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mCP stars with photometrically simple behaviour

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Abstract. We analyzed *ubvy* and $H_{\rm p}$ light curves of 19 well-observed magnetic CP stars selected from the *On-line Database of Photometric Observations of mCP Stars*, of which light curves in all the five colours were similar. We assumed that among these stars with photometrically simple behaviour (PSB) could be found ones with a single photometric spot. The knowledge gained by analysing those simple situations would help us comprehend more complicated cases.

Light curves of the 19 PSB mCP stars proved generally to be nearly symmetrical, but surprisingly diverse. The analysis shows that only in the case of HD 110956B, HD 188041, and perhaps HD 193722 are we able to explain their photometric behaviour by a simple one-spot model. Occurrence of more than one photometric spot on an mCP star is therefore more typical.

Key words: stars: chemically peculiar – stars: variables: light curves – methods: data analysis

1. Introduction

It is generally accepted that the rotationally-modulated photometric variability of a magnetic CP star originates as a consequence of the non-uniform horizontal structure of its atmosphere induced by a strong global magnetic field and an uneven surface distribution of the chemical elements.

Recently we successfully simulated the observed light-variability of the He-strong CP star HD 37776 in *uvby* colours by adducing an inhomogeneous elemental horizontal distribution. Although this star displays a relatively complex surface pattern with several relatively bright and/or dark regions (see Krtička *et al.* 2007) and a quadrupole-dominated magnetic field (Thompson, Landstreet 1985), its light curve has a fairly uncomplicated single wave form. However, HD 37776 is not a typical representative for its considerably complex magnetic field geometry, which can make the stellar surface a bit disordered. A still better subject could be the Si star HD 177410 (Krtička *et al.*, 2008), which has only two bright spots on the surface, and we do not exclude the existence of mCP stars with even simpler photometric structure and only one dominant spot associated with the spectroscopic or magnetic structures on their surfaces.

In this brief preliminary study we attempt to seek out and study mCP stars which could contain such easily readable surface structures. Understanding the simplest case should pave the way for understanding the common, more complicated, ones.

2. mCP stars with photometrically simple behaviour

Mikulášek *et al.*, (2007 a) showed that the variable part of a light curve (LC), Δm_c in the colour c of an mCP star, can be expressed as a linear combination of two normalized orthogonal phase functions $f_1(\varphi), f_2(\varphi)$, which can be found easily by means of the advanced principal component analysis (Mikulášek, 2007):

$$\Delta m_c(\varphi) \cong A_{1c}\, f_1(\varphi) + A_{2c} f_2(\varphi); \tag{1}$$

$$\sum_{j=1}^{N} f_1^2(\varphi_j) = \sum_{j=1}^{N} f_2^2(\varphi_j) \cong \frac{N}{2}; \quad \sum_{j=1}^{N} f_1(\varphi_j) f_2(\varphi_j) = 0, \tag{2}$$

where N is the number of measurements, φ_j is phase of the j-th measurement.

We quantify the similarity of two-colour LCs by the ratio

$$r^2 = \sum_{c=1}^{5} A_{2c}^2 / \sum_{c=1}^{5} A_{1c}^2, \tag{3}$$

and we assume that the LCs of an mCP star are mutually similar if $r < 0.15$. In such a degree of similarity the LCs can be described sufficiently by a unique phase function, which implies mathematically that the second term in Eq. 1 can be neglected.

Out of the 85 stars with known ephemerides and with the *uvby* and H_p from the *On-line Database of Photometric Observations of mCP Stars* (Mikulášek *et al.*, 2007 b), only 19 mCP stars satisfy the above-mentioned criterion of similarity: two He-weak, twelve Si, and five SrCrEu-type stars. Rather surprisingly, the shapes of their LCs are very diverse (see Fig. 3); we qualify that as follows:

We assume the phase function $f_1(\varphi)$ has the form:

$$f_1(\varphi) = \sqrt{1 - a_1^2 - a_2^2}\ \cos(2\pi\varphi) + a_1 \cos(4\pi\varphi) + a_2 \sin(4\pi\varphi). \tag{4}$$

If the timing of the linear ephemeris is set so that the term with $\sin(2\pi\varphi)$ is zero, then the basic extrema of the LCs occur near phases 0 and 0.5. The variable part of the LCs of a PSB star is then characterized by a set of amplitudes A_{1c} which can be arranged into a vector $\overrightarrow{A} = [A_{1u}, A_{1v}, A_{1b}, A_{1H_\mathrm{p}}, A_{1y}]$, and by the two parameters a_1, a_2 from equation 4. A LC characterized by $a_1 > 0$ has a sharper maximum at phase 0 and a flatter minimum (see e. g. HD 197322), and vice

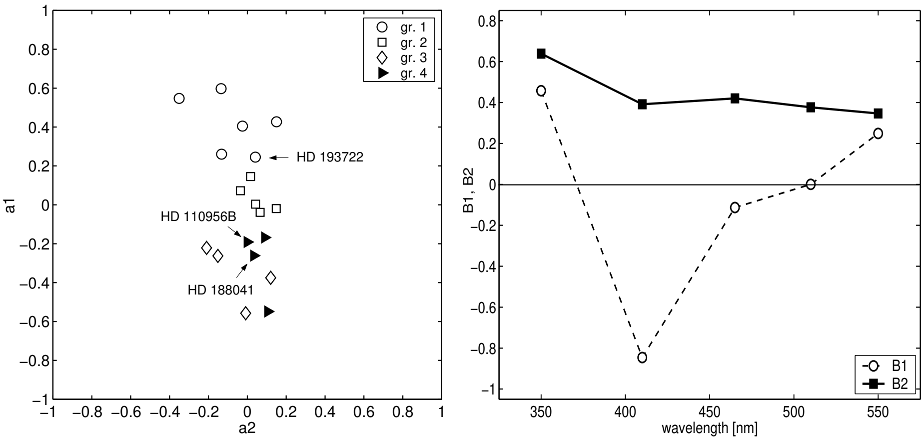

Figure 1. Left: The relation between LC parameters a_1 and a_2 shows that the LCs of our PSB stars are only slightly asymmetric. LCs can be divided into four groups. The three stars whose LCs can be interpreted by the one-spot model are denoted by their HD names. **Right:** Two basic dependencies of LC amplitudes upon effective wavelength.

versa for $a_1 < 0$. The parameter a_2 expresses the measure of asymmetry of an LC: the larger $|a_2|$, the larger the asymmetry. The relation between parameters a_1, a_2 is depicted in Fig. 1 left.

The components of the amplitude vectors $\overrightarrow{A}$ of a PSB star are not independent. They can be expressed by a linear combination of two basic normalized vectors $\overrightarrow{B_1}$, $\overrightarrow{B_2}$ (courses of $B_{1,2}(\lambda)$ – see Fig. 1 right, where the wavelength λ denotes the maximum transmissivity of the photometric filter concerned) with coefficients A_1, A_2, namely $\overrightarrow{A} = A_1\,\overrightarrow{B_1} + A_2\,\overrightarrow{B_2}$. For the relationship of parameters A_1 and A_2 see Fig. 2. This indicates that there are at least two different mechanisms responsible for the contrast of a photometric spot with respect to the surrounding stellar surface. The surface of an mCP star therefore shows at least two types of photometric spots which differ in their colour grades. Those spots can of course coincide positionally, thus either strengthening or suppressing the resultant contrasts in particular photometric colours.

The first mechanism which appears to be effective in all types of mCP stars creates bright spots in *uvby* owing to a redistribution of energy from the UV region to the optical one originating at least partly in bound-free transitions of overabundant ions. In hot CP stars the most important elements seem to be silicon, iron and helium. The symptomatic feature of this mechanism is the monotonous decline of the amplitude of light variations B_2 with increasing effective wavelength, as shown in Fig. 1 right. The effect is reproduced well by our models (Krtička *et al.*, 2008).

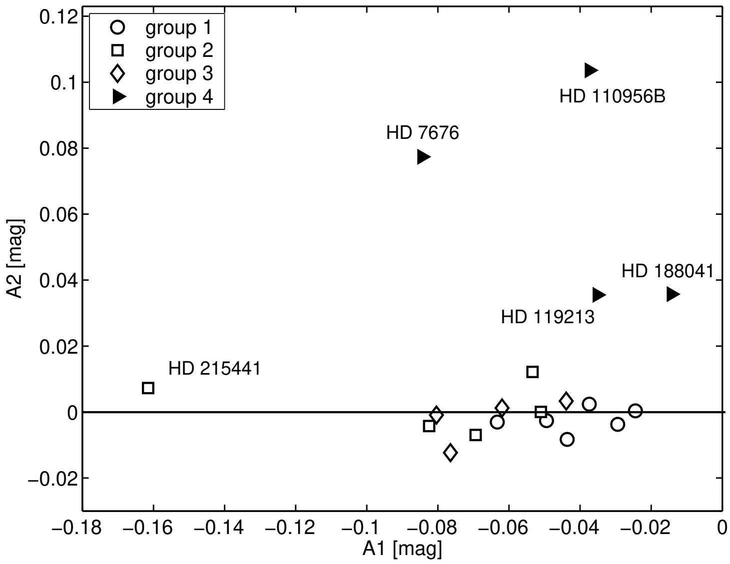

Figure 2. The relation between the effective amplitudes A_1 and A_2, corresponding to $\overrightarrow{B_1}, \overrightarrow{B_2}$. The cool mCP stars (group 4) strongly differ from other PSBS.

The second mechanism, manifesting itself through strong variations of the c_1 index and characterizing the height of the Balmer jump, is present only in the coolest mCP stars. The photometric spots caused by this mechanism are markedly dark in the v band, which is where the largest light variations are observed. We speculate that the strong opacity caused by various overabundant elements in a cool atmosphere suppresses the Balmer jump. The purest example of the light variations controlled by this mechanism is HD 110956B, which has the largest amplitude among all mCP stars (see Fig. 3).

3. Parametrization and classification of PSB stars

The set of $uvby$ and H_p light curves of each of the PSB stars can be satisfactorily described by the parameter set $\{a_1, a_2, A_1, A_2\}$.

According to those parameters, we sort out all the PSB stars into four groups.

- **Group 1**: $A_2 \cong 0,\ a_1 \geq 0.24$, double wave LCs with two unequally prominent bright spots centered on the phases $\varphi = 0$ and 0.5. Example: HD 177410.
- **Group 2**: $A_2 \cong 0,\ |a_1| \leq 0.24$, single-wave LCs. Example: HD 215441.
- **Group 3**: $A_2 \cong 0,\ a_1 \leq -0.24$, double-wave LCs with two unequally prominent bright spots centered in the vicinity of $\varphi = 0$. Example: HD 49333.

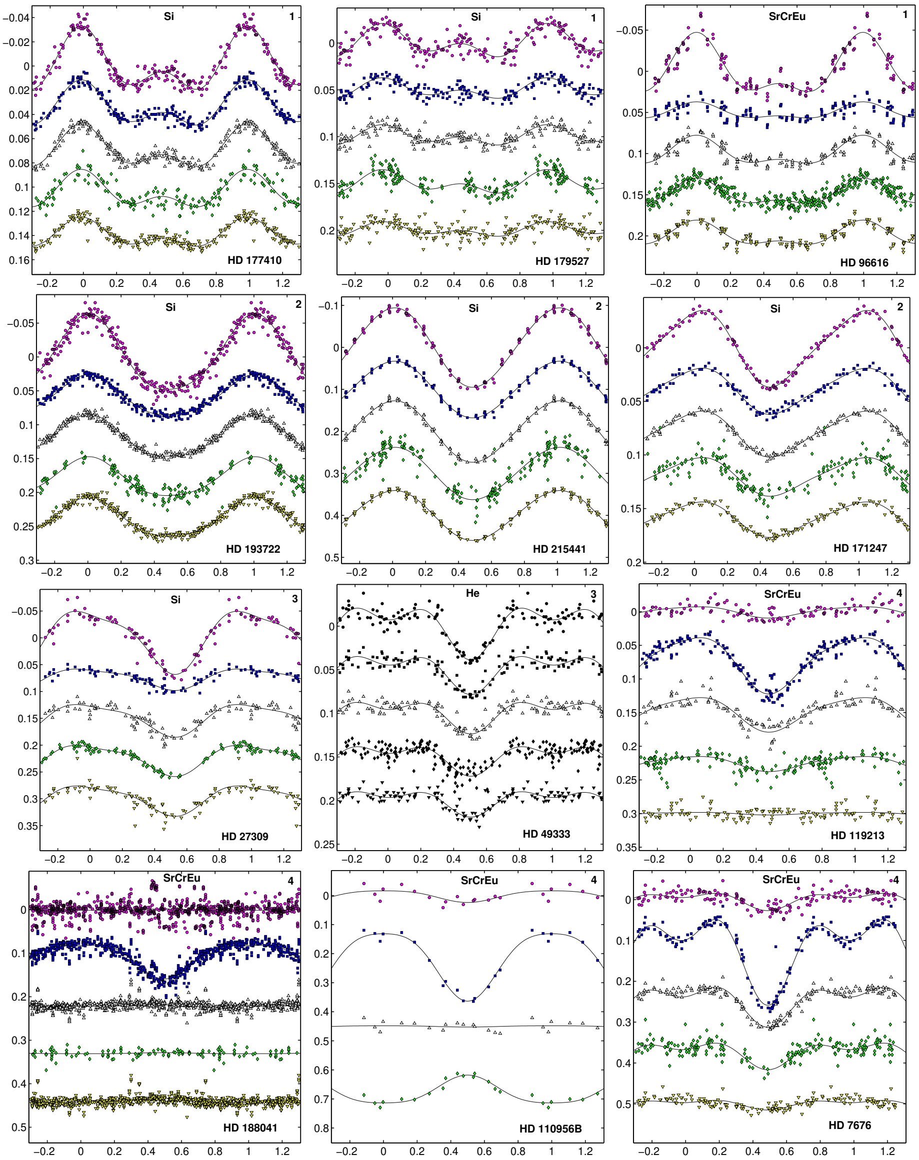

Figure 3. Light curves of 12 out of the 19 photometrically simply behaving mCP stars. In each panel there are displayed u, v, b, H_p, y light curves, the name of the star, its CP type and the number of the photometric group.

– **Group 4**: $A_2 \neq 0$, cool CP stars showing the largest variations in v, caused by a dominating dark spot (e.g. HD 110956B) with a minimum near $\varphi =$

0.5. In addition, another dark spot (as in HD 7676) or a bright one (as in HD 119213) can also be present on the surface.

4. Conclusions

All the stars with asymmetric LCs (e.g. HD 171247), as well as all the stars with double-wave LCs (groups 1 and 3) must be eliminated from the short list of 19 candidates in which LCs can be explained by the simple one-spot model. all the stars of the group 2 with $a_1 < 0$ must also be eliminated as they have two or more undistinguished bright spots centered on $\varphi = 0$. Thus, out of the stars in the groups 1, 2 and 3 only the Si-star HD 193732 remains a candidate to be explained by the simple one-spot model. Our analysis of the LCs produced by the one-spot model shows that, for $a_1 < 0.15$, the spot covers almost the whole hemisphere of the star.

HD 188041 and HD 110956 are candidates in group 4. However, it should be noted that, owing to specific geometry, the dominant photometric spot may suppress the visibility of another spot.

We conclude that the presence of two or more photometric spots on mCP stars is quite typical. It seems that the photometrically simple stars do not differ from the others, and that their belonging to the privileged group is probably only the consequence of the distributions of spots on the surface with respect to the rotational axis.

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