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ASTRONOMY AND ASTROPHYSICS

Late-type giants with infrared excess

I. Lithium abundances*

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Abstract. de la Reza et al. (1997) suggested that all K giants become Li-rich for a short time. During this period the giants are associated with an expanding thin circumstellar shell supposedly triggered by an abrupt internal mixing mechanism resulting in the surface Li enrichment. In order to test this hypothesis twenty nine late-type giants with far-infrared excess from the list of Zuckerman et al. (1995) were observed in the Li-region to study the connection between the circumstellar shells and Li abundance. Eight giants have been found to have log ϵ(Li) $>$ 1.0. In the remaining giants the Li abundance is found to be much lower.

HD 219025 is found to be a rapidly rotating (projected rotational velocity of 23 ± 3 km s^{-1}), dusty and Li-rich (log ϵ(Li) = 3.0 ± 0.2) K giant. Absolute magnitude derived from the Hipparcos parallax reveals that it is a giant and not a pre-main-sequence star. The evolutionary status of HD 219025 seems to be similar to that of HDE 233517 which is also a rapidly rotating, dusty and Li-rich K giant.

The Hipparcos parallaxes of all the well studied Li-rich K giants show that most of them are brighter than the "clump" giants. Their position in the H-R diagram indicates that they have gone through mixing and the initial abundance of Li is not preserved. There seems to be no correlations between Li abundances, rotational velocities and carbon isotope ratios. The only satisfactory explanation for the overabundance of lithium in these giants is the creation of Li by the extra deep mixing and the associated "cool bottom processing".

Key words: stars: abundances – stars: circumstellar matter – stars: evolution – stars: individual: HD 219025 – stars: late-type – infrared: stars

1. Introduction

About one percent of G-K giants show strong Li lines. Some of the Li-rich giants show Li abundances larger than that of the interstellar medium (log ϵ(Li) = 3.1, da Silva et al. 1995a,b). The overabundance of Li is unexpected from the standard first dredge-up evolutionary models, which predicts a strong Li depletion. Lithium is expected to be destroyed in all but the outermost layers (1 to 2 percent by mass) of a main-sequence star. On ascent of the red giant branch, a deepening convective envelope dilutes the remaining lithium and so reduces the photospheric lithium abundance by a large factor. G and K giants are therefore expected to have very low lithium abundances as a result of convective dilution. Iben's (1967 a,b) models of solar metallicity predict the dilution at the tip of the red giant branch to amount to a factor of 60 for a 3 $M_\odot$ star to a factor of 28 for a 1 $M_\odot$ star. Therefore the red giants of solar metallicity are expected to have a maximum Li abundance of log ϵ(Li) $\leq$ 1.5, assuming that their main-sequence progenitors retained the log ϵ(Li) = 3.0. However, since many main-sequence stars show significant amount of dilution of Li, theoretical predictions refer to the maximum amount of Li abundance expected in a red giant. From observations of large sample of G and K giants it has been found that the average Li abundance in a typical G-K giant is of the order of log ϵ(Li) = 0.1 (Brown et al. 1989). This clearly indicates that there is extra Li dilution during the evolution from the zero age main-sequence phase to the tip of the red giant phase. However, a few (of the order of one percent) of the red giants have been observed to have lithium abundances in excess with the standard predictions (Wallerstein and Sneden 1982, Gratton and D'Antona 1989, Brown et al. 1989, Pilachowski et al. 1990). Some of these Li-rich G and K giants have been found to have Li abundance log ϵ(Li) = 3.0 and higher than the present interstellar medium abundance (da Silva et al. 1995a,b, de la Reza and da Silva 1995, de la Reza et al. 1996). Recently it has been found that several of these Li-rich red giants have infrared excesses, interpreted as associated circumstellar dust shells (Gregorio-Hetem et al. 1993, Castilho et al. 1998, de la Reza et al. 1997). Gregorio-Hetem et al. (1993) studied the IRAS colours of Li-rich G and K giants and concluded that the Li-rich giants define a locus on the IRAS color-color diagram (see also Castilho et al. 1998, de la Reza et al. 1997).

Recently, Zuckerman et al. (1995) from an analysis of IRAS point source catalogue have found that about one percent of G and K giants have circumstellar dust. From a similar analysis

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* Based on observations obtained at the European Southern Observatory, La Silla, Chile, and at the Observatoire de Haute Provence, France.

of the IRAS data Plets et al. (1997) also found several G and K giants with infrared excess. Since the post-main-sequence, first-ascent giants are not expected to show overabundance of Li and circumstellar dust, several theories have been proposed to explain the overabundance of Li and also to account for the circumstellar dust in G and K giants (Plets et al. 1997, de la Reza et al. 1996, 1997). De la Reza et al. (1996, 1997) proposed a scenario linking the high Li abundance of some of these stars to the evolution of circumstellar shells. In this model, every K giant becomes Li-rich during the red giant branch stage, and the internal mixing mechanism responsible for the Li enhancement will initiate a prompt mass-loss event. Recently, de la Reza et al. (1997) discovered several Li-rich giants with large infrared excesses. These Li-rich giants have not yet reached the AGB, and most of them are first-ascent low mass giants and have not experienced hot bottom burning. Therefore the overabundance of Li and circumstellar dust is a puzzle. In fact the study of Pilachowski et al. (1993) shows that there is extra lithium depletion by large factors occurring on the RGB subsequent to first dredge-up.

In order to further understand the connection between the infrared excess (circumstellar dust) and Li abundance in G and K giants we have obtained high resolution spectra of several G and K giants with circumstellar dust. The G and K giants with far-infrared emission excess were selected from the list published by Zuckerman et al. (1995). An analysis of the high resolution spectra of these stars in the Li line region is presented in this paper, first of a series. Other papers will follow with spectroscopic analysis of the same stars in other wavelength regions and with CORAVEL data.

2. Observations

In this research work we use spectra obtained during three observing runs: two at the Observatoire de Haute Provence (France), from February 7 to February 11, 1997 and from July 31 to August 6, 1997; one at La Silla (ESO, Chile) in remote mode from Garching (Germany) from May 29 to June 2, 1997.

For northern stars high-resolution spectra (R$\approx$ 0.17 Å) centered on the Li λ6708 Å line were obtained with the *Aurélie* spectrograph (Gillet et al. 1994) installed on the 1.52m telescope at Observatoire de Haute Provence. This spectrograph uses a cooled 2048-photodiode detector forming a $13\,\mu$m pixel linear array. The entrance spherical diaphragm was $3''$. A grating with 1800 grooves mm^{-1} was used, giving a mean dispersion of 4.7 Å mm^{-1}. The spectral coverage was about 120 Å.

For southern stars, high-resolution spectra (R$\approx$ 0.10 Å) were obtained with the Coudé Echelle Spectrometer (CES) mounted on the Auxiliary Telescope (CAT) at La Silla, in the Long Camera mode. An RCA high resolution CCD with 640 x 1024 pixels was used as detector. The pixel size was $15 \times 15\,\mu$m corresponding to 0.56$''$ and 0.45$''$ in the dispersion and slit directions respectively. The spectral coverage was about 77 Å.

Spectrophotometric flux standards recommended by Massey et al. (1988), Breger (1976) and Taylor (1984) were observed several times each night. Thorium lamps were observed before and after each stellar observation for wavelength calibration. At the beginning, the end and the middle of each night, a series of flat-fields were obtained using an internal lamp (Tungstene or quartz). Flat-field corrections and wavelength calibrations were performed at Montpellier using the MIDAS package.

We have selected G and K giants with far infrared excess from the paper of Zuckerman et al. (1995). All these stars are IRAS sources with significant fluxes in 12, 25 and 60 microns and with flux quality flags 3 or 2. The IRAS fluxes of our program stars and their 25 and 60 micron excess can be found in the papers of Zuckerman et al. (1995) and Plets et al. (1997). In all we obtained the spectra of 29 giants (Table 1) in the Li region. All the spectra have a signal to noise ratio about 100.

3. Analysis

We adopted the same spectral synthesis method as Lèbre et al. (1998) to derive the resonance Li I line ($\lambda 6708$ Å) abundances. We refer to this paper for a description of our abundance analysis assuming LTE. Only minor changes were done and are described below.

3.1. Atmospheric parameters

All the red giants that we selected for the present study have well determined spectral types and colors. In order to determine the effective temperature of our program stars we used the effective temperature scales of G and K giants given by Bell & Gustafsson (1989), Dyck et al. (1996) and Perrin et al. (1998). The spectral type, color, and effective temperature calibration for red giants derived by Perrin et al. (1998) and Bell & Gustafsson (1989) are in good agreement. For the present purpose we adopted the effective temperature scale for G8 to K5 giants derived by Perrin et al. (1998). In our sample we do not have giants cooler than K4. For giants earlier than G8 we have used the effective temperature scale given by Bell & Gustafsson (1989). The uncertainty in $T_{\rm eff}$ is about ± 100 K.

From data in Table 1 (Hipparcos parallaxes, spectral types, bolometric corrections from Allen 1973) we computed the luminosities and gravities of the observed stars using the relation between log g, mass (2 $\mathrm{M}_\odot$, for a typical red giant (McWilliam 1990)), luminosity and effective temperature. These log $g$values are given in Table 1 and used in Sect. 3.2; they are affected only by ± 0.3 dex if the mass of the star is between 1 and 3 $\mathrm{M}_\odot$. We emphasize that the Li abundances of G and K giants derived in Sect. 3.2 are not very sensitive to uncertainties as large as 0.5 dex in log $g$values.

3.2. Spectrum synthesis and lithium abundances

The grid of model atmospheres used in Lèbre et al. (1998) and computed with the code of Asplund et al. (1997) has been extended to lower $T_{\rm eff}$ and gravities. All the models were calculated for a microturbulence parameter $\xi_{\rm turb} = 2.0\ \mathrm{km\,s^{-1}}$ and solar metallicity. We checked the consistency of these low effective temperature models by comparing them with some

Table 1. G and K giants observed in the Li region at OHP and ESO.

HD	HIP	Sp. type	m_V	B-V	π (mas)	$\sigma(\pi)$ (mas)	M_V	Bol. Corr.	$\log g$
27497	20268	G8III	5.76	0.914	7.62	0.93	0.17	−0.3	2.7
30834	22678	K2III	4.79	1.414	5.81	0.82	−1.84	−0.6	1.5
31553	23068	G8III	5.79	1.109	6.92	1.03	−0.52	−0.3	2.4
34043	24450	K4III	5.50	1.369	5.45	0.97	−0.82	−1.0	1.6
34810	24977	K0III	6.20	1.229	5.22	0.98	−0.90	−0.3	2.1
43827	29895	K3III	5.15	1.293	5.75	0.71	−1.11	−1.0	1.6
80989		K1III	9.0	1.3					
92253	51873	K0III	7.42	1.187	5.20	0.59	0.43	−0.3	2.7
94363	53240	K0III	6.12	0.913	12.51	0.84	1.61	−0.3	3.1
111830	62964	K0III	7.78	1.248	6.41	0.73	1.06	−0.3	2.9
118344	66574	K3III	6.11	1.415	7.44	0.58	0.05	−0.8	2.1
129456	72010	K3III	4.06	1.356	15.89	0.71	−0.20	−0.8	2.0
138688	76259	K2III	5.13	1.306	8.84	1.02	−0.59	−0.6	2.0
145206	79195	K4III	5.39	1.446	6.60	0.91	−0.72	−1.0	1.7
146834	79945	K0III	6.29	1.066	6.65	0.84	0.19	−0.3	2.6
146850	79938	K3III	5.97	1.475	3.77	0.85	−1.75	−0.8	1.4
152786	83081	K3III	3.12	1.552	5.68	0.91	−3.95	−0.8	0.5
153687	83262	K4III	4.82	1.483	8.11	1.07	−0.93	−1.0	1.6
157457	85312	G8III	5.19	1.055	8.19	0.88	−0.58	−0.3	2.3
169689	90313	G8III	5.64	0.884	4.04	0.69	−1.33	−0.3	2.0
175492	92818	G4III	4.57	0.782	6.71	0.63	−1.30	−0.3	2.2
176884	93537	K0III	5.96	1.158	2.20	0.88	−2.81	−0.3	1.4
183526		K3III	8.4	2.2					
190299	98844	K4III	5.67	1.301	5.60	0.84	−0.59	−1.0	1.7
204540	106036	K2III	6.56	1.293	3.33	0.76	−1.22	−0.6	1.8
212320	110532	G6III	5.92	0.998	7.10	0.93	0.00	−0.3	2.6
218527	114273	G8III	5.42	0.908	11.64	1.28	0.75	−0.3	2.9
219025	114678	K2III	7.67	1.208	3.25	0.81	0.08	−0.6	2.3
221776	116365	K5III	6.18	1.586	4.81	0.73	−0.68	−1.0	1.7

Table 2. Lithium abundances (Li I λ6708 Å) of the Li-rich stars of Table 1. Solar chemical abundances are from Grevesse et al. (1996), $[Fe/H]_\odot$=7.50. The abundances of the other metals have been scaled to [Fe/H] for each star.

Star	$T_{\rm eff}$	$\xi_{\rm turb}$	$V_{\rm rot}$	[Fe/H]	$\log \epsilon(Li)$
HD 027497	5100	2.0	1.0	−0.3	< 0.4
HD 030834	4500	2.0	1.0	−0.5	2.4
HD 043827	4270	2.0	1.0	< -0.5	< 0.0
HD 111830	4800	2.0	1.0	+0.3	< 0.5
HD 138688	4450	2.0	1.0	+0.2	0.5
HD 145206	4100	2.0	1.0	−0.4	< 0.0
HD 146850	4270	1.5	1.0	+0.4	2.0
HD 152786	4270	2.0	1.0	+0.2	1.3
HD 153687	4100	2.0	1.0	+0.4	0.1
HD 157457	4950	2.0	1.0	−0.3	1.5
HD 169689	4950	2.0	10.0	−0.2	1.0
HD 175492	5280	2.0	3.0	−0.2	1.3
HD 176884	4800	2.0	15.0	+0.2	1.2
HD 204540	4450	2.0	1.0	−0.4	−0.2
HD 219025	4500	2.0	23.0	−0.1	3.0

NMARCS models incorporating much improved line opacity (Plez, private comm., described in detail in Bessell et al., 1998). There is a very good agreement between the model structures given by these two grids. Only the coolest models differ by ~ 100 K in their most external layers while the agreement is kept satisfactory for $\tau_{\rm Ross} > 10^{-3}$. We therefore are confident in the models we use for this analysis.

We used the same line list as in Lèbre et al. (1998). Since the stars studied in this paper are slighty cooler, we also added lines from the C2 molecule and its isotopes. Line data of the Phillips red system for these three molecules ($^{12}C^{12}C$, $^{12}C^{13}C$, $^{13}C^{13}C$) were predicted as in de Laverny & Gustafsson (1998). Lines of the C2 Swan system tabulated by Kurucz (private communication) were also included. The synthetic spectra of the giants were convolved to mimic the stellar rotation of each star (cf. Table 2) and then with an instrumental profile to match the resolution of the observations. We furthermore assumed for these stars evolving on the red giant branch a carbon isotopic ratio $^{12}C/^{13}C$= 20 (Charbonnel 1994). Finally, the microturbulent velocity in late type giants is of the order of 2 km s^{-1} (McWilliam 1990). For all our program stars we assumed 2 km s^{-1} for the microturbulent velocity in computing the synthetic spectra in the Li region, and corrected it when necessary.

As already described in Lèbre et al. (1998), the major source of uncertainty in this abundance analysis is due to errors in the determinations of $T_{\rm eff}$. Uncertainties on log $g(\pm 0.5$ dex) and the rotational and microturbulence velocities lead to a total error smaller than ± 0.1 dex in [Fe/H] and have almost no effect on the derived Li abundance. An uncertainty of $\pm$200 K on $T_{\rm eff}$ results in a change of [Fe/H] of less than $\pm$0.1 dex and around $\pm$0.2 dex in log ϵ(Li). On another hand, considering model atmospheres with metallicity in the range $+$0.5 dex to -0.5 dex (extreme cases) lead to an error smaller than $\pm$0.1 dex in log ϵ(Li). Combining all these sources of errors, we find a final expected uncertainty for the derived Fe and Li abundances close to $\pm$0.2 dex. However, let's note that a $\pm$200 K error on $T_{\rm eff}$ is pessimistic since this parameter is rather well constrained when fitting the several Fe I lines with different excitation energies found in the synthesized spectral range.

From an analysis of the Li region spectra of our 29 red giants (Table 1) with excess flux at 25 and or 60 microns (Zuckerman et al. 1995) we found eight stars with log ϵ(Li) larger than 1.0 (Table 2). In the remaining 22 stars the Li abundances are very low: log ϵ(Li)≤ 0.0. In Table 2 we have given the Li and [Fe/H] abundances of 15 stars derived from the spectrum synthesis calculations. From our limited sample of G and K giants with far infrared excess it appears that about 28 percent of G-K giants with circumstellar dust may have Li abundance log ϵ(Li) $>$ 1.0. All the eight stars in Table 2 with log ϵ(Li) $>$ 1.0 have 60 micron excess more than a factor of 3. The IRAS fluxes of all the eight Li-rich stars in Table 2 indicate that they have probably detached cold dust shells. In our sample the infrared excess, the amount circumstellar dust and Li abundance in the case of HD 219025 are significant.

Two stars in our sample are found to have previous Li abundance determinations. Brown et al. (1989) found HD 30834 to be a Li-rich K giant and found the Li abundance to be log ϵ(Li) = 1.8. From the analysis of our spectra of HD 30834 we derived the Li abundance log ϵ(Li) = 2.4 (Fig. 1). A difference in the atmospheric parameters and the coarse determination of abundances by Brown et al. (1989) in their survey probably explain this discrepancy.

For HD 146850 Castilho et al. (1995) derived log ϵ(Li) = 1.6. From the analysis of our spectrum of HD 146850 we derived the Li abundance log ϵ(Li) = 2.0 (Fig. 1). For HD 146850 Castilho et al. (1995) give Teff = 4000 K, log g = 1.5, [Fe/H] = -0.3, log ϵ(Li) = 1.6. We computed the synthetic spectrum of HD 146850 with the parameters used by Castilho et al. (1995) and compared it with our observed spectrum. We found that the above parameters can not match our spectrum of HD 146850 and favour our value parameters.

3.3. HD 219025

HD 219025 (m$_V$ = 7.67, K2III) is a dustier K giant with warm and cold circumstellar dust. It is an IRAS source with large far-infrared excess at 25 and 60 microns (12 μm: 17.06 Jy, 25 μm: 10.26 Jy, 60 μm: 3.86 Jy and 100 μm: 1.7 Jy) with good quality flux flags (3) (Zuckerman et al. 1995). Whitelock et al. (1991) find strong near-IR (JHKL) excesses. They speculate on whether or not it might be a RS CVn binary or a pre-main-sequence star. Bopp and Hearnshaw (1983) found moderate Ca II H and K emission. From our observations we found strong and broad Li line (Fig. 1). The very broad absorption lines clearly indicate that HD 219025 is a rapid rotator.

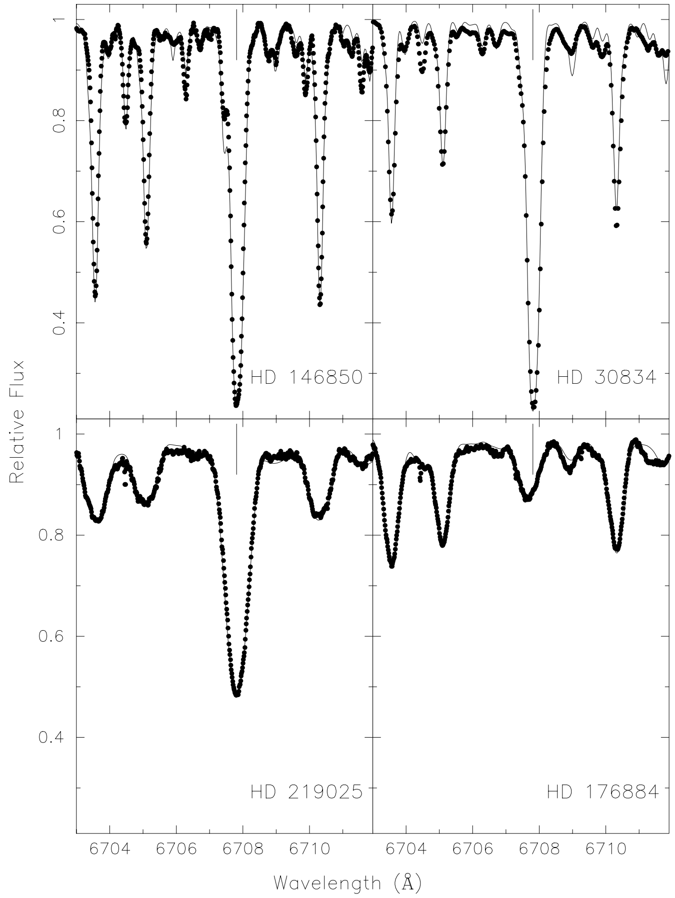

Fig. 1. Observed (filled circles) and synthetic spectra (solid line) of four Li-rich giants.

From the analysis of the spectrum of HD 219025 we find log ϵ(Li) = 3.0 ± 0.2, [Fe/H] = -0.1 ± 0.1 and the rotational velocity to be 23$\pm$3 km s^{-1} (Table 2) (Fig. 1). The Hipparcos parallax of HD 219025 (Table 1) yields an absolute magnitude of M$_V$ =+0.08, which clearly indicates that HD 219025 is a red giant in the (M$_V$, T$_{\rm eff}$) plane. It is not a pre-main-sequence or T-Tau star. HD 219025 is a high galactic latitude star $b_{\rm gal} = 46.3°$, and therefore the interstellar reddening is not significant. The E(B-V) is found to be 0.05, and hence the uncertainty in the absolute magnitude is of the order of 0.1 magnitude.

The evolutionary status of HD 219025 seems to be very similar to that of the Li-rich rapidly rotating K giant HDE 233517. Fekel et al. (1996) found HD 233517 to be a Li-rich K2III star with high rotational velocity (V$_{\rm rot}$ = 15 km s^{-1}). They derived the Li abundance to be log ϵ(Li) = 3.3. It is an IRAS source with large far-infrared excess. The giant status of HDE 233517 is determined directly from luminosity-sensitive line ratios and is further supported by a large radial velocity (46.5 km s^{-1}) and

Table 3. Lithium rich K giant stars with data taken from literature. Log $\epsilon(Li)$ and ^{12}C / ^{13}C values can be found in da Silva et al. (1995). Rotational velocities are coming from de Medeiros et al. (1996), except for HD 120602 and HD 121710 (Fekel & Balachandran 1993) and HD 233517 (Fekel et al. 1996).

HD	HIP	Sp. type	m_V	B-V	π (mas)	$\sigma(\pi)$ (mas)	M_V	Log $\epsilon(Li)$	^{12}C / ^{13}C	V_{rot} (km s^{-1})
787	983	K5III	5.29	1.48	5.33	0.87	−1.08	2.2	15	2
9746	7493	K1III	6.20	1.21	7.77	0.82	+0.23	2.75	28	9
19745		K1III	9.1	1.09				4.75	15	1
30834	22678	K2III	4.79	1.41	5.81	0.82	−2.14	1.8	13	3
39853	27938	K5III	5.62	1.53	4.37	0.72	−1.27	3.9	6	3
40827	28829	K1III	6.32	1.10	6.92	0.74	+0.43	1.60		2
57669	35907	K0III	5.23	1.22	4.48	0.96	−2.17	1.50	10	4.5
95799		K0III	8.00	0.9				3.22		
108471	60804	G8III	6.36	0.93	4.54	0.90	−0.36	2.00	25	4.1
112127	62944	K2III	6.91	1.26	8.09	0.85	+1.15	2.7	22	1.7
120602	67545	K0III	6.00	0.9	8.09	0.81	+0.54	2.0	16	5
121710	68103	K3III	5.02	1.43	5.03	0.78	−1.95	1.5		1.5
126868	70755	G2III	4.81	0.69	24.15	1.0	+1.72	2.3		13
146850	79938	K4III	5.97	1.52	3.77	0.85	−1.57	1.6		1.0
148293	80161	K2III	5.26	1.12	11.09	0.47	+0.48	2.0	16	1.2
183492	95822	K0III	5.57	1.05	11.38	0.73	+0.58	2.0	9	1.0
205349	106420	K1Ib	6.27	1.84	2.17	0.61	−3.43	1.9		
233517		K2III	9.72	1.32				3.3		15

small proper motion. We have not found HDE 233517 in the Hipparcos parallax catalogue. Fekel et al. (1996) suggest that the processes causing rapid rotation, large Li abundance, and infrared excess are triggered at the base of the giant branch when the convection zone reaches the rapidly rotating core of low-mass stars.

We found HD 169689 and HD 176884 also to be rapidly rotating Li-rich K giants (Table 2). The Li abundance and rotational velocities are found to be log ϵ(Li) = 1.0 and V_{rot} = 10 km s^{-1} and 1.2 and 15 km s^{-1} respectively. Both these stars have far-infrared 60 micron excess by a factor of 3. Finally, we find HD 175492 also to be a Li-rich K giant (log ϵ(Li) = 1.3) with a rotational velocity of 3 km s^{-1} (Table 2).

4. Discussion

Since the discovery of the Li-rich K giants several mechanisms to explain the overabundance of Li have been suggested (Wallerstein and Sneden 1982, Gratton and D'Antona 1989, Brown et al. 1989, Pilachowski et al. 1990, de la Reza et al. 1996, 1997). Engulfing orbiting planets and/or brown dwarfs, binarity and mass loss were some of the suggestions to account for the overabundance in Li and far-infrared excess. A model scenario has recently been introduced by de la Reza and colleagues. In this scenario all ordinary, Li-poor, K giants become Li-rich during a short time (10^5 years) when compared to the red giant phase of 5×10^7 years. In this "Li-period" a large number of the G and K giants are associated with an expanding thin circumstellar shell supposedly triggered by an abrupt internal mixing mechanism resulting in a surface Li enrichment.

4.1. Absolute magnitudes

In order to study the position of Li-rich and Li-poor (normal) red giants in the H-R diagram we have determined the absolute visual magnitudes M_V of all the well studied Li-rich K giants from their Hipparcos parallaxes (Table 3).

Many of these are bright and relatively nearby stars and therefore the interstellar reddening is not too large. Using the B-V colors and spectral types we derived the E(B-V) values. The M_V values given in Table 3 are corrected for the extinction. The uncertainty in M_V values as a result of extinction corrections are of the order of 0.25 magnitude. We have also determined the M_V values of our program stars from their Hipparcos parallaxes (Table 1). Fig. 2 shows the position of the Li-rich red giants (Table 3) and a few normal red giants (Table 1) in the H-R diagram together with the evolutionary tracks taken from Schröder (1998) and adapted from Schröder et al. (1998).

From Fig. 2 it seems that Li-rich giants have a range of masses and luminosities. Most of them are more luminous than the "clump- giants". HD 205349 was found to be a Li-rich (log ϵ(Li) = 1.9) supergiant by Brown et al. (1989). The Hipparcos parallax yield an absolute magnitude M_V = -3.43 (Table 3) confirming the supergiant status of this star. From our analysis we find HD 152786 also to be supergiant with M_V = -3.95 and log ϵ(Li) = 1.3. Fig. 2 suggests that whatever may be the mechanism for the overabundance of Li, it is not confined to a narrow range of luminosities and masses of giants. Two Li-rich giants HD 19745 (log ϵ(Li) = 4.75) and HD 95799 (log ϵ(Li) = 3.22) are not in the Hipparcos catalogue. For HD 19745 we adopt the absolute magnitude 0.42 given by de la Reza & da Silva (1995), and for HD 95799 we estimated the M_V value in assuming the

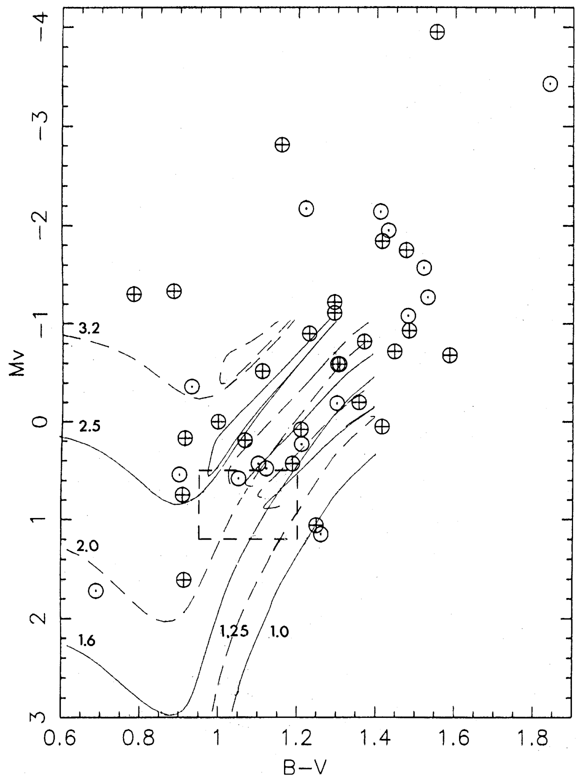

Fig. 2. The position of Li-rich giants in the H-R diagram. The absolute visual magnitudes (M_v) of Li-rich giants are calculated from their Hipparcos parallaxes. ⊕ symbols are stars observed in this paper (Table 1); ⊙ symbols are Lithium-rich K giants stars from Table 3. The position of "clump giants" (indicated by a rectangle) and the evolutionary tracks of giants from 1 to 3.2 solar masses are adapted from Fig. 1 in Schröder et al. (1998).

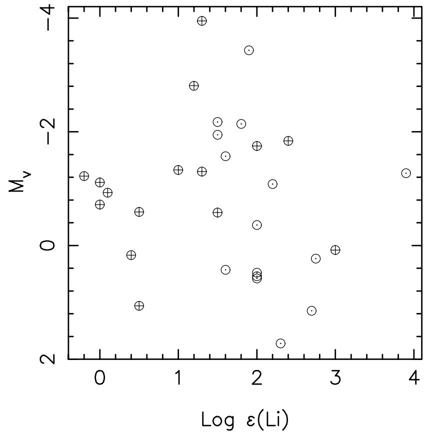

Fig. 3. The Li abundance of Li-rich giants plotted against their absolute visual magnitudes. ⊕ symbols are stars observed in this paper (Table 2); ⊙ symbols are Lithium-rich K giants stars from Table 3.

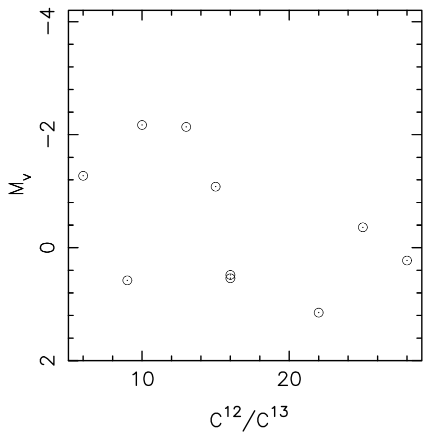

Fig. 4. The carbon isotope ratios of Li-rich giants plotted against their absolute visual magnitudes. ⊙ symbols are Lithium-rich K giants stars from Table 3.

star as a member of the NGC 3532 open cluster. Fig. 2 clearly shows that the Li-rich giants are not pre-main-sequence stars. Some authors have speculated that these are Li-rich because they are pre-main-sequence stars.

From Fig. 3 we can explore a possible connection between Li abundance and absolute magnitude. There seems to be a weak correlation between Li abundance and absolute magnitude, which indicates that among the Li-rich giants, relatively less luminous giants are more Li-rich. This result indicates that the low mass giants which spend long time on the Red Giant Branch (RGB) may produce more Li as they are expected to undergo several episodes mixing. However we need to find more Li-rich giants and derive their luminosities in order to fully explore the relation between Li abundance and luminosity among the Li-rich giants.

4.2. $^{12}C/^{13}C$

da Silva et al. (1995) discussed the carbon isotope ratios in Li-rich giants. There is no clear correlation between Li abundance and $^{12}C/^{13}C$ratio. They found that the three most Li-rich giants HD 19745 (log ϵ(Li) = 4.08 (LTE) or 4.75 (NLTE)), HD 39853 (log ϵ(Li) = 2.9 or 3.9) and HD 95799 (log ϵ(Li) = 3.22) to show $^{12}C/^{13}C \leq 15$, indicating extra mixing. The $^{12}C/^{13}C$ ratio in the Li-rich giants ranges from 6 to 28 (Table 3, Fig. 4) similar to that found for normal K-giants (Gilroy 1989). There seems to be no clear relation between the $^{12}C/^{13}C$ ratio and absolute visual magnitude (Fig. 4). The position of Li-rich giants in the H-R diagram and their carbon isotope ratio indicate that they are evolved and have experienced normal amount of convective mixing. Some of them with low carbon-isotope ratio may have gone through additional mixing on the giant branch.

4.3. Rotational velocities

de Medeiros et al. (1996) determined precise rotational velocities of several Li-rich giants (Table 3) using CORAVEL spectrometer. Except for a few, the Li-rich giants show normal rotational velocities with respect to typical Li-normal giants of the same spectral type. de Medeiros et al. (1996) found no indication of binarity for the Li-rich giants. Fig. 5 shows that there is no correlation between Li abundance and rotation for the Li-rich giants. There are few rapidly rotating Li-rich giants (Table 3)

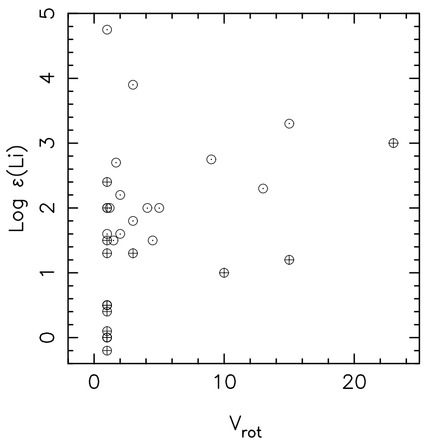

Fig. 5. The Li abundances of Li-rich giants plotted against their rotational velocities (same symbols as Fig. 3).

(for example HD 9746, HD 219025 and HDE 233517). Fekel and Balachandran (1993) suggest a connection between rapid rotation and high Li abundance in giants. They suggested a scenario in which the surface convection zone reaches the rapidly rotating core as a star begins its first ascent of the giant branch and dredges up to the surface high angular momentum material and freshly synthesized Li. Fekel et al. (1996) suggest that the processes causing rapid rotation, large Li abundance, and infrared excess are triggered at the base of the giant branch when the convection zone reaches the rapidly rotating core of low-mass stars. This explanation is not able to account for the slowly rotating Li-rich giants.

Finally most of the Li-rich giants show moderate or weak chromospheric activity (de la Reza and da Silva 1995, Fekel and Balachandran 1993) indicating no correlation between stellar activity and Li-abundance (Randich et al. 1993, 1994)

4.4. Infrared excess

The dust shells around some of the Li-rich giants are cold and probably detached, though detachment has not yet been proved. Whitelock et al. (1991) and Zuckerman (1993) have suggested that binarity is implicated when large amounts of dust are found near evolved stars. There is no evidence that these stars are preferentially members of binary systems. Among the stars analyzed in this work, HD 169689 is known as an eclipsing binary of Algol type (period of 385 days), and HD 176884 is a member of a visual binary. Besides, HD 9746 = OP And is a chromospherically active star with a rotational period of 2.36 days (ESA HIPPARCOS catalogue) and is not known as a binary. Further investigation on binarity among G-K giants with infrared excess is in progress with the spectrovelocimeter CORAVEL and will be published soon.

Some giants like HDE 233517 and HD 219025 are very Li-rich, have high rotational velocities and also have large infrared excesses but others have excess Li and no far-infrared excess and vice versa. To account for the circumstellar dust around the late-type giants evaporation of planets, brown-dwarfs, and cometary belts are suggested, as the star evolves from the main-sequence phase to a giant (Zuckerman et al. 1995, Plets et al. 1997). To account for the overabundance of Li also such scenarios were proposed (Brown et al. 1989, Gratton and D'Antona 1989). The presence of Li-rich giants with no circumstellar dust, with no enhanced chromospheric activity and with slow rotation indicates that the Li-enrichment may not be linked to any of these parameters.

4.5. Creation of Li

Recently Sackmann and Boothroyd (1998) demonstrated that Li can be created in low mass red giant stars via the Cameron–Fowler mechanism, due to extra deep mixing and the associated "cool bottom processing". They conclude that the amount of Li produced can exceed log ϵ(Li) = 4 but depends critically on the details of the extra mixing mechanism (mixing speed, geometry, episodicity). Sackmann and Boothroyd (1998) predicted that if the deep circulation is a relatively long-lived, continuous process, lithium-rich red giants should be completely devoided of beryllium and boron. In this context determination of Be abundance in the Li-rich red giants (Table 3) is important. The study of Sackmann and Boothroyd (1998) is able to explain the overabundance Li in the red giants. However, they have not considered the rapid rotation and mass loss process during this deep circulation. It is not yet clear whether this deep circulation and cool bottom processing triggers mass loss. Also the effect of rapid rotation on deep circulation and cool bottom processing needs to be explored in order to understand the Li-rich red giants with high rotational velocities and circumstellar dust.

5. Conclusions

From our analysis of the Li region spectra of 29 giants from the list of Zuckerman et al. (1995) with infrared excess, eight stars were found to show log ϵ(Li) $>$ 1.0. In the remaining stars log ϵ(Li) $<$ 0.0. There seems to be no correlation between Li abundance and infrared excess.

HD 219025 is found to be a Li-rich (log ϵ(Li) = 3.0), rapidly rotating, and dusty K giant. The absolute visual magnitude of HD 219025 derived from the Hipparcos parallax shows that it is a K giant and not a pre-main-sequence star.

HD 169689 and HD 176884 are also found to be rapidly rotating Li-rich giants. HD 205349 and HD 152786 are found to be Li-rich K supergiants.

The position of Li-rich K giants in the HR diagram shows that most of them are brighter and more evolved than the "clump giants". The overabundance of Li is not confined to narrow range of luminosities. The Li-abundances of Li-rich giants is not correlated with their luminosities, rotational velocities, infrared excesses, chromospheric activity and carbon isotope ratios.

There are Li-poor (normal) giants with circumstellar dust, Li-rich giants with dust and with no dust. The number of Li-rich and dusty giants is much smaller than the number of Li-poor dusty giants. This indicates that they destroy their freshly synthesized Li much faster than they disperse their circumstellar dust. However, the presence of Li-rich giants with no circumstellar dust is a puzzle. Rotation, binarity, mass and evolutionary age on the red giant branch, and the dependence of extra deep mixing and the associated cool bottom processing on these parametres need to be explored in order to understand the dust and Li problem in late-type giants.

Preserving the initial pre-main-sequence Li or accreting Li from external sources (such as engulfing planets or brown dwarfs during the giant phase) will not be able to explain the Li-rich K giant phenomenon. Li seems to have been created inside the star and brought to the surface. Recently Sackmann and Boothroyd (1998) demonstrated that Li can be created in low mass red giants via the Cameron-Fowler mechanism, due to extra deep mixing and the associated "cool bottom processing". It is not yet clear whether this will trigger mass loss. Also the effect of rapid rotation on deep circulation and cool bottom processing needs to be explored in order to understand the Li-rich red giants with rapid rotation and circumstellar dust.

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Note added in Proof: Recently Fekel & Watson (AJ in press) also searched for Li-rich giants among stars with infrared excess from the list of Zuckerman et al. (1995).