than halo dwarfs, have non convective atmospheres and the Ap are strongly magnetic. In halo stars there are no abundance anomalies which have been ascribed to diffusion. In fact Li is the only element for which diffusion has been claimed to be effective in halo dwarfs. First computations of the effects of diffusion on the Li abundances in halo stars have been performed by Michaud et al. (1984). Diffusion causes Li to sink below the photosphere and Michaud et al. (1984) found that the process is more efficient at the hot end of the plateau producing a pronounced downturn of the Li abundance for $T_{\text{eff}}>6000$ K. The depth of the surface convection zone is sensitive to opacities and to the mixing length, so that some model dependence is present. However the downturn persists in the various assumptions (Chaboyer & Demarque 1994, Vauclair & Charbonnel 1995). From an initial $A(\text{Li})=2.5$, at $T_{\text{eff}}=6500$ K the predicted Li abundance becomes $A(\text{Li})=1.5$, while our observed abundance is 0.72 dex higher. The total absence of any bend at the warmer edge of the plateau makes uninhibited diffusion unlikely in depleting lithium. Moreover, an age spread of only 3 Gyrs would produce a dispersion of 0.2 dex on the plateau, which, again, has not been observed.

Vauclair (1988) suggested rotation induced turbulence as the agent leading to a nuclear destruction of Li from an abundance as high as $A(\text{Li})=3.0$ down to the observed plateau value, still approximately preserving the plateau shape. Similar computations with a different formulation of the rotation induced turbulence have been performed by Pinsonneault et al. (1992) and Chaboyer & Demarque (1994). These models predict a bending of the Li abundance on the warmer stars very similar to that predicted by diffusive models. In these models a considerable dispersion is expected depending on the stellar initial angular momenta. Only assuming an identical initial rotational velocity it is possible to deplete Li in a uniform way down to the observed value. Moreover, the initial rotational velocity has to be rather high, which then requires an efficient breaking mechanism to slow down the stars to the low rotational velocities observed. Vauclair & Charbonnel (1995) started from an initial value of 100 kms$^{-1}$ going down to the 2 kms$^{-1}$ presently observed. From an initial value of $A(\text{Li})=2.7$ their model predicts at $T_{\text{eff}}=6500$ K a $A(\text{Li})=1.6$, with a negative slope on the plateau resembling the one obtained by pure diffusive models. These authors found it difficult to account for lithium dispersion less than about 20 to 50 % in the plateau with such models. It is also to note that an age spread of 3 Gyrs alone would produce a dispersion of 0.3 dex on the plateau.

Li depletion induced by winds has been recently proposed by Vauclair & Charbonnel (1995). A mass loss flux between $10^{-13}$ and $10^{-12}$ $M \odot$ yr$^{-1}$ can deplete Li producing a positive slope on the plateau as a function of the stellar mass (i.e. $T_{\text{eff}}$). Higher mass loss rates would destroy Li entirely, while smaller rates would deplete less Li. A stellar wind of $10^{-13}$ $M \odot$ yr$^{-1}$ produces an almost unnoticeable Li depletion, while a wind of $10^{-12}$ $M \odot$ yr$^{-1}$ produces a slope of 0.4 dex along $\approx 1000$ K; that is a slope of the same order of that detected by Thorburn (1994) or Ryan et al. (1996). As a comparison the solar wind is of $10^{-14}$ $M \odot$ yr$^{-1}$, but there are no measurements of winds in Pop II dwarfs. The absence of such a slope as well as the absence of any detectable dispersion is arguing against the mass loss model. If the winds were of different rates in different stars they would produce a dispersion on the Li abundances, and an age spread of 3 Gyr would produce a dispersion of 0.25 dex.

In summary, all depletion mechanisms predict features which are not observed in the present data. The absence of a downturn in Li abundance at the hottest edge of the plateau and the absence of dispersion on the plateau itself argue strongly against significant depletion by diffusion or rotational mixing (Vauclair 1988, Pinsonneault et al. 1992); the absence of a significant slope with $T_{\text{eff}}$ and the absence of intrinsic dispersion rule out stellar winds as a possible source for Li depletion (Vauclair & Charbonnel 1995). Thus we consider that our results strongly support the view that the observed $A(\text{Li})$ in Pop II stars coincides with the primordial value.

5.2 Primordial Li

The absence of dispersion and of significant trends in our analysis, in particular when the small trend with $T_{\text{eff}}$, expected from standard models, is considered, allows to take the mean value of Li of the 41 stars on the plateau as the value of the primordial Li. The weighted mean, in which each abundance is weighted inversely by its own variance, is $A(\text{Li})=2.20$ with an uncertainty of the mean value of only ±0.012. When we take the values corrected for the mild depletion predicted by standard models and NLTE effects the weighted mean is:

$$A(\text{Li})_p = 2.238 \pm 0.012$$

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This value is in excellent agreement with the NLTE corrected value of $A(\text{Li}) = 2.224 \pm 0.013$ by Molaro et al. (1995a). It is significant that the two samples, which make use of a spectroscopically determined $T_{\text{eff}}$ and of the semi-direct method of the IRFM, give the same average Li abundance.

Any offset in the zero point of the different $T_{\text{eff}}$ scales would affect the absolute value of the plateau, while different slopes in the $T_{\text{eff}}$ scales may introduce (or suppress) trends with $T_{\text{eff}}$. The Alonso et al. (1996a) and Fuhrmann et al. (1994) scales are on average hotter than photometric scales and this explains why old mean values for the Li on the plateau were close to $A(\text{Li}) = 2.08$ (Molaro 1991). As already mentioned in section 2, the zero-point of $T_{\text{eff}}$ scales in the low main sequence is difficult to establish. The Alonso et al. (1996a) scale is able to reproduce both the Procyon and Sun $T_{\text{eff}}$, within the measurement errors, and therefore no significant offsets are expected. Alonso et al. (1996a) estimate in their $T_{\text{eff}}$ a systematic error of $\approx 1.25\%$ at $T_{\text{eff}} = 6000$ K, related to the uncertainty of the calibrations of J, H and K magnitudes. This implies a systematic error for Li of $\pm 0.05$ dex, which we have considered separately since it is not eliminated in the averaging process.

The determination of the value of primordial Li is therefore dominated by systematic rather than random errors. Still larger systematic errors can be hidden in our ultimate ability of modelling stellar atmospheres (Kurucz 1995). Our estimate for the primordial lithium is:

$$A(\text{Li})_p = 2.238 \pm 0.012_{\text{sys}} \pm 0.05_{\text{yst}}$$

In Fig. 9 the SBBN theoretical Li yields are shown, computed by using the parametrization provided by Sarkar (1996). The Li Pop II value corresponds to two possible values for $\eta = n_B/n_\gamma$: $\eta_{10} = 1.7^{+0.5}_{-0.3}$ or $\eta_{10} = 4.0^{+0.8}_{-0.3}$, where $\eta_{10} = 10^{10}\eta$. The minimum of the theoretical Li yield is excluded when one considers $1\sigma$ errors in the theoretical predictions and $1\sigma$ errors, plus the full systematic error, in the Li abundances. However, considering the $2\sigma$ errors, both in the theoretical yields and in the observations ($2\sigma_{\text{stat}} + 1\sigma_{\text{yst}}$), the minimum of the Li curve is allowed, increasing considerably the allowed $\eta$ range to $1.3 < \eta_{10} < 5.4$.

Our low $\eta$ intercept coincides with the $\eta_{10} = 1.8 \pm 0.3$ obtained from high D/H ($\approx 10^{-4}$) values (Songaila et al. 1994, Carswell et al. 1996, Wampler et al. 1996, Rugers & Hogan 1996) and is in good agreement with the $\eta$ derived from the primordial He, $Y_p = 0.228 \pm 0.005$ (Pagel et al. 1992), with three neutrino flavours. The high $\eta$ intercept is more consistent with the $\eta_{10} \approx 3$ implied by the primordial helium $Y_p=0.241 \pm 0.003$ obtained by Izotov, Thuan & Lipovetsky (1994) by using revised recombination coefficients for the He I lines.

Our low $\eta$ value is inconsistent with the values $\eta_{10} = 6.4^{+0.9}_{-0.7}$ from the low D/H=$2 \times 10^{-5}$ observed in high redshift absorption systems (Tytler et al. 1996, Burles & Tytler 1996; but see Wampler 1996). To achieve consistency between the low D/H value and Li a 0.5 dex of depletion in Li is required, which is not supported by the present analysis. However, considering the $2\sigma$ errors, the total allowed window for $\eta$ overlaps with the $\eta$ window implied by the low D/H observations.

Turner et al. (1996) use the presolar value of $D+^3\text{He}$ from the recent measurement of $^3\text{He}$ in the local ISM of Gloeckler & Geiss (1996) to deduce the value of $\eta$ for different assumptions on the evolution of $^3\text{He}$ in low-mass stars and of metal ejection by massive stars. Their allowed window for $\eta$ ($2 < \eta_{10} < 7$) overlaps with ours, although our low $\eta$ value is close to their lower limit. Comparison of figure 2 of Turner et al. (1996) with our $\eta$ range seems to suggest that $^3\text{He}$ is preserved but
not produced by low-mass stars.

The two intercepts on the Li theoretical curve correspond to two values for the baryonic density. From the relation $\Omega_B h^2 = 0.00366 \eta_{10}$ we have:

\[
\Omega_B h^2 = 0.0062^{+0.0018}_{-0.0011} \quad \text{or} \quad \Omega_B h^2 = 0.0146^{+0.0029}_{-0.0033}
\]

where the Hubble parameter is $H_0 = 100h$ km s$^{-1}$ Mpc$^{-1}$. Considering that the luminous matter has a contribution to $\Omega$ of $\Omega_{LUM} = 0.004 + 0.0007h^{-3/2}$ (Persic & Salucci 1996), we have that over the entire range of allowed $H_0$ the baryonic density from SBBN remains always greater than $\Omega_{LUM}$ suggesting the presence of dark baryons.

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