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Identifying Li-rich giants from low-resolution spectroscopic survey

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Abstract. In this paper we discuss our choice of a large unbiased sample used for the survey of red giant branch stars for finding Li-rich K giants, and the method used for identifying Li-rich candidates using low-resolution spectra. The sample has 2000 giants within a mass range of 0.8 to $3.0M_{\odot}$. Sample stars were selected from the Hipparcos catalogue with colour (B–V) and luminosity ($L/L_{\odot}$) in such way that the sample covers RGB evolution from its base towards RGB tip passing through first dredge-up and luminosity bump. Low-resolution (R $\approx$ 2000, 3500, 5000) spectra were obtained for all sample stars. Using core strength ratios of lines at Li I 6707 Å and its adjacent line Ca I 6717 Å we successfully identified 15 K giants with A(Li) > 1.5 dex, which are defined as Li-rich K giants. The results demonstrate the usefulness of low-resolution spectra to measure Li abundance and identify Li-rich giants from a large sample of stars in relatively shorter time periods.

Keywords. Stars—RGB—abundances—lithium rich—stellar atmospheres—spectroscopy.

1. Introduction

Standard stellar evolutionary models predict severe depletion of surface Li abundance, which is as low as 1.4 dex in K giants (Iben 1967), a factor of about 80 lower than the maximum value of about 3.3 dex observed in main sequence stars (Lambert & Reddy 2004). Observations confirm model predictions (Brown *et al.* 1989) show much less Li compared to model predictions in most red giant branch RGB stars.

Contrary to predictions and general observational trends, the discovery of high Li abundance (A(Li) $\sim$2.95) in a normal K giant (Wallerstein & Sneden 1982) has questioned our understanding of Li evolution in RGB stars. Since then, more Li-rich giants have been discovered (Hanni 1984; Gratton & D'Antona 1989), many of them serendipitously. Large-scale systematic surveys designed for discovering Li-rich giants (e.g. Brown *et al.* 1989) among RGB stars resulted in the discovery of more Li-rich giants, and also showed that they are quite rare, under 1% of giants. Some of the surveys led to new suggestions as well, such as correlations between Li in giants and infrared excess, and stellar rotation. For example, the Pico Dias Survey (PDS) by Gregorio-Hetem *et al.* (1993) resulted in the discovery of a number of Li-rich giants with significant IR excess (Drake *et al.* 2002; Reddy *et al.* 2002; Reddy & Lambert 2005). Following the PDS, more surveys were conducted based on infrared colours, adding more Li-rich giants with IR excess (Castilho *et al.* 1998; Jasniewicz *et al.* 1999). Such biased surveys led to conclusions that Li enhancement is probably connected to IR excess (de La Reza *et al.* 1996, 1997).

Although there is no consensus about the real cause for such significant enhancement of Li in the photosphere of RGB stars, there are, however, three principal scenarios that were put forth in the literature: (a) preservation of main sequence Li due to inefficient mixing, (b) internal nucleosynthesis via Cameron and Fowler mechanism (Cameron & Fowler 1971) followed by some kind of mixing, and (c) External cause such as engulfment of planet/brown dwarf (Alexander 1967). Each one of these scenarios was tested, but none of them has been identified as the sole mechanism responsible for Li enhancement without ambiguity. Many studies suggested more than one mechanism for Li enhancement in giants which may not be an unreasonable conclusion to make (e.g. Casey *et al.* 2016).

One of the keys to understanding Li enhancement origin in K giants is determination of the exact location of Li-rich giants in the Hertzsprung–Russel (HR) diagram. Do Li-rich giants happen all along RGB or they belong to a particular location such as luminosity bump or red clump regions in the HR diagram? The answer to this question may shed light on high Li in giants. However, most of the earlier surveys were conducted in the pre-Hipparcos era. Thus, the lack of reliable parallaxes might have led to large uncertainties in the determination of luminosities, and hence their location in the HR diagram led to ambiguous interpretations. Charbonnel & Balachandran (2000) analysed a number of Li-rich giants with the aid of a HR diagram based on accurate luminosities derived using Hipparcos parallaxes. For the first time, based on location, they separated genuine Li-rich K giants, which are low mass ($\approx < 3M_{\odot}$) and ascending RGB, from early AGB stars and intermediate mass sub-giants (more than $3M_{\odot}$) which are known to have high Li due to different process. Their analysis suggested that most of the Li-rich K giants occupy a narrow region, coinciding with the luminosity bump in the HR diagram. This observation led to theoretical modeling to explain Li enhancement such as Li-flash during the bump evolution (Palacios *et al.* 2001).

In this paper, we describe our survey of a large unbiased set of K giants chosen from the Hipparcos catalogue with good parallaxes. Also, we describe the methodology with which Li abundance estimations were made based on low resolution spectra. This is, probably, the first such large survey of an unbiased sample which led to more than a dozen new Li-rich K giants. Results based on high-resolution spectra of new Li-rich K giants discovered in this survey have been published elsewhere (Kumar & Reddy 2009; Kumar *et al.* 2011).

2. Sample Selection

The main aim of this survey was to find Li-rich K giants from a well-defined and unbiased sample of K giants with the aim of finding clues for the origin of Li enhancement in giants by determining their location in the HR diagram, and frequency of their occurrence among RGB stars. The sample was chosen from the Hipparcos catalogue (Perryman *et al.* 1997; van Leeuwen 2007) which contains about one-hundred-thousand stars with accurate astrometry such as proper motions and parallaxes. One of the principal requirements of the sample was to have stars in the HR diagram along the RGB starting from the first dredge-up to well above the luminosity bump. To meet this requirement the following criteria were drawn up: (a) stars with (B–V) colour ranging from 0.9 to 1.4, (b) luminosity, log ($L/L_{\odot}$), between 1.0 and 2.5 covering RGB, (c) distances up to 200 pc with parallax errors within 20%, in order to minimize errors due to interstellar extinction to a large extent, (d) stars with masses $\leq 3M_{\odot}$), and (e) stars with brightness of $m_v \leq 8.5$, and declination range of $+90$ to $-60°$ to make it easy to observe with 2 m class telescopes in India located at latitude of 34° and 10°.

To apply the above criteria and select the sample from Hipparcos, we required apart from parallax, the values of luminosity (log ($L/L_{\odot}$)) and the effective temperature ($T_{\rm eff}$) or the (B–V) colour. Luminosity values were derived using the relation, $\log (L/L_{\odot}) = 0.4(M_{bol}\odot - M_{bol})$, where $M_{bol} = M_v + BC$, and distance modulus, $(m_v - M_v) = 5\log_{10}d + A_V$. For $M_{bol}\odot$, we adopted a value of 4.74 (see Allen's astrophysical quantities in Cox 2000) and bolometric corrections (BC) were calculated using the relation given by (Alonso *et al.* 1999) as a function of metallicity ([M/H]) and $T_{\rm eff}$. We have assumed [M/H] to be solar for the entire star sample. Values of $T_{\rm eff}$ were found based on (B–V) colour and empirical calibrations of (Alonso *et al.* 1999) as a function of [M/H] and interstellar extinction (A_V). There may be a few stars with [M/H] much lower or higher than the value we adopted. Extreme values of [M/H], about $+0.3$ to -0.5 dex, will have an impact of 80 K to 120 K in $T_{\rm eff}$. Extinction (A_V) or reddening (E(B–V)) may be negligibly small as the sample stars were nearby, and hence were not taken into account in deriving either luminosity or $T_{\rm eff}$. However, for a few farthest stars in our sample, in certain directions, we found extinction values as large as E(B–V) = 0.03–0.05 (Schlegel *et al.* 1998) which corresponds to the underestimation of $T_{\rm eff}$ by 50–100 K, which is quite small for our purpose.

Finally, we culled all the stars with mass greater than $3M_{\odot}$ and less than $0.8M_{\odot}$ by superposing sample stars over computed stellar evolutionary tracks in the HR diagram. The criteria resulted 2000 giants, mostly with spectral type K, which are shown in Fig. 1. A representative list of the sample is provided in Table 1.

3. Observations and data processing

Due to constraints on the availability of telescope time, sample stars were observed with three different telescopes and spectrographs. This resulted in having spectra of slightly different resolutions. Three-fourth of spectra (1400) were obtained using Himalayan Faint Object Spectrograph Camera (HFOSC) on the 2 m

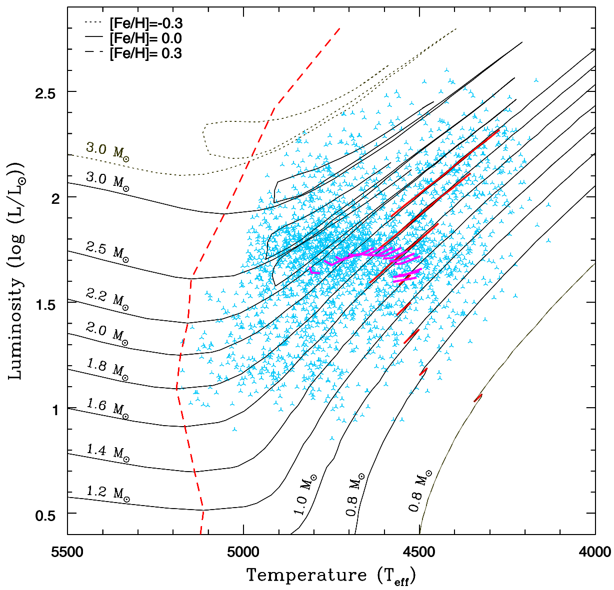

Figure 1. Sample stars of the survey are shown in the HR diagram. Evolutionary tracks of stars of masses from 0.8 to $3.0M_{\odot}$ and of solar metallicity, [Fe/H] = 0.0, computed by Bertelli *et al.* (2008) are also shown. The base of the RGB (red dotted line) and the extent of RGB bump (solid red line) are marked. The RGB clump region is shown as a thick magenta line.

Himalayan Chandra Telescope (HCT) at Indian Astronomical Observatories, Ladakh. HFOSC is a dedicated instrument for imaging and spectroscopy with 2K × 4K CCD with a pixel size of 15 μ. Spectra were obtained in the Echelle mode with a combination of Grism (Gr9) and cross-disperser (Gr11) combined with a slit width of 0.77$''$. This resulted in spectra with a resolution of R ≈ 3500 covering a spectral range from 4500 Å to 9000 Å over eight orders. Since stars are brighter, we could get good (> 100) signal-to-noise ratio (SNR) with exposure times as small as 5–20 min.

Most of the bright stars (V < 6 mag) with southern declination (250) were observed using the medium resolution Zeiss Universal Astro Grating Spectrograph (UAGS) at the Cassegrain focus of 1 m Carl-Zeiss telescope at Vainu Bappu Observatory, Kavalur. Spectra were recorded on 1K × 1K CCD with a pixel size of 24 µ m. We used the grating with 1800 mm^{-1} which gives a dispersion of 0.6 Å per pixel which translates into spectral resolution of about R ≈ 5000. We have obtained spectra centered at 6700 Å to cover Li line at 6707 Å. The typical SNR for most of the spectra is about 100 or more at 6700 Å . About 350 samples stars were observed using the Optometrics medium Resolution spectrograph (OMRS) at the Cassegrain focus of the 2.3 m Vainu Bappu Telescope at VBO. Spectra were recorded on 1K × 1K Tektronix CCD with a pixel size of 24 µm. We used a grating with 1200 mm^{-1} which gives dispersion of 1.4 Å per pixel (R ≈ 2000). Most of the spectra have good SNR with 100 or more.

A few spectra of Fe–Ne arc lamp were obtained during each observing night for wavelength calibration. Also, obtained were images of dark, bias and flat field to correct for thermal noise and pixel-to-pixel variation in the CCD, respectively. The log of observations for a few sample stars is given in Table 2.

The raw two-dimensional spectra were reduced with an image reduction software known as Image Reduction and Analysis Facility (IRAF) developed by NOAO, USA. The reduction procedure differs slightly from one set of observations to the other set as the spectra are obtained from three different instruments with different resolutions and coverage. Also, in different modes such as echelle (orders) and long-slit modes. As a first step, all the images were trimmed for bad edges, corrected for dark, and applied normalized flat images to correct for pixel-to-pixel variation. The flat-corrected images were reduced to one-dimensional spectra using aperture extraction tools available within IRAF. Using the calibration arc spectrum of Fe–Ne, a polynomial fit was obtained between pixel positions and wavelength of emission features. The derived polynomial was applied to program stars' spectra resulting in spectra of intensity versus wavelengths. Two or three such polynomials were obtained for each night to see if there was any shift in pixel position over night. In general, we found the instruments were quite stable. A similar procedure was applied to all the data. Finally, to obtain relative strengths of different absorption features, the spectra were normalized to unity, i.e. continuum fitting was done, using continuum task available in IRAF by applying Legendre polynomial of order 3 to 6. However, few spectra of cool stars in our sample are normalized using cubic spline of order 3 or 4. While fitting continuum, the lower and upper rejection, sigmas are set to 1 and 3, respectively, to take care of absorption features. The spectra of known Li-rich K giant, HD 233517 obtained from three instruments are shown in Fig. 2. Note the lines in the spectrum of higher resolution are relatively sharper and deeper.

4. Method of identification of Li-rich giants from low-resolution spectra

Generally, Li abundances are measured using high-resolution spectra which, for a sample as large as in this study, is quite time-consuming and take many years.

Table 1. Basic data of few sample stars covering the survey.

HIP No.	HD No.	RA	DEC	V (mag)	Sp type	π (arcsec)	σ_π (%)	Dist pc	B − V	T_{eff} (K)	$\log(L/L_\odot)$
2081	2261	00 26 16.87	−42 18 18.4	2.40	K0.5IIIb	0.0385	1.85	25.9	1.11	4644.8	1.849
5928	6319	01 16 12.62	+87 08 44.0	6.20	K2III:	0.0093	5.39	106	1.08	4588.9	1.590
6939	9033	01 29 23.49	+25 16 31.2	6.66	K2III	0.0081	12.14	122.3	1.199	4442.6	1.785
7837	10212	01 40 49.74	+45 01 08.7	8.13	K0III	0.0077	11.42	129.8	0.970	4860.7	1.095
12070	16202	02 35 38.44	−14 56 41.9	6.84	K1III	0.0061	9.91	163.9	1.122	4574.7	1.412
12146	16295	02 36 33.97	−14 39 24.0	6.91	K0III	0.0081	15.06	122.8	1.03	4736.0	1.795
15677	20924	03 21 58.79	−15 27 31.4	7.26	K0III	0.0079	9.04	125.7	1.152	4522.3	1.247
22240	30790	04 47 06.85	−59 08 13.6	6.80	K0III	0.0067	9.07	149.2	1.01	4717.1	1.759
28417	40460	06 00 06.05	+27 16 20.5	6.61	K1III	0.0069	13.18	144.9	1.10	4758.9	1.754
37901	62902	07 46 02.16	−06 46 20.2	5.49	K5III	0.0122	6.72	82.1	1.378	4163.7	1.731
40407	69280	08 14 56.71	−35 41 19.6	6.80	K2III	0.0051	11.11	196.0	1.270	4327.5	1.957
43026	74794	08 46 02.45	−02 02 55.6	5.70	K0III:	0.0108	7.25	92.5	1.01	4619.4	1.647
43388	75790	08 50 18.94	−44 43 16.1	7.50	K0III	0.0067	9.53	149.2	0.980	4840.8	1.369
45439	79917	09 15 36.76	−38 34 11.7	4.92	K1III	0.0145	3.72	68.8	1.084	4643.0	1.769
46363	81841	09 27 14.19	−33 47 28.5	7.16	K2III	0.0051	14.6	194.5	1.154	4518.9	1.826
52338	92354	10 41 48.31	+68 26 36.8	5.74	K3III	0.00635	10.79	157.4	1.315	4257.7	2.379
53240	94363	10 53 25.04	−02 15 18.0	6.12	K0III	0.0126	3.40	79.3	0.913	4977.7	1.353
75119	136514	15 21 02.01	00 42 56.1	5.35	K3III	0.0136	6.42	73.3	1.18	4456.0	1.647
84455	156362	17 15 58.92	+27 08 03.6	6.57	K2III	0.0087	8.66	115.3	1.187	4462.7	1.623
96014	184293	19 31 19.36	+50 18 23.7	5.55	K1III	0.0071	6.56	141.6	1.274	4321.2	2.232
112731	216174	22 49 46.23	+55 54 09.7	5.43	K1III	0.0082	6.60	121.8	1.167	4496.5	2.034
114449	218792	23 10 42.62	+17 35 40.0	5.68	K4III	0.0064	12.55	155.5	1.330	4234.9	2.282
115444	220363	23 23 04.56	+12 18 50.2	5.09	K3III	0.0084	8.29	119.0	1.315	4257.7	2.139

Table 2. Log of observations for a few survey sample.

HD	RA	DEC	V	Expt time	SNR	Year of obs
HCT + HFOSC + 67s + Gr9 + Gr11 + 1K × 3K CCD						
947	00 14 22.39	+76 01 19.8	7.72	510	100	2006
16302	02 37 34.35	+20 34 29.8	6.92	270	200	2007
19551	03 09 00.94	+12 51 34.7	7.23	510	150	2006
22572	03 37 50.37	+00 08 28.0	7.18	360	250	2006
146388	16 15 28.68	+18 48 29.9	5.72	150	200	2009
183491	19 28 57.08	+24 46 07.3	5.82	180	250	2007
186648	19 46 21.82	−19 45 39.2	4.87	90	250	2007
187614	19 49 55.81	+27 05 06.6	6.46	240	200	2007
193342	20 17 00.58	+56 54 17.0	8.07	480	250	2007
194056	20 21 14.12	+52 24 38.0	7.61	420	250	2007
196912	20 39 59.83	+08 26 49.4	6.85	300	250	2007
198236	20 44 33.08	+69 45 06.8	6.50	260	250	2007
224533	23 58 40.41	−03 33 20.9	4.88	100	300	2006
1 m CZT + UAGS + 120 μ + 1800 mm^{-1} + 1K × 1K CCD						
20640	03 17 26.6	−47 45 06.3	5.84	900	150	2008
22663	03 37 05.68	−40 16 28.2	4.57	900	200	2006
23319	03 42 50.12	−37 18 48.0	4.59	900	200	2009
45984	06 27 04.14	−58 00 07.6	5.82	1800	200	2009
70002	08 18 17.39	−35 27 06.1	5.59	1200	200	2009
88399	10 10 37.70	−41 42 53.8	5.98	1500	200	2009
VBT + OMRS + 300 μ + 1200 mm^{-1} + 1K × 1K CCD						
26833	04 11 58.89	−53 24 43.5	7.07	600	300	2009
28700	04 29 20.04	−46 30 55.3	6.13	420	350	2007
77120	08 58 30.75	−50 48 25.2	7.57	720	300	2009
133904	15 09 23.25	−57 04 01.6	8.00	900	300	2009
159194	17 35 06.28	−38 47 58.3	6.76	300	300	2009

Importantly, high-resolution spectrographs are not common instruments on 2 m class telescopes. To overcome these constraints and have large sample stars surveyed to achieve stated goals, we devised a simple and effective methodology to estimate Li abundance based on low-resolution spectra which are relatively easy to obtain as many small telescopes available to us are equipped with low-resolution spectrographs.

Given the fact that Li abundance in stars is independent of stars' metallicity (Brown *et al.* 1989), and that the sample stars have small range in $T_{\rm eff}$ and log g, we adopted the measuring of line strength of Li transition at 6707 Å resonance line, relative to an adjacent neutral calcium (Ca I) line at 6717 Å. Ca I line is relatively insensitive to the adopted star sample range of stellar parameters. As a result, the ratio of the core strengths of these adjacent lines (Li/Ca) can be used for the estimation of Li abundances as it is known to vary a few orders of magnitude in K giants. This has been illustrated in Fig. 3 by showing low-resolution spectra of a sample of known Li-rich K giants from the literature. Note, Ca I line strength varies very little compared to Li line at 6707 Å. This is also true for other metallic lines such as Fe I lines. We chose Ca I line at 6717 Å as this is the only prominent line which is close to Li line that helps to place the continuum more reliably, and any uncertainties in the continuum may be nullified due to proximity of the lines. Due to the spectral resolution, weak Li lines cannot be measured as lines get smeared out. Sample spectra of K giants with known Li abundance show that K giants with Li abundance of $A(\mathrm{Li}) \geq 1.0$ dex can be identified. This limit is much lower than the limit set for Li-rich K giants, which is $A(\mathrm{Li}) \geq 1.5$ dex.

To estimate Li abundances quantitatively using this method, we observed a set of K giants with known Li

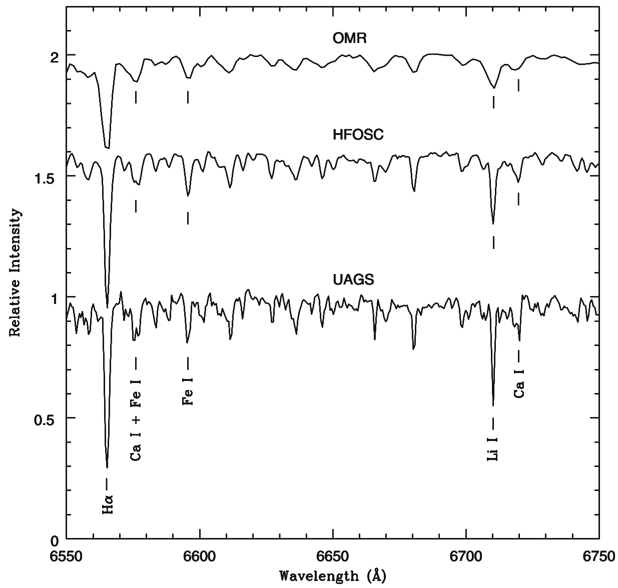

Figure 2. Sample spectra of a known Li-rich giant HD 233517 taken with all the three instruments. Note, spectrum taken from UAGS with R ≈ 5000 shows relatively sharper and deeper lines compared to OMR and HFOSC spectra.

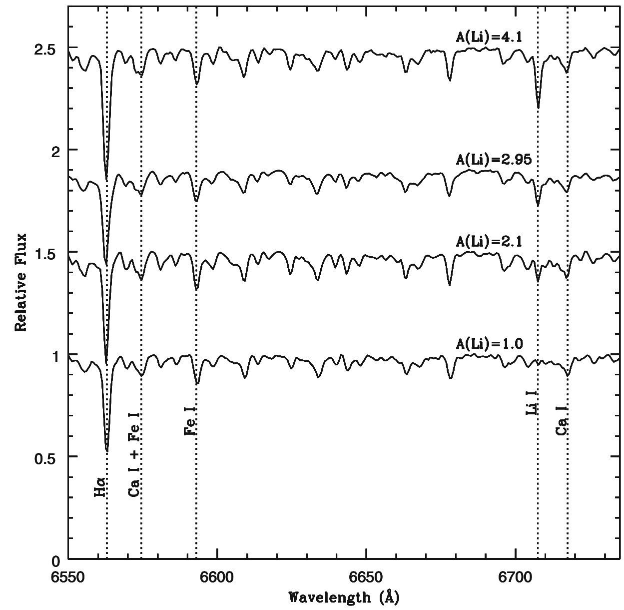

Figure 3. Spectra of few K giants with known Li abundance. Li line at 6707 Å Ca line at 6717 Å and Fe line at 6592 Å are marked. Note strength variation of Li line relative to other lines which vary very little compared to Li line.

abundances with each of the three instruments. The known sample is chosen such a way that it's stellar parameters are similar to survey sample. This would help to minimize errors arising out of differential sensitivity of Li and Ca profiles to stellar parameters. In Fig. 4, strength ratios, Li6707/Ca6717 obtained in the current study, are plotted against measured Li abundances from literature (Kumar *et al.* 2011 and references therein). They are well correlated and relations between ratios and abundances are fitted with a polynomial (Fig. 4). In Table 3, comparison between the derived abundances based on polynomial relations in this study and abundances from the literature is given. The differences are small and acceptable for studies such as this with the limited goal of identifying Li-rich K giants. The average difference between Li abundances from the derived relations and the input Li abundances is about 0.05 dex with a standard deviation of 0.25 dex. Differences in the two abundances arise mainly due to the fact that Li and Ca lines behave differently to stellar parameters.

$$A(Li)_{R5000} = \left(\frac{(Li/Ca_{6717}) - (0.6196 \pm 0.1839)}{0.7474 \pm 0.0492}\right) \tag{1}$$

$$A(Li)_{R3500} = \left(\frac{(Li/Ca_{6717}) - (0.5391 \pm 0.1272)}{0.7081 \pm 0.0475}\right) \tag{2}$$

$$A(Li)_{R2000} = \left(\frac{(Li/Ca_{6717}) - (0.133 \pm 0.175)}{0.5447 \pm 0.0572}\right) \tag{3}$$

The basic principle on which our survey is based on is the assumption that the strength of the Li line is relatively insensitive to the range of stellar parameters of the sample except for Li abundance. A similar assumption is made for the Ca line as well. To understand the sensitivity of line strength ratio with respect to stellar parameters, we synthesized spectra (e.g. for R ≈ 3500) using the Kurucz model atmospheres (Castelli & Kurucz 2004) and latest version of MOOG (Sneden 1973) for a full range of sample stellar parameters, and measured their corresponding line strength ratios. Within the sample range, the ratio of core strengths vary little. Major uncertainty arises due to the relatively high sensitivity of Li line to $T_{\rm eff}$ compared to Ca I. For extreme metallicity values, the line strength ratio also varies significantly compared to $T_{\rm eff}$ and log g; For log g variation in ratio is quite small. As shown in Fig. 5(b), the effect of $T_{\rm eff}$ on the ratio of Li6707/Ca6717 leads to uncertainty of about 0.2 dex in Li abundance, similarly the effect of log g and [Fe/H] on the ratio leads to 0.05 dex and 0.3 dex, respectively. The cumulative uncertainty is the quadratic sum of uncertainties of the three parameters, which is about 0.35 dex and is very similar to the value arrived based on polynomial fitting to the low-resolution spectra.

5. Results and discussion

The method, as discussed above and validated using K giants with known Li abundance, seems to be good enough to identify Li-rich K giants. We obtained low-resolution spectra for stars in the survey sample using any one of the three telescopes depending on their availability. We measured line depths of Li I at 6707 (Li6707) and Ca I at 6717 (Ca6717) with respect to their continuum positions. For most of the spectra Li line at 6707 Å is undetectable. Of the 2000 stars, Li6707/Ca6717 could be measured only for about 600 stars with a detectability

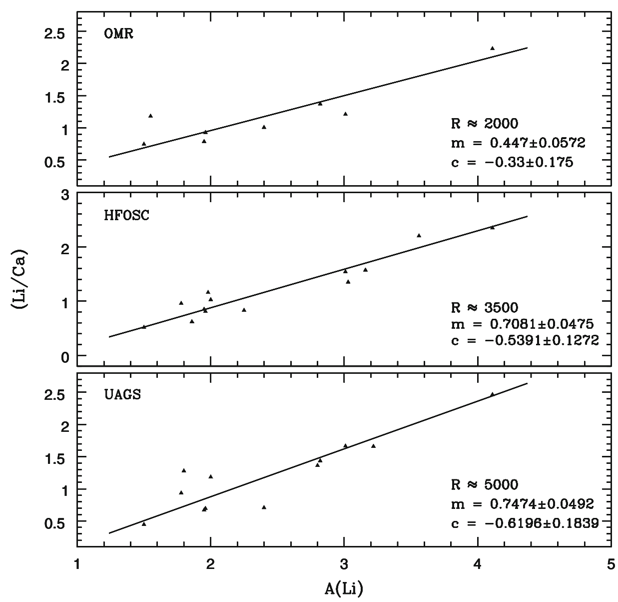

Figure 4. Derived relations between Li abundance and measured Li to Ca strength ratios for a set of giants with known Li abundance for the three different instrument resolutions. The corresponding resolution, slope, and intercepts are also given in each of the boxes.

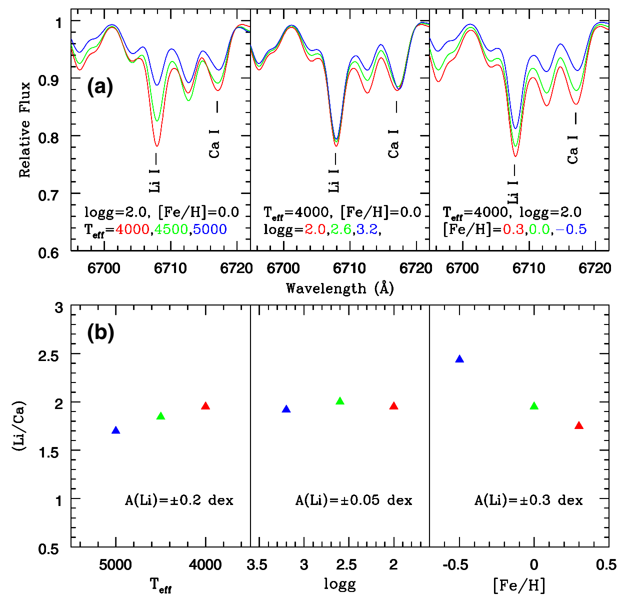

Figure 5. Synthetic spectra around Li region for a range stellar parameters and for a given Li abundance. Spectra is convolved for R ≈ 3500. One may notice significant variation of Li line or Ca line alone for changes in $T_{\rm eff}$ and [Fe/H] (top panel). In the bottom panel, variation of Li6707/Ca6717 ratio against stellar parameters is shown.

Table 3. Comparison of derived Li abundances of K giants with known Li abundances from the literature.

HD No.	$A(\mathrm{Li})^{1,2}_{Lit}$	T_{eff}	log g	[Fe/H]	$A(\mathrm{Li})_{HFOSC}$	$\Delta A(\mathrm{Li})^{a}$	$A(\mathrm{Li})_{UAGS}$	$\Delta A(\mathrm{Li})^{b}$	$A(\mathrm{Li})_{OMR}$	$\Delta A(\mathrm{Li})^{c}$
6665	3.03	4700	2.70	0.20	2.67	−0.36	–	–	–	–
9746	3.56	4425	2.30	−0.05	3.87	+0.31	–	–	–	–
40827	1.78	4575	1.80	0.10	2.01	+0.23	2.08	0.3	–	–
63798	1.86	5000	2.50	−0.10	1.63	−0.23	–	–	–	–
90633	1.98	4600	2.30	0.02	2.29	+0.31	–	–	–	–
108471	1.96	4970	2.80	−0.01	1.91	−0.05	1.76	−0.20	1.95	0.01
112127	3.01	4340	2.10	0.09	2.93	−0.08	3.06	0.05	2.66	−0.34
116292	1.50	5050	3.00	−0.01	1.49	−0.01	1.43	−0.07	1.61	0.11
120602	1.95	5000	3.00	−0.08	1.96	+0.01	1.73	−0.22	1.68	−0.27
183492	2.00	4700	2.40	−0.08	2.21	+0.21	–	–	–	–
203136	2.25	5100	2.80	0.05	1.93	−0.32	–	–	–	–
214995	3.16	4740	2.56	0.0	2.98	−0.18	–	–	–	–
233517	4.11	4475	2.25	−0.37	4.07	−0.04	4.12	0.01	4.34	0.23

[1] $A(\mathrm{Li}) = \log(n(Li)/n(H)+12$; [2] Kumar *et al.* (2011); [a] (HFOSC-Lit), $\mu = -0.015$, $\sigma = 0.22$; [b] (UAGS-Lit), $\mu = -0.02$, $\sigma = 0.19$; [c] (OMR-Lit), $\mu = -0.05$, $\sigma = 0.25$

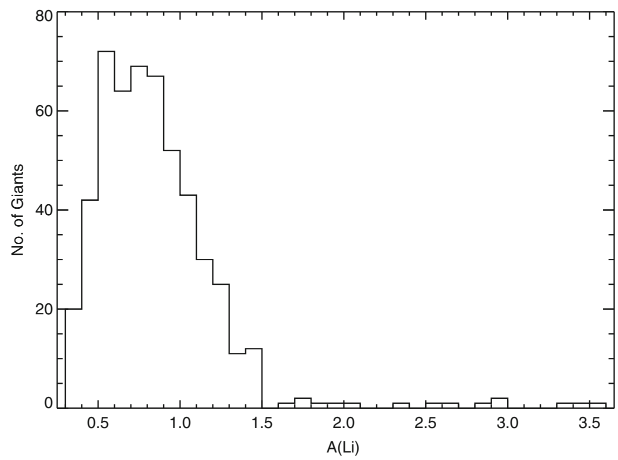

Figure 6. Histogram of K giants for which Li abundance is measured. Note the Li-rich giants are in the tail portion.

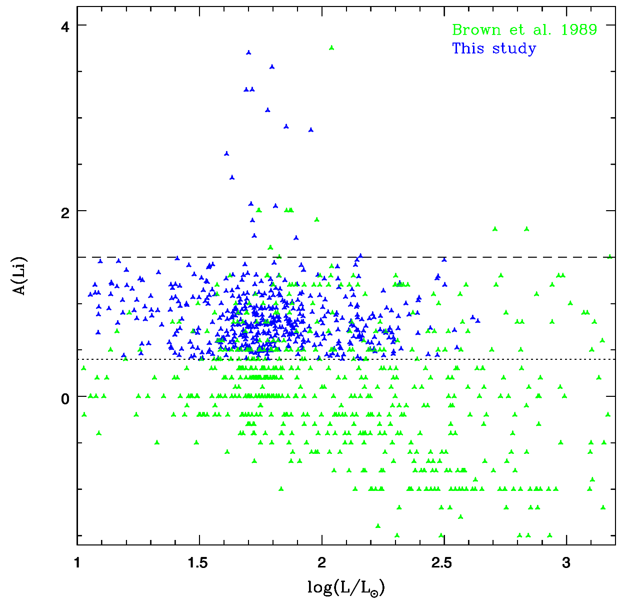

Figure 7. Plot of derived Li abundances from this study (blue) and Brown *et al*. study (green) are plotted against luminosity. K giants above the dashed line are Li-rich giants. The dotted line indicates the detection limit of Li abundance for the sample stars in this study. Note Li-rich giants are confined to a narrow luminosity range which coincides with luminosity bump.

limit at about 0.4 dex, i.e. about 30% of the sample. As a result, we cannot measure extremely low values of Li abundances, which may be either due to lower spectral resolution or very low Li abundance of stars. However, in general, low Li abundances for most of the stars of the current sample are in agreement with the canonical stellar evolutionary model predictions (Iben 1967) and observational studies (e.g. Brown *et al.* 1989). In fact, observations suggest Li abundances in K giants, in many cases, are much lower than model predictions (e.g. Brown *et al.* 1989).

Distribution of Li abundances of K giants for which the line ratios could be measured and derived using the above polynomial relations is shown in Fig. 6. The histogram, due to detectability limit of Li abundance, shows a sharp cut-off at lower end of Li but it tails off relatively smoothly at A(Li) $\approx$ 1.5 dex. For the current study, we treated all the K giants with A(Li) $\leq$ 1.5 dex are normal. As shown in the histogram there are 15 K giants with A(Li) > 1.5. We designated them as Li-rich K giants, which constitute just about 1% of the sample. The rarity of Li-rich K giants is in agreement with many recent systematic surveys in different populations: 10 Li-rich giants out of 644 field giants (Brown *et al.* 1989), 6 out of 400 bulge giants (Gonzalez *et al.* 2009), 5 out of 824 thick disk giants (Monaco *et al.* 2011), 8 out of 700 halo giants (Ruchti *et al.* 2011), 14 out of 2000 giants of dSphs (Kirby *et al.* 2012).

Results from our study for about 600 stars along with Brown *et al.* (1989) are shown in Fig. 7. Interestingly, Li-rich stars (with A(Li) $\geq$ 1.5 dex) from both the samples seems to be concentrated within a narrow range of luminosity $\log(L/L_{\odot}) = 1.6 - 2.0$. This is an important result which also coincides with the luminosity bump and red clump for low-mass stars of 0.8 to 3 $M_{\odot}$. As shown in Fig. 7 measured Li abundances from Brown *et al.* (1989) reach as low as − 1.0 dex and also the K giants with higher luminosity (towards RGB tip) show severe depletion of Li. Due to the limitation of low resolution in the current study we cannot comment on overall distribution and, in particular, very low Li abundances.

Subsequently, all the Li-rich candidate giants identified in this study were observed with high-resolution spectra and were confirmed as genuine Li-rich K giants. Results of which along with detailed discussions on possible scenarios were published elsewhere (see Kumar *et al.* 2011). The K giants with A(Li) > 1.5 dex are tabulated in Table 4 along with (B–V) colour, estimated $T_{\rm eff}$, Vmag, Parallax, derived luminosity, Li abundance(this study), Li abundance (based on high resolution), and difference. As shown in Table 4, results based on this method are in agreement with results from high-resolution spectra before applying non-LTE corrections (Fig. 8). The average difference between results obtained in this study and high resolution is about 0.3 dex.

Table 4. Comparison of derived Li abundances of Li-rich giants with those derived from high-resolution spectra of Kumar *et al.* (2011).

HD	(B–V)	$T_{\rm eff}$	V	π	log $(L/L_\odot)$	A(Li)	A(Li)LTE[a]	A(Li)NLTE[a]	ΔA(Li)[b]
8676	1.050	4705.07	7.77	4.27	1.701	3.70	3.86	3.55	0.16
10437	1.073	4660.60	6.57	6.72	1.796	3.54	3.76	3.48	0.22
12203	1.004	4804.46	6.75	6.58	1.716	1.89	2.01	2.08	0.12
37719	1.092	4655.10	7.62	4.23	1.779	3.08	2.70	2.71	− 0.38
40168	1.009	4771.50	6.88	3.75	2.158	1.51	1.49	1.70	−0.3
51367	1.147	4530.49	6.99	7.09	1.611	2.61	2.58	2.60	− 0.03
77361	1.161	4549.62	6.20	9.25	1.691	3.30	3.96	3.80	0.46
88476	0.910	4941.12	6.86	4.97	1.894	1.74	2.12	2.21	0.38
107484	1.180	4504.67	7.72	4.06	1.809	2.03	2.04	2.14	− 0.01
118319	1.008	4752.32	6.48	7.58	1.710	2.07	1.88	2.02	− 0.19
133086	0.981	4831.96	6.83	6.25	1.724	1.77	2.03	2.14	0.26
145457	1.027	4731.41	6.57	7.98	1.633	2.35	2.49	2.49	0.14
150902	1.084	4664.27	7.93	3.36	1.853	2.85	2.64	2.65	− 0.21
167304	1.057	4729.52	6.36	6.07	1.955	2.81	2.95	2.85	0.14
170527	0.987	4812.28	6.84	6.31	1.715	3.30	3.31	3.12	0.01

[a] Kumar *et al.* (2011) (KRL11); [b] This study, $\mathrm{KRL11}_{LTE}$

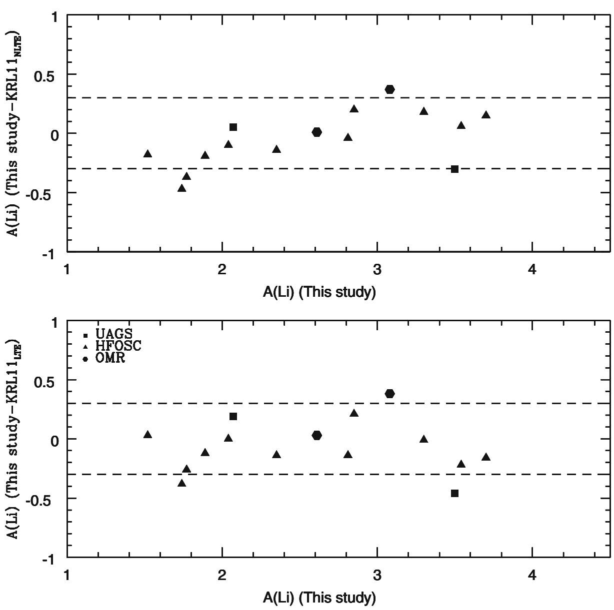

Figure 8. Li abundances estimated from the current study for Li-rich giants using low resolution spectra are compared with Li abundances derived using high resolution spectra from Kumar *et al.* (Top panel: Non-LTE; bottom panel: LTE abundances). Note most of them are within 0.3 dex errors.

6. Conclusions

A large systematic survey of 2000 K giants based on low-resolution spectra was conducted for the sole purpose of identifying K giants with Li abundances more than 1.5 dex. We used the ratio of line strength of Li I at 6707 Å to adjacent Ca I line at 6717 Å to identify Li-rich giants. We constructed simple polynomials between line strength ratio (Li6707/Ca6717) based on low resolution spectra obtained in this study and estimated Li abundances of a number of giants. This procedure resulted to identify 15 new Li-rich K giants with uncertainties of ±0.3 dex. Subsequently, these were confirmed as bonafide Li-rich K giants from detailed high resolution spectroscopic studies. This study demonstrates the effectiveness of low-resolution spectra for identifying Li-rich giants and as a useful tool for implementation in large surveys which otherwise may take much longer time to complete using high-resolution spectra.

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