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Li-rich giants: A survey based on IRAS colours⋆

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Abstract. In a previous work we studied the IRAS colours of known Li-rich red giants and showed that they have flux ratios F_{12}/F_{25} and F_{25}/F_{60} in well defined ranges. By using this result as a selection criterion, we prepared a list of 280 IRAS Point Source candidates to be Li-rich giant stars.

Up to the present we have obtained spectra for 57% of our target list. We identified five stars showing a strong LiI 670.079 nm line and six ones with a Li line of medium strength. Most of the candidates show features typical of normal giants having circumstellar dust, as indicated by their IRAS colours.

Key words: stars: abundances — infrared: stars — stars: late type

1. Introduction

In Gregorio-Hetem et al. (1993) and Castilho (1995) the far-infrared emission of Li-rich giants (LRG) was analyzed, based on data from the IRAS Point Source Catalog for the sample of LRG discovered by Brown et al. (1989, hereafter BSLD). BSLD obtained coudé spectra for 644 giants, and found 9 new LRG ($\log N(\mathrm{Li}) > 1.8$), which corresponds to ∼1.5% of their sample of $G-K$ giants. They also found 8 stars with $1.3 < \log N(\mathrm{Li}) < 1.8$ (∼ 1.2% of their sample).

In terms of IRAS colours the distribution of LRG is different from that of Li-normal giants. A large number of LRG are found within the "box" $-0.7 < [25-12] < -0.3$ and $0.0 < [60-25] < 0.25$ as shown by Gregorio-Hetem et al. (1993) (these colours are defined by: $[\lambda_i - \lambda_j] = \log(S_{\lambda_i}/S_{\lambda_j})$, where $\lambda = 12$, 25, and 60 μm).

Following the criterion of flux ratios given above, we have selected 280 candidates from the IRAS PSC and started an all sky survey of these stars (Barbuy et al. 1995, 1996). In this paper results of this survey are presented.

In Sect. 2 the selection criterion and the observations are described. In Sect. 3 the results are presented and discussed.

2. Selection of candidates and observations

Using the "box" in IRAS colours $-0.7 < [25-12] < -0.3$ and $0.0 < [60-25] < 0.25$ (Gregorio-Hetem et al. 1993), 280 candidates to be LRG were selected from the IRAS PSC I and II (Joint IRAS Science Working Group 1985 & 1988).

Spurious objects were avoided by retaining only sources having good quality IRAS measurements. All sources previously identified as early-type stars, extragalactic or non-stellar objects were not considered.

The observations were collected at the *Laboratório Nacional de Astrofísica* (LNA), Brazil; European Southern Observatory (ESO), Chile and *Observatoire de Haute Provence* (OHP), France.

The northern hemisphere observations were developed at OHP by using the *AURELIE* high resolution spectrometer (Gillet et al. 1994) at the 1.52 m coudé Telescope. The observations cover the spectral range $640-680$ nm, with spectral resolution of 0.02 nm.

The southern candidates were observed at LNA and ESO. At LNA spectra were obtained at the coudé focus of the 1.6 m telescope, using a GEC CCD covering the spectral range $663-677$ nm, with spectral resolution of 0.3 Å. The ESO observations were collected at the 1.52 m ESO telescope with the Boller & Chivens Spectrograph and a CCD FA2K, using the grating #26, which gives a resolution of ∼ 1 Å in the spectral range $530-730$ nm.

We have observed 158 IRAS sources in the period 1994-1996. In the case of IRAS sources associated to two stars, both were observed so that the total sample includes 164 stars.

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⋆ Observations collected at the Laboratório Nacional de Astrofísica - LNA, Brazil; Observatoire de Haute Provence - OHP, France; European Southern Observatory - ESO, Chile.

Table 1. List of observed stars which show high and medium equivalent width of the Li 670.782 nm line

IRAS name	α_{1950}	δ_{1950}	identification	S.T.	m_V	W(Li)	W(Li)/W(Ca)
07559−5859	07 55 54.5	−58 59 22	HD 65750, SAO 235638	M0III	6.3	0.31	1.41
16161−1445	16 16 11.4	−14 45 10	HD 146850, SAO 159846	K3III	7.2	0.37	1.32
18241−1443	18 24 06.6	−14 43 41	GCSS557	SRa	10.4	0.21	0.95
18585−0430	18 58 30.6	−04 30 39	HD 176588, SAO 142919	K2III	7.1	0.27	1.00
19012−0747	19 01 15.6	−07 47 06				0.41	1.71
00483−7347	00 48 18	−73 47 00				0.10	0.53
06215−0902	06 21 33.9	−09 02 26	HD 44889, SAO 133209	K0	8.2	0.18	0.60
10204−6135	10 20 26.0	−61 35 51	HD 90082, SAO 250932	M3	7.5	0.20	0.83
11024−6241	11 02 27.0	−62 41 26	HD 96195, SAO 251247	K5	8.0	0.17	0.61
19038−0026	19 03 49.9	−00 26 04				0.13	0.77
19049−0234	19 04 59.5	−02 34 32	HD 178168	K5	9.0	0.12	0.53

We use "GCSS" to identify an object in the General Catalog of S stars (Stephenson 1976).

3. Results

We have observed about half of the list of candidates, and found 5 new LRG.

Among the 164 observed stars we have found: 5 Li-rich giants; 6 with a moderate Li line; 20 normal giants showing a weak Li line, and 56 showing no Li line; 54 stars present strong molecular TiO bands; and 23 remaining ones correspond to other kinds of objects. The different groups of objects are described in Appendix A.

We estimate the strength of the Li line relative to the Ca I 671.768 nm line. The candidates were classified in three groups, according to the the ratio between the Equivalent Width (W) of these lines: W(Li)/W(Ca) $\gtrsim$1, 0.5 $\lesssim$ W(Li)/W(Ca) $<$ 1, and W(Li)/W(Ca) $<$ 0.5 are considered strong, moderate and weak, respectively.

3.1. Li-rich giants

The stars showing strong and moderate Li line are listed in Table 1, where are given: the IRAS name; equatorial coordinates; other identification; the visual magnitude and the spectral type when available; the equivalent width (in Å) of the Li I 670.782 nm doublet W(LiI); and the ratio W(LiI)/W(CaI). Comments on individual objects are presented in Appendix A.

It should be noted that the equivalent width of the Hα line for all these stars is $\sim$ 1 Å, in agreement with results found for G5 − M5 red giants. In Figs. 1 and 2 we show the spectra obtained for stars in Table 1. For one of them (HD 146850) we carried out a detailed analysis based on high resolution spectroscopy (Castilho et al. 1995). Files containing the spectra in the Li I line region for all these stars, and an *échelle* spectrum of HD 146850, are available in CD ROM (Castilho et al. 1997).

The lithium is expected to be strongly diluted in giant stars according to the standard models. Observations show that in disk stars (BSLD) and globular clusters (e.g. Pasquini & Molaro 1996) the Li abundance for most of the giants is even lower than expected from the models.

Li abundances 200 times larger than the mean value indicate that, either (a) in some stars the original Li is not destroyed, or (b) there should be a process of Li production during the evolution of the star.

Smith & Lambert (1989, 1990) have shown that evolved (AGB) red giants could produce Li during particular phases of their evolution. Theoretical predictions for such production of Li in intermediate mass stars ($3 - 7\ M_\odot$) were presented by Sackmann & Boothroyd (1992). Sackman & Boothroyd (1997) using deep circulation computations extend the mass range of Li production to stars of $1 - 3\ M_\odot$.

Some groups of LRG are found in other locations of the IRAS colours diagram, suggesting that they are following tracks in this diagram, probably caused by mass loss (Castilho 1995; de la Reza et al. 1996). In order to test this hypothesis, other regions in the IRAS diagram should be investigated such as the region between the *locus* studied by us and the T Tauri *locus* (Gregorio-Hetem et al. 1992). A tentative list of IRAS sources in this region has 400 sources, but the number of identified stars is very poor.

Except for the high Li abundance, the LRG are normal red giants. No correlation was found between mass, rotation or ^{12}C/^{13}C ratio and Li abundance (da Silva et al. 1995; de Medeiros et al. 1996). This fact and their far infrared emission features suggest that we may be observing not a unique class of stars, but a short phase of the stellar evolution of ordinary stars, when Li is created (Sackmann & Boothroyd 1997).

Detailed analyses for the present sample of LRGs, based on high resolution spectroscopy, will be presented elsewhere. Also, the measurement of B and Be would be of great interest (Sackmann & Boothroyd 1997).

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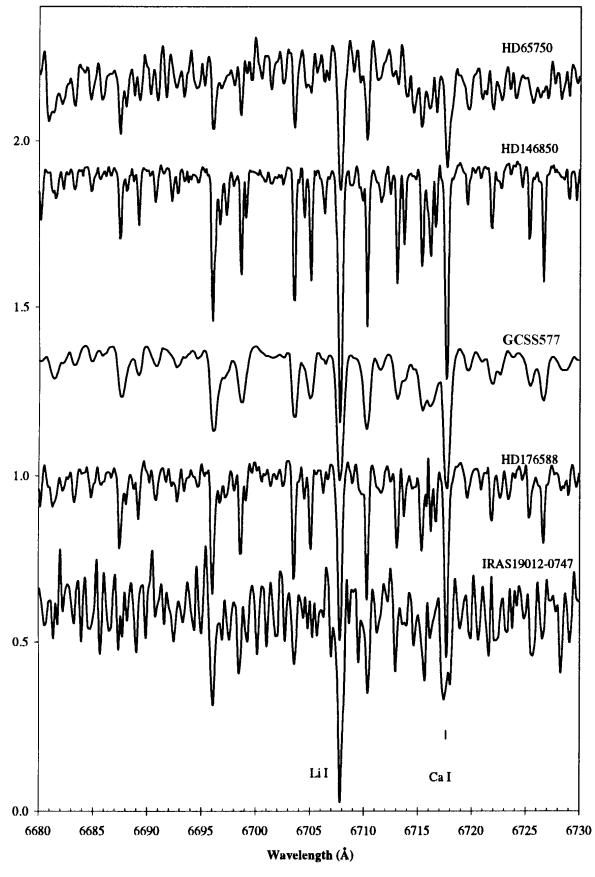

Fig. 1. Spectra of the five giants showing large Li-line. Differences in line widths are due to spectral resolution, see Sect. 2

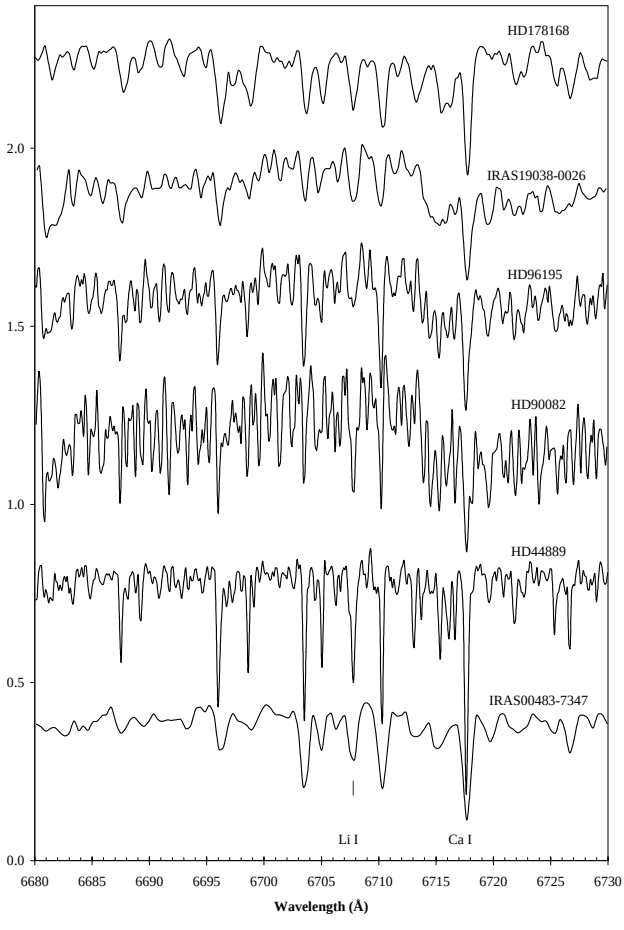

Fig. 2. Spectra of the six giants showing mid strength Li-line. Differences on line widths are due to spectral resolution, see Sect. 2

at OHP. This work benefited from the SIMBAD database operated by *Centre des Données Stellaires* (CDS) in Strasbourg. We acknowledge partial financial support by CNPq, Fapesp (Brazil) and CNRS (France). BC and JGH acknowledge the CNPq PhD (Proc. No. 840417/97-7) and Post-Doc (Proc. No. 300267/92-4) fellowships.

Appendix

A. Description of observed stars

A.1. Normal giants

In recent work it has been shown that the mass loss rate in the red giant branch appears to be higher than previously thought (Zuckerman et al. 1995). Most of the objects observed in our survey are normal giants showing a far-infrared emission typical of circumstellar dust. In Table 2 we list the 20 normal giants showing a faint Li line. The 57 normal stars, with no Li line, are listed in Table 3.

de la Reza et al. (1997) argue that the presence of dust around normal-Li giants is connected to a Li depletion occurring faster than the shell dissipation. The normal giants are located apart from the LRG, the latter being redder. We note that in the IRAS diagram "*box*" surveyed in the present work this effect is not observed.

A.2. Cool giants

A large group of stars with strong molecular bands is listed in Table 4. The bandheads are mainly at 665.1, 668.0, and 671.7 nm, corresponding to TiO bands.

A.3. Other objects

A few stars, listed in Table 5, show features not typical of the groups above discussed and we classified them as spurious objects. Most of them show a large Hα absorption line, that could represent early-type stars. We have detected 4 stars with faint Hα emission line, which we tentatively classify as possible weak T Tauri stars. We also detected 2 Carbon stars.

Table 2. List of stars showing features of normal giants, with low equivalent width of the Li line

IRAS name	identification	S.T.	m_V	W(Li)	W(Li)/W(Ca)
01504+5953	DO24938	M3		0.05	0.32
02401+8139	SAO432	K2	8.5	0.10	0.43
03396+5111	SAO24181	K7	8.5	0.08	0.36
05505+0932	SAO113234	K2	8.1	0.03	0.13
07365−1923				0.10	0.20
12100−6952	S Mus			0.01	0.05
13027−6024A				0.09	0.08
14262−5805	CGCS2163			0.04	0.33
16583−0408	BSC6318	K4I	4.8	0.06	0.28
17464+6739				0.01	0.25
18232+0800	BSC6902	G8I	5.6	0.01	0.05
18416+0232				0.03	0.30
18453+1949	SAO104107	K3	8.0	0.06	0.23
19019−1039A				0.01	0.06
19246+2826	DY Cyg			0.01	0.48
19425+4939	SAO48778	K0	7.6	0.06	0.32
19575+7618	SAO9582	MA		0.03	0.18
20550+6418				0.06	0.29
21121+4920	DO39334			0.03	0.25
21196+4648	SAO50754	K3I	7.8	0.01	0.35

We use "CGCS" to identify an object in the General Catalogue of Cool Carbon Stars (Stephenson 1989, also designed by GCGCS); "DO": Dearborn Observatory Catalogue of Faint Red Stars; "BSC": Bright Star Catalogue.

Table 5. Other objects

IRAS name	identification	S.T.	m_V	note
05142+7910	SAO 5496	F8	5.1	a
06444+0038	CGCS 580			c
06489−0511	CGCS 597			c
08197−3447	CGCS 1143			b
08217−4518	CGCS 1158			d
08249−4425B				a
13301−5516D	ER Cen			a
15053−5322	CGCS 2214			d
17275−1016				a
18339−1323A				b
18339−1323B				a
18587+0947				a
19019−1039B				a
19136+2127				d
19160+4641				d
19235+1054				d
19263+1214				a
19337+1620				a
19431+3014				a
19572+5157A	CM Cyg			b
19572+5157B	CM Cyg N			d
21270+4100				b
23481+6154				a

Notes: a) large Hα absorption, b) Hα emission, c) Carbon star, d) other.

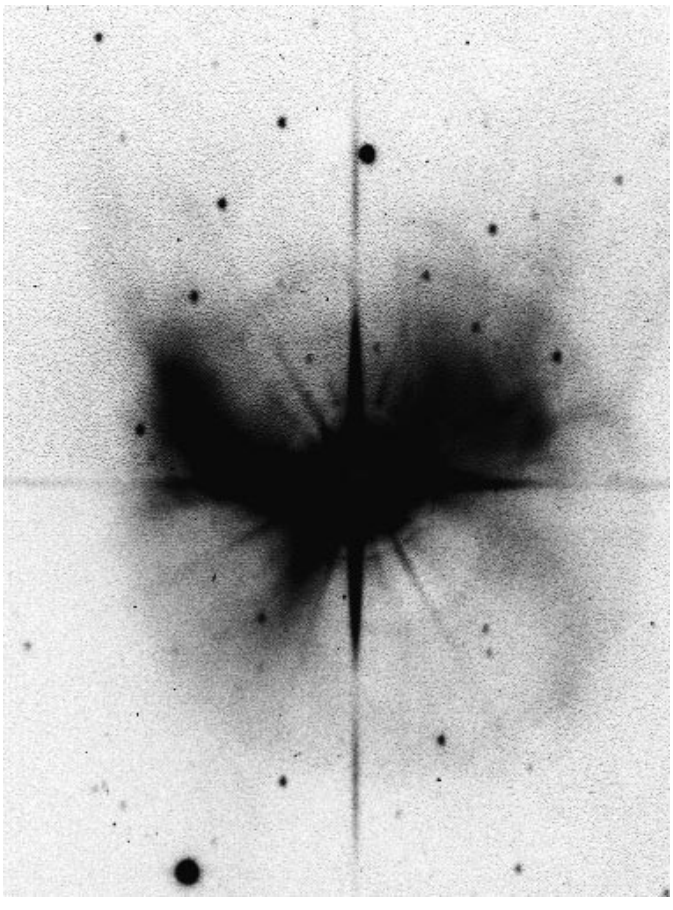

Fig. 3. I band image of HD 65750, showing the large envelope ($3' \times 5'$). North is up and West is to right

A.4. Comments on individual objects

IRAS 16161−1445 (HD 146850) - In Castilho et al. (1995) we carried out a detailed analysis of this star and found $\log N(\mathrm{Li}) = 1.6$, [Fe/H] $= -0.3$ and solar ratios of α elements O,Mg, Ca, Ti relative to Fe. This star is a typical disk star.

IRAS 07559 − 5859 (HD 65750) - This 5 $M_\odot$ (Pesce et al. 1989) oxygen-rich star is very interesting because of its large (3 − 4 arcmin) dust and gas envelope. Reimers (1977) estimated a $2 - 4\ 10^{-7}$ $M_\odot$/year mass loss rate, and an envelope mass of $\sim 0.7\ M_\odot$. Witt & Rogers (1991) estimated that this mass loss rate is not enough to form the observed envelope and they proposed that a past and more efficient mass loss event occurred about 32 000 years ago. Its evolutionary *status* is not well defined due to the large uncertainties in the mass and luminosity determinations. Probably HD 65750 is at the base of the AGB.

The presence of this large envelope confirms our previous suggestion (Gregorio-Hetem et al. 1993) that the Li-rich giants are associated with circumstellar dust and gas envelopes emitting mostly in the infrared, and that this

characteristic could be related with the high Li abundances (Castilho 1995; de la Reza et al. 1996).

In Fig. 3 we present an I band CCD image of HD 65750, showing its large envelope (IC 2220). The image was obtained with a 60 s. exposure at the 60 cm B&C telescope at LNA (Brazil).

IRAS 10204 − 6135 (HD 90082) - Although the Li line doublet in this star is comparable to the Ca I line (λ671.7 nm), the molecular lines in this region do not permit a good estimation of the W(Li).

IRAS 19012 − 0747 and IRAS 19038 − 0026 - We found no identification for the optical counterparts of these two IRAS sources and no previous work on then. Both seem to be K stars. The W(Li)/W(Ca) ratio for IRAS 19012−0747 is the largest of our sample.

IRAS 18241 − 1443 (GCSS 577) - Chen & Kwok (1993) used this star in their circumstellar material study. It was identified as a S star by Kershbaum & Hron (1992). Its low resolution IRAS spectrum shows no peculiar features in the range 8 − 22 μm (Olnon & Raimond 1986).

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Table 3. List of normal stars with no Li line

IRAS name	identification	S.T.	m_V
01068+5428	SAO 2204	K0	7.0
03421+0146	SAO 111338	K2	8.0
03557+0118	SAO 111532	K5	7.2
05074−0037	SAO 131834	K0	6.3
05461−0148	SAO 132556	K2	7.7
07150−4034	SAO 218604	G0	7.3
07310−1918	SAO 153062	K0	5.0
08158−3554	SAO 199051	K5	6.5
08175−4602	SAO 219783	K0	7.0
08389−4145			
09184−4457	SAO 221077	K0I	6.5
09270−5855	SAO 237018		8.8
09337−5301			
11418−5809	SAO 239336	K2	7.5
12392−5429	SAO 240165	K5I	6.5
12401−6224			
13027−6024B			
13086−5643	CV Cen		
13301−5516B	ER Cen		
13301−5516C	ER Cen		
13399−5605			
13432−1210	SAO 158152	K0	5.7
14121−5155	CGCS2151		
14130−5305	SAO 241582	K5	7.7
14244−5448	SAO 241733	MA	8.5
14311−5311			
14359−5855			
16094−4600	GCSS502	A	
16103−5321			
16111−3253	SAO 207480	K0I	6.0
16255−5738	SAO 243874	K0	6.0
16553−1417	SAO 160195	K2	7.2
17158+1323			
17388−4333	SAO 228311	K2	7.3
17402+5150	SAO 30522	K0	6.0
17477−2146	SAO 185836	K5	
17499−1352	GCVS9795		
17547+0012	SAO 122953	K5	8.9
18048−0636			
18073+0032			
18120−0237	SAO 142176	K5	7.8
18383+0708	DO5000	K5	9.0
18405−1732			
18420−1834			
18500+1428	SAO 104203	K0	6.5
19049+1702			
20001+4358	SAO 49105	M0	7.2
20027+2534			
20035−0413	SAO 144062	K0	6.5
20052+3551			
20227+5605			
20375+2925	DO19235		
21181+5406	CCS3011		
21217−8501	SAO 258899	K2	6.4
22209−0726	SAO 146062	G6I	6.0
23579+5916	BSC9079	G9I	6.1

We use "GCVS" to identify an object in the General Catalog of variable stars.

Table 4. List of the candidates with spectra showing TiO bands

IRAS name	identification	S.T.	m_V	note
00135+4736	DO23016			ab
06262+0727				ab
06319+0500	SAO 114079	MB	7,1	c
07081−2248	SAO 173118	M		ab
07417−3343	SSSC0741−337			ab
08194−4509				a
08234−3536	GCSS 311			b
08249−4425A				ab
08346−5626				b
08577−4003				b
10109−5357				a
10551−5250	GCSS 418			a
11252−5510				ab
11396−5547	UMSA	A3III		a
11516−3935	UMSA	M3III		a
12200−5620				a
12454−7411				a
13057−7115				a
13301−5516A	ER Cen			c
13552−5529				a
13575−5529				c
14066−5657				a
14244−5448	SAO 241733	MA	8.5	ab
14528−5134				ab
15353−6325				c
15363−4918				c
15591+8313	SAO 2638		9.0	a
16166−5426				c
16237−5627				b
16345+0728				a
17050+1449	DO15795			ab
17167+1517	SAO 102733	M	9.1	b
17283−4240				c
17462−0907	2μ I10380			c
18060−0740				a
18160−2636				a
18338+0911	DO4926			a
18405−1732				c
19043+2021				abc
19066−0624				ab
19136+0423				b
19316+1636				a
19468+4019				c
19490+3706	V1294 Cyg			c
19579+2518				ab
20061+4131	V426 Cyg			a
20062+0451	SAO 125493	M0	9.0	a
20283+7414	DO19235			ab
20333+3127				b
20447+3808				ab
21440+5113				ab
22131+5557				c
23115+5651				ab
23591+6154	DO 43982			ab

We use "SSSC" to identify an object in the IRAS Small Scale Structure Catalog; "UMSA": University of Michigan Spectral Atlas; "2μ I": Two Micron Sky Survey Improved.
Notes: Detected spectral lines: a) Hα, b) Ca I, c) Li I.