Effective temperatures from A5 to G5 spectral types, using Balmer line profiles

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Abstract. We show how previous works (Fuhrmann et al., van 't Veer-Menneret & Mégessier) demonstrate the efficiency of the use of Balmer line profiles for effective temperature determination. In agreement with them, we insist on the physical interest of this method based on the behaviour of these lines with the variations of the parameters involved in the treatment of the convective transport. The comparison between Fuhrmann's results and ours, independently obtained, exhibits a quite good agreement. We show new results of effective temperature, gravity and metallicities for a few of our programme stars, ranging from solar to overabundant metallicities.

Key words: Stars: atmospheres – Stars: fundamental parameters

1. Introduction

The first step, in a detailed abundance analysis, is to obtain an accurate effective temperature. The quality of the other fundamental parameters, gravity and metallicity, will follow. Reliable fundamental parameters are also required for internal structure models used for computing diffusion processes or for asteroseismology.

The wings of the first four members of the Balmer line series are very sensitive to effective temperature (hereafter $T_{\rm eff}$), and almost insensitive to gravity changes for $T_{\rm eff}$ less than 8500 K, with a limit around 5000 K, from where Stark broadening becomes inefficient. Recent works (Fuhrmann et al., 1993, 1994; van 't Veer-Menneret and Mégessier, 1996, hereafter VM) have shown that Balmer Line Profiles (hereafter BLP) are also sensitive to the temperature structure of the models used to interpret them. This means that BLPs depend on the treatment of the convection transport and on the metallicity entering the Opacity Distribution Functions (ODF).

In section 2 we describe and comment on these previous works. In section 3 we present our results, and compare them to Fuhrmann's ones.

2. Previous Works

In a series of papers, Fuhrmann et al. (1993, 1994) and Axer et al. (1994) have largely demonstrated the reliability of deriving $T_{\rm eff}$ from the first 4 BLPs. Their

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most important finding can be summarized in this way: *in order to fit simultaneously the 4 observed profiles with the ones computed using a single model, they had to lower the mixing-length free parameter α of the convection from 1.5 down to 0.5, its usual values being in the range 1.25, 2.0.* Their extensive analyses show that their finding is valid for a large range of temperatures and metallicities, mainly for atmospheres cooler than 6500 K, with solar and deficient metal content.

In fact the H_α profile was found to be insensitive to the choice of α, whereas the three other lines were found to be strongly affected, the line depth increasing with decreasing α. This behaviour is due to the fact that the H_α profile is formed above the convective zone, and the other lines inside it, as it was demonstrated by Fuhrmann et al. (1993). We refer to Figures 3 and 4 of the same paper, for an extensive view of the effects on computed BLPs of model parameters $T_{\rm eff}$, gravity, metallicity and the mixing length to pressure scale-height ratio $\alpha = l/H_{\rm p}$.

The main interesting consequence is that the BLPs are effective indicators of stellar atmosphere structure, as long as H_α and following lines are jointly interpreted, and constitute a direct evidence of the depth stratification of a stellar atmosphere.

In a more recent paper Fuhrman et al. (1997) achieved these analyses by using the Mg Ib triplet for gravity detemination. Indeed these pressure-broadened lines are powerful gravity indicators, assuming that $T_{\rm eff}$ has been determined independently and that weak Mg I lines are available for Mg abundance determination.

In VM, with our own observational material and reduction procedures, we reached the same conclusions as Fuhrmann et al. (1993, 1994) about the influence of model structure on BLPs and consequently on derived $T_{\rm eff}$, as for instance for the Sun and Procyon. We have confirmed the necessity to lower the value of α down to 0.5 for a simultaneous fitting of H_α and H_β. We extend this result for hotter stellar atmospheres with overabundant metal content as well.

3. Our Method and Results

3.1. Observations and reduction

The observational material was described in VM. We recall that we used the CCD receptor combined with the spectrograph AURÉLIE attached to the Coudé Focus of the 152-cm reflector at the Observatoire de Haute-Provence. We observed in H_α and H_β ranges with a spectral resolution of 18 000, and in the 613.5 nm and 552.0 nm ranges with a resolution of 30 000 for abundance analyses, the signal-to-noise ratio being around 400 for most of the exposures.

We present in this paper some results for stars which were former targets for the unfortunate EVRIS space mission, and the analysis of which remains interesting to pursue. Some of them may be candidates for future asteroseismology

Table 1. The occurence of effects on BLPs of parameters involved in model computation

	Atmosphere			— Convective Zone				
	[M/H]	T_{eff}	gravity	α	oversh.	A/V	y	k
H_α	yes	yes	no	no	yes	no	no	no
H_β	yes	yes	no	yes	yes	yes	yes	yes

programs, others for programs concerning δ Scuti stars and chemically peculiar stars.

We recall (see VM) that we used Kurucz' code ATLAS9 (1993) for computing the models entering the calculation of profiles by the code BALMER9. As explained in VM, the study of convection treatment in ATLAS9 showed that the overshooting option used hypotheses which were not physically acceptable. Then we decided to remove this option in the computation of the models we needed. This difficulty was confirmed by Castelli et al. (1997).

We mention as an information that we have carried out, under the UNIX system, an efficient automatisation of Kurucz' codes, allowing computations of grids of models, fluxes and Balmer lines.

3.2. Procedure

Table 1 summarizes the occurence of an effect on Balmer line broadening due to a change of the parameters involved in the model computation. We refer to Figure 4 in VM, which displays in what direction the variation of each parameter acts, and how much. In Table 1 we have added 3 parameters entering the mixing length theory of convection: A/V is the surface over volume ratio of the convective element, y is a weighting factor on the optical depth in the convection efficiency parameter averaged on optically thin and thick cases, and k is a factor on the convective flux taking into account the vertical motions of the elements. We refer to VM and Castelli et al. (1997) for more details, comments and references about them. They are free parameters, which act on the BLPs in the same way as α. In all cases presented here these parameters are chosen and fixed once and for all, only α was changed and the overshooting option was switched off. The metallicity and the gravity being chosen as starting values, we proceed as follows: (i) first of all T_{eff} is derived by fitting observed and computed H_α profiles, (ii) then we select the model which best fits both H_α and H_β by adjustment of α, (iii) the metallicity is derived by an iterative method through an abundance analysis which allows to determine the gravity and the microturbulence velocity. The results of such an iteration appear in the first 2 rows of Table 2, where the 1st row gives the results before the iteration and the second one the results retained after the first and only iteration.

Table 2. Results for Procyon. The first 2 columns give the metallicity of the ODFs and the gravities used for the starting models, ξ_t is the microturbulence velocity in km s^{-1}. (*) refers to Fuhrmann et al. 1997

$[M/H]$	log g	$T_{\rm eff}$	σ	log g	σ	ξ_t	σ	$[Fe/H]$	σ	rem.
0.00	4.0	6450K	±50	3.8	±0.1	2.3	±0.3	-0.1	±0.05	pres. work
-0.10	3.8	6480K		3.9		2.3		-0.07		"
-0.16		6470K		4.0		2.09		+0.01		*

Table 3. Results for other programme stars. The second row gives the metallicity of the ODF used, ξ_t is the microturbulence velocity in km s^{-1}.

	β Vir	η Cas	η Boo	63 Tau	τ Uma
Sp	F9V	G0IV	G0IV	Am	Am
$[M/H]$	+0.1	-0.3	+0.3	+0.5	+0.5
$T_{\rm eff}$	6000K	5800K	5900K	7200K	7050K
log g	4.0	4.2	3.5	3.8	
ξ_t	1.5	1.5	1.5	3.0	
$[Fe/H]$	+0.1	-0.33	+0.2	+0.45	

3.3. Results

Table 2 and 3 show respectively our results for Procyon, and for a few other stars from our programme. In all cases $\alpha = 0.5$. Uncertainties can be summarized as follows, with [M/H] being the metallicity in the ODFs: $\Delta[M/H] = +0.5$ leads to $\Delta T_{\rm eff} = -200$ K, and that leads to a decrease in the resulting [Fe/H] of -0.15 dex. A change in α of 0.75 corresponds to a change in $T_{\rm eff}$ of about 300 K, depending on $T_{\rm eff}$ and metallicity. Figure 1 shows, in the case of Procyon, the adequacy of the resulting model which represents both profiles. It is exactly as good for the other stars presented here. Moreover, we have to add that the ionization and excitation equilibria are well fulfilled, and that is the only disagreement with Fuhrman et al. (1997) which remains to explain. In the same way the discrepancy with the gravity deduced from the orbital parameters is not yet completely resolved.

We recall that in VM we have shown the quite good agreement between the $T_{\rm eff}$ derived, for the 2 Am stars, from the 2 independent methods BLP and IRFM. The latter gave 7175 K for 63 Tau and 7025 K for τ Uma, to be compared with the values from BLPs in Table 3.

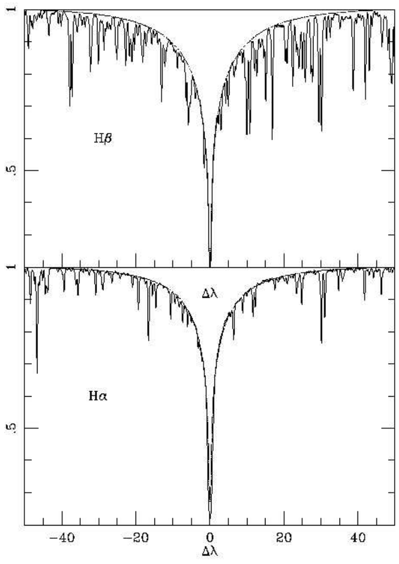

Figure 1. Observed profiles (full lines) of Procyon fitted to the ones computed (dotted lines) with the 2nd model in Table 2

4. Conclusion

We conclude by stressing the remarkable internal consistency in the results of Fuhrmann and collaborators, likewise in our results, and the significant agreement between these two completely independant works. As a consequence, the value $\alpha = 0.5$ for the mixing length parameter, can be considered as the recommended value to be introduced in the models used for $T_{\rm eff}$ determination of all stars with $T_{\rm eff}$ between 8500 K and 5000 K, when H_α is not available.

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