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The influence of Stark broadening on Cr II spectral line shapes in stellar atmospheres

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ABSTRACT

Aims. We consider the effect of Stark broadening on the shapes of Cr II spectral lines observed in stellar atmospheres of the middle part of the main sequence.
Methods. Stark broadening parameters were calculated by the semiclassical perturbation approach. For stellar spectra synthesis, the improved version SYNTH3 of the code SYNTH for synthetic spectrum calculations was used.
Results. Stark broadening parameters for Cr II spectral lines of seven multiplets belonging to 4s – 4p transitions were calculated. New calculated Stark parameters were applied to the analysis of Cr II line profiles observed in the spectrum of Cr-rich star HD 133792.
Conclusions. We found that Stark broadening mechanism is very important and should be taken into account, especially in the study of Cr abundance stratification.

Key words. stars: chemically peculiar – line: profiles – atomic processes

1. Introduction

Chromium is one of the most peculiar elements in the atmospheres of magnetic, chemically peculiar stars, where a large number of Cr I and Cr II lines in wide range of excitation energies are identified. Ionized chromium spectral lines are third in number and intensity among metals, before Fe II and Ti II in Ae/Be Herbig Star V 380 Ori, where Shevchenko (1994) found 25 Cr II lines. Ionized chromium lines were found for example in α UMi (Polaris) and HR 7308 by Andrievski et al. (1994) and in the spectrum of XX Oph. Meril (1951) found 58 emission Cr II lines, and Babel & Lanz (1992) investigated the influence of stratification on chromium lines in the Ap 53 Cam star spectrum. Consequently, data on the Stark broadening of Cr II lines are obviously of interest when modelling and analyzing stellar spectra.

Transition probabilities of Cr II lines are known with rather good accuracy due to laboratory measurements (Pinnington et al. 1993; Nilsson et al. 2006) and improved theoretical calculations (Raassen & Uylings 1998)[1], but the Stark damping-constants come mainly from theoretical calculations by Kurucz (1993). There is only one experimental result on the Stark broadening of Cr II spectral lines by Rathore et al. (1984). The Stark width and shift of Cr II 3120.36 Å, 3124.94 Å and 3132.05 Å of the multiplet 5 (4s ^{4}D – 4p ^{4}F°) have been measured in a T-tube plasma. The results have been compared with values predicted from established systematic trends and regularities. Using regularities, Lakićević (1983) also made an attempt to determine Stark broadening parameters of the Cr II 2065.65 Å line. Experimental values of the Stark widths turned out to be more than 1 dex higher than the theoretical values by Kurucz. In the recent stratification study of different chemical elements, including Cr in the atmosphere of Ap star HD 133972, Kochukhov et al. (2006) were obliged to change Stark broadening parameters of Cr II 3421.202, 3422.732 Å lines (multiplet 3) using experimental data for multiplet 5 as a template, in order to obtain closer agreement with observations.

In our previous works (Popović et al. 1999, 2001; Dimitrijević et al. 2003, 2005) we have shown that the Stark effect may change the spectral line equivalent widths by 10–45%. Neglecting this mechanism may therefore introduce significant errors into abundance determinations for A-type stars where the Stark broadening is the most important pressure broadening mechanism. Similarly, Lanz et al. (1988) showed that the influence of Stark broadening on the high-excitation Si II multiplets may be critical for the abundance analysis. On the other hand, high-resolution spectra allowed us to study different broadening effects using well-resolved line profiles.

Taking the importance of Stark broadening for different types of spectroscopic studies into account, we calculated Stark widths and shifts for the strongest Cr II multiplets. In Sect. 2 a description of the Stark broadening parameter calculation is given. Section 3 presents the obtained electron-, proton and ionized helium-impact broadening (Stark) parameters and compares them with the existing experimental data (Rathore et al. 1984) and estimates based on regularities and systematic trends from Rathore et al. (1984). In Sect. 4 the obtained Stark broadening data are used for comparison with Cr II lines observed in the spectrum (from the ESO archive) of the Ap star HD 133792

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[1] `ftp://ftp.wins.uva.nl/pub/orth`

and the influence of Stark broadening and stratification are discussed.

2. The Stark broadening parameter calculation

Calculations were made within the semi-classical perturbation formalism in Sahal-Bréchot (1969a,b). This formalism, as well as the corresponding computer code, have been optimized and updated several times (see e.g. Sahal-Bréchot 1974; Dimitrijević & Sahal-Bréchot 1984a; Dimitrijević 1996).

Within this formalism, if we make the conversion of the corresponding expressions in Sahal-Bréchot (1969a) from angular frequency units to Ångstrøms, the full width of isolated spectral line broadened by electron impacts can be expressed in the case of an ionized emitter in terms of cross sections for elastic and inelastic processes as

$$\begin{aligned} W_{if} &= 2\frac{\lambda_{if}^2}{2\pi c} n_\mathrm{e} \int v f(v) \mathrm{d}v \Big(\sum_{i' \neq i} \sigma_{ii'}(v) \\ &\quad + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_\mathrm{el} + W_R\Big), \end{aligned} \qquad (1)$$

and the corresponding line shift as

$$d_{if} = \frac{\lambda_{if}^2}{2\pi c} n_\mathrm{e} \int v f(v) \mathrm{d}v \int_{R_3}^{R_D} 2\pi\rho \mathrm{d}\rho \sin 2\phi_p. \qquad (2)$$

Here, λ_{if} is the wavelength of the line originating from the transition with the initial atomic energy level i and the final level f, c the velocity of light, n_e the electron density, $f(v)$ is the Maxwellian velocity distribution function for electrons, and ρ denotes the impact parameter of the incoming electron. The inelastic cross section $\sigma_{jj'}(v)$ is determined according to Chapter 3 in Sahal-Bréchot (1969b), elastic cross section σ_el according to Sahal-Bréchot (1969a), and the contribution of Feshbach resonances W_R according to Fleurier et al. (1977). The cut-offs, included in order to maintain the unitarity of the S-matrix, are described in Sect. 1 of Chapter 3 in Sahal-Bréchot (1969b).

The formulae for the ion-impact broadening parameters are analogous to the formulae for electron-impact broadening. We note that the fact that the colliding ions could be treated within the impact approximation in the wings should be checked, even for stellar densities. If the ions are quasi-static for the line profile being considered, than their influence is weaker than if they are treated within the impact approximation and, as an approximation, only electron-impact broadening may be taken into account.

3. Results

The atomic energy levels needed for Stark broadening calculations were taken from Wiese & Musgrove (1989). Oscillator strengths were calculated by using the method of Bates & Damgaard (1949) and the tables of Oertel & Shomo (1968). For higher levels, the method described in van Regemorter et al. (1979) was applied.

Our results for electron-, proton-, and ionized helium-impact line widths and shifts for the seven Cr II multiplets considered for a perturbed density of 10^{14} cm^{-3} and temperatures T = 5000–100 000 K are shown in Table 1. This table shows electron-, proton-, and ionized helium-impact broadening parameters for Cr II for a perturber density of 10^{14} cm^{-3} and temperatures from 5000 up to 100 000 K. The quantity C (given in Å cm^{-3}), when divided by the corresponding full width at half maximum, gives an estimate for the maximum perturber density for which tabulated data may be used. There, *FWHM*(Å) denotes full line width at half maximum in Å, while SHIFT(Å) denotes line shift in Å. We note that, in the wings, impact approximation for ions should be checked and that ions will be quasi-static in the far wings. For perturber densities lower than those tabulated here, Stark broadening parameters vary linearly with perturber density. The nonlinear behavior of Stark broadening parameters at higher densities is the consequence of the influence of Debye shielding and was analyzed in detail in Dimitrijević & Sahal-Bréchot (1984b).

After testing the density dependence of Stark broadening parameters, we found that the width and shift are linear functions of density for perturber densities lower than 10^{17} cm^{-3}. They can be scaled by the simple formula

$$(W, d)_N = (W, d)_0 \left(\frac{N}{10^{14}}\right), \qquad (3)$$

where $(W, d)_N$ are the width and shift at a perturber density N (cm^{-3}), and $(W, d)_0$ are width and shift given in Table 1.

To simplify the use of Stark broadening data in the codes for stellar spectral synthesis, we found an analytical expression for Stark widths and shifts

$$\frac{(W, d)}{n_\mathrm{e}}[\text{Å}] = C \cdot (A + T^B). \qquad (4)$$

The constants A, B, and C are given in Table 2. We take T as T[K]/10000. The analytical fit is present in Fig. 1. As one can see from the Fig. 1, the analytical expression fits the calculated value in both Stark widths and shifts.

In Table 3 and in Figs. 2 and 3, our calculations are compared with the experimental results of Rathore et al. (1984), and with results of their estimates on the basis of regularities and systematic trends. One can see that our theoretical and the experimental shifts of Rathore et al. (1984) are in good agreement, while their experimental widths have a very different behavior with temperature. We note here that in Konjević & Wiese (1990) these experimental results were critically evaluated and an accuracy of ±50% was attributed. Estimates of Stark broadening parameters based on the regularities and systematic trends of Rathore et al. (1984) give better results for widths than for shifts where the sign of estimates of Rathore et al. (1984) is different from their experimental values and our semiclassical perturbation results. New experimental determination of Cr II Stark broadening parameters will evidently be of interest.

4. Comparison with the line profiles observed in the spectra of Ap stars

It is not possible to check Stark damping constants using the spectra of the normal stars. The Cr II lines in the whole optical region are not strong enough to show substantial Stark wings in hotter stars, while in cooler stars, in the Sun for example, the van der Waals effect is absolutely dominant. Therefore we can investigate the Stark broadening effect only in the spectra of chemically peculiar (Ap) stars. Ryabchikova et al. (2004) find a strong dependence of the Cr abundance in Ap stars on the effective temperature with a maximum between 9000–10 000 K. We can expect to see the influence of Stark broadening effect on Cr II line profiles in the spectra of Ap stars lying in this temperature region.

Table 1. Stark broadening parameters for Cr II 4s – 4p multiplets.

Perturbers are:		Electrons		Protons		Helium ions	
Transition	T(K)	*FWHM*(Å)	Shift(Å)	*FWHM*(Å)	Shift(Å)	*FWHM*(Å)	Shift(Å)
	5000	0.413E-03	–0.108E-03	0.484E-05	–0.433E-05	0.687E-05	–0.404E-05
CrII	10 000	0.306E-03	–0.945E-04	0.896E-05	–0.700E-05	0.106E-04	–0.604E-05
^{4}D–^{6}P$^{\circ}$	20 000	0.224E-03	–0.804E-04	0.134E-04	–0.973E-05	0.139E-04	–0.823E-05
3483.7 Å	30 000	0.182E-03	–0.786E-04	0.154E-04	–0.111E-04	0.154E-04	–0.915E-05
C = 0.36E+18	50 000	0.152E-03	–0.669E-04	0.178E-04	–0.127E-04	0.172E-04	–0.104E-04
	100 000	0.133E-03	–0.583E-04	0.212E-04	–0.151E-04	0.195E-04	–0.123E-04
	5000	0.396E-03	–0.105E-03	0.462E-05	–0.378E-05	0.659E-05	–0.354E-05
CrII	10 000	0.285E-03	–0.847E-04	0.845E-05	–0.616E-05	0.101E-04	–0.534E-05
^{4}D–^{6}D$^{\circ}$	20 000	0.199E-03	–0.742E-04	0.126E-04	–0.856E-05	0.131E-04	–0.728E-05
3355.5 Å	30 000	0.160E-03	–0.676E-04	0.143E-04	–0.985E-05	0.144E-04	–0.810E-05
C = 0.33E+18	50 000	0.132E-03	–0.568E-04	0.165E-04	–0.113E-04	0.161E-04	–0.927E-05
	100 000	0.113E-03	–0.488E-04	0.196E-04	–0.135E-04	0.184E-04	–0.110E-04
	5000	0.330E-03	–0.822E-04	0.437E-05	–0.389E-05	0.609E-05	–0.359E-05
CrII	10 000	0.249E-03	–0.749E-04	0.768E-05	–0.607E-05	0.913E-05	–0.524E-05
^{4}D–^{4}D$^{\circ}$	20 000	0.185E-03	–0.641E-04	0.115E-04	–0.834E-05	0.116E-04	–0.692E-05
2872.3 Å	30 000	0.156E-03	–0.652E-04	0.129E-04	–0.932E-05	0.128E-04	–0.770E-05
C = 0.18E+18	50 000	0.133E-03	–0.567E-04	0.149E-04	–0.107E-04	0.144E-04	–0.882E-05
	100 000	0.120E-03	–0.479E-04	0.177E-04	–0.127E-04	0.159E-04	–0.102E-04
	5000	0.413E-03	–0.105E-03	0.485E-05	–0.527E-05	0.671E-05	–0.488E-05
CrII	10 000	0.310E-03	–0.957E-04	0.884E-05	–0.808E-05	0.103E-04	–0.705E-05
^{4}D–^{4}F$^{\circ}$	20 000	0.230E-03	–0.829E-04	0.136E-04	–0.111E-04	0.134E-04	–0.910E-05
3128.8 Å	30 000	0.193E-03	–0.840E-04	0.155E-04	–0.123E-04	0.150E-04	–0.102E-04
C = 0.19E+18	50 000	0.164E-03	–0.735E-04	0.180E-04	–0.142E-04	0.168E-04	–0.116E-04
	100 000	0.147E-03	–0.621E-04	0.217E-04	–0.169E-04	0.194E-04	–0.136E-04
	5000	0.443E-03	–0.115E-03	0.497E-05	–0.514E-05	0.695E-05	–0.474E-05
CrII	10 000	0.331E-03	–0.101E-03	0.922E-05	–0.809E-05	0.108E-04	–0.695E-05
^{4}D–^{4}P$^{\circ}$	20 000	0.246E-03	–0.866E-04	0.140E-04	–0.111E-04	0.142E-04	–0.926E-05
3391.5 Å	30 000	0.201E-03	–0.857E-04	0.161E-04	–0.124E-04	0.157E-04	–0.103E-04
C = 0.28E+18	50 000	0.172E-03	–0.736E-04	0.188E-04	–0.143E-04	0.177E-04	–0.117E-04
	100 000	0.155E-03	–0.620E-04	0.226E-04	–0.172E-04	0.204E-04	–0.137E-04
	5000	0.147E-03	–0.135E-04	0.272E-05	–0.445E-06	0.404E-05	–0.440E-06
CrII	10 000	0.111E-03	–0.101E-04	0.485E-05	–0.840E-06	0.608E-05	–0.790E-06
^{6}D–^{6}P$^{\circ}$	20 000	0.846E-04	–0.802E-05	0.691E-05	–0.138E-05	0.782E-05	–0.120E-05
2758.2 Å	30 000	0.732E-04	–0.686E-05	0.780E-05	–0.167E-05	0.844E-05	–0.146E-05
C = 0.26E+18	50 000	0.636E-04	–0.597E-05	0.858E-05	–0.212E-05	0.918E-05	–0.174E-05
	100 000	0.568E-04	–0.510E-05	0.961E-05	–0.254E-05	0.999E-05	–0.209E-05
	5000	0.159E-03	–0.340E-06	0.268E-05	–0.127E-06	0.397E-05	–0.127E-06
CrII	10 000	0.115E-03	–0.736E-06	0.474E-05	–0.251E-06	0.594E-05	–0.245E-06
^{6}D–^{6}D$^{\circ}$	20 000	0.837E-04	–0.740E-06	0.671E-05	–0.455E-06	0.758E-05	–0.421E-06
2677.2 Å	30 000	0.706E-04	–0.630E-06	0.754E-05	–0.606E-06	0.818E-05	–0.534E-06
C = 0.24E+18	50 000	0.592E-04	–0.828E-06	0.827E-05	–0.777E-06	0.888E-05	–0.678E-06
	100 000	0.503E-04	–0.807E-06	0.922E-05	–0.103E-05	0.965E-05	–0.846E-06

As an example we chose the Ap star HD 133792, for which careful abundance and stratification analysis has recently been performed by Kochukhov et al. (2006). We used the same spectrum as in Kochukhov et al. (2006), obtained with the UVES instrument of the ESO VLT on 26 February 2002 in the program 68.D-0254 and retrieved through the ESO archive. Data reduction and the choice of the atmospheric parameters are described by Kochukhov et al. (2006). HD 133792 has an effective temperature of $T_{\rm eff}$ = 9400 K, log g = 3.7, and a mean Cr overabundance +2.6 dex relative to the solar Cr abundance. All calculations were carried out with the improved version SYNTH3 (Kochukhov 2006) of the code SYNTH (Piskunov 1992) for synthetic spectrum calculations. Stark damping-parameters were introduced in the spectrum synthesis code in the same way as described in Dimitrijević et al. (2003). We used the stratified Cr distribution in the atmosphere of HD 133972 derived by Kochukhov et al. (2006). Figures 4–6 show a comparison between the observed line profiles of four Cr II lines in 3400–3425 Å spectral region (multiplet 3) and our synthetic calculations with the Stark damping constants from the Kurucz (1993) line lists and with the data of the present paper. Good agreement between observations and calculations for a set of weak Cr II lines proves the use of the stratified Cr distribution, while all four strong Cr II lines demonstrate a good accuracy of the Stark constants obtained in the present work.

The maximal electron density in the atmospheric layers of Cr II lines formation is 3 × 10^{14} cm^{-1}, therefore Stark shifts are negligible in the whole atmosphere.

In principle, with a reliable atomic parameters (oscillator strengths, radiative, Stark & van der Waals damping constants), the line profiles of a few strong Cr II lines, when observed with high-resolution and high signal-to-noise ratio are enough for stratification analysis, because different parts of their profiles are formed in very different atmospheric layers and provide us with information on abundances in these layers. We illustrate it by calculating Cr distribution in the atmosphere of HD 133792 for

Table 2. The parameters A, B, and C of the approximate formulae for Stark widths and shifts.

Line	3483.7 Å	3355.5 Å	2872.3 Å	3128.8 Å	3391.5 Å	2758.2 Å	2677.2 Å
				Width			
				electrons			
C	10^{-17}	10^{-17}	10^{-17}	10^{-17}	10^{-17}	10^{-17}	10^{-17}
A	–0.685922	–0.706106	–0.74501	–0.682028	–0.660412	–0.885381	–1.29524
B	–0.105141	–0.106105	–0.0769182	–0.0993309	–0.108879	–0.0311979	–0.285293
				protons			
C	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-19}	10^{-19}
A	–0.910013	–0.915241	–0.922335	–0.909957	–0.906847	–0.516939	–0.528894
B	0.0522688	0.0479476	0.0429101	0.0538065	0.0561925	0.188986	0.180773
				He II			
C	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-19}	10^{-19}
A	–0.896066	–0.901514	–0.90565	–0.899215	–0.894385	–0.404331	–0.419323
B	0.0404476	0.0376583	0.0285055	0.0405015	0.0427824	0.165405	0.158879
				Shift			
				electrons			
C	10^{-17}	10^{-17}	10^{-18}	10^{-17}	10^{-17}	10^{-18}	10^{-20}
A	–1.09498	–1.08827	–1.74697	–1.09556	–1.10183	–1.10571	–1.57075
B	0.0163305	0.0181325	0.102826	0.0138044	0.0170876	0.0269544	-0.152403
				protons			
C	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-19}	10^{-19}
A	–1.0702	–1.06173	–1.06076	–1.08115	–1.08077	–1.09105	–1.02872
B	–0.0369441	–0.03324	–0.0299512	–0.0397908	–0.0411124	–0.076047	–0.0313582
				He II			
C	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-18}	10^{-19}	10^{-20}
A	–1.0608	–1.05364	–1.05241	–1.07005	–1.06967	–1.08248	–1.29524
B	–0.0280754	–0.0252721	–0.0225028	–0.0296004	–0.0305523	–0.058643	–0.285293

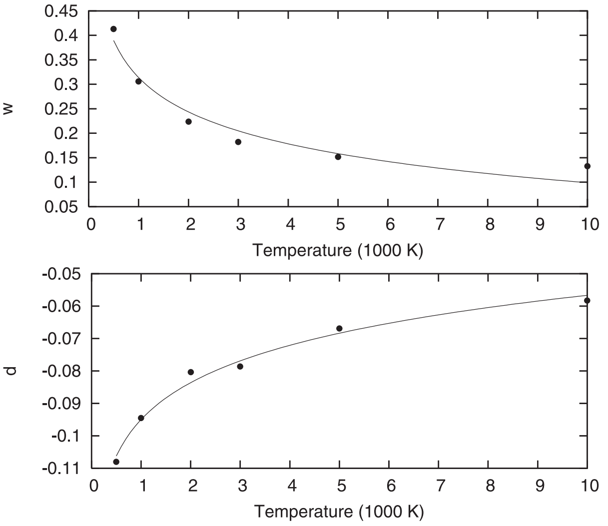

Fig. 1. The calculated Stark width (*up*) and shift (*down*) fitted with Eq. (4) for Cr II λ 3483.7 Å.

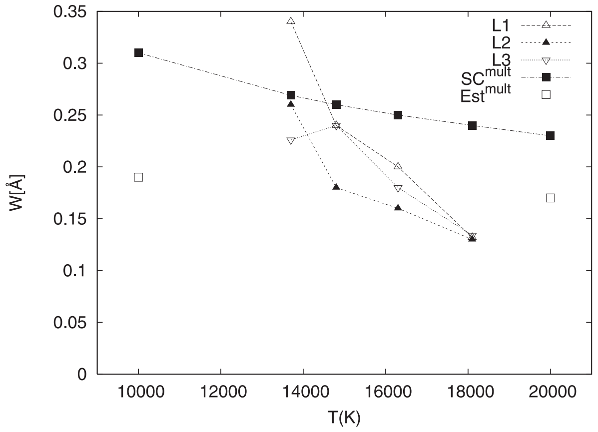

Fig. 2. Stark widths for the Cr II multiplet 4s ^{4}D – 4p ^{4}F° (3128.80 Å) as a function of temperature. Experimental results (Rathore et al. 1984) for each line in multiplet are denoted with L1 (3120.36 Å), L2 (3124.94 Å), and L3 (3132.05 Å), and our results with SC$^{\rm mult}$, and values estimated by Rathore et al. (1984) with Est$^{\rm mult}$.

two sets of spectral lines: only optical lines from the list given by Kochukhov et al. (2006) and four lines of mult. 3 (3403.30, 3408.76, 3421.20, 3422.73). The results with the Cr distribution derived with mult. 3 lines, and with the optical lines, are compared in Fig. 7. Stratification calculations were made using a step function approximation for element distribution (see Ryabchikova et al. 2005). This figure also shows maximal error boxes for the transition zone width (derived for optical lines) and abundance in the deeper atmospheric layers (derived for mult. 3 lines). As we see both distributions agree within the error boxes.

5. Conclusions

We have calculated Stark broadening parameters for Cr II spectral lines by the semiclassical perturbation approach and used the results to investigate the influence of the Stark broadening effect on these lines in the stellar atmosphere. From our investigation we can conclude:

(i) that newly calculated Stark widths for a number of strong Cr II lines agree with the scarce laboratory data and provide a good fit to the line profiles observed in Ap stars.

(ii) that the line wings of Cr II lines (see e.g. Cr II λ 3421.20 Å in Fig. 6) in the Ap stars are caused by the Stark-broadening mechanism.

Table 3. Stark full widths at half maximum and shifts for an electron density of 10^{17} cm^{-3} for various temperatures for spectral lines within the multiplet 4s ^{4}D – 4p ^{4}F°. Experimental results (Rathore et al. 1984) for widths and shifts are denoted with $W_{\rm exp}$, $d_{\rm exp}$, our results with $W^{\rm mult}_{\rm SC}$, $d^{\rm mult}_{\rm SC}$ (3128.80 Å) and estimated results (Rathore et al. 1984) with $W^{\rm mult}_{\rm RLCP}$, $d^{\rm mult}_{\rm RLCP}$ (3128.80 Å).

Transition	T(K)	$W_{\rm exp}$(Å)	$W^{\rm mult}_{\rm SC}$(Å)	$W^{\rm mult}_{\rm RLCP}$(Å)	$d_{\rm exp}$(Å)	$d^{\rm mult}_{\rm SC}$(Å)	$d^{\rm mult}_{\rm RLCP}$(Å)
4s ^{4}D – 4p ^{4}F° 3120.36 Å	10 000		0.310	0.190		–0.104	0.070
	13 700	0.340	0.269		–0.100	–0.088	
	14800	0.240	0.260		–0.070	–0.086	
	16 300	0.200	0.250		–0.050	–0.085	
	18 100	0.132	0.240		–0.049	–0.083	
	20 000		0.230	0.170		–0.062	0.055
4s ^{4}D – 4p ^{4}F° 3124.94 Å	10 000		0.310	0.190		–0.104	0.070
	13 700	0.260	0.269		–0.120	–0.088	
	14800	0.180	0.260		–0.080	–0.086	
	16 300	0.160	0.250		–0.060	–0.085	
	18 100	0.130	0.240		–0.048	–0.083	
	20 000		0.230	0.170		–0.062	0.055
4s ^{4}D – 4p ^{4}F° 3132.05 Å	10 000		0.310	0.190		–0.104	0.070
	13 700	0.226	0.269		–0.110	–0.088	
	14800	0.240	0.260		–0.090	–0.086	
	16 300	0.180	0.250		–0.070	–0.085	
	18 100	0.134	0.240		–0.047	–0.083	
	20 000		0.230	0.170		–0.062	0.055

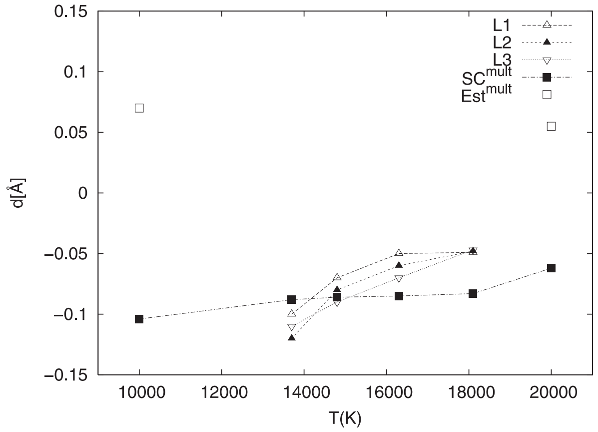

Fig. 3. Stark shifts for the Cr II multiplet 4s ^{4}D – 4p ^{4}F° (3128.80 Å) as a function of temperature. Experimental results (Rathore et al. 1984) for each line in the multiplet are denoted with L1 (3120.36 Å), L2 (3124.94 Å), and L3 (3132.05 Å), and our results with SC$^{\rm mult}$, and values estimated by Rathore et al. (1984) with Est$^{\rm mult}$.

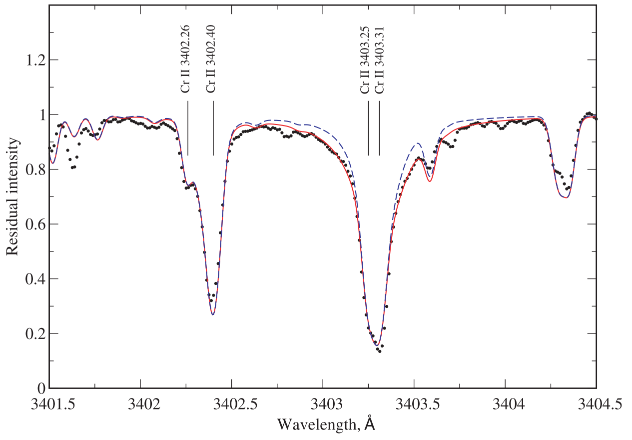

Fig. 4. Comparison between the observed Cr II 3403.30 line profile (dots) and synthetic calculations with the Stark parameters from present paper (full red line) and those from Kurucz (1993) (blue dashed line).

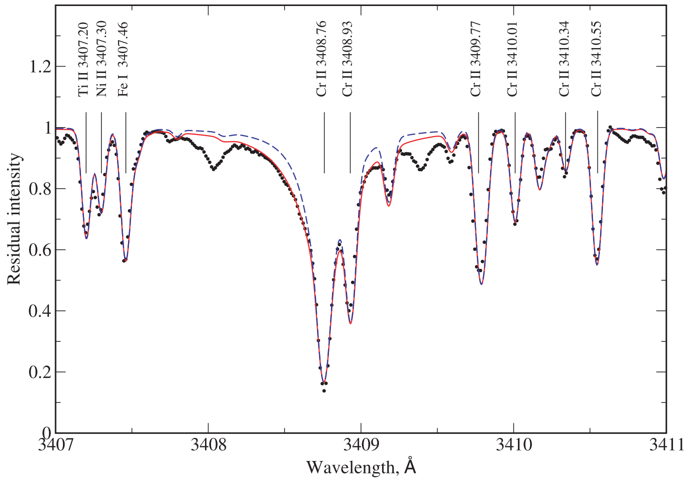

Fig. 5. The same as in Fig. 4 but for the Cr II 3408.76 line.

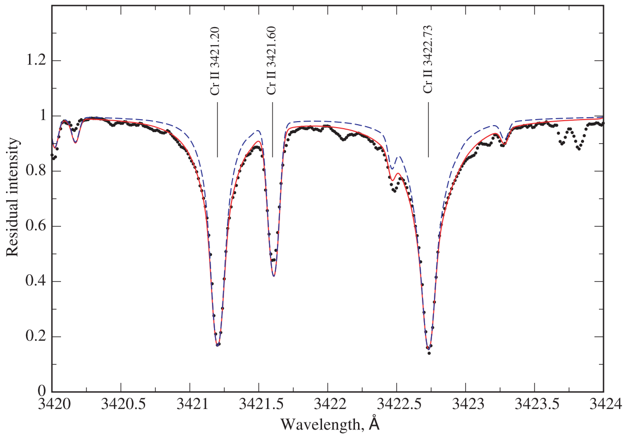

Fig. 6. The same as in Fig. 4 but for the Cr II 3421.20, 3422.73 lines.

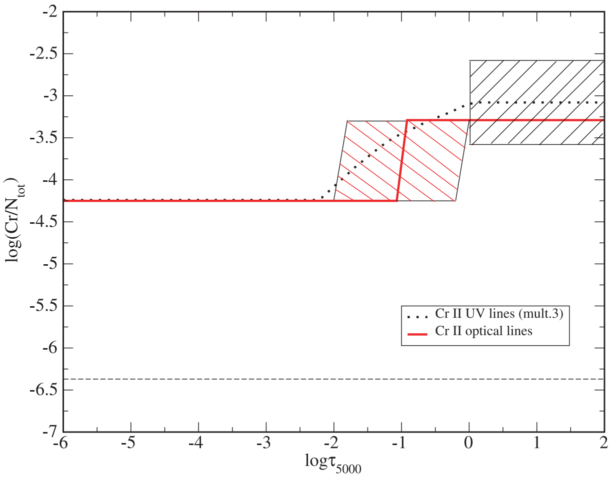

Fig. 7. Comparison between Cr distributions derived using UV mult. 3 lines only (dotted line) and using optical Cr lines only (solid line). The dashed line shows the solar atmospheric Cr abundance. Dashed areas mark maximal error boxes for the transition zone width (derived for optical lines) and abundance in the deeper atmospheric layers (derived for mult. 3 lines).

In the end, we note that new Stark parameters are particularly important for the study of Cr stratification in Ap stars in the 9000–10 000 K temperature region, where this stratification may be obtained from careful study of the line profiles of only multiplet 3 Cr II lines.

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