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LITHIUM AND METALLICITY IN THE URSA MAJOR GROUP

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ABSTRACT

High-resolution (0.1–0.2 Å), high signal-to-noise (200–700) spectra have been taken of several F dwarfs in the UMa group with the coudé spectrographs of the Canada-France-Hawaii Telescope with a Reticon detector and the Palomar 5 m telescope with a TI CCD. The spectra are centered at 6700 Å and cover 135 Å (CFHT) or 110 Å (Palomar). Abundances of both Li and Fe have been determined through a model atmosphere abundance analysis. Several conclusions are drawn from this study: (1) The metal content of the UMa group has been found to be [Fe/H] = -0.079 ± 0.053 from the 16 stars with the best determined temperatures and abundances. When this value for the *younger* UMa group at the age of 3×10^8 yr is compared with -0.07 ± 0.02 for Coma and $+0.12 \pm 0.03$ for the Hyades, which are $5–7 \times 10^8$ yr old, it appears that mixing in the disk has been nonuniform in the solar vicinity $3–7 \times 10^8$ yr ago. (2) The relationship between Li and temperature for the UMa group resembles that of the Hyades for the F stars with a deep deficiency in Li in the middle-F stars. The width in temperature of the Li-deficient region for the UMa group appears to be 300–400 K at the log N(Li) = 2.0 level compared to only ~220 K in the Hyades. Hotter stars in UMa and probably in the field can deplete Li even when the Hyades do not. This is possibly related to initial angular momentum and/or mass loss. (3) Among the late-F stars there are three (whose membership is suspect) that are much more Li-deficient than cluster members of similar temperature. They are probably non-members, but if they are UMa group stars, it is suggested that the extra depletion can arise from differences in the initial physical parameters such as rotation, magnetic field strength, epoch of formation, etc. (4) The stars on the cool side of the Li dip seem to have lower Li/H than those on the hot side, implying that depletion has already occurred in the cooler stars; this seems to be the case for the Hyades, Coma, and NGC 752 also. (5) In the temperature range 5800–6400 K for UMa, Coma, and Hyades the Li-temperature relation is flat and log N(Li) = 2.7 for those young clusters at $\sim 5 \times 10^8$ yr; for NGC 752 at 1.7×10^9 yr, log N(Li) = 2.4. This is compared to the flat Li-temperature profile for halo stars at 1.5×10^{10} yr where log N(Li) = 2.1, which suggests that the halo stars have also undergone Li depletion. (6) The "initial" Li/H for the UMa group is 1.2×10^{-9}; meteorites, field F stars, visual binaries, other clusters such as Hyades, Coma, and NGC 752, and T Tau stars show this value also. There is no evidence for significant Li enrichment in the Galactic disk since the time of the formation of the solar system.

Subject headings: clusters: open — stars: abundances — stars: evolution

I. INTRODUCTION

The pattern of Li content as a function of temperature—the Li-temperature profile—for the Hyades is remarkable in the depth and the regularity of the Li depletions in the middle-F stars (Boesgaard and Tripicco 1986*a*), and in the smoothness of the decline in Li content with decreasing temperature in the G stars (Cayrel *et al.* 1984). Boesgaard and Tripicco showed that in the range of $(B-V) = 0.40–0.47$ the Hyades F dwarfs have Li deficiencies with a steep decline in Li down to limits more than two orders of magnitude below the values found for stars both 300 K hotter and 300 K cooler than $T_{eff} \sim 6650$ K. Deficiencies of Li for a few middle-F stars were then found by Hobbs and Pilachowski (1986) in NGC 752 and by Boesgaard (1987) in the Coma Berenices cluster. In order to understand the phenomenon and its cause and the internal stellar structure involved, we have made observations of the Li I resonance line in F dwarfs of several clusters and groups which are characterized by various potentially relevant parameters, including age, metal content, rotation, chromospheric/magnetic activity, and galactic position.

The UMa stream (a name associated with Kapteyn's star streams) was the subject of a major study by Roman (1949) who discussed both the nucleus members and the moving group members. She listed 365 potential members and presented a second list of 135 probable members based on kinematics. Eggen (1960, 1983) has published membership lists for both the "Sirius Group" and the Sirius moving supercluster, which contain the UMa group. From the H-R diagram and theoretical models, ages have been estimated for the UMa group by several authors, including Levato and Abt (1978) who find $\sim 3 \times 10^8$ yr, Giannuzzi (1979) who gives 2.7×10^8 yr from a careful study of eclipsing binaries, Eggen (1983) who finds 2.4×10^8 yr for the Sirius supercluster, and Palouš and Hauck

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(1986) who give $4.9(\pm 1.3) \times 10^8$ yr from a study of the A stars. We will adopt the Giannuzzi value for the age.

Lithium abundances have been published for some UMa group stars by Danziger (1967), by Soderblom (1983, 1985*a*), and by Duncan (1981). Danziger estimated the Li/Ca abundance ratio for eight UMa nucleus members from spectral types F1–M0; his sample included two F stars, but both are rapid rotators. Soderblom's 12 stars are primarily G stars and have temperatures from 5500 to 6200 K. We have observed five stars in common. His sample provides an interesting supplement to our F dwarf sample. Except for one possible UMa group member, γ Lep, Duncan's sample of six stars was observed by us and/or by Soderblom. The Li content has been used by Soderblom (1985*a*) to confirm or reject stars as UMa group members.

Chromospheric activity in UMa group stars has been investigated by Walter *et al.* (1984) with IUE and X-ray data, by Soderblom (1985*b*) from the Ca II H and K features, and by Soderblom and Clements (1987) with IUE and HK data. All three papers question the membership of some UMa group stars because they have moderate, rather than strong, chromospheric emission. For the Hyades Soderblom (1985*b*) and Soderblom and Clements (1987) show that there is very little scatter in the amount of chromospheric emission from star to star. In the second paper they suggest that since the dispersion for the UMa group stars is 3 times that of the Hyades, not all the stars in their sample are members. They give an alternate explanation that the greater spread in chromospheric activity in UMa could result from a greater spread in age for the cluster stars. However, their study of the kinematics shows that the "probable" and "possible" members have a smaller range in the space velocity, V, than the "probable nonmembers," which have lower chromospheric emission.

The kinematical properties of the UMa nucleus and stream have been studied by Roman (1949), Eggen (1960, 1983), Krisciunas (1979), Palouš and Hauck (1986), Soderblom and Clements (1987), Johnson and Soderblom (1987), and apparently by Soderblom and Jones (unpublished, but quoted in the Soderblom references). Johnson and Soderblom (1987) give the average $\boldsymbol{U}$, $\boldsymbol{V}$, $\boldsymbol{W}$ velocities and dispersions for the nucleus and the solar-type stars, making use of the Soderblom and Clements (1987) judgments on membership. They show graphically the velocity distributions in the $(\boldsymbol{U}-\boldsymbol{V})$ and $(\boldsymbol{U}-\boldsymbol{W})$ planes of their results and those of both Palouš and Hauck (1986) and Eggen (1983) for the nucleus and the "supercluster" stars. For our purposes in assessing membership for our F stars, we will adopt Johnson and Soderblom's averages for the 10 solar-type stars.

In this work we report on the Li abundances for the UMa group F stars and compare the UMa Li-temperature profile with that of the Hyades and the Coma Berenices clusters. We also determine [Fe/H] abundances which not only provide spectroscopic calibration for photometric indices and another criterion for UMa Group membership, but also can be compared with the metallicity of other young clusters to study the degree of mixing in the Galactic disk in the solar neighborhood.

II. OBSERVATIONS

A sample of F dwarfs in the UMa group has been selected from those listed by Roman (1949) as probable members (her Table 18) from among those in the longer list (her Table 17).

TABLE 1

STARS OBSERVED

Name	HR	HD	Sp.	S/N CFHT	S/N Palomar	Night[a]	Photometry B-V	Photometry β	Photometry R–I	v sin i (km s^{-1})
ϕ^2 Cet	235	4813	F8 V		360	8	0.50	2.625	0.28	3.5
80 Psc	330	6763	F1:V		450	8	.34	2.708	.18	...
		11131	G1 V		175	9	.61	2.595	...	...
	534	11257	F0 Vs		360	8	.30	2.718	.17	...
	647	13594	F3 V		200	8	.40	2.655	.25	<26
χ^1 Ori	2047	39587	G1 V	1730		*	.59	2.599	.31	9.4
9 Pup	3064	64099	G1 V	200,630		4	.60	...	.36	<17
π^1 UMa	3391	72905	G1 V	1360		*	.62	2.596	.33	9.5
34 Leo	3998	88355	F7 V	650		4	.46	2.664	.27	...
35 LMi	4150	91752	F3 V	460,600		2,5	.39	2.639	...	8
		94686	F8 V+F8 V	350		6	.55	...	.33	...
ι Leo	4399	99028	F3 III	700		1	.41	2.686	.21	20
	4803[b]	109799	F2 IV-V	510		3	.32	2.703	.19	0
κ^1 Boo	5328	124674	F3 V	370		6	.39	...	...	40
18 Boo	5365	125451	F6 V	580		6	.38	2.672	.19	39
45 Boo	5634	134083	F6 V	500		1	.43	2.664	.21	45
	5830	139798	F2 V	280		1	.36	...	.18	...
		151044	F8 V	700		4	.54	...	.26	5.4
110 Her	7061	173667	F6 V		380,410	8	.46	2.648	.26	14
11 Aql	7172	176303	F8 IV	580	360	1,7	.53	2.617	.30	26
59 Dra	7312	180777	F0 Vs	900		4	.31	...	.17	63
	7451	184960	F8 V	580	200	1,7	.48	2.642	.28	6.5
	8170	203454	F8 V	700	300	4,7	0.53	2.619	0.34	18.0

[a] Night numbers (UT): 1 = 1985 May 29; 2 = 1985 Jun 10; 3 = 1985 Jun 11; 4 = 1986 Apr 19; 5 = 1986 Apr 20; 6 = 1986 Apr 21; 7 = 1986 Aug 21; 8 = 1986 Oct 23; 9 = 1986 Nov 12.

* Spectra added from nights of 1984 Dec 11, 1985 Jan 10, 11, 12, 13, and Apr 7.

[b] Data for HR 4803 in Boesgaard and Tripicco (1986*b*).

The membership is based on the kinematics. (In § IV we will rediscuss the question of membership in this moving group.) Spectra were obtained of 18 stars at the Canada-France-Hawaii Telescope (CFHT) on Mauna Kea on two observing runs in 1985 and one in 1986 and of eight at the 5 m Hale telescope at Palomar on three observing runs in 1986; spectra of three stars were obtained with both systems. The stars observed are listed in Table 1 which gives spectral types from Levato and Abt (1978), Strömgren Hβ photometry from Hauck and Mermilliod (1980), $(B-V)$ from Nicolet (1978) or the Bright Star Catalogue, $(R-I)$ from Mendoza (1967) or the Bright Star Catalogue, and $v \sin i$ from the Bright Star Catalogue (fourth edition) and from Soderblom (1983).

The spectra from CFHT were taken with the f/8.2 coudé spectrograph camera with the 830 lines mm^{-1} mosaic grating in the first order and a liquid-nitrogen cooled Reticon detector. The detector has 1872 pixels. A Richardson image slicer optimized for the red was used, along with the red mirror train. The spectra are centered at 6700 Å and cover 135 Å. The dispersion of 4.8 Å mm^{-1} or 0.072 Å pixel^{-1} coupled with the measured FWHM of the comparison lines of 1.5 pixel gives a resolution of about 0.11 Å. Many of the UMa group stars are quite bright ($V = 4$–6) so signal-to-noise ratios (S/N) of 300–700 were easily obtainable (see Table 1). The flat-fielding and normalization procedures have been described in previous papers, e.g., Boesgaard and Tripicco (1986*b*), Boesgaard (1987). Some samples of the CFHT spectra are shown in Figure 1. Two of the stars, 34 Leo and HD 94686, are double-lined spectroscopic binaries (SB2's). At our resolution and phase the two sets of lines can be distinguished.

The spectra from the Palomar 5 m telescope were taken with the 72-inch coudé camera with the first order of the 600 lines mm^{-1} mosaic grating #1 and a uv-flooded, liquid-nitrogen cooled Texas Instruments CCD. (See Gunn *et al.* [1987] for details on the Palomar CCD camera.) The detector has 800 × 800 pixels. A Bowen-Walraven type image slicer was used, giving typically eight slices of spectrum. The spectra were centered at 6700 Å and cover 110 Å. The nominal dispersion of 9.1 Å mm^{-1} corresponds to 0.14 Å pixel^{-1}. The measured FWHM of the comparison lines is about 1.5 pixel for a spectral resolution of about 0.21 Å. The spectra have S/N of 200–450 (see Table 1).

Two or three master flat-field exposures were taken each night by means of a diffuse reflection of an incandescent bulb through the image slicer and spectrograph. The spectra were divided by the mean flat field. Cosmic rays, if any, were removed by a routine that replaces the intensity of the affected pixel(s) by the average of its neighbors. The slices were then summed along the direction perpendicular to the dispersion. Examples of the Palomar spectra are shown in Figure 2.

Continua were fitted by splines to the spectra via interactively selected continuum points through each spectrum. The continuum-flattened spectra were added in proportion to their exposure level for the stars for which there was more than one spectrum obtained with the same system. Equivalent widths could be determined by a simple integration over the line profile, and were measured for Li I λ6707, Fe I $\lambda\lambda$6678, 6703, 6705, 6727, 6750, and 6752, and Ca I λ6717. For HR 7451 and HR 8170 the agreement between the CFHT and the Palomar equivalent widths is excellent, within 1–2 mÅ for most of the lines. For 11 Aql, the Palomar numbers are systematically 15 (±16)% lower, for reasons which we do not understand. Special care was taken in measuring the equivalent widths in the two SB2's. The separation of the two components of HD 94686 is clear, but in the blueward spectrum (at the time of our observation) the lines of Fe I at 6705, 6727, and 6750 Å are blended with lines in the redward spectrum, while Fe I at

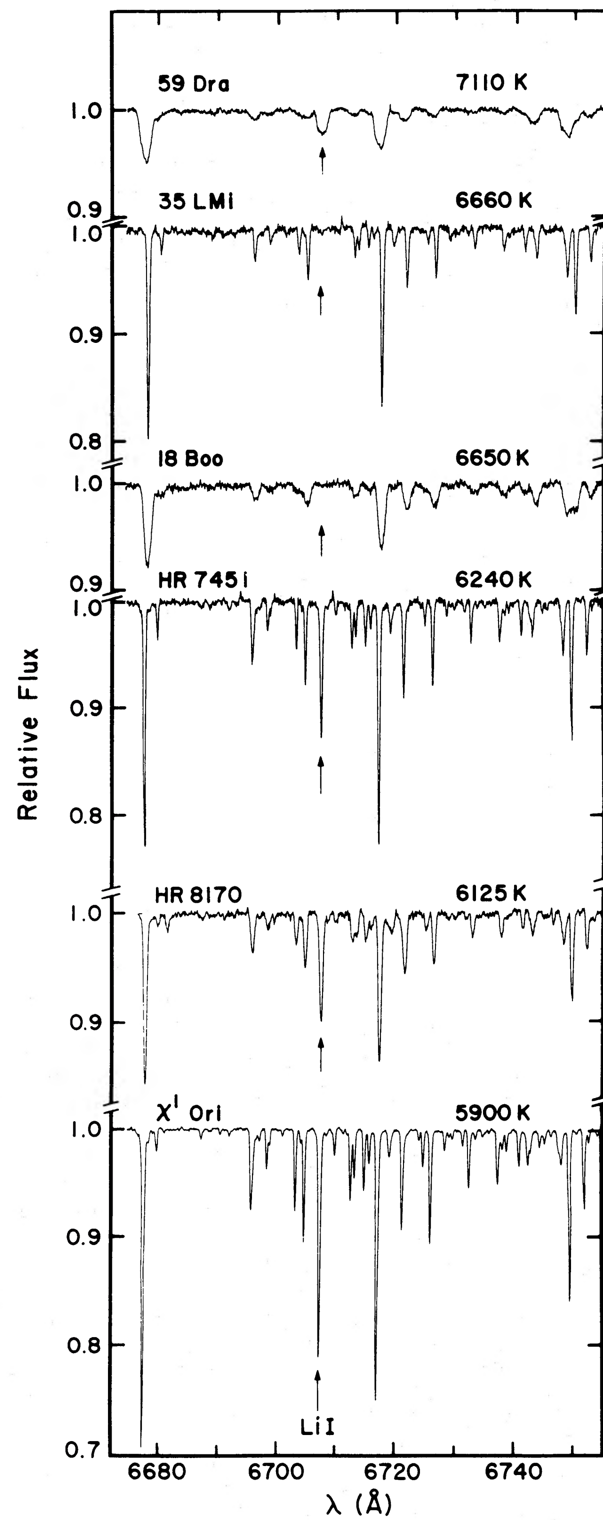

FIG. 1.—Examples of the CFHT spectra, arranged in order of decreasing temperature. The position of the Li I feature is indicated on each spectrum; it is clearly present in 59 Dra, HR 7451, HR 8170, and χ^1 Ori, but weak or absent in 35 LMi and 18 Boo.

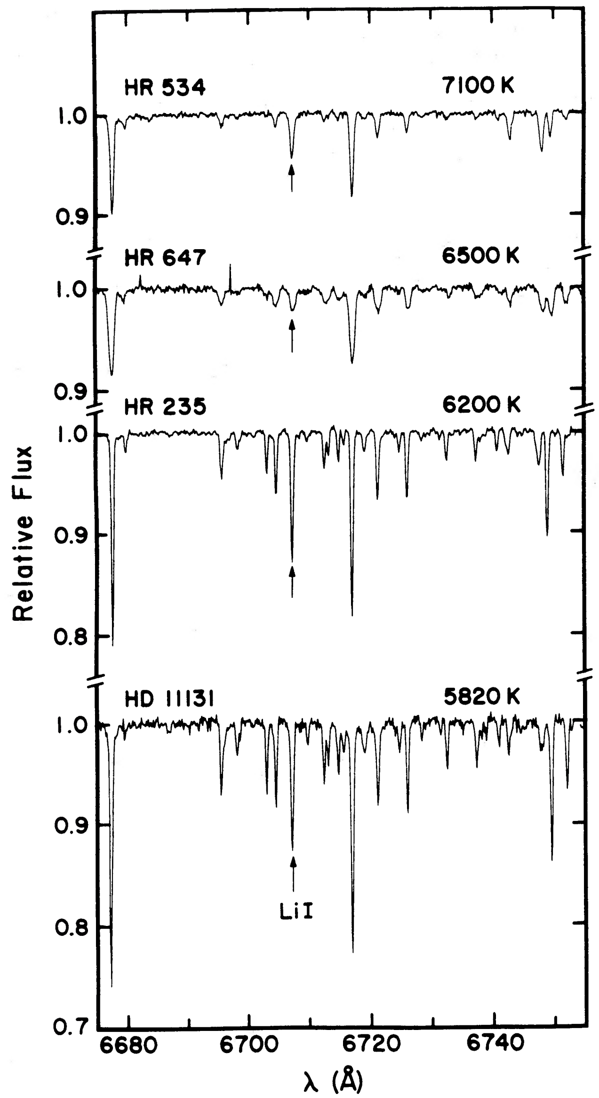

FIG. 2.—Examples of the Palomar spectra, arranged in order of decreasing temperature. The Li I feature is indicated, but it is clearly weaker in HR 647, a star with T_{eff} = 6500 K.

6703 Å is blended in the redward spectrum. In 34 Leo, the lines are all doubled, but blended, making measurements difficult and less accurate. It is clear, however, that the blueward spectrum has no Li I line, while the redward one does.

The equivalent widths are given in Table 2 for all the stars, in order of decreasing temperature (see § III). For the two SB2's the measured strengths are listed in parentheses; they are multiplied by the factors given in the line below to correct for the combined continuum flux and differences in the Planck function at 6700 Å and in radius as discussed by Boesgaard and Tripicco (1986*b*). For the three stars with spectra from both telescopes, the mean equivalent widths are given, except for 11 Aql where the CFHT results are weighted by three, because both the signal-to-noise ratio (580 vs. 360) and the resolution (0.072 vs. 0.14 Å pixel^{-1}) are greater for the CFHT spectrum.

We can estimate the reliability of the equivalent width measures in a number of ways. For three stars we have two spectra each taken at the same telescope; for those the mean difference in the equivalent widths is 1.7 mÅ. For three stars we have two spectra taken at the two different telescopes; for two stars the mean difference is 2.1 mÅ and for 11 Aql it is 5.4 mÅ, as mentioned above, We have examples of the same stellar spectrum measured by two combinations of two of us; the mean difference for those measurements is 0.9 mÅ. Furthermore we can assess the repeatability of the equivalent widths as a function of S/N and of $v \sin i$. For S/N $\gtrsim$ 700 the repeatability is 0.2 mÅ and for S/N $\sim$ 300 it is 1.4 mÅ. At S/N levels of 500–600, the measurements for the sharp-lined stars repeat to 0.3 mÅ, while those of stars rotating near 40 km s^{-1} repeat to 0.8 mÅ. Thus we feel confident that we can measure equivalent widths to a high degree of accuracy from these high S/N, high-resolution spectra; a conservative estimate of the errors is ± 2 mÅ.

III. TEMPERATURES AND ABUNDANCES

In order to define the Li-temperature profile for any galactic cluster, it is necessary to determine the temperatures in a consistent way. This is especially true for a moving group like the UMa group where cluster membership is more difficult to determine than for more spatially cohesive groups. For clusters the photometry is often done by one observer in a few nights of observing, which gives a uniform data set. The photometric observations are from more diverse sources for the UMa group stars. We have, therefore, tried to use photometric information from many indices, specifically, Hβ, $(R-I)$, and $(B-V)$. In order to compare the Li results with those of other clusters, we have used the temperature calibrations that have been used in previous studies of Li in galactic clusters. In addition, the relative spectral line strengths of W(Fe I λ6703)/W(Fe I λ6705) of Boesgaard and Tripicco (1986*b*) and of I(Cr I λ6748)/I(Fe I λ6750) and I(Cr I λ6748)/I(Fe I λ6752) of Boesgaard and Tripicco (1987) can be used to find temperature, more directly, from our own spectra and the Boesgaard and Tripicco calibrations.

Table 3 gives temperatures for each star from the photometry in Table 1 and from the measured intensity ratio of Cr I λ6748 to Fe I λ6750. The calibrations used were: Böhm-Vitense (1981) and Saxner and Hammarbäck (1985) for $(B-V)$, Saxner and Hammarbäck for Hβ, and Carney (1983) and Hearnshaw (1974) for $(R-I)$. For the early F stars, $(B-V) \lesssim 0.45$, Böhm-Vitense remarks that the ultraviolet data suggest two branches in the T_{eff} versus $(B-V)$ diagram, with the lower one populated by more rapidly rotating stars. The temperatures of our hotter stars are therefore less certain than those with $(B-V)$ greater than 0.45. In Table 3 we give the temperatures from the various indicators and calibrations along with the adopted temperature. For several of the stars the temperatures from different sources do not agree well, far less well than those for the Hyades and Coma cluster stars; this is possibly due to the nonuniformity of the sources for the photometry. Discrepant values are indicated by a colon and are given lower weight in the temperature averaging. The last column in the table gives the standard deviation about the adopted value. Realistically, the temperatures are known to no better than 1% to 2%.

For the SB2's the photometric indices are not realistic temperature indicators since two spectra contribute to the colors. The spectroscopic line ratios were used. The intensity ratios of both Cr I λ6748 to Fe I λ6750 and Cr I λ6748 to Fe I λ6752 were measured for both components of 34 Leo and resulted in similar values for the temperature. The adopted temperatures are 6580 K (blueward) and 6300 K (redward) although these values are quite uncertain because of the line blending. For

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TABLE 2

EQUIVALENT WIDTHS (mÅ)

Name	T_{eff}(K)	Fe I 6677.993Å	Fe I 6703.573Å	Fe I 6705.117Å	Fe I 6726.668Å	Fe I 6750.152Å	Fe I 6752.724Å	Fe I + Li I 6707.441Å + 6707.761Å 6707.912Å	Ca I 6717.685Å
59 Dra	7110	89.6	7.:	15.:	12.2	...	12.:	45.4	70
HR 534	7100	70.4	...	7.9	11.9	14.0	5.4	33.9	56.1
HR 5830	6930	92.3	6.:	9.:	17.3	18.:	...	10.4:	87.6
80 Psc	6930	85.6	...	...	19.3	...	...	≤5.0	59.6
HR 4803	6900	95.5	...	...	22.4	22.:	...	56.0	83.9
κ^1 Boo	6760	89.8	8.7	12.3	15.6	32.:	14.:	≤1.1	75.9
35 LMi	6660	91.2	10.9	21.8	19.2	36.4	14.4	≤4.3	82.2
ι Leo	6660	113.2	12.3	28.9	26.1	41.5	19.7	85.8	103.1
18 Boo	6650	102.6	11.2	25.2	27.8	36.:	18.:	≤3.9	88.3
45 Boo	6600	104.4	9.0	26.4	32.3	40.:	19.:	≤2.0	91.9
34 Leo b	6580	...	(11.0)	(20.2)	...	. .	(12.6)	(≤2.2)	(75.7)
*mf=1.77		...	19.5	35.8	...	...	22.3	≤3.9	134
HR 647	6500	92.6	7.0	18.8	18.4	26.2	14.5	25.1	...
110 Her	6370	105.3	15.6	28.2	27.8	43.5	20.8	11.7	92.2
34 Leo r	6300	...	(7.9)	(12.2)	(9.6:)	(18.8:)	(11.5:)	(11.8)	(38.3:)
*mf=2.29		...	18.1	28.0	22.:	43.:	26.:	27.1	87.7
HR 7451	6240	100.6	15.3	30.6	30.3	48.8	20.7	61.6	99.3
ϕ^2 Cet	6200	97.9	16.8	28.0	31.1	50.9	21.7	67.2	86.5
HD 151044	6130	111.3	24.4	37.7	37.0	59.8	27.9	75.2	...
HR 8170	6125	104.6	16.0	29.0	28.4	47.7	23.4	67.6	88.9
11 Aql	6115	118.5	17.9	32.0	36.6	57.4	24.9	13.6	105.2
HD 94686 b	6100	...	...	...	(15.:)	...	(12.3)	(38.9)	(54.2)
*mf=1.90		...	...	...	30:	...	23.4	74.1	103.2
HD 94686 r	6000	(56.5)	...	(16.6)	(17.1)	(27.1)	(11.7)	(41.6)	(57.2)
*mf=2.11		119	...	35.0	36.0	57.1	24.6	87.6	120
9 Pup	5910	122.9	27.4	35.2	36.3	61.4	29.2	24.2	106.7
χ^1 Ori	5900	126.8	28.6	41.1	42.6	62.6	29.7	103.5	114.0
π^1 UMa	5850	124.4	30.2	41.0	42.7	65.0	26.8	106.9	117.8
HD 11131 B	5820	137.8	29.3	39.3	41.6	65.3	31.0	70.5	128.9
sun	5770	137	38	47	48	75	38	<2	120

* Multiplication factors for the equivalent widths to correct for the contributions to the continuum from the two stars due to the differences in the Planck function at 6700 Å and in the radius (see Boesgaard and Tripicco 1986*b*).

TABLE 3

EFFECTIVE TEMPERATURE (K)

Name	T(B−V)	T(β)	T(R−I)	T(6748/6750)	T(adopted)	σ
ϕ^2 Cet	6310,6280	6130	6105	6100	6200	±100
80 Psc	7000,6850	6970	6925	bl.	6930	±65
HD 11131 B	5890	5810,5710[a]	...	5890	5820	±85
HR 534	7225,6990	7060	7020	...	7100	±110
HR 647	6630	6440	6330	6600	6500	±140
χ^1 Ori	5950	5880	5895	5890	5900	±30
9 Pup	5915	...	...	5900	5910	±10
π^1 UMa	5850	5840	5765:	5860	5850	±20
34 Leo b	...	...	...	6580	6580	±200:
34 Leo r	...	...	...	6300	6300	±200:
35 LMi	6860,6660	6280:	...	6450	6660	±200
HD 94686 b	...	...	...	6100	6100	±200:
HD 94686 r	...	...	...	bl.	6000	±200:
ι Leo	6600	6745	6660	...	6660	±75
HR 4803	7350,6920	6900	6830	...	6900	+200,−70
κ^1 Boo	6860,6660	...	...	bl.	6760	±100
18 Boo	6700	6600	6800	bl.	6650	±100
45 Boo	6600	6530	6660	bl.	6600	±70
HR 5830	7060,6800	...	6920	bl.	6930	±130
HD 151044	6130	...	6250	6020	6130	±115
110 Her	6450	6370	6250	...	6370	±100
11 Aql	6170	6050	5960	6360	6115	±150
59 Dra	7360,6950	...	7020	bl.	7110	±200
HR 7451	6375	6310	6105	6170	6240	±125
HR 8170	6175	6075	...	6110	6125	±50

[a] Ducan 1984.

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HD 94686 the line of Cr I λ6748 of the redward spectrum coincides with Fe I λ6750 of the blueward spectrum, so only the ratio of Cr I λ6748 to Fe I λ6752 in the blueward spectrum could be used. In addition, the Fe I λ6703 line in the redward spectrum was coincident with Fe I λ6705 of the blueward spectrum. The temperature of the star with the blueward spectrum is 6100 K. From this and the spectral types of F8 V and F9 V of Abt (1981) and Levato and Abt (1978) a temperature of 6000 K was assigned to the star with the redward spectrum. These temperatures were used to determine the factors by which the equivalent widths should be multiplied, both in the determination of the Planck factor and in the determination of the radius taken from the radius-effective temperature relation for main-sequence stars from Allen (1973).

The procedure and details of the model atmosphere abundance analysis were described by Boesgaard and Tripicco (1986*b*). The only modifications made here were the values used for the microturbulent velocities, ξ, and the inclusion of the Fe I λ6752 line. These were discussed by Boesgaard (1987) in the study of the Coma Berenices cluster. The Li/H results are not sensitive to the choice of microturbulence, and the Fe/H results are only weakly sensitive for some lines, and not at all for others. For Li, the curves of growth for the Fe-Li blend were used with the solar Fe abundance. (The cluster mean [Fe/H] is -0.10; see below.) The values for log N(Li) on the scale where log $N(\mathrm{H}) = 12.00$ are given in Table 4. The final Fe abundances come from the results of line-by-line, stellar-to-solar ratios, $(\mathrm{Fe/H})_*/(\mathrm{Fe/H})_\odot$. The mean of these values and the standard deviations were found; the logs of these numbers are given in Table 4. The errors listed for log N(Li) are a combination of the random errors in (1) the photometry and the temperature calibrations from the last column of Table 3, (2) the abundance determination scatter as revealed by the Fe I lines, and (3) for the lines with Li upper limits, the ~ 2 mÅ value from the equivalent width measures discussed at the end of § II. (Representative values of $\sigma[\log N(\mathrm{Li})]$ due to temperature errors are ± 0.02 for $T \sim 5900$ K and $\sigma[T] \sim 20$ K; ± 0.06 for $T \sim 6600$ K and $\sigma[T] \sim 100$ K; ± 0.10 for $T \sim 6900$ K and $\sigma[T] \sim 150$ K.)

As part of the regular observing program at Mount Wilson of Ca II HK fluxes, 12 of our UMa group stars have measured mean S values. This survey is described by Vaughan and Preston (1980). These $\langle S \rangle$ values were supplied to us through the courtesy of Laura Woodard and Sallie Baliunas. These values have been converted to fractions of the total flux, R'_{HK}, by the prescriptions given by Noyes *et al.* (1984) and are listed in Table 5. (Three of the stars, κ^1 Boo, 18 Boo, and 59 Dra, are quite blue for those prescriptions so the values of log R'_{HK} are followed by a colon to indicate that they are uncertain.) The level of chromospheric activity has been used to estimate membership probability for UMa stars; Soderblom and Clements (1987) find for stars with $\log R'_{HK} > -4.75$, that $\log R'_{HK} = (0.62 \pm 0.33)(B-V) - (4.86 \pm 0.08)$ with $\sigma_{HK} = 0.11$ dex. For those stars with $\log R'_{HK} > -4.5$, they find $\langle \log R'_{HK} \rangle = -4.39 \pm 0.04$. We note that HR 8170 is a close binary, so that although it has normal Ca emission for UMa stars, it might be an older field star with enhanced emission from the closeness of the companion.

TABLE 4

ABUNDANCES

Name	T_{eff}(K)	Li/H	Log N(Li)	σ	[Fe/H]	σ
59 Dra	7110	1.4(−9)	3.15	±0.20	−0.03	±0.16
HR 534	7100	9.8(−10)	2.99	±0.15	−0.29	±0.13
HR 5830	6930	1.9(−10):	2.28:	±0.27	−0.13	±0.21
80 Psc	6930	≤7.0(−11)	≤1.85	±0.23	−0.04	...
HR 4803	6900	1.3(−9)	3.11	±0.15	+0.01	±0.13
κ^1 Boo	6760	≤1.0(−12)	≤0.00	±0.33	−0.14	±0.13
35 LMi	6660	≲1.5(−11)	≲1.18	±0.23	−0.10	±0.08
ι Leo	6660	1.6(−9)	3.20	±0.16	+0.08	±0.14
18 Boo	6650	≤2.1(−11)	≤1.32	±0.27	−0.02	±0.13
45 Boo	6600	≤2.0(−12)	≤0.30	±0.33	−0.00	±0.12
34 Leo b	6580	≤2.0(−11)	≤1.30	±0.45	+0.10	...
HR 647	6500	2.6(−10)	2.41	±0.15	−0.26	±0.10
110 Her	6370	5.2(−11)	1.72	±0.10	−0.08	±0.04
34 Leo r	6300	2.0(−10)	2.30	±0.17	−0.10	±0.08
HR 7451	6240	5.0(−10)	2.70	±0.12	−0.12	±0.06
ϕ^2 Cet	6200	5.4(−10)	2.73	±0.10	−0.14	±0.07
HD 151044	6130	5.3(−10)	2.72	±0.12	−0.00	±0.09
HR 8170	6125	4.5(−10)	2.65	±0.06	−0.18	±0.04
11 Aql	6115	5.6(−11)	1.75	±0.18	−0.07	±0.08
HD 94686 b	6100	5.2(−10)	2.72	±0.19	−0.18:	...
HD 94686 r	6000	5.2(−10)	2.72	±0.17	−0.10	±0.06
9 Pup	5910	8.0(−11)	1.90	±0.06	−0.12	±0.06
χ^1 Ori	5900	5.4(−10)	2.73	±0.06	−0.05	±0.04
π^1 UMa	5850	5.0(−10)	2.70	±0.05	−0.08	±0.05
HD 11131 B	5820	2.5(−10)	2.40	±0.11	−0.07	±0.09

IV. RESULTS AND DISCUSSION

The [Fe/H] results given in Table 4 are plotted as a function of effective temperature in Figure 3. The horizontal line represents the mean [Fe/H] and the vertical line at the right shows the 1 σ error in the mean. Excluding the SB2's and the two stars for which only two or three Fe I lines could be measured (80 Psc and HR 4803), the mean [Fe/H] is -0.085 ± 0.087. Figure 3 shows no systematic trend of [Fe/H] with temperature which indicates that the temperature scale is internally consistent. The dispersion about the mean for the UMa group is greater than for Coma: $[\mathrm{Fe/H}] = -0.07 \pm 0.02$ (Boesgaard 1987) or Hyades: $[\mathrm{Fe/H}] = +0.12 \pm 0.03$ (Cayrel, Cayrel de Strobel, and Campbell 1985). If the three most discrepant points are removed for UMa, then $[\mathrm{Fe/H}] = -0.079 \pm 0.053$. However, it does appear that metallicity could be useful as a criterion of membership in the UMa group. These three clusters of similar age (3, 5, and 7×10^8 yr old) show a real spread in [Fe/H] of 0.22 dex, which implies a nonuniform metallicity in the Galactic disk in the solar vicinity.

The results for the Li abundances can be seen as a function of temperature in Figure 4. Five of the stars in the temperature

TABLE 5

CHROMOSPHERIC ACTIVITY

Star	< S >	log R'_{HK}	Member?
ϕ^2 Cet	0.1736	−4.849	N?
HD 11131	0.3364	−4.420	Y
χ^1 Ori	0.3122	−4.451	Y
π^1 UMa	0.3561	−4.394	Y
34 Leo	0.1713	−4.812	?
κ^1 Boo	0.2081	−4.825:	?
18 Boo	0.2363	−4.692:	Y
45 Boo	0.2082	−4.628	Y
11 Aql	0.1876	−4.780	?
59 Dra	0.2542	−4.657:	Y
HR 7451	0.1414	−5.029	N?
HR 8170	0.3031	−4.434	Y

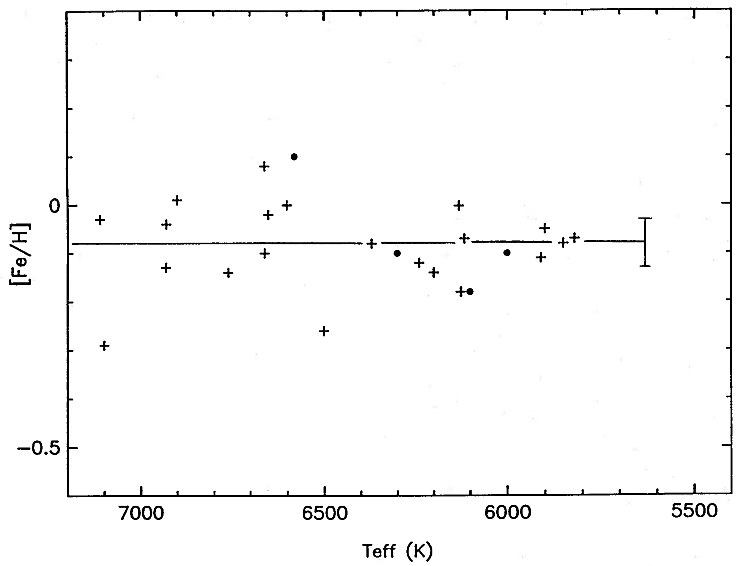

FIG. 3.—The logarithmic ratio of stellar Fe/H to solar Fe/H as a function of temperature. The results for the components of the SB2's are plotted as small dots due to their greater uncertainty. The horizontal line represents the mean [Fe/H], −0.079, and the short vertical line the standard error of the mean, ±0.053, excluding the SB2's and five other uncertain points.

range 6500–6900 K show Li depletions of factors of 50–1000 relative to the maximum Li abundances. This pattern is similar to that found in the Hyades (Boesgaard and Tripicco 1986*a*) and in Coma (Boesgaard 1987), yet extends over a broader temperature region. Figure 4 shows one star, ι Leo, right in the middle of the Hyades Li gap. Some field stars in this temperature region do show Li abundances like that at the temperature of ι Leo (Boesgaard and Tripicco 1986*b*), but the results for Hyades, Coma, and NGC 752 (Hobbs and Pilachowski 1986) clusters lead to the expectation that this would not occur in clusters. It is possible that ι Leo is *not* a bona fide member of the UMa Group or that we have assigned an incorrect temperature. If the Levato and Abt (1978) spectral type of F3 III is correct, it is either not a member (due to the conflict of luminosity class and absolute magnitude) or should not be plotted on our graph with main-sequence stars. The primary, ι Leo, has a G dwarf companion which is 1″.1 away and 2.7 mag fainter. The spectral types in the Bright Star Catalogue are F2 IV and G3 V, while Walter *et al.* (1984) give F4 IV and G5 V. Our spectrum is of the primary only. The Photometry is for the combined light, but the companion is 12 times fainter in V and contributes little; the temperatures from the four sources agree quite well, within ±70 K. To match the Hyades pattern, the temperature would have to be 200 K lower, which does not seem justified especially since the correction for the possible influence of the companion would be to increase the adopted temperature. Three of the cooler stars, 11 Aql, 9 Pup, and 110 Her, seem to be more depleted than their counterparts at those temperatures. The reality of their membership should be examined also.

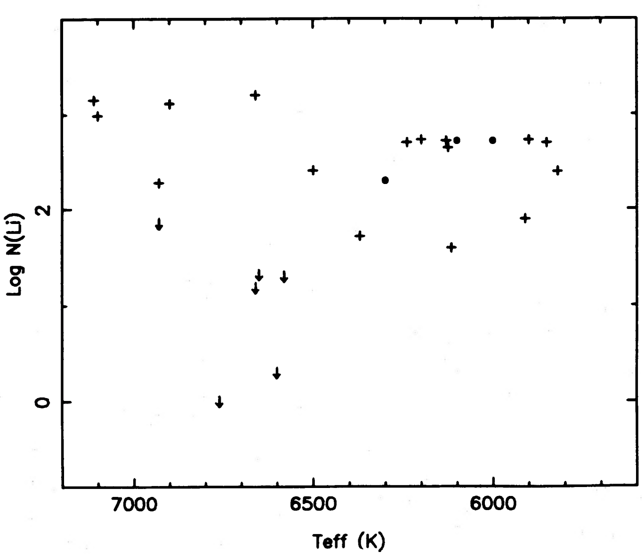

FIG. 4.—The values for log N(Li), on the scale where log N(H) = 12.00, as a function of effective temperature for all the stars observed. The membership of some of the stars in the UMa group is in question; see text. The arrows represent upper limits.

There are two hypotheses: (1) the stars that do not fit the Hyades pattern are non-members, and (2) most or all of the stars in Figure 4 are members and the difference in the Li-temperature pattern from that of the Hyades (and Coma) can be ascribed to age since the UMa group is younger than the Hyades and Coma clusters. A component of these hypotheses is an assessment of the membership probability of the stars in Table 1.

First, we examine the likelihood of membershop for ι Leo, 11 Aql, 9 Pup, and 110 Her, the stars that do not fit the Hyades pattern. The kinematic criterion for membership is the strongest. Table 6 gives the $\boldsymbol{U}$, $\boldsymbol{V}$, $\boldsymbol{W}$ velocities calculated from the formulae given by Boesgaard and Tripicco (1986*b*) and Bright Star Catalogue parameters or by Eggen (1960, 1983), Johnson and Soderblom (1987), and Soderblom and Clements (1987), According to Johnson and Soderblom the averages for the UMa Group are $\boldsymbol{U} = 12.3 \pm 2.5$, $\boldsymbol{V} = 1.3 \pm 2.5$, and $\boldsymbol{W} = -7.9 \pm 3.3$ km s^{-1}. The $\boldsymbol{U}$, $\boldsymbol{V}$, $\boldsymbol{W}$ averages found by Palouš and Hauck (1986) are 11.1, 3.3, −8.2 km s^{-1}, respectively, the same as Johnson and Soderblom within the errors. For all four of the stars that do not fit the Hyades pattern, the $\boldsymbol{U}$ velocity is too high by several sigma. The $\boldsymbol{W}$ velocities for 9 Pup and 110 Her also do not fit well. In addition, excessive $\boldsymbol{U}$

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TABLE 6

URSA MAJOR GROUP VELOCITIES (in km s^{-1}) AND MEMBERSHIP PROBABILITIES

					Member?			
Star	U	V	W	Source[1]	Kinematics	Chromosphere	[Fe/H]	Li
ϕ^2 Cet	20.7	2.6	−17.1	B3	?	N?		
80 Psc	40.6	6.7	−21.6	B3	N?			
HD 11131	16	2	−4	SC	Y	Y		
HR 534	4.9	8.9	−13.5	B3	Y:		?	
HR 647	14.4	−0.7	−11.4	E2	Y		?	
χ^1 Ori	12.9	5.9	−6.8	JS	Y	Y		
9 Pup	25.1	0.8	−18.1	B3	N?	N?		?
π^1 UMa	9.6	0.3	−9.1	JS	Y	Y		
34 Leo	14.6	2.5	−10.6	B3	Y	N?		
35 LMi	18.2	−4.0	−17.4	B3	Y:			
HD 94686								
ι Leo	20.4	3.3	−5.5	B3	?		?	?
HR 4803	15.6	1.2	−8.8	E2	Y			
κ^1 Boo	14	1	−17	E1	Y?	?		
18 Boo	10.9	4.9	−7.2	B3	Y	Y		
45 Boo	13.7	−2.3	−15.2	JS	Y	Y		
HR 5830	81.6	−3.3	−15.7	B3	N?			
HD 151044						N?		
110 Her	39.8	0.9	8.0	B3	N	N?		?
11 Aql	22.2	1.7	−7.4	B3	N?	?		?
59 Dra	13.0	4.3	−9.6	E2	Y	Y		
HR 7451	15.1	0.8	−9.8	E2	Y	N?		
HR 8170	21.4	−2.8	−16.9	B3	?	Y		
UMa Ave.	12.3±2.5	1.3±2.5	−7.9±3.3	JS				

[1] B3 = this paper; SC = Soderblom and Clements 1987; E2 = Eggen 1983; JS = Johnson and Soderblom 1987; E1 = Eggen 1960.

velocities are found for 80 Psc and possibly HR 5830, which has a very small parallax and thus uncertain space velocities.

The level of chromospheric activity can be used as a secondary indicator of membership. The results of the values of R'_{HK} from Table 5 show that ϕ^2 Cet, 34 Leo, κ^1 Boo, 11 Aql, and HR 7451 may not be members when the relationship of Soderblom and Clements is applied. The membership of both 9 Pup and 110 Her have been questioned on the basis of their chromospheric activity level by Soderblom and Clements (1987), and Walter *et al.* (1984) have questioned the membership of 9 Pup based on its chromospheric emission. But in addition to these four misfits—as judged by their Li content and kinematics, and possibly their chromospheric intensity—we have observed other stars that are probable nonmembers according to Soderblom and Clements based on UV spectra: ϕ^2 Cet, 34 Leo, HD 94686, HD 151044, and HR 7451. (They did not include ι Leo in their survey.) Walter *et al.* (1984) had also cast some doubt on 34 Leo; they did include ι Leo and gave its spectral type as F4 IV and G5 V. If one considers metallicity as a membership criterion, then ι Leo has too high an Fe/H abundance. As mentioned, Levato and Abt (1978) classify ι Leo as F3 III, which makes it too faint in absolute magnitude if it is a cluster member. If in fact it is a giant, its main-sequence predecessor would have been a hotter star that would not have depleted or diluted its Li yet; if that is the case, it should not be plotted along with the dwarf stars in Figure 4.

Without those four stars, the match with the Hyades pattern is very good, as seen in Figure 5*a*. The good match with the Coma Berenices cluster can be seen in Figure 5*b*. The "Li chasm" may be wider in the UMa group stars. On the basis of the available data, we would not include ι Leo as a member and would say that the Li gap at the level of log N(Li) = 2.0 (a pseudo-FWHM) extends from 6550 to 6950 K. This is to be compared to the narrow gap in the Hyades at log N(Li) = 2.0 of 220 K extending from 6550 to 6770 K. But are 80 Psc and HR 5830, which help to define the hot edge of the chasm, members of the UMa group? If they are not, then the hot edge is determined by HR 4803 and κ^1 Boo, making it somewhat narrower. The situation remains unclear; unassailable credentials for UMa group membership and reliable temperatures are needed of sharp-lined stars to define the high temperature side of the Li gap.

The initial Li for the UMa group as determined from the three hot stars 59 Dra, HR 534, and HR 4803 is Li/H $= 1.2 \times 10^{-9}$ or log N(Li) = 3.08. The average of the six stars with temperatures between 5900 and 6400 K (HR 7451, ϕ^2 Cet, HR 8170, HD 151044, χ^1 Ori, and π^1 UMa) is Li/H $= 5.10\,(\pm 0.35) \times 10^{-10}$ or log N(Li) $= 2.71 \pm 0.03$.

The alternate hypothesis is to assume that all the stars are probably members—within the accuracy of the velocity determinations (and the metallicities)—and try to understand the differences in the depletions compared to the Hyades pattern. Inasmuch as the UMa group is half the Hyades' age, it could be argued that whatever is causing the Li depletion in the mid-F stars has not had enough time to act, so that not all the stars are depleted, e.g., ι Leo and HR 4803. Michaud (1986) has attributed the Hyades Li defficiency to diffusion acting below the surface convection zone and depleting the atmosphere of Li. To match the Hyades level of depletion, some mass loss, $\sim 10^{-14}$ $M_\odot$ yr^{-1}, is needed also. Even with no mass loss

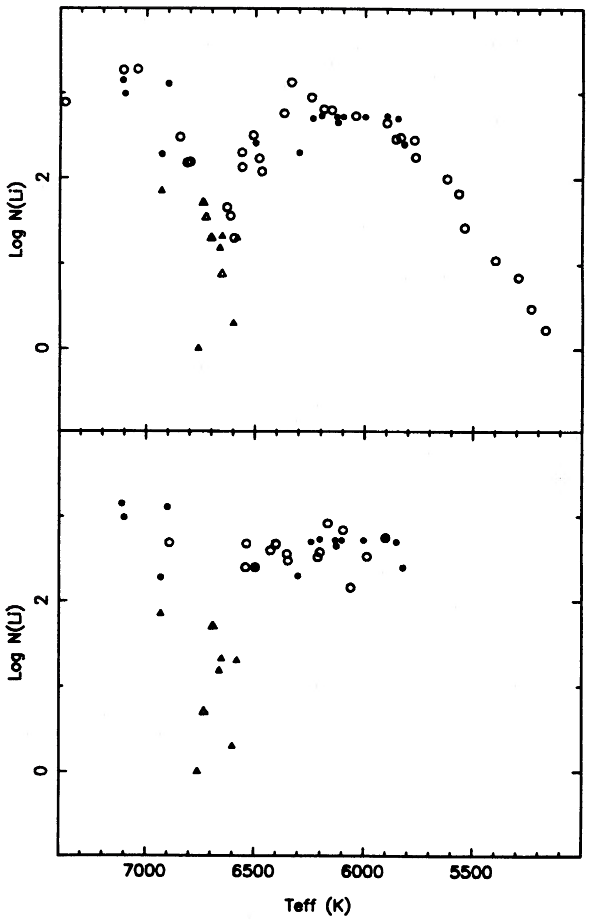

FIG. 5.—The results for log N(Li) for the UMa stars (some with questionable membership credentials are not included), plotted as solid symbols, compared with the Hyades, open symbols, in the upper panel and the Coma Berenices cluster, also open symbols, in the lower panel. Both open and filled triangles represent upper limit values. The UMa points clearly follow the same pattern as the Hyades (and Coma), but the Li gap may extend to higher temperatures in the UMa group than it does in the Hyades. Note that in the temperature region 5800–6400 K the Li-temperature relation is quite flat and the mean value appears to be somewhat less than the stars on the high temperature side of the Li gap. This flatness in the Li-temperature relation is reminiscent of the flatness in this temperature regime found in the halo stars.

though, some reduction in surface Li would be expected if diffusion can act. In contrast to ι Leo, the three cooler stars, 110 Her, 9 Pup, and 11 Aql, have depleted *more* Li than their counterparts, by factors of 7–10. Additional explanations are required for those stars. Have they experienced greater mass loss? less rotation? more effective diffusion? It is possible that the Hyades is an exceptionally well-ordered example of the Li depletion patterns in both the F and the G dwarfs. For other clusters there may be a greater range in other relevant parameters such as rotation, magnetic field strength, individual ages, etc., that influence the Li depletion. The first hypothesis, that those three stars and ι Leo are nonmembers, is clearly more straightforward.

V. CONCLUSIONS

From this study the metallicity of the UMa group is [Fe/H] = -0.079 ± 0.053, based on the 16 stars with the best determined temperatures and abundances. This value is comparable, but more reliable, than the photometrically determined values, e.g., "near -0.1" of Eggen (1983). This result yields the spectroscopic calibration for the photometry needed by Palouš and Hauck (1983). Although the UMa group is *younger* than the Hyades, it appears to have *lower* metallicity. The Hyades at 7×10^8 yr has [Fe/H] = $+0.12 \pm 0.03$ (Cayrel *et al.* 1984), while Coma at 5×10^8 yr has [Fe/H] = -0.07 ± 0.02 (Boesgaard 1987). The metal content of the UMa group is like that of the Coma Berenices cluster. The range in metallicity for the three clusters is 0.20 dex and it is in the opposite sense that one would expect from the enrichment due to galactic chemical evolution. Based on these three examples, there does not seem to be a good relation between age and metallicity for the young clusters in the disk in the solar vicinity. This implies that the mixing of enriched material from which the cluster stars were made was not uniform 3–7 $\times 10^8$ years ago.

The Li-temperature profile for the UMa group resembles that of the Hyades, particularly if the star ι Leo is excluded. Its membership can be challenged on the basis of its ***U*** velocity, its [Fe/H] value, and the conflict between its luminosity class (III) and its absolute magnitude as based on cluster membership. If it is a member and is a giant star, it should not be included on our graph of UMa dwarf stars.

Three other cooler stars, 9 Pup, 11 Aql, and 110 Her, seem not to fit the Hyades pattern in that they are more Li-depleted by factors of 7–10 than their counterparts at those temperatures. The membership of 9 Pup and 110 Her has been questioned on the basis of their ***U*** and ***W*** velocities and on their level of chromospheric activity, while the membership of 11 Aql is in doubt because of its ***U*** velocity and chromospheric activity. Although we think that those stars are not members, if they are, then the extra depletion found in them can result from variations in their initial physical parameters. The stars in this moving group may not have been born as coevally and with as uniform properties, such as rotation and magnetic field strength, as the Hyades. There are theoretical and/or observational reasons to believe that age, rotation, mass loss, metallicity, and magnetism influence Li depletion.

The membership of two other stars can be questioned on kinematical grounds, especially the ***U*** velocities: 80 Psc and HR 5830 although for HR 5830 the parallax is so small that the velocities are all unreliable. The remaining 18 stars seem to be acceptable members based on velocities and Li content, but five others (including the two SB2's) have been questioned because of their chromospheric activity level (Walter *et al.* 1984; Soderblom and Clements 1987).

It is possible that the Li gap in the UMa group is wider than that in the Hyades at the high temperature side. For the Hyades, and apparently for Coma, the width at log N(Li) = 2.0 is 6550–6770 K, only 220 K. For UMa it extends up to ~6900 K. Even in the case that 80 Psc and HR 5830 are nonmembers, we see that hotter stars apparently can deplete Li, even if they do not in the Hyades. Possibly mass loss plays a bigger role for these stars.

The "initial" Li abundance for the UMa group derived from the three undepleted stars on the hot side of the Li gap, 59 Dra, HR 534, and HR 4803, is Li/H = 1.2×10^{-9} or log N(Li) = 3.08. Six probable/possible members in the temperature range 5850–6400 K have a mean Li/H of 5.10 (± 0.35) $\times 10^{-10}$ or log N(Li) = 2.71 (± 0.03). This indicates that some depletion may have already occurred in these cooler stars. This seems to be the case for the Hyades and the Coma clusters also from the appearance of Figures 5*a* and 5*b*, as well

TABLE 7

Li ABUNDANCES IN THE GALACTIC DISK

Group	Age (yr)	log <N(Li)>	σ	n	Li References
Chondrites	4.5×10^9	3.3	±0.07	...	Nichiporuk and Moore 1974
Field Stars	$<2 \times 10^9$	3.01	±0.15	18	Boesgaard and Tripicco 1986b
NGC 752	1.7×10^9	3.0	...	4	Hobbs and Pilachowski 1986
Visual Binaries	1.3×10^9	3.08	±0.14	5	Boesgaard and Tripicco 1987
Hyades	7×10^8	3.1	±0.2	6	Boesgaard and Tripicco 1986a
Coma	5×10^8	$\gtrsim 2.9$	...	2	Boesgaard 1987
UMa Group	3×10^8	3.08	...	3	This paper
T Tau	$\sim 10^6$	3.04	±0.11	5	Mundt, et al. 1983

as for NGC 752 studied by Hobbs and Pilachowski (1986), which at an age of 1.7×10^9 yr has log N(Li) = 2.4 in this temperature region. Another interesting feature of Figures 5*a* and 5*b* is the flatness of the Li-temperature relationship between 5800 and 6400 K. This is very reminiscent of the same flatness found in the halo stars for the group with common [Fe/H] (≤ -1.4) and kinematics ($V_{\rm LSR} \geq 100$ km s^{-1}) as reported by Hobbs and Duncan (1987) in this temperature range. The values of log N(Li) = 2.7 for clusters at $\sim 5 \times 10^8$ yr, then log N(Li) = 2.4 at 1.7×10^9 yr for NGC 752, and log N(Li) = 2.1 for the halo "family" at $\sim 1.5 \times 10^{10}$ yr, provide some empirical support for the speculation that the halo stars have indeed undergone Li depletion over the course of their long lifetimes, presumably by diffusion below the convection zone.

Maximum, and presumably "initial," Li abundances are available for a number of different aggregations of stars. For 18 field stars with ages less than 2×10^9 yr, log N(Li) = 3.01 (±0.15) (Boesgaard and Tripicco 1986*b*); for NGC 752 at 1.7×10^9 yr, it is 3.0 (Hobbs and Pilachowski 1986); for visual binaries with an average age of 1.3×10^9 yr, it is 3.08 (±0.14) (Boesgaard and Tripicco 1987; for the Hyades and Coma at 8×10^8 yr it is 3.1 (±0.2) and greater than ~2.9, respectively; and for the UMa Group at 3×10^8 yr it is 3.1. Within the accuracy of the measurements all of these Population I samples show the same value of Li/H over an order of magnitude in age. The T Tauri stars (Zappala 1972; Mundt *et al.* 1984) and meteorites (Nichiporuk and Moore 1974; Reeves and Myer 1978; Cameron 1982) also show the same value. This information is summarized in Table 7. There is no evidence for significant Li enrichment in the Galactic disk since the formation of the solar system.

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