Atomic diffusion in metal-poor stars

II. Predictions for the Spite plateau

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Abstract. We have computed a grid of up-to-date stellar evolutionary models including atomic diffusion, in order to study the evolution with time of the surface Li abundance in low-mass metal-poor stars. We discuss in detail the dependence of the surface Li evolution on the initial metallicity and stellar mass, and compare the abundances obtained from our models with the available Li measurements in Pop II stars. While it is widely accepted that the existence of the Spite Li-plateau for these stars is a strong evidence that diffusion is inhibited, we show that, when taking into account observational errors, uncertainties in the Li abundance determinations, in the $T_{\rm eff}$ scale, and in particular the size of the observed samples of stars, the Spite plateau and the Li abundances in subgiant branch stars can be reproduced also by models including fully efficient diffusion, provided that the most metal-poor field halo objects are between 13.5 and 14 Gyr old. We provide the value of the minimum number of plateau stars to observe, for discriminating between efficient or inhibited diffusion. From our models with diffusion we derive that the average Li abundance along the Spite plateau is about a factor of 2 lower than the primordial one. As a consequence, the derived primordial Li abundance is consistent with a high helium and low deuterium Big Bang Nucleosynthesis; this implies a high cosmological baryon density as inferred from the analyses of the cosmic microwave background.

Key words. stars: metal-poor – low-mass – evolution – abundances – physical processes: diffusion

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1. Introduction

Microscopic diffusion is a fundamental physical mechanism, which in principle has to be considered when computing stellar models. In particular, since the highly accurate seismic determination of the solar sound speed profile has become available, diffusion is an integral part of the standard solar model. Taking diffusion into account, not only the sound speed, but also the depth of the solar convective zone and the present surface helium abundance are in very good agreement with observations (see, for example Richard et al. 1996; Bahcall et al. 1997). Only in the region immediately below the convective envelope the theoretical models deviate from the seismic Sun significantly, indicating that diffusion might not operate exactly in the way calculated or pointing to some neglected additional physical process partially counter-working diffusion (Brun et al. 1999).

With the Sun as our best laboratory for stellar physics strengthening the case for the presence of atomic diffusion, it immediately becomes mandatory to consider it also for other stars. Since diffusion is an intrinsically slow process operating over cosmic times, long-lived low-mass stars, in particular those of Population II, are evidently the best suited candidates.

Atomic diffusion affects the evolution of stars in two ways. In the deep interior, the sinking of helium towards the core leads to an effectively faster nuclear aging of the star, thus reducing its Main Sequence (MS) lifetime. For age determinations of globular clusters making use of the absolute brightness of the colour-magnitude diagram (CMD) turn-off (TO), when the cluster distance is known, diffusion eventually leads to lower ages; the effect accounts for a reduction of the order of 1 Gyr for old globular clusters (Chaboyer et al. 1992; Castellani et al. 1997). The modified chemical structure also affects later evolutionary stages, such that age determination methods using differential quantities, for example the brightness difference between TO and horizontal branch, are less affected (about 0.5 Gyr; Cassisi et al. 1998; Castellani & Degl'Innocenti 1999).

In the envelope of the star, diffusion leads to a depletion of the heavy elements and helium. This has the direct consequence that the present abundance of metals is lower than the initial one. In Salaris et al. (2000) we discussed in detail the consequences for the MS fitting method, the resulting distances, and subdwarfs ages. Furthermore, due to the decreased metals, the colours of the star change. The stellar radius and thus the effective temperature, however, also depend on the molecular weight in the star's core, which is increased in the presence of sedimentation. Taking diffusion into account, a much better agreement between models and observed colours or effective temperature results, as has been noted by Lebreton et al. (1999; see also Morel & Baglin 1999 and Salaris et al. 2000). Similarly, an improved isochrone fitting for globular clusters, and consistency between the age from the cluster CMD and that from its integrated spectrum might be obtained (Vazdekis et al. 2001 for 47Tuc).

A general prediction of models including atomic diffusion is that very metal-poor low-mass stars, with their high effective temperatures and thus very shallow convective envelopes, are readily depleted of metals over the MS lifetime (see the seminal paper by Deliyannis et al. 1990); this prediction can be contrasted with observations. In the present paper, we will therefore confront theoretical models with the observational result that the ^{7}Li abundance in such stars of $T_{\rm eff} \gtrsim 5900$ K forms a well-defined plateau below [Fe/H] ≈ -1.5 (Spite & Spite 1982). In the past, this so-called Li- or Spite-plateau has been used repeatedly as an, if not *the* argument against the full efficiency of diffusion (Deliyannis & Demarque 1991; Vauclair & Charbonnel 1998; Ryan et al. 1996), because the degree of depletion by diffusion increases with effective temperature. Stated differently, the necessity for an additional effect counteracting diffusion was claimed (Chaboyer et al. 1995a; Vauclair 1999). Candidate processes are rotationally induced mixing (Chaboyer et al. 1995a, 1995b) or a rather strong mass loss by a stellar wind (Vauclair & Charbonnel 1995).

Although, therefore, the Li-plateau seems to make a strong case against diffusion, there are a number of issues that warrant a new look at this problem. First of all, the input physics for the stellar models has changed a lot in the last few years, and the improved equations of state, opacities and nuclear reaction rates all affect the stellar models (see Cassisi et al. 1998 for an overview). Secondly, and as a consequence, the deduced ages for the oldest clusters and stars has been reduced from 16-18 Gyr to 12-14 Gyr (Salaris et al. 1997). Thirdly, the observed field stars have a distribution of metallicities and possibly of ages, while often the comparison is performed by considering models of different masses all with the same age and metallicity (as, e.g., in Deliyannis et al. 1990 or Vauclair & Charbonnel 1998). Finally, it is important to consider, when comparing theory with observations, not only the observational errors, but also the actual size of the sample of stars with Li abundance determinations.

The inclusion of diffusion does not only lead to a depletion of the surface lithium content, but to a second effect which could be measurable; the diffused Li is stored immediately below the thin convective envelope (see Vauclair & Charbonnel 1998 for illustrative interior profiles) but remains at temperatures too low for lithium-destruction by proton capture. After the TO, the deepening convective envelope at first mixes this surplus to the surface, such that for some time subgiants should have Li-abundances somewhat *above* the Spite-plateau level which, in the case of effective diffusion, does not represent the primordial abundance. To recall, in case of no diffusion there is no difference between the initial Li-abundance and that on the main sequence and subgiant branch. With further expansion the convective envelope deepens until regions where the initial lithium was destroyed are diluting the envelope lithium content and a decrease in the surface abundance will ensue. Pilachowski et al. (1993) have investigated this effect in detail and compared with observations of metal-poor subgiant. They indeed found indications of this variation in lithium abundance as a function of evolutionary state.

In this paper we will therefore investigate theoretical predictions for the Li-abundance[1] of low-mass metal-poor stars, making use of the latest stellar models, which will be presented in Section 2. The calculations were used to prepare data about the lithium abundance as a function of metallicity, effective temperature and age. The comparison with the observed Li abundances of plateau and subgiant branch stars will be described in Section 3, while in Section 4 we will discuss the consequences of our results and, in particular, to which extent the Spite plateau can be used to make statements about the efficiency of diffusion operating in old metal-poor stars.

2. Calculations and models

We started out with stellar evolution calculations using the same input physics as in Salaris & Weiss (1998) and Salaris et al. (2000). We computed α-enhanced models (average enhancement by 0.4 dex, as in Salaris & Weiss 1998) for initial iron contents $[\mathrm{Fe/H}]_\mathrm{o} = -3.2, -2.6, -2.3, -1.8$ (corresponding to $Z = 0.000025, 0.0001, 0.0002, 0.0006$) and masses between 0.6 and 1.0 $M_\odot$, from the pre-MS phase until the beginning of the Red Giant Branch (RGB). The initial He content has been fixed at $Y = 0.23 + 3Z$, and we used an initial lithium abundance $[\mathrm{Li}]_\mathrm{o}$=2.50. Diffusion was included by solving the Burgers equations following Thoul et al. (1994), and considered for H, He, Li, C, N, O, and Fe. The other elements have been assumed to diffuse like Fe. The rates for the Li destruction reactions are from the NACRE compilation (Angulo et al. 1999).

Pre-MS evolution was followed to assess the possible Li-depletion in this phase, although it is expected to lead to substantial lithium destruction only for stellar masses below $0.8\,M_\odot$ (D'Antona & Mazzitelli 1984; Deliyannis et al. 1990). For these pre-MS calculations, the Garching stellar evolution code was used (see, e.g., Weiss & Schlattl 2000 and references therein), in contrast to the variant of the FRANEC program for all other calculations. Both codes use in most aspects essentially the same and in some (opacities, diffusion coefficients) identical physics and produce very similar results, as shown, for example, in Weiss & Schlattl (2000). The derived Li abundances at the Zero Age Main Sequence where then provided to the code we have employed in all our previous evolutionary computations. Selected results about the surface Li-depletion exclusively due to nuclear burning are summarized in Table 1.

[1] Throughout the paper we will indicate the abundance of Li with [Li], defined as [Li]=12+log[N(Li)/N(H)]. We consider only ^{7}Li in our theoretical predictions for [Li], since the cosmological production of ^{6}Li is negligible in comparison with ^{7}Li. Observations, however, determine the sum Li=^{7}Li+^{6}Li. We will come back to this point in the discussion at the end of the paper.

Table 1. Surface Lithium depletion (in dex) – due to nuclear burning only – along the pre-MS and MS, for various selected masses ($M/M_{\odot}$) and initial metallicities (Z). The four lines for each case correspond to the depletion after 10 and 100 Myr, 1 and 10 Gyr. For simplicity, we omit lines of higher age when the lithium abundance does not change any longer.

$M/M_{\odot}$ | Z	$2.5\,10^{-5}$	$2\,10^{-4}$	$6\,10^{-4}$
0.60	-0.75	-0.63	-0.42
	-1.03	-0.90	-0.79
	-1.36	-0.96	-0.89
	-1.83	-1.83	-1.76
0.65	-0.19	-0.20	-0.19
	-0.19	-0.21	-0.23
	-0.19	-0.22	-0.25
	-0.19	-0.22	-0.26
0.70	-0.03	-0.06	-0.07
	-0.04	-0.06	-0.07
	-0.04	-0.06	-0.08
0.75	-0.01	-0.02	-0.03
0.80	-0.00	-0.01	-0.01

Table 2. Lithium depletion, given as $\mathrm{Li}(t)/\mathrm{Li}_0$, in models with diffusion. The third column shows results of Vauclair & Charbonnel (1998) for [Fe/H] $= -2$ ("VC"), the fourth one those of the present paper at the same [Fe/H], and the last one at the same total metallicity, [M/H]. The comparison is done for three masses (column 1) in common and two ages, 12 and 14 Gyr (column 2).

$M/M_{\odot}$	t	VC	[Fe/H] $= -2.$	[M/H] $= -2.$
0.65	12	0.700	0.431	0.436
	14	0.662	0.412	0.427
0.70	12	0.652	0.695	0.667
	14	0.595	0.657	0.622
0.75	12	0.465	0.482	0.398
	14	0.384	0.365	0.245

These numbers can be compared with, for example, the results of Deliyannis et al. (1990). We get a definitely higher depletion at the lower masses than in these older calculations (with older opacities and equation of state). For example (see their Fig. 14), our 0.60 $M_{\odot}$ model shows strong depletion already on the pre-MS for all metallicities, and continuing depletion on the MS, while the depletion in the Z=0.0001 models by Deliyannis et al. (1990) levels off at -0.4 dex already at the beginning of the MS phase. This behaviour is similar to that found by Ventura et al. (1998), when comparing with their older models (D'Antona & Mazzitelli 1984): the more up-to-date physics leads to a higher depletion.

When comparing our diffusion calculations with the results from the scaled-solar models by Vauclair & Charbonnel (1998), for ages of 12 and 14 Gyr, we find good agreement, with large differences only for the $M = 0.65 M_{\odot}$ models, which are mainly due to differences in the pre-MS phase, since for these masses and ages the depletion due to diffusion from the convective envelope is only a small contribution.

Figure 1 shows the surface [Li] value as a function of age for three selected masses (0.65, 0.70 and 0.80 $M_{\odot}$) and initial metallicity $[\mathrm{Fe/H}]_0 = -2.6$ ($Z = 0.0001$), along the MS. All the three masses show a steady decrease of [Li] as a function of time due to the effect of diffusion. The $0.80 M_{\odot}$ star shows a slightly higher [Li] value during the first MS stages (due to its lower pre-MS depletion), then, due to the shrinking of the envelope convection when approaching the TO, [Li] quickly drops below the values of the 0.65 and 0.70 $M_{\odot}$ objects. The latter two masses, with larger convective envelopes all along the MS phase, show a much more similar trend of [Li] as a function of time, the steady [Li] decrease of the 0.70 $M_{\odot}$ star being however slightly steeper due to its thinner convective

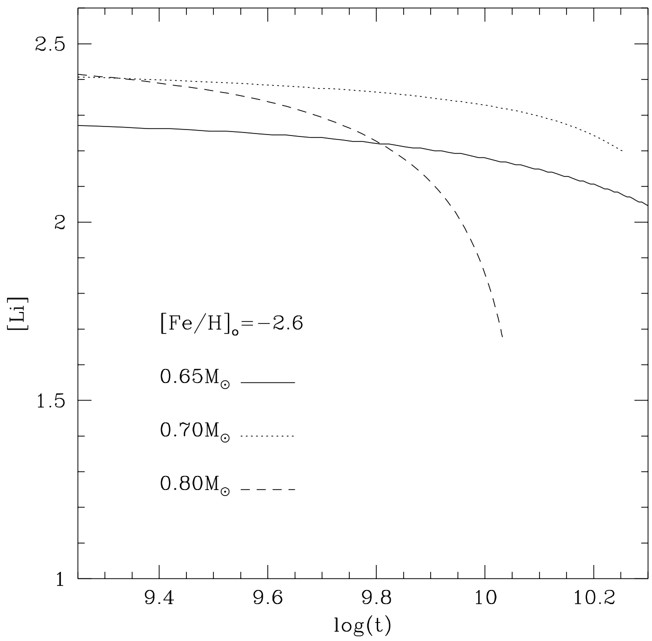

Fig. 1. Li abundance as a function of the age (t), along the MS, for three selected masses and initial metallicity $[Fe/H]_o = -2.6$.

envelope; the difference in the absolute [Li] values is mainly due to the different amount of pre-MS depletion.

From the computed grid of stellar models we then produced Li-isochrones (i.e. Li-abundances along isochrones as in Deliyannis et al. 1990) for different ages and different initial [Fe/H] values. It is important to remark here that along an isochrone the surface [Fe/H] is not constant, again due to the effect of diffusion (Morel & Baglin 1999, Salaris et al. 2000). At a given age of some Gyr, the surface [Fe/H] is lower than the initial value; it also shows a decrease towards the TO and than increases along the Sub Giant Branch (SGB) until it reaches the initial value along the RGB (see Fig. 4). Therefore our isochrones, for ages larger than ∼5 Gyr, cover a range of surface [Fe/H] between ~ -2.0 and ~ -3.8.

Figure 2 displays Li-isochrones as a function of $T_{\rm eff}$ and mass for ages of 12, 13, 14 Gyr and initial metallicity $[Fe/H]_o = -2.6$, from the unevolved lower main sequence up to the TO. The shape of the isochrones looks very similar for the various ages apart from the different value of $T_{\rm eff}$ at both the TO and at the cool end. Li depletion at the coolest end of the isochrones is dominated by the pre-MS depletion (masses populating these region range from 0.60 up to $\sim$0.65 $M_\odot$), while for $T_{\rm eff}$ larger than ∼5800 K Li diffusion is mainly responsible for the surface Li depletion, since pre-MS depletion is negligible. The isochrones for $t = 12$ Gyr show more depletion at the TO since, in spite of the shorter time available for diffusion to deplete the surface Li, TO stars are hotter and have shallower convective regions and therefore the surface Li depletion is more efficient. The Li-isochrones show also an extended region, with $T_{\rm eff}$ ranging between ∼5800 and 6300 K (the extension depends on the age), in which the depletion does not change by more than 0.2 dex. At these ages the depletion at the level of this plateau is of the order of 0.3 dex.

In Fig. 3 we compare the [Li] values along two isochrones with the same age of 12 Gyr and two different initial metallicities. The shape of the isochrones is again very similar, with the more metal-rich models being less depleted at the TO (larger convective envelopes) and in general more Li-rich at a given value of $T_{\rm eff}$.

Finally, in Fig. 4 we display the run of [Li] as a function of $T_{\rm eff}$ for 12 and 14 Gyr isochrones with $[Fe/H]_o = -2.6$, from the MS to the base of the RGB. It is very interesting to notice that after the TO [Li] continues to decrease for the next 50 K, with a

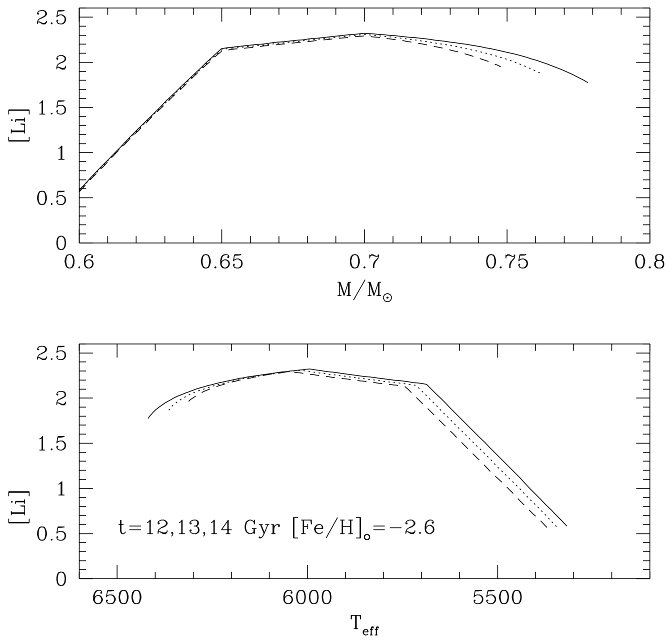

Fig. 2. (upper panel) Run of [Li] as a function of the stellar mass for isochrones with initial metallicity $[Fe/H]_o = -2.6$ and ages of 12 (solid line), 13 (dotted line) and 14 Gyr (dashed line). (lower panel) As in the upper panel, but for the run of [Li] as a function of $T_{\rm eff}$.

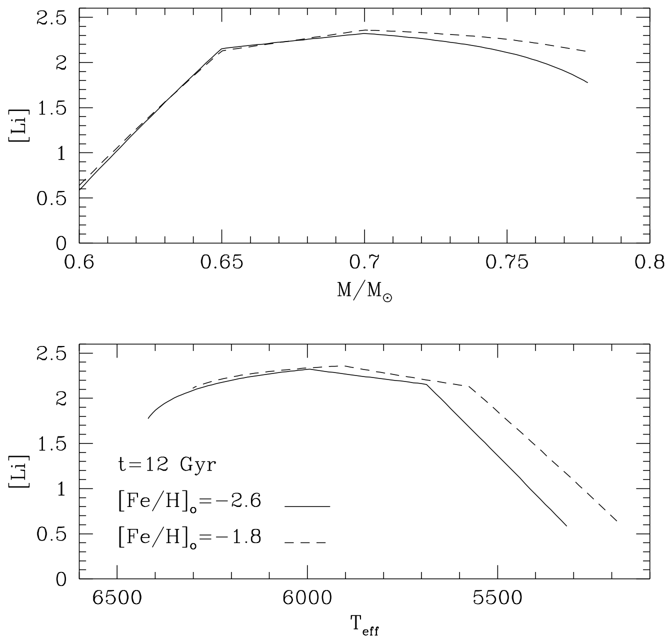

Fig. 3. As in the previous figure but for isochrones with $t = 12$ Gyr and initial metallicities $[Fe/H]_o = -2.6$ and $[Fe/H]_o = -1.8$.

further depletion by about 0.1 dex. The maximum depletion is a function of age, strongly decreasing for increasing age. It also depends on metallicity, in the sense that at a given age the maximum depletion decreases with increasing metallicities. This behaviour is easy to understand if one recalls that the extension of the convective envelope in TO stars increases for increasing age at a given metallicity, or for increasing metallicity at a given age, reducing thus the effect of diffusion on the surface abundances.

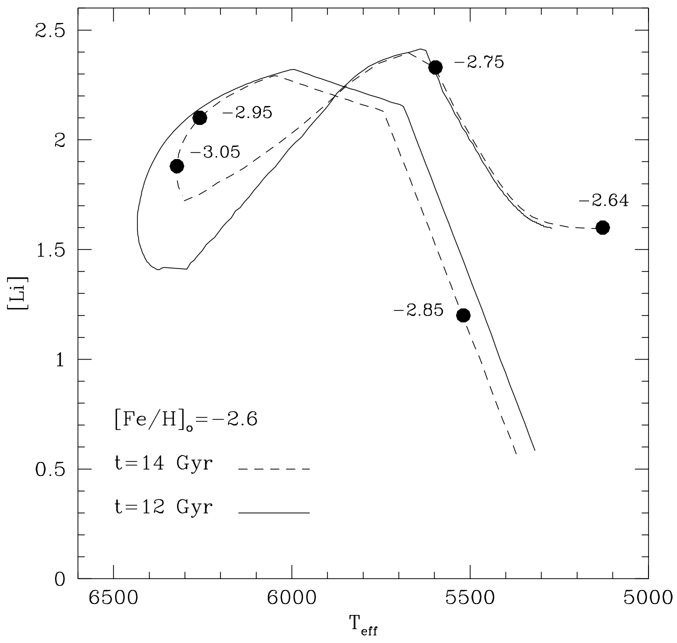

Fig. 4. [Li] as a function of $T_{\rm eff}$ for isochrones of 12 and 14 Gyr, with $[{\rm Fe/H}]_{\rm o} = -2.6$, from the MS to the lower RGB. Selected values of [Fe/H] along the 14 Gyr isochrone are also shown.

Later on, with decreasing temperature, the [Li] abundance starts to rise again due to the deepening of the convective region which returns to the surface the Li diffused outside the envelope along the MS. [Li] reaches a peak when $T_{\rm eff} \simeq 5600 - 5700$ K, with an abundance within 0.1 dex from the initial one; then the Li surface abundance starts to drop, since the convective envelope reaches regions where Li had been burned due to the higher temperatures of the stellar matter. We note that the location and level of the Li abundance peak is fairly independent of age and metallicity (see Fig. 11) and, in addition, is within 0.1 dex of the primoridial value, independent of the effectiveness of diffusion. Subgiants at effective temperatures around 5600 K are therefore ideally suited for determining the primordial Li abundance to this accuracy.

3. Comparison with observations

In this section we will compare the behaviour of the [Li] abundances obtained from our MS and SGB models with the observations of metal-poor field and globular cluster stars. We concentrate our attention on stars with $[{\rm Fe/H}] \leq -2.0$, which constitute the largest fraction of the currently available samples of PopII Li-plateau stars; in the last part of this section we will discuss briefly also the case of stars with [Fe/H] up to ~ -1.5, which is approximately the upper metallicity boundary of the Spite plateau.

3.1. Field MS stars

Observations of Li abundances in metal-poor MS field stars provide a qualitative picture that is basically consistent among the different authors, but which can differ a lot in the details (see, e.g., Thorburn 1994, Ryan et al. 1996, Spite et al. 1996, Bonifacio & Molaro 1997, Ryan et al. 1999, Ryan et al. 2001 and references therein). The main result (as an example we show in Fig. 5 the Thorburn 1994 data for the metallicity range spanned by our models) is that metal-poor MS stars with $T_{\rm eff}$ larger than approximately 5800 K show a remarkably constant [Li] value (Li-plateau), while there is a larger depletion at lower temperatures, increasing for decreasing temperature. Moreover, in the plateau region, a handful of stars show a much lower [Li] than the plateau counterpart (e.g. Thorburn 1994).

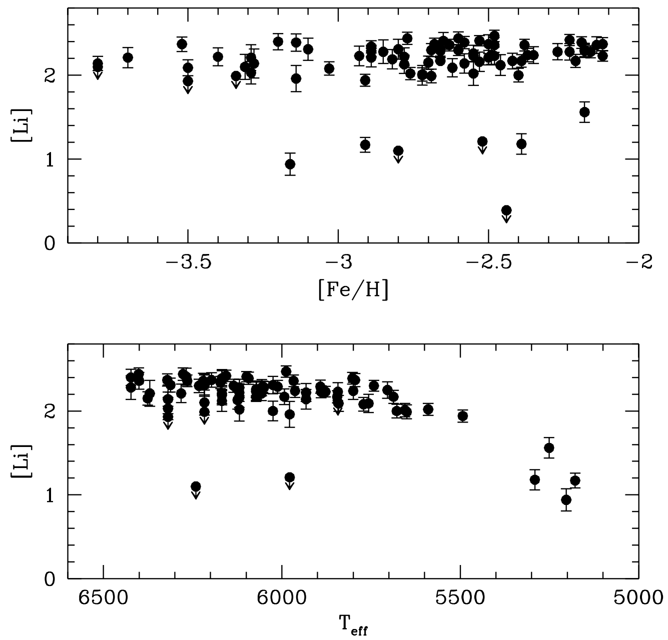

Fig. 5. Run of [Li] as a function of [Fe/H] (upper panel) and $T_{\rm eff}$ (lower panel) from the Thorburn (1994) data for MS stars with [Fe/H]≤ -2.0. Upper limit detections are also shown. For the sake of clarity we did not plot the error bars on the $T_{\rm eff}$ values (of the order of, typically, 80-100 K, see Thorburn 1994 for more details).

The details of this picture, however, differ from author to author. The exact $T_{\rm eff}$ location and extent of the plateau varies slightly; some trend of [Li] with $T_{\rm eff}$ along the plateau was detected by Thorburn (1994) and Ryan et al. (1996), but it is absent in the analyses by Bonifacio & Molaro (1997) and Ryan et al. (1999). A trend of [Li] with respect to [Fe/H] for plateau stars is claimed by Thorburn (1994), Ryan et al. (1996), Ryan et al. (1999) and Ryan et al. (2001), while it is missing in Bonifacio & Molaro (1997). Also the absolute average value of [Li] for plateau stars shows differences between different authors.

In addition to the purely observational errors and differences in the adopted metallicity scale, there are other sources of uncertainty that should be mentioned. The first one is the set of model atmospheres used in the spectral analyses. As dicussed by Ryan et al. (1996), the differences between Li abundances derived from different sets of model atmospheres show trends with respect to both $T_{\rm eff}$ and [Fe/H]. Very recently Asplund et al. (1999) discussed the differences in the [Li] values derived using either 1D, plane parallel, hydrostatic model atmospheres, like the MARCS (Gustafsson et al. 1975 with subsequent updates) and ATLAS9 (Kurucz 1993) ones used in all recent papers on [Li] abundances, or their 3D hydrodynamical model atmospheres. A remarkable result is that not only the absolute values of [Li] are changed when passing from 1D to 3D models, but that also the spread in [Li] values is changed. They discuss the case of HD140283 and HD84937 whose [Li] derived from MARCS models is, respectively, 2.12 and 2.28. Using their 3D hydrodynamical models, Asplund et al. (1999) obtain 1.78 and 2.08; the difference between the two values is almost doubled with respect to the case of 1D hydrostatic models. Keeping in mind their cautionary remarks about the assumption of LTE in their models, it is nevertheless important to notice that the derived [Li] spread may underestimate the real variation.

Another important source of uncertainty is the $T_{\rm eff}$ scale itself. Different authors use temperature scales which often differ not just by a constant offset, but also show differential trends with respect to the metallicity. As an example, we show in Fig. 6 the values of $T_{\rm eff}$ for 8 plateau stars in common among three of the previously mentioned investigations.

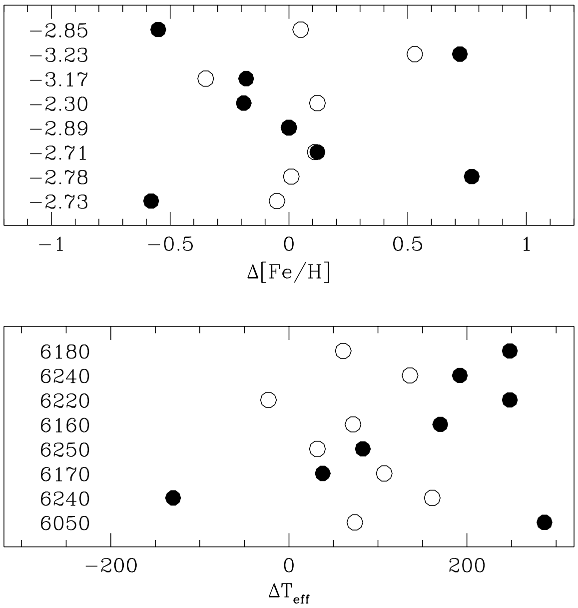

Fig. 6. Differences in [Fe/H] (upper panel) and $T_{\rm eff}$ (lower panel) for a sample of 8 plateau stars with [Fe/H]≤ -2.0, in common among two or more of the investigations mentioned in the text. Each line corresponds to a different star with [Fe/H] and $T_{\rm eff}$ from Ryan et al. (1999) indicated on the left side. The difference to Bonifacio & Molaro (1997) is indicated by a filled circle, that to Thorburn (1994) by an open one.

Clearly the spread of the $T_{\rm eff}$ values is not constant and in some cases quite remarkable. If one takes into account that a $T_{\rm eff}$ variation by 100 K changes the derived [Li] value by about 0.07 dex (Ryan et al. 1999), it may well be that the current uncertainty about Li trends along the plateau is due mainly to uncertainties in the temperature scale. Also the [Fe/H] values adopted in different investigations show a spread which reaches values larger than 0.5 dex (Fig. 6).

In order to analyze the predictions of theoretical diffusive models regarding the trends of [Li] with respect to $T_{\rm eff}$ and [Fe/H] in metal-poor stars, we resorted to Monte-Carlo (MC) simulations using our own isochrones. In this way we will be able to take into account the fact that the subdwarfs with [Li] measurements have a metallicity distribution and possibly an age distribution. As we have shown before, the initial metallicity and age alter the location and shape of Li–isochrones, and it is important to take these two factors into account. Moreover, with MC simulations we will be also able to account for the actual number of MS stars with [Li] measurements. This point – as we will see later on – is of fundamental importance when trying to constrain the efficiency of diffusion from Li-plateau stars. It is important to remark at this stage that, since the observations provide contradictory results about the properties of the Spite plateau, we can just discuss whether our models with diffusion are able to reproduce the plateau, and if its derived properties are within the range allowed by existing data.

In our simulations we assumed that present [Li] observations of field MS subdwarfs cover also TO stars. We prescribed an age–initial metallicity relationship and, by interpolating among our isochrones, we have drawn a large sample of 10000 MS stars, according to a Salpeter Initial Mass Function, with an initial [Fe/H] distribution adjusted (by trial and error) in such a way that the 10000 stars show a metallicity distribution in agreement with the typical metallicity distribution of halo stars as determined by Ryan & Norris (1991). For each star we determined the value of its mass, bolometric luminosity, surface [Fe/H] and [Li], and $T_{\rm eff}$. We then added to the values of [Fe/H], [Li], and $T_{\rm eff}$ 1σ random observational errors by, respectively, 0.20 dex, 0.07 dex and 65 K. These observational

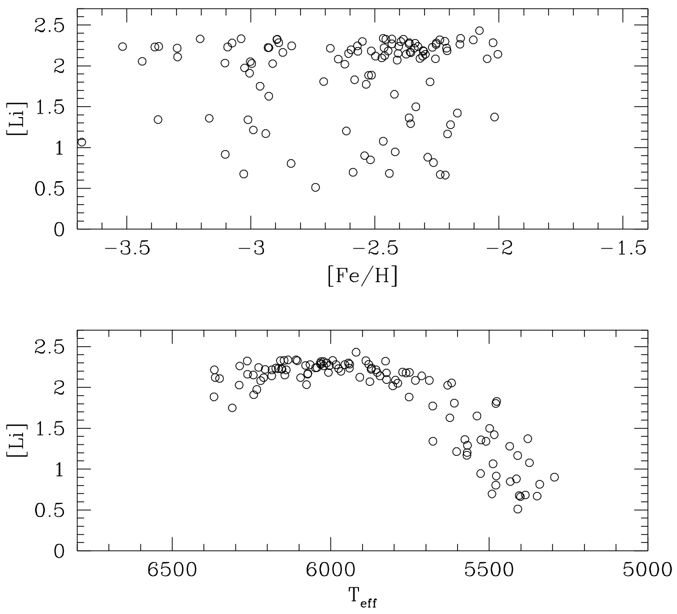

Fig. 7. Run of [Li] as a function of [Fe/H] (upper panel) and $T_{\rm eff}$ (lower panel) for stars in one of our MC simulations (see text) considering an age randomly distributed between 13.5 and 14 Gyr.

errors are approximately an average of the values quoted by Thorburn (1994), Ryan et al. (1996), Spite et al. (1996), Bonifacio & Molaro (1997).

From this sample of 10000 stars representing the halo population we have randomly drawn 30 smaller samples of 120 stars each, which represent the MC realizations of the observational data; about 65 objects populate the plateau region (which we define as being the region with $T_{\rm eff} > 5800\,$K). This number of plateau stars correponds approximately to the largest sample with [Li] abundances and [Fe/H]≤ -2.0 available to this day (see, e.g., Thorburn 1994, Ryan et al. 1996). For each of these samples we studied the distribution of stars in the [Li]-$T_{\rm eff}$ and [Li]-[Fe/H] planes.

We have been able to obtain a plateau-like feature for $T_{\rm eff} > 5800\,$K only when the age of the sample is equal or higher than about 13.5 Gyr. Lower ages show a pronounced drop of [Li] at the TO which is not observed. Above this age, in the limit of the actual available observational samples and typical errors, the theoretical plateau region looks quite similar to the observational counterpart. In Fig. 7 we display the outcome of one simulation, where the age of the stars is randomly distributed between 13.5 and 14 Gyr. The outcome of this simulation is quite typical of the ensemble of the 30 samples we have drawn with this age distribution. The plateau for $T_{\rm eff}$ larger than about 5800 K is clearly visible together with a drop at lower $T_{\rm eff}$ due to the effect of pre-MS depletion.

Figure 8 displays only the plateau stars from the same simulation. The solid line in the plane [Li]-$T_{\rm eff}$ shows the average [Li] value ($\langle$[Li]$\rangle$), while the dashed lines indicate $\langle$[Li]$\rangle \pm 3\sigma$, where σ is the typical observational error on [Li] adopted in our simulations (0.07 dex). Only 4 stars appear to be outside the zone limited by the dashed lines (with lower [Li] values). If we take out these 4 stars and recompute $\langle$[Li]$\rangle$, its value is not affected appreciably and all the remaining stars still lie within 3σ of $\langle$[Li]$\rangle$. For the stars within 3σ of $\langle$[Li]$\rangle$ there is no significant correlation between [Li] and $T_{\rm eff}$. Stars outside this region we will call 'outliers'. In all our simulations the outliers lie always below $\langle$[Li]$\rangle - 3\sigma$, and they look like the theoretical counterpart of the observed Li-depleted stars in the plateau region (see Fig. 5, Thorburn 1994 and Ryan et al. 2001). It is important to notice that in the observational analyses of the plateau, the (few) stars showing a substantial depletion with respect to the average plateau value, are not considered in the derivation of the

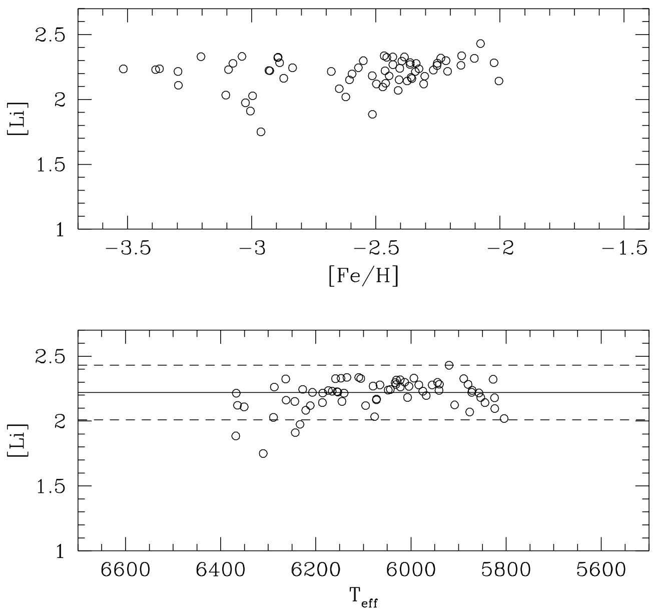

Fig. 8. As in the previous figure, but only for plateau stars, i.e. with $T_{\rm eff} > 5800\,{\rm K}$ (see text for details).

plateau properties. As we did the same with our outliers, our selection closely mimicks the observational analyses.

By averaging over the 30 realizations with this same age distribution, we derived for the plateau stars a [Li] depletion by 0.27 dex and a derivative Δ[Li]/Δ[Fe/H]=0.06. The average number of outliers (Li-depleted stars) is 6. This latter number compares well with the actually observed number of Li-depleted stars in this same [Fe/H] and $T_{\rm eff}$ range (see Thorburn 1994). Also the average plateau value [Li]=2.23, obtained from an initial lithium abundance $[{\rm Li}]_{\rm o}$=2.50, agrees well with the values provided in the literature, which span a relatively large range from $\sim$2.10 (Ryan et al. 1999) up to $\sim$2.40 (Gratton et al. 2000). The slope Δ[Li]/Δ[Fe/H] is halfway between the value 0.118 ± 0.023 claimed by Ryan et al. (1999), and the results by Bonifacio & Molaro (1997), who did not find any dependence on [Fe/H] for the plateau [Li] values.

The lower $T_{\rm eff}$ limit off the plateau has been, somewhat arbitrarily, set at 5800 K, which is a typical value as deduced from the observations. Had we increased it up to 5900 K (again, compatible with observations), the situation would have changed only slightly, with just a small decrease of the average [Li] depletion along the plateau, and a somewhat narrower distribution of the plateau stars around $\langle[{\rm Li}]\rangle$.

We made simulations also assuming a constant age of, respectively, 13.5 and 14.0 Gyr, and ages between 14 and 15 Gyr; the results are substantially the same, in the sense that a plateau-like feature is always found, without a significant depletion at its hotter end. We did not explore ages larger than about 15 Gyr because of the constraints put on the ages of field halo stars by the current estimates of globular clusters ages (see next section), and also by the fact that the horizontal extension of the plateau region is very much reduced and, even taking into account current uncertainties in the $T_{\rm eff}$, it is too much reduced in comparison with observational data.

We now investigate whether our assumed metallicity distribution for halo stars leads to properties of the simulated sample in agreement with observed ones. To this end we compare in Fig. 9 the distribution of plateau stars ($T_{\rm eff} > 5800\,{\rm K}$) as a function of the actual metallicity [Fe/H] and $T_{\rm eff}$ in case of one of our MC samples, and the data by Thorburn (1994) with [Fe/H]< -2.0 (the bin size is equal to 70 K in $T_{\rm eff}$ and 0.20 dex in [Fe/H]). The number of plateau stars in both cases is the same.

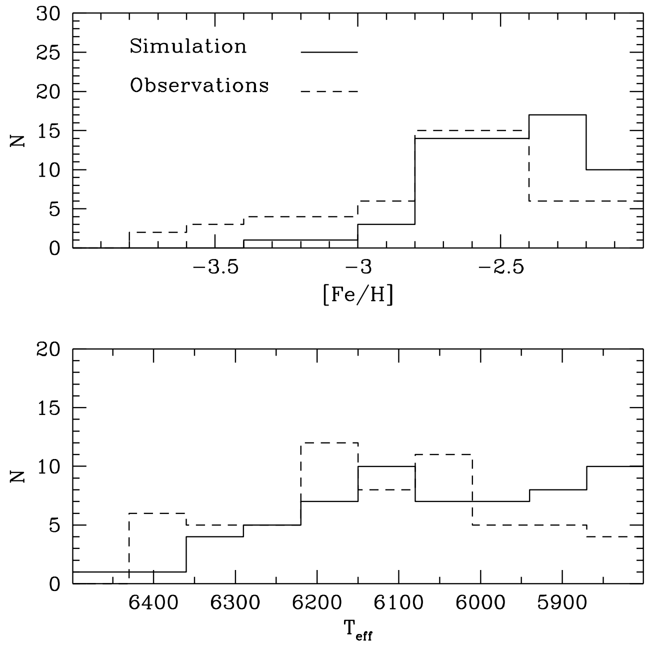

Fig. 9. Comparison of the number of plateau stars as a function of their [Fe/H] (upper panel) and $T_{\rm eff}$ (lower panel), between one of our MC samples and the observational data by Thorburn (1994) (see text for details).

If one takes into account the spread of the empirical determinations of $T_{\rm eff}$ and [Fe/H] shown in Fig. 6, the differences between the distributions of stars in the observed and synthetic samples are probably not very significant. However, as a test, we computed a series of MC simulations in the same way as before (ages again distributed uniformly between 13.5 and 14.0 Gyr), but considering an actual metallicity distribution biased towards lower metallicities with respect to the Ryan & Norris (1991) one. This corresponds, basically, to have synthetic samples of plateau stars with a higher fraction of very metal-poor stars, in the assumptions that the observations were biased towards the most metal poor objects.

The distribution of plateau stars as a function of [Fe/H] and $T_{\rm eff}$ for one of these latest simulations is shown in Fig. 9; the agreement between the two distributions is improved. The analysis of the [Li] abundances in these latest samples does not reveal any appreciable change with respect to the case of a standard halo metallicity distribution. This strenghtens our conclusions, in the sense that they are not critically dependent on the actual [Fe/H] distribution adopted in the simulations.

Before concluding this section, we would like to discuss briefly the spread of the plateau ($\sigma^p_{[Li]}$) obtained in our simulations. If we consider all stars in the plateau region bar the outliers, we obtain a dispersion $\sigma^p_{[Li]}$=0.09. This number compares very well with the values of $\sigma^p_{[Li]}$ derived by, e.g., Spite et al. (1996) and Bonifacio & Molaro (1997), for observational errors in [Li] similar to the ones used in our simulations. On the other hand, $\sigma^p_{[Li]}$=0.09 is definitely larger than the value given by Ryan et al. (1999). They have reobserved a sample of known plateau stars (thus avoiding contamination from Li-depleted objects), claiming average 1σ errors by $\sim$30 K in the stellar temperatures, and by 0.033 dex in the derived [Li] values. They selected 22 stars around the TO of the field population, with $T_{\rm eff}$ between 6100±50 K and 6300±50 K, [Fe/H] between −2.5 and −3.5, and found that the 1σ dispersion of [Li] around an average value of 2.11 is equal to 0.053 dex (they went on discarding 3 stars more discrepant from the average to obtain an even smaller dispersion).

We performed a series of MC simulations by drawing samples of 25 stars among the samples of plateau stars obtained from the previous simulations. We selected the stars in the same [Fe/H] range as Ryan et al. (1999); under the hypothesis that their hottest

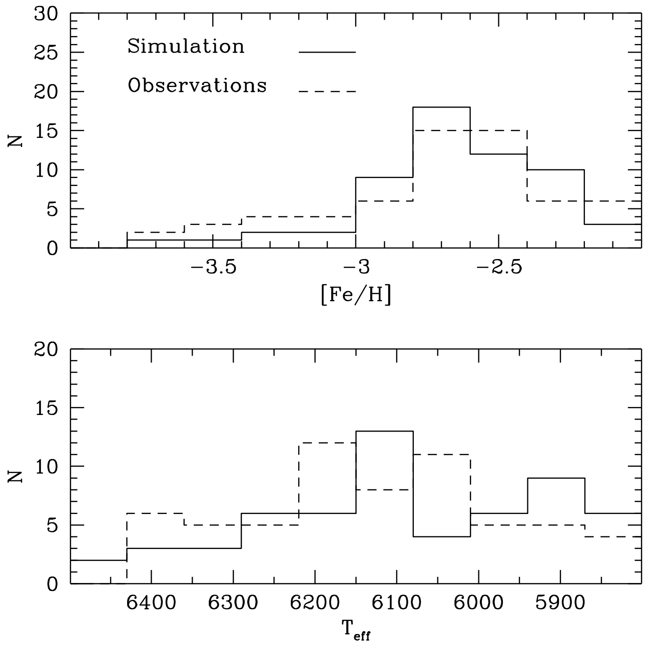

Fig. 10. As in the previous figure, but for a synthetic sample drawn from a metallicity distribution biased towards the most metal poor objects (see text for details).

stars were stars at the TO, and for avoiding problems related to zero-point uncertainties in the temperature scale, we restricted our sample to stars with $T_{\rm eff}$ ranging between the hottest value reached in our simulations and a value 200 K lower. The extremes of this $T_{\rm eff}$ range are similar to the values adopted by Ryan et al. (1999). By averaging over 30 of these realizations we obtained an average [Li]=2.17, with a 1σ dispersion of 0.075 dex. This average [Li] value is lower than the value derived previously; that is easily explained by the derivative Δ[Li]/Δ[Fe/H]=0.06 obtained before, and the fact that in these latter simulations we are considering only [Fe/H]≤ -2.5. What is probably relevant is that the spread we find is larger than the value obtained by Ryan et al. (1999), but we would like to recall the results by Asplund et al. (1999) which clearly raise the possibility that current determinations of the plateau dispersion (and this would hold also for the larger samples discussed earlier) are underestimated appreciably.

3.2. Field subgiant branch stars

If one accepts, as a working hypothesis, an age between 13.5 and 14 Gyr for the most metal-poor field stars, it is necessary to see if this value satisfies constraints coming from Li abundances in the SGB phase.

We compare our models with observational data by Pilachowski et al. (1993) for metallicities lower than [Fe/H]=-2. In Fig. 11 we show the comparison of the data with the SGB part of our isochrones, for an initial [Fe/H]$_{\rm o}$ equal to -3.2 (solid line) and -1.8 (dashed line), and $t = 14$ Gyr. Because of the extremely low number of data points on the SGB and the size of their error bars, we simply compared the position of the observational data with SGB isochrones bracketing the metallicity range spanned by the observations. Keeping in mind possible systematic errors in the $T_{\rm eff}$ scale (which translates also into systematic errors in [Li]), with respect to the data for the MS, it is interesting to notice that the models with diffusion together with our assumed initial [Li]$_{\rm o}$=2.50, are not in contradiction with observations.

The steep decrease of [Li] for decreasing $T_{\rm eff}$ (equivalently: for increasing luminosity) along the RGB is neither reproduced by models with diffusion, nor by standard models (see the discussion in Pilachowski et al. 1993). At temperatures lower than the endpoint of the isochrones shown in Fig. 11, [Li] would stay constant, since the convective envelope

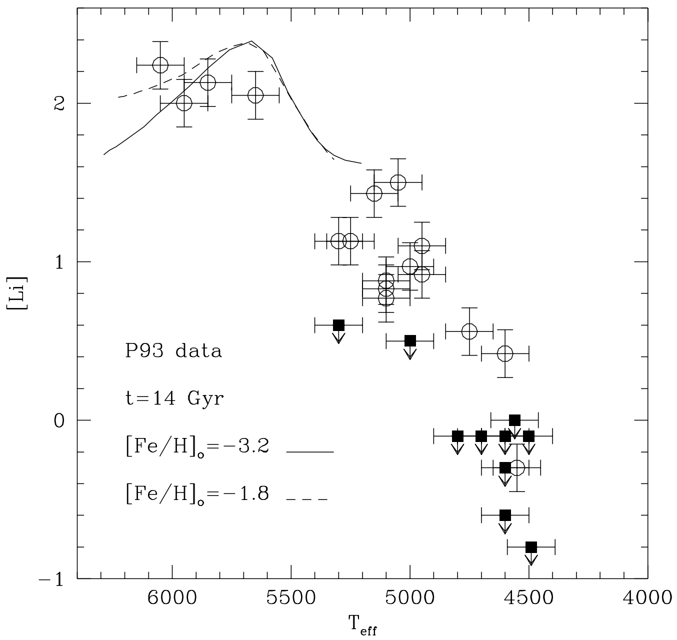

Fig. 11. Comparison in the [Li]-$T_{\rm eff}$ plane, between the field subgiant data by Pilachowski et al. (1993) ("P93") for [Fe/H]≤ -2.0, and our isochrones with $t = 14$ Gyr for two different initial metallicities. Squares correspond to upper limits.

has reached its maximum extension and starts now to recede slowly due to the outward movement of the H-burning shell. The further depletion can be explained only by invoking extra deep mixing (see, e.g., Kraft 1994; Denissenkov & Weiss 1996; Weiss et al. 2000).

3.3. Globular cluster subgiant branch stars

Figs. 12 and 13 show a comparison with Li abundances in globular cluster SGB stars. In a globular cluster, all stars have the same initial chemical composition and the same age; in case of NGC6397 we adopted an initial [Fe/H]$_{\rm o}$ equal to -1.8, following the results by Carretta & Gratton (1997) for RGB stars belonging to this cluster. This choice is justified by the fact that at the photosphere of RGB stars the metallicity is restored to the initial value due to the deepening of the convective envelope, which engulfs almost all the metals diffused towards the core during the MS phase (Fig. 4). Ages of 11 and 12 Gyr have been employed, according to the results by Salaris & Weiss (1998). It is worth noticing that in this case the constraint on the stellar ages comes from a method completely unrelated to the Li abundance determinations.

The observational data are from Pasquini & Molaro (1996) for SGB stars and Castilho et al. (2000) for RGB stars. The $T_{\rm eff}$ values by Pasquini & Molaro (1996) have been reduced by 60 K to take into account the fact that their assumed reddening was 0.01 mag larger than the one used by Castilho et al. (2000); the corresponding [Li] values consequently have been reduced according to the derivative Δ[Li]/$\Delta T_{\rm eff}$ provided in the mentioned papers.

The comparison of the few observed SGB stars with models including diffusion is satisfactory. Notice also the problem along the RGB – very similar to the case of field stars – where models (standard and diffusive ones) cannot reproduce the trend of [Li] with repect to $T_{\rm eff}$.

The M92 data displayed in Fig. 13 come from Boesgaard et al. (1998); we considered both temperature scales mentioned in the paper (C83 is the scale from Carney 1983, while K93 is from King 1993); this permits us to highlight in a quantitative way the effect of $T_{\rm eff}$ scale uncertainties in the [Li] abundances. It is evident from the figure that, with our selection of initial [Li], the C83 scale provides a better match to the models. The

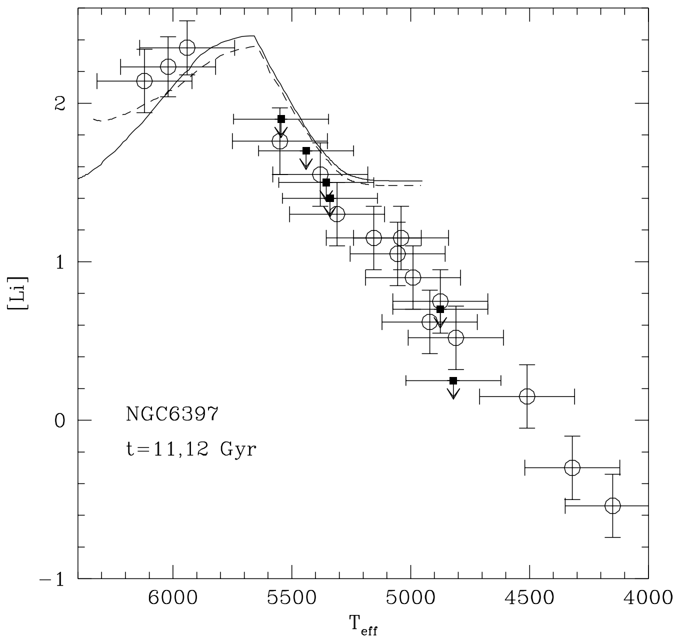

Fig. 12. Run of [Li] as a function of $T_{\rm eff}$ for SGB and base of the RGB stars in the globular cluster NGC6397. Isochrones for ages of 11 and 12 Gyr, and initial $[{\rm Fe/H}]_{\rm o}$ equal to -1.8 are plotted. Symbols are as in Fig. 11.

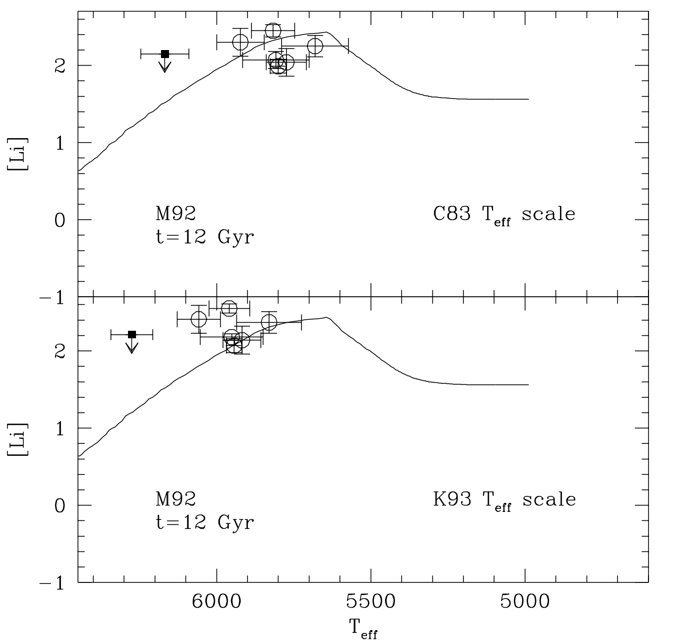

Fig. 13. As in Fig. 13 but for the globular cluster M92. The theoretical models correspond to ages of 11 and 12 Gyr and an initial $[{\rm Fe/H}]_{\rm o}$ equal to -2.3. The upper panel corresponds to the $T_{\rm eff}$ scale by C83, the lower panel to the scale by K93.

K93 scale would imply a higher initial [Li] in order to reproduce better the observations. In both cases models including diffusion are not in contradiction with observational data. The dispersion of [Li] for the sample of stars observed – about which a long analysis is presented in Boesgaard et al. (1998) – may be explained by the fact that (see Fig. 13) the stars are located around the peak of the [Li] abundance along the SGB, in a region where, according to the stellar models, a small change of $T_{\rm eff}$ (within the quoted error

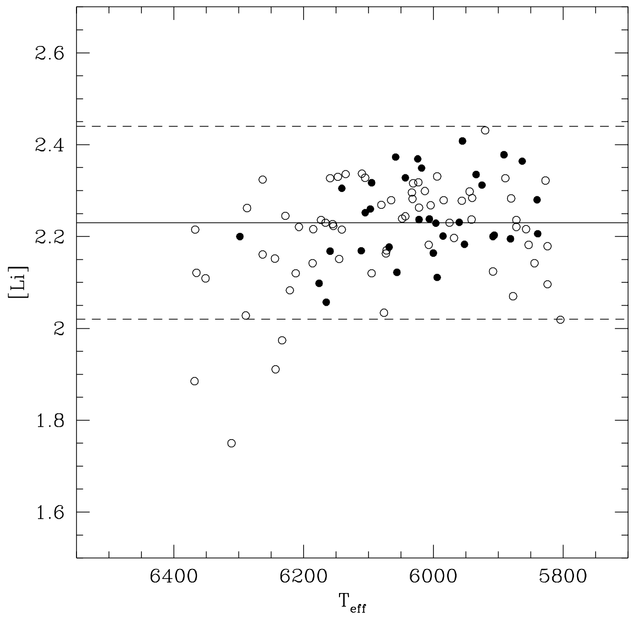

Fig. 14. Run of [Li] as a function of $T_{\rm eff}$ for stars in one of our MC simulations (see text for details); open circles are stars with [Fe/H]$\leq$ -2.0, while filled circles are stars with -2.0 <[Fe/H]< -1.5.

bars) produces a sensible change of [Li]. This peak is present only if diffusion on the main sequence has been effective (Fig. 4).

It is also interesting to notice that in both cases the point corresponding to an upper limit detection lies in a region where models with diffusion predict a lower abundance with respect to the other stars in the plot.

3.4. Field stars with -2.0 *<[Fe/H]<* -1.5

Up to now we concentrated on the low-metallicity end of the Spite-plateau, which, however extends also to higher [Fe/H]. We now consider stars with -2.0 <[Fe/H]< -1.5, in order to see if a plateau can be found also when including this metallicity range. We computed a series of models and Li-isochrones with initial iron content [Fe/H]$_{\rm o}$=-1.3 (Z = 0.002) and then performed MC simulations selecting this time a sample of $\sim$35 plateau stars with -2.0 <[Fe/H]< -1.5 (which is approximately the size of the observed sample in this metallicity range). In Fig. 14 we plot (filled circles) the result of one simulation (only plateau stars), together with the result for the stars with [Fe/H] ≤ -2.0 (open circles) from Fig. 8. The solid and dashed lines have the same meaning as in Fig. 8. Here we have assumed an age randomly distributed between 12.5 and 13 Gyr, to simulate a decrease of the average age of Pop II field stars for increasing metallicity, above [Fe/H]=-2.0. The average value of [Li] is still 2.23, as in the case of the sample including only stars with [Fe/H]≤ -2.0. The selected age does not play a decisive role. Variations of the order of $\pm$1 Gyr do not affect appreciably the overall picture.

Fig. 15 compares the Li abundances from our models with the observations by Pilachowski et al. (1993) for -2.0 <[Fe/H]< -1.5. There appears no inconsistency between theory and observations besides the fact that also in this metallicity range there is the well-known problem of an additional depletion observed in RGB stars.

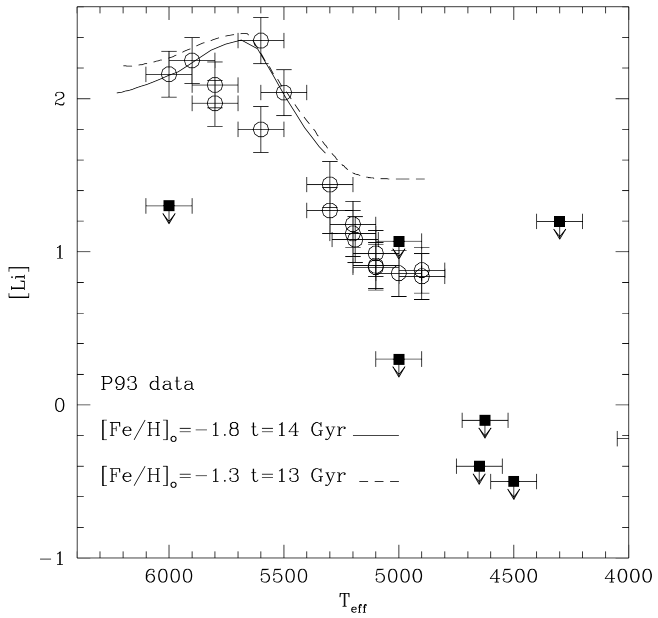

Fig. 15. Comparison in the [Li]-$T_{\rm eff}$ plane, between the SGB data by Pilachowski et al. (1993) ("P93") for $-2.0 <$[Fe/H]< -1.5, and our isochrones with two different initial metallicities and ages. Squares correspond to upper limits.

4. Discussion and conclusions

In the previous section we have compared our stellar models including uninhibited atomic diffusion with observations of [Li] in metal-poor ([Fe/H]≤ -2.0) halo field and globular clusters stars. We have shown that there is no apparent contradiction with observations, at least with the present observational data, as long as the age of field subdwarfs is of the order of 13.5 Gyr or more when [Fe/H]≤ -2.0. This is, of course, not a proof that diffusion is fully efficient in halo stars (since in general also standard isochrones can explain the observations; e.g., Vauclair & Charbonnel 1995); however, our analysis shows that it is not justified to discard models with fully efficient diffusion on the base of current measurements of [Li] in metal-poor stars.

In particular, the Li-plateau region is satisfactorily reproduced by our MC simulations, for the ages discussed before. This is at odds with conclusions from previous analyses which were based mainly on the comparison of an isochrone of a given age and a single value of [Fe/H] with the moderately small observational samples of stars with different metallicities and possibly different ages. In our MC simulations we could take into account the actual number of stars with [Li] measurements, their observed metallicity distribution and the typical observational errors. The fact that we do not find in the simulations a clear depletion of [Li] at the hotter end of the plateau is only partly due to the ages we selected for the stars with [Fe/H]< -2.0. In fact, lower ages (see Fig. 2) produce a more visible depletion at the TO, but still, even for ages of about 14 Gyr and taking into account the observational errors, when [Fe/H] ≤ -2.6, a drop at the highest end of the plateau has to be visible, provided that a sufficiently high number of stars is observed. From our simulations we derive that [Li] measurements of a sample of about 200 plateau stars (about 40-50 of them at the hottest end of the plateau) with [Fe/H]≤ -2.6 are needed in order to clearly detect this drop, keeping unchanged the observational errors (see Fig. 16).

For the more metal-rich objects of section 3.4 with [Fe/H] above -2.0 an increase of the observed sample size would not change the plateau morphology, since at these metallicities there is no abrupt drop of [Li] at the TO region, but an almost constant value of [Li] all along the plateau region.

In our simulations we have treated the age of field stars as a free parameter, requiring that it is not too far from current estimates of globular clusters ages, and that with

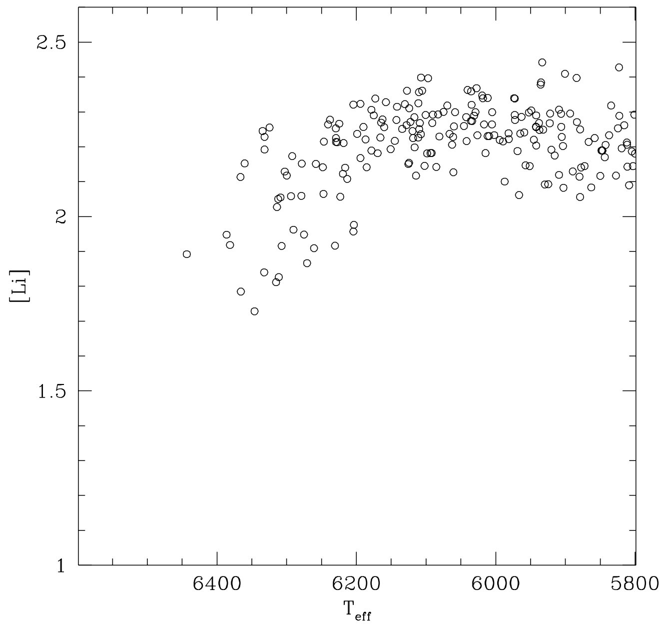

Fig. 16. Results of a MC simulation with ~200 plateau stars and [Fe/H]≤ -2.6 (see text for details). The drop in [Li] at the TO due to diffusion is now clearly apparent.

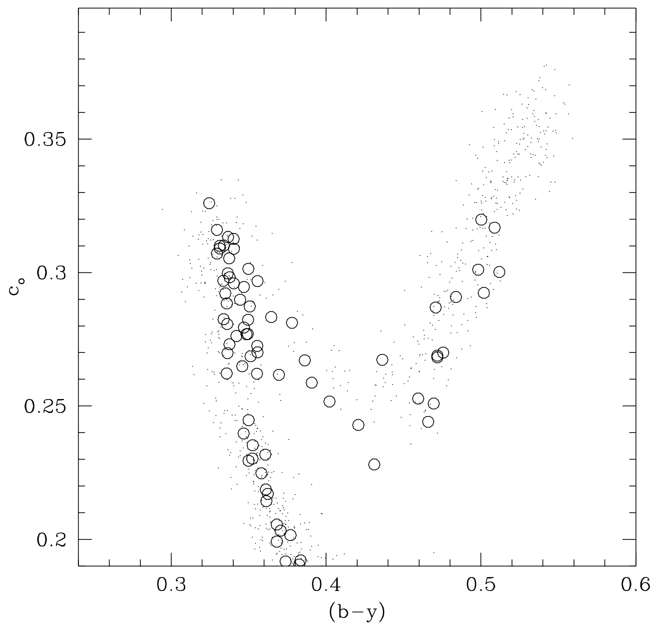

Fig. 17. c_0–(b-y) diagram for a simulated sample of field stars (open circles), and for a synthetic globular cluster with [Fe/H]=-2.3 and t = 12 Gyr (dots – see text for details).

the actual samples of observed stars the plateau is well reproduced. Is an age of 13.5–14.0 Gyr for field Population II stars of [Fe/H] ≤ -2.0 compatible with their CMD? It is hard to answer this question with confidence. Due to the uncertainties in current colour–transformations (see, e.g., Weiss & Salaris 1999) the best thing to do, in our opinion, is to determine the location of field subdwarfs in a CMD or colour–colour diagram, in relation to data for a globular cluster of known age and similar metallicity, as predicted by theory, and then check its consistency with observations.

From the observational point of view Grundahl (1999) has shown how, in Stroemgren colours, M92 stars overlap with the metal-poor field objects ([Fe/H]≤ -2.5) in the sample by Schuster et al. (1996). In Fig. 17 we show the theoretical counterpart of the comparison performed by Grundahl (1999); we used our stellar models with diffusion, coupled to the colour transformations provided by Kurucz (http://cfaku5.harvard.edu/). The open circles represent a MC realization of a sample of field stars with age between 13.5 and 14 Gyr, an actual [Fe/H]≤ -2.5, observed metallicity distribution according to Ryan & Norris (1991), 1σ observational errors by 0.010 mag in (b-y) and c_0, and 0.20 dex in [Fe/H]; this sample simulates the sample by Schuster et al. (1996). Dots are a MC realization of a sample of stars with the same initial metallicity ([Fe/H]$_o$=-2.3), an age of 12 Gyr, and with 1σ observational errors by 0.010 mag in (b-y) and c_0. This sample simulates the data of M92.

It is clear from the figure that the two samples nicely overlap, in agreement with observations (see Fig. 1b in Grundahl 1999). Even if the constraint put by this comparison is not too stringent, in the sense that a variation of the relative age between cluster and field by 1-2 Gyr would not affect this comparison appreciably, it is still a nice consistency check for the results derived from the shape of the lithium plateau.

It has been mentioned several times in the literature that ^{6}Li, which is destroyed by proton-captures at even lower temperatures than ^{7}Li ($2 \cdot 10^6$ K), would be an additional and strong indicator of ^{7}Li destruction (see, for example, Vangioni-Flam et al. 1999). What observations provide is the sum ^{7}Li+^{6}Li. Disentangling the abundance of one isotope from the other one is a very difficult task; it is based on fitting the observed profile of the Li I blend with theoretical profiles calculated from model stellar atmospheres characterized by different ^{6}Li/^{7}Li ratios (see, e.g., Hobbs et al. 1999). Until now all (very few) measured Li-isotope ratios (e.g. Nissen et al. 1999; Hobbs et al. 1999; Nissen et al. 2000) are either upper limits only or are so high ($^6\mathrm{Li}/(^7\mathrm{Li} + ^6\mathrm{Li}) \approx 0.05$) that they exceed limits from Big Bang Nucleosynthesis by orders of magnitude, such that galactic chemical evolution (Vangioni-Flam et al. 1999) has to be taken into account to explain them. From this point on, of course, all conclusions about stellar depletion of lithium isotopes are subject to the acceptance of these chemical evolution models. The quoted papers arrive at conclusions both excluding (Vangioni-Flam et al. 1999) and requiring stellar depletion (Hobbs et al. 1999). We therefore conclude that presently ^{6}Li does not provide additional conclusive information about diffusive processes in low-mass stars. We note that along the MS diffusion alone would only mildly change the isotope ratio, anyway, with an increase of the initial $^6\mathrm{Li}/(^7\mathrm{Li} + ^6\mathrm{Li})$ value by at most 40%.

In principle, useful constraints on diffusion in low-mass stars could come from spectroscopy along globular cluster CMDs, as the one shown in Fig. 12 for NGC6397. Recently, Gratton et al. (2001) have presented VLT/UVES results about element abundances in stars at the TO and at the RGB base in NGC6397 and NGC6752. The results, however, are far from being conclusive. In NGC6752 large star-to-star scatter in light element abundances is present, indicating additional stellar processes. This applies also to lithium (Gratton, private communication). In NGC6397 rather constant abundance values are found, and in particular [Fe/H] appears to be exactly the same in both groups of stars, a fact which would strongly disfavour diffusion. However, in a paper about the same cluster, Castilho et al. (2000) discussed the uncertainty in metal abundance determinations, finding an iron *decrease* by 0.2 dex when moving along the RGB, if the temperature scale of Gratton et al. (1996) is used. Also Gratton et al. (2001) find a metallicity at the TO and base of the RGB that is 0.2 dex lower than the Carretta & Gratton (1997) value. Since the depletion of iron due to diffusion that our models predict for NGC6397 is of the same order, one should remain cautious about the reality of constant [Fe/H] values determined. More work is needed to clarify this.

Ramirez et al. (2001) have very recently presented results about [Fe/H] abundances for stars from the RGB tip to the TO of the metal rich globular cluster M71 ([Fe/H]$\approx$0.70). They found that the iron abundances are approximately constant along these evolutionary phases. However, as we verified with appropriate calculations, in this metallicity range the maximum depletion at the TO, for ages of the order of 10 Gyr (Salaris & Weiss 1998) is $\sim$0.15 dex. Such a small depletion is not in contradiction with the values provided by Ramirez et al. (2001) in their Table 4.

Assuming that diffusion indeed has taken place in Spite-plateau stars, our results have significant bearings for the question concerning the cosmological baryon density. We reproduce the observed Spite-plateau [Li]-abundance when assuming a primordial value of [Li] = 2.5. According to standard Big Bang Nucleosynthesis (see, for example, the recent calculations by Vangioni-Flam et al. 2000), this corresponds to a baryon-to-photon ratio η of $5.1 \cdot 10^{-10}$ (see Fig. 4 of the quoted paper), which is in almost perfect agreement with the low deuterium value ($\mathrm{D/H} = 3 \ldots 4 \cdot 10^{-5}$) by Tytler et al. (2000) and the high ^{4}He abundance of 0.244 by Izotov & Thuan (1998). Since η is related to the baryonic density via $\eta = 273 \cdot 10^{-10} \Omega_{\mathrm{B}} h^2$ (with h being the Hubble constant in units of $100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$), this results in $\Omega_{\mathrm{B}} = 1.87 \cdot 10^{-2} h^{-2}$. Taking $h = 0.71$ (Mould et al. 2000) yields $\Omega_{\mathrm{B}} = 0.037$, almost consistent with the value inferred from the BOOMERANG and MAXIMA-1 experiments (Jaffe et al. 2000; Balbi et al. 2000).

Our derived cosmological baryon density is under the assumption of no significant galactic production of ^{7}Li. ^{6}Li measurements can in principle be used also to put useful constraints on the amount of ^{7}Li produced by galactic chemical evolution, but the available measurements of the abundance ratio of these two isotopes (see also previous discussion) do not provide yet a consistent picture. As an example, the value $^6\mathrm{Li}/(^7\mathrm{Li} + ^6\mathrm{Li}) \approx 0.05$ for the metal poor ([Fe/H]≈ -2.3) TO star HD 84937 points to a non-negligible contribution of ^{6}Li – and therefore also ^{7}Li – from cosmic ray production. However, measurements of the same quantity for HD 218502, a star with similar metallicity and evolutionary status, provide an upper limit of only 0.02 and a best fit value equal to zero (see Hobbs et al. 1999), consistent with no contribution from galactic chemical evolution. If in the future ^{6}Li measurements will consistently indicate a significant influence of galactic production of ^{7}Li (of order 0.1 dex or more), one will have to reconsider our conclusions about the cosmological baryon density.

One could in principle worry about the fact that our adopted initial [Li] abundance implies a primordial $Y \sim 0.24$, while in our models we used $Y = 0.23$. However, as we have verified with appropriate computations, the effect of using $Y = 0.24$ as the initial He abundance for our models is just an age shift. More in detail, the [Li] abundance as a function of T_{eff} along an isochrone of fixed initial $[\mathrm{Fe/H}]_{\mathrm{o}}$ and age computed with an initial $Y = 0.23$ would be equal to the abundances of an isochrone with the same initial $[\mathrm{Fe/H}]_{\mathrm{o}}$ but an age lower by 1 Gyr, if an initial $Y = 0.24$ is used. The same holds for the [Fe/H] values along an isochrone. Our conclusions about the Li-plateau are therefore not affected at all, apart from the fact that in this case the minimum age required to reproduce the observed plateau would be 12.5 Gyr.

We finally mention that our treatment of diffusion does not take into account the effect of radiative levitation. The diffusive velocities by Thoul et al. (1994), which we are using, might be overestimated by 25% on average, at least in the case of the Sun, according to Turcotte et al. (1998). It is plausible, but not certain, that a similar overestimate might happen for metal-poor stars. We neither included mass loss in the calculations, which is also known to reduce the effect of diffusion. For mass loss rates compatible with current observations the surface abundances depletion is not affected appreciably, but strong stellar wind on the MS may inhibit diffusion completely (Vauclair & Charbonnel 1995). Due to the neglect of both radiative levitation and mass loss, our models probably overestimate the depletion to some degree, even if we cannot quantify this up to now.

We can conclude that the Spite plateau, given present day observational sample sizes, can be reproduced by models including atomic diffusion and is therefore (alone) no strong argument against the presence of sedimentation in low-mass metal-poor stars. We also recall that the motivation for this work was the fact that sedimentation in the *cores* of such stars (in globular clusters) affects their evolutionary speed and thereby age determinations. What the Spite plateau represents, however, is related to diffusion from the *envelopes* of field stars. Both things have the same physical origin, but conclusions regarding the latter might not be applied straightforwardly to the former.

Acknowledgements. A.W. is grateful for the hospitality at the Institute for Advanced Study and Princeton Observatory and for a Fulbright fellowship which allowed visiting both places. Helpful discussions with J. Truran, L.M. Hobbs, R. Cayrel, C. Deliyannis, K. Jedamzik, and F. D'Antona are acknowledged.

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