Astron. Astrophys. 364, 674–682 (2000)

ASTRONOMY
AND
ASTROPHYSICS

Detailed analysis of a sample of Li-rich giants[⋆,⋆⋆]

B.V. Castilho[1,2], **J. Gregorio-Hetem**[1], **F. Spite**[3], **B. Barbuy**[1], **and M. Spite**[3]

[1] Universidade de São Paulo, CP 3386, São Paulo, SP, 01060-970, Brazil
[2] Laboratório Nacional de Astrofísica, CP 21, Itajubá, MG, 37500-000, Brazil
[3] Universidade de São Paulo, CP 3386, São Paulo, SP, 01060-970, Brazil
[4] Observatoire de Paris-Meudon, DASGAL, URA 8633 CNRS, F-92195 Meudon Cedex, France

Received 24 July 2000 / Accepted 18 October 2000

Abstract. A detailed analysis has been carried out for a sample of 16 red giants showing a strong Li I 670.8 nm line. Ten of them were detected in a survey by Castilho et al. (1998), and the other 6 stars are Li-rich giants selected from the literature.

Element abundances in the sample Li-rich giants are similar to those in normal red giants, differing only by their high Li abundance and infrared excess. This suggests that Li-rich giants may correspond to a phase of stellar evolution of normal red giants, when Li is produced and transported to the atmosphere.

Key words: stars: late-type – stars: evolution – stars: atmospheres – stars: abundances

1. Introduction

The first detection of a Li-rich giant was a serendipitous discovery by Wallerstein & Sneden (1982). A systematic survey was carried out by Brown et al. (1989), by observing 644 giants, where 10 of them were revealed to be Li-rich. In a survey to search for T Tauri stars Gregorio-Hetem et al. (1992) detected 4 Li-rich giants. Other Li-rich giants were reported in the literature and about 30 Li-rich giants are currently known.

A systematic search of Lithium-rich giants (LRG) based on IRAS colours has been carried out by Castilho et al. (1998). Spectra including the Li I 670.78 nm line have been obtained for a list of candidates with IRAS colours on a [25−12] vs. [60−25] diagram in the locus defined by the already known LRG (Gregorio-Hetem et al. 1993; Castilho et al. 1998). In the present work, we show the results of a detailed analysis for a sample of 16 stars, among which 10 were discovered in our survey: 4 with a strong Li line, and 6 with a moderate Li line (Gregorio-Hetem et al. 2000) and the other 6 ones are previously known LRG. In Castilho et al. (1995) a detailed analysis was already presented for HD 146850.

In Sect. 2 the observations and data reduction are described. In Sects. 3 and 4 the detailed analysis of the atmospheric parameters is presented. In Sect. 5 the abundances are derived, and general discussion and conclusions are drawn in Sects. 6 and 7.

2. Observations and data reduction

Two sets of spectra were obtained: for 10 stars the wavelength coverage permits a detailed analysis, whereas for the other 6 stars only an estimation of parameters and Li abundance can be given. The program stars are listed in Table 1.

Spectra for 10 sample giants were obtained in 1996, December at the 1.4m ESO CAT telescope, using the CES (Coudé Echelle Spectrometer) with the long camera and the Loral CCD ESO # 38 of 2688×512 pixels, with pixel size 15×15μm. For each star eleven spectral regions between 534.8 nm and 806.6 nm were observed. These spectra have a resolving power of R $\approx$ 58,000 over four pixels, and dispersion of about 0.03Å/pixel. Most of them were obtained with S/N $>$ 100, and only for one object (HD 19745) of this set, the spectra have S/N $\approx$ 50 - 80.

For the other 6 stars, spectra corresponding to one order were obtained at the *Laboratório Nacional de Astrofísica* (LNA, Brazil), and the *Observatoire de Haute Provence* (OHP-France). For this set of observations only one spectral range is available, with S/N $\approx$ 30–95.

The LNA observations, carried out in 1993 March, 1993 November, and 1994 March were obtained at the coudé focus of the 1.6m telescope using a GEC CCD of 1152×770 pixels with 22μm×22μm pixel size, and a grating of 1800 l/mm yielding a resolution over two pixels of $\approx$ 25,000 covering the wavelength range $\lambda\lambda$ 663–677 nm.

The OHP observations were carried out in 1994 July, and 1995 July, with the AURELIE spectrometer at the Coudé focus of the 1.52m telescope (Gillet et al. 1994), with a resolving power R $\approx$ 11,000 in the range 530–730 nm.

The spectra of hot stars observed during the runs were inspected for telluric lines and bad CCD columns. The spectra of the 6 stars observed at the LNA and OHP are available in FITS format (Castilho et al. 1997).

Send offprint requests to: B.V. Castilho

⋆ Observations collected at the European Southern Observatory – ESO, Chile, *Laboratório Nacional de Astrofísica* – LNA, Brazil and *Observatoire de Haute Provence* – OHP, France

⋆⋆ Table 7 is available only in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strsbg.fr/Abstract.html

Table 1. List of program stars: IRAS name, spectral type (when available), and the equivalent width of the Li I 670.782 nm doublet (in mÅ). Last columns indicate the Observatory where the data were obtained, and the reference of LRG identification.

Object	IRAS name	S.T.	W_{Li}	Obs.	Ref.
HD 787	00096-1812	K4III	398	ESO	1
HD 19745	03062-6538	K1III	489	ESO	5
HD 30238	04429-2122	K4III	173	ESO	7
HD 31993	04575+0312	K2III	228	ESO	3
HD 39853	05523-1146	K5III	474	ESO	4
HD 95799		G8III	335	ESO	6
HD 44889	06215-0902	K0III	180	ESO	2
HD 65750	07559-5859	M0III	310	ESO	2
HD 90082	10204-6135	M3III	200	ESO	2
HD 96195	11024-6241	K5III	170	ESO	2
HD 4893		K2III	100	LNA	2
GCSS 577	18241-1443	SRa	210	OHP	2
HD 176588	18585-0430	K2III	270	LNA	2
I 19012	19012-0747		410	OHP	2
I 19038	19038-0026		130	OHP	2
HD 178168	19049-0234	K5III	120	OHP	2

(*) IRAS name; "GCSS" is used to identify an object in the General Catalogue of S stars (Stephenson 1976). Refs.: 1 – Brown et al. (1989); 2 – Castilho et al. (1998); 3 – Fekel & Balachandran (1993); 4 – Gratton & D'Antona (1989); 5 – Gregorio-Hetem et al. (1992); 6 – Luck (1994); 7 – Pilachowski et al. (1990)

Table 2. Johnson-Cousins *UBVRI* photometric data for the program stars. Average values were used for objects with different sources of data. The references are indicated in the last column.

Object	$U-B$	$B-V$	V	$V-R$	$R-I$	Notes
HD 787	1.63	1.47	5.23	0.93	0.71	a
HD 19745	0.94	1.09	9.32	0.56	0.52	18
HD 30238		1.48	5.72			b
HD 31993	1.14	1.28	7.56			23
HD 39853	1.84	1.53	5.65	0.90*		c
HD 95799	0.78	1.00	8.01	0.51	0.48	d
	0.79	1.00	8.14	0.53	0.51	2
HD 44889		1.71	7.55			3
HD 65750	2.24	2.01	6.33	1.54	1.16	e
HD 90082		1.72	7.5			3
	1.95	1.67	7.50	1.03	1.15	2
HD 96195		2.33	8.32			3
	1.61	2.28	7.94	1.42	1.56	2
HD 4893	1.64	1.40	8.45			29
	1.88	1.48	8.50	0.76	0.66	2
GCSS 577			13.26	3.13	2.35	2
HD 176588		1.78	6.88	1.31*		21
	2.10	1.65	6.89	0.97	0.88	2
I 19012	2.30	1.83	11.17	1.02	0.93	2
HD 178168		1.83	9.00			3
	2.17	2.03	9.06	1.09	0.97	2
HD 146850**	1.95	1.52	5.97	1.23*		f
	1.70	1.48	6.10	0.91	0.79	2

Notes – (*) R from *WBVR* photometric system; (**) HD 146850 has been included to compare previous results (Castilho et al. 1995) with the parameters obtained from colours.

References: 1 – Hoffleit & Warren (1991); 2 – Castilho & Lorenz-Martins (2000); 3 – CDS; 4 - Clariá & Lapasset (1988); 5 – Corben (1966); 6 – Corben (1971); 7 – Cousins (1964); 8 – Cousins et al. (1966); 9 – Cousins & Stoy (1963); 10 – Dachs et al. (1978); 11 – Eggen (1992); 12 – Eggen (1989a); 13 – Eggen (1974); 14 – Eggen (1981); 15 – Eggen (1989b); 16 – Eggen (1968); 17 – Eggen & Stokes (1970); 18 – Gregorio-Hetem et al. (1992); 19 – Irwin (1961); 20 – Johnson et al. (1966); 21 – Kornilov et al. (1991); 22 – Lake (1963); 23 - Lloyd Evans & Koen (1987); 24 – MacConnell (1974); 25 – Nicolet (1979); 26 – Olsen (1993); 27 – Roman (1955); 28 – Rybka (1969); 29 – Wesselink (1962).

a (refs. 1, 7, 12, 15, 16, 19, and 20); **b** (refs. 1, 8, 9, 20, 22, and 25); **c** (refs. 1, 6, 17, 20, 21, 24, 25, and 27); **d** (refs. 4, 14, and 26); **e** (refs. 1, 5, 10, 11, and 13); **f** (refs. 1, 6, 21, 25, and 28).

3. Calculations

An updated version of the code by Spite (1967), extended to include molecular lines by Barbuy (1982), where LTE is assumed, is used for the spectrum synthesis calculations.

Oscillator strengths by Wiese et al. (1969), Fuhr et al. (1988) and Martin et al. (1988) were used whenever available, otherwise they were obtained by inverse solar analysis, using the solar atmospheric model by Holweger & Müller (1974) and the solar atlas by Delbouille et al. (1973). Solar abundances are adopted from Grevesse & Sauval (1998). The molecular lines of C_2 ($A^3\Pi$-$X^3\Pi$), CN red ($A^2\Pi$-$X^2\Sigma$) and TiO γ ($A^3\Phi$-$X^3\Delta$) are taken into account in the calculations.

Model atmospheres employed have been interpolated in tables computed with the MARCS code by Plez et al. (1992, 1997). The calculations for two objects of our sample (HD 19745 and HD 95799) could not be done by using the grids from Plez et al., due to their higher temperatures, and for these two stars, the grid of Gustafsson et al. (1975) was adopted.

3.1. Stellar parameters

3.1.1. Temperature

A first guess of temperature is derived from colours. The photometric data are indicated in Table 2, except for one object of our sample (IRAS 19038-0026), since photometry is not available for this star.

We obtained additional *UBVRI* photometry at the LNA 60cm Zeiss telescope with the FOTRAP photometer (Jablonski et al. 1994), thus providing data for 8 stars of our sample. For stars with data from several sources, we used a weighted average. The LNA photometric data (Castilho & Lorenz-Martins 2000) are included in Table 2. The derived stellar parameters are reported in Table 3. We have corrected the colours with the Bond (1980) extinction law, where the distances were derived from parallaxes given in the Hipparcos catalogue when available (Column 2 in Table 3); for the other stars the distances were estimated from a Colour Magnitude Diagram for Hipparcos field stars (Perryman et al. 1995).

Table 3. Hipparcos Parallax, distance, and parameters determined from photometry. [Fe/H] and microturbulent velocity (V_t) adopted were obtained from curves of growth (Columns 10 and 11). The adopted atmospheric models are shown in the three last columns

Object	π (m")	r (pc)	E(B−V)	A_V	$\langle T \rangle$	log g	BC_V	M_{Vo}	[Fe/H]	V_t	Model Parameters T_{eff}	log g	[Fe/H]
HD 787	5.33	187	0.03	0.09	3939	1.4	−0.90	−1.05	0.0	1.5	4000	1.5	0.0
HD 19745[a]		362	0.04	0.11	4757	2.9	−0.50	1.64	0.1	1.2	4750	2.5	0.0
HD 30238	5.20	192	0.03	0.09	3925	1.4	−1.20	−0.61	0.0	1.5	4000	1.0	0.0
HD 31993	4.20	238	0.04	0.13	4367	2.4	−0.60	0.80	0.1	3.0	4500	2.5	0.0
HD 39853	4.37	229	0.04	0.12	3837	1.6	−1.50	−1.04	−0.3	1.5	4000	1.0	-0.3
HD 95799[a]		162	0.04	0.12	4900	3.2	−0.40	2.15	0.0	1.5	4900	2.5	0.0
HD 44889	1.20	833	0.12	0.12	3775	0.4	−2.40	2.17	−0.2	1.5	3800	0.5	0.0
HD 65750	3.37	297	0.10	0.32	3600[b]	0.6[b]	−2.25	−0.72	−0.4	1.5	3600	0.0	-0.3
HD 90082		492	0.10	0.32	3686	0.0[b]	−1.63	−0.64	−0.2	1.2	3600	0.0	0.0
HD 96195	1.12	893	0.18	0.94	3407	−0.5[b]	−2.60	−0.50	0.2	1.5	3600	-0.5	0.0
HD 4893		622	0.04	0.13	4057	1.8	−0.75	−0.34	0.2	3.0	4000	1.5	0.0
GCSS 577		3113	0.56	1.75	3300	0.0[b]	−3.00	2.54	0.0	2.0	3400	0.0	0.0
HD 176588	4.25	235	0.05	0.26	3793	1.6	−1.47	0.29	0.0	1.5	4000	1.5	0.0
I 19012		2330	0.24	0.74	3810	1.5	−1.65	0.07	0.0	1.5	3800	1.5	0.0
I 19038[c]									0.0	2.0	3600	1.0	0.0
HD 178168		1508	0.18	0.71	4000[b]	1.0	−1.63	−1.12	0.0	2.5	4000	1.0	0.0
HD 146850[d]	3.77	265	0.04	0.11	3957	1.3	−1.15	−0.91					

Notes: (a) The calculations for HD 19745 and HD 95799 were carried out employing the Gustafsson et al. models. For the other stars we used Plez et al.; (b) parameters obtained from the excitation equilibrium of the Fe I lines; (c) IRAS19038-0026 has no available photometry; (d) HD 146850 was analysed in Castilho et al. (1995): parameters obtained from photometry are compared here to those previously obtained.

The temperatures are derived by using the tables of colours *vs.* temperatures for cool giants by Bessell et al. (1998) and Lejeune et al. (1998). An effect of intrinsic reddening may probably be important for the stars of our sample, considering their far-infrared excess. Different values of temperature were calculated based on the colours for both calibration tables mentioned above. A mean value showing a typical r.m.s. deviation of 65 K was derived, leading to the first guess ⟨T⟩ listed in Table 3.

These temperature values were checked and in some cases modified for reaching the excitation equilibrium of the Fe I lines in the curves of growth. The final effective temperatures adopted are indicated in Table 3.

3.1.2. Gravity

A first guess of the surface gravity is estimated by using the calibration of colour indices as a function of log g by Lejeune et al. (1998), corresponding to the evolutionary track of a giant star of solar metallicity with 1 $M_{\odot}$ (Schaller et al. 1992). In order to compare this procedure with a different method, we also used the classical relations involving luminosity, mass and radius where the bolometric magnitudes were determined by assuming the visual-to-selective absorption R = 3.1, and bolometric corrections by Lejeune et al. (1998). By considering that most of the LRG has about 2 $M_{\odot}$, this value was applied in the calculations of this second method. The r.m.s. deviation between both methods is about 0.21 dex, showing that errors in log g are not significant, when the mass variation is small. In Table 3 we give the log g obtained. Finally, the gravities were checked and modified if necessary, from the ionization equilibrium of the Fe I and Fe II lines. The adopted gravities are listed in Column 13 of Table 3. For the star HD 176588 no Fe II line could be identified in the observed region, and the log g determination comes only from the photometric data.

HD 146850 is included in Table 3 to illustrate the good agreement of the stellar parameters derived from photometry and those derived from spectroscopy (T_{eff} = 4000 K, log g = 1.5, Castilho et al. 1995). Note that Jasniewicz et al. (1999) found different parameters which do not seem to be compatible with our data.

For the star HD 65750, Dachs et al. (1978) found a variability of m_V = 6.2 to 7.1, but it was not clear if this variation was regular or not. They estimated M_V = −2.4 from the spectral type, and assuming d = 400 pc, R = 3.5, E(B-V)= 0.28, A_V = 0.98, and (m−M) = 8.47, a mass of 5 $M_{\odot}$ was obtained. These values are different from those obtained here, indicating the errors produced in a calibration based on the spectral type, as well as other sources of errors due to differences in distance (of about 35%), or the circumstellar envelope contribution in E(B−V).

HD 19754 and HD 31993 are RS CVn type stars. Objects of this class generally present an excess Li abundance with respect to the values typically observed in evolved stars of the same spectral type. Strassmeier et al. (1999) reported the *VRI* variability of HD 31993, probably due to rotational modulation of an asymmetrically spotted stellar surface. They found a maximal amplitude of 0.05 mag for this star. The errors due to this variability are not significant on the estimation of gravity based on the colour calibration.

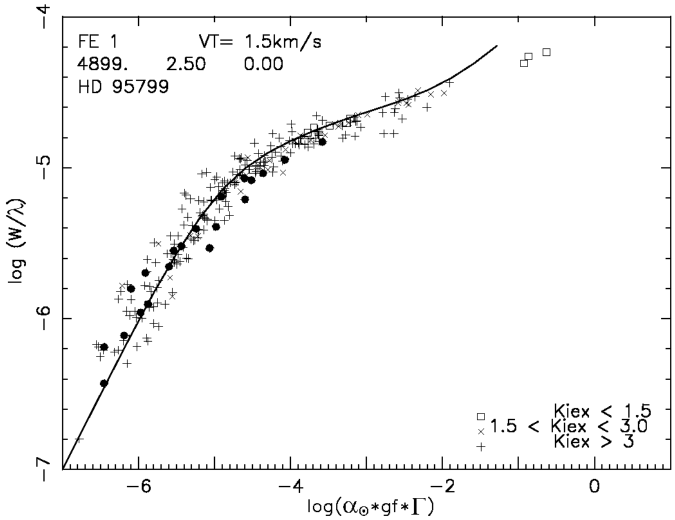

Fig. 1. Curve of growth of Fe lines for the star HD 95799. Different symbols indicate three ranges of excitation potential. The Fe II lines are represented by filled circles. The full line is a theoretical curve of growth. $\alpha_\odot$ is the solar abundance of the element, *gf* the line transition probability of the line, and Γ is a function of the element and of the stellar model.

3.2. *Curves of growth: metallicity and v_t*

Curves of growth were used to check the excitation equilibrium of Fe lines, to estimate the value of metallicity [Fe/H] and microturbulent velocity v_t. The Plez et al. (1992, 1997) grid of model atmospheres and the code RENOIR by M. Spite were used.

Fig. 1 shows the curves of growth of Fe I and Fe II lines, measured for one object (HD 95799) of our sample. Different symbols are used to represent three ranges of excitation potential, in this plot: their distribution shows that the excitation equilibrium is reached.

The parameters [Fe/H] and v_t are obtained by calculating a theoretical curve which gives the best fit of the data and compared to the solar value log N(Fe) = 7.50 in the usual scale where log N(H) = 12.0 (Grevesse & Sauval 1999). The dispersion of points displayed in Fig. 1 is quite the same for most of our stars. A larger dispersion is found only for those observed with lower resolution.

4. Influence of atmospheric parameters on abundances

In order to estimate the errors due to uncertainties on the atmospheric parameters, the variation of the equivalent width of the Li line W(Li) as a function of temperature, gravity and lithium abundance was calculated, by adopting a model with solar abundances. The lithium abundance is hereafter designated by log N(Li). We are interested here in analysing the computed W(Li) sensitivity for variations of the atmospheric parameters in both cases: lower and higher temperatures.

Fig. 2 shows W(Li) as a function of the adopted parameters. It can be noted for temperatures around 3500 K that log N(Li) has an important dependence on shifts in log g. For temperatures

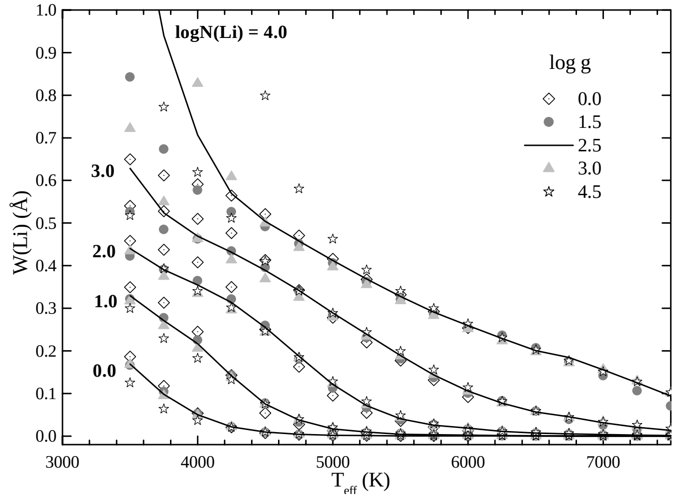

Fig. 2. Variation of the equivalent width (expressed in Å) of the Li I 670.78 nm line, as a function of temperature, gravity, and abundance. Curves are plotted to represent 4 different abundance values. For lower temperatures, log N(Li) is most sensitive to variations in log g, and for higher temperatures it is sensitive to T_{eff} variations

Table 4. The sensitivity of log N(Li) to shifts in the atmospheric parameters, verified for W(Li) ≈ 300 mÅ. Three different values of temperature were adopted. The shifts ΔT_{eff} and Δlog g correspond to the maximal uncertainties of the adopted parameters.

Temperature	$\Delta\ T_{eff}$		Δlog g	
(K)	−125K	+125K	−0.5 dex	+0.5 dex
3750	−0.23	+0.18	−0.20	+0.23
5000	−0.16	+0.21	+0.06	+0.02
6000	−0.08	+0.09	−0.13	+0.10

around 5000 K, log N(Li) is mainly sensitive to variations in T_{eff}. An evaluation of these dependencies is shown in Table 4, which gives the variation of log N(Li) corresponding to shifts on T_{eff} and log g for three different values of temperature. The mean errors derived from the maximal shifts on T_{eff} and log g are slightly different for lower and higher temperatures. Errors of 0.3 dex for stars with $T_{eff} <$ 4000 K, and of ∼0.2 dex for $4000 < T_{eff} < 5000$ K are predicted.

5. Results

5.1. *Lithium abundance*

For the stars observed with the CAT, the lithium abundance was determined by fitting synthetic spectra to the Li I 670.78 nm and 610.36 nm lines. Carlsson et al. (1994) and Ortega-Terra (1997) showed that non-local thermodynamical equilibrium (NLTE) effects play an important role in the abundance determination based on the Li I 670.78 nm line. In our calculations, we adopted the corrections for Li abundance proposed by Carlsson et al. (1994). The other Li I line, at 610.36 nm, is not clearly identified in some of the spectra, due to a blend with Fe I lines. This Li line was used for ten sample stars; for six of them only upper

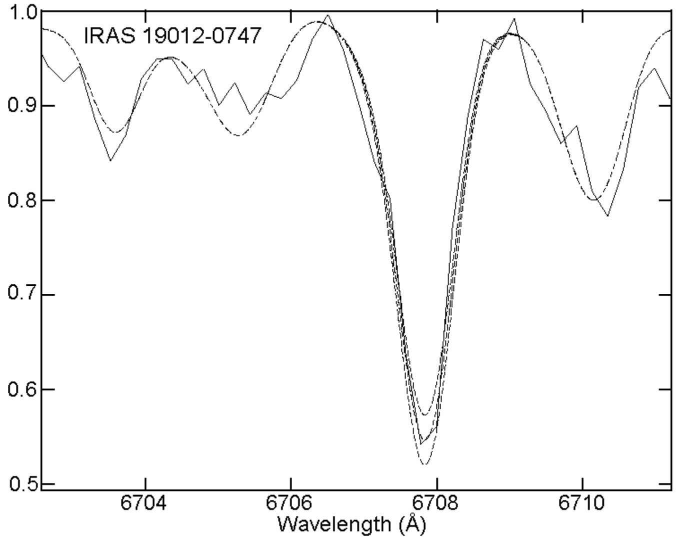

Fig. 3. Examples of synthetic (dashed lines) and observed (full line) spectra used in the fit of the Li I 670.78 nm line, for different values of abundance: log N(Li) = 2.5, 2.3, and 2.8 for IRAS19012-0747

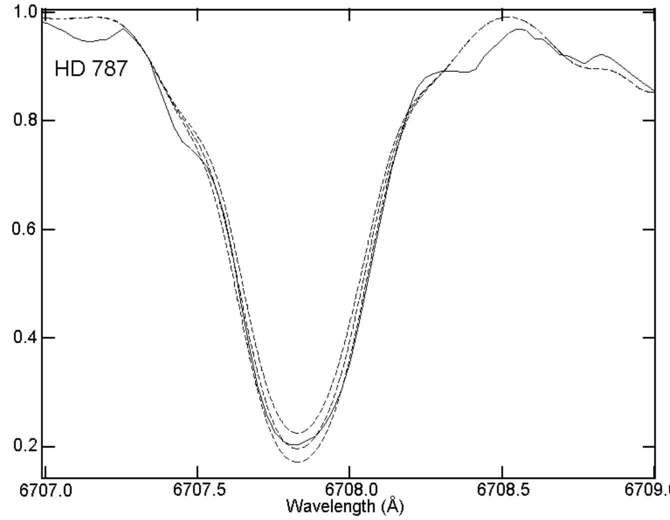

Fig. 4. The same as Fig. 3, with log N(Li) = 2.0, 1.8, and 2.2 for HD 787

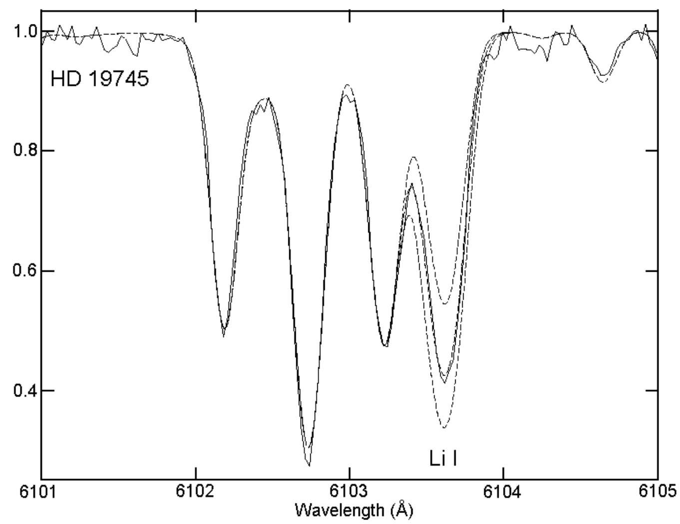

Fig. 5. Examples of synthetic (dashed line) and observed (full line) spectra used in the fit of the Li I 610.36nm line, for different values of abundance: log N(Li) = 4.0, 3.7, and 4.3 for HD 19745

Table 5. Lithium abundances (logN(Li)) obtained in the present work and from literature for both Li I 670.78 nm and 610.36nm (when available) lines. NLTE corrections were applied to the abundances obtained using the 670.78 nm line (see text).

Object	670.78 λ_1	610.36 λ_2	NLTE λ_1	Lit. λ_1	Lit. λ_2	Ref.
HD 787	2.0	2.2	2.3	2.2	3.1*	1, 2
HD 19745	3.7	4.0	3.7	4.1	3.9	2, 3
HD 30238	0.8	<1.0	1.2	1.2	–	7
HD 31993	1.7	<2.5	1.8	1.4	–	4
HD 39853	2.6	3.0	2.6	2.8	3.9*	5, 2
HD 95799	3.3	3.1	3.1	3.2	–	6
HD 44889	0.5	<1.0	0.8	–	–	–
HD 65750	1.0	<1.5	1.4	–	–	–
HD 90082	−0.1	<1.0	0.2	–	-	–
HD 96195	0.1	<1.0	0.4	–	–	–
HD 4893	0.4	–	0.9	–	–	–
GCSS 577	0.3	–	0.7	–	–	–
HD 176588	1.1	–	1.6	–	–	–
I 19012	2.5	–	2.6	–	–	–
I 19038	0.3	–	0.6	–	–	–
HD 178168	0.5	–	0.9	–	–	–

Note – (*) NLTE value. Refs.: 1 – Brown et al. (1989); 2 – de la Reza & da Silva (1995); 3 – Drake (1998); 4 – Fekel & Balachandran (1993); 5 – Gratton & D'Antona (1989); 6 – Luck (1994); 7 – Pilachowski et al. (1990).

limits for abundances were estimated. For the other six stars, abundances could not be derived from the Li I 610.36 nm line.

In Table 5 the adopted NLTE correction and the Li abundance obtained by using both lines are presented. Li abundances from the literature are also presented where available. Figs. 3 and 4 illustrate two examples of the synthetic spectra fitting to the observed Li I 670.78 nm line and Figs. 5 and 6 show the examples of the Li I 610.36 nm line fitting. For each log N(Li) determined by the best fit, two additional synthetic spectra are shown, which roughly indicates a confidence test. The mean error in the Li abundance estimated by this test is less than 0.2 dex, in agreement with the errors estimated in Sect. 4.

Note that among the stars showing a strong Li line in our survey, only one (GCSS 577) has actually a low Li abundance, despite the strong (310 mÅ) equivalent width measured for the Li I 670.8 nm line. This is in agreement with the discussion presented in Sect. 4, showing that lower temperatures correspond to lower abundances, for a fixed equivalent width of the Li line.

5.2. Other elements

The abundance of other chemical elements were derived by using curves of growth, for cases where several lines of a species

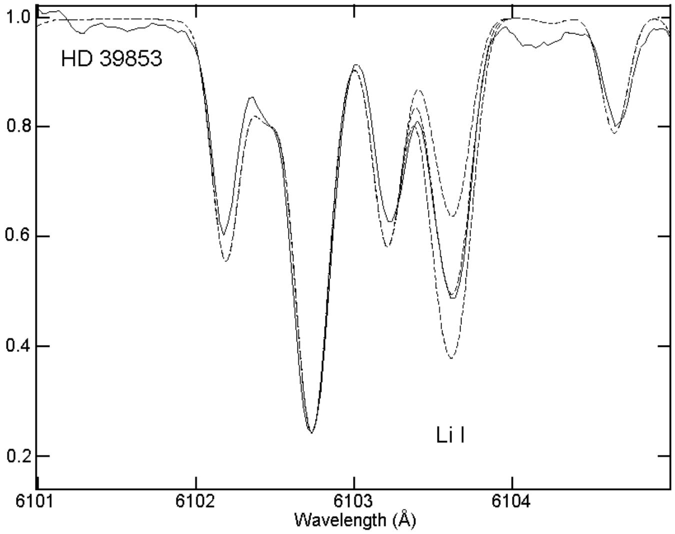

Fig. 6. The same as Fig. 5, with log N(Li) = 3.3, 3.0, and 3.6 for HD 39853

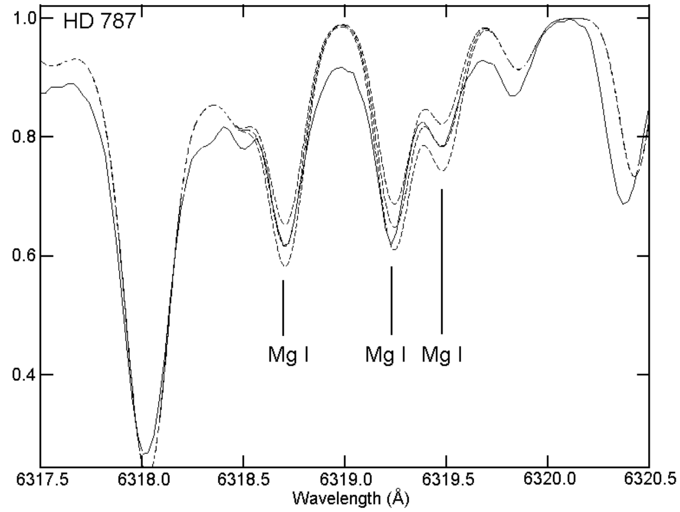

Fig. 7. Examples of synthetic (dashed line) and observed (solid line) spectra for HD787 used to fit the Mg I 631.9nm line, for different values [Mg/Fe] = −0.5, 0.1, and 0.25.

were available, and for all others by using spectrum synthesis. The errors in the abundances are estimated to be about 0.20 dex per element, mostly due to inaccuracies in determining the atmospheric parameters and oscillator strengths.

We compared our results for HD 39853 with those obtained by Gratton & D'Antona (1989). They used atmospheric parameters (T_{eff} = 3900 K, log g = 1.16, and [Fe/H] = -0.5) consistent with the present work and their estimation of abundances are in good agreement with ours. Their results of oxygen and α element overabundances are confirmed by us. They did not find overabundance of the observed s-elements (Zr, La), at contrast with our results of [Zr/Fe] = 0.30 and [La/Fe] = 0.25. These differences are not significant by considering the expected errors on abundances.

McWilliam (1990) determined abundances for HD 787, adopting atmospheric parameters (T_{eff} = 3980 K, log g = 1.74, [Fe/H] = 0.03), which are in good agreement with those adopted in the present work. For the s-elements a solar value of $[s/Fe]$ was found. Based on the results for Ba, the only s-element measured in this star, we also determine a solar value for $[Ba/Fe]$. For the α elements, McWilliam (1990) found underabundances of -0.2, in rough agreement with our results of solar values or slight overabundance for some elements. The results are compatible given the mean errors in abundance determination.

In Table 6 the abundance ratios relative to iron are given. Fig. 7 shows an example of a best fit of synthetic spectra to the Mg I lines with [Mg/Fe] = 0.1 for HD 787. The list of equivalent widths measured for the lines used in the analysis is presented in Table 7 (available only in electronic form).

6. General discussion

Strong Li lines appear in a variety of stars. However, a reliable Li abundance can only be derived through a detailed analysis. This is illustrated in Fig. 2, where the equivalent width of Li lines are plotted against stellar atmospheric parameters effective temperature ($T_{\rm eff}$) and gravity (log g), for different values of the Li abundance.

According to predictions of the standard models of stellar evolution, Li should be strongly diluted in giant stars. The observations show that Li abundance is even lower than expected in most giant stars of the galactic disk (Brown et al. 1989). Pasquini & Molaro (1996) and Castilho et al. (2000) found the same in globular clusters, but Boesgaard et al. (1998) have studied a sample of seven sub-giants in the globular cluster M92, finding one object with high Li abundance, the remaining ones showing a dispersion covering a range of a factor 3 in abundance. Several authors have also reported the eventual occurrence of one LRG in globular clusters, where the other observed giants show no Li detection (Carney et al. 1998; Smith et al. 1999; Kraft et al. 1999).

Pilachowski (1986) studied the abundance of Li in the moderately old galactic cluster NGC 7789, revealing an exceptionally high Li abundance in one of the cluster giants. Hill & Pasquini (1999) found one Li-rich star in an old open cluster, among several normal (Li-poor) giants.

Different explanations have been discussed: differential depletion, accretion of another object (brown dwarf or planet) by giant stars, or the Li production during a particular phase on the AGB evolution.

The occurrence of Li abundance 200 times larger than the mean values indicates that either these Li-rich giants have not destroyed their original Li, or, on the other hand, there is a process of Li production during the stellar evolution. Smith & Lambert (1989, 1990) showed that stars in the asymptotic giant branch have a large abundance of Li in agreement with the theoretical predictions of Sackmann & Boothroyd (1992) for the Li production in AGB stars of intermediate mass (3 - 7 $M_{\odot}$). Recently the same authors extended the range of mass (1 - 3 $M_{\odot}$) for which the Li production is possible, by considering the "cool bottom processing" in stars of the RGB (Sackmann & Boothroyd 1999).

Table 6. Chemical abundances [X/Fe], and number of lines used in the abundance derivation.

Object	Na		Mg		Al		Si		Ca		Sc		Ti	
HD 787	0.40	2	0.10	3	0.10	2	0.30	20	0.00	26	0.30	17	0.30	30
HD 19745	−0.10	2	−0.20	3	−0.10	2	0.20	26	−0.40	21	0.20	20	0.00	50
HD 30238	0.20	2	0.10	3	0.10	2	0.30	20	0.00	27	0.10	17	0.20	44
HD 31993	–	–	0.30	1	0.30	1	–	–	0.10	13	0.50	3	0.30	17
HD 39853	0.20	2	0.10	3	0.00	1	0.30	17	0.10	19	0.40	14	0.30	30
HD 95799	−0.10	2	0.10	3	−0.20	2	0.00	26	−0.10	24	0.00	19	0.00	40
HD 4893	–	–	–	–	–	–	0.30	3	−0.20	11	–	–	−0.20	8
HD 44889	0.00	2	0.10	4	0.00	3	0.00	6	0.00	20	0.10	15	0.20	42
HD 65750	0.00	3	0.20	4	–	–	0.20	16	−0.20	18	0.00	13	0.00	20
HD 90082	0.10	2	0.10	4	0.20	2	0.00	5	0.10	15	0.50	16	0.20	26
HD 96195	0.20	2	0.00	3	−0.20	2	0.00	8	−0.20	13	0.10	24	0.30	20
HD 176588	–	–	–	–	0.00	2	0.50	3	0.10	2	–	–	0.00	5
HD 178168	–	–	–	–	−0.10	2	0.20	6	0.00	5	–	–	−0.10	8
GCSS 577	–	–	–	–	0.00	2	0.20	5	0.10	6	–	–	0.00	6
I 19012	–	–	–	–	0.20	2	–	–	−0.20	7	−0.70	1	−0.40	6
I 19038	–	–	–	–	0.20	2	–	–	0.20	8	–	–	−0.20	9

Object	V		Co		Ni		Sr		Y		Zr		Ba		La	
HD 787	0.50	40	0.50	22	0.20	50	–	–	−0.30	4	–	–	0.00	2	–	–
HD 19745	0.20	35	0.15	18	0.00	25	0.20	1	−0.30	4	−0.10	3	0.00	2	0.50	4
HD 30238	0.40	34	0.20	18	0.00	50	0.20	1	−0.40	4	–	–	0.00	2	–	–
HD 31993	0.20	10	0.80	7	0.50	8	–	–	−0.50	2	0.80	6	0.70	2	–	–
HD 39853	0.60	18	0.30	13	0.10	30	–	–	−0.40	4	0.30	6	−0.10	2	0.25	4
HD 95799	0.00	27	0.00	20	−0.20	39	–	–	−0.40	4	0.10	5	0.10	2	0.40	5
HD 4893	−0.20	8	0.00	5	−0.10	11	–	–	–	–	–	–	–	–	–	–
HD 44889	−0.10	35	0.20	15	0.20	52	–	–	–	–	–	–	–	–	0.70	5
HD 65750	0.20	22	0.20	20	−0.10	40	–	–	–	–	0.90	9	0.40	2	–	–
HD 90082	0.40	20	–	–	0.20	20	–	–	−0.10	4	–	–	–	–	0.20	2
HD 96195	0.40	20	0.00	15	–	–	–	–	0.40	5	–	–	–	–	1.00	5
HD 176588	–	–	−0.30	2	0.00	4	–	–	–	–	0.00	1	–	–	–	–
HD 178168	0.00	11	–	–	0.00	11	–	–	−0.50	3	–	–	0.60	1	–	–
GCSS 577	0.00	9	−0.10	6	0.00	13	–	–	–	–	–	–	–	–	0.50	2
I 19012	0.00	5	0.60	4	0.10	10	–	–	−0.70	3	−0.60	1	−0.80	1	–	–
I 19038	0.00	5	–	–	0.20	8	–	–	0.20	4	–	–	–	–	–	–

Determinations of $^{12}C/^{13}C$ ratios are available for a number of Li-rich giants (e.g. Brown et al. 1989; Gratton & D'Antona 1989; da Silva et al. 1995; Berdyugina & Savanov 1995). Although some Li-rich giants present $^{12}C/^{13}C$ ratios in agreement with the standard mixing models, most of them require an extra-mixing mechanism relative to the first dredge-up predictions.

Two LRG and a normal giant have been observed for Be lines in the UV range (Castilho et al. 1999; Castilho 2000), providing evidence that the observed Li has been added in a later phase: the initial Li and Be have been both depleted in the two LRG. The low Be abundances found for the 2 LRG are not in agreement with the proposition that high Li abundance observed in K giants originate from the accretion of a giant planet or a brown dwarf (e.g. Kraft et al. 1999; Siess & Livio 1999; Denissenkov & Weiss 2000). Such an accretion should also enrich the giant star with Be, while this element is very depleted as we already noted.

The abundance pattern of the Li-rich giants do not differ significantly from the solar pattern nor from star to star, within the errors. In Fig. 8 we present a plot of log N(X) normalized to the solar [Fe/H] vs. atomic number Z for all giants analysed.

In order to verify a possible correlation between depletion in grains and infrared excess, the IRAS colours of our sample have been checked. Most of the stars are located in a well defined part of the [60−25] vs. [25−12] diagram, which is coincident with the region where are located both normal and Li-rich giants showing a recently expelled dust envelope (see region III in Fig. 3 presented by de la Reza et al. 1997). The ejected mass could be mostly in the form of carbon grains, decreasing C, but depletions of Na, Al, Ca, and Si would also be expected. The observations do not support the hypothesis for a depletion pattern in connection with the mass loss in Li-rich giants, given that no clear correlation is found between IR-excess and abundances of C and other metals.

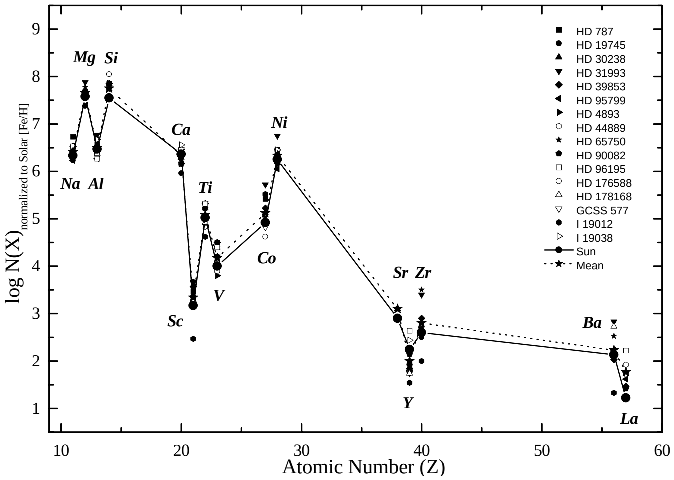

Fig. 8. log N(X) normalized to the solar [Fe/H] vs. atomic number Z for the sun (solid line), a mean of the giants analysed (dashed line) and all sample giants (data points)

7. Conclusions

The results obtained in the detailed analysis developed in the present work confirm the hypothesis (Castilho 1995; de la Reza et al. 1996) that LRG are quite normal stars, except for their high Li abundance and large infrared excess. The similarities with normal giants, concerning mass, chemical composition, temperature and metallicity, combined with the far-infrared emission indicate that LRG do not form a unique class of objects. The low Be abundance found in two Li-rich giants strongly suggests that Li has been produced in the stars (Castilho et al. 1999). The LRG probably correspond to a rapid phase of stellar evolution, in which the star normally produces Li (Castilho 1995; de la Reza et al. 1996).

Acknowledgements. We acknowledge partial financial support from CNPq and Fapesp (Brazil) and CNRS (France). BC acknowledges the Fapesp PhD and pos-doc fellowships n^o 97/007814-4 and 99/05282-6. This work has made use of the SIMBAD data base.

References

Barbuy B., 1982, Ph.D. Thesis, Univ. Paris VII
Bessell M.S., Castelli F., Plez B., 1998, A&A 333, 231
Berdyugina S.V., Savanov I.S., 1995, Mem. Soc. Astron. Ital. 66, 425
Boesgaard A.M., Deliyannis C.P., Stephens A., King J.R., 1998, ApJ 493, 206
Bond H.E., 1980, ApJS 44, 517
Brown J.A., Sneden C., Lambert D.L., Dutchover E., 1989, ApJS 71, 293
Carlsson M., Rutten R.J., Bruls J.H.M.J., Shchukina N.G., 1994, A&A 288, 860
Carney B., Fry A.M., Gonzalez G., 1998, AJ 116, 2984
Cayrel de Strobel G., Soubiran C., Friel E.D., Ralite N., François P., 1997, A&AS 124, 299
Castilho B.V., 1995, Master Degree Dissertation, Depto. de Astronomia, IAG/USP, São Paulo
Castilho B.V., 2000, In: da Silva L., Spite M., De Medeiros J.R. (eds.) IAU Symposium 198, The Light Elements and Their Evolution. ASP Conference Series, in press
Castilho B.V., Barbuy B., Gregorio-Hetem J., 1995, A&A 297, 503
Castilho B.V., Gregorio-Hetem J., Barbuy B., 1997, Journal of Astronomical Data, 3, 1
Castilho B.V., Gregorio-Hetem J., Spite F., Spite M., Barbuy B., 1998, A&AS 127, 139
Castilho B.V., Spite F., Barbuy B., et al., 1999, A&A 345, 249
Castilho B.V., Lorenz-Martins S., 2000, in preparation
Castilho B.V., Pasquini L., Allen D.M., Barbuy B., Molaro P., 2000, A&A in press
Clariá J.J., Lapasset E., 1988, MNRAS 235, 1129
Corben P.M., 1966, Mon. Not. Astr. Soc. Sth. Africa 25, 44
Corben P.M., 1971, Mon. Not. Astr. Soc. Sth. Africa 30, 37
Cousins A.W.J., 1964, Mon. Not. Astr. Soc. Sth. Africa 23, 10
Cousins A.W.J., Stoy R.H., 1963, Royal Obs. Bull. 64
Cousins A.W.J., Lake R., Stoy R.H., 1966, Royal Obs. Bull. 121, 1
Dachs J., Isserstedt J., Rahe J., 1978, A&A 63, 353
da Silva L., de la Reza J.R., Barbuy B., 1995, ApJ 448, L41
de la Reza J.R., da Silva L., 1995, ApJ 439, 917
de la Reza J.R., Drake N.A., da Silva L., 1996, ApJ 456, L115
de la Reza J.R., Drake N.A., da Silva L., Torres C.A.O., Martin E.L., 1997, ApJ 482, L77
Delbouille L., Roland G., Neven L., 1973, Atlas photométrique du spectre solaire de λ 3,000Å λ 10,000Å, Université de Liège, Institut d'Astrophysique, Liège
Denissenkov P.A., Weiss A., 2000, A&A 358, L49
Drake N., 1998, Ph.D. Thesis, Observatório Nacional (ON/CNPq), Rio de Janeiro
Eggen O.J., 1968, Royal Obs. Bull. No. 137
Eggen O.J., 1974, PASP 86, 960
Eggen O.J., 1981, ApJ 246, 817
Eggen O.J., 1989a, PASP 101, 45
Eggen O.J., 1989b, PASP 101, 54
Eggen O.J., 1992, AJ 104, 275
Eggen O.J., Stokes N.R., 1970, ApJ 161, 199
Fekel F.C., Balachandran S., 1993, ApJ 403, 708
Fuhr J.R., Martin G.A., Wiese W.L., 1988, Atomic Transition Probabilities: Iron, throught Nickel. Journal of Physical and Chemical Reference Data vol. 17, suppl. 4
Gillet D., Burnage R., Kohler D., et al., 1994, A&AS 108, 181
Gratton R.G., D'Antona F., 1989, A&A 215, 66
Gregorio-Hetem J., Lépine J.R.D., Quast G.R., Torres C.A.O., de la Reza R., 1992, AJ 103, 549
Gregorio-Hetem J., Castilho B.V., Barbuy B., 1993, A&A 268, L25
Gregorio-Hetem J., Castilho B.V., Barbuy B., Spite F., Spite M., 2000, In: da Silva L., Spite M., De Medeiros J.R. (eds.) IAU Symposium 198: The Light Elements and Their Evolution. ASP Conference Series, in press
Grevesse N., Sauval A.J., 1998, Space Sci. Rev. 85, 161
Grevesse N., Sauval A.J., 1999, A&A 347, 348
Gustafsson B., Bell R.A., Eriksson K., Nordlund Å., 1975, A&A 42, 407
Hill V., Pasquini L., 1999, A&A 348, L21
Hoffleit D., Warren Jr. W.H., 1991, Bright Star Catalogue, 5th Revised Ed., Astronomical Data Center, NSSDC/ADC
Holweger H., Müller E.A., 1974, Solar Phys. 39, 19
Irwin J.B., 1961, ApJS 6, 253
Jasniewicz G., Parthasarathy M., De Laverny P., Thevenin F., 1999, A&A 342, 831
Jablonski F., Baptista R., Barroso Jr. J., et al., 1994, PASP 106, 1172
Johnson H.L., Mitchell R.I., Iriarte B., Wisniewski W.Z., 1966, Comm. Lunar Plan. Lab. IV No. 63

Kraft R.P., Peterson R.C., Guhathakurta P., et al., 1999, ApJ 518, L53
Kornilov V.G., Volkov I.M., Zakharov A.I., et al., 1991, Tr. Gos. Astron. Inst. Shternberga 63
Lake R., 1963, Mon. Not. Astr. Soc. Sth. Africa 22, 79
Lejeune T., Cuisinier F., Buser R., 1998, A&AS 130, 65
Lloyd Evans T., Koen M.C.J., 1987, South African Astron. Obs. Circ. 11, 21
Luck R.E., 1994, ApJS 91, 309
MacConnell D.J., 1974, unpublished
Martin G.A., Fuhr J.R., Wiese W.L., 1988, Atomic Transition Probabilities: Scandium through Manganese. Journal of Physical and Chemical Reference Data vol. 17, suppl. no. 3
McWilliam A., 1990, ApJS 74, 1075
Nicolet B., 1979, A&AS 34, 1
Olsen E.H., 1993, A&AS 102, 89
Ortega-Terra M.A., 1997 Ph.D. Thesis, Observatório Nacional (ON/CNPq), Rio de Janeiro
Pasquini L., Molaro P., 1996, A&A 307, 761
Perryman M.A.C., Lindgren L., Kovalewsky J., et al., 1995, A&A 304, 69
Pilachowski C.A., 1986, ApJ 300, 289
Pilachowski C.A., Dean H., Sneden C., 1990, AJ 99, 1225
Plez B., Brett J.M., Nordlund Å., 1992, A&A 256, 551
Plez B., 1997, unpublished
Roman N.G., 1955, ApJS 2, 195
Rybka E., 1969, Acta Astron. 19, 229
Sackmann I.-J., Boothroyd A.I., 1992, ApJ 392, L71
Sackmann I.-J., Boothroyd A.I., 1999, ApJ 510, 217
Schaller G., Schaerer D., Meynet G., Maeder A., 1992, A&AS 96, 269
Strassmeier K.G., Serkowitsch E., Granzer Th., 1999, A&AS 140, 29
Siess L., Livio M., 1999, MNRAS 308, 1133
Smith V.V., Lambert D.L., 1989, ApJ 345, L75
Smith V.V., Lambert D.L., 1990, ApJ 361, L69
Smith V.V., Shetrone M.D., Keane M.J., 1999, ApJ 516, 73
Spite M., 1967, Ann. Astrophys. 30, 211
Stephenson C.B., 1976, Publ. Warner & Swasey Obs. 2, 21
Wallerstein G., Sneden C., 1982, ApJ 255, 577
Wesselink A.J., 1962 MNRAS 124, 358
Wiese W.L., Martin G.A., Fuhr J.R., 1969, Atomic Transition Probabilities: Sodium through Calcium. NSRDS-NBS 22