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Observational signatures for depletion in the Spite plateau: solving the cosmological Li discrepancy?

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Abstract. We present Li abundances for 73 stars in the metallicity range –3.5 < [Fe/H] < –1.0 using improved IRFM temperatures (Casagrande *et al.* 2010) with precise *E(B-V)* values obtained mostly from interstellar NaI D lines, and high-quality equivalent widths ($\sigma_{EW} \sim 3\%$). At all metallicities we uncover a fine-structure in the Li abundances of Spite plateau stars, which we trace to Li depletion that depends on both metallicity and mass. Models including atomic diffusion and turbulent mixing seem to reproduce the observed Li depletion assuming a primordial Li abundance $A_{\rm Li}$ = 2.64 dex (MARCS models) or 2.72 (Kurucz overshooting models), in good agreement with current predictions ($A_{\rm Li}$ = 2.72) from standard BBN. We are currently expanding our sample to have a better coverage of different evolutionary stages at the high and low metallicity ends, in order to verify our findings.

Keywords. nucleosynthesis – cosmology: observations – stars: abundances, Population II

1. Introduction

One of the most important discoveries in the study of the chemical composition of stars was made in 1982 by M. and F. Spite, who found an essentially constant Li abundance in warm metal-poor stars (Spite & Spite 1982), a result interpreted as a relic of primordial nucleosynthesis. Due to its cosmological significance, there have been many studies devoted to Li in metal-poor field stars (e.g. Meléndez & Ramírez 2004; Boesgaard *et al.* 2005; Charbonnel & Primas 2005; Nissen *et al.* 2005; Asplund *et al.* 2006; Bonifacio *et al.* 2007; Shi *et al.* 2007; Hosford *et al.* 2009; Aoki *et al.* 2009), with observed Li abundances at the lowest [Fe/H] from as low as $A_{\rm Li}$ = 1.94 to as high as $A_{\rm Li}$ = 2.37.

Using the theory of big bang nucleosynthesis (BBN) and the baryon density obtained from WMAP data, a primordial Li abundance of $A_{\rm Li} = 2.72^{+0.05}_{-0.06}$ is predicted (Cyburt *et al.* 2008), which is a factor of 2–6 times higher than the Li abundance inferred from halo stars. There have been many theoretical studies on non-standard BBN trying to explain the cosmological Li discrepancy by exploring the frontiers of new physics (e.g. Coc *et al.* 2009; Jedamzik & Pospelov 2009; Kohri & Santoso 2009). Alternatively, the Li problem could be explained by a reduction of the original Li stellar abundance due to internal processes (i.e., by stellar depletion). In particular, stellar models including atomic diffusion and mixing can deplete a significant fraction of the initial Li content (e.g., Richard *et al.* 2005; Korn *et al.* 2006; Lind *et al.* 2009).

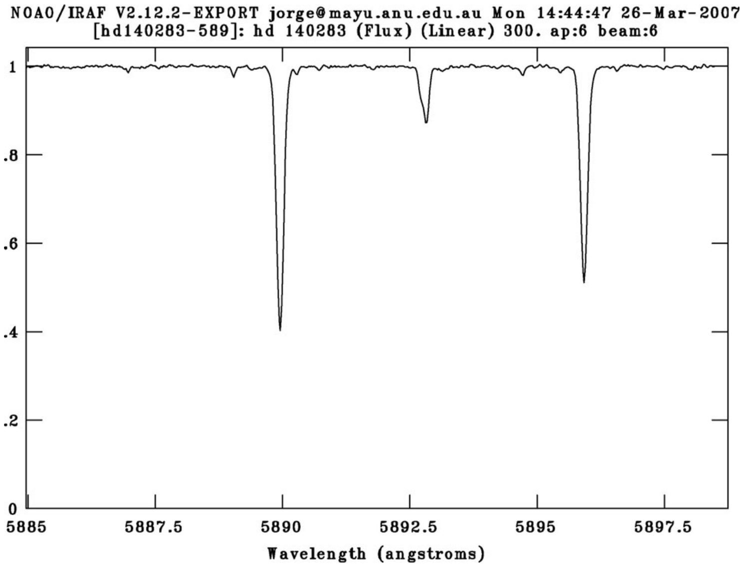

Figure 1. Keck HIRES spectrum around the NaD lines for the nearby (57 pc) metal-poor ([Fe/H] = −2.4) star HD 140283. The only stellar lines that can be easily seen are NaD (the two strongest features) and a blend of NiI/FeI around 589.3nm. The other features are mostly due to weak telluric water vapor lines. From the absence of IS NaD lines we infer E(B-V) = 0.000 for this star, although small amounts of reddening (at the level of 0.001 magnitudes) can not be excluded.

Due to the uncertainties in the Li abundances and to the limited samples available, only limited comparisons of models of Li depletion with stars in a broad range of mass and metallicities have been performed. We are performing such a study (Meléndez *et al.* 2010), achieving errors in Li abundance lower than 0.035 dex, for a large sample of metal-poor stars (–3.5 < [Fe/H] < –1.0), for the first time with precisely determined $T_{\rm eff}$ (Casagrande *et al.* 2010) and masses in a relatively broad mass range (0.6–0.9 $M_\odot$).

Our new temperature scale (Casagrande *et al.* 2010) is highly accurate, since it has been calibrated using solar twins (Meléndez *et al.* 2009; Ramírez *et al.* 2009), and it has also been tested using stellar diameters and absolute flux spectra (Casagrande *et al.* 2010). Our temperatures are also very precise because for most stars the interstellar (IS) NaI D lines were used in the determination of E(B-V) (see e.g. Ramírez *et al.* 2006), implying thus in relatively low errors in our IRFM effective temperatures. An example of a nearby halo star (HD 140283) showing no detectable IS NaD lines (E(B-V) = 0.00) is presented in Fig. 1.

2. Li depletion in Spite plateau stars

Our work shows that Li is depleted in Spite plateau stars (Fig. 2). The spread of the Spite plateau at any metallicity is much larger than the error bar, as can be clearly seen in Fig. 2. Also, there is a correlation between Li and stellar mass at any probed metallicity (Fig. 3), showing thus that Li has been depleted in Spite plateau stars at any metallicity. In Fig. 3 we confront the stellar evolution predictions of Richard *et al.* (2005) with our inferred stellar masses and Li abundances. The models include the effects of atomic diffusion, radiative acceleration and gravitational settling but moderated by a parametrized turbulent mixing. The agreement is very good when adopting a turbulent model of T6.25 and an initial $A_{\rm Li}$ = 2.64. The stellar NLTE Li abundances used above

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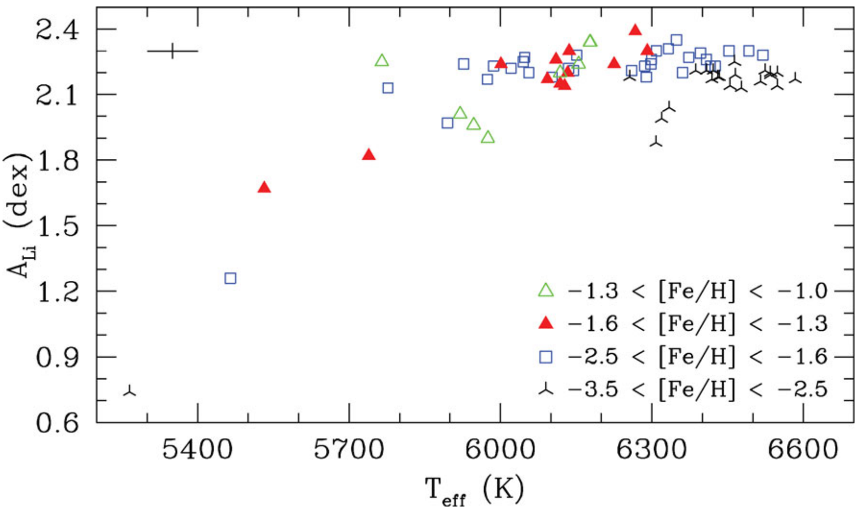

Figure 2. Li abundances vs. T_{eff} for our sample of metal-poor stars in different metallicity ranges. The spread at any given metallicity is much larger than the error bar. Figure taken from Meléndez *et al.* (2010).

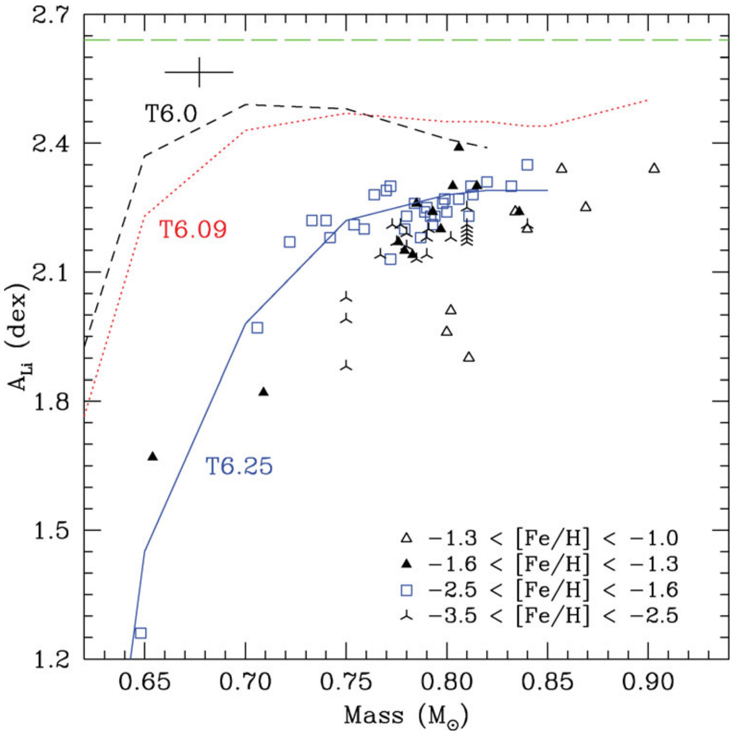

Figure 3. Li abundances as a function of stellar mass in different metallicity ranges. Models at [Fe/H] = −2.3 including diffusion and T6.0 (short dashed line), T6.09 (dotted line) and T6.25 (solid line) turbulence (Richard *et al.* 2005) are shown. The models have been rescaled to an initial $A_{\rm Li}$=2.64 (long dashed line). Figure taken from Meléndez *et al.* (2010).

were obtained with the latest MARCS models (Gustafsson *et al.* 2008), but if we use instead the Kurucz convective overshooting models, then the required initial abundance to explain our data would be $A_{\rm Li} = 2.72$.

Our results imply that the Li abundances observed in Li plateau stars have been depleted from their original values and therefore do not represent the primordial Li abundance (see also Korn *et al.* 2006 and Lind *et al.* 2009 for additional signatures of Li depletion in stars of the globular cluster NGC 6397). It appears that the observed Li abundances in metal-poor stars can be reasonably well reconciled with the predictions from standard Big Bang nucleosynthesis (e.g. Cyburt *et al.* 2008) by means of more realistic stellar evolution models that include Li depletion through diffusion and turbulent mixing (Richard *et al.* 2005). We caution however, that, although encouraging, our results should not be viewed as proof of the correctness of the Richard *et al.* models until the free parameters required for the stellar modeling are better understood from basic physical principles. In this context, new physics should not be discarded yet as a solution of the cosmological Li discrepancy, as perhaps the low Li-7 abundances in metal-poor stars might be a signature of supersymmetric particles in the early universe, which could also explain the Li-6 detections in metal-poor stars (e.g. Asplund *et al.* 2006; Asplund & Meléndez 2008).

We are expanding our sample to have a better coverage of different evolutionary stages at all metallicities. Our expanded sample (Meléndez *et al.* 2010) will allow us to verify if the Li plateau is indeed depleted at low and high metallicities.

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