Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **408,** 1225–1232 (2010) doi:10.1111/j.1365-2966.2010.17195.x

High-resolution spectroscopic study of red clump stars in the Galaxy: iron-group elements

E. Puzeras,[1]* G. Tautvaišienė,[1] J. G. Cohen,[2] D. F. Gray,[3] S. J. Adelman,[4] I. Ilyin[5] and Y. Chorniy[1]

[1]*Institute of Theoretical Physics and Astronomy, Vilnius University, Goštauto 12, Vilnius 01108, Lithuania*
[2]*Palomar Observatory, Mail Stop 249-17, California Institute of Technology, Pasadena, CA 91125, USA*
[3]*Department of Physics & Astronomy, University of Western Ontario, London, ON N6A 3K7, Canada*
[4]*Department of Physics, The Citadel, Charleston, SC 29409-0270, USA*
[5]*Astrophysikalisches Institut Potsdam, An der Sternwarte 16, Potsdam 14482, Germany*

Accepted 2010 June 14. Received 2010 June 14; in original form 2010 May 20

ABSTRACT

The main atmospheric parameters and abundances of the iron-group elements (vanadium, chromium, iron, cobalt and nickel) are determined for 62 red giant 'clump' stars revealed in the Galactic field by the *Hipparcos* orbiting observatory. The stars form a homogeneous sample with the mean value of temperature $T_{\rm eff} = 4750 \pm 160$ K, of surface gravity $\log g = 2.41 \pm 0.26$ and the mean value of metallicity $[{\rm Fe/H}] = -0.04 \pm 0.15$ dex. A Gaussian fit to the [Fe/H] distribution produces the mean $\langle[{\rm Fe/H}]\rangle = -0.01$ and dispersion $\sigma_{[{\rm Fe/H}]} = 0.08$. The near-solar metallicity and small dispersion of $\sigma_{[{\rm Fe/H}]}$ of clump stars of the Galaxy obtained in this paper confirm the theoretical model of the *Hipparcos* clump by Girardi & Salaris. This suggests that nearby clump stars are (in the mean) relatively young objects, reflecting mainly the near-solar metallicities developed in the local disc during the last few Gyr of its history. We find iron-group element to iron-abundance ratios in clump giants to be close to solar.

Key words: stars: abundances – stars: atmospheres – stars: horizontal branch.

1 INTRODUCTION

The clump of core helium burning stars is a prominent feature in the colour–magnitude diagrams of open clusters. Cannon (1970) predicted that the red clump stars should also be abundant in the solar neighbourhood. Many photometric studies have tried with varying success to identify such stars in the Galactic field (see Tautvaišienė 1996 for a review); however, we had to wait for the *Hipparcos* mission. The presence of red clump stars in the solar neighbourhood was clearly demonstrated in the HR diagrams by Perryman, Lindegren & Kovalevsky (1995). The *Hipparcos* catalogue (Perryman et al. 1997) contains about 600 clump stars with parallax error lower than 10 per cent, and hence an error in absolute magnitude lower than 0.12 mag. This accuracy limit corresponds to a distance of about 125 pc within which the sample of clump stars is complete. Now it is important to investigate their distributions of masses, ages, colours, magnitudes and metallicities, which may provide useful constraints to chemical evolution models of the local Galactic disc. Moreover, clump stars may be useful indicators of ages and distances for stellar clusters and the Local Group galaxies (cf. Hatzidimitriou & Hawkins 1989; Hatzidimitriou 1991; Udalski 1998; Girardi & Salaris 2001).

In this paper we report on the primary atmospheric parameters and the abundances of iron-group elements in the 62 clump stars of the Galactic field obtained from the high-resolution spectra. The results are discussed in detail together with results of other studies of the clump stars. Preliminary results of this paper were published by Tautvaišienė et al. (2005) and Tautvaišienė & Puzeras (2009).

In Fig. 1, we show a HR diagram constructed for the *Hipparcos* stars with $\sigma_\pi/\pi < 0.1$ and $\sigma_{B-V} < 0.025$ mag. On the giant branch is a distinct red clump at $B - V \approx 1.0$, $M(H_p) \approx 1.0$ mag. The sample of the 63 stars investigated in our study is indicated by open circles.

2 OBSERVATIONAL DATA

The red clump stars were selected from the *Hipparcos* Catalogue (Perryman et al. 1997). Spectra for partially overlapping star samples were observed on several telescopes, described below.

Spectra for 17 stars were obtained at the Nordic Optical Telescope (NOT, La Palma) with the SOFIN échelle spectrograph (Tuominen, Ilyin & Petrov 1999). The second optical camera ($R \approx 80\,000$)

---

*E-mail: eduardas.puzeras@tfai.vu.lt

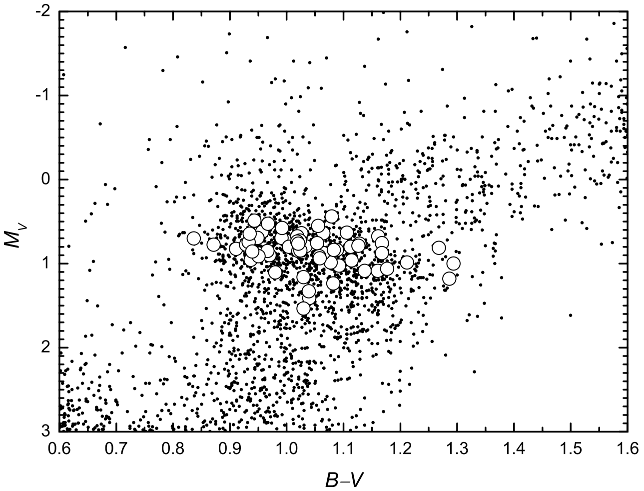

Figure 1. Colour–magnitude diagram for the *Hipparcos* catalogue. The programme stars are indicated by open circles.

was used to observe simultaneously 13 spectral orders, each of 40–60 Å in length, located from 5650 to 8130 Å. Reduction of the CCD images, obtained with SOFIN, was done using the 4A software package (Ilyin 2000). Procedures of bias subtraction, cosmic ray removal, flat-field correction, scattered-light subtraction and extraction of spectral orders were used for image processing. A Th–Ar comparison spectrum was used for the wavelength calibration. The continuum was defined from a number of narrow spectral regions, selected to be free of lines.

The spectra of 14 stars were observed with the HIRES spectrograph on the 10-m Keck Telescope. A 1.1 × 7 arcsec slit ($R \approx 34\,000$) was used, and 19 spectral orders located from 5620 to 7860 Å were extracted. The spectra were reduced using IRAF and MAKEE packages.

The spectra of 17 stars were observed with the long camera of the 1.22-m Dominion Astrophysical Observatory telescope's coudé spectrograph ($R \approx 40\,000$). The interactive computer graphics program REDUCE by Hill, Fisher & Poeckert (1982) was used to rectify them. The scattered light was removed during the extraction procedure by the program CCDSPEC described in Gulliver & Hill (2002).

The spectra for 18 stars in the spectral interval from 6220 to 6270 Å were obtained at the Elginfield Observatory (Canada) with the 1.2-m telescope and the high-resolution coudé spectrograph ($R \approx 100\,000$). Spectra were recorded using an 1872 diode Reticon self-scanned array light detector, mounted in a Schmidt camera, with a focal length of 559 mm. See Brown, Gray & Baliunas (2008) for further discussion concerning the equipment and operation.

These observational data were supplemented by spectroscopic observations ($R \approx 37\,000$) of red clump stars obtained on the 2.16-m telescope of the Beijing Astronomical Observatory (China) taken from the literature (Zhao, Qiu & Mao 2001).

In Fig. 2, we show examples of observed spectra for several common stars using different instruments. A careful selection of spectral lines for the analysis has allowed us to avoid systematic differences in analysis results obtained from the different instruments. For example, the star HD 216228 has been observed on four telescopes, a comparison of the measured equivalent widths (EWs) of its Fe I lines is shown in Fig. 3.

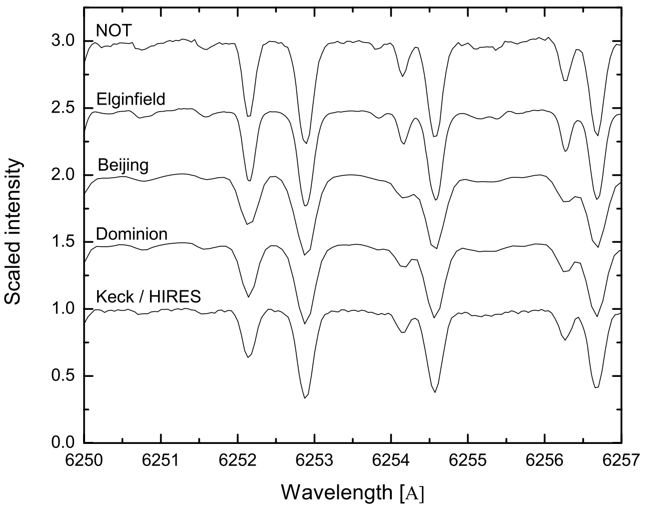

Figure 2. The spectrum of the star HD 216228 in the region 6250–6257 Å as observed on four different telescopes. Since this star was not observed on the Keck Telescope, we present a spectrum of the very similar star HD 11037 instead.

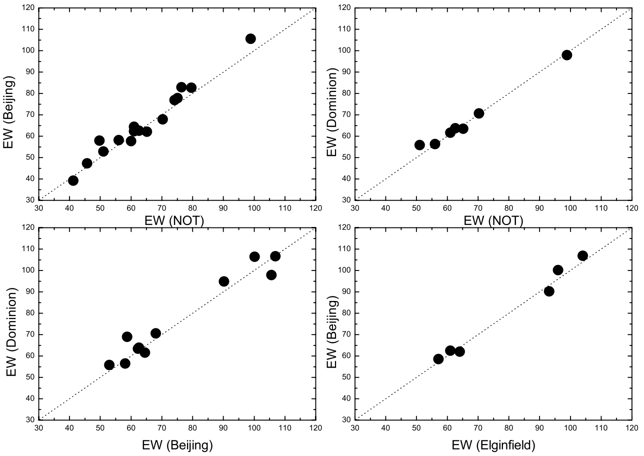

Figure 3. Comparisons of EWs of Fe I lines in overlapping spectral regions observed with different telescopes for the star HD 216228.

3 METHOD OF ANALYSIS AND PHYSICAL DATA

The spectra were analysed using a differential model atmosphere technique. The program packages, developed at the Uppsala Astronomical Observatory, were used to calculate the theoretical EWs and the line profiles. A set of plane-parallel, line-blanketed, constant-flux local thermodynamic equilibrium (LTE) model atmospheres was computed with an updated version of the MARCS code (Gustafsson et al. 2003).

The Vienna Atomic Line Data Base (VALD; Piskunov et al. 1995) was extensively used in preparing the input data for the calculations. Atomic oscillator strengths for the spectral lines analysed in this paper were taken from an inverse solar spectrum analysis done in Kiev (Gurtovenko & Kostik 1989).

Because of the asymmetric nature of line-measurement errors (i.e. problems such as blending and telluric line superposition always increase measured linewidth), we used a 'quality over quantity' approach when selecting lines for abundance calculations. All lines used for calculations were carefully selected. Inspection of the solar spectrum (Kurucz et al. 1984) and the solar line identifications of Moore, Minnaert & Houtgast (1966) were used to avoid blends and lines blended by telluric absorption lines. All line profiles in all spectra were hand-checked requiring that the line profiles be sufficiently clean to provide reliable EWs. Only lines with equivalent widths between 20 and 150 mÅ were used for abundance determinations. Spectral lines systematically producing outlier abundances in a number of stars, indicating spectral (observational) defect, undetected blends or erroneous atomic data, were rejected as well. The EWs of the lines were measured by fitting of a Gaussian profile using the 4A software package (Ilyin 2000).

Effective temperature, gravity and microturbulence were derived using traditional spectroscopic criteria. The preliminary effective temperatures for the stars were determined using the $(B - V)_0$ and $(b - y)_0$ colour indices and the temperature calibrations by Alonso, Arribas & Martínez-Roger (2001). For some stars the averaged temperatures also included the values obtained from the infrared flux method (IRFM). All the effective temperatures were carefully checked and corrected if needed by forcing Fe I lines to yield no dependency of iron abundance on excitation potential by changing the model effective temperature. Surface gravity was obtained by forcing Fe I and Fe II lines to yield the same [Fe/H] value by adjusting the model gravity. Microturbulence value corresponding to minimal line-to-line Fe I abundance scattering was chosen as the correct value. Depending upon the telescope, the number of Fe I lines analysed was up to 65 and of Fe II up to 12.

Using the *gf* values and solar EWs of analysed lines from Gurtovenko & Kostik (1989) we obtained the solar abundances, used later for the differential determination of abundances in the programme stars. We used the solar model atmosphere from the set calculated in Uppsala with a microturbulent velocity of 0.8 km s^{-1}, as derived from Fe I lines.

In addition to thermal and microturbulent Doppler broadening of lines, atomic line broadening by radiation damping and van der Waals damping were considered in the calculation of abundances. Radiation damping parameters of lines were taken from the VALD data base. In most cases the hydrogen pressure damping of metal lines was treated using the modern quantum mechanical calculations by Anstee & O'Mara (1995), Barklem & O'Mara (1997) and Barklem, O'Mara & Ross (1998). When using the Unsöld (1955) approximation, correction factors to the classical van der Waals damping approximation by widths (Γ_6) were taken from Simmons & Blackwell (1982). For all other species a correction factor of 2.5 was applied to the classical $\Gamma_6(\Delta \log C_6 = +1.0)$, following Mäckle et al. (1975). For lines stronger than $W = 100$ mÅ the correction factors were selected individually by inspection of the solar spectrum.

Cobalt abundances were investigated with hyperfine structure (HFS) effects taken into account. We calculated the HFS corrections for every line in every star with the LTE spectral synthesis program MOOG (Sneden 1973) and the HFS input data adopted from Prochaska et al. (2000).

3.1 Estimation of uncertainties

The sources of uncertainty can be divided into two distinct categories. The first category includes the errors that affect a single line (e.g. random errors in EWs, oscillator strengths), i.e. uncertainties of the line parameters. Other sources of observational error, such as continuum placement or background subtraction problems also are partly included in the EW uncertainties. The second category includes the errors which affect all the lines together, i.e. mainly the model errors (such as errors in the effective temperature, surface gravity, microturbulent velocity, etc.).

Table 1. The sensitivity of stellar atmosphere abundances to changes in atmospheric parameters. Example for the star HD 218031.

Element	$\Delta T_{\rm eff}$ -100 K	$\Delta \log g$ $+0.2$ dex	Δv_t $+0.3$ (km s^{-1})	ΔTotal
V I	−0.17	0.00	−0.08	0.19
Cr I	−0.06	0.01	−0.05	0.08
Mn I	−0.06	0.01	−0.01	0.06
Fe I	−0.05	0.04	−0.07	0.09
Fe II	0.09	0.11	−0.08	0.16
Co I	−0.06	0.06	−0.03	0.09
Ni I	−0.05	0.06	−0.05	0.09

Typical internal error estimates for the atmospheric parameters are ±100 K for $T_{\rm eff}$, ±0.2 dex for log *g* and ±0.3 km s^{-1} for $v_{\rm t}$. The sensitivity of the abundance estimates to changes in the atmospheric parameters by the assumed errors is illustrated for the star HD 218031 in Table 1. It is seen that possible parameter errors do not affect the abundances seriously; the element-to-iron ratios, for which we use the neutral species for both and use in our discussion, are even less sensitive.

The scatter of the deduced line abundances σ, presented in Tables 2 and 3, gives an estimate of the uncertainty due to the random errors in the line parameters (the mean value of σ is 0.07). Thus the uncertainties in the derived abundances that are the result of random errors amount to approximately this value.

4 RESULTS AND DISCUSSION

Table 2 presents the adopted atmospheric parameters for our stellar sample, the numbers of Fe I and Fe II lines investigated, the line-to-line scatter and sources of spectral observations used. Some stars were observed on several telescopes. For them the main atmospheric parameters were not redetermined from the new observations, since several checks gave a good agreement. The new observing material was used to increase the number of chemical elements with reliable detections. The elemental abundances relative to hydrogen [El/H] of iron group chemical elements, line-to-line scatters and numbers of lines investigated are presented in Table 3.

The sample of clump stars investigated forms quite a homogeneous sample with no obvious division into metallicity-dependent groups as was suggested by Zhao et al. (2001). The effective temperature ranges from 4300 to 5100 K with the mean value $T_{\rm eff} = 4750 \pm 160$ K; log *g* is between 1.8 and 3.3 with the mean value $\log g = 2.41 \pm 0.26$; the mean microturbulent velocity $v_{\rm t} = 1.34 \pm 0.19$ km s^{-1}; the metallicity range is from +0.3 to −0.60 dex; however, the majority of stars concentrate at the mean value [Fe/H] = −0.04 dex with a rms deviation about the mean of 0.15 dex.

4.1 Comparison with results by McWilliam (1990)

There is an overlap of 35 stars between our sample of clump stars and that of high-resolution spectroscopic analysis by McWilliam (1990). McWilliam & Rich (1997) noted that the McWilliam (1990) study was hampered by the narrow wavelength (6550–6800 Å) coverage and the lack of metal-rich model atmospheres, which caused an underestimation of metallicities for metal-rich stars. Our

Table 2. Atmospheric parameters of the programme stars.

HD	$T_{\rm eff}$	$\log g$	v_t	[Fe/H]	$\sigma_{\rm Fe\,I}$	$n_{\rm Fe\,I}$	$\sigma_{\rm Fe\,II}$	$n_{\rm Fe\,II}$	Observations
2910	4730	2.3	1.7	−0.07	0.11	52	0.08	8	5
3546	4980	2.0	1.4	−0.60	0.06	52	0.07	12	5
3627	4360	2.1	1.8	0.01	0.12	31	0.04	3	2
4188	4870	2.9	1.2	0.10	0.07	11	–	1	4
5268	4870	1.9	1.4	−0.48	0.06	47	0.06	8	5
5395	4870	2.1	1.3	−0.34	0.06	54	0.07	10	5
5722	4910	2.3	1.3	−0.14	0.05	45	0.03	5	2
6805	4530	2.0	1.5	−0.02	0.08	39	0.05	6	5
6976	4810	2.5	1.6	−0.06	0.10	49	0.11	8	5
7106	4700	2.4	1.3	0.02	0.07	33	0.07	6	1
8207	4660	2.3	1.4	0.09	0.07	31	0.04	4	1
8512	4660	2.1	1.5	−0.19	0.09	46	0.03	6	5
8763	4660	2.2	1.4	−0.01	0.06	19	0.07	4	1
8949	4650	2.4	1.7	0.02	0.11	51	0.10	8	5
9408	4780	2.1	1.3	−0.28	0.06	33	0.07	6	1
11037	4830	2.3	1.2	−0.02	0.07	44	0.09	5	2
11559	4990	2.7	1.5	0.04	0.08	51	0.03	9	5
12583	4930	2.5	1.6	0.02	0.10	50	0.09	8	5
15779	4810	2.3	1.2	−0.03	0.05	19	0.06	4	1
16400	4800	2.4	1.3	0.00	0.07	34	0.04	5	1
17361	4630	2.1	1.4	0.03	0.09	42	0.05	6	5
18322	4660	2.5	1.4	−0.04	0.07	44	0.06	5	5
19476	4980	3.3	1.5	0.17	0.07	38	0.08	8	5
19787	4760	2.4	1.6	0.06	0.08	41	0.06	7	5
25604	4770	2.5	1.6	0.02	0.08	41	0.04	6	5
28292	4600	2.4	1.5	−0.06	0.09	40	0.05	5	5
29503	4650	2.5	1.6	−0.05	0.09	41	0.06	5	5
34559	5060	3.0	1.5	0.07	0.07	37	0.04	8	5
35369	4850	2.0	1.4	−0.21	0.08	49	0.04	7	5
54810	4790	2.5	0.9	−0.15	0.06	10	–	1	4
58207	4800	2.3	1.2	−0.08	0.06	33	0.05	6	1
61935	4800	2.4	1.2	−0.02	0.06	14	0.04	2	1
74442	4700	2.5	1.2	0.06	0.08	10	–	1	4
82741	4850	2.5	1.0	0.00	0.05	12	–	1	4
86513	4590	2.3	1.1	0.13	0.08	16	0.05	5	3
94264	4730	2.7	1.0	−0.04	0.08	11	–	1	4
95272	4670	2.5	1.3	0.00	0.09	10	–	1	4
100006	4590	2.3	1.2	−0.03	0.10	22	0.09	5	3
104979	4880	2.1	0.9	−0.24	0.06	12	–	1	4
108381	4700	3.0	1.4	0.25	0.09	8	–	1	4
131111	4740	2.5	1.1	−0.17	0.05	34	0.06	6	1
133165	4590	2.3	1.2	−0.05	0.09	19	0.08	5	3
141680	4900	2.5	1.3	−0.07	0.07	34	0.08	5	1
146388	4700	2.5	1.3	0.18	0.06	31	0.09	6	1
153210	4450	2.3	1.3	0.15	0.09	54	–	1	3
161096	4550	2.5	1.4	0.18	0.11	64	0.07	5	3
163588	4400	2.4	1.4	−0.01	0.11	65	0.04	5	3
169414	4550	2.3	1.5	−0.09	0.09	40	0.08	5	2
172169	4360	2.2	1.5	0.02	0.10	40	0.07	4	2
181276	4940	2.7	1.3	0.13	0.07	31	0.22	2	2
188310	4730	2.5	1.2	−0.11	0.07	11	–	1	2
188947	4760	2.5	1.3	0.06	0.08	58	–	1	3
197989	4760	2.3	1.1	−0.07	0.07	13	–	1	4
203344	4730	2.4	1.2	−0.06	0.06	34	0.04	5	1
207134	4540	2.3	1.6	−0.04	0.01	41	0.07	5	2
212943	4660	2.3	1.2	−0.24	0.05	19	0.08	4	1
216131	4980	2.7	1.3	0.07	0.07	44	0.05	5	2
216228	4740	2.1	1.3	−0.05	0.06	15	0.07	4	1
218031	4780	2.3	1.3	−0.08	0.04	19	0.09	4	1
219916	4980	2.6	1.4	−0.04	0.08	38	0.05	5	2
221115	5000	2.7	1.3	0.05	0.06	18	0.04	4	1
222842	4980	2.8	1.3	−0.02	0.04	18	0.06	4	1

Observations: 1 – NOT, 2 – Keck, 3 – Dominion, 4 – Eglifield, 5 – Beijing.

Table 3. Element abundances of the programme stars.

HD	[V/H]	σ	*n*	[Cr/H]	σ	*n*	[Co/H]	σ	*n*	[Ni/H]	σ	*n*
2910	0.04	0.10	11	−0.10	0.12	4	−0.01	0.08	4	0.03	0.09	32
3546	−0.46	0.06	12	−0.65	0.07	4	−0.47	0.07	4	−0.47	0.07	29
3627	0.23	0.09	6	0.07	0.11	3	0.11	0.08	2	0.04	0.08	10
4188	0.20	0.07	6	–	–	–	0.15	–	1	0.18	0.05	2
5268	−0.53	0.10	8	−0.55	0.15	2	−0.56	0.07	4	−0.48	0.10	29
5395	−0.23	0.04	12	−0.26	0.06	6	−0.28	0.09	4	−0.22	0.07	26
5722	−0.17	0.07	6	−0.21	0.05	5	−0.26	0.03	3	−0.18	0.06	22
6805	0.19	0.08	8	−0.03	0.08	5	0.00	0.01	3	0.13	0.11	29
6976	0.07	0.07	9	−0.11	0.05	4	0.05	0.04	2	0.04	0.09	31
7106	0.25	0.11	13	0.09	0.07	6	0.13	0.08	4	0.08	0.06	15
8207	0.17	0.09	10	0.18	0.07	4	0.04	0.10	3	0.18	0.08	16
8512	−0.02	0.06	10	−0.23	0.06	6	−0.06	0.05	2	−0.03	0.08	25
8763	0.17	0.08	10	0.04	0.04	2	−0.06	0.07	2	0.05	0.04	9
8949	0.18	0.06	6	−0.16	0.07	4	0.14	0.05	2	0.18	0.09	30
9408	−0.21	0.06	13	−0.33	0.02	3	−0.18	0.01	2	−0.26	0.05	17
11037	−0.16	0.07	6	−0.15	0.02	4	−0.14	0.00	3	−0.09	0.08	12
11559	0.13	0.06	12	0.06	0.08	5	0.08	0.05	5	0.12	0.08	29
12583	0.03	0.07	10	−0.02	0.09	4	−0.06	0.04	3	0.05	0.08	30
15779	0.05	0.08	10	0.02	0.02	2	−0.13	0.06	2	−0.01	0.05	10
16400	0.01	0.06	13	0.04	0.05	5	−0.07	0.09	3	0.02	0.07	17
17361	0.24	0.03	5	0.08	0.07	4	0.03	–	1	0.15	0.10	32
18322	0.13	0.07	6	−0.10	0.04	5	0.02	0.06	3	0.05	0.10	30
19476	0.33	0.05	7	0.24	0.08	4	0.17	0.07	6	0.28	0.08	20
19787	0.08	0.10	11	0.06	0.11	5	0.03	0.06	4	0.18	0.09	30
25604	0.10	0.09	11	0.03	0.05	5	0.12	0.09	5	0.16	0.09	32
28292	0.14	0.09	9	−0.11	0.09	5	0.06	0.06	2	0.07	0.10	32
29503	0.29	0.08	7	−0.06	0.10	5	0.15	0.03	3	0.12	0.11	25
34559	0.12	0.05	10	0.15	0.08	5	0.03	0.06	5	0.15	0.08	32
35369	−0.23	0.05	7	−0.20	0.10	4	−0.31	0.08	4	−0.13	0.07	32
54810	0.01	0.07	5	–	–	–	−0.05	–	1	−0.13	0.00	2
58207	0.01	0.07	13	−0.02	0.04	6	−0.08	0.08	3	−0.07	0.05	17
61935	0.00	0.05	4	0.08	0.07	3	–	–	–	−0.03	0.04	7
74442	0.25	0.12	5	–	–	–	0.28	–	1	0.20	0.08	2
82741	0.02	0.07	6	–	–	–	0.06	–	1	−0.04	0.03	2
86513	0.06	0.04	10	–	–	–	–	–	–	0.19	0.05	9
94264	0.20	0.09	6	–	–	–	0.05	–	1	0.05	0.11	2
95272	0.14	0.10	6	–	–	–	0.14	–	1	0.13	0.14	2
100006	−0.16	0.06	8	–	–	–	–	–	–	0.00	0.06	10
104979	−0.33	0.07	7	–	–	–	−0.11	–	1	−0.23	0.09	2
108381	0.56	0.08	5	–	–	–	0.50	–	1	0.39	0.18	2
131111	0.01	0.07	11	−0.11	0.07	5	−0.20	0.08	3	−0.18	0.05	16
133165	−0.09	0.06	7	–	–	–	–	–	–	−0.04	0.04	9
141680	0.04	0.06	13	0.02	0.08	5	−0.02	0.04	4	−0.07	0.05	16
146388	0.40	0.09	11	0.27	0.06	5	0.14	0.08	3	0.26	0.09	17
153210	0.13	0.13	9	0.07	0.09	7	0.08	0.05	3	0.24	0.12	12
161096	0.37	0.12	7	0.22	0.09	6	0.36	0.08	3	0.32	0.15	12
163588	0.03	0.12	9	−0.11	0.18	7	0.01	0.07	3	0.06	0.12	15
169414	0.20	0.06	5	−0.13	0.10	4	0.01	0.02	2	−0.11	0.09	12
172169	0.38	0.09	6	−0.08	0.07	4	0.00	–	1	0.04	0.09	10
181276	0.03	0.10	8	0.09	0.11	4	−0.08	0.04	3	0.06	0.11	12
188310	0.10	0.08	6	–	–	–	–	–	–	0.04	0.07	2
188947	0.29	0.05	17	0.18	0.06	6	−0.15	0.03	2	0.19	0.08	18
197989	0.02	0.08	6	–	–	–	−0.10	–	1	−0.01	0.04	3
203344	0.06	0.08	12	−0.03	0.13	3	−0.02	0.13	3	−0.03	0.06	17
207134	0.26	0.08	6	−0.01	0.12	4	0.05	0.04	3	−0.04	0.09	12
212943	−0.06	0.08	10	−0.21	–	1	−0.23	0.08	2	−0.22	0.04	9
216131	−0.02	0.07	7	−0.01	0.06	5	−0.14	0.02	3	−0.03	0.07	12
216228	0.08	0.07	7	0.00	0.04	2	−0.07	0.11	2	0.00	0.03	8
218031	0.09	0.06	10	−0.07	0.05	2	−0.11	0.08	2	−0.06	0.04	10
219916	−0.08	0.08	6	−0.11	0.06	5	−0.20	0.06	3	−0.12	0.05	12
221115	0.09	0.05	10	0.08	0.05	2	0.00	0.06	2	0.06	0.04	8
222842	0.09	0.05	10	0.06	0.05	2	−0.06	0.05	2	−0.01	0.05	9

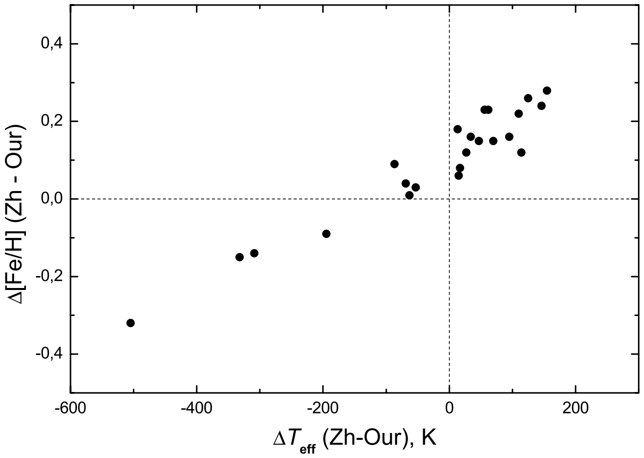

Figure 4. The differences of temperature and metallicity caused by the the erroneous temperature calibration used by Zhao et al. (2001).

results confirm this; we find for the stars in common $[\mathrm{Fe/H}]_{(\mathrm{McW})} - [\mathrm{Fe/H}]_{(\mathrm{Our})} = -0.13 \pm 0.07$.

It is also noticeable that the effective temperature calibrations of McWilliam (1990) and Alonso et al. (2001), which was used in our work, have a slight systematic temperature determination difference of 50 ± 50 K, the temperatures of McWilliam being lower.

4.2 Comparison with results by Zhao et al. (2001)

A study of 39 red clump giants was carried out by Zhao et al. (2001). Unfortunately, the determination of effective temperatures in this paper was done using the erroneous temperature calibration by Alonso, Arribas & Martínez-Roger (1999), which was subsequently updated by Alonso et al. (2001). Fig. 4 demonstrates the consequences of this misunderstanding on a sample of 24 stars re-analysed in our study.

For the stars with [Fe/H] greater than solar, the temperatures and metallicities were overestimated by up to 200 K and 0.2 dex, respectively. For the metal-deficient stars, temperatures and metallicities were underestimated by up to 200 K and 0.2 dex. Considering the stars with no temperature difference, it is also clear that the [Fe/H] values determined in our study are about 0.1 dex lower. This is most likely caused by a very careful selection of unblended lines in our analysis and a careful choice of the continuum level in a number of regions.

4.3 Comparison with recent studies

Chemical composition of 177 clump giants of the Galactic disc were investigated by Mishenina et al. (2006) on a basis of spectra ($R = 42\,000$) obtained on the 1.93-m telescope of the Haute Provence Observatoire (France). A sample of 63 Southern hemisphere red clump stars were investigated by Liu et al. (2007). Spectra ($R = 48\,000$) were obtained on the 1.52-m ESO telescope (La Silla, Chile). A spectroscopic analysis of a sample of 298 nearby giants, with red clump stars among them, was done by Luck & Heiter (2007) based on high-resolution spectra ($R = 60\,000$) with spectral coverage from 4750 to 6850 Å. We selected a subsample of 138 red clump giants for further comparison analysis based on the luminosity and effective temperature diagram provided by Luck & Heiter in their fig. 20. All stars located in the box limited by luminosities $\log(L/\mathrm{L}_\odot)$ from 1.5 to 1.8 and effective temperatures from 4700 to 5200 K were included in the subsample.

A number of stars have been investigated in two or more studies. With one exception, iron-abundance differences across different papers are negligible and random in nature: $[\mathrm{Fe/H}]_{\mathrm{Our}} - [\mathrm{Fe/H}]_{\mathrm{LH}} = +0.01 \pm 0.06$ (16 stars), $[\mathrm{Fe/H}]_{\mathrm{Our}} - [\mathrm{Fe/H}]_{\mathrm{L}} = +0.04 \pm 0.10$ (eight stars), $[\mathrm{Fe/H}]_{\mathrm{Our}} - [\mathrm{Fe/H}]_{\mathrm{M}} = +0.01 \pm 0.12$ (24 stars) and $[\mathrm{Fe/H}]_{\mathrm{L}} - [\mathrm{Fe/H}]_{\mathrm{LH}} = -0.04 \pm 0.04$ (nine stars), where Our – this paper, LH – Luck & Heiter (2007), M – Mishenina et al. (2006), L – Liu et al. (2007). The exception is the clear systematic discrepancy between results of Luck & Heiter and Mishenina et al.: $[\mathrm{Fe/H}]_{\mathrm{LH}} - [\mathrm{Fe/H}]_{\mathrm{M}} = +0.07 \pm 0.07$ (41 stars). It is interesting to note that while the systematic difference of [Fe/H] exists between common stars in these two studies, there are no systematic differences between [Fe/H] values in our study and studies by Luck & Heiter and Mishenina et al. Probably this is because the difference between these works is more prominent for the metal-deficient stars, while our common stars are more metal abundant. So, we cannot determine which of these studies is right. There are only three common stars between Liu et al. and Mishenina et al.

Concerning the agreement of effective temperature and surface gravity determinations, our results are in a very good agreement with the study by Mishenina et al. (2006) despite the different methods of effective temperature determination. The so-called ‘spectroscopic’ effective temperature values in the work by Luck & Heiter (2007) are systematically higher by almost 100 K, and $\log g$ by +0.4 dex; however, their ‘physical’ determinations are in good agreement with our work and Mishenina et al. Effective temperatures in the work by Liu et al. are in the mean by about 60 K lower and $\log g$ by about 0.3 dex higher than that in our work, as evaluated from eight common stars. The systematic difference in temperatures between the studies of Luck & Heiter (spectroscopic) and Liu et al. is 160 K.

5 METALLICITY DISTRIBUTION IN CLUMP STARS OF THE GALAXY

There have been few attempts to derive typical metallicities for *Hipparcos* clump stars. The first was an indirect method by Jimenez, Flynn & Kotoneva (1998); they obtained $-0.7 < [\mathrm{Fe/H}] < 0.0$. However, they modelled the clump with star formation rate (SFR) strongly decreasing with Galactic age. Consequently, they were considering, essentially, the behaviour of the old clump stars, with masses of about 0.8–1.4 $\mathrm{M}_\odot$. Intermediate-mass clump stars with mass more than 1.7 $\mathrm{M}_\odot$ were absent in their simulations (cf. Girardi & Salaris 2001). Thus their description of the clump stars was incomplete.

Girardi et al. (1998) considered the full mass range of clump stars and models with constant SFR up to 10 Gyr ago. They demonstrated that the best fit is achieved with a Galaxy model which in the mean has solar metallicity, with a very small metallicity dispersion of about 0.1 dex.

Girardi & Salaris (2001) collected the spectroscopic abundance determinations for the *Hipparcos* clump stars in the catalogue by Cayrel de Strobel et al. (1997). They found that the histogram of [Fe/H] values is fairly well represented by a quite narrow Gaussian curve of mean $\langle[\mathrm{Fe/H}]\rangle = -0.12$ dex and standard deviation of 0.18 dex, as derived by means of a least-squares fit.

In the same paper a theoretical simulation of the *Hipparcos* clump was made. Girardi & Salaris (2001) found that the total range of metallicities allowed by their model is quite large ($-0.7 \leq [\mathrm{Fe/H}] \leq 0.3$); however, the distribution for clump stars is very narrow: a Gaussian fit to the [Fe/H] distribution produces a mean $\langle[\mathrm{Fe/H}]\rangle = +0.03$ dex and dispersion $\sigma_{[\mathrm{Fe/H}]} = 0.17$. Actually, the [Fe/H] distribution presents an asymmetric tail at lower metallicities, which

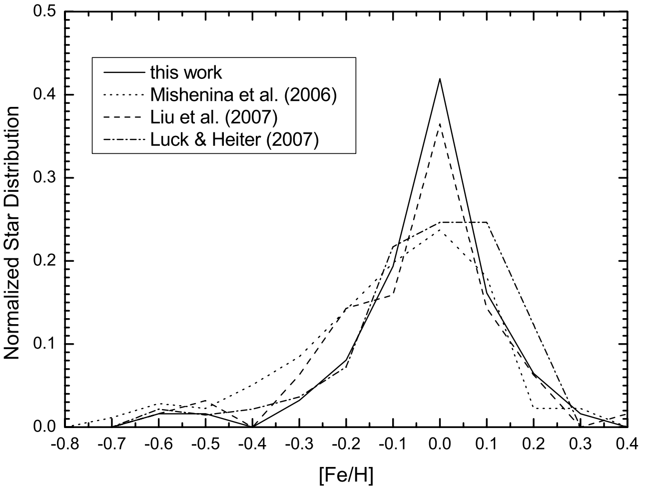

Figure 5. Distributions of [Fe/H] in the Galactic clump stars investigated in this paper and other studies.

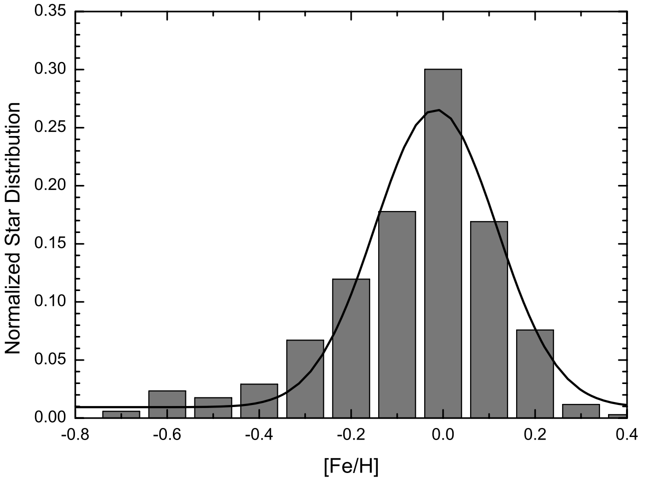

Figure 6. Metallicity distribution in the sample of 342 Galactic clump stars (the [Fe/H] values are averaged for the common stars investigated in this paper, Mishenina et al. (2006), Liu et al. (2007) and Luck & Heiter (2007).

causes the straight mean of [Fe/H] to be -0.04 dex. The near-solar metallicity and so small $\sigma_{\rm [Fe/H]}$ imply that nearby clump stars are (in the mean) relatively young objects, reflecting mainly the near-solar metallicities developed in the local disc during the last few Gyr of its history. From the same simulation they determined that the peak of age distribution in the *Hipparcos* clump is at about 1 Gyr.

In our study, the results of [Fe/H] determinations in clump stars of the Galaxy confirm the theoretical model by Girardi & Salaris (2001). The metallicity range in our study is from $+0.3$ to -0.6 dex; however, the majority of stars concentrate near the mean value $\langle$[Fe/H]$\rangle = -0.04 \pm 0.15$. A Gaussian fit to the [Fe/H] distribution produces the mean $\langle$[Fe/H]$\rangle = -0.01$ and very small dispersion $\sigma_{\rm [Fe/H]} = 0.08$.

In order to see what the metallicity distribution is in all the sample of Galactic clump stars investigated to date using high-resolution spectra, we present in Fig. 5 metallicity distributions for the samples of Galactic clump stars investigated in this paper (62 stars), Mishenina et al. (177 stars), Liu et al. (63 stars) and Luck & Heiter (138 stars); and in Fig. 6, the metallicity distribution in the entire sample of 342 Galactic clump stars is presented. The metallicity values were averaged for the stars with multiple analysis. In the study of Mishenina et al. a special attempt was made to include the metal-deficient stars, so the distribution slightly reflects this selection effect.

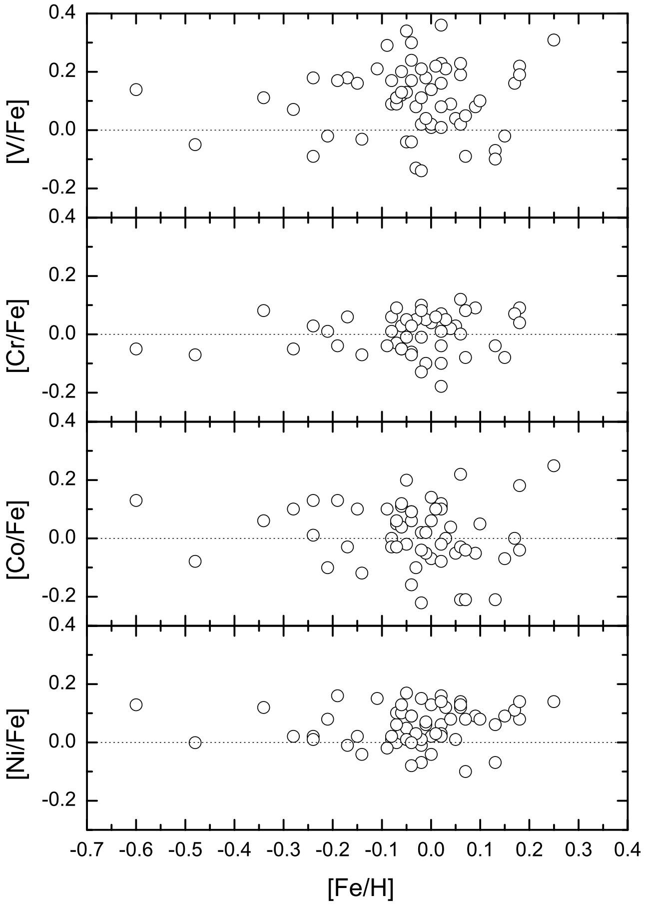

Figure 7. Abundance trends of iron-group elements.

The [Fe/H] values of clump stars in Fig. 6 range from $+0.4$ to -0.8 dex. A Gaussian fit to the [Fe/H] distribution produces a mean $\langle$[Fe/H]$\rangle = -0.02$ and dispersion $\sigma_{\rm [Fe/H]} = 0.13$ dex, which is in agreement with the theoretical model by Girardi & Salaris (2001).

5.1 Abundances of iron-group elements

Fig. 7 presents the observed [El/Fe] ratios for iron-group elements in our sample of stars, always using the neutral species. Nickel abundances always closely follow solar nickel-to-iron ratios in the Galactic disc. In our study [Ni/Fe] = 0.06 ± 0.07, in Mishenina et al. (2006) – [Ni/Fe] = 0.11 ± 0.03, in Liu et al. (2007) – [Ni/Fe] = 0.02 ± 0.05 and in Luck & Heiter (2007) – [Ni/Fe] = 0.01 ± 0.03, so it can be said that the [Ni/Fe] ratios in clump stars are approximately solar.

Vanadium was investigated in our and two other studies. We obtain the mean value of [V/Fe] = 0.11 ± 0.12, Liu et al. derived 0.02 ± 0.10 and Luck & Heiter found -0.05 ± 0.09, which means that this element also has solar [V/Fe] ratios.

Chromium and cobalt were investigated in our work and by Luck & Heiter. The mean [Cr/Fe] ratios are exactly solar in both studies. [Co/Fe] is enhanced by about 0.07 ± 0.06 dex in the work by Luck & Heiter. In our study, cobalt abundances were investigated with

HFS effects taken into account; we find [Co/Fe] = 0.02 ± 0.11, which is close to solar.

5.2 Final remarks

The main atmospheric parameters $T_{\rm eff}$, log g, v_t, [Fe/H] and abundances of vanadium, chromium, cobalt and nickel were determined for 62 red clump stars revealed in the Galactic field by the *Hipparcos* orbiting observatory.

The stars form a homogeneous sample with the mean value of temperature $T_{\rm eff} = 4750 \pm 160$ K, of surface gravity $\log g = 2.41 \pm 0.26$ and the mean value of metallicity $[{\rm Fe/H}] = -0.04 \pm 0.15$. It is especially interesting to note that metallicities of stars in the Galactic clump lie in quite a narrow interval. A Gaussian fit to the [Fe/H] distribution produces the mean $\langle[{\rm Fe/H}]\rangle = -0.01$ and dispersion $\sigma_{\rm [Fe/H]} = 0.08$.

The near-solar metallicity and small dispersion of $\sigma_{\rm [Fe/H]}$ of clump stars of the Galaxy obtained in this paper confirm the theoretical model of the *Hipparcos* clump by Girardi & Salaris (2001) which suggests that nearby clump stars are (in the mean) relatively young objects, reflecting mainly the near-solar metallicities developed in the local disc during the last few Gyr of its history.

The iron-group element to iron-abundance ratios in the investigated clump giants are close to solar. This allows us to use the clump stars to study the chemical and dynamical evolution of the Galaxy. Clump giants may provide a very useful information on mixing processes in evolved low-mass stars. We plan to address this question in our further study of the Galactic clump.

ACKNOWLEDGMENTS

This project has been supported by the European Commission through the Baltic Grid project as well as through 'Access to Research Infrastructures Action' of the 'Improving Human Potential Programme', awarded to the Instituto de Astrofísica de Canarias to fund European Astronomers' access to the European Nordern Observatory, in the Canary Islands. EP and GT acknowledge support from the Lithuanian National Science and Studies Foundation through GridTechno project. JGC acknowledges the inspiration of the late Bohdan Paczynski for stimulating her interest in this area and is grateful to NSF grant AST-0507219 and AST-0908139 for partial support. DFG is grateful for financial support from the Natural Sciences and Engineering Research Council of Canada. SJA thanks Dr James E. Hesser, Director of the Dominion Astronomical Observatory, for the observing time used for this project and Dr Austin Gulliver for help in reducing the DAO Spectrograms. Financial support was provided to SJA by The Citadel Foundation.

REFERENCES

Alonso A., Arribas S., Martínez-Roger C., 1999, A&AS, 140, 261

Alonso A., Arribas S., Martínez-Roger C., 2001, A&A, 376, 1039

Anstee S. D., O'Mara B. J., 1995, MNRAS, 276, 859

Barklem P. S., O'Mara B. J., 1997, MNRAS, 290, 102

Barklem P. S., O'Mara B. J., Ross J. E., 1998, MNRAS, 296, 1057

Brown K. I. T., Gray D. F., Baliunas S. L., 2008, ApJ, 679, 1531

Cannon R. D., 1970, MNRAS, 150, 111

Cayrel de Strobel G., Soubiran C., Friel E. D., Ralite N., Fran cois P., 1997, A&AS, 124, 299

Girardi L., Salaris M., 2001, MNRAS, 323, 109

Girardi L., Groenewegen M. A. T., Weiss A., Salaris M., 1998, MNRAS, 301, 149

Gulliver A. F., Hill G., 2002, in Bohlender D. A., Durand D., Handley T. H., eds, ASP Conf. Ser. Vol. 108, Astronomical Data Analysis Software and Systems XI. Aston. Soc. Pac., San Francisco, p. 232

Gurtovenko E. A., Kostik R. I., 1989, Fraunhofer's Spectrum and a System of Solar Oscillator Strengths. Naukova Dumka, Kiev, p. 200

Gustafsson B., Edvardsson B., Eriksson K., Jørgensen U. G., Mizuno-Wiedner M., Plez B., 2003, in Piskunov N., Weiss W. W., Gray D. F., eds, Proc. IAU Symp. 210, Modelling of Stellar Atmospheres. Astron. Soc. Pac., San Francisco, A4

Hatzidimitriou D., 1991, MNRAS, 251, 545

Hatzidimitriou D., Hawkins M. R. S., 1989, MNRAS, 241, 667

Hill G., Fisher W. A., Poeckert R., 1982, Publ. Dom. Astrophys. Obser., 16, 27

Ilyin I. V., 2000, PhD thesis, Univ. Oulu, Finland

Jimenez R., Flynn C., Kotoneva E., 1998, MNRAS, 299, 515

Kurucz R. L., Furenlid I., Brault J., Testerman L., 1984, Solar Flux Atlas from 296 to 1300 nm. National Solar Observatory, Sunspot, New Mexico

Liu Y. J., Zhao G., Shi J. R., Pietrzynski G., Gieren W., 2007, MNRAS, 382, 553

Luck R. E., Heiter U., 2007, AJ, 133, 2464

Mäckle R., Holweger H., Griffin R., Griffin R., 1975, A&A, 38, 239

McWilliam A., 1990, ApJS, 74, 1075

McWilliam A., Rich R. M., 1997, ApJS, 91, 749

Mishenina T. V., Bienaymé O., Gorbaneva T. I., Charbonnel C., Soubiran C., Korotin S. A., Kovtyukh V. V., 2006, A&A, 456, 1109

Moore C. E., Minnaert M. G. J., Houtgast J., 1966, The Solar Spectrum 2935 Å to 8770 Å, NBS Monogr., No. 61

Perryman M. A. C. et al.,1997, A&A, 323, L49

Perryman M. A. C., Lindegren L., Kovalevsky J., 1995, A&A, 304, 69

Piskunov N. E., Kupka F., Ryabchikova T. A., Weiss W. W., Jeffery C. S., 1995, A&AS, 112, 525

Prochaska J. X., Naumov S. O., Carney B. W., McWilliam A., Wolfe A. M., 2000, AJ, 120, 2513

Simmons G. J., Blackwell D. E., 1982, A&A, 112, 209

Sneden C., 1973, PhD thesis, Univ. Texas

Tautvaišienė G., 1996, Baltic Astron., 5, 503

Tautvaišienė G., Puzeras E., 2009, in Andersen J., Bland-Hawthorn J., Nordström B., eds, Proc. IAU Symp. 254, The Galaxy Disk in Cosmological Context. Cambridge Univ. Press, Cambridge, p. 75

Tautvaišienė G., Stasiukaitis E., Puzeras E., Gray D. F., Ilyin I., 2005, in Favata F., Hussain G., Battrick B., eds, ESA SP-560, Proceedings of the 13th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun. ESA, Noordwijk, p. 989

Tuominen I., Ilyin I., Petrov P., 1999, in Karttunen H., Piirola V., eds, Astrophysics with the NOT. Turku Univ., Piikio, p. 47

Udalski A., 1998, Acta Astron., 48, 383

Unsöld A., 1955, Physik der Stern Atmosphären (Zweite Auflage). Springer-Verlag, Berlin

Zhao G., Qiu H. M., Mao S., 2001, ApJ, 551, L85

This paper has been typeset from a TEX/LATEX file prepared by the author.