Astron. Astrophys. 345, 936–942 (1999)

ASTRONOMY AND ASTROPHYSICS

Lithium and rotation on the subgiant branch

I. Observations and spectral analysis*

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Received 13 May 1998 / Accepted 5 March 1999

Abstract. We have obtained new high resolution spectroscopic observations of the lithium line at 6707.81 Å and derived lithium abundances ($A_{\rm Li}$) by spectral synthesis for a sample of about 120 F-, G- and K-type Population I subgiant stars. For each of these stars, high precision rotational velocity obtained with the CORAVEL spectrometer is available. We present the behavior of the lithium abundance as a function of effective temperature, which shows a sort of discontinuity around 5600 K, somewhat later than the well known rotational discontinuity.

Key words: line: profiles – stars: abundances – stars: rotation

1. Introduction

The behavior of the rotation along the subgiant branch of Population I stars is now well established. A sudden drop in rotational velocity near the spectral type F8IV – corresponding to the index color (B$-$V) = 0.55, was first pointed out by Gray & Nagar (1985), and confirmed by de Medeiros & Mayor (1989). On the left side of the rotational discontinuity, namely for stars earlier than F8IV, the Vsini values are spread on a large range, from a few $\rm km.s^{-1}$ to about 180 $\rm km.s^{-1}$. On the right side of the discontinuity, only very few binaries present large rotational velocity, whereas the mean value of Vsini slowly decreases along the G and K spectral regions, from about 6 $\rm km.s^{-1}$ at G0IV to about 1 $\rm km.s^{-1}$ at K5IV (De Medeiros 1990; De Medeiros et al. 1996). Such a discontinuity is attributed to an abrupt magnetic braking due to the deepening of the convective envelope. This induces a very strong dynamo-generated magnetic field, which in turn couples to the stellar wind, reducing the rotational velocity in a very short interval of time (Gray 1981, Gray & Nagar 1985).

When the stars evolve from the main sequence to the subgiant branch, other clear signatures of the sinking of the convective envelope appear at the stellar surface. In particular, the surface lithium abundance is expected to decrease due to dilution when the convection zone reaches the region where this element was previously destroyed by nuclear reactions (Iben 1965). Numerous evolved stars show lithium abundances smaller than expected from standard evolutionary models (see Balachandran 1990, 1993 for references). This can reflect extra lithium depletion either on the main sequence, or/and in later stages in addition to convective dilution. In this context, one needs to investigate the lithium behavior in the spectral region where the rotational discontinuity is observed.

In this paper, we present new lithium line 6707.81 Å high resolution spectroscopic observations and we derive lithium abundances for a sample of about 120 subgiant stars with spectral types ranging from F5IV to K3IV. We combine these data with precise radial and rotational velocity measurements obtained with the CORAVEL spectrometer by de Medeiros & Mayor (1999). On the basis of such a homogeneous and uniform observational data set, we present, for the first time for subgiant stars, the distribution of lithium abundance as a function of the effective temperature.

2. Data and observations

We have selected for this study all the 200 subgiant stars from the "Catalogue of rotational and radial velocities for evolved stars" by De Medeiros & Mayor (1999). However, this present spectroscopic survey involves about 120 stars with reliable measurements. These stars are issued mostly from the Bright Star Catalog and supplement (Hoffleit and Jaschek 1982; Hoffleit et al. 1983), with spectral types ranging from F5IV to K2IV. Bahcall et al. (1987) have shown that the Bright Star Catalog is complete to apparent visual magnitude of about 6.5. This finding is also easily confirmed for our sample of about 120 stars, for which the integral distribution function of the apparent visual magnitude shows that no flattening occurs for visual magnitude lower than about 6.3.

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* based on observations collected at the Observatoire de Haute–Provence (France) and at the European Southern Observatory, La Silla (Chile).

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Our present sample has as main characteristics: the high precision and homogeneity of the rotational and radial velocities as well as, for the lithium line observations, the high resolution spectroscopy and a good signal to noise ratio. We made available at CDS two general tables listing the stars of our present sample (single and binary stars) and displaying basic and observational data: spectral type, (B−V) index, radial and rotational velocities, measured Li equivalent width, binary status.

2.1. The rotational velocity measurements

Rotational velocity discussed in the present work were taken from de Medeiros & Mayor (1999). These ones, obtained with the CORAVEL spectrometer (Baranne et al. 1979), show a typical uncertainty of about 1.0 $\mathrm{km.s^{-1}}$– at least for those stars showing low to moderate rotation rates, typically Vsini values lower than about 50 $\mathrm{km.s^{-1}}$. For rapid rotators (Vsini $>$ 50 $\mathrm{km.s^{-1}}$) the accuracy is about 10%. The reader is referred to de Medeiros & Mayor (1999) for a complete discussion on the observational procedure and error analysis.

2.2. Lithium spectroscopic observations

We observed the spectral region around the lithium line at 6707.81 Å with two different instrumentations: the 1.52m telescope at the OHP equipped with the AURELIE spectrometer (Gillet et al. 1994) and the CAT telescope at ESO/La Silla equipped with the Coude Echelle Spectrometer (Kaper & Pasquini, 1996). For northern star observations at OHP, the covered spectral range was 120 Å large, the resolving power was R = $\lambda/\Delta\lambda$ = 45,000, the linear dispersion 4.59 Å/mm and the signal-to-noise ratio between 45 and 150. For southern star observations at ESO, the covered spectral range was 56 Å large, the resolving power was 95,000, the linear dispersion 1.83 Å/mm and the signal-to-noise ratio between 75 and 200.

For data reduction we used the ESO IHAP software and we performed the wavelength calibration in the stellar rest frame using the radial velocities determined with the CORAVEL (de Medeiros & Mayor, 1999). These radial velocity measurements present an uncertainty of about 0.3 $\mathrm{km.s^{-1}}$. Finally, the observed spectra have been normalized to a pseudo–continuum via cubic spline function.

Table 1. Northern and southern single stars (Part 1): rotational velocity, stellar parameters and derived Fe and Li abundances. The derived Li abundances have an expected error always smaller than ±0.2 dex.

HD	Vsini	$T_{\rm eff}$	log g	[Fe/H]	$A_{\rm Li}$	comment
400	5.6	6208	4.13	-0.2	2.3	(s)
645	1.8	4830	3.30	-0.1	0.5	(a)
3229	5.0	6280	3.81	-0.2	<1.3	(s)
3303	1.0	4850	3.30	<-0.3	<0.4	(a)
5268	<1.0	4755	4.00	<-0.3	<0.4	(d),(s)
6269	4.8	6020	3.98	0.2	<0.9	(a),(s)
6301	20.3	6400	4.11	0.0	<1.0	(s)
9562	4.2	5801	3.60	0.1	2.4	(s)
10142	2.5	6020	3.95	>0.3	<1.1	(a),(s)
12235	5.2	6180	4.10	0.3	<1.3	(s)
12583	1.5	4890	3.60	0.0	<0.4	
13421	9.9	6170	3.79	0.3	<1.3	(s)
16417	2.0	5848	4.51	0.1	1.8	(s)
18907	1.2	5471	4.41	-0.3	1.1	(s)
26923	4.3	5968	4.37	0.0	2.8	(s)
27536	<1.0	5200	3.00	-0.1	1.2	
29613	<1.0	6000	3.82	0.2	<1.5	(b),(s)
33021	<2.0	5822	3.91	-0.2	2.0	(s)
34642	6.9	4850	3.30	0.0	<0.3	
41700	16.1	6139	4.35	0.0	2.8	(s)
48737	70	6464	3.81	0.0	3.2	(c),(s)
60532	8.1	6120	3.68	0.0	1.6	(s)
66011	13.6	6140	3.69	0.3	<1.2	(s)
72954	1.7	5420	4.00	<-0.3	<0.4	
75487	20.9	6608	3.93	0.0	3.2	(s)
78154	5.8	6150	3.94	0.0	<1.1	(s)
80956	2.0	5120	3.50	<-0.3	<0.5	(a)
82074	<2.1	5188	3.50	<-0.3	<0.3	
82210	5.5	5650	3.58	0.1	<1.5	(s)
82734	3.8	4840	3.30	>0.3	1.1	
85655	1.4	3930	3.20			(e),(s)
89449	17.3	6440	4.22	0.1	<1.3	(s)
92588	<1.0	6030	4.07	0.3	<1.0	(s)
94386	<1.0	4560	3.20	0.2	<0.2	
99491	2.6	6030	4.09	>0.3	1.4	(a),(s)
100219	5.2	6370	4.32	0.2	<1.4	(s)
104055	<2.0	4500	3.20	0.3	<0.2	(d)
105678	29.6	6220	3.93	0.1	<1.6	(c),(s)
107295	3.7	5300	3.60	0.2	<0.5	

3. Determination of lithium abundances

3.1. Stellar parameters: effective temperature and surface gravity determination

Special care should be done for the $T_{\rm eff}$ estimations since the derived Li abundances are rather sensitive to this parameter. Most of the stars in the present work fall into the spectral range for which the Strömgren $ubvy\beta$ photometry offers a reliable way to determine effective temperature and surface gravity. Calibrations for Strömgren index are available from different authors (Magain 1987; Moon 1985; Schuster and Nissen 1989). For our sample we have applied the calibration from Moon (1985) to obtain $T_{\rm eff}$ and log g, that essentially consists of an interactive program which dereddens $ubvy$ colors and estimates $T_{\rm eff}$ and log g from observed $ubvy$ photometry. Such a procedure was applied for about 95 stars of the present sample with Strömgren photometric index available in the literature. For the stars with no available Strömgren photometric index we have estimated the effective temperature from Böhm-Vitense (1981) with an accurate relationship Log$T_{\rm eff}$ versus (B−V) index for subgiant stars. For these later stars log g was estimated from a log g versus spectral type calibration from Schmidt-Kaler (1982). All the estimated effective temperatures and surface gravities are given in Tables 1, 2 and 3.

We have compared the $T_{\rm eff}$ values computed in the present work with those available in the literature, obtained from differ-

Table 2. Northern and southern single stars (Part 2).

HD	Vsini	$T_{\rm eff}$	log g	[Fe/H]	$A_{\rm Li}$	comment
119992	8.3	6293	4.38	0.0	2.7	(s)
124570	5.6	6220	4.01	-0.3	2.8	(a),(s)
125451	46.0	6780	4.54	0.2	<1.8	(c),(s)
126400	1.4	4970	3.40	<-0.3	<0.3	(a)
127243	3.6	5580	3.01	-0.1	<0.6	(s)
127986	5.7	6310	3.90	0.1	<1.6	(s)
130945	18.7	6480	4.11			(c),(e),(s)
131040	29.2	6760	4.34	0.2	2.7	(s)
133484	21.2	6330	3.61	0.1	2.7	(s)
136064	5.0	6210	4.08	0.2	2.0	(s)
136202	4.8	6120	3.50	0.1	<1.0	(s)
150012	35.5	6457	3.39	0.0	2.5	(s)
151769	11.3	6350	3.70	0.2	<1.2	(s)
154160	1.2	5750	3.30	> 0.3	1.6	(s)
156846	4.9	6180	3.88	0.2	<0.8	(s)
162003	12.9	6406	3.50	0.0	2.6	(s)
162076	3.2	4970	3.50	0.3	1.1	
163989	5.0	6240	4.11	0.1	<1.0	(s)
164507	2.2	5590	3.50	0.3	<0.5	(s)
176095	13.2	6300	4.20	-0.1	2.9	(s)
176668	1.6	5050	3.50	-0.2	< 0.3	
181096	6.6	6240	3.95	-0.2	<1.1	(s)
191570	36.3	6635	4.32	> 0.3	2.6	(a),(s)
196755	3.3	5500	3.50	-0.2	1.1	(s)
197373	30.9	6580	4.41	0.0	<1.0	(s)
201507	70	6780	3.69			(e),(s)
202582	3.1	5986	4.47	0.0	2.2	(s)
207978	7.2	6320	4.15	<-0.3	<1.0	(s)
208177	80	6170	3.34	0.0	2.3	(c),(s)
213051	68	6340	3.60	-0.3	3.0	(s)
215648	7.9	6225	4.25	-0.2	2.3	(s)
216385	5.9	6370	3.40	0.0	<1.2	(s)
218640	6.4	5640	3.60	>0.3	<1.3	(a),(d),(s)
219291	53.1	6170	3.39			(e),(s)
223346	18.5	6220	3.83	-0.2	<1.0	(s)

ent calibrations, for a common sample of 14 stars (Balachandran 1990; Pallavicini et al. 1986; Randich et al. 1993; Brown et al. 1989). Table 4 presents these common data, and shows a good agreement with a r.m.s. of the $T_{\rm eff}$ differences of about 100 K and log g of 0.2 dex. However, an extreme discrepancy in $T_{\rm eff}$ is found for HD 219 834, and seems to be associated, in principle, with the different procedures applied in this work and in Pallavicini et al. (1986). These authors have derived a temperature for HD 219 834 by using (B$-$V) colors. In this context, we have also estimated $T_{\rm eff}$ values for all the stars of our present sample, by using the Log$T_{\rm eff}$ versus (B$-$V) from Böhm-Vitense (1981). Except for a few stars, HD 6269, HD 10142, HD 29613, HD 92588, HD 99491, HD 157853 and HD 219834, the values of $T_{\rm eff}$ based on Strömgren and on Böhm-Vitense colors present a very good agreement. In fact the stars presenting important discrepancy are mostly binaries or single K-type stars. In particular the stars HD 157853 and HD 219834 are confirmed spectroscopic binary systems. For these later, the presence of

Table 3. Northern and southern binary stars. The * indication on the name of the star stands for suspected binaries, i.e. stars presenting some variability on the radial velocity but their binarity status is not yet completly confirmed.

HD	Vsini	$T_{\rm eff}$	log g	[Fe/H]	$A_{\rm Li}$	note
*4813	3.9	6202	4.44	-0.1	2.8	(s)
11443	80	6240	3.71	0.0	<1.3	(s)
19826	2.7	5284	3.01	0.0	1.1	(s)
*26913	3.9	5630	3.90	-0.2	2.2	(s)
32503	<1.0	4490	3.30	-0.2	<0.4	
*34411	1.9	5857	4.02	0.0	2.0	(s)
61421	6.1	6250	3.57	-0.1	<1.3	(s)
73752	4.4	5470	3.50	0.0	1.3	
78418	1.7	5040	4.20	<-0.3	1.3	
*82328	8.3	6360	4.10	-0.1	3.3	(s)
82543	4.8	6220	3.28	>0.3	<1.6	(a),(s)
89010	3.5	5756	3.90	0.1	2.3	(s)
102713	11.5	6362	3.82	-0.1	3.1	(s)
*104304	2.0	5500	4.23	0.2	<0.9	(d),(s)
104307	1.1	4450	3.30	0.2	<0.1	
107700	3.9	6760	3.26	>0.3	2.5	(a),(s)
*120136	15.4	6370	3.70	>0.3	<1.6	(s)
121370	13.0	6160	3.71	>0.3	<1.1	(s)
123999	12.7	6135	4.00	-0.1	2.4	(s)
*125184	1.3	5592	3.68	0.2	<0.8	(s)
*126868	14.4	5540	3.20	0.0	2.4	(s)
137052	10.2	6373	3.90	0.0	3.0	(s)
*137510	6.9	6080	3.78	>0.3	<1.1	(s)
*139777	5.4	5710	3.70	0.1	3.0	
142267	2.0	5830	4.54	-0.3	<1.2	(s)
*142980	<1.0	4590	3.30	0.3	<0.4	
144070	19.4	6490	3.70	0.0	2.8	
144284	28.	6290	4.00	0.2	1.8	(s)
*144585	3.7	5690	3.50	>0.3	<1.5	(a),(s)
150680	4.8	6010	3.86	-0.3	<1.0	(s)
*155078	52.5	6430	4.00	0.0	2.6	(s)
*157853	3.2	6240	3.57	0.3	2.2	(a),(s)
*158170	8.0	6300	3.42	0.2	<1.2	(s)
*161797	1.7	5400	4.00	0.2	1.1	(d),(s)
172088	7.5	6062	4.11	0.0	2.4	(a),(s)
186185	15.6	6450	4.01	0.1	<1.0	(s)
190771	2.7	5710	3.50	0.0	2.3	
196524	49.8	6450	3.50	0.0	3.0	(s)
196885	7.8	6102	4.21	0.2	2.6	(s)
198084	4.1	6121	4.07	0.0	<1.0	
199766	32.2	6470	4.12			(c,e,s)
206901	11.7	6560	4.00	-0.3	2.9	(s)
210334	50.	5500	3.60			(c),(e)
218804	17.8	6222	4.00	-0.3	<1.0	(d),(s)
219834	3.1	5760	3.70	<-0.3	<0.4	(c),(s)

(a) The FeI features are not very well fitted.
(b) Li line is blended with some unknowned feature.
(c) Due to high rotational velocity, the Li abundance determination is unaccurate or impossible
(d) stellar parameters($T_{\rm eff}$, log g, [Fe/H]) from Cayrel et al. (1997)
(e) Complex spectrum; Li abundance estimation is impossible
(s) Strömgren photometric index available.

the companion could affect the observed colors and, therefore, the estimated effective temperatures. For two stars, HD 27536 and HD 133484, Table 4 shows also a significant discrepancy in $\Delta\log g > 0.5$ dex. These parameters, $T_{\rm eff}$ and log g, were also systematically checked when fitting the observations with synthetic spectra.

3.2. Spectral synthesis and abundance of lithium

We generated synthetic spectra over the whole observed spectral range common to the northern and southern stars (i.e., from 6 675 to 6 735 Å). Model atmospheres were interpolated into a new grid of models computed with an enhanced version of the original MARCS code (Asplund et al. 1997). The models are flux constant, plane-parallel, line-blanketed, hydrostatic, in LTE and convective flux in the mixing-length approximation. They were calculated for a microturbulence parameter $\xi_{\rm micro} = 2.0~{\rm km.s^{-1}}$ and solar composition. Our line list includes atomic lines from VALD (Piskunov et al. 1995) with some gf-values corrected using the Holweger-Müller solar model (1974), solar chemical abundances from Grevesse et al. (1996) with $A_{\rm Li}$ = 1.16 (where $A_{\rm Li}$ = log($n_{\rm Li}/n_{\rm H}$) + 12) and the Kurucz solar flux atlas (Kurucz et al. 1984). The accurate data of Andersen et al. (1984) are used for the Li I 6 707 features. The fine structure of the Li doublet was taken explicitely into account and we assumed that Li was entirely $\rm Li^7$. The broadening by radiation and van der Waals damping were calculated as in de Laverny & Gustafsson (1998) and Edvardsson et al. (1993). The classical van der Waals damping constant of the Li lines was multiplied by a factor 1.5 (Andretta et al., 1991). ^{12}CN and ^{13}CN lines from Jørgensen & Larsson (1990), with line positions corrected as in de Laverny & Gustafsson (1998), were also included. After some minor corrections of our line list and comparison with the works of Cunha et al. (1995) and King et al. (1997), we got a very good fit of the solar spectrum.

The synthetic spectra of the subgiants were convolved to mimic the stellar rotation and the instrumental profile. We considered a starting value of 1.0 ${\rm km.s^{-1}}$ for the microturbulence parameter, and only minor corrections were sometimes done to improve the fit. We furthermore assumed for these stars evolving from the main sequence to the red giant branch (RGB) a carbon isotopic ratio ^{12}C/^{13}C= 60, intermediate value between the solar ^{12}C/^{13}C and estimates at the base of the RGB (Charbonnel, 1994).

Through comparison of synthetic and observed spectra, the goal was first to constrain the iron abundance since the Fe I 6 707.4 line blends the Li feature. We checked the derived stellar metallicity with other metal lines. Then, the Li abundance was determined and is reported in Tables 1, 2 and 3, together with the estimated [Fe/H]. In Fig. 1, we present the Li I 6707.81 Å spectral region for some relevant observed and synthetic spectra.

A classical error analysis shows that a change in $T_{\rm eff}$ by $\pm$200 K results in a change of [Fe/H] of $\pm$0.07 dex. Varying log g by $\pm$0.5 dex and the other stellar parameters has only weak effects on the derived iron abundance. Combining all these

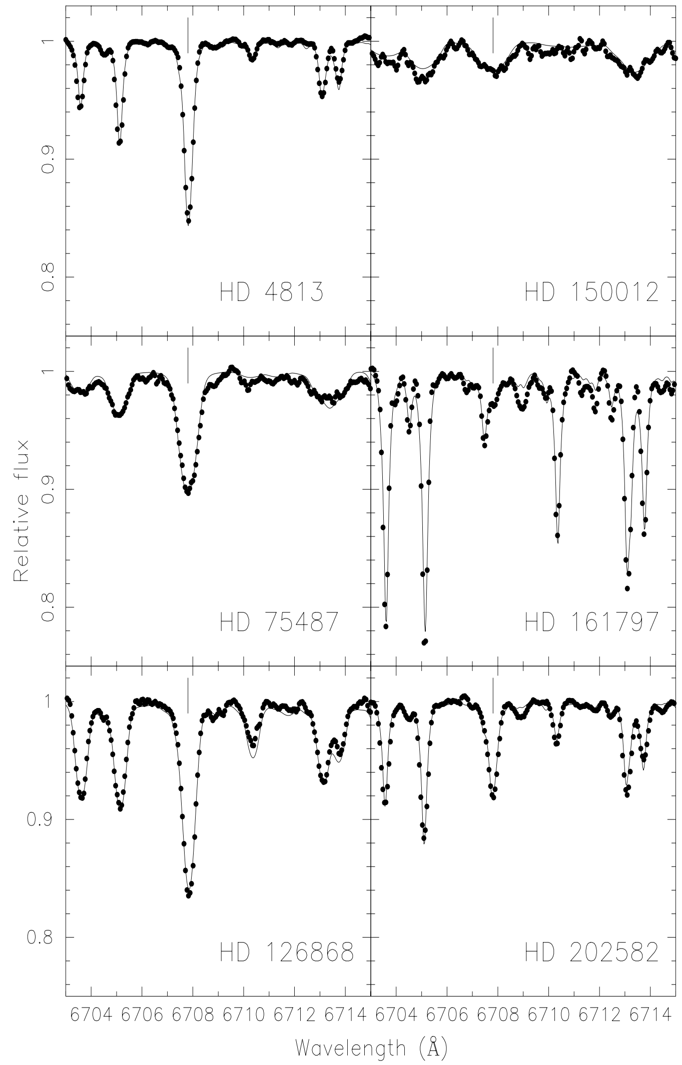

Fig. 1. Lithium line 6707.81 Å observed spectral region (dashed line) and its synthetic spectrum (thin line). The Li I line is indicated with a short and vertical line.

sources of errors, we find a final expected uncertainty for the derived Fe abundances smaller than $\pm$0.1 dex. On another hand, $A_{\rm Li}$ is much more sensitive to the effective temperature of the models. A variation of $\pm$100 K and $\pm$200 K in $T_{\rm eff}$ changes the Li abundance by $\pm$0.09 dex and $\pm$0.19 dex, respectively. We checked that the Li abundance is almost insensitive to the stellar gravity and to the microturbulence parameter. Since we considered model atmospheres with solar composition for the whole sample, we also compared synthetic spectra computed from models with metallicity in the range +0.5 dex to -0.5 dex. The Fe lines are not strongly affected by these variations. The Li abundance is found rather insensitive to the metallicity adopted in the model atmosphere for Li-poor spectra. For extreme Li-rich stars, adopting a model atmosphere with a metallicity varying by $\pm$0.5 dex could however lead to an error of $\pm$0.1 dex in $A_{\rm Li}$. Finally, the Li abundances derived in this work have an expected error always smaller than $\pm$0.2 dex and most probably close to $\pm$0.1 dex.

Table 4. Comparison between the stellar parameters, Li and Fe abundances of this work and previous studies.

HD	This work				Previous studies				
	$T_{\rm eff}$	log g	[Fe/H]	$A_{\rm Li}$	$T_{\rm eff}$	log g	[Fe/H]	$A_{\rm Li}$	Ref.
400	6208	4.1	-0.2	2.3	6071	4.2	-0.4	2.3	(a)
9562	5801	3.6	0.1	2.4	5800			2.5	(b)
27536	5200	3.0	-0.1	1.2	5100	3.7	0.0	1.1	(c)
					4900			0.7	(b)
82328	6360	4.1	-0.1	3.3	6364	4.1	-0.1	3.3	(a)
123999	6135	4.0	-0.1	2.4	6221	4.1	0.0	2.6	(a)
126868	5540	3.2	0.0	2.4	5495	3.2	-0.2	2.3	(d)
133484	6330	3.6	0.1	2.7	6572	4.2	0.2	3.0	(a)
137052	6373	3.9	0.0	3.0	6405	4.0	-0.3	3.1	(a)
155078	6430	4.0	0.0	2.6	6439	4.1	0.0	2.6	(a)
176095	6300	4.2	-0.1	2.9	6293	4.0	-0.1	2.9	(a)
196885	6102	4.2	0.2	2.6	6388	4.3	0.2	2.8	(a)
206901	6560	4.0	-0.3	2.9	6579	4.0	-0.4	3.1	(a)
215648	6225	4.2	-0.2	2.3	6176	4.2	-0.4	2.5	(a)
219834	5760	3.7	-0.4	$<$0.4	5250			1.7	(b)

(a) Balachandran (1990)
(b) Pallavicini et al. (1986)
(c) Randich et al. (1993)
(d) Brown et al. (1989)

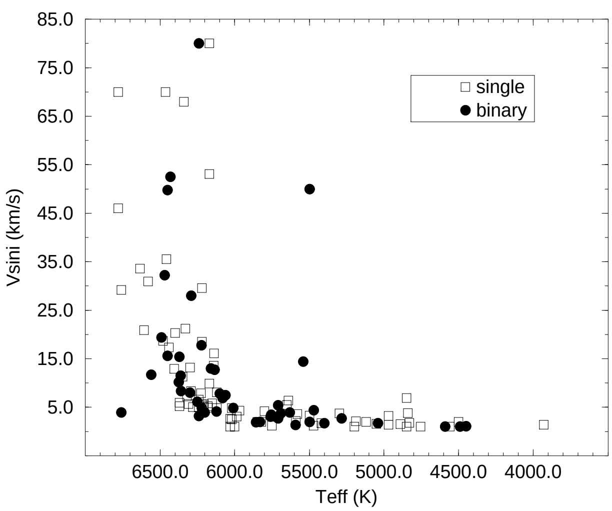

Fig. 2. Rotational velocity as a function of the effective temperature. The well–defined cut–off appears around $T_{\rm eff}$ = 6200 K (i.e, B$-$V = 0.55 or spectral type F8IV).

LTE has been assumed in this abundance analysis. We have checked the validity of this assumption using the results of Carlsson et al. (1994). The non-LTE corrections are always much smaller than 0.1 dex for the hottest stars of the sample (whatever metallicity and gravity). Non-LTE effects are however stronger for cooler stars with low $A_{\rm Li}$. They can reach up to $\sim$0.3 dex for $T_{\rm eff}$ = 4 500 K, log g = 4.0, solar composition and $A_{\rm Li}$ = 1.0. Therefore, non-LTE effects should be taken into account only for the coolest and Li-poorest stars, since they can be larger than the expected errors of the abundance analysis.

Before discussing the results of the present work we intend to illustrate how accurate are our lithium abundances. We compare our abundance determinations with previous works in Table 4. For most stars in common, our results are in good agreement. Except for HD27536 and HD 219834 for which the adopted effective temperature strongly differs with respect to Pallavicini et al. (1986), the r.m.s of the abundance differences for the other stars listed in Table 4 is indeed close to 0.12 dex. Moreover for binaries, the contribution from the secondary is largely unknown and it can alter the observed colours (then the derived effective temperature) as well as the spectrum of the primary, thus leading to larger incertitude on the derived abundances.

Regarding stellar metallicity on its own, rather good agreements (r.m.s. $\sim$ 0.08 dex) are also found with determinations reported in Cayrel de Strobel et al. (1997).

4. Lithium and rotation behaviors

4.1. The rotational dicontinuity

In Fig. 2 we present the rotational velocity as a function of the effective temperature we derived for all the stars of our sample. The rotational discontinuity near 6200 K (B$-$V = 0.55 or F8IV) is very clear. The broad range of values of the Vsini on the left side of the rotational discontinuity certainly reflects the distribution of rotational velocities for the progenitors of the Pop I subgiant stars while they were on the main sequence. On the right side of the discontinuity, the gradual decrease of the rotation with colors along the G to K spectral regions is also very clear. All the stars have low rotation rates (< 10 km.s^{-1}) except for the binary stars HD 210334 and HD 126868. HD 210334 is already known as a component of a synchronized binary system (Batten et al. 1989; Strassmeier et al. 1993), and its high rotational velocity should be due to the synchronisation itself.

4.2. The lithium behavior

4.2.1. Single stars

In Fig. 3, we present the derived lithium abundance as a function of the effective temperature for the single stars of our sample. The rotational velocity is also indicated. One can see an obvious decreasing feature of the lithium abundance. Moreover for the slow rotators (smallest symbols) the lithium behavior displays a sort of discontinuity around 5,600 K - 5,700 K; no subgiants cooler than this value show high lithium abundance.

For the stars hotter than this value, the distribution presents a large dispersion both in the lithium abundance (many stars even present only upper limits) and in the rotational velocity. This reflects the fact that, depending on their masses and histories, some stars already deplete their lithium while they were on the main sequence (e.g. Pasquini et al. 1994 for G stars). In addition, for most of the slow rotators, rotational braking very probably occurred on the main sequence, where it can have led to lithium destruction as suggested by Zahn (1987, 1992). In order to disentangle these effects, it seems important to study the stellar mass distribution of our sample stars; this will be done in a forthcoming paper. For the stars showing nearly cosmic lithium abundance, the more rapid the rotator, the more important the lithium abundance is.

For the stars cooler than 5,600 K all single stars are slow rotators presenting also low lithium abundances ($A_{\rm Li} \leq 1.5$). Many stars even show only upper limits.

In a parallel study, de Medeiros et al. (1997) have suggested, on the basis of a combination of lithium abundance from the literature for a limited sample of 65 stars, the existence of a similar discontinuity in the abundance of lithium for subgiant stars paralleling the rotational discontinuity at F8IV which corresponds to a (B−V) of about 0.55. Nevertheless, the present large and homogeneous data sample reinforces our previous results (Lèbre et al. 1996) and allows us to conclude that a shift exists in the location of the discontinuities, the lithium abundance decreasing later than the sudden decline in rotation.

4.2.2. Binaries

Another important result of the present study emerges from Fig. 4, in which we present the distribution of the lithium abundance as a function of the effective temperature for both single and binary subgiants. The decrease in lithium content with decreasing $T_{\rm eff}$ is again well observed. However, the lithium discontinuity for the binaries appears at a somewhat lower value of $T_{\rm eff}$. Indeed, around $T_{\rm eff}$ = 5,400 K, a few binary stars (HD 26913, HD 89010, HD 139777, HD 126868 and HD 190771) show lithium abundance enhanced compared to their single counterparts at the same $T_{\rm eff}$. This fact is already known for cool halo and old disk dwarf stars (Zahn, 1994; Spite et al., 1994) and is also observed in the Hyades (Soderblom et al. 1990). Several works also mentioned Li enhancement in active binaries. However for Population I subgiants this find seems to be the first one presented up to date.

For both single and binary sub-giants, there is no clear correlation between rotational velocity and lithium abundance.

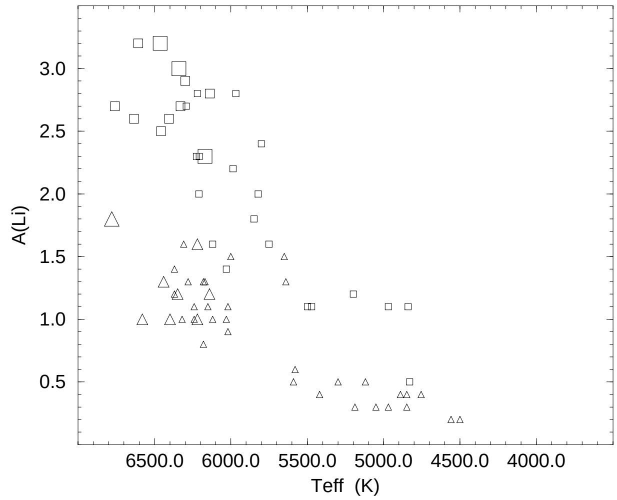

Fig. 3. Lithium behavior as a function of the effective temperature for single stars only. Triangles stand for upper limit. The size of the symbols (squares and triangles) is proportional to the Vsini of the star: V sin i < 10 km.s^{-1} for the smallest; 10 km.s^{-1} $<$ V sin i $<$ 40 km.s^{-1} for the intermediate; 40 km.s^{-1} $<$ V sin i for the largest

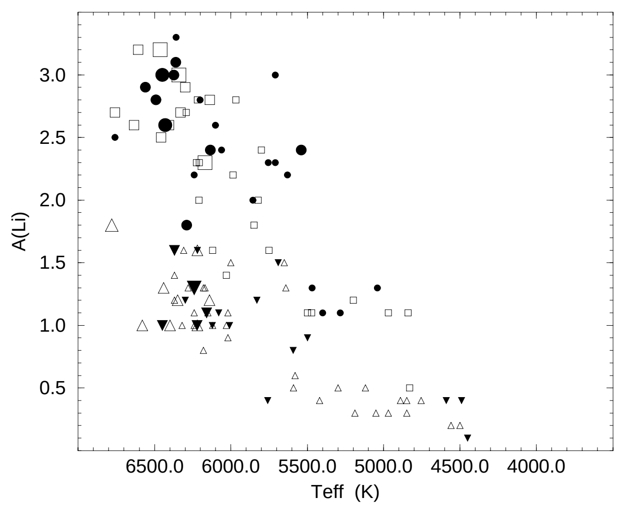

Fig. 4. Lithium abundance as a function of effective temperature for all the program stars. Single and binary stars are represented with open squares and filled circles, respectively. Triangle symbols stand for upper limit in both case (single/binary). The size of the symbols is proportional to the Vsini of the star as indicated in Fig. 3

5. Conclusions

We performed new high resolution spectroscopic observations of the lithium line 6707.81 Å for a large sample of about 120 field subgiant stars. We derived lithium abundances and we present the behavior of lithium abundance as a function of effective temperature.

We confirm the presence of a sudden decrease in the lithium abundance of single subgiants around $T_{\rm eff}$ = 5,600 K, corresponding to a spectral type near G2IV. Such a feature occurs slightly later than the rotational discontinuity at F8IV. No single subgiants cooler than $T_{\rm eff}$ = 5,600 K show high lithium abundance. For binaries the lithium distribution presents a decrease at still a slightly lower $T_{\rm eff}$ value. Binaries with 5,400 K $< T_{\rm eff} <$ 5,700 K present indeed larger lithium content than their single counterparts. A close examination of the stellar parameters is now needed in order to understand the effects of the binary environment on the lithium depletion in subgiant stars.

In a forthcoming paper, we will perform comparisons with theoretical evolutionary models in order to analyse the physical processes that underline the rotational and lithium discontinuities.

Acknowledgements. The authors would like to thank the referee, Lucas Pasquini, for valuable suggestions. M. Asplund is warmly thanked for computing the grid of model atmospheres. Data from the VALD data base at Vienna, Austria, were used for the preparation of this paper. This work has made use of the SIMBAD data base and the Vizier tool, operated at the CDS, Strasbourg, France. Patrick de Laverny acknowledges financial support from the *Société de Secours des Amis des Sciences*. J.R. de Medeiros acknowledges partial financial support from the CNPq Brazilian Agency.

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