Stratification of chromium abundance in CP-stars α^2 Canum Venaticorum, ϵ Ursae Majoris, Sirius and Vega

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Abstract. High S/N Reticon spectra of α^2 CVn, ϵ UMa, Sirius and Vega are investigated to estimate the Cr-abundance and its possible depth distribution. While three of the stars show practically normal (homogeneous) distribution of the element, α^2 CVn was found to be anomalous: the abundance of chromium decreases outwards of the atmosphere.

Key words: stars: CP - stars: atmospheres - stars: individual - stars: α^2 CVn, ϵ UMa, Sirius and Vega - elemental abundances: vertical stratification - spectrum: synthesis

1. Introduction

The vertical stratification of chemical elements in the atmospheres of CP-stars was predicted as a result of radiative diffusion processes. In quantitative analyses of the atmospheres, stratification effects manifest themselves on curves of growth (e.g. Alecian, 1982) or as differences between abundances derived from different ionization stages of an element (Michaud, 1970, Zverko, 1974). Babel (1994) detected calcium abundance stratification in a large sample of Ap-stars. Attempts to find such stratification for iron peak elements were made by Romanyuk et al. (1992) and Khokhlova & Topil'skaya (1992). The former derived the iron abundance in the upper layers of α^2 CVn to be twice as large as in the deeper ones. The latter, investigating the CrII Mult. No.30 lines formed at different depths, found the distribution of the element to be vertically homogeneous. Both the studies were based on photographic spectra, the former used the reciprocal dispersion of 0.67 nm mm^{-1} and S/N = 20, the latter 0.17 nm mm^{-1} and S/N = 70.

Zverko & Žižňovský (1994) performed an investigation, based on the same idea as Khokhlova & Topil'skaya (1992), using Reticon spectra of α^2 CVn and Sirius with 0.85 nm mm^{-1} and S/N = 350 and 950 respectively. The result was surprising: while in Sirius the abundance of chromium had (if not homogeneous)

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a mild tendency to increase outwards, in α^2 CVn there was a remarkable decrease towards the upper layers. α^2 CVn, however, is a line-variable star and the spectra were taken at phase 0.8 only. The picture, of course, could strongly depend on which side of the spotty surface of the star is turned to the observer.

2. Spectra

New Reticon spectra were obtained with the coudé spectrograph of the 2-m telescope of the Astronomical Institute, Academy of Sciences of the Czech Republic, Ondřejov, in March and April 1994. The reciprocal dispersion was 0.85 $\mathrm{nm\,mm^{-1}}$, the wavelength region 475 - 496 nm. Six spectra of Sirius were taken on March 5 which, coadded yield S/N $\approx$ 500, three spectra of Vega were taken on March 5 and coadded yield S/N $\approx$ 400. One spectrum of ϵ UMa taken on March 5 has S/N $\approx$ 200 and five spectra of α^2 CVn taken on March 5 and April 8 have individual S/N $\approx$ 150.

The spectra were reduced with the SPEFO code (Horn, 1993) and equivalent widths measured with the EQWREC code (Budaj, 1993).

Fig.1 shows sections of the observed spectra.

3. Analysis

The atmosphere parameters of individual stars were determined or taken from the literature as listed in the following table:

Star	HD No.	$T_{\rm eff}$	$\log g$	**Source**
α^2 CVn	112 413	11 500	3.8	H_β profile, this paper
Sirius	48 915	10 000	4.5	Savanov (1987)
Vega	172 167	9 550	3.95	Castelli and Kurucz (1994)
ϵ UMa	112 185	9 550	3.6	Renson et al.(1991)

The model atmospheres we used were Kurucz's (1993) ATLAS9 models interpolated to the values of effective temperatures and gravities of the individual stars; for the two hotter stars with metal abundance of ten times the Solar, for the two cooler ones with normal metal abundances. The abundances were derived by fitting the observed equivalent widths with the computed widths using the SYNSPEC code (Hubený, 1987) modified by Zboril (1993) to include elements up to Z = 82. The $gf-$data are from Kurucz's (1993) "iron set".

3.1. α^2 CVn

The five new spectra of α^2 CVn (EuSiCr) are distributed over phases from 0.122 to 0.582, and together with the 'old' ones taken at a phase 0.802 reasonably cover

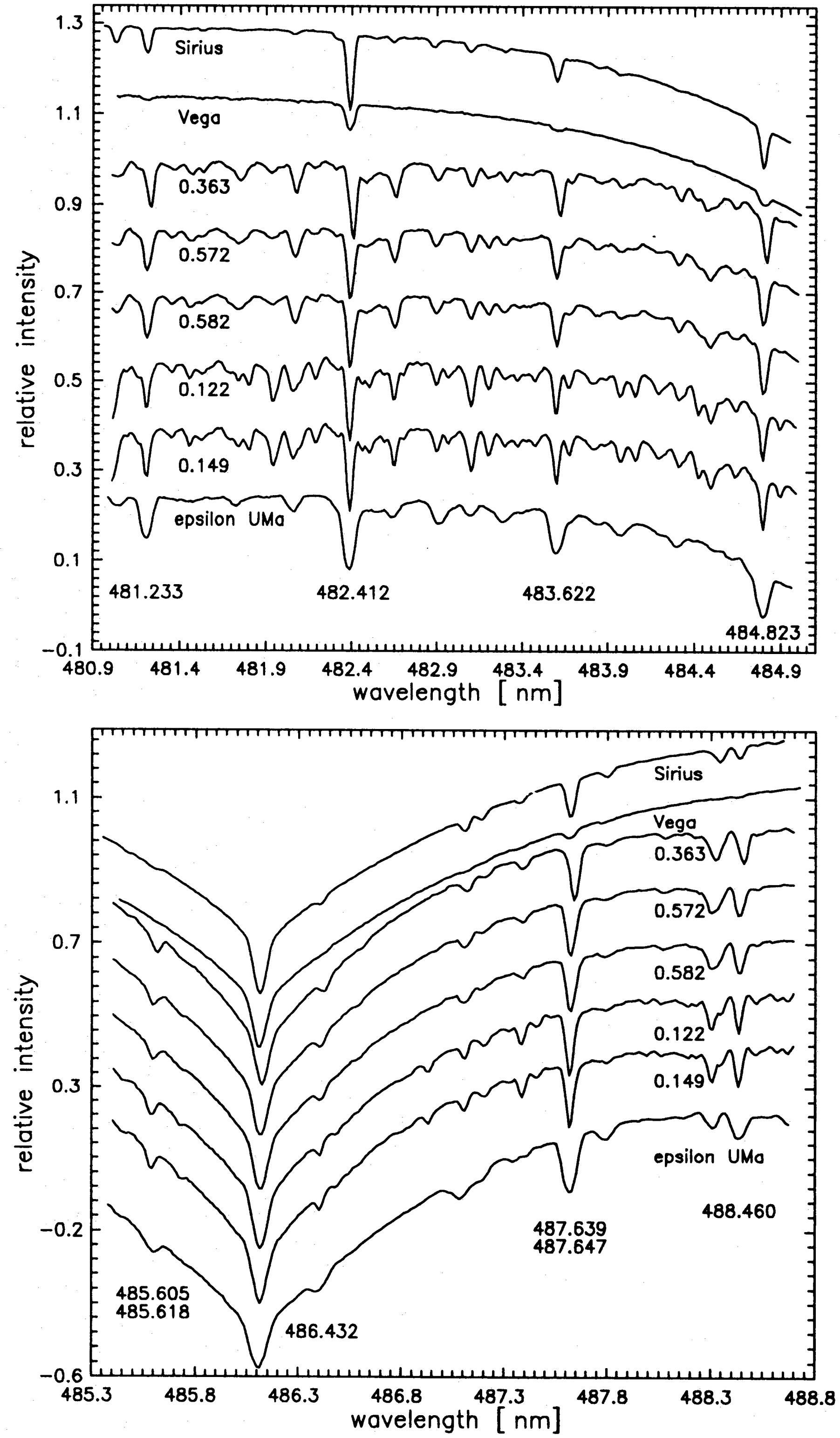

Figure 1. The observed spectra of the program stars. For α^2 CVn phases of individual spectra are shown

the rotational period. Fig.2 shows the results of the abundance determination from the individual lines of CrII Mult. No. 30 for each of the phases. It is clear that the individual abundance does not depend on the rotational phase. This does not confirm the possibility we suggested in our previous paper namely, that the abundance variation with depth might depend on the phase of rotation, i.e. on the configuration of two chromium spots on the visible hemisphere. Also the overall trend, suggesting a decrease of the chromium abundance outwards of the atmosphere, is conserved during the whole rotation. The scatter of the individual lines will be mentioned below.

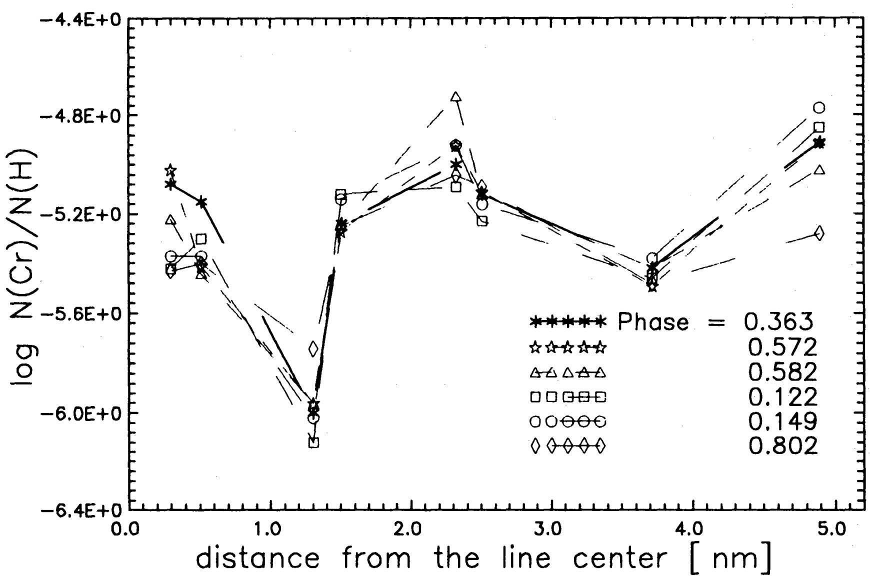

Figure 2. The Cr abundance *vs.* distance of a line from the center of H_β for individual spectra of α^2 CVn

3.2. ϵ UMa, Vega and Sirius

The result of our analysis for all the stars studied is displayed in Fig. 3. The least-squares fits are depicted as straight lines. The accuracy corresponding to the error $\lesssim \pm 0.5$ pm in the measurement of equivalent widths for the individual non-coadded spectra, is $\lesssim \pm$ 0.1 in log A (A=N(Cr)/N(H)). The three comparison stars are remarkably different in their peculiarity types: while Vega is rather underabundant in metals, Sirius belongs to Am-stars, and ϵ UMa is a Cr-type CP2-star, magnetic- and line-variable. In spite of this they show the same $\log(A) - \Delta\lambda$ dependence. Regardless of the moderate increase towards upper layers being real, or due to the imperfect fit of the model to the real atmosphere. The main result is that different types of A-stars have atmospheres of the same character. Only α^2 CVn, which is of practically the same peculiarity type as ϵ UMa, behaves anomalously. The picture, obviously, requires a theoretical investigation of the diffusion of the iron-peak elements.

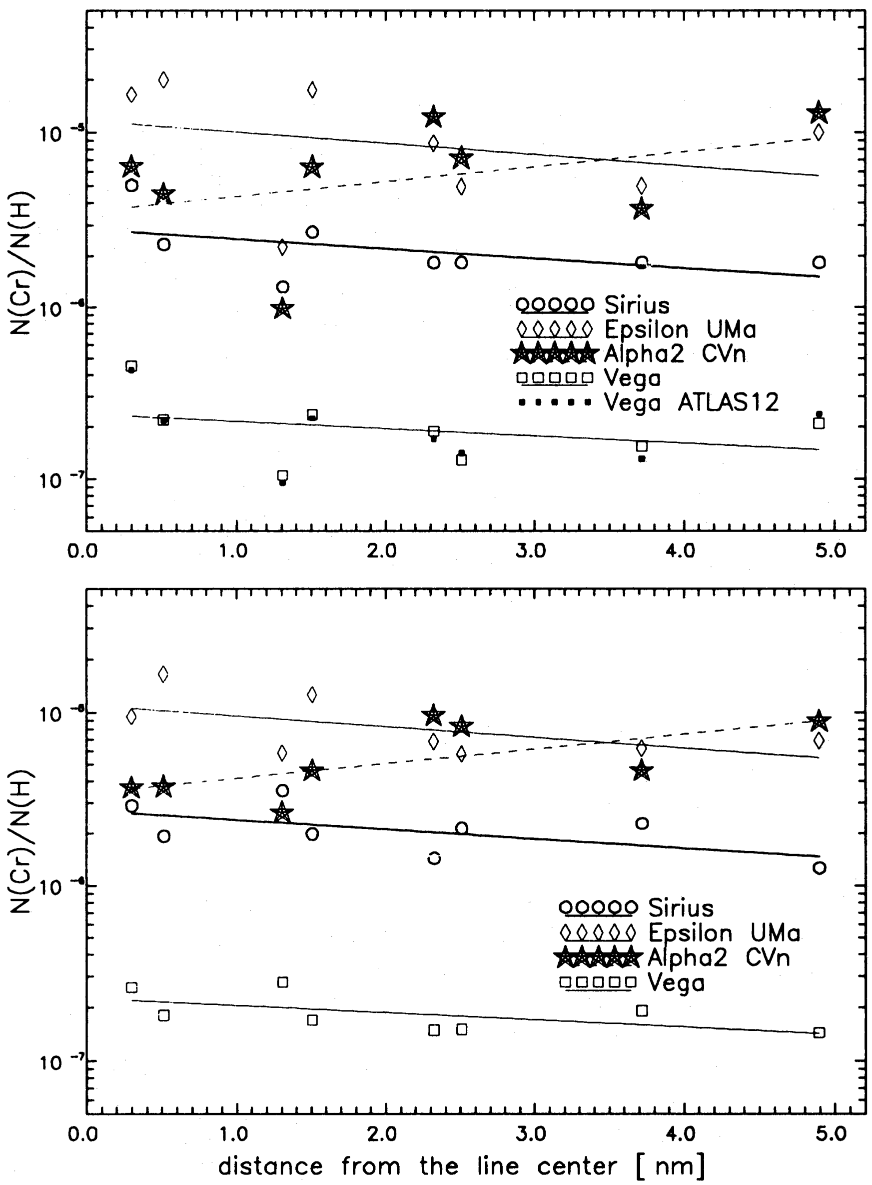

Figure 3. Top: the Cr abundance *vs.* distance of a line from the center of H_β. The ATLAS12 model after Castelli & Kurucz (1994). Bottom: the same, corrected for systhematic shifts, see text. The dashed line is the least-square fit for α^2 CVn

The individual values show remarkable scatter around their best-fit lines. As the individual deviations seem to be systematically shifted mostly with the same bias (Fig.3 top) which may be due to the inaccuracy in the *gf*−data, we corrected the values of *gf* for the average systematic shifts (Fig.3 bottom). The result is that the points are distributed more closely around their lines of fit without altering the character of the dependence.

4. Conclusions

We have investigated the high S/N Reticon spectra of four various CP-type stars to test the hypothesis that CP-stars should have their over/underabundant elements stratified with depth. Three of the four stars studied show identical and practically normal behaviour, while α^2 CVn is anomalous in the sense that some increase of the Cr abundance inwards of the atmosphere is indicated. This, of course, is a positive answer to the question whether some stratification exists, however, it was expected to be of an opposite sign. If this is a positive answer, another question arises: Why does ϵ UMa, another Cr-type CP-star, not behave in the same way?

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