New Lithium Measurements in Metal-Poor Stars

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ABSTRACT. We provide $\lambda$6708 Li I measurements in 37 metal-poor stars, most of which are poorly studied or have no previous measurements, from high-resolution and high-S/N spectroscopy obtained with the McDonald Observatory 2.1 m and 2.7 m telescopes. The typical line-strength and abundance uncertainties, confirmed by the thinness of the Spite plateau manifested by our data and by comparison with previous measurements, are $\leq$4 mÅ and $\leq$0.07–0.10 dex, respectively. Two rare moderately metal-poor solar-$T_{\text{eff}}$ dwarfs, HIP 36491 and 40613, with significantly depleted but still detectable Li are identified; future light-element determinations in the more heavily depleted HIP 40613 may provide constraints on the Li depletion mechanism acting in this star. We note two moderately metal-poor and slightly evolved stars, HIP 105888 and G265-39, that appear to be analogs of the low-Li moderately metal-poor subgiant HD 201889. Preliminary abundance analysis of G265-39 finds no abnormalities that suggest that the low Li content is associated with AGB mass transfer or deep mixing and $p$-capture. We also detect line doubling in HIP 4754, heretofore classified as SB1.

Online material: extended table

1. INTRODUCTION

The discovery of near-constant Li abundances in warm little-evolved metal-poor stars by Spite & Spite (1982) quickly spawned a vigorous cottage industry seeking to derive the cosmological baryonic density under the assumption that the Li abundances in such stars reflect the product of big bang nucleosynthesis. While WMAP observations (Dunkley et al. 2009) have obviated the use of light-element abundances to provide precision cosmological parameters, the study of metal-poor stellar Li abundances still has considerable import. Even recent studies with warmer metal-poor $T_{\text{eff}}$ scales, which result in higher Li abundances ceteris paribus, find that stellar estimates of the primordial Li abundance is a factor of 3 smaller than that suggested by WMAP-based baryonic densities (Hosford et al. 2010). The adequacy of our understanding of big bang nucleosynthesis remains unclear given this discrepancy.

A salient question in considering this discrepancy is the degree to which metal-poor stellar Li abundances are postprimordial—i.e., possibly afflicted by stellar depletion, Galactic enrichment, or both. Indeed, evidence exists that the Li abundances in the most metal-poor warm little-evolved stars are not constant, but decline with declining [Fe/H] (Sbordone et al. 2010). The adequacy of our understanding of big bang nucleosynthesis remains unclear given this discrepancy.

Determination of Li abundances in large samples of metal-poor stars of various evolutionary state, mass, and metallicity is needed to provide the context in which to understand the relation of those abundances with the primordial value. Large samples also yield rare examples of stars with anomalous light-element abundances that can provide constraints on Galactic enrichment and stellar depletion processes (King et al. 1996; Ryan & Deliyannis 1995; Boesgaard 2007; Koch et al. 2011).

Here, we make a modest contribution to expanding the size of such samples by providing Li measurements based on high-resolution spectroscopy in 37 metal-poor stars. Our stars were selected from our existing observations connected with unrelated programs and are metal-poor objects from the surveys of Carney et al. (1994) and Ryan & Norris (1991) that have kinematics hotter than evinced by thin-disk stars. The stars selected are also poorly studied with respect to light-element abundances; the majority have no previous Li measurements.

2. OBSERVATIONAL DATA

Spectra were obtained during observing runs in 1994 January and August and 2004 October with the McDonald Observatory 2.7 m Harlan J. Smith Telescope and its 2D coudé spectrograph (Tull et al. 1995), and in February and September 1994 with the McDonald Observatory 2.1 m Otto Struve Telescope and its Sandiford Cassegrain Echelle Spectrograph (McCarthey et al. 1993). The nominal spectral resolution is $R \sim 60,000$, except
for the 1994 January 2.7 m observations, for which smaller slits and pre-Textronix CCDs with smaller pixels yielded resolutions of 67,000–90,000. The per-pixel signal-to-noise ratio in the λ6708 Li i region ranges from 80–450 and is in the smaller range of 150–200 for most stars. The echelle package within IRAF was used to perform standard reductions, including bias subtraction, flat-fielding, order tracing and summation, and wavelength calibration to Th-Ar lamp spectra. Examples of the spectroscopic data can be seen in Figure 1. The stars considered here are listed in Table 1; select cross-identifications are listed in the final column.

3. ABUNDANCE ANALYSIS AND UNCERTAINTIES

3.1. General Approach

While most metal-poor star Li abundance studies are conducted using measured line strengths, our preference is to fit realistic models of the data (i.e., synthetic spectra) to the data and report the equivalent widths associated with these model fits. Synthetic spectra were calculated in LTE using an updated version of MOOG (Sneden 1973) and the λ6708 Li i region line list from King et al. (1997) modified using more recent laboratory-based atomic data from the Vienna Atomic Line Database (VALD; Kupka et al. 1999), semiempirical atomic data from Kurucz, and the molecular CN data of Mandell et al. (2004). We utilized model atmospheres interpolated within ATLAS9 grids that correspond to the stellar parameters described next.

3.2. Stellar Parameters

Inasmuch as our main goal is fitting model spectra to the data in order to determine a line strength (rather than an abundance per se) that reflects the absorption flux, accurate stellar parameters are of little consequence. In principle, the parameters could have a second-order influence due to curve of growth effects and the presence of blending (primarily CN for the λ6708 Li i feature at our resolution and given the small macroscopic line broadening associated with our stars). However, even these second-order effects are negligible; the weakness of the Li i feature and the distribution of its absorbed flux over multiple hyperfine components nulls the curve of growth effects, and the metal-poverty of our stars nulls blending effects (especially so for diatomic CN blends). While adopted stellar parameters need only be reasonably plausible for the purpose of measuring line strengths via model profile fits, it should be said that accurate stellar parameters are certainly required to determine reliable abundances from the syntheses. These parameter-dependent abundances enable us to empirically examine our claimed estimated uncertainties by examining abundance scatter, compare our results with those of others, and identify any stars with anomalous Li abundances that may provide additional insight into metal-poor stellar Li depletion or Galactic or stellar Li production.

The parameters were estimated through extant literature data, as described next. Even for the poorly studied stars, color-based $T_{\text{eff}}$ estimates on modern infrared flux method-based scales are easily determined, metallicity estimates from low-resolution spectroscopic measurements are available, and gravities can be determined using isochrones and information about evolutionary status from Hipparcos parallaxes and/or Strömgren photometry. The proof of the relative quality of the parameters (most importantly, $T_{\text{eff}}$ for the Li abundance determinations) will be found in the abundance results, which evince only small scatter ($\pm 0.07$ dex) about the visible Spite plateau at warm $T_{\text{eff}}$.

3.2.1. Effective Temperature

Effective temperatures were estimated using four primary sources: excitation balance-based results from spectroscopic fine analyses in the literature (unavailable for many of our objects), Balmer line fitting-based results in the literature, the color-based values from Carney et al. (1994), Alonso & Martinez-Roger (1996), and Casagrande et al. (2010). For a few stars, original color-based estimates were made using the new color-$T_{\text{eff}}$ calibrations of Casagrande et al. (2010); in those cases, appropriate reddening corrections were applied using the appropriate transformations from Schlegel et al. (1998) and extinctions or reddenings taken from Schuster et al. (2006), Schuster & Nissen (1989), and/or Carney et al. (1994). Mean $T_{\text{eff}}$ values, uncertainties in those means, and corresponding references are given in columns (2) and (3) of Table 1. Uncertainties based on one source are taken from the source, while those based on two sources are simply the difference between the source values.

3.2.2. Gravity

Gravities were estimated from high-resolution spectroscopic fine analyses and/or Yale-Yonsei isochrones (Demarque et al. 2004) based on our $T_{\text{eff}}$ value and/or $M_V$ inferred from Hipparcos parallax measurements or Strömgren calibrations. In the former case, log $g$ is double-valued in general, depending on whether the star is on the main-sequence or subgiant branch. Such ambiguities were cleanly resolved based on the Hipparcos and Strömgren-based $M_V$ values, with only a few exceptions: G16-20.—The spectroscopic gravity derived by Nissen & Schuster (2010) and that adopted on the basis of catalog-based distance and isochrone-based mass by Reddy & Lambert (2008) differ by a factor of 20, making it unclear whether this star is a dwarf or warm subgiant. The Strömgren photometry of Schuster et al. (1993) suggests that the star is a subgiant, given its placement in the $c_1$ versus $(b - y)$ classification diagram of
Schuster et al. (2004). However, the extensive efforts of Arnadottir, Feltzing & Lundstrom (2010) to identify Strömgren-based evolutionary discriminants suggest that distinguishing between dwarfs and subgiants at \((b - y) \leq 0.55\) (which holds for G16–20) on the basis of Strömgren photometry cannot be done reliably. We assume subgiant status.

\(G130-65\).—The \(\log g\) values inferred from \(T_{\text{eff}}\) and the Carney et al. (1994) distance (which assumes dwarf status) are in considerably better agreement than the subgiantlike \(\log g\) values inferred from the \(T_{\text{eff}}\) and the Schuster et al. (2006) Strömgren-based \(M_V\). We assume dwarf status.

\(G265-39\).—Given the negligible Hipparcos parallax, we assume subgiant status when estimating the gravity of this star from isochrones and our adopted \(T_{\text{eff}}\) value. The so-derived \(\log g\) value also yields good agreement between Fe abundances derived from Fe I and Fe II lines; moreover, abundances of Ba and Y derived from gravity-sensitive singly ionized lines are in good agreement with similarly metal-poor stars analyzed in Edvardsson et al. (1993). Details can be found in § 4.

Notes concerning the gravity estimates of a few other stars are made in Table 1. In those cases, we believe that dwarf/subgiant status is clearly resolved. The gravity estimates and associated references/notes can be found in columns (4) and (5) of Table 1. Those stars with multiple \(\log g\) estimates, from both spectroscopic fine analyses and parallaxes/isochrones, suggest that the \(\log g\) estimates are good to within 0.10–0.15 dex; regardless, the Li line strengths and abundances are insensitive to the adopted \(\log g\) values. The 15 stars with Hipparcos parallaxes \(\geq 2\) times their parallax uncertainties are plotted in the H-R diagram of Figure 2 with a selection of Yale-Yonsei isochrones (Demarque et al. 2004) for context.

3.2.3. Metallicity and Microturbulence

Metallicity estimates from the literature and references therein are given in columns (6) and (7) of Table 1. Mean uncertainties are determined as they were for the \(T_{\text{eff}}\) values. For metallicities coming from the Carney et al. (1994) estimates alone, the uncertainties are internal values based on their measurements from

![Sample 6708 Li I region data (solid points) and syntheses (lines) with input Li abundances stepped by 0.2 dex.](image-url)
| Name        | \(T_{\text{eff}}\) K | \log g | \[\text{Fe/H}\] | \(\xi\) \(\text{km/s}\) | \(A(\text{Li})\) \(\text{LTE}\) mÅ | \(A(\text{Li})\) \(\text{NLTE}\) Notes |
|-------------|-----------------|------|-------------|----------------|-----------------|--------------------------------|
| G158-30     | 5546 ± 75       | 1    | 4.50        | 1              | 1.79 ± 0.09     | 23.4 1.84 G31-26               |
| G130-65     | 6121 ± 86       | 3,4  | 4.50        | 5              | 2.30 ± 0.12     | 28.1 2.28 7                   |
| HIP4754     | 5534 ± 100      | 8    | 3.50        | 1.4            | 2.20 ± 0.06     | 36.5 2.21                      |
| G2-38       | 5950 ± 50       | 11   | 4.57        | 1.3            | 2.26 ± 0.08     | 48.8 2.36 G71-55               |
| G172-58     | 6186 ± 57       | 3,16 | 4.38        | 1.3            | 2.26 ± 0.08     | 30.0 2.25 G4-36, G76-25       |
| G133-45     | 5767 ± 35       | 3,16 | 4.57        | 5              | 1.50 ± 0.03     | 1.40 1.20 20                   |
| G159-33     | 5734 ± 100      | 8    | 4.63        | 5              | 1.54 ± 0.10     | 1.40 1.20 20                   |
| HIP12710    | 6000 ± 51       | 11,17,18,19 | 4.26      | 1.83 ± 0.13    | 11,17,18,19 1.40 11,18,19 2.26 ± 0.08 | 30.0 2.25 20 G4-36, G76-25   |

REFERENCES.—(1) Stephens & Boesgaard 2002; (2) \(A(\text{Li}) = 1.59\) and \(EW(\text{Li}) = 16.5 ± 1.0\) Boesgaard et al. 2005; (3) Carney et al. 1994; (4) Casagrande et al. 2010; (5) Estimated from 12 Gyr \(\alpha/\text{Fe} = +0.3\) Yale-Yonsei isochrones (Demarque et al. 2004) with Lejeune et al. (1998) color transformations using the \(T_{\text{eff}}\) and assuming evolutionary status of Carney et al. (1994) and/or \(M_V\) value of Schuster et al. (2006) and/or the Hipparcos-based parallax; (6) Adopted here; (7) The Yale-Yonsei dwarflike log \(g\) values inferred from \(T_{\text{eff}}\) and Schuster et al. (2006) \(M_V\) values. We thus assume dwarf evolutionary status and adopt the Carney et al. (1994)-based values; (8) Reddy & Lambert 2008; (9) Estimated from 12 Gyr \(\alpha/\text{Fe} = +0.3\) Yale-Yonsei isochrones (Demarque et al. 2004) with Lejeune et al. (1998) color transformations using the \(T_{\text{eff}}\) and assuming subgiant/dwarf status inferred by Reddy & Lambert (2008); (10) SB 1 with \(P = 347\) days and \(e = 0.38\) according to Latham et al. (2002)—the double-lined nature of the star is detected in our spectrum; (11) Axer et al. 1994; (12) Binary with 25" separation and 5.5 photographic magnitude brightness difference (Allen et al. 2000); (13) Zhang & Zhao 2005; (14) The log \(g\) value of Reddy & Lambert (2008) is 0.5 dex larger than that implied for their spectroscopic \(T_{\text{eff}}\) by the Yale-Yonsei isochrones. The log \(g\) value is determined from our \(T_{\text{eff}}\) value assuming dwarf status implied by the results of Reddy & Lambert (2008) and Zhang & Zhao (2005); (15) Zhang & Zhao 2003 find \(EW(\text{Li}) = 37.4\) mÅ and \(A(\text{Li}) = 2.20\); (16) Alonso & Martinez-Roger 1996; (17) Cenarro et al. 2007; (18) Ivanov et al. 2003; (19) James 2000; (20) Ivanov et al. (2003) find \(EW(\text{Li}) = 32.7\) mÅ and \(A(\text{Li}) = 2.35\). Table is published in its entirety in the electronic edition of the PASP. A portion is shown here for guidance regarding its form and content.
multiple spectra. For stars with measurements from multiple independent sources, comparison of metallicity estimates suggests 0.15–0.2 dex as a more realistic mean uncertainty for the Carney et al. (1994) values alone. Microturbulence has negligible influence on the derived abundances and inferred line strengths. In the interest of full disclosure, columns (8) and (9) list the values we adopted and their origin.

3.3. Results and Uncertainties

Our object spectra are narrow-lined, showing no discernible signatures of rotation-dominated profiles. The synthetic spectra were smoothed to account for instrumental and thermal (and any small rotational) broadening by convolution with a Gaussian. The FWHM used in the smoothing was empirically determined for each star by direct measurement of weak metal lines throughout the spectra, fits to the $\lambda$6717 Ca i feature, and fits to the metal lines in the $\lambda$6104 Li i region using the line list of King et al. (2010). Examples of the synthetic fits to the spectra can be seen in Figure 1. The resulting LTE Li abundances are listed in column (10) of Table 1. The equivalent widths corresponding to the best-fit synthetic profiles, as determined from traditional residual minimization compared with the observed data over the line profile, are given in column (11) of Table 1. NLTE abundance corrections (which do not impact the line-strength measurements) were taken from Carlsson et al. (1994) and applied to the LTE abundances; the resulting NLTE abundances are listed in column (12) of Table 1.

Uncertainties in the LTE Li abundances are dominated by uncertainties in the smoothing, continuum placement, fitting, and $T_{\text{eff}}$ estimates. Uncertainties in metallicity (including the direct effect of blending), gravities, and microturbulence are negligible for the $\lambda$6708 Li I line in our stars. The effects of uncertainties in our measurements of smoothing, our choice of continuum normalization, and our $T_{\text{eff}}$ estimate (given in col. [2] of Table 1) on the derived abundances were measured by refitting syntheses that were accordingly adjusted; the abundance uncertainties are attached to the LTE abundances in Table 1. Sources of uncertainty in the line strength are those listed previously, excluding those for $T_{\text{eff}}$. These amount to a 10–15% uncertainty in the reported line strengths.

Notes are made concerning two of the objects in our sample: HIP4754.—Latham et al. (2002) classify HIP 4754 as a single-lined spectroscopic binary with a 347 day period. In our spectrum, the lines consistently evince a very weak blue asymmetry that can be seen in the $\lambda$6708 Li I feature in Figure 1. This asymmetry is confirmed in Fourier space; the cross-correlation function formed from HIP 4754 and other warm stars in our sample (utilized as templates) shows a weak but distinct blue hump. Fitting the cross-correlation functions with a two-component Gaussian indicates that the radial velocity separation in our spectrum is $\sim$5 km s$^{-1}$.

G130-65.—The red wing of the Li I feature appears to exhibit an absorption asymmetry not seen in other lines (see Fig. 1). Our fit to the profile ignores this asymmetry. Additional spectroscopy would be desirable to confirm the presence or absence of a real asymmetry and any association with $^6$Li. We note that the asymmetry in the profile of HIP 36491 seen in Figure 1 is simply the $^7$Li hyperfine structure, which is manifest for this object due to the higher spectral resolution used when observing this star.
4. DISCUSSION

The main product provided here is the line strengths contained in column (11) of Table 1, which can be utilized in future homogenized meta-analyses of Li in metal-poor stars. A few remarks concerning the results can be made with the help of Figure 3, which plots the derived abundances versus $T_{\text{eff}}$. Metal-poor ([Fe/H] $\leq -1.29$) dwarfs or mildly evolved subgiants are shown as solid squares; more metal-rich ($-0.92 \leq$ [Fe/H] $\leq -0.44$) dwarfs or little-evolved subgiants are shown as open squares. Cooler, more highly evolved subgiants and giants ($T_{\text{eff}} \leq 5576$ K, log $g \leq 3.77$) are shown as open circles.

4.1. The Spite Plateau and Quality Estimates

The metal-poor dwarfs evince the well-known pattern of near-constant Li abundance for $T_{\text{eff}} \geq 5700$ K [referred to as the “Spite plateau” after Spite & Spite (1982)], declining Li abundance at cooler $T_{\text{eff}}$. The decline is due to standard stellar model Li burning during the pre–main-sequence and main-sequence phases, with the proportion of each being mass-dependent (Deliyannis et al. 1990), as well as the probable effects of rotationally induced mixing (Ryan & Deliyannis 1995). The scatter in Li on the metal-poor Spite plateau provides information about the quality of our results. We confine our attention to the metal-poor dwarfs with $T_{\text{eff}} \geq 5692$ K in order to avoid the effects of the most significant depletion. We fit these data with a second-order polynomial that is shown as the dashed line in Figure 1. The data exhibit a scatter of only 0.070 dex around this fit. The larger expected value of 0.099 dex, based on the uncertainties in Table 1, suggests that we may have overestimated the latter. Inasmuch as we believe the $T_{\text{eff}}$ and fitting uncertainties have been realistically estimated, this indicates that the subjectively assessed uncertainties in continuum normalization and smoothing are overestimated. The uncertainties in $T_{\text{eff}}$ in Table 1 lead to an estimate of an expected abundance scatter of 0.062 dex. Subtracting this in quadrature from the observed scatter implies that the line strengths’ uncertainties (which are controlled by uncertainties in fitting, continuum normalization, and smoothing) are $\lesssim 8\%$—translating to an equivalent width uncertainty of $\lesssim 2 - 4$ mÅ.

An alternative estimate of the line-strength uncertainties is provided by comparison of our measurements with the 11 previous measurements in the notes to Table 1. The standard deviation of the differences between our line-strength differences and those of others is $\pm 5.4$ mÅ (the average difference, in the sense of our measures minus others’, is $-2.6$ mÅ). Assuming equivalent uncertainties in our measurements and others’ implies a typical uncertainty in our measurements of $\pm 3.8$ mÅ—in good accord with the Spite plateau-based estimate.

Our mean Spite plateau abundance of $\log N_{\text{Li}} \sim 2.3$ agrees with numerous other measures of similarly warm and metal-poor stars. We do not address the pregnant issue here of the inconsistency of such a primordial Li abundance inferred from stellar measurements with that implied by WMAP observations for two reasons. First, the absolute $T_{\text{eff}}$ scale of metal-poor stars remains uncertain, perhaps by as much as 100–200 K (King 1993; Casagrande et al. 2010; Hosford et al. 2010), especially for stars with [Fe/H] $\leq -2$; this scale has significant implications for the primordial Li abundance derived from metal-poor stars (King 1994; Melendez & Ramirez 2004). Second, the Li abundance in the warmest little-evolved halo stars may decline with decreasing metallicity at ultralow metallicities—behavior predicted by Ryan et al. (1999), observed by Sbordone et al. (2010), but disputed by Melendez et al. (2010). Whether the Spite plateau is in fact a plateau at very low [Fe/H] remains uncertain. However, we simply note that the slope of our Spite plateau stars’ NLTE Li abundances with [Fe/H], $0.14 \pm 0.05$ dex dex$^{-1}$, is in good agreement with the value ($0.15 \pm 0.05$) derived by Hosford et al. (2009) for main-sequence stars in the metallicity range of $-3.3 \leq$ [Fe/H] $\leq -2.3$ using temperatures derived from Fe excitation under the LTE assumption, and with the value ($0.14 \pm 0.12$) derived by Hosford et al. (2010) using temperatures derived from Fe excitation in a NLTE framework ignoring H collisions.

4.2. The Warm Moderately Metal-Poor Dwarfs

The four more moderately metal-poor ($-0.92 \leq$ [Fe/H] $\leq -0.44$) dwarfs evince a real factor of $\sim 7$ scatter in their Li abundance. From a theoretical perspective, such a spread can naturally be accommodated by the inclusion of rotationally induced mixing (with or without an age spread) in stellar models. Figures 4 and 5 of Pinsonneault et al. (1992) show that such models produce a wider dispersion in pre–main-sequence and main-sequence depletion compared with more metal-poor models. From an observational context, the situation is more complex and interesting. Nearly all field dwarfs with near-solar $T_{\text{eff}}$ values in the preceding metallicity range have Li abundances of $\sim 2.1$ with modest scatter ($\sim 0.2$ dex), as seen in Figure 2 of Lambert et al. (1991). Stars with significantly lower abundances (like HIP 36491 and 40613 in our sample) appear to be very rare, as seen in Figure 2 of Lambert et al. (1991).

What is interesting about our measurements of HIP 36491 and 40613 is that they reveal Li to be more heavily depleted in these stars, but still detectable. As described in detail in § 5.1 of Stephens et al. (1997), observations of Be in such stars can place constraints on numerous candidate mechanisms responsible for the Li depletion in these objects. The Be abundance derived by Smiljanic et al. (2009) places HIP 36491 just above the mean Galactic Be-Fe trend at our metallicity in both their Figure 10, as well as in Figure 2 of the independent study of Boesgaard et al. (2010). Any Be depletion in this star is apparently limited to $\lesssim 0.1$ dex if one compares the abundance to the upper envelope of the Smiljanic et al. (2009) and Boesgaard et al. (2010) Be-Fe data. The inequality of inferred Li and Be depletion, $\sim 0.4$ dex versus $\sim 0$ dex, would seem to exclude diffusion as a causal mechanism. The relative depletions are qualitatively consistent with mass loss, gravity waves,
meridional circulation, and rotationally induced mixing. Determination of the Be abundance in the more highly Li-depleted HIP 40613 would be of interest in perhaps providing stronger constraints on these remaining depletion mechanisms.

4.3. The Evolved Stars

The Li abundances of the five subgiants and giants with \( T_{\text{eff}} \leq 5600 \) K are lower than the Spite plateau values and consistent with the values expected from nondiffusive dilution (e.g., Fig. 8 of Pilachowski et al. 1993) that occurs when the stellar surface convection zone dips into deeper hotter Li-depleted regions. The two more metal-rich ([Fe/H] \( \sim -0.7 \)) subgiants with \( T_{\text{eff}} \geq 5700 \) K, HIP 105888 and G265-39, show Li abundances significantly lower than the trend formed by the other subgiants and the aforementioned dilution models. These two stars are reminiscent of HD 201889, a subgiant with similar \( T_{\text{eff}} \) and [Fe/H] that also demonstrates a rare anomalously low Li abundance compared with other warm subgiants at this \( T_{\text{eff}} \) in Figure 7 of Pilachowski et al. (1993).

A possible explanation for the low Li abundances in HIP 105888 and G265-39 is an environmental origin—perhaps these stars were contaminated with the Li-depleted products of a former asymptotic giant branch (AGB) companion or have undergone unexpected \( p \)-capture processing and deep mixing that have destroyed Li and brought this Li-depleted material to the surface. The first possibility might lead to \( s \)-process enhancements, while the second possibility might also be accompanied by Ne \( \rightarrow \) Na and O \( \rightarrow \) N cycling. We have conducted a preliminary search for these signatures in G265-39, but failed to find them.

We measured the line strengths of a few Fe I, Fe II, O I, Na I, Zr II, Y II, and Ba II lines in G265-39 and a daytime sky (solar proxy) spectrum acquired with the McDonald 2.7 m telescope. The lines, line strengths, and resulting absolute logarithmic number abundances derived from the line strengths using MOOG are listed in Table 2. Atomic data are taken from Edvardsson et al. (1993), King et al. (1998), and Schuler et al. (2006). The mean Fe abundance from the five lines is \([\text{Fe/H}] = -0.73\), which is in outstanding agreement with the value adopted in Table 1 \((-0.71)\) within the mean measurement uncertainty (\( \pm 0.05 \) dex) alone. Because of the particular sensitivities of the individual lines, the complementary ratios [O I, Zr II, Y II, Ba II/Fe II] and [Na I/Fe I] are essentially free of uncertainties in the stellar parameters (at least compared with measurement uncertainties). The ratios\(^5\) in G265-39 are similar to those exhibited by stars of the same [Fe/H] in Figure 15 of Edvardsson et al. (1993). In particular, O does not appear underabundant, nor does Na appear overabundant, as might occur if our star was contaminated by material having undergone O \( \rightarrow \) N and Ne \( \rightarrow \) Na cycling and deep mixing (either in situ or from a former AGB companion), nor is there any indication of an \( n \)-capture element overabundance that might accompany contamination by material from a former AGB companion.

More extensive surveys of metal-poor stars are needed to identify larger numbers of objects with anomalous Li abundances. Subsequent or accompanying determination of abundances of a suite of elements in these stars is needed to understand what information they provide about the effects of stellar physics and Galactic chemical evolution on Li abundances. Coupled with a solid theoretical framework, such data will be required to establish the existence or absence of a decline of stellar Li at extremely low metallicities and to place the current apparent mismatch of these Li abundances with WMAP results into an appropriate cosmological context.

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\(^5\)Our permitted O I-based ratio was placed on \( \lambda 6300 \) forbidden O I-based scale of Edvardsson et al. (1993) using their eq. (11).
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