Astronomy & Astrophysics

Precise radial velocities of giant stars[*,**]

III. Spectroscopic stellar parameters

S. Hekker[1] and J. Meléndez[2]

[1] Leiden Observatory, Leiden University, PO Box 9513, 2300 RA Leiden, The Netherlands
e-mail: saskia@strw.leidenuniv.nl
[2] Research School of Astronomy & Astrophysics, Mount Stromlo Observatory, Cotter Road, Weston Creek, ACT 2611, Australia

ABSTRACT

Context. A radial velocity survey of about 380 G and K giant stars is ongoing at Lick observatory. For each star we have a high signal to noise ratio template spectrum, which we use to determine spectroscopic stellar parameters.

Aims. The aim of this paper is to present spectroscopic stellar parameters, i.e. effective temperature, surface gravity, metallicity and rotational velocity for our sample of G and K giant stars.

Methods. Effective temperatures, surface gravities and metallicities are determined from the equivalent width of iron lines, by imposing excitation and ionisation equilibrium through stellar atmosphere models. Rotational velocities are determined from the full width at half maximum (*FWHM*) of moderate spectral lines. A calibration between the *FWHM* and total broadening (rotational velocity and macro turbulence) is obtained from stars in common between our sample and the sample from Gray (1989, ApJ, 347, 1021). Macro turbulence is determined from the macro turbulence vs. spectral type relations from Gray (2005, The Observation and Analysis of Stellar Photospheres).

Results. The metallicity we derive is essentially equal to the literature values, while the effective temperature and surface gravity are slightly higher by 56 K and 0.15 dex, respectively. A method comparison is performed with 72 giants in common with Luck & Heiter (2007, AJ, 133, 2464), which shows that both methods give similar results. Our rotational velocities are comparable with those obtained by Gray (1989, ApJ, 347, 1021), but somewhat higher than those of de Medeiros & Mayor (1999, A&AS, 139, 433), which is consistent with the different diagnostics used to determine them.

Conclusions. We are able to determine spectroscopic stellar parameters for about 380 G and K giant stars uniformly (112 stars are being analysed spectroscopically for the first time). For stars available in the literature, we find reasonable agreement between literature values and values determined in the present work. In addition, we show that the metallicity enhancement of companion hosting stars might also be valid for giant stars, with the planet hosting giants being 0.13 ± 0.03 dex (i.e. 35 ± 10%) more metal rich than our total sample of stars.

Key words. stars: abundances – stars: fundamental parameters – stars: rotation – methods: observational – techniques: spectroscopic

1. Introduction

For the determination of spectroscopic stellar parameters, one needs high resolution spectra with high signal to noise ratio. These spectra are available from radial velocity surveys and are often used to determine stellar parameters. For instance, properties of cool stars from the Keck, Lick and AAT planet search are described by Valenti & Fischer (2005). Atmospheric parameters for stars observed by the N2K consortium (Fischer et al. 2005) are described by Robinson et al. (2007a). Santos et al. (2004, 2005) present stellar parameters and metallicities from the planet search using ESO facilities and the ELODIE spectrograph at the 1.93 m telescope at the Observatoire de Haute Provence. Also, basic stellar parameters for 72 evolved stars, previously studied for radial velocity variations, are presented by da Silva et al. (2006). Some of these results are not only interesting in terms of the stellar parameters, but also reveal which stars are most likely to harbour sub-stellar companions. As first shown by Gonzalez (1997), and confirmed with larger samples by

Fischer & Valenti (2005) and Santos et al. (2005), metal rich stars are more likely to harbour companions than metal poor ones.

Spectroscopic stellar parameters are most commonly determined by fitting the observed spectrum directly, see for instance Valenti & Fischer (2005), or by imposing excitation and ionisation equilibrium for metal lines, using an LTE analysis and a grid of model atmospheres, see for instance Santos et al. (2004, 2005), da Silva et al. (2006), Takeda et al. (2002) and Luck & Heiter (2007).

Rotational velocity and macro turbulence can only be determined directly with the Fourier transform technique, see for instance Gray (1989). Benz & Mayor (1981) have shown that accurate rotational velocities can also be deduced for dwarfs from a cross correlation function, by performing a calibration with the direct measurements of Gray (1989). de Medeiros & Mayor (1999) extended this technique for giant stars. Fekel (1997) used the full width at half maximum (*FWHM*) of weak to moderate spectral lines to determine rotational velocities, also by performing a calibration with the results of Gray (1989).

In 1999, a radial velocity survey of about 180 K giant stars was started at UCO/Lick Observatory, USA. This ongoing survey has recently been expanded to about 380 G and K giants.

From the initial sample of 180 stars, companions have been announced for ι Draconis (Frink et al. 2002) and Pollux (Reffert et al. 2006). Stars with radial velocity variations of less than 20 ms^{-1} were presented as stable stars by Hekker et al. (2006), and an investigation into the mechanism(s) causing the radial velocity variations is presented by Hekker et al. (2007). Some binaries discovered with this survey, as well as an extensive overview of the sample, will be presented in forthcoming papers.

In this paper, we determine stellar parameters, i.e. effective temperature ($T_{\rm eff}$), surface gravity (log g) and metallicity ([Fe/H]), as well as rotational velocity ($v \sin i$) for all stars in the sample. In Sect. 2, we describe the observations. In Sects. 3 and 4, we present the methods used, and results for the stellar parameters and rotational velocity, respectively. In Sect. 5 a summary of our results is presented.

2. Observations

For the radial velocity survey, giants were selected from the Hipparcos catalog (Perryman & ESA 1997), based on the criteria described by Frink et al. (2001). The selected stars are all brighter than 6 mag, are presumably single and have photometric variations <0.06 mag. These criteria are the same for the initial sample (K1 and later giants) as well as for the extension (G and K0, K1 giants). The survey started in 1999 at Lick observatory using the Coude Auxiliary Telescope (CAT) in conjunction with the Hamilton echelle spectrograph ($R = 60\,000$). The radial velocity measurements are performed with an iodine cell in the light path as described by Marcy & Butler (1992) and Valenti et al. (1995). Radial velocities are determined from the comparison of a stellar spectrum obtained with an iodine cell in the light path, and the convolution of a template iodine spectrum and a template stellar spectrum obtained without an iodine cell in the light path (Butler et al. 1996). For each target star we have a high signal to noise ratio template spectrum. These templates are used for the determination of the stellar parameters described in this paper. Thorium-argon images taken at the beginning and end of each night are used for wavelength calibration.

3. Effective temperature, surface gravity, and metallicity

Spectroscopic stellar parameters ($T_{\rm eff}$, log g and [Fe/H]) are determined by measuring the equivalent width (EW) of iron lines. The iron lines used in this work are listed in Table 1. The lines were carefully selected to avoid blends by atomic and CN lines. CN blends were visually inspected by comparing a synthetic spectrum computed with laboratory CN lines (Meléndez & Barbuy 1999) with the high resolution visible atlas of the cool giant Arcturus (Hinkle et al. 2000). The log gf values are based on laboratory works, in some cases with small adjustments using the Arcturus atlas. For Fe I, they are from the Oxford group (e.g. Blackwell et al. 1995), Hannover group (e.g. Bard & Kock 1994; O'Brian et al. 1991; May et al. 1974; and Milford et al. 1994). For Fe II, the log gf values are from the laboratory normalisation performed by Meléndez et al. (2006).

It is very time consuming to determine EWs for about 380 stars by hand, using for instance the "splot" routine from IRAF[1], we therefore used the publicly available Automatic Routine for line Equivalent widths in stellar Spectra (ARES)

[1] IRAF is distributed by National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation, USA.

Table 1. Iron lines considered in our analysis.

| Ion	λ [Å]	χ [eV]	log gf
Fe I	5775.080	4.220	−1.30
Fe I	5848.129	4.607	−0.9
Fe I	5902.473	4.593	−1.75
Fe I	5916.247	2.453	−2.99
Fe I	6027.050	4.076	−1.3
Fe I	6093.644	4.607	−1.41
Fe I	6096.665	3.984	−1.81
Fe I	6098.244	4.558	−1.8
Fe I	6120.249	0.915	−5.95
Fe I	6151.618	2.176	−3.30
Fe I	6187.990	3.943	−1.65
Fe I	6240.646	2.223	−3.39
Fe I	6498.939	0.958	−4.70
Fe I	6574.228	0.990	−5.00
Fe I	6703.567	2.759	−3.15
Fe I	6725.357	4.103	−2.30
Fe I	6726.666	4.607	−1.17
Fe I	7421.558	4.638	−1.80
Fe I	7547.896	5.099	−1.10
Fe I	7723.208	2.279	−3.62
Fe II	5264.812	3.230	−3.13
Fe II	5425.257	3.200	−3.22
Fe II	6247.557	3.892	−2.30
Fe II	6369.462	2.891	−4.11
Fe II	6432.680	2.891	−3.57
Fe II	6456.383	3.904	−2.05
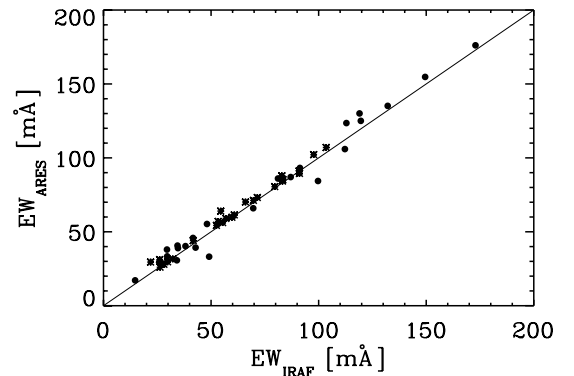
Fig. 1. EWs obtained with the ARES software as a function of EWs computed using IRAF. The dots indicate a star with $T_{\rm eff} = 4050$ K ("cool") and the asterisks a star with $T_{\rm eff} = 4900$ K ("hot"). The solid line is a 1 to 1 relation.

(Sousa et al. 2007). To check for possible differences between the EWs determined with ARES and those obtained with IRAF, we plot the EWs obtained with ARES vs. those obtained using IRAF (see Fig. 1). This comparison is done for a "hot" ($T_{\rm eff} = 4900$ K) and a "cool" ($T_{\rm eff} = 4050$ K) star in the sample. The mean differences between the EWs measured with ARES and IRAF are: $\langle EW_{\rm ARES} - EW_{\rm IRAF} \rangle = 1.6$ mÅ and 2.2 mÅ, with standard deviations of 6.6 mÅ and 2.6 mÅ, for the "cool" and "hot" star respectively. The nearly 1 to 1 relation between the EWs obtained with both methods shows that it is reasonable to use EWs obtained with ARES. For some stars one or more lines appeared to be too strong (stronger than 200 mÅ) for a reliable parameter estimate. These lines are discarded.

From the EWs, stellar parameters are determined by imposing excitation and ionisation equilibrium through stellar atmosphere models. The micro turbulence (v_t) was obtained by requiring no dependence of Fe I against equivalent width. We
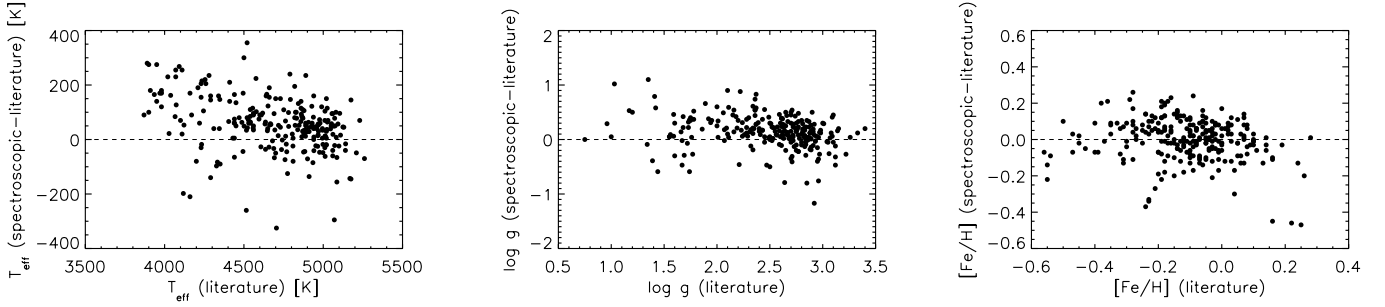
Fig. 2. Difference between our spectroscopic values and literature values as a function of literature values for the effective temperature (*left*), the logarithm of the surface gravity in cgs units (*centre*) and metallicity (*right*).

performed a spectroscopic LTE analysis using the 2002 version of MOOG (Sneden 1973) and Kurucz model atmospheres, which include overshooting (Castelli et al. 1997). The resulting stellar parameters for each star are listed in Table 4 (only available in the online version). The reference solar iron abundance used in this study is $A(\text{Fe})_\odot = 7.49$ and was obtained using the same grid of Kurucz models.

Based on the scatter of the Fe lines, we obtained observational errors (standard errors) of 0.024 dex for Fe I and 0.037 dex for Fe II. Furthermore, we compute internal errors for a change of +80 K, +0.2 dex and +0.2 km s^{-1} in T_{eff}, log g and micro turbulence, respectively. The errors due to change in stellar parameters are shown for three stars with different temperatures in Table 2.

3.1. Comparison with the literature

We compare our spectroscopic stellar parameters with values obtained from the literature. These literature values are from an updated version (Ramírez & Meléndez 2005) of the Cayrel de Strobel et al. (2001) [Fe/H] catalogue (254 stars in common), including the Luck & Heiter (2007) catalogue. If possible, suspicious literature values were corrected according to the normalisation suggested by Taylor (1999). In Fig. 2 the difference between our spectroscopic and literature values are plotted for the temperature, surface gravity and metallicity. We find the following trimean difference and pseudo-sigma for the stellar parameters:

$$\langle [\text{Fe/H}]^{\text{spec}} - [\text{Fe/H}]^{\text{lit}} \rangle = 0.01 \text{ dex} \quad \sigma = 0.10 \text{ dex}$$

$$\langle \log g^{\text{spec}} - \log g^{\text{lit}} \rangle = 0.15 \text{ dex} \quad \sigma = 0.22 \text{ dex}$$

$$\langle T_{\text{eff}}^{\text{spec}} - T_{\text{eff}}^{\text{lit}} \rangle = 56 \text{ K} \quad \sigma = 84 \text{ K}.$$

The trimean T is a robust estimate of central tendency: $T = (Q1 + 2 \times \text{median} + Q3)/4$ where Q1 and Q3 are the first and third quartile. The pseudo-standard deviation σ is obtained from the quartile deviation QD = (Q3 − Q1)/2, employing $\sigma = 3/2$ QD (Meléndez et al. 2006).

The difference in our spectroscopic metallicity and the literature value is essentially zero and we conclude that our metallicity scale is correct. Furthermore, our T_{eff} values are in good agreement with the literature, with a scatter of only 84 K, and a zero point difference of 56 K, our T_{eff} values being higher than the values in the literature. From the left panel of Fig. 2 one can see that the difference is largest for the coolest stars in the sample. This might be due to the fact that the models are less accurate for low temperatures. In addition, the number of spectral lines increases with decreasing temperature, the spectra might be too crowded at lower temperatures, and also the lines get stronger

Table 2. Internal errors due to changes in stellar parameters for three stars with different temperatures. The total error in the last column includes the observational errors (0.024 dex for Fe I and 0.037 dex for Fe II).

Ion	ΔT_{eff} +80 K	$\Delta \log g$ +0.2 dex	Δv_t +0.2 km s^{-1}	$\sqrt{\Sigma x^2}$
HD 156681	(T = 4170 K)			
Fe I	−0.01	+0.07	−0.07	0.10
Fe II	−0.15	+0.16	−0.03	0.22
HD 214868	(T = 4445 K)			
Fe I	+0.01	+0.07	−0.06	0.10
Fe II	−0.12	+0.18	−0.04	0.22
HD 165634	(T = 4980 K)			
Fe I	+0.06	+0.02	−0.06	0.09
Fe II	−0.06	+0.10	−0.07	0.14

and more dependent on the micro turbulence. Our results below 4000 K should be interpreted with caution.

The spectroscopic gravities we derived also agree well with the literature, with a scatter of only 0.22 dex, and a zero point difference of 0.15 dex. We checked whether the enhanced log g values from our spectroscopic analyses are related to the higher temperatures we obtained, compared to literature values. We therefore performed a test for three stars with T_{eff} 4170 K, 4445 K and 4980 K, respectively. We increased T_{eff} with 100 K and determined log g, while keeping the micro turbulence fixed. For all three stars we obtained higher log g values for the increased temperatures. This reveals that the higher values for log g, compared to the literature values, are related to the higher effective temperatures.

3.2. Comparison with Luck & Heiter (2007)

Recently, Luck & Heiter (2007) presented a homogeneous spectroscopic analysis of 298 giants in the local region, using between 300 and 400 Fe I lines for each star and MARCS stellar models (Gustafsson et al. 2003) on spectra with $R = 60\,000$. We used the 72 stars in common between Luck & Heiter (2007) and our sample, to see how well we can determine spectroscopic stellar parameters with just two dozen carefully selected iron lines instead of a few hundred iron lines. Note that different models are used for the two analyses, however spectra have the same resolution. A comparison for each parameter is shown in Fig. 3. We find the following trimean difference and pseudo-sigma:

$$\langle [\text{Fe/H}]^{\text{spec}} - [\text{Fe/H}]^{\text{Luck}} \rangle = -0.05 \text{ dex} \quad \sigma = 0.06 \text{ dex}$$

$$\langle \log g^{\text{spec}} - \log g^{\text{Luck}} \rangle = 0.0 \text{ dex} \quad \sigma = 0.15 \text{ dex}$$

$$\langle T_{\text{eff}}^{\text{spec}} - T_{\text{eff}}^{\text{Luck}} \rangle = -43 \text{ K} \quad \sigma = 35 \text{ K}.$$
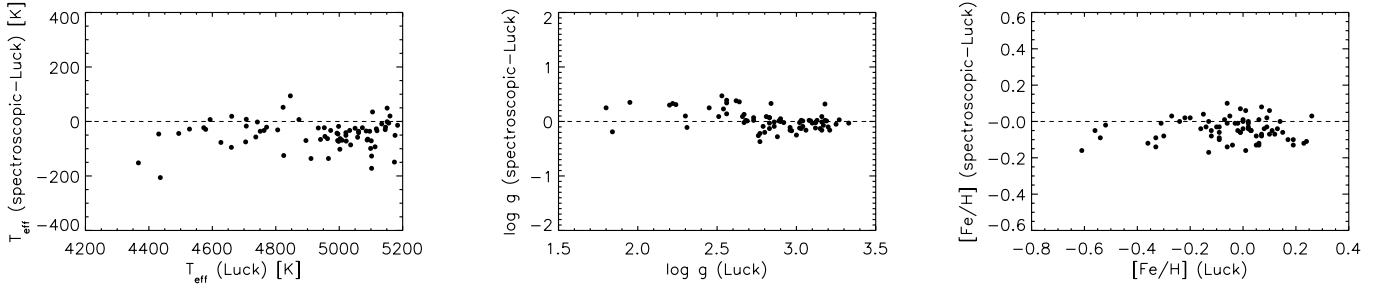
Fig. 3. Difference between our spectroscopic values and values from Luck & Heiter (2007) as a function of Luck & Heiter (2007) values for the effective temperature (*left*), the logarithm of the surface gravity in cgs units (*centre*) and metallicity (*right*) for the 72 stars in common between the samples.

Table 3. Companion hosting giants with their mean metallicities and literature sources.

HIP	HD	[Fe/H]	literature
4297	5319	+0.04	Robinson et al. (2007b)
8928	11977	−0.19	da Silva et al. (2006), Sousa et al. (2006)
10085	13189	−0.57	Schuler et al. (2005), Sousa et al. (2006)
	17092	+0.19	Niedzielski et al. (2007)
19921	27442	+0.33	Santos et al. (2003), Valenti & Fischer (2005)
20889	28305	+0.10	Mishenina et al. (2006), Schuler et al. (2006), Sato et al. (2007), this work
31688	47536	−0.64	Sadakane et al. (2005), da Silva et al. (2006)
36616	59686	+0.11	Santos et al. (2005), Sadakane et al. (2005), Mishenina et al. (2006), this work
37826	62509	+0.06	Sadakane et al. (2005), Luck & Heiter (2007), this work
42527	73108	−0.24	Luck & Heiter (2007), Doellinger et al. (2007)
58952	104985	−0.29	Santos et al. (2005), Takeda et al. (2005), Luck & Heiter (2007)
68581	122430	−0.10	da Silva et al. (2006)
75458	137759	+0.07	Santos et al. (2003), Sadakane et al. (2005), this work
92895	175541	−0.18	Valenti & Fischer (2005)
93746	177830	+0.35	Santos et al. (2003), Valenti & Fischer (2005)
99894	192699	−0.26	Johnson et al. (2007)
109577	210702	+0.01	Luck & Heiter (2007), Johnson et al. (2007)
114855	219449	0.00	Santos et al. (2005), Sadakane et al. (2005), Luck & Heiter (2007), this work
116727	222404	+0.21	Luck & Heiter (2007)
NGC 2423-3	BD-13 2130	+0.06	Twarog et al. (1997)

Our spectroscopic values are in good agreement with those obtained by Luck & Heiter (2007), with a scatter of only 0.06 dex for [Fe/H], 0.15 dex for log g and 35 K for the effective temperature. The mean difference in log g values is zero, while our metallicities and temperatures are slightly lower than those reported by Luck & Heiter (2007). These are probably systematic differences between both methods, because the pseudo-sigmas are relatively small. Luck & Heiter (2007) have benchmarked their codes against Kurucz's WIDTH and SYNTHE codes and claim that all codes yield the same result to within expected numerical accuracy and differences due to different assumptions, primarily partition functions and damping. It is therefore likely that the different adopted model atmospheres (MARCS vs. Kurucz) and different log gf values cause the small systematic difference. Luck & Heiter (2007) did not publish their line list and log gf values. Since they have used a much larger number of iron lines a comparison with our log gf values is probably not meaningful.

3.3. Metallicity in companion hosting giants

By now 20 sub-stellar companions are announced as orbiting giant stars. Some recent publications, e.g. Sadakane et al. (2005) and Pasquini et al. (2007), suggest that giant stars with companions are metal poor, which is quite different from the known metallicity enhancement in dwarf stars hosting companions.

Schuler et al. (2005) and da Silva et al. (2006) argue that giant stars with companions may be metal poor, due to a stellar mass-companion relation instead of a metallicity-companion relation. Indeed, Fischer & Valenti (2005) also find a relation between stellar mass and companions, but conclude that this is likely spurious. Here, we look at the metallicities of the giants with announced companions and compare these with the metallicities of the giants in our sample. For consistency with our work, the companion hosting giants are selected to encompass the same range in stellar parameters as our sample of giants, i.e. stars with $T_{\mathrm{eff}} \approx 4600 \pm 750$ K and log $g \approx 2.1 \pm 1.5$.

The companion hosting giants and their metallicities adopted for the comparison are listed in Table 3. In order to perform a homogeneous comparison between the metallicities of the total and the companion hosting giant sample we determined the metallicity zero-points of the literature works we are using for the companion hosting giant stars. We found the following zero-points: −0.05 dex for Luck & Heiter (2007), −0.10 dex for Schuler et al. (2005), −0.02 dex for da Silva et al. (2006) and Doellinger et al. (2007), −0.07 dex for Santos et al. (2003, 2005) and Sousa et al. (2006), −0.11 dex for Johnson et al. (2007), Valenti & Fischer (2005) and Robinson et al. (2007b), 0.00 dex for Mishenina et al. (2006), −0.05 dex for Sadakane et al. (2005), Sato et al. (2007) and Takeda et al. (2005), and −0.85 dex for Twarog et al. (1997). Note that Twarog et al. (1997) only provide a mean metallicity for the cluster NGC 2423 based on photometry. The
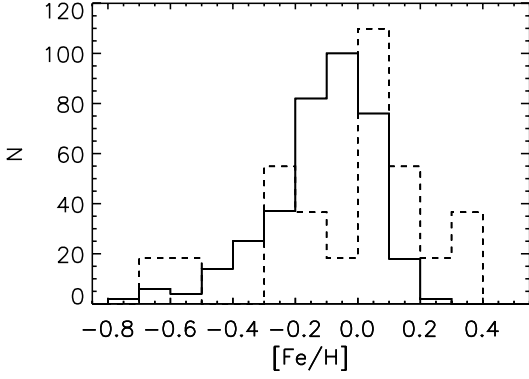
Fig. 4. Distribution of metallicities of all stars in our sample with mean, median and trimean values of −0.12, −0.09 and −0.095 dex, respectively. The metallicity of 20 giants with an announced companion in the literature (see text for selection criteria) are plotted with the dashed histogram. The latter distribution is normalised to the total number of giants in our sample. These giants have mean, median and trimean metallicity values of −0.05, +0.025 and −0.015 dex, respectively.

normalisation factor is based on the Hyades. For Niedzielski et al. (2007) we do not have any stars in common, so we adopted a zero-point of +0.01 dex, which we obtained from the global comparison with the literature. In the event that more individual measurements of a star were available in the literature, the mean metallicity was adopted. The literature sources are mentioned in the last column of Table 3.

In Fig. 4 the metallicity distribution of all stars in the present sample is shown together with the metallicity distribution of giant stars with announced companions. The companion hosting giant star distribution shows a gap at −0.1 dex. We do not know whether this gap is real or due to low number statistics. The mean, median and trimean metallicities are −0.12, −0.09 and −0.095 dex and −0.05, +0.025 and −0.015 dex for the total and companions hosting sample, respectively, while the peaks of the histograms are at −0.05 dex and +0.05 dex. Gaussians fitted through the two distribution have their centres at −0.06 dex and +0.09 dex (+0.085 dex in case one Gauss is fitted and +0.09 for 2 Gaussian fits) for the total and companion hosting sample, respectively. Therefore, the metallicity enhancement for companion hosting giants is 0.13 ± 0.03 dex. This is similar to the metallicity enhancement found by Fischer & Valenti (2005). Their comparison between metallicities of all stars in the sample and companion hosting dwarfs reveals that companion hosting dwarfs are more metal rich by 0.13 dex. If they compare the metallicity enhancement as a function of stellar mass, they find also that, independent of mass, the metallicity distribution of dwarfs with companions is 0.12 dex higher than the average metallicity of all stars in the sample.

Although the determination of precise stellar masses, for both our sample of field giant stars and the companion hosting giant stars, is beyond the scope of the present paper, we stress that overall both samples have comparable masses. Using the masses given by Allende Prieto & Lambert (1999), we estimate a typical mass of 2.0 $M_\odot$ for our sample, with the bulk of the field giant sample in the range 1.4–2.9 $M_\odot$ (first to third quartiles), which is the typical range covered by companion hosting giants according to Sadakane et al. (2005) and Johnson et al. (2007).

The metallicity enhancement for companion hosting giants should be taken with caution. First, it is still based on low number statistics. Second, for nearly 200 stars in our sample, we do

not have a long enough time span of radial velocity observations to detect companions, in case these are present. Third, there is still some discussion ongoing about some of the companion hosting giants with companions in (nearly) circular orbits. The observed radial velocity variations could in principle also be due to a mechanism intrinsic to the star.

The present conclusion that companion hosting giants are on average metal rich is rather different compared to other studies. Sadakane et al. (2005) and Pasquini et al. (2007) both agree that the giant stars with companions are typically not much more metal rich than [Fe/H] = 0.0. Sadakane et al. (2005) analysed only a few giants, therefore their results may be due to statistics based on small numbers. However, Pasquini et al. (2007) used a total of 14 giants, slightly less than our sample of 20 giants. The two samples have only 10 stars in common (HD 11977, HD 13189, HD 28305, HD 47536, HD 62509, HD 73108, HD 104985, HD 122430, HD 137759, HD 222404), which include the most metal poor giants in the sample, but does not contain some of the more metal rich ones. Since their histogram for the companion hosting giants does not include stars with [Fe/H] > +0.2 dex, we suspect that the four candidates which are not available in the literature are also not as metal rich as for example HD 27442 and HD 177830, both with [Fe/H] > +0.3 (Santos et al. 2003; Valenti & Fischer 2005). Note that Pasquini et al. (2007) did not correct for potential systematic errors in the literature [Fe/H] values for giant stars with companions.

Finally, caution should be taken when comparing dwarfs with giants, since systematic errors are expected due to differences in their atmospheric structures and parameters (Asplund 2005). Indeed, in a large study of several hundreds of giants and dwarfs, Luck & Heiter (2007) show that the abundances of Fe, Mn and Ba in giants may be affected by systematic uncertainties when compared with dwarf stars. A consistent study such as ours, comparing field giants to companion hosting giants, is therefore more reliable.

4. Rotational velocity

We computed rotational velocities for our sample of giant stars, using the method described by Fekel (1997). The *FWHM* for moderate spectral lines at 6432.68, 6452.33, 6454.99, 6455,60, 6456.38, 6469.15 and 6471.66 Å is determined and averaged. The dispersion of the *FWHM* resulting from individual lines is typically 0.025 mÅ. The instrumental broadening is determined from thorium-argon (ThAr) images taken at the beginning and end of each night. The *FWHM* of several ThAr lines, in the same spectral region as the stellar lines, are determined and averaged. The intrinsic stellar broadening is computed as $FWHM_{intrinsic} = \sqrt{FWHM_{measured}^2 - FWHM_{instrumental}^2}$.

The intrinsic stellar broadening is converted to rotational velocity $v \sin i$, using the results from Gray (1989). For the 51 stars in common (excluding 2 outliers, for which we find higher velocities than Gray 1989), the intrinsic broadening is plotted as a function of the total broadening ($\sqrt{(v \sin i)^2 + v_{macro}^2}$) determined by Gray (1989), as shown in Fig. 5. A second order polynomial is fitted:

$$FWHM_{intrinsic} = 0.10963 + 0.002758X + 0.001278X^2, \qquad (1)$$

with X the value of Gray's total broadening. The dispersion of this fit is 0.015 Å. This fit is used as calibration to convert the $FWHM_{intrinsic}$ in Å to total broadening in km s^{-1}. Note that we
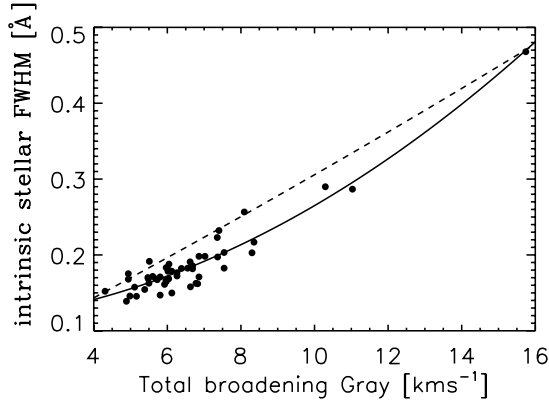
Fig. 5. The intrinsic stellar *FWHM* of spectral lines as a function Gray's total broadening, for 51 stars in common between our sample and Gray (1989). The best fit (Eq. (1)) is shown as the solid line, while the best fit obtained by Fekel (1997) is shown as the dashed line.
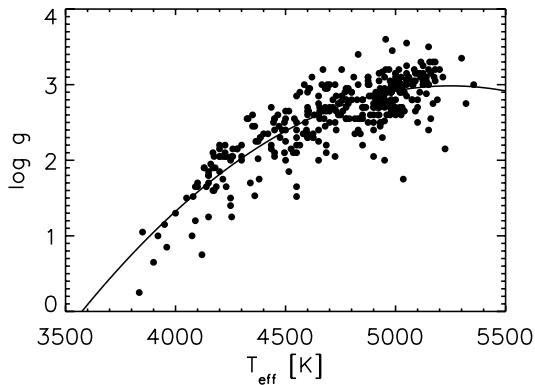

Fig. 6. Log g vs. $T_{\rm eff}$ for all stars in our sample. The solid line shows the best fit (Eq. (2)).

only cover a total broadening between 4 and 16 km s^{-1}. All stars in our sample fall in this range. Furthermore, our fit in Fig. 5 is different from that of Fekel (1997), which is shown in Fig. 5 with the dashed line. Fekel (1997) covers a much wider range in total broadening and might not be sensitive to the curvature in the particular region discussed here. In this study we used Eq. (1) to derive the total broadening in km s^{-1}. From this total broadening we derive the rotational velocity as

$$v \sin i = \sqrt{FWHM_{\rm total}^2 - v_{\rm macro}^2}.$$

4.1. Macro turbulence

The macro turbulence is derived from the spectral type as shown in Fig. 17.10 from Gray (2005). Each luminosity class has its own relation. We estimate the luminosity class from a log g vs. $T_{\rm eff}$ relation (Fig. 6). Most stars in the sample are luminosity class III stars, and therefore, the second order best fit relation, shown in Eq. (2), is used for class III stars. This relation has a robust sigma scatter of 0.25 dex.

$$\log g_{\rm III} = -26.332 + 1.117 \times 10^{-2} T_{\rm eff} - 1.064 \times 10^{-6} T_{\rm eff}^2. \quad (2)$$

Stars within a factor of 2 of the log $g_{\rm III}$ relation are considered to be class III giants, resulting in the following subdivision:

giants: $\log g = \log g_{\rm III} \pm 0.3$ dex,

subgiants: $\log g > \log g_{\rm III} + 0.3$ dex,

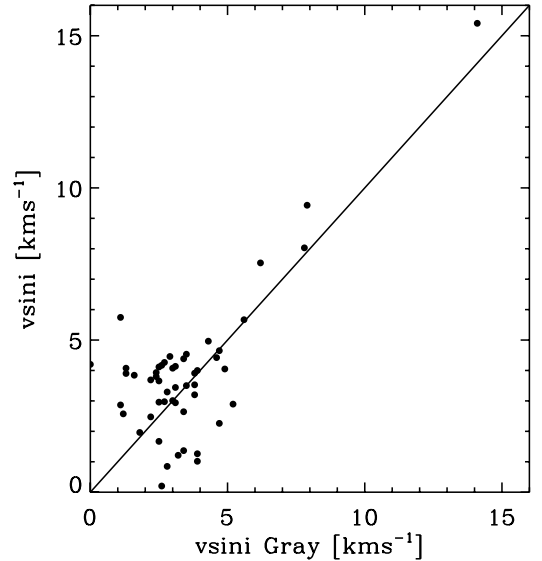luminousgiants: $\log g < \log g_{\rm III} - 0.3$ dex.

Fig. 7. $v \sin i$ obtained here vs. $v \sin i$ obtained by Gray (1989). The solid line is a 1 to 1 relation.

With the luminosity classes, we used Fig. 17.10 from Gray (2005) to determine relations between $v_{\rm macro}$ and $T_{\rm eff}$ for luminosity classes II, III and IV. We found the following relations:

classII: $v_{\rm macro} = -0.214 + 0.00158 T_{\rm eff}$ $\sigma = 0.55$ km s^{-1} (3)

classIII: $v_{\rm macro} = -3.953 + 0.00195 T_{\rm eff}$ $\sigma = 0.45$ km s^{-1} (4)

classIV: $v_{\rm macro} = -8.426 + 0.00241 T_{\rm eff}$ $\sigma = 0.23$ km s^{-1}. (5)

In the case that $v_{\rm macro}$ appeared to be higher than the total broadening, we used $v_{\rm macro}$ from a higher luminosity class to determine $v \sin i$. In case $v_{\rm macro}$ was still too high, we adopted $v_{\rm macro} = 3$ km s^{-1}, as used by Fekel (1997) for G and K giants.

4.2. Comparison with the literature

We checked our final $v \sin i$ values by comparing the values of the 51 stars in common between our sample and Gray (1989), see Fig. 7. The values are located around the 1 to 1 relation indicated by the solid line, which shows that the results of both samples are consistent. We also have 184 stars in common with de Medeiros & Mayor (1999) and compare our $v \sin i$ values with theirs in Fig. 8. Our values are on average higher than those obtained by de Medeiros & Mayor (1999). This is probably due to the different diagnostics used. de Medeiros & Mayor (1999) show that the relation between their $v \sin i$ values, and those obtained by Gray (1989) for class III and IV, has an offset of 1.15 and a correlation coefficient of 1.18. We plotted the 1 to 1 relation, solid line, as well as the relation between $v \sin i$ obtained by Gray (1989) and de Medeiros & Mayor (1999) in Fig. 8, dashed line. The data are located around this latter relation. This indicates that the difference between the results obtained here and from de Medeiros & Mayor (1999) are due to the different diagnostics used to determine $v \sin i$. Also, Luck & Heiter (2007) find that the CORAVEL $v \sin i$ values may suffer from systematic differences with respect to values derived from other techniques. For all stars $v \sin i$ and $v_{\rm macro}$ are listed in Table 4 (only available at the CDS).
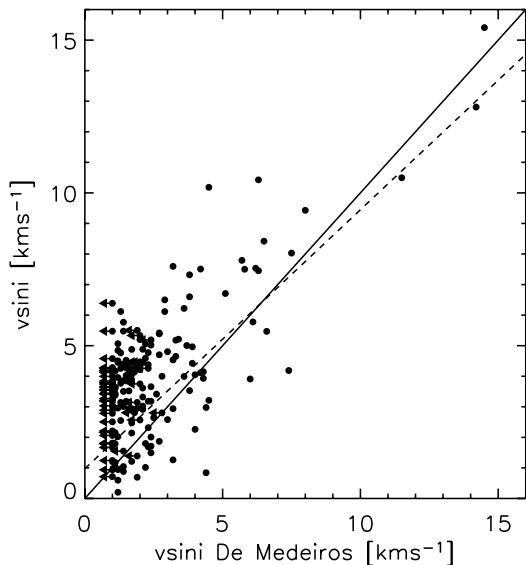
Fig. 8. $v \sin i$ obtained here vs. $v \sin i$ obtained by de Medeiros & Mayor (1999). The solid line is a 1 to 1 relation and the dashed line is the relation between $v \sin i$ obtained by Gray (1989) and de Medeiros & Mayor (1999). The arrows indicate upper limits.

5. Summary

We have determined spectroscopic stellar parameters for a sample of about 380 G and K giant stars. Among these, 112 stars are analysed spectroscopically for the first time. Our metallicities agree with values found in the literature and we conclude that our metallicity scale is not severely affected by systematic errors. Our temperatures are ~50 K higher compared to those from the literature. The difference is largest for stars with lowest temperatures. This is probably due to the lower accuracy of atmosphere models in this temperature range, the increased number and strength of spectral lines and increasing dependence on micro turbulence in cooler stars. An increase in temperature causes an increase in surface gravity and our values are 0.15 dex higher compared to the literature values.

The comparison between the mean metallicity of our total sample of giant stars and giant stars with announced companions reveals that the companion hosting stars have a 0.13 ± 0.03 dex higher metallicity than the mean metallicity of our total sample. This is in agreement with the enhanced metallicity of companion hosting dwarf stars, but is based on low number statistics.

Rotational velocities are determined using the method described by Fekel (1997). Stars in common between our sample and that observed by Gray (1989) are used to convert *FWHM* of moderate lines [Å] to total line broadening [km s^{-1}]. We used a log g vs. $T_{\rm eff}$ correlation to determine the luminosity class of the stars. This luminosity class was subsequently used to calculate the macro turbulence, which has a different relation with temperature for different classes. Our data are in agreement with those obtained by Gray (1989), but are on average larger than the values obtained by de Medeiros & Mayor (1999). This is due to the different diagnostics used to determine $v \sin i$.

References

Allende Prieto, C., & Lambert, D. L. 1999, A&A, 352, 555
Asplund, M. 2005, ARA&A, 43, 481
Bard, A., & Kock, M. 1994, A&A, 282, 1014
Benz, W., & Mayor, M. 1981, A&A, 93, 235
Blackwell, D. E., Lynas-Gray, A. E., & Smith, G. 1995, A&A, 296, 217
Butler, R. P., Marcy, G. W., Williams, E., et al. 1996, PASP, 108, 500
Castelli, F., Gratton, R. G., & Kurucz, R. L. 1997, A&A, 324, 432
Cayrel de Strobel, G., Soubiran, C., & Ralite, N. 2001, A&A, 373, 159
da Silva, L., Girardi, L., Pasquini, L., et al. 2006, A&A, 458, 609
de Medeiros, J. R., & Mayor, M. 1999, A&AS, 139, 433
Doellinger, M., Hatzes, A., Pasquini, L., et al. 2007, in astro-ph, 3672
Fekel, F. C. 1997, PASP, 109, 514
Fischer, D. A., & Valenti, J. 2005, ApJ, 622, 1102
Fischer, D. A., Laughlin, G., Butler, P., et al. 2005, ApJ, 620, 481
Frink, S., Quirrenbach, A., Fischer, D., Röser, S., & Schilbach, E. 2001, PASP, 113, 173
Frink, S., Mitchell, D. S., Quirrenbach, A., et al. 2002, ApJ, 576, 478
Gonzalez, G. 1997, MNRAS, 285, 403
Gray, D. F. 1989, ApJ, 347, 1021
Gray, D. F. 2005, The Observation and Analysis of Stellar Photospheres, 3rd edn., ed. D. F. Gray (Cambridge, UK: Cambridge University Press)
Gustafsson, B., Edvardsson, B., Eriksson, K., et al. 2003, in Stellar Atmosphere Modeling, ed. I. Hubeny, D. Mihalas, & K. Werner, ASP Conf. Ser., 288, 331
Hekker, S., Reffert, S., Quirrenbach, A., et al. 2006, A&A, 454, 943
Hekker, S., Snellen, I., Aerts, C., et al. 2007, A&A, in preparation
Hinkle, K., Wallace, L., Valenti, J., & Harmer, D. 2000, Visible and Near Infrared Atlas of the Arcturus Spectrum 3727−9300 A, ed. K. Hinkle, L. Wallace, J. Valenti, & D. Harmer (San Francisco: ASP)
Johnson, J. A., Fischer, D. A., Marcy, G. W., et al. 2007, ApJ, 665, 785
Luck, R. E., & Heiter, U. 2007, AJ, 133, 2464
Marcy, G. W., & Butler, R. P. 1992, PASP, 104, 270
May, M., Richter, J., & Wichelmann, J. 1974, A&AS, 18, 405
Meléndez, J., & Barbuy, B. 1999, ApJS, 124, 527
Meléndez, J., Shchukina, N. G., Vasiljeva, I. E., & Ramírez, I. 2006, ApJ, 642, 1082
Milford, P. N., O'Mara, B. J., & Ross, J. E. 1994, A&A, 292, 276
Mishenina, T. V., Bienaymé, O., Gorbaneva, T. I., et al. 2006, A&A, 456, 1109
Niedzielski, A., Konacki, M., Wolszczan, A., et al. 2007, ArXiv e-prints, 705
O'Brian, T. R., Wickliffe, M. E., Lawler, J. E., Whaling, J. W., & Brault, W. 1991, J. Opt. Soc. Am. B Opt. Phys., 8, 1185
Pasquini, L., Doellinger, M. P., Weiss, A., et al. 2007, ArXiv e-prints, 707
Perryman, M. A. C., & ESA 1997, The HIPPARCOS and TYCHO catalogues, Astrometric and photometric star catalogues derived from the ESA HIPPARCOS Space Astrometry Mission (Noordwijk, Netherlands: ESA Publications Division), ESA SP Ser., 1200
Ramírez, I., & Meléndez, J. 2005, ApJ, 626, 446
Reffert, S., Quirrenbach, A., Mitchell, D. S., et al. 2006, ApJ, 652, 661
Robinson, S. E., Ammons, S. M., Kretke, K. A., et al. 2007a, ApJS, 169, 430
Robinson, S. E., Laughlin, G., Vogt, S. S., et al. 2007b, ArXiv e-prints, 708
Sadakane, K., Ohnishi, T., Ohkubo, M., & Takeda, Y. 2005, PASJ, 57, 127
Santos, N. C., Israelian, G., Mayor, M., Rebolo, R., & Udry, S. 2003, A&A, 398, 363
Santos, N. C., Israelian, G., & Mayor, M. 2004, A&A, 415, 1153
Santos, N. C., Israelian, G., Mayor, M., et al. 2005, A&A, 437, 1127
Sato, B., Izumiura, H., Toyota, E., et al. 2007, ApJ, 661, 527
Schuler, S. C., Kim, J. H., Tinker, Jr., M. C., et al. 2005, ApJ, 632, L131
Schuler, S. C., Hatzes, A. P., King, J. R., Kürster, M., & The, L.-S. 2006, AJ, 131, 1057
Sneden, C. A. 1973, Ph.D. Thesis, AA (The University of Texas in Austin.)
Sousa, S. G., Santos, N. C., Israelian, G., Mayor, M., & Monteiro, M. J. P. F. G. 2006, A&A, 458, 873
Sousa, S. G., Santos, N. C., Israelian, G., Mayor, M., & Monteiro, M. J. P. F. G. 2007, A&A, 469, 783
Takeda, Y., Ohkubo, M., & Sadakane, K. 2002, PASJ, 54, 451
Takeda, Y., Sato, B., Kambe, E., et al. 2005, PASJ, 57, 109
Taylor, B. J. 1999, A&AS, 134, 523
Twarog, B. A., Ashman, K. M., & Anthony-Twarog, B. J. 1997, AJ, 114, 2556
Valenti, J. A., & Fischer, D. A. 2005, ApJS, 159, 141
Valenti, J. A., Butler, R. P., & Marcy, G. W. 1995, PASP, 107, 966