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FUNDAMENTAL PARAMETERS OF AP-STARS 78 VIR (HD~118022) AND AX CVN (HD~110066)

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Determination of the fundamental parameters of stars is one of the main tasks of astrophysics. Magnetic chemically peculiar (Ap) stars HD~118022 (78 Vir) and HD~110066 (AX CVn) have similar strengths of the surface magnetic field ~3 – 4 kGs..The atmospheric analysis of the these two Ap stars results in the determination of the effective temperatures T_{eff}, surface gravities $\lg g$, radii $R/R_{\odot}$ and luminosities $L/L_{\odot}$, as well as element abundances by self-consistent way. It allows to define more accurately their position on the Hertzsprung-Russell diagram. Additionally, we derived the vertical distribution (stratification) of Fe and Cr elements for all spectra. Our analysis is based on high-resolution (R = 65000), high S/N spectra of 78~Vir obtained with the NARVAL spectropolarimeter attached to the 2 m telescope of the Pic du Midi observatory (7 phases of rotation), and on one spectrum at the phase of magnetic maximum which was obtained with the UVES (R = 80000) spectrograph of the VLT. For star AX CVn the spectra were obtained with ESPaDOnS (R = 81000) spectropolarimeter of CFHT. HD 118022 and HD 110066 show nearly similar element abundance pattern and element stratification.

Keywords: Fundamental parameters – Magnetic stars – Chemically peculiar stars

1. INTRODUCTION

The magnetic chemical peculiar stars 78 Vir (HD 118022) and AX CVn (HD 110066) are well studied variable stars of spectral classes A1p SrCrEu and A0p SrCrEu respectively. According to current estimates the averaged surface magnetic fields are $B_s = 3000$ Gs for 78 Vir and $B_s = 4100$ for AX CVn [1, 2].

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Spectra of Ap stars are characterized by anomalous chemical abundances of many elements. Usually light elements, He, CNO, show a deficiency compared to the solar abundunces while heavier elements, especially rare earth elements (lanthanoids), are enhanced by few orders of magnitudes [3]. To explain the anomalous chemical compositions in magnetic stars, Michaud proposed a mechanism of diffusion separation in the atmospheres of Ap stars [4] under the combined action of several forces, the main of which are gravitational pressure directed toward the center of the star, and the radiation pressure force that pushes particles into the outer layers of the atmosphere. This fact creates conditions for the diffusion of chemical elements (vertical stratification).

Studies of the stratification of chemical elements by spectral observations showed that most of the elements to Ba mainly are concentrated closer to the photosphere (deep layers of the atmosphere) with an abrupt decrease of abundance towards the upper layers [5]. Heavier rare earth elements are concentrated in the upper layers of the star's atmosphere [6]. Anomalous chemical abundance with the stratification affects the spectral energy distribution (SED) through absorption in lines, which distinguishes it from SED in normal stars.

2. MODEL ATMOSPHERE

When we know initial fundamental parameters of the star ($T_{eff}, \lg\, g\,, metallicity and B_s$), it is possible to calculate the model atmosphere. For studied stars initial parameters were taken from [7]. The initial model atmosphere was calculated using the ATLAS9 program [8]. After that the atmosphere parameters were refined by comparing the observed (calibrated in asolute flux units) and theoretical energy distribution taking into account the individual chemical anomalies and the element stratification in stellar atmosphere. In subsequent iterations the models atmospheres were calculated by LLmodels [9], where the line absorption is calculated with the individual abundances and stratification.

The synthetic spectrum calculations with taking into account the magnetic field were carried out using program Synmast [10]. Atomic parameters were taken from the 3rd version of the Vienna Atomic Line Database VALD3 [11].

3. CHEMICAL ABUNDANCES

The average abundance of an element was determined by equivalent widths measurements with the help of a code WidSyn [12], where magnetic (Zeeman) splitting of spectral lines was taken into account. The abundance is given as the logarithm of the ratio of the number of given element atoms to the total number of atoms of all elements - $\log(N_{el}/N_{tot})$. The abundances of the following elements are determined: C, N, O, Na, Mg, Al, Si, S, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Sr, Y, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Er, Tm, Yb.

Abundances in HD 118022 and HD 110066 are similar, and show a typical pattern for Ap stars: deficiency of light elements of CNO, then nearly solar Na and Mg abundances, an excess of an order of magnitude for iron-peak elements, and a large excess of the rare-earth elements (REEs) (Fig. 1).

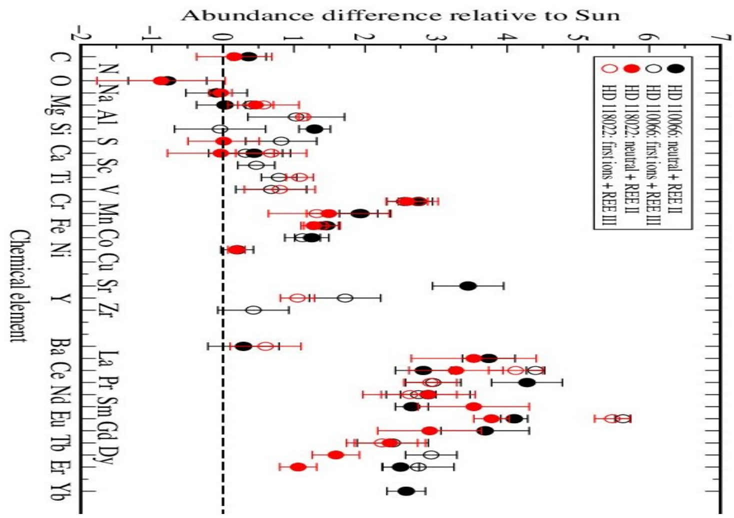

Fig. 1. Abundances of stars relative to solar values.

4. STRATIFICATION

The chemical stratification depends on the effective temperature T_{eff} and $\lg g$ magnetic field strength $\langle B_{\rm s}\rangle$ of the star [13]. As follows from the theoretical stratification calculations [14], the abundance distribution may be represented by a step function with four parameters: the element abundance in the upper atmosphere, the element abundance in the lower atmosphere, the position of abundance jump in the atmosphere and the width of this jump. It was then widely used in empirical stratification analysis (e. g. [5, 9]).

A sample of unblended lines with different excitation potentials $E_{\rm i}$ and various intensities was selected to study the stratification in the atmosphere of Ap stars. This choice suggests the formation of spectral lines at different optical depths, which makes it possible to probe the different atmospheric layers of a star. Fe and Cr elements were condsidered because their lines provide the main contribution to the observed line spectrum. 24 lines of Fe and 15 Cr lines in both ionization stages were selected for HD~118022, and 24 Fe lines and 19 Cr lines - for HD~110066. The stratification of the elements was calculated by the programm DDAFIT [9].

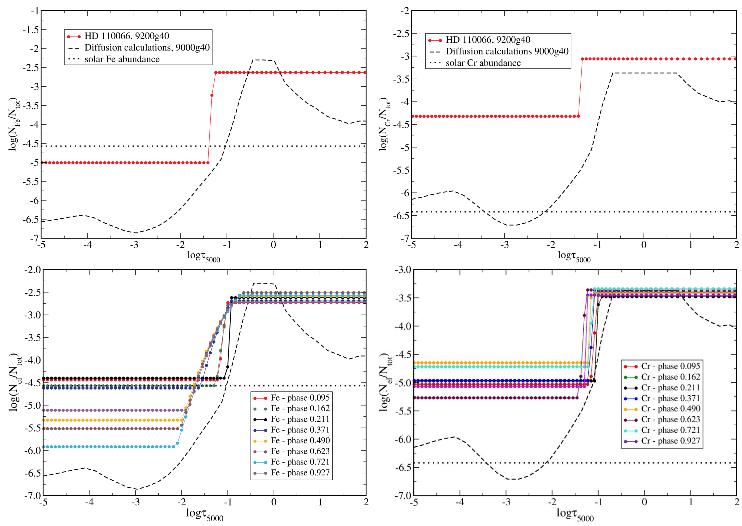

Fig. 2. Stratification of Fe and Cr in the atmospheres of HD 110066 (upper panel) and HD 118022 (lower panel). The dashed line shows the theoretical distributions of Cr and Fe for the 9000g40 model. The dotted line shows the solar abundance.

Abundance distributions in the atmospheres of both stars are shown in Fig.2, where the empirical stratifications were compared with the theoretical diffusion calculations [13, 15].

5. FUNDAMENTAL PARAMETERS

To compare the observed fluxes from the star with the theoretical flux at different wavelengths, we need to know the radius of the star and the distance (parallax) to it. Theoretical fluxes are calculated using an atmospheric model. We optimize stellar radius, T_{eff}, and $\lg g$ for a given abundance pattern and stratification to reach the best fit to the observed energy distribution. This approach allows us to refine the atmospheric parameters and the radius of the star simultaneously. The final parameters of the atmospheric models for HD~118022 and HD~110066 are presented in Table~1.

Table 1. Fundamental parameters of stars of study.

Stars	T_{eff}, K	$\lg g$	B_s, kG	$R/R_\odot$	$L/L_\odot$	Parallax, mas [Reference]
HD 118022	9142±30	4.2±0.2	3.0	2.10±0.02	1.44±0.05	17.65 [16]
HD 110066	9200±100	4.1±0.1	4.1	2.68±0.02	1.66±0.02	7.131 [17]

6. CONCLUSION

In this work we carried out a detailed atmospheric analysis of two Ap stars employing high-resolution spectroscopy. HD 118022 and HD 110066 show nearly similar element abundance pattern: CNO deficiency, practically solar Na and Mg abundance, 1-2 dex overabundance of the iron peak elements, and a large excess of the rare-earth elements (REEs). Our empirical abundance stratification for Fe and Cr analysis is in a good agreement with the predictions of modern diffusion models. The fundamental atmospheric parameters are determined.

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