THE ASTRONOMICAL JOURNAL, 150:2 (10pp), 2015 July doi:10.1088/0004-6256/150/1/2

PROJECT VeSElkA: ANALYSIS OF BALMER LINE PROFILES OF SLOWLY ROTATING CHEMICALLY PECULIAR STARS*

V. KHALACK AND F. LEBLANC
Département de Physique et d'Astronomie, Université de Moncton, Moncton, N.-B., E1A 3E9, Canada; khalack.viktor@umoncton.ca
Received 2014 September 8; accepted 2015 April 29; published 2015 June 5

ABSTRACT

We present results for the estimation of gravity, effective temperature, and radial velocity of poorly studied chemically peculiar stars recently observed with the spectropolarimeter Echelle SpectroPolarimetric Device for Observations of Stars at the Canada–France–Hawaii Telescope in the frame of the Vertical Stratification of Element Abundances project. The effective temperature and surface gravity values are determined for the very first time for four of the stars from our sample (HD 23878, HD 83373, HD 95608, and HD 164584). Grids of stellar atmosphere models with the corresponding fluxes have been calculated using version 15 of the PHOENIX code for effective temperatures in the range of 5000–15,000 K, for the logarithm of surface gravities in the range of 3.0–4.5 and for the metallicities from −1.0 to +1.5. We used these fluxes to fit the Balmer line profiles employing the code FITSB2 that produces estimates of the effective temperature, gravity, and radial velocity for each star. When possible, our results are compared to those previously published. The physical characteristics of 16 program stars are discussed with the future aim to study the abundance anomalies of chemical species and the possible vertical abundance stratification in their stellar atmosphere.

Key words: atomic processes – line: profiles – stars: abundances – stars: atmospheres – stars: chemically peculiar

1. INTRODUCTION

Despite of the fact that some chemically peculiar (CP) stars have "stable" atmospheres, they sometimes also show variability of their spectra with the period of stellar rotation due to the horizontal inhomogeneous distribution of element abundance in their stellar atmosphere (Khokhlova 1975). A significant fraction of CP stars shows signatures of strong magnetic fields (Bychkov et al. 2003), and their structure correlates with the patches of overabundance (or underabundance) of some elements (Kochukhov et al. 2002; Shavrina et al. 2010). It appears that the magnetic field can intensify accumulation or depletion of chemical elements at certain optical depths (Ryabchikova et al. 2008; Alecian & Stift 2010). Some stars also show vertical stratification of the abundance of several chemical species (Savanov & Kochukhov 1998; Ryabchikova et al. 2004; Khalack et al. 2013), which can be explained in terms of the mechanism of atomic diffusion (Michaud 1970).

Accumulation or depletion of chemical elements at certain optical depths brought about by atomic diffusion can modify the structure of stellar atmospheres (Hui-Bon-Hoa et al. 2000; LeBlanc et al. 2009, 2010) and it is, therefore, important to gauge the intensity of such stratification. The slowly rotating CP stars with $V \sin i < 40\ \mathrm{km\ s^{-1}}$ are good candidates to study the abundance stratification of elements with optical depth. Their small rotational velocities result in comparatively narrow and unblended line profiles that are well suited for abundance analysis. Based on their slow rotation, we may assume the hypothesis of a hydrodynamically stable atmosphere in these stars which is necessary for the diffusion process to take place.

The diffusion velocities of different chemical species depend on the relative values of gravity and radiative acceleration resulting from the momentum transfer from the radiation field to these chemical species (e.g., Gonzalez et al. 1995). The momentum transfer depends on the opacity of the species under consideration and on the local monochromatic radiation field, which, in turn, via the monochromatic opacities, depends on the local abundances of the different species. In a hydrodynamically stable atmosphere, the diffusion process may result in vertical stratification of chemical abundances. Detection of vertical abundance stratification of chemical species in atmospheres of slowly rotating CP stars is an indicator of the effectiveness of the diffusion mechanism responsible for the observed peculiarities of chemical abundances. Comparing the observed characteristics of the vertical stratification of chemical abundances with the results of theoretical modeling will help to verify and improve the self-consistent models of stellar atmospheres. Such models were calculated with a modified version of the PHOENIX code (LeBlanc et al. 2009). These models were mostly applied to blue horizontal-branch stars (LeBlanc et al. 2010). Stift & Alecian (2012) also have calculated chemically stratified atmospheric models using the CARATSTRAT code applied to ApBp stars.

Vertical stratification of the chemical abundances in stars can be estimated through the analysis of multiple lines that belong to the same ion of the studied element (Khalack & Wade 2006; Khalack et al. 2007) using the ZEEMAN2 code (Landstreet 1988). This procedure was successfully implemented to detect vertical abundance stratification in the atmospheres of several blue horizontal-branch stars (Khalack et al. 2007, 2008, 2010).

Therefore, we have initiated a new project entitled "Vertical Stratification of Element Abundances" (VeSElkA—meaning rainbow in Ukrainian) aimed to search for and study the signatures of abundance stratification of chemical species with optical depth in the atmospheres of slowly rotating CP stars. A list of suitable candidates has been compiled based on the catalog of Ap, HgMn, and Am stars of Renson & Manfroid

* Based on observations obtained at the Canada–France–Hawaii Telescope (CFHT) which is operated by the National Research Council of Canada, the Institut National des Sciences de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

(2009). From the very beginning, we concentrated our attention on the relatively bright, slowly rotating, and poorly studied CP stars that can be easily observed with Echelle SpectroPolarimetric Device for Observations of Stars (ESPaDOnS) in spectropolarimetric mode. Up until now, we have obtained high signal-to-noise ratios (S/N) and high resolution spectra for a sample of selected CP stars (see Section 2) and found indications of vertical stratification of iron abundance in HD 95608 and HD 116235 (Khalack et al. 2013). Not all stars in our sample are expected to contain vertical stratification of elements in their atmosphere. For instance, AmFm stars are expected to have chemically homogeneous atmospheres due to convective mixing (Richer et al. 2000; Richard et al. 2001). Our analysis will, however, give estimates for the average abundances in the atmospheres of these stars. Such results could help confirm or disprove their classification as CP stars.

This paper aims to present results for the determination of the fundamental parameters ($T_{\rm eff}$ and $\log g$) as well as radial velocity of 16 selected stars. This is the first estimation of $T_{\rm eff}$ and $\log g$ for four of them. The observations and the reduction procedure are described in Section 2. The models used and the fitting procedure are discussed in Sections 3 and 4, respectively. The main results are presented in Section 5 together with the description of the properties of each studied star. A discussion follows in Section 6.

2. OBSERVATIONS

High resolution ($R = 65{,}000$) Stokes IV spectra of several CP stars with $V \sin i < 40$ km s^{-1} were recently obtained with ESPaDOnS employing the deep-depletion e2v device Olapa. ESPaDOnS allows the acquisition of an essentially continuous spectrum throughout the spectral range from 3700 to 10500 Å in a single exposure (Donati et al. 1999). The optical characteristics of the spectrograph as well as the instrument performances are described by Donati et al. (2006).[1] The obtained spectra were reduced using the dedicated software package Libre-ESpRIT (Donati et al. 1997) which yields both the Stokes I spectrum and the Stokes V circular polarisation spectrum. To infer the effective temperature and gravity of the observed stars, we have used their non-normalized spectra.

Table 1 presents a list of the observed slowly rotating CP stars. The first and second columns provide the name of the star and its apparent visual magnitude, respectively, while the third and the fourth columns contain the accumulation time and the maximal S/N for the acquired Stokes I spectra.

Table 1
List of the Observed Slowly Rotating CP Stars

Star	m_V	Δt (s)	S/N
HD 15385	6.2	1600	1100
HD 22920	5.5	920	1150
HD 23878	5.2	660	950
HD 53929	6.1	1160	1000
HD 68351	5.6	920	1100
HD 71030	6.1	1140	1100
HD 83373	6.4	1524	1000
HD 90277	4.7	520	1000
HD 95608	4.4	416	1300
HD 97633	3.3	152	1300
HD 110380	3.6	200	1300
HD 116235	5.9	1040	870
HD 164584	5.4	880	1300
HD 186568	6.0	1300	1000
HD 209459	5.8	1160	1000
HD 223640	5.2	680	1200

3. GRID OF MODELS

A new library of high resolution synthetic spectra has been created in order to determine the effective temperature and gravity of the stars observed in the frame of the project VeSElkA. A grid of stellar atmosphere models and corresponding fluxes has been calculated using version 15 of the PHOENIX code (Hauschildt et al. 1997) for 5000 K $\leqslant T_{\rm eff} \leqslant$ 15,000 K and $3.0 \leqslant \log g \leqslant 4.5$. For the effective temperatures from 5000 to 9000 K, we used a 250 K step, while for the higher temperatures up to 15,000 K a 500 K step was used. The gravities were calculated with a step 0.5. The theoretical fluxes have a resolution of 0.05 Å in the visible range from 3700 to 7700 Å. We calculated grids of models for solar metallicity (Grevesse et al. 2010) as well as for the metallicities [M/H] = −1.0, −0.5, +0.5, +1.0, +1.5. For all the grids, the microturbulent velocity is assumed to be zero. The synthetic spectra have been corrected for the air wavelength using the equation given by Morton (1991).

By exploiting the possibilities of the PHOENIX code (Hauschildt et al. 1997), we have calculated spherically symmetric models of stellar atmospheres for which the gravity depends on the stellar radius. In this case, all of the structure of the atmosphere can be calculated knowing the effective temperature $T_{\rm eff}$, the surface gravity $\log g$, and the stellar mass M_*. For the given values of effective temperature and surface gravity, we derived the respective stellar mass trough the interpolation of data for physical parameters of normal main sequence stars (Popper 1980).

To verify the accuracy of the grids of stellar atmosphere models, we used the spectra of α Leo (HD 87901) and 108 Vir (HD 129956)[2] obtained with ESPaDOnS in the spectropolarimetric mode. The profiles of nine Balmer lines in the non-normalized spectra of α Leo and 108 Vir were fitted with the help of the FITSB2 code (Napiwotzki et al. 2004) using the grid of models calculated for the metallicity [M/H] = −0.5 and 0.0, respectively (see Figure 1). In order to model a continuum in the vicinity of the analyzed Balmer lines, the code FITSB2 uses a linear function fitted over the line profile region and the continuum as a part of the fitting procedure. This approach provides a better fit quality than the standard procedure in which one tries to fit the continuum regions (relatively free of lines) to the left and to the right of the analyzed Balmer line profile separately (R. Napiwotzki 2014, private communication).

In the case of α Leo, assuming its $V \sin i = 300$ km s^{-1} (Abt et al. 2002), the best fit is obtained for solar metallicity, $T_{\rm eff}$ = 11890 K and $\log g = 3.68$, resulting in $\chi^2/\nu = 12.26$ (see right panel of the Figure 1). A similar simulation that employs the grid of models calculated with PHOENIX-16 code (Husser et al. 2013) gives the best fit for the solar metallicity, $T_{\rm eff}$ = 11976 K and $\log g = 3.75$ ($\chi^2/\nu = 11.57$). These results are

[1] For more details about this instrument, the reader is invited to visit www.cfht.hawaii.edu/Instruments/Spectroscopy/Espadons/.

[2] Spectra of 108 Vir and of α Leo where downloaded from the CADC database via http://www4.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/en/cfht/.

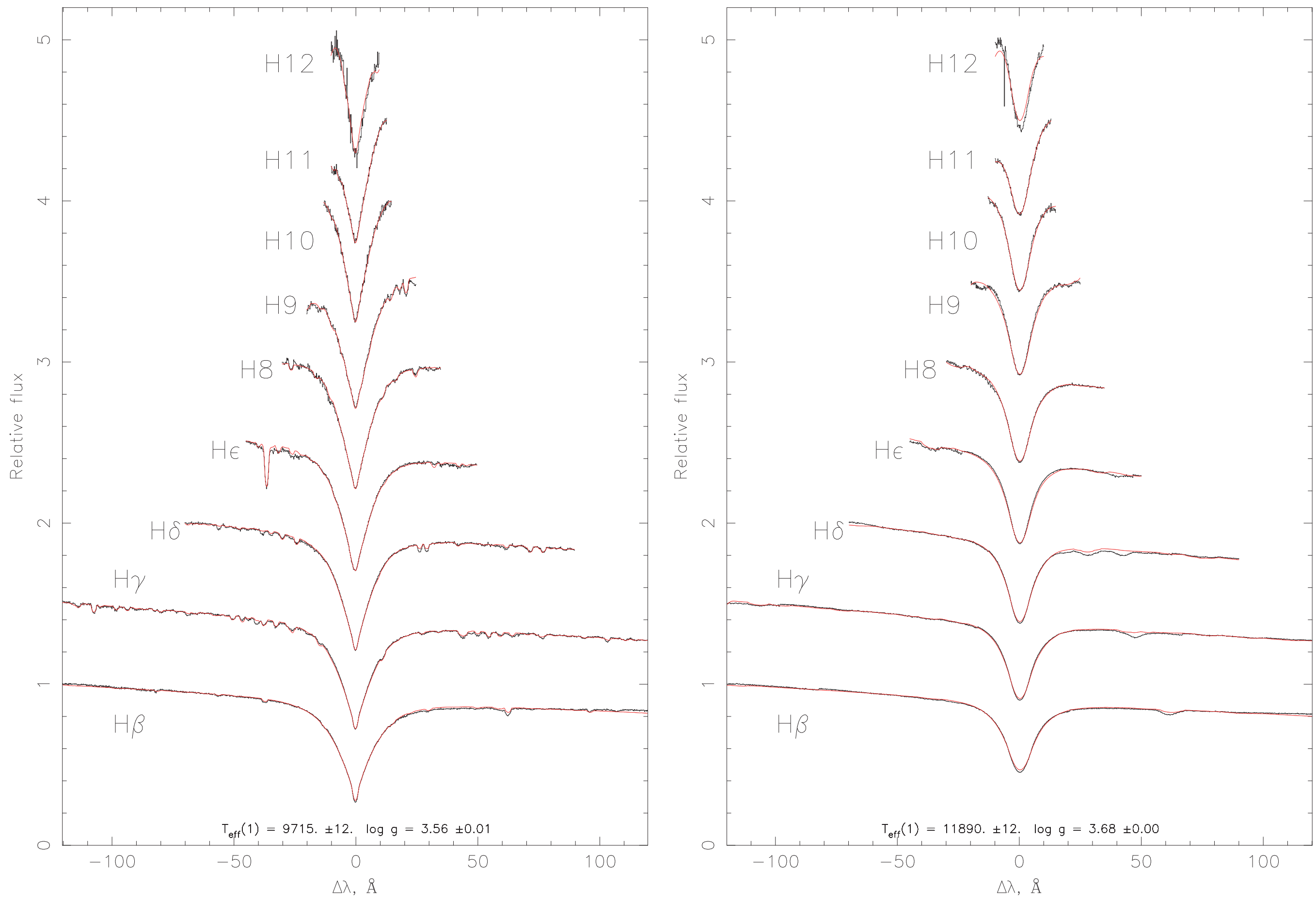

Figure 1. Observed spectrum (thick line) of 108 Vir (left) and α Leo (right) is well fitted by the synthetic spectrum (thin dotted line) that corresponds to $T_{\rm eff}$ = 9715 K, log g = 3.56, [M/H] = −0.5 (χ^2/ν = 2.64), and $T_{\rm eff}$ = 11890 K, log g = 3.68, and [M/H] = 0.0 (χ^2/ν = 12.26), respectively.

close to each other and to the values $T_{\rm eff} = 11962 \pm 115$ K and log g = 3.56 obtained by Gray et al. (2003) from fitting low resolution spectra of α Leo and its photometric data. Meanwhile, using the Atlas9 grids[3] (Castelli & Kurucz 2004) to fit the Balmer line profiles in the same spectrum of α Leo, the best fit is obtained for the metallicity [M/H] = −0.3, $T_{\rm eff}$ = 12,660 K, and log g = 3.80 (χ^2/ν = 13.76). It appears that for α Leo the use of the Atlas9 grids leads to the best fit with a comparatively higher value of χ^2/ν and higher values of effective temperature and surface gravity.

In the case of 108 Vir, assuming its $V \sin i$ = 83 km s^{-1} (Ammler-von Eiff & Reiners 2012), the best fit is obtained for the metallicity [M/H] = −0.5, $T_{\rm eff}$ = 9715 K, and log g = 3.56, resulting in χ^2/ν = 2.64 (see left panel of Figure 1). The grids calculated with PHOENIX-16 code and the Atlas9 grids result in the best fits with [M/H] = −0.2, $T_{\rm eff}$ = 10280 K, log g = 3.86 (χ^2/ν = 2.57), and [M/H] = −0.3, $T_{\rm eff}$ = 9760 K, and log g = 3.64 (χ^2/ν = 2.88), respectively. Our estimate of the effective temperature is close to the one obtained with the Atlas9 grids and to $T_{\rm eff}$ = 9840 K found by Ammler-von Eiff & Reiners (2012), but is significantly smaller than the effective temperature obtained using the PHOENIX-16 grids (Husser et al. 2013). Our estimate of the surface gravity is similar to the one obtained for the Atlas9 grids, but smaller than the one obtained with the PHOENIX-16 grids.

By comparing our results for α Leo and 108 Vir with the relatively well-established values for $T_{\rm eff}$ and log g, we may roughly estimate the uncertainties of the results presented here as ±200 K for effective temperature and ±0.2 for surface gravity.

4. FITTING PROCEDURE

4.1. Sensitivity to the Set of Analyzed Balmer Lines

In order to study the sensitivity of the determined values of $T_{\rm eff}$ and log g to the set of analyzed Balmer line profiles, we have compared the best-fit results obtained when one of the Balmer lines is omitted from the analysis with the best-fit results obtained from the analysis of all nine Balmer line profiles for HD 129956 (108 Vir) and HD 87901 (α Leo) using the Phoenix-15 grids and the Atlas9 grids. The fitting procedure was performed with the help of FITSB2 code (Napiwotzki et al. 2004) employing the aforementioned grids of stellar atmosphere models with the respective simulated spectra. The left panel of Figure 2 shows the differences between the values of $T_{\rm eff}$ obtained by omitting one of the Balmer lines from the analysis and the value of $T_{\rm eff}$ given in Section 3 for HD 129956 and HD 87901, respectively. The corresponding differences for log g are shown in the right panel of Figure 2 for the same stars. In the case of $T_{\rm eff}$ and log g, the zero difference

[3] The Atlas9 grids are available at the http://zuserver2.star.ucl.ac.uk/~idh/NewGrids/Atlas9.C04/.

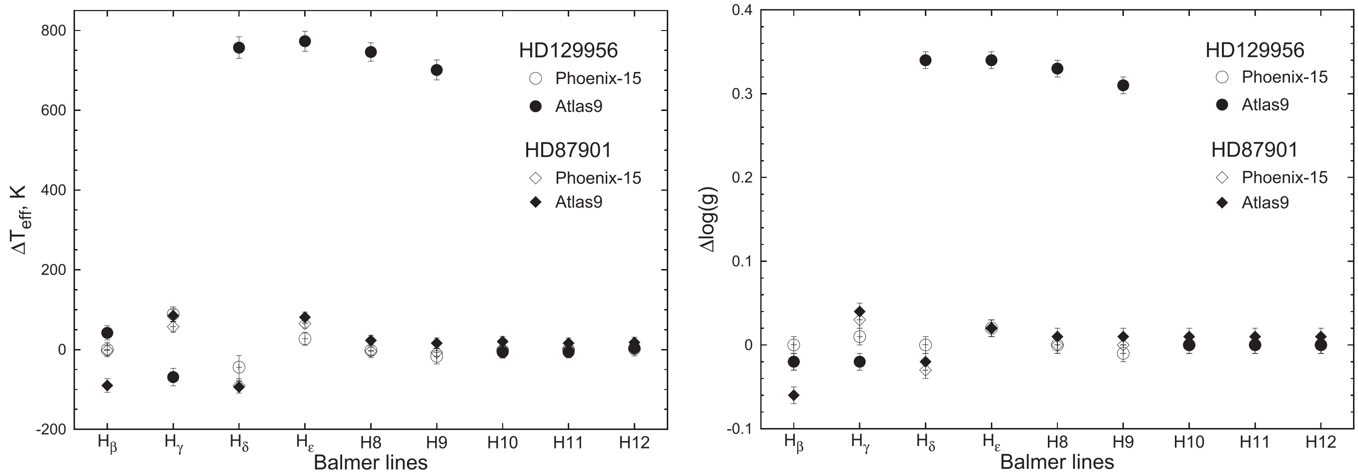

Figure 2. Variation of the best-fit results obtained when one of the Balmer lines (indicated at the *X*-axis) is omitted from the analysis, with respect to the values of $T_{\rm eff}$ (left) and log *g* (right) obtained from the analysis of all nine Balmer line profiles (see Figure 1) for HD 129956 (108 Vir) using the Phoenix-15 grids (open circles) and the Atlas9 grids (filled circles), and for HD 87901 (α Leo) using the Phoenix-15 grids (open diamonds) and the Atlas9 grids (filled diamonds). The error bars represent the internal errors of the fitting procedure with the FITSB2 code and are much smaller than the true errors (see Section 3).

corresponds to the respective values obtained using the Phoenix-15 grids and presented in Figure 1 for each reference star. Meanwhile, the results shown in the Figure 2 for the Atlas9 grids are compared to the corresponding values of stellar parameters found for the reference stars in Section 3 using the Atlas9 grids.

For HD 129956 (108 Vir), we can see that its best-fit values of $T_{\rm eff}$ and log *g* jump up if one uses the Atlas9 grids and excludes from the analysis one of the following Balmer lines H_δ, H_ϵ, $H8$, or $H9$. Meanwhile, the use of the Phoenix-15 grids results in a relatively small variation of $T_{\rm eff}$ and log *g* when one of these Balmer lines is excluded from the analysis.

In the case of HD 87901 (α Leo), application of the Atlas9 grids or of the Phoenix-15 grids leads, under the same conditions, to relatively small variations of $T_{\rm eff}$ and log *g* that do not exceed 100 K and 0.06, respectively (see Figure 2). The errors chosen for $T_{\rm eff}$ ($\pm$200 K) and log *g* ($\pm$0.2) therefore seem reasonable. It appears that the use of the Phoenix-15 grids results in more stable best-fit data for $T_{\rm eff}$ and log *g* with respect to the set of Balmer line profiles employed for the analysis. Meanwhile, the use of the Atlas9 grids may cause significant errors in the determination of fundamental stellar parameters if the effective temperature is close to 10,000 K, depending on which set of Balmer lines is used.

The variations of $T_{\rm eff}$ and log *g* are most sensitive to the H_β, H_γ, H_δ, and H_ϵ Balmer lines when one employs the Phoenix-15 grids. It seems that this sensitivity does not vary much in the range of effective temperatures from 9700 to 12,000 K (see Figure 2).

4.2. The Best-fit Results

Nine Balmer line profiles have been fitted in the observed spectra of the selected slowly rotating CP stars to find their effective temperature and surface gravity. For each star, the fitting procedure has been performed for the metallicities [M/H] = −1.0, −0.5, 0.0, +0.5, and +1.0 using the Phoenix-15 grids. Among the obtained results, the fundamental parameters associated to the fit with the smallest value χ^2/ν are chosen. These best-fit results for effective temperature, surface gravity, radial velocity, and metallicity are presented, respectively, in the second, third, fourth, and fifth columns of Table 2 together with the fit quality in the sixth column. The values of the effective temperature and the surface gravity found for these stars by other authors are given in the seventh and eighth columns, respectively. Meanwhile, the previously published values for $V \sin i$ are presented in the ninth column. Examples of best fits for HD 23878 and HD 164584, and for HD 95608 and HD 209459 are shown in Figures 3 and 4, respectively.

5. INDIVIDUAL STARS

5.1. HD 15385

Künzli & North (1998) classified HD 15385 (HR 723) as an A2m star having a mass $M_* = 1.85 M_\odot$ and age log $t = 8.79 \pm 0.12$. Taking into account its relatively small value of rotational velocity $V \sin i = 29$ km s^{-1} (Royer et al. 2002), this star was chosen for the VeSElkA project. Our estimate of the effective temperature $T_{\rm eff} = 8230 \pm 200$ K and the surface gravity log $g = 4.0 \pm 0.2$ are in good agreement with the values found by Künzli & North (1998; see Table 2). Our estimate of the radial velocity for HD 15385 (see Table 2) is similar to the value of $V_r = 21.3$ km s^{-1} obtained by Welson (1953), but is significantly higher than the value $V_r = 15$ km s^{-1} reported by Palmer et al. (1968).

5.2. HD 22920

The silicon star HD 22920 (22 Eri, HR 1121) shows a weak photometric variability with the period $P = 3\overset{\rm d}{.}95$ (Bartholdy 1988) and the presence of a rather weak longitudinal magnetic field $B_l = 310 \pm 160$ G (Bychkov et al. 2003). Catanzaro et al. (1999) found $T_{\rm eff} = 13{,}700$ K and log $g = 3.72$ for this star. Similar parameters ($T_{\rm eff} = 13{,}700$ K and log $g = 3.72$) have been adopted by Leone & Manfrè (1996) to reproduce the observed spectrum of HD 22920. Our estimate of the effective temperature and the surface gravity (see Table 1) are consistent with these results. Meanwhile, the radial velocity $V_r = 20.0 \pm 2.0$ km s^{-1} obtained in the present study seems to be higher than the previously reported values 16.4 ± 3.1 km s^{-1} (Leone & Manfrè 1996; Wielen et al. 2000) and 17.2 ± 0.7 km s^{-1}

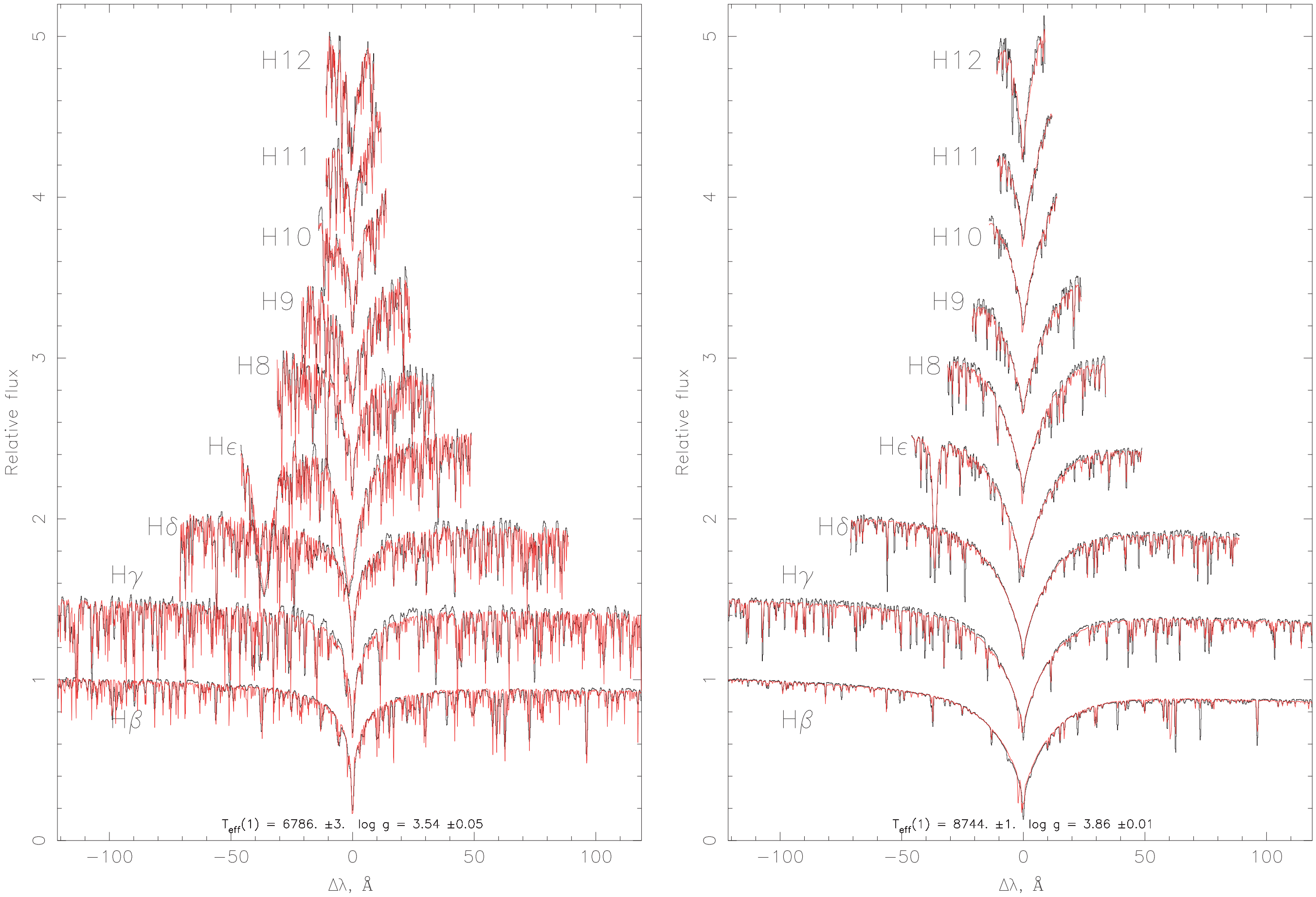

Figure 3. Observed spectrum (thick line) of HD 164584 (left) and HD 23878 (right) is well fitted by the synthetic spectrum (thin dotted line) that corresponds to $T_{\rm eff} = 6800$ K, $\log g = 3.54$ ($\chi^2/\nu = 1.16$) and $T_{\rm eff} = 8740$ K, $\log g = 3.86$ ($\chi^2/\nu = 0.62$), respectively.

(Gontcharov 2006). From the analysis of HD 22920 spectra, Leone & Manfrè (1996) have also found its rotational velocity $V \sin i = 30$ km s^{-1}.

We have acquired several Stokes IV spectra for this star that show a strong variability of Si II, Ti II, Cr II, and Fe II line profiles with rotational phases, while Mg II and He I line profiles seem to be less variable. Our high S/N spectra (see Table 2) reveal a weak variability of the He I 5876 Å line profile for which Catanzaro et al. (1999) have found no variability.

5.3. HD 23878

Based on the measurement of the anomalously low line strength ratio Sc II 4246 Å/Sc II 4215 Å, Conti (1965) suggested that HD 23878 might be an Am star. HD 23878 (28 Eri, HR 1181) appears to be a low amplitude variable star with a period of about $7^{\rm d}.17$ (Mathys et al. 1985) having a rotational velocity $V \sin i = 24$ km s^{-1} (Royer et al. 2002). Meanwhile, Abt & Morrell (1995) reported $V \sin i = 18$ km s^{-1} for this star. HD 23878 has not previously been studied spectroscopically in detail and the fitting of the Balmer line profiles (see right panel of Figure 3) results in $T_{\rm eff} = 8740 \pm 200$ K and $\log g = 3.86 \pm 0.20$. Our estimate of radial velocity is in agreement with the value $V_r = 28.4 \pm 0.5$ km s^{-1} obtained by Gontcharov (2006; see Table 2).

5.4. HD 53929

HD 53929 is a HgMn star with mild but significant enhancement of manganese abundance $\log N_{\rm Mn}/N_{\rm H} = -5.85 \pm 0.20$ (Smith & Dworetsky 1993) and with a mercury abundance $\log N_{\rm Hg}/N_{\rm H} = -9.90 \pm 0.20$ at the level of normal stars (Smith 1997). This star has also much lower abundance of chromium, cobalt and nickel as compared to their solar abundances (Smith & Dworetsky 1993). The analysis of Balmer line profiles in the single spectrum available for HD 53929 results in an effective temperature which is in good agreement with the temperature obtained by Smith & Dworetsky (1993) (see Table 2). Meanwhile, our estimate of the surface gravity $\log g = 3.90 \pm 0.20$ seems to be a little higher than the value $\log g = 3.60 \pm 0.25$ reported by Smith & Dworetsky (1993).

Royer et al. (2002) have obtained $V \sin i = 25$ km s^{-1} for HD 53929. Its radial velocity increased over the last 50 years going from 6.1 km s^{-1} (Evans 1967; Hube 1970), to 11.2 ± 1.3 km s^{-1} (Gontcharov 2006) and to 15.0 ± 1.0 km s^{-1} found in this study. Is seems that HD 53929 may be a member of a long periodic double system.

5.5. HD 68351

In the catalog of Renson & Manfroid (2009), this object is classified as a star of spectral class A0 with the strong lines of Si and Cr. According to Abt & Morrell (1995), the rotational

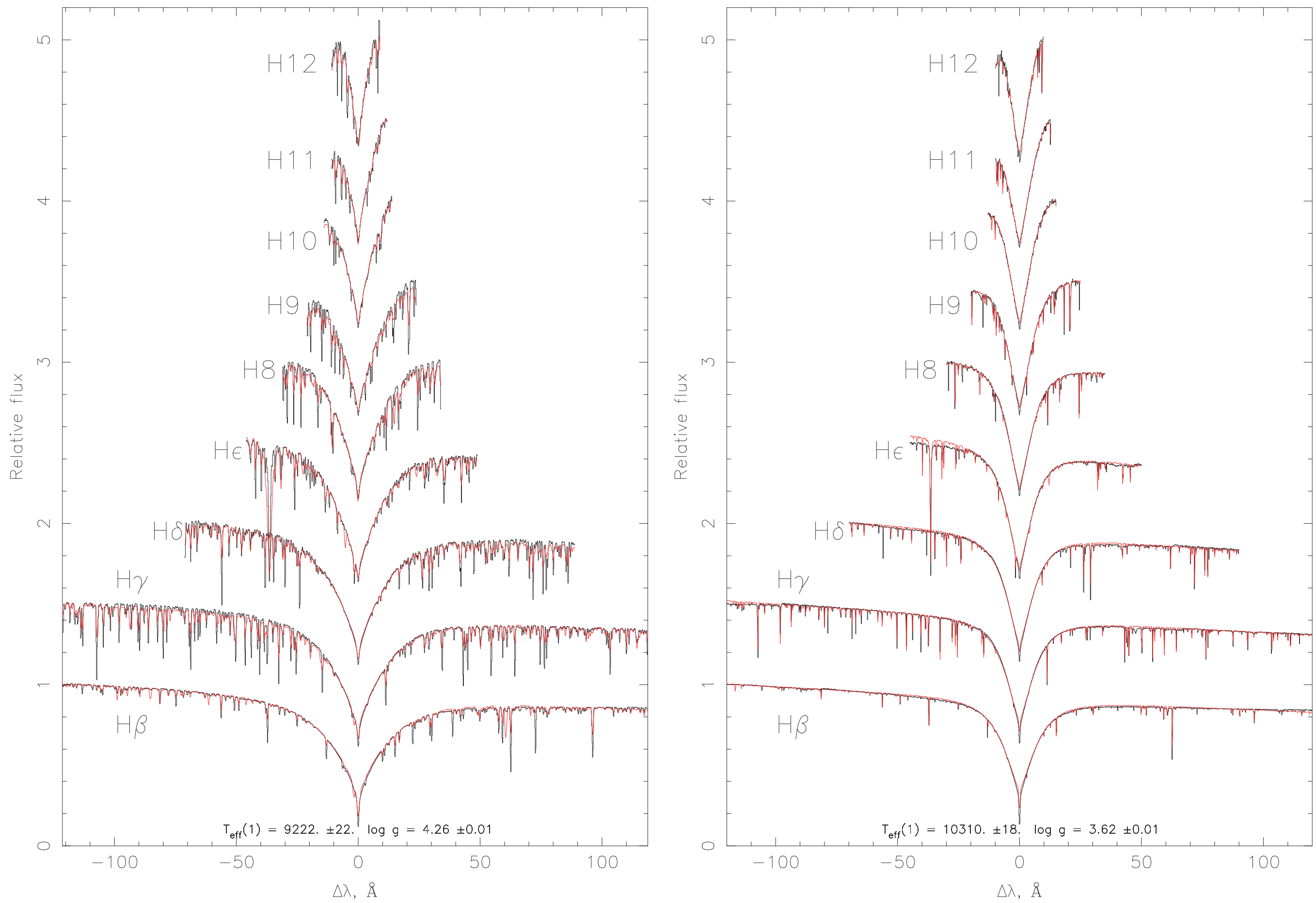

Figure 4. Observed spectrum (thick line) of HD 95608 (left) and HD 209459 (right) is well fitted by the synthetic spectrum (thin dotted line) that corresponds to $T_{\rm eff}$ = 9200 K, log g = 4.26 (χ^2/ν = 0.59) and $T_{\rm eff}$ = 10310 K, log g = 3.62 (χ^2/ν = 0.97), respectively.

velocity of HD 68351 is $V \sin i = 25$ km s^{-1}, while Royer et al. (2002) and Aurière et al. (2007) reported $V \sin i = 33$ km s^{-1}. Its rotational period $P = 4\overset{\rm d}{.}116$ was determined by Stepień (1968). In this study, we present the results for its fundamental parameters $T_{\rm eff} = 10080 \pm 200$ K and log $g = 3.22 \pm 0.20$ based on the analysis of Balmer line profiles that are in agreement with the data previously published by Aurière et al. (2007) for this star. Our estimate of the radial velocity seems to be a little smaller than the value $V_r = 19.9$ km s^{-1} obtained by Evans (1967; see Table 2).

Taking into account the high values of luminosity $L_* = 466 \pm 225 L_\odot$ and radius $R_* = 6.6 \pm 2.4 R_\odot$ of HD 68351 (Aurière et al. 2007) and its low surface gravity log g = 3.22 ± 0.20, this star is beyond the end of the main sequence and most probably belongs to the III luminosity class. Aurière et al. (2007) detected the presence of a longitudinal magnetic field $B_l = 325 \pm 45$ G from the analysis of HD 68351 LSD profiles.

For this star, we obtained two Stokes IV spectra with a time gap of 2 days. The Stokes I spectrum of HD 68351 appears to be strongly variable, while the Stokes V does not show signatures of the presence of a strong magnetic field. This is consistent with the results of Aurière et al. (2007) that observed HD 68351 15 times, but found the magnetic field signatures in only five spectra. A preliminary analysis of the two obtained spectra results in slightly different values of radial velocity V_r = 18.1 ± 1.0 and 14.7 ± 1.0 km s^{-1} that can be an indicator of possible binarity of HD 68351.

5.6. HD 71030

Cenarro et al. (2007) reported HD 71030 (25 Cnc, HR 3299) to be a main sequence star of spectral class F6. Based on the analysis of a low resolution spectrum, Balachandran (1990) has reported a higher than solar lithium abundance log $N_{\rm Li}/N_{\rm H}$ = −9.37 and slightly underabundant iron log $N_{\rm Fe}/N_{\rm H}$ = −4.80 ± 0.05 for this star. Meanwhile, Khalack et al. (2013) found nearly solar abundance of Fe II log $N_{\rm Fe}/N_{\rm H}$ = −4.43 ± 0.34, Cr II log $N_{\rm Cr}/N_{\rm H}$ = −6.27 ± 0.09, and Ni I log $N_{\rm Ni}/N_{\rm H}$ = −5.77 ± 0.26. They also found that Fe, Cr, and Ni are uniformly distributed with respect to the optical depth in the atmosphere of this star.

Our estimation of the surface gravity for HD 71030 is the same as the value log g = 4.03 ± 0.05 published by Prugniel et al. (2011) (see Table 2), while our estimation of the effective temperature $T_{\rm eff}$ = 6780 ± 200 K seems to be slightly higher as compared to the results of Prugniel et al. (2011) (but within the given error bars). The value for the radial velocity determined in this work is in agreement with the previously obtained results of 37.4 km s^{-1} (Nordström et al. 2004) and 37.1 ± 0.4 km s^{-1} (Gontcharov 2006). The estimate of $V \sin i = 9 \pm 2$ km s^{-1} (Khalack et al. 2013) is also in good agreement with the value $V \sin i = 8$ km s^{-1} provided by Balachandran (1990).

Table 2
Determined Values of the Effective Temperature and the Surface Gravity for the Program CP Stars

Star	Balmer lines					Previous publications		
	T_{eff} (K)	log g	V_r (km s^{-1})	[M/H]	χ^2/ν	T_{eff} (K)	log g	V sin i (km s^{-1})
HD 15385	8230 ± 200	4.00 ± 0.2	22.0 ± 1.0	0.0	0.65	8154[a]	4.12[a]	21[a], 29[b]
HD 22920	13640 ± 200	3.74 ± 0.2	20.0 ± 2.0	−0.5	5.67	13700[c]	3.72[c]	30[d], 39[b]
HD 23878	8740 ± 200	3.86 ± 0.2	29.5 ± 1.0	0.0	0.62			24[b]
HD 53929	13950 ± 200	3.90 ± 0.2	15.0 ± 1.0	−1.0	3.20	14050 ± 250[e]	3.60 ± 0.25[e]	25[b], 30[e]
HD 68351	10080 ± 200	3.22 ± 0.2	18.1 ± 1.0	0.0	1.17	10290 ± 340[f]		33[b]
HD 71030	6780 ± 200	4.04 ± 0.2	38.1 ± 1.0[h]	0.0	0.28	6541 ± 47[g]	4.03 ± 0.05[g]	9 ± 2[h]
HD 83373	9800 ± 200	3.81 ± 0.2	26.5 ± 1.0	0.0	0.92			28[b]
HD 90277	7250 ± 200	3.62 ± 0.2	14.5 ± 1.0	0.0	1.29	7440[i]	3.46[i]	34[b]
HD 95608	9200 ± 200	4.25 ± 0.2	−10.4 ± 1.0[h]	+0.5	0.59			21[b], 17 ± 2[h]
HD 97633	8750 ± 200	3.45 ± 0.2	8.2 ± 1.0	0.0	0.61	8790 ± 351[j]	3.59 ± 0.89[j]	23[b]
HD 110380	6980 ± 200	4.19 ± 0.2	−17.6 ± 1.0	0.0	0.31	6720[k]	4.20[k]	23[b]
HD 116235	8900 ± 200	4.33 ± 0.2	−10.3 ± 1.0[h]	+0.5	0.49	8570[l]	4.23[l]	20 ± 2[h]
HD 164584	6800 ± 200	3.54 ± 0.2	−11.2 ± 1.0	0.0	1.16			
HD 186568	11070 ± 200	3.44 ± 0.2	−9.5 ± 1.0	−0.5	1.81	11596 ± 120[m]	3.39 ± 0.15[m]	18[m]
HD 209459	10310 ± 200	3.62 ± 0.2	−0.3 ± 1.0	0.0	0.97	10455 ± 400[m]	3.52 ± 0.15[m]	14[b]
HD 223640	12500 ± 200	4.08 ± 0.2	17.0 ± 2.0	+1.0	1.65	12429 ± 435[g]	3.93 ± 0.23[g]	28[b]

Note. [a] Künzli & North (1998), [b] Royer et al. (2002), [c] Catanzaro et al. (1999), [d] Leone & Manfrè (1996), [e] Smith & Dworetsky (1993), [f] Aurière et al. (2007), [g] Prugniel et al. (2011), [h] Khalack et al. (2013), [i] Berthet (1990), [j] Koleva & Vazdekis (2012), [k] Boesgaard & Trypicco (1986), [l] Erspamer & North (2003), [m] Hubrig & Castelli (2001).

5.7. HD 83373

HD 83373 (34 Hya, HR 3832) is reported by Renson & Manfroid (2009) as a CP star of spectral class A1 that has an enhanced silicon abundance. Royer et al. (2002, 2007) measured its rotational velocity $V \sin i = 28$ km s^{-1}. This star has not been previously studied spectroscopically and we provide here first estimates of its effective temperature $T_{\text{eff}} = 9800 \pm 200$ K and surface gravity $\log g = 3.81 \pm 0.20$. Our estimate of the radial velocity for HD 83373 (see Table 2) is in good agreement with the value $V_r = 26.9 \pm 0.5$ km s^{-1} reported by Gontcharov (2006).

5.8. HD 90277

Abundance analysis of HD 90277 (HR 4090) was performed by Berthet (1990) who found a strong overabundance of Y, Zr, and Ba, while Ti, Cr, Mn, Fe, and Ni appear to be slightly overabundant. Royer et al. (2002, 2007) reported $V \sin i = 34$ km s^{-1} for HD 90277. Our estimates of the effective temperature and the surface gravity are similar to the values obtained by Berthet (1990) taking into account the error bars (see Table 2). The value for the radial velocity determined in this work agrees well with the previously obtained result $V_r = 13.7$ (Evans 1967) and 13.7 ± 0.6 km s^{-1} Gontcharov (2006).

5.9. HD 95608

Cowley et al. (1969) classified HD 95608 (60 Leo, HR 4300) as a CP star of spectral class A1m. From the fitting of Balmer line profiles of HD 95608 (see left panel of Figure 4), we found its effective temperature $T_{\text{eff}} = 9200 \pm 200$ K and surface gravity $\log g = 4.25 \pm 0.20$ (see Table 2). The value for radial velocity determined in this work $V_r = -10.4 \pm 1.0$ km s^{-1} agrees well with the previously obtained results -10.1 km s^{-1} (Wielen et al. 2000) and -11.1 ± 0.7 km s^{-1} (Gontcharov 2006). The rotational velocity $V \sin i = 17.2 \pm 2.0$ km s^{-1} obtained by Khalack et al. (2013) for HD 95608 seems to be smaller than the value $V \sin i = 21$ km s^{-1} reported by Royer et al. (2002), but higher than $V \sin i = 13$ km s^{-1} published by Abt & Morrell (1995).

Preliminary abundance analysis has shown that Ti II is slightly underabundant, while Fe I and Fe II are overabundant in this star, as compared to their solar abundance (Khalack et al. 2013). This same study also found that the iron abundance appears to be vertically stratified in the stellar atmosphere of HD 95608.

5.10. HD 97633

Renson & Manfroid (2009) have classified HD 97633 (θ Leo, HR 4359) as a CP star of spectral class A2 that has enhanced Sr and Eu abundances (Hill 1995). Royer et al. (2002) have found $V \sin i = 23$ km s^{-1} for this star. Our estimates of its effective temperature and surface gravity (see Table 2) are in good agreement with the results obtained by Koleva & Vazdekis (2012). The radial velocity $V_r = 8.2 \pm 1.0$ km s^{-1} found in this work is consistent with the value $V_r = 7.3$ km s^{-1} reported by Gontcharov (2006).

5.11. HD 110380

HD 110380 (HR 4826) is in a binary system with HD 110379 with an orbital period $P = 171.4$ years and a separation $a = 3\farcs75$. HD 110380 has $V \sin i = 23$ km s^{-1} (Royer et al. 2002) and an enhanced lithium abundance (Boesgaard & Trypicco 1986). Our estimate of its effective temperature seems to be a little higher than the value $T_{\text{eff}} = 6720$ K obtained by Boesgaard & Trypicco (1986), but the surface gravity is in good agreement with the value $\log g = 4.2$ they found (see Table 2). The value for the radial velocity determined in this work $V_r = -17.6 \pm 1.0$ km s^{-1} is consistent with the value $V_r = -19.5$ km s^{-1} obtained by Nordström et al. (2004).

5.12. HD 116235

Cowley et al. (1969) have classified HD 116235 (HR 5040, 64 Vir) as a CP star of spectral class A2m. The effective temperature $T_{\rm eff} = 8900 \pm 200$ K obtained in this study for HD 116235 appears to be higher than the previously published values 8570 K (Erspamer & North 2003) and 8373 K (Ammler-von Eiff & Reiners 2012). Meanwhile, the surface gravity obtained here is similar to $\log g = 4.23$ reported by Erspamer & North (2003). The estimate of $V \sin i = 20 \pm 2.0$ km s^{-1} (Khalack et al. 2013) is in a good agreement with the value 19.3 ± 1.0 km s^{-1} obtained by Ammler-von Eiff & Reiners (2012) for this star. The radial velocity $V_r = -10.3 \pm 1.0$ km s^{-1} obtained in this study is consistent with the previously published values -10.2 km s^{-1} (Welson 1953) and -8.4 ± 2.3 km s^{-1} (Gontcharov 2006).

A preliminary abundance analysis of this star shows an enhanced abundance of Ni I, Fe I, Fe II, Cr I, and Cr II (Khalack et al. 2013) in agreement with the results of Erspamer & North (2003), who also reported a strong overabundance of Sr, Y, and Ba. Moreover, Khalack et al. (2013) also found signatures of vertical stratification of iron abundance in the atmosphere of HD 116235.

5.13. HD 164584

Renson & Manfroid (2009) have reported that HD 164584 (7 Sgr, HR 6724) has a spectral class A6-F4. From the analysis of Balmer line profiles (see left panel of Figure 3), we have obtained $T_{\rm eff} = 6800 \pm 200$ K and $\log g = 3.54 \pm 0.20$.

Our estimate of radial velocity (see Table 2) is in good agreement with the value $V_r = -11.2 \pm 1.6$ km s^{-1} obtained by Gontcharov (2006) for this star.

5.14. HD 186568

HD 186568 (HR 7512) belongs to the normal B-type stars (B9 II; Hubrig & Castelli 2001). Nevertheless, it was included by Renson & Manfroid (2009) to the list of CP stars. From the analysis of equivalent widths of iron line profiles Hubrig & Castelli (2001) found its solar abundance in the atmosphere of this star.

The effective temperature obtained for HD 186568 in this study is smaller than the value derived by Hubrig & Castelli (2001), while our value for the surface gravity is almost the same as the one determined by these authors (see Table 2). Our estimate for radial velocity is close to $V_r = -8.8 \pm 0.1$ km s^{-1} reported by Gontcharov (2006) and to the value -8.0 ± 1.4 km s^{-1} reported by Morrell & Abt (1992) who have used this star as a radial velocity standard.

5.15. HD 209459

HD 209459 (21 Peg, HR 8404) is a normal B-type star (B9.5 V) that is often used as a comparison star (Dworetsky & Budaj 2000) because of its sharp-lined spectrum with $V \sin i = 4$ km s^{-1} (Smith 1992) and absence of chemical abundance peculiarities. Based on the analysis of equivalent widths of iron line profiles in the spectrum of HD 209459, Hubrig & Castelli (2001) have found an iron abundance that is close to its solar value. We also aim to use this object as a comparison star in the VeSElkA project.

Our estimate of effective temperature and surface gravity (see Table 2) obtained from the analysis of Balmer line profiles (see right panel of Figure 4) is in agreement with the previously published results $T_{\rm eff} = 10455 \pm 400$ K and $\log g = 3.52 \pm 0.15$ of Hubrig & Castelli (2001), but smaller than the results $T_{\rm eff} = 11015 \pm 301$ K and $\log g = 3.99 \pm 0.12$ reported by Prugniel et al. (2011). The radial velocity found in this study (see Table 2) is also in a good agreement with the value $V_r = 0$ km s^{-1} reported by Smith (1992).

5.16. HD 223640

Renson & Manfroid (2009) have reported HD 223640 (108 Aqr, HR 9031) as a CP star of spectral class B9. It shows an overabundance of Si, Sr, and Cr (North et al. 1992). Bailey & Landstreet (2013) have found $V \sin i = 31 \pm 3$ km s^{-1} for this star and that Cr and Si abundances exceed their respective solar values more than by 1 dex. Analysis of the polarization in the Balmer lines reveals the presence of a longitudinal magnetic field $B_l = 643 \pm 218$ G (Bychkov et al. 2003) which varies with a period of $P = 3^{\rm d}.73$ (North et al. 1992). The same period $P = 3^{\rm d}.735239 \pm 0^{\rm d}.000024$ has been found by North et al. (1992) from photometric variability of HD 223640.

The effective temperature and the surface gravity obtained in this study (see Table 2) are in good agreement with the results of Prugniel et al. (2011), but seem to be slightly different (though still inside the error bars) with respect to the values $T_{\rm eff} = 12300 \pm 500$ K and $\log g = 4.4 \pm 0.2$ reported by Bailey & Landstreet (2013). Our estimate of the radial velocity seems to be larger (though still within the error bars) than the value $V_r = 12.7 \pm 2.8$ km s^{-1} reported by Gontcharov (2006).

6. DISCUSSION

Based on the catalog of Ap, HgMn, and Am stars (Renson & Manfroid 2009) and the available measurements of rotational velocities of CP stars (Royer et al. 2002, 2007) we have compiled a list of CP stars (see Table 1) suitable for searching for signatures of abundance stratification of chemical species with respect to optical depth in their atmospheres. These stars have recently been observed in the frame of the VeSElkA project with the ESPaDOnS at CFHT. The method developed for the analysis of vertical stratification of chemical abundances (Khalack & Wade 2006) allows the slope of abundance change relative to the optical depth to be determined.

In order to study vertical stratification of chemical abundances, one needs to adopt an appropriate model of the stellar atmosphere and determine its parameters, such as the effective temperature, surface gravity, and metallicity. We were able to derive these parameters for the listed stars (see Table 2) based on the analysis of nine Balmer lines (see, for example, Figures 3 and 4) using the FITSB2 code (Napiwotzki et al. 2004) that employs a grid of theoretical fluxes calculated for different values of $T_{\rm eff}$, $\log g$, and metallicity. Taking into account that the resolution of the ESPaDOnS spectra $R = 65{,}000$, we have calculated a new library of synthetic spectra with a similar spectral resolution to properly fit the profiles of nine Balmer lines of stars observed in the frame of the project VeSElkA (see Section 4). Grids of stellar atmosphere models and corresponding fluxes have been calculated with the PHOENIX code (Hauschildt et al. 1997) for $5000\ {\rm K} \leqslant T_{\rm eff} \leqslant 15{,}000$ K and $3.0 \leqslant \log g \leqslant 4.5$ for the metallicities $[{\rm M/H}] = -1.0, -0.5, +0.5, +1.0, +1.5$.

We have used the spectra of 108 Vir (HD 129956) and α Leo (HD 87901) obtained with ESPaDOnS in the spectropolarimetric mode to verify the accuracy of our grids of synthetic fluxes. The results obtained for for these reference stars are close to the previously published data for their effective temperatures and surface gravities (see Section 3).

In order to study the sensitivity of the determined values of $T_{\rm eff}$ and $\log g$ for the set of Balmer lines used, we have compared the best-fit results obtained when one of the Balmer lines is omitted from the analysis with the best-fit results obtained from the analysis of all nine Balmer line profiles for the reference stars using the Phoenix-15 and Atlas9 grids. We found that the use of the Atlas9 grids may produce some ambiguity in the determination of fundamental stellar parameters if the effective temperature is close to 10,000 K, depending on which set of Balmer lines is used. Employing our Phoenix-15 grids for simulations with different sets of Balmer lines, we have shown that the estimates of $T_{\rm eff}$ and $\log g$ are most sensitive to the H_β, H_γ, H_δ, and H_ϵ Balmer lines. This sensitivity does not change significantly in the range of effective temperatures from 9700 to 12,000 K (see Figure 2).

We roughly estimate uncertainties of ± 200 K and ± 0.2 for the values of effective temperature and surface gravity, respectively. The relatively small variabilities found for $T_{\rm eff}$ and $\log g$ when using subsets of Balmer lines (see Section 4.1) seem to show that this choice of the errors is reasonable. It should be also noted that Husser et al. (2013) calculated grids of theoretical fluxes for $T_{\rm eff}$ below 12,000 K. Therefore, we cannot use those grids to determine $T_{\rm eff}$ and $\log g$ of all the stars selected for this study because some are much hotter than 12,000 K (see Table 2). Meanwhile, our grids of synthetic spectra provide similar results as the grids of Husser et al. (2013) for the selected stars with $T_{\rm eff}$ below 12,000 K. Since our grids go up to $T_{\rm eff} = 15{,}000$ K, they can be applied for all of the stars in our sample.

Our final results for effective temperature and surface gravity obtained for 12 of the stars presented in Table 2 are consistent with the previously published data. For four other stars (HD 23878, HD 83373, HD 95608, and HD 164584), this study gives the first estimates of their $T_{\rm eff}$ and $\log g$.

It should be noted that some stars observed in the frame of the project VeSElkA have low $T_{\rm eff}$ (see Table 2) and won't have vertical stratification of chemical species due to the presence of mixing due to convection (Richer et al. 2000; Richard et al. 2001). Nevertheless, they provide the possibility to verify the validity of the method applied to analyze the vertical stratification of chemical abundances (Khalack & Wade 2006) and to determine their abundance peculiarities. For instance, Khalack et al. (2013) found no signatures of vertical stratification in HD 71030 and found that the abundance of the analyzed chemical species is close to their solar abundance. Our sample of analyzed stars includes the reference stars HD 186568 and HD 209459 which are known to be a normal B-type stars (Dworetsky & Budaj 2000) without abundance peculiarities (Hubrig & Castelli 2001). These stars can also be used to verify the applied method and also to test the results for average abundances as well. The abundance analysis for all stars, even those where no stratification is found or expected, will be presented in upcoming papers. This analysis may be useful to confirm or disprove their CP type classification.

Khalack et al. (2013) have already analyzed several of the selected stars with the aim to detect vertical stratification of chemical abundances in their atmospheres and found signatures of vertical stratification of iron in HD 95608 and HD 116235. A detailed abundance analysis for the other stars in our sample is underway. We also plan to add more suitable stars to the project VeSElkA. A large amount of observational data relative to the vertical abundance stratification of chemical species obtained for CP stars with different effective temperatures will allow us to search for a dependence of the vertical abundance stratification relative to the effective temperature, similar to that found for BHB stars (Khalack et al. 2010; LeBlanc et al. 2010). Our results will also be useful for comparison with theoretical modeling of vertical abundance stratification in stellar atmospheres (i.e., LeBlanc et al. 2009; Stift & Alecian 2012) and to better understand the diffusion process in the atmospheres of certain CP stars.

We are sincerely grateful to Ralf Napiwotzki and John Landstreet for fruitful discussions and suggestions that led to a significant improvement of this work. We thank the Faculté des Études Supérieures et de la Recherche de l'Université de Moncton and NSERC for research grants. The calculations have been carried out on the supercomputer *briarree* of l'Université de Montréal under the guidance of Calcul Québec and Calcul Canada. The use of this supercomputer is funded by the Canadian Foundation for Innovation (CFI), NanoQuébec, RMGA, and the Research Fund of Québec—Nature and Technology (FRQ-NT).

REFERENCES

Abt, H. A., Levato, H., & Grosso, M. 2002, ApJ, 573, 359
Abt, H. A., & Morrell, N. I. 1995, ApJS, 99, 135
Alecian, G., & Stift, M. J. 2010, A&A, 516, 53
Ammler-von Eiff, M., & Reiners, A. 2012, A&A, 542, 116
Aurière, M., Wade, G. A., Silvester, J., et al. 2007, A&A, 475, 1053
Bailey, J. D., & Landstreet, J. D. 2013, A&A, 551, 30
Balachandran, S. 1990, ApJ, 354, 310
Bartholdy, P. 1988, in Comptes Rendus des Journées de Strasbourg, 10-me Reunion, ed. J.-L. Halbwachs, G. Jasniewicz, & D. Egret (Strasbourg: Observatoire Astronomique de Strasbourg), 77
Berthet, S. 1990, A&A, 227, 156
Boesgaard, A. M., & Trypicco, M. J. 1986, AJ, 303, 724
Bychkov, V. D., Bychkova, L. V., & Madej, J. 2003, A&A, 407, 631
Castelli, F., & Kurucz, R. L. 2004, in Proc. IAU Symp. 210, Modelling of Stellar Atmospheres, ed. N. Piskunov et al. (San Francisco, CA: ASP), A20
Catanzaro, G., Leone, F., & Catalano, F. A. 1999, A&AS, 134, 211
Cenarro, A. J., Peletier, R. F., Sanchez-Blazquez, P., et al. 2007, MNRAS, 374 664
Conti, P. S. 1965, ApJ, 142, 1594
Cowley, A., Cowley, C., Jaschek, M., & Jaschek, C. 1969, AJ, 74, 375
Donati, J.-F., Catala, C., Wade, G. A., et al. 1999, A&AS, 134, 149
Donati, J.-F., Catala, C., Landstreet, J. D., & Petit, P. 2006, in ASP Conf. Ser. 358, Solar Polarization 4, ed. R. Casini, & B. W. Lites (San Francisco, CA: ASP), 362
Donati, J.-F., Semel, M., Carter, B. D., et al. 1997, MNRAS, 291, 658
Dworetsky, M. M., & Budaj, J. 2000, MNRAS, 318, 1264
Erspamer, D., & North, P. 2003, A&A, 398, 1121
Evans, D. C. 1967, IAUS, 30, 57
Gontcharov, G. A. 2006, PAZh, 32, 844
Gonzalez, J.-F., LeBlanc, F., Artru, M.-C., & Michaud, G. 1995, A&A, 297, 223
Gray, R. O., Corbally, C. J., Garrison, R. F., et al. 2003, AJ, 126, 2048
Grevesse, N., Asplund, M., Suaval, A. J., & Scott, P. 2010, Ap&SS, 328, 179
Hauschildt, P. H., Baron, E., & Allard, F. 1997, ApJ, 483, 390
Hill, G. M. 1995, A&A, 294, 536
Hube, D. P. 1970, MNRAS, 72, 233
Hubrig, S., & Castelli, F. 2001, A&A, 375, 963
Hui-Bon-Hoa, A., LeBlanc, F., & Hauschildt, P. H. 2000, ApJL, 535, L43
Husser, T.-O., Wende-von Berg, S., Dreizler, S., et al. 2013, A&A, 553, 6
Khalack, V., LeBlanc, F., Bohlender, D., Wade, G., & Behr, B. B. 2007, A&A, 466, 667
Khalack, V., & Wade, G. 2006, A&A, 450, 1157

Khalack, V., Yameogo, B., Thibeault, C., & LeBlanc, F. 2013, in Proc. IAU Symp. 302, Magnetic Fields Throughout Stellar Evolution, ed. P. Petit (Cambridge: Cambridge Univ. Press), 272
Khalack, V. R., LeBlanc, F., & Behr, B. B. 2010, MNRAS, 407, 1767
Khalack, V. R., LeBlanc, F., Behr, B. B., Wade, G. A., & Bohlender, D. 2008, A&A, 477, 641
Khokhlova, V. L. 1975, AZh, 52, 950
Kochukhov, O., Piskunov, N., Ilyin, I., et al. 2002, A&A, 389, 420
Koleva, M., & Vazdekis, A. 2012, A&A, 538, 143
Künzli, M., & North, P. 1998, A&A, 330, 651
Landstreet, J. D. 1988, ApJ, 326, 967
LeBlanc, F., Hui-Bon-Hoa, A., & Khalack, V. R. 2010, MNRAS, 409, 1606
LeBlanc, F., Monin, D., Hui-Bon-Hoa, A., & Hauschildt, P. H. 2009, A&A, 495, 337
Leone, F., & Manfrè, M. 1996, A&A, 315, 256
Mathys, G., Manfoid, J., & Heck, A. 1985, IBVS, 2738, 1
Michaud, G. 1970, ApJ, 160, 641
Morrell, N., & Abt, H. A. 1992, ApJ, 393, 666
Morton, D. C. 1991, ApJS, 17, 119
Napiwotzki, R., Yungelson, L., Nelemans, G., et al. 2004, in ASP Conf. Ser. 318, Spectroscopically and Spatially Resolving the Components of Close Binary Stars, ed. R. W. Hilditch, H. Hensberge, & K. Pavlovski (San Francisco, CA: ASP), 402
Nordström, B., Mayor, M., Andersen, J., et al. 2004, A&A, 418, 989
North, P., Brown, D. N., & Landstreet, J. T. 1992, A&A, 258, 389
Palmer, D. R., Walker, E. N., Jones, D. H. P., & Wallis, R. E. 1968, R. Obs. Bull., 135, 385
Popper, D. M. 1980, ARA&A, 18, 115
Prugniel, P., Vauglin, I., & Koleva, M. 2011, A&A, 531, 165
Renson, P., & Manfroid, J. 2009, A&A, 498, 961
Richard, O., Michaud, G., & Richer, J. 2001, ApJ, 558, 377
Richer, J., Michaud, G., & Turcotte, S. 2000, ApJ, 529, 338
Royer, F., Grenier, S., Baylac, M.-O., Gomez, A. E., & Zorec, J. 2002, A&A, 393, 897
Royer, F., Zorec, J., & Gomez, A. E. 2007, A&A, 463, 671
Ryabchikova, T., Kochukhov, O., & Bagnulo, S. 2008, A&A, 480, 811
Ryabchikova, T., Leone, F., Kochukhov, O., & Bagnulo, S. 2004, in Proc. IAU Symp. N224, The A-Star Puzzle, ed. J. Zverko et al. (Cambridge: Cambridge Univ. Press), 580
Savanov, I. S., & Kochukhov, O. P. 1998, AstL, 24, 516
Shavrina, A. V., Glagolevskij, Yu. V., Silvester, J., et al. 2010, MNRAS, 401, 1882
Smith, K. C. 1992, PhD thesis, Univ. London
Smith, K. C. 1997, A&A, 319, 928
Smith, K. C., & Dworetsky, M. M. 1993, A&A, 274, 335
Stepień, K. 1968, ApJ, 154, 945
Stift, M. J., & Alecian, G. 2012, MNRAS, 425, 2715
Welson, R. E. 1953, General Catalogue of Stellar Radial Velocities (Washington, DC: Carnegie Institution of Washington), 601
Wielen, R., Schwan, H., Dettbarn, C., et al. 2000, Veroeff. Astron. Rechen-Inst. Heidelberg, 37, 1