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DISCOVERY OF THE MOST LITHIUM-RICH DWARF: DIFFUSION IN ACTION[1]

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ABSTRACT

Using WIYN/Hydra observations, we report the first discovery of a super–Li-rich dwarf, the star J37 of the Hyades-aged cluster NGC 6633. This star's gargantuan surface Li abundance of $A(\mathrm{Li}) = 4.29 \pm 0.07$ [$A(\mathrm{X}) \equiv 12 + \log(N_{\mathrm{X}}/N_{\mathrm{H}})$] is a factor of 10 larger than the Li abundances observed in meteorites and in minimally depleted young open cluster stars. J37 may be the smoking gun for the action of diffusion, models of which predict the existence of striking Li overabundances due to radiative acceleration (the "Li peak") in the extremely narrow T_{eff} range of 6900–7100 K. The low-C, high-Fe, and higher Ni abundances in J37 also support the diffusion model, although other elemental abundances do not agree as well with the model predictions. We have discounted other Li-enrichment scenarios (spots, asymptotic giant branch contamination, planetesimal accretion). While slow mixing seems to be the universally dominant Li-depleting mechanism during the main-sequence evolution of F, G, and K dwarfs, the F dwarf J37 illustrates that Li diffusion can occur in solar-type stars under the right circumstances.

Subject headings: diffusion — stars: abundances — stars: atmospheres — stars: chemically peculiar — stars: evolution — stars: rotation

1. INTRODUCTION

The light-element tracers, lithium, beryllium, and boron (Li, Be, and B), reveal, and improve understanding of, the physical processes occurring in the stellar interior. Star clusters provide ideal laboratories for investigating these processes because they contain stars of common and knowable age and initial composition. For example, Hyades and Pleiades data demonstrate the action of some mechanism(s) that conspicuously deplete(s) Li in F stars during the main sequence (the "Li gap"; Boesgaard & Tripicco 1986; Boesgaard, Budge, & Ramsey 1988; Pilachowski, Booth, & Hobbs 1987), in stark contrast to the strictures of standard theory. Initially, diffusion was proposed as the responsible mechanism (Michaud 1986); however, subsequent evidence (the Li-Be depletion correlation [Deliyannis et al. 1998], higher Li in short-period binaries [Thorburn et al. 1993; Deliyannis et al. 1994; Ryan & Deliyannis 1995], moderately rapid Li depletion in M67 subgiants [Sills & Deliyannis 2000], the existence of a moderate-Be gap [Boesgaard & King 2002] but the absence of a B gap [Boesgaard et al. 1998], and the extensive width of the Li gap [see Fig. 2 below][4] and the timing of its formation [Balachandran 1995; A. Steinhauer & C. P. Deliyannis 2002a, 2002b, 2002c, in preparation]) suggests that slow mixing is instead the predominant mechanism. Furthermore, slow mixing induced by rotation and/or waves is also believed to cause the main-sequence Li depletion observed in cooler G and K dwarfs (Deliyannis 2000; Jeffries 2000; Pasquini 2000). Nonetheless, diffusion can occur when internal mixing is insufficient to inhibit it, such as in slowly rotating chemically peculiar B and A stars with reasonably stable radiative layers. The Sun, which has presumably been rotating slowly for gigayears, is the only solar-type star for which some evidence exists that diffusion has occurred; helioseismology betrays the signature of helium diffusion (e.g., Guzik & Cox 1991; Bahcall, Pinsonneault, & Wasserburg 1995). If similar diffusion has occurred in halo stars, then globular cluster age estimates must be reduced by up to 25% (Deliyannis, Demarque & Kawaler 1990; Proffitt & Vandenberg 1991). Even in the Li gap, diffusion may still play a role. For all these reasons, it remains important to decipher the role(s) of diffusion in solar-type stars. The degeneracy of Li-depletion mechanisms complicates the evaluation of their relative contributions; however, diffusion is the only mechanism that also predicts *overabundances* of Li. The diffusion models of RM93 predict a striking overabundance of Li in the very narrow T_{eff} range of 6900–7100 K—a very sharp "Li peak," just hotter than the Li gap (§ 3). *We report discovery of a* Li *peak star in the Hyades-aged* (∼700 Myr) *open cluster NGC 6633* (*d* ∼ 320 pc). This Li peak star, star J37 of Jeffries (1997),[5] was first noted by Jeffries as having a strong Li line and a high [Fe/H] relative to NGC 6633. However, Jeffries considered it possible that a neighboring foreground star (H8 = S121 = V49) had been observed instead. We (and Jeffries et al. 2002, hereafter J02) find that the star identified *by coordinates* as J37 in Table 1 of Jeffries (1997) has the same Li line strength, radial velocity, and $v \sin i$ as reported by Jeffries (1997). Moreover, J37 is a proper-motion member, a radial velocity member, and a photometric member of NGC 6633.

2. DATA AND ANALYSIS

NGC 6633 was observed with the WIYN[6] 3.5 m Hydra multi-object spectrometer on 2002 August 9–11 UT, using the blue cable, X19 filter, 316 line mm^{-1} echelle grating, bench camera, and T2KC 2048^2 CCD. The spectra cover the region 6450–6850 Å containing the Li I doublet at 6707.8 Å, with $R = 15{,}000 = 2.3$ pixels. Eight exposures of a single Hydra configuration containing 50 stars and 22

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[4] Pleiades Li data were taken from Pilachowski et al. (1987), Boesgaard et al. (1988), and Soderblom et al. (1993). Hyades Li data were taken from Boesgaard & Tripicco (1986), Boesgaard & Budge (1988), Burkhart & Coupry (1989), and Thorburn et al (1993). Note that interpolation for 700 Myr was made from the 600 and 800 Myr models of Richer & Michaud (1993, hereafter RM93); extrapolation for $A(\mathrm{Li}) > 4$ was also made.

[5] Star 9 of Hiltner, Iriarte, & Johnson (1958, hereafter HIJ58), 126 of Sanders (1973), and 53 of Vasilevskis, Klemola, & Preston (1958).

[6] The WIYN Observatory is a joint facility of the University of Wisconsin–Madison, Indiana University, Yale University, and the National Optical Astronomy Observatories.

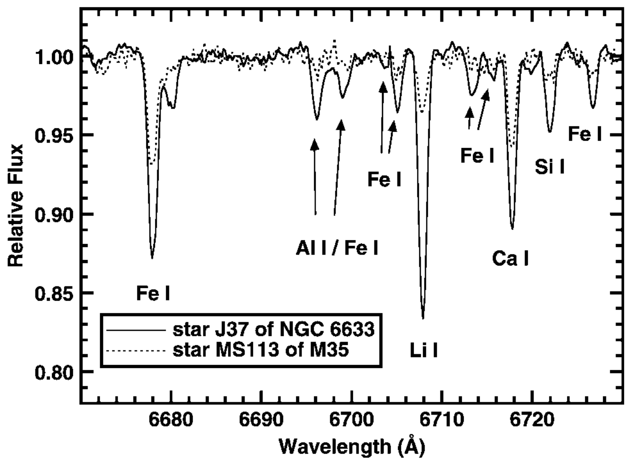

FIG. 1.—Spectra near the Li I 6708 Å region for the star J37 from NGC 6633 (*solid line*) and the normal comparison star MS113 from M35 (*dotted line*; A. Steinhauer & C. P. Deliyannis 2002a, in preparation), near $T_{\rm eff}$ = 7100 K. The large Li line strength of W(Li) = 191 mÅ for J37 contrasts sharply with that of W(Li) = 44 mÅ for the more "normal" (see text) dwarf star MS113. The resulting Li abundance for J37, $A({\rm Li})_{\rm J37} = 4.29 \pm 0.07$, is a factor of 10 larger than (1) that for MS113, $A({\rm Li})_{\rm MS113} = 3.26 \pm 0.07$, and (2) that for the meteorites, $A({\rm Li})_{\rm meteoritic} = 3.30 \pm 0.04$.

skies were taken (August 9: 25 and 6 m; August 10: 40 and 30 m; August 11: 4 × 60 m). Here we report the results for star J37. On each UT date, about 10–15 biases, 13 dome flats, and 1–3 daytime sky spectra were taken. Th-Ar arcs surrounded the NGC 6633 frames no less than every 2 hr. The fiber throughput correction was calculated using fits to the daytime sky. The empirically determined signal-to-noise ratio (S/N) per pixel near Li for each exposure is 90, 70, 240, 140, 155, 160, 260, and 235, respectively. Figure 1 shows the final co-added spectrum that has S/N = 425 pixel^{-1}. J37's Li line is exceedingly strong since it is stronger than Ca I λ6717.7; Li is weaker than Ca in the normal comparison star 113 of McNamara & Sekiguchi (1986; "MS113") from M35 that has the same $T_{\rm eff}$ (7125 ± 75 K) as J37. MS113 has a "normal" A(Li) = 3.26 ± 0.07 and also has normal abundance ratios of other elements (§ 3.1). By comparison, J37's W(Li) = 191 mÅ is huge. Equivalent widths are summarized in Table 1.

Stellar parameters were evaluated as follows. Jeffries (1997) measured a CCD-based (V, $B-V$) of (10.91, 0.49), in excellent agreement with HIJ58's photoelectric values (10.92, 0.47) and WOCS's CCD-based preliminary values (10.88, 0.48). Using (1) the average $B-V = 0.48$, (2) the average $E(B-V) = 0.16$ between HIJ58's value of 0.17 and Jeffries's (1997) value of 0.15, (3) $[{\rm Fe/H}]_{6633} \sim 0.0$ (Jeffries 1997),[7] (4) $[{\rm Fe/H}]_{\rm Hyades} = +0.17$ (C. P. Deliyannis et al. 2002a, in preparation), and (5) $T_{\rm eff} = 8575 - 5222.27(B-V)_0 + 1380.92(B-V)_0^2 + 701.7(B-V)_0([{\rm Fe/H}]^* - [{\rm Fe/H}]_{\rm Hyades})$ (Deliyannis et al. 1994; C. P. Deliyannis et al. 2002b, in preparation) resulted in an initial estimate of $T_{\rm eff}$ = 7013 K for this star; log g was then determined using Y2 isochrones (Yi et al. 2001). With this $T_{\rm eff}$ and log g, ξ was determined with the help of Edvardsson et al. (1993). [Fe/H] was calculated for each line relative to the Sun, using the isolated weak Fe I lines listed in Table 1, the corresponding solar lines from our daytime spectra, Kurucz 1992 model atmospheres with convection (but no overshoot; R. Kurucz 1992, private communication), and MOOG (Sneden 1973). The stellar [Fe/H] was calculated by averaging n(Fe)/n(H) (not the logs). For improved self-consistency, this calculated stellar [Fe/H] was now taken back to step 5 above, and a revised $T_{\rm eff}$ was derived, then a revised g and ξ, and then [Fe/H]. This procedure was iterated until Δ[Fe/H] < 0.01. The final values are $T_{\rm eff} = 7086 \pm 85$ K, log $g = 4.11 \pm 0.05$ (F1 V), $\xi = 2.62 \pm 0.12$ km s^{-1}, and [Fe/H] = +0.36 ± 0.07; $\sigma(T_{\rm eff})$ corresponds to an assumed $\sigma[(B-V)_0] = 0.02$, which includes errors in the photometry and in $E(B-V)$. The errors in log g and ξ are the corresponding shifts. The error in [Fe/H] includes a component, $\sigma_{[{\rm Fe/H}],\mu}$ = 0.05 dex, which is the σ_μ for the (linear) n(Fe)/n(H) ratios, added in quadrature to a component of 0.05 dex that results from uncertainties in the parameters. Regarding the latter, [Fe/H] depends most sensitively on $T_{\rm eff}$ and depends negligibly on the other parameters; $\Delta T_{\rm eff}$ = 85 K implies Δ[Fe/H] = 0.05 dex. In addition, there may be systematic errors in the $T_{\rm eff}$ scale of at least 100 K. A further check on J37's $T_{\rm eff}$ was made using the Hα wings. Synthesis using Kurucz (1993) and Gardiner, Kupka, & Smalley (1999) models, with $\alpha = 1.25$ (no overshoot), [Fe/H] = +0.3, log g = 4.3, ξ = 2 km s^{-1}, and v = 30 km s^{-1}, yields $T_{\rm eff} = 7100 \pm 100$ K, in superb agreement with 7086 ± 85 K. The synthesis is insensitive to reasonable changes in g, ξ, v, and the instrumental FWHM. But using [Fe/H] = 0 raises $T_{\rm eff}$ to 7250 K, in contrast to the photometrically derived 7013 K; this also supports our supersolar [Fe/H] for J37. All other abundances in Table 1 have been calculated using the final stellar parameters. When possible, our daytime spectrum was used as a solar reference; otherwise, W(X) was measured from the integrated-flux solar atlas of Kurucz, Furenlid, & Brault (1984). The Fe and Ni abundances are the most robust since they come from multiple lines yielding excellent agreement. The single-lined elements are less reliable. The rms of the individual single-lined [Fe/H] and [Ni/H] abundances of 0.11 and 0.07 dex, respectively, suggests that 0.1 dex is a reasonable estimate for the 1 σ error of a single-lined abundance, but we caution that the error could be larger.[8] Although the C I 6587.61 Å line is blended, it is easy to distinguish between [C/H] = −0.51 in J37 (depleted), +0.06 in MS113 (normal), and +0.4 (accretion;

TABLE 1
EQUIVALENT WIDTHS (mÅ) AND ABUNDANCES

Line	J37		MS113	
	W(X)	[X/H]	W(X)	[X/H]
Li I λ6707.8	191	4.29 ± 0.07[a]	44	3.26 ± 0.07[a]
Fe I λ6609.12	44	+0.26	…	…
Fe I λ6726.67	38	+0.35	15	−0.17
Fe I λ6733.15	27	+0.55	…	…
Fe I λ6750.16	48	+0.39	21	−0.08
Fe I λ6752.72	28	+0.34	…	…
Fe I λ6806.86	13	+0.20	…	…
Fe I λ6810.27	42	+0.35	20	−0.08
Average Fe		+0.36 ± 0.05		−0.11 ± 0.03
Ni I λ6643.64	94	+0.49	34	−0.28
Ni I λ6767.78	76	+0.60	72	−0.09
Ni I λ6772.32	46	+0.56	…	…
Average Ni		+0.53 ± 0.04		$-0.17^{+0.08}_{-0.11}$
C I λ6587.61	20	−0.51	48	+0.06
S I λ6757.17	86	+0.57	52	+0.18
Si I λ6721.84	55	+0.35	19	−0.26
Ca I λ6717.69	…	+0.15 ± 0.2	…	−0.31 ± 0.2
Al I (see text)	…	+0.4 ± 0.2	…	−0.36 ± 0.3

[a] For Li, the abundance scale is $A({\rm Li}) = 12 + \log(N_{\rm Li}/N_{\rm H})$.

[7] J02 find that the [Fe/H] of NGC 6633 is −0.1, about 0.2 dex lower than their Hyades value of ∼+0.1.

[8] Note that the extreme variation in the single-lined [Fe/H] is a factor of 2, although the extreme variation from the mean [Fe/H] is only about half of that. Note also that $\sigma_{W({\rm X})} \sim 3$ mÅ (see below).

see below). The Ca I 6717.69 Å feature is blended with Fe I and Ti II, and the two lines Al I λλ6696.03, 6698.67 are blended with neighboring Fe I lines (Burkhart & Coupry 1989). Synthesis using the King et al. (1997) line list yields (1) $A(\mathrm{Ca})_{\odot} = 6.36$ and $A(\mathrm{Al})_{\odot} = 6.42$, in excellent agreement with the value of 6.36 and 6.47, respectively, of Grevesse, Noels, & Sauval (1996), (2) $[\mathrm{Ca/H}]_{\mathrm{J37}} = +0.15 \pm 0.2$ and $[\mathrm{Al/H}]_{\mathrm{J37}} = +0.4 \pm 0.2$, and, (3) $[\mathrm{Ca/H}]_{\mathrm{MS113}} = -0.31 \pm 0.2$ and $[\mathrm{Al/H}]_{\mathrm{MS113}} = -0.36 \pm 0.3$. We stress that the derived [Fe/H] of M35 dwarfs, from which the normal comparison star MS113 has been drawn, remains constant over the large range in T_{eff} from 7100 to 5600 K (C. P. Deliyannis et al. 2002b, in preparation). Thus, the peculiar abundances of J37 are not an artifact of the analysis.

Using curves of growth constructed from Kurucz 1992 models (R. Kurucz 1992, private communication) with fine and hyperfine structure, $W(\mathrm{Li}) = 191$ mÅ translates into $A(\mathrm{Li}) = 4.29$. We assign $\sigma_W = 3$ mÅ, which is a conservative combination of the error based on the S/N (Cayrel 1988; Deliyannis, Pinsonneault, & Duncan 1993) and continuum placement. For σ_A, σ_W contributes only ± 0.02 dex, and $\Delta T_{\mathrm{eff}} = 100$ K implies ± 0.07 dex. J37's enormous Li abundance, a factor of 10 above A(Li) in meteorites (Anders & Grevesse 1989) and in young clusters, is by far the largest ever reported for any dwarf.

3. DISCUSSION: THE ORIGIN OF THE Li OVERABUNDANCE

Star J37 of NGC 6633 exhibits an extremely large $A(\mathrm{Li}) = 4.29 \pm 0.07$ (Fig. 2). Even if the errors were stretched beyond reasonable bounds, A(Li) must clearly be larger than about 4. Furthermore, given that (1) $A(\mathrm{Li})_{\mathrm{meteoritic}}$ is only 3.30 ± 0.04, (2) A(Li) in young clusters does not exceed this level, and (3) no other star in NGC 6633 is known to exceed $A(\mathrm{Li}) \sim 3.04 \pm 0.08$ (J02), there is very little chance that J37's initial A(Li) could have been much different than about 3.0–3.3. Dwarfs are also not known to manufacture significant amounts of Li. Thus, the Li overabundance in J37 must be a concentration or accretion effect.

3.1. *Diffusion*

Our super–Li-*rich star might be the smoking gun for the action of diffusion in the extremely narrow T_{eff} range of the* Li *peak* (Fig. 2). In this T_{eff} range, there is a substantial region below the extremely thin (model) surface convection zone (SCZ) where the Li atom retains one electron. Below this region, Li is completely ionized and diffuses downward (via gravitational settling and thermal diffusion) relative to hydrogen. By contrast, the electron-retaining Li within this region is radiatively accelerated upward and thus enriches the SCZ. These diffusive motions can be rendered inefficient if sufficient mixing occurs locally, such as mixing induced by rotation. In particular, the meridional circulation can wipe out diffusion in faster rotators (Charbonneau & Michaud 1991). However, if the unknown inclination angle is not too large, our value[9] of $v \sin i = 29 \pm 2$ km s^{-1} classifies J37 as a rather slower rotator for its spectral class; the outer layers may thus be stable enough to allow diffusion.

The Li peak prediction of RM93 assumed stable radiative layers. Subsequent model improvements include the incorporation of the detailed background opacities from OPAL and consideration of the effects of diffusion in the presence of turbulence (Richer, Michaud, & Turcotte 2000, hereafter RMT00). The RMT00 models do not show a Li peak, but the reasons for this are not clear. The absence of a Li peak may be due to the lack of resolution in the T_{eff} coverage of the models near 7100 K (see Fig. 14 of RMT00), but it may also be physical. Future models should address this. NGC 6633's slightly subsolar [Fe/H] might be of relevance through opacity and structure effects (delayed onset of a Fe convection zone?).

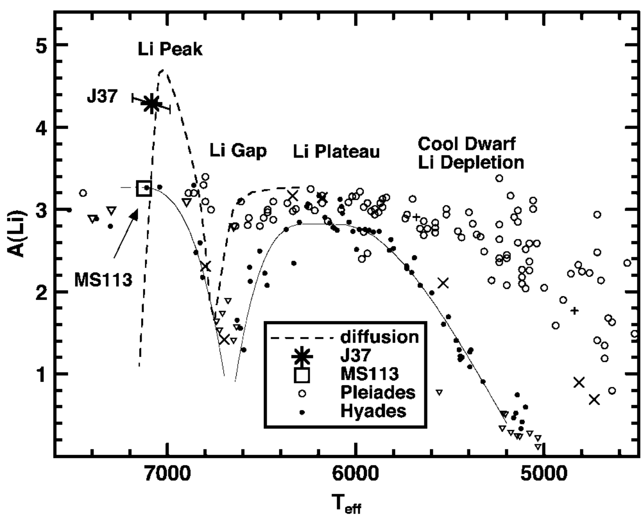

FIG. 2.—Li abundances in the Hyades (detections: *filled circles*; upper limits: *small inverted triangles*; short-period binaries: *mult crosses*) and Pleiades (detections: *open circles*; upper limits: *large inverted triangles*; short-period binaries: *plus signs*) open clusters, in J37, and in MS113. The solid line follows the mean Hyades trend. The dashed line is a solar-metallicity diffusion model from RM93 at 700 Myr, normalized to an initial abundance of $A(\mathrm{Li}) = 3.30$. Extrapolating RM93, the Li peak at $[\mathrm{Fe/H}] = -0.15$ should be roughly 50 K hotter, in even better agreement with J37.

Of our other elemental abundances, the more robust ones (Fe and Ni) and C provide further support for diffusion. The low C, high Fe, and even higher Ni are all predicted by RMT00 (see their Figs. 3 and 14). Our overabundant S, Si, Al, and Ca abundances do not agree as well with their models, which show underabundances. (By contrast, in the more normal star MS113, C, Fe, and Ni are normal to within the errors, with S, Si, Ca, and Al perhaps just slightly less normal ($[\mathrm{Fe/H}]_{\mathrm{M35}} = -0.17 \pm 0.03$; C. P. Deliyannis et al. 2002b, in preparation). The challenge remains to identify and model all the relevant physics, and we call for the calculation of models with general elemental abundances (including Eu, *s*, and rare earth elements) for Li peak stars. A comparison can also be made with several AmFm stars in Praesepe (Burkhart & Coupry 2000, hereafter BC00), another Hyades-aged cluster, that has $[\mathrm{Fe/H}] = +0.04$ (Friel & Boesgaard 1992). Like J37 (and diffusion models), BC00 find enhanced $[\mathrm{Fe/H}] = +0.4$ and even more enhanced $[\mathrm{Ni/H}] = +0.6$. The BC00 enhancements in [Si/H], [S/H], and [Al/H] of +0.2, +0.1, and +0.2 are smaller than in J37 but larger than the diffusion model underabundances. Note, however, that according to the criterion of Burkhart & Coupry (1991), which states that Ca I λ6717/Fe I λ6678 < 0.6 for an AmFm star and >0.8 for a normal star, both J37 and MS113 are marginal cases, with identical Ca/Fe = 0.66.

3.2. *Other Possibilities*

Spots.—Some magnetic, chemically peculiar stars show strong variations in the profile and position of the Li line (North et al. 1998), although these stars are hotter than J37. This

[9] Synthesis yields 28 ± 1 km s^{-1}, while a comparison to standard stars using IRAF's FXCOR yields 31 ± 2 km s^{-1}. These are in good agreement with the value 32 ± 3 km s^{-1} from Jeffries (1997).

possibly suggests concentrations of Li in spots near the magnetic poles, which move in and out of view as the star rotates. The reported A(Li) are in the range of 2.7–3.8 for HD 83368 (Shavrina et al. 2001). The rotational period of J37 is no larger than a few days, and yet, to better than $\sigma = 0.011$ Å, we find no evidence for shifts in the position of the Li line in J37 nor for any variations in the line profile. Also, our W(Li) agrees with Jeffries (1997) and J02.

Asymptotic giant branch (*AGB*) *contamination.*—A handful of super–Li-rich [$A(\mathrm{Li}) > 4$] S and C stars are known (Abia et al. 1993) and are thought to be self-enriched by the ^{7}Be transport mechanism (Cameron & Fowler 1971; King, Deliyannis, & Boesgaard 1996). Conceivably, the surface of J37 could have been contaminated by a companion that was formerly a super–Li-rich AGB star. Such enrichment might carry s-production signatures, unusual CNO abundances, and an unusual ^{12}C/^{13}C ratio. However, (1) to better than 0.5 km s^{-1} ($\sigma = 0.011$ Å), we have no evidence of radial velocity variations in our spectra (although J37 should be monitored further), (2) our radial velocity of 29 ± 3 km s^{-1} agrees with those in Jeffries (1997) and J02, and (3) it is not clear why such contamination would be accompanied by enrichment in Fe and Ni.

Planetesimal accretion.—Dwarf models at 7100 K have extremely shallow SCZs (e.g., RMT00); if a planetesimal as small as a medium-sized moon or large asteroid were to be accreted, the surface stellar abundances could be affected. One would then expect that volatiles with low-condensation temperatures (C, N, O, S, Zn) will be less enhanced than other refractory elements with high-condensation temperatures (Si, Ti, V, Fe, Co, Ni; Takeda et al. 2001). Contrary to this, we find that J37 has more enhanced S than Si and Fe. Furthermore, it is not clear why C should be underabundant.

Two other dwarfs have high A(Li): the SB2, "Hyades group," A3m, $q \sim 1$, pair HR 8293 A and B, which show $A(\mathrm{Li}) \sim 3.8$ and 3.6, respectively (Burkhart & Coupry 1991).[10] BC00 comments that the overabundances are probably real, although the exact A(Li) are uncertain due to the difficulties of working with SB2 spectra. These stars are much hotter ($T_{\mathrm{eff}} \sim 7920$ K) than J37 and the diffusion-predicted Li peak. A few other cluster stars have reported $A(\mathrm{Li}) \sim 3.4$–3.5 (see Fig. 7 of BC00); if the Li overabundances are real, then they too may contain clues about the physical processes occurring in the outer layers of these stars.

4. SUMMARY AND COMMENTS

We report the discovery of a large overabundance of surface Li, $A(\mathrm{Li}) = 4.29 \pm 0.07$, in the Hyades-aged dwarf J37, a member of NGC 6633. We have argued that the most likely explanation is upward, radiatively driven diffusion, consistent with the pure diffusion models of RM93. Additional effects (on structure due to Fe diffusion; mixing) may temper the predictions of RM93. Other interesting predictions of RM93 through which diffusion and competing effects can be tested further are that (1) the Li peak forms at least as early as 100 Myr, (2) its location depends on age and metallicity (slightly cooler with advancing age and higher metallicity), and (3) a Be peak also forms but is of order 200 K cooler than the Li peak at the age of NGC 6633 (and the Hyades), and thus at 7100 K, Be will be grossly underabundant. Thus, strikingly, the super–Li-rich J37 should have no observable Be.

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[10] Balachandran (1990) reports $A(\mathrm{Li}) = 3.76$ for HR 2264, with $T_{\mathrm{eff}} \sim$ 6800 K and [Fe/H] $= +0.27 \pm 0.13$. However, using her equivalent widths, we find $A(\mathrm{Li}) = 3.44$, $T_{\mathrm{eff}}(B-V = 0.43) = 6543$ K, and [Fe/H] $= 0.05 \pm 0.04$, in agreement with $A(\mathrm{Li}) = 3.35$, $T_{\mathrm{eff}} = 6500$K, and [Fe/H] ~ 0.0 from Vanture & Wallerstein (1999).

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