Microturbulence in the atmosphere of CP stars Vega and *o* Pegasi

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Abstract. Using the neutral and singly ionized lines of Fe and singly ionized lines of Ti and Cr in visual part of the spectrum, microturbulence was investigated in the atmospheres of Vega and *o* Pegasi by using a conventional method. In the case of *o* Peg the data were re-analyzed by including the magnetic field in line opacity. The microturbulent value for Vega was found to be slightly higher than 1 km/s.

In the case of *o* Pegasi the microturbulent value is significantly higher than 1 km/s and the trend of dependence upon atmospheric height was marginally detected in the Fe II ion. No trend of microturbulent dependence on atmospheric height was found after including the magnetic field in line opacity.

Key words: stars - chemically peculiar - microturbulence

1. Introduction

In elemental abundance analyses of stellar atmospheres value of the classical microturbulence is obtained as a by-product parameter. This value provides a fragmentary information on motion in the stellar atmosphere (if any). It is known mainly from spectroscopic studies that the value of microturbulence is considerably higher in atmospheres of giants and supergiants as compared with main sequence stars. The assumption that microturbulence does not vary with optical depth is applied in most abundance analyses. In main sequence stars the estimations of microturbulence are about 2 km/s or slightly higher in contrast with chemically peculiar stars, where the estimations are less than 2 km/s in many cases.

Of stars the microturbulent depth-dependence was recently studied only in Arcturus, where the value tends to grow as atmospheric height increases (Takeda 1992a). *O* Peg (HD 214 994) being one of the prototypes of hot metallic-lined stars was studied for the same purpose (Zboril 1992). However, the detection of a magnetic field in this star make us to re-investigate the microturbulence analysis. Moreover, in this contribution we have also attempted to check the interval in which microturbulent values occur in two CP stars and to investigate on the

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basis of high S/N data the possible microturbulent dependence on atmospheric height in the case of Vega.

2. Atmospheric parameters

In the case of *o* Peg we started with the model atmosphere with $T_{eff} = 9550K$ and *log g* = 1.55 (SI) and solar composition (Kurucz 1979). These model parameters were as the result of the abundance analyses of the group participating in the workshop on elemental Abundance Analyses (Adelman, Lanz 1988). Equivalent widths were measured using digitized data kindly provided by dr. T. Lanz.

As regards Vega, we also used Kurucz's line-blanketed model atmosphere with $T_{eff} = 9500K$ and *log g* = 1.9 and solar composition though there is still a problem with the model for Vega. All the models used so far do not predict correctly the Paschen dicontinuity and the hydrogen Paschen lines which computed come out too weak. None of the models reproduces the ultraviolet flux correctly. A new model for Vega after Castelli and Kurucz (1992) is more successful, it reproduces the observed ultraviolet and visual energy distributions, and the Balmer profiles well. It also confirmes the mild-underabundance of metals in Vega. Nevertheless, the model we adopted, i.e. with solar composition, should yield the same synthetic spectrum.

The equivalent widths for Vega were taken from Adelman and Gulliver (1990) and from Gulliver et al.(1991). These are based on the Reticon spectra covering the spectral range of about 382.0-543.0 nm. Table 1 summarizes the adopted stellar parameters used in our analysis.

Table 1. Atmospheric parameters and spectral data

Star	Sp. region (nm)	T_{eff}	log g (SI)	Composition	S/N ratio
oPeg	386.0 - 464.0Å	9550 K	1.55	solar	80-100
Vega	431.0 - 480.0Å	9500 K	1.90	solar	1000
Vega	449.0 - 454.0Å	9500 K	1.90	solar	2500

3. Procedure

In microturbulent analysis we applied the conventional method (de Jager et al. 1984) to Fe I,Fe II, Ti II and Cr II lines. First,the abundances were calculated for a set of three microturbulence values for several lines to check the linear trend. Nonlinearity was not found and we proceeded with the set of two microturbulence values for the remainder of the lines. Detailed line profiles and equivalent widths were computed with using the modified Synspec code. A gf-values were taken from Martin et al.(1988) for *o* Peg and from the reference list published in Adelman and Gulliver (1990) for Vega.

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3.1. Line profiles with the presence of the magnetic field

A magnetic field of about 0.2 Tesla with signs of a complex structure was confirmed in o Peg (Mathys and Lanz 1991). Therefore, the line profiles have to be computed under this condition. We used two methods in computing the detailed line profiles of a pair of Fe II lines:

- (1) introducing the magnetic field into the Doppler width term as pseudoturbulence (Adelman 1973)
- (2) solving the usual *scalar* equation of radiative transfer instead of *vector* equation in $W_\lambda - H$ relation (Takeda 1992b)

Pseudoturbulence is included into the Doppler width term in a simple form

$$v\ [km/s] = k.H.z.\lambda \tag{1}$$

where k is constant, H stands for the strength of magnetic field in Tesla, λ the central line wavelength in nm, and z the effective Lande factor for the transition considered.

In the presence of a magnetic field, the line profile and the corresponding equivalent width can be calculated by solving the normal transfer equation using line opacity

$$l(v,H) = (l/3).[\sum_i w_j^- .\varphi(v-\alpha_i^- .v_H) + \sum_j w_j^+ .\varphi(v-\alpha_j^+ .v_H) + \sum_k w_k^0 .\varphi(v-\alpha_k^0 .v_H)] \tag{2}$$

where each term corresponds to the σ_-,σ_+ and π components, w's are the weights (intensities) of the component normalized as

$$\sum w_i^- = \sum w_j^+ = \sum w_k^0 = 1$$

and α's indicate the positions of the components in units of Zeeman widths. In the absence of the magnetic field, the line opacity is expressed in the usual way: $l(v,0) = l.\varphi(v)$ where $\int \varphi(v)dv = 1$.

In Table 2 we give the basic data for two transitions we studied to investigate both methods where g values correspond to Lande factors.

Table 2. Transitions data for Fe II ion

lower level			upper level		
$\lambda_0(nm)$	Desig.	g	g_{eff}	Desig.	g
462.0521	$4_{F_3\ 1/2}$	1.238	1.467	$4_{D_3\ 1/2}$	1.429
430.3176	$4_{P_1\ 1/2}$	1.733	1.333	$4_{D_1\ 1/2}$	1.200

The Zeeman patterns of the Fe II transitions are shown in Fig.1 in the conventional manner: the length of vertical bar is proportional to its relative strength.

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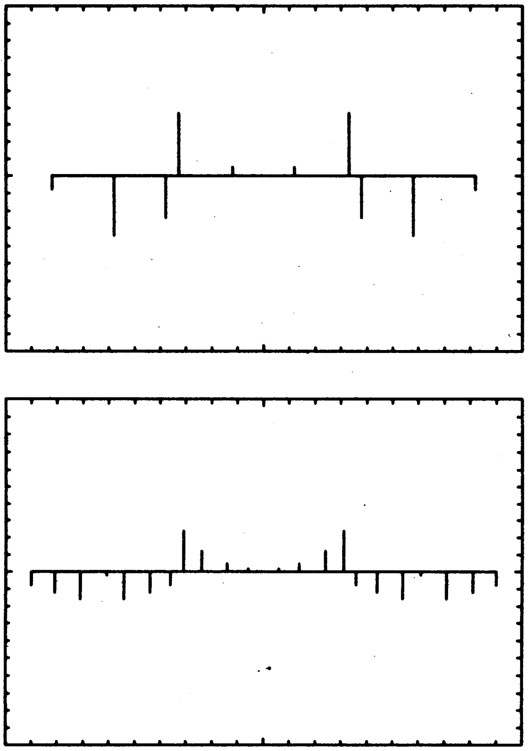

Figure 1. Zeeman patterns for two Fe II transitions with data in Table 2.

The π component appears above the horizontal axis, while the σ components are below it. The relative strength can be obtained by using Wigner 3j symbols (Sobelman 1979). However, the overall widths of lines are small; for the 430.3 transition (upper panel) the value is 0.0035 nm while for the 462.0 transition 0.0038 nm. The lines were selected from the line list to check the effect of saturation. We chose the transitions to satisfy the relation

$$\lambda_1 . g_1 = \lambda_2 . g_2 \tag{3}$$

but they differ significantly in equivalent widths. In the case of the saturated line, the difference between two methods practically disappears and amounts to 6 per cent for the weak line. However, neglecting the magnetic field in calculations of emergent line profiles causes a much larger error. In subsequent calculations we included the magnetic field in line opacity after Adelman's method. The results of microturbulence analysis are presented in Table 3.

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Table 3. Microturbulence analysis in Vega and *o* Peg

Ion	v_{turb}	log N	r^2	No. of lines	Remark
		o Pegasi			
Fe I	2.44±0.27	-4.45±0.05	0.9	11	-
Fe I	2.19±0.18	-4.24±0.04	0.7	53	mag. field
Fe II	1.56±0.27	-4.35±0.05	0.7	19	-
Fe II	1.89±0.22	-4.20±0.06	0.7	30	mag. field
Cr II	1.36±0.57	-5.68±0.08	0.8	11	-
Cr II	2.35±0.32	-5.70±0.06	0.8	11	mag. field
Ti II	2.11±0.30	-6.85±0.06	0.7	22	-
Ti II	2.54±0.18	-6.80±0.05	0.9	31	mag. field
		Vega			
Fe I	1.22±0.30	-5.00±0.03	0.7	8	S/N 1000
Fe II	0.79±0.20	-5.10±0.03	0.6	11	S/N 1000
Cr II	2.75±0.85	-6.92±0.08	0.7	6	S/N 1000
Ti II	1.24±0.44	-7.34±0.05	0.4	14	S/N 1000
Fe II	1.65±0.27	-5.07±0.04	0.9	6	S/N 2500

4. Interpretation and conclusions

In our previous paper concerning *o* Peg (Zboril 1992) the investigation based on a limited number of Ti, Fe and Cr lines shows that microturbulence may grow as atmospheric height increases. This behaviour was indicated in **all** ions independently. As every transition is sensitive to the value of the magnetic field in different manner, it was desirable to consider it in the line opacity calculations.

In the first step, a considerably larger dataset of transitions was used for every ion, and the trend of microturbulence dependence on atmospheric height was detecable only for Fe II transitions. However, after including the magnetic field in line opacity, the trend disappeared completely, and the values of standard deviations were also reduced. The value of microturbulence in *o* Peg after including the magnetic field in line opacity was still considerably higher than 1 km/s, except for the Cr II transitions. The microturbulence determined by using the lines of this ion is typical, with enhanced scatter. This also applies to the investigation of Vega's Cr II lines.

As concerns Vega, apart from the fact that a model atmosphere is still not available for this star, we found the microturbulent value to be slightly above 1 km/s, confirming the mild-deficiency in Vega. In comparison with the *o* Peg these data display a substantially higher S/N ratio but, unfortunately, this was outweighted by a smaller number of lines being used in the analysis of *o* Peg in some cases. Scatter in Cr transitions is unexpectedly large.

Therefore, it may prove more promising in microturbulent-depth dependence analysis of this type to add UV data. However, special attention should in this case be paid to individual opacities, autoionization features, atomic data (e.g. photoionization cross-sections) and blends.

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