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The light variations of some CP2 SrCrEu stars*

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Abstract. — In the framework of a programme of checking the periods of chemically peculiar stars, eight southern stars have been observed in the *uvby* system. Seven stars have been previously known to be light variables, but for some stars the periods were not accurate enough to phase together different kinds of observations carried out several years apart. The periods of HD 83368, HD 98088, and HD 153882 are confirmed. For the stars HD 49976, HD 111133, HD 118022, and HD 164258 we present here more refined values of the period. No variability has been detected for the star HD 137949 within a time scale of the order of ten days. (The observations are available via ftp. 130.79.128.5 at the CDS).

Key words: stars: chemically peculiar — stars: variables: other

1. Introduction

In the vast majority of cases the variability of CP stars is currently explained in terms of the oblique rotator model. In the framework of this model, the period of the observed light, spectrum and magnetic field variations is nothing else than the rotation period. Accurate knowledge of the period of variability of CP stars is hence a fundamental step in understanding their complex behavior, especially as far as the phase relation between the magnetic, spectral and light variations is concerned.

In a recent paper (Catalano et al. 1991a) we have discovered CP stars to be variable also in the infrared, but for too many stars of the sample the period has not been determined with the requested accuracy to investigate the phase relation between the near infrared light curves and the visible light, spectroscopic and magnetic field variations. Since the most convenient way to determine the period is to make multicolor photometric observations, we have started a program in order to accurately determine the periods on the basis of new photometric observations and to supplement those available in the literature.

In this paper we report the results concerning eight CP2 stars of the subgroup showing overabundances of Sr Cr and Eu.

*Based on observations collected at the European Southern Observatory, La Silla Chile

2. Observations

The observations have been carried out in *uvby* with the 50 cm Danish photometric telescope at ESO-La Silla, Chile, during an observing run in March 1991. As in previous papers (Catalano & Leone 1993a,b), program stars were measured by choosing closeby comparisons showing as similar color and brightness as possible (Table 1)[1].

The starting point for our period search was the value given in the literature (see Catalano & Renson 1984, 1988, and Catalano et al. 1991b, 1993). In the cases of the stars HD 83368, HD 98088, and HD 153882 the periods available in the literature do match quite well our data, hence no period search was carried out. For the stars HD 49976, HD 98088, HD 111133, and HD 118022 we could combine our data with others available in the literature and the complete four-colour data sets were analyzed with Renson's algorithm (Renson 1978, 1980). To eliminate the aliases, or at least to reduce them, we compare Deeming's (1975) power-spectrum with $1/\theta_1$ Renson criterion plots. We select as trial frequencies those giving rise to coinciding maxima in both diagrams. Hence we perform the fit of the data with the corresponding period and look for the minimum standard deviation σ of the fit. The analysis of σ into an appropriate range of possible periods allows to discriminate among different possible periods and the aliases are eliminated. Finally a check is also done on the

[1]The observations are available in electronic form via an anonymous ftp copy at the CDS as LATEX tables of magnitude differences (program star minus comparison star) versus JD

Table 1. Programme Stars, their characteristics and ephemeris elements used to compute the phases of the variations. Spectral types for the program stars are taken from the *General Catalogue of CP stars* (Renson et al. 1991), those of comparison stars are from the Bright Star Catalogue (Hoffleit & Jaschek 1982)

Program Stars							Comparison Stars			
HD	HR	Sp. type	m_V	JD($\phi = 0$)	Instant of	P(days)	HD	HR	Sp. type	m_V
49976	2534	A1 SrCrEu	6.29	2441615.10	*uvby* max.	2.97666	49481	—	B8	6.7
83368	3831	A7 SrCrEu	6.17	2444576.169	$-B_e$ extr.	2.851982	82578	—	A9 IV/V	6.54
98088	4369	A9 SrCrEu	6.14	2434419.130	periastron	5.905130	96620	4315	F0 Vn	6.09
111133	4854	A1 SrCrEu	6.34	2439253.78	*uvby* max.	16.48281	109860	4805	A1 V	6.33
118022	5105	A2 CrEuSr	4.94	2434816.90	*y* max.	3.722084	121607	5244	A8 V	5.91
137949	—	F0 SrEuCr	6.7	—	—	—	138268	5756	A8 V	6.22
153882	6326	A1 CrEu	6.31	2432752.730	pos. crossover	6.00890	153809	—	A0	7.0
164258	6709	A3 SrCrEu	6.37	2448339.77	*uvby* min.	0.829	164259	6710	F2 IV	4.62

magnetic and spectroscopic data, if available. The error in the period value is evaluated according to the relation given in Horne & Baliunas (1986).

The assumed ephemeris elements are reported in Table 1. For each light curve a least-square fit of all data has been performed with a function of the type:

$$\Delta m = A_0 \; + A_1 * \cos(2\pi(t-t_0)/P + 2\pi\phi_1) \\ + A_2 * \cos(4\pi(t-t_0)/P + 2\pi\phi_2) \quad (1)$$

In this relation Δm is the magnitude difference in each filter between the CP star and the comparison star, t is the JD date, t_0 is the assumed initial epoch, P is the period in days. This procedure can be partially accounted for by considering that within the accuracy of the measurements a sine wave and its first harmonic appear to be generally adequate to describe the light curves (North 1984; Mathys & Manfroid 1985) and the magnetic field variations (Borra & Landstreet 1980; Bohlender et al. 1993).

The parameters of least-squares fits and their errors are listed in Table 2. The error for a given parameter of the fit is defined as the change in parameter value which increases the rms deviation of the observed Δm values with respect to the fitted curve by 1σ. In the figures, where the light variations are plotted, filled circles represent our data, while other symbols represent the observations of other authors.

2.1. *HD 49976 = HR 2534 = V592 Mon*

A rather strong magnetic field was measured in HD 49976 by Babcock (1958a) who also found evidence of an extraordinary range of variation of the SrII lines.

Photometric observations were carried out in *uvby* by Pilachowski et al. (1974) who derived a period of 2.976 days. These authors carried out a detailed analysis of the magnetic field and the spectral line variations. According to Pilachowski et al. (1974), the SrIIλ4215 and CaIIλ4933 line strength variations are in phase with the *uvby* light variations, the maximum coinciding with the phase of positive crossover. Two further magnetic observations have been performed by Mathys (1991).

On the basis of photometric and spectroscopic observations Maitzen & Albrecht (1975) improved the value of the period to 2.9760($\pm$0.0001) d.

To refine the period value we have combined the observations by Pilachowski et al. (1974) and by Maitzen & Albrecht (1975). The best representation of all photometric data was obtained with the period 2.97666 d. Let us note here that, because of the complex behavior of the light variations, the error in the period obtained from Horne & Baliunas (1986) formula, based on the fit of the observations by means of a mean curve, is quite high: an empirical estimate of $\pm$0.00008 d was obtained by minimizing the displacement of the maximum light among the various sets of data. The light curves of HD 49976 are plotted in Fig. 1 versus the phase computed by means of the ephemeris elements:

$$\mathrm{JD}(uvby\,\mathrm{max.}) \;=\; 2441615.10 \;+\; 2.97666\,E \quad (2)$$

where the assumed initial epoch is the actual time of maximum light as taken from the observations of Pilachowski et al. (1974). The light variations are double-waved, in phase with each other, and show the same general behavior as the SrIIλ4215 and CaIIλ4933 line strength variations with a secondary maximum more pronounced in v and y than in u and b. The amplitude is the largest in the u filter ($\sim$ 0.06 mag. peak to peak), and decreases to $\sim$ 0.04 mag. in b and to $\sim$ 0.03 mag. in v and y.

Table 2. Parameters of the least-square fit of the light curves according to formula (1) in the text and their relative errors

HD	filter	A_0	A_1	A_2	φ_1	φ_2
49976	u	-0.0060 ± 0.001	-0.0174 ± 0.007	0.0140 ± 0.001	0.135 ± 0.005	-0.135 ± 0.008
	v	-0.4445 ± 0.001	-0.0067 ± 0.001	0.0110 ± 0.001	0.134 ± 0.012	-0.145 ± 0.012
	b	-0.5752 ± 0.001	-0.0124 ± 0.001	0.0143 ± 0.001	0.162 ± 0.013	-0.153 ± 0.022
	y	-0.5842 ± 0.001	-0.0101 ± 0.001	0.0085 ± 0.001	0.132 ± 0.014	-0.136 ± 0.024
83368	u	-0.2774 ± 0.0005	-0.0176 ± 0.0008	0.0222 ± 0.0011	0.174 ± 0.012	0.233 ± 0.005
	v	-0.3282 ± 0.0005	-0.0061 ± 0.0008	0.0225 ± 0.0011	-0.002 ± 0.022	0.226 ± 0.005
	b	-0.3629 ± 0.0005	-0.0029 ± 0.0008	-0.0041 ± 0.0007	0.032 ± 0.049	-0.055 ± 0.038
	y	-0.3585 ± 0.0005	-0.0014 ± 0.0009	-0.0105 ± 0.0009	0.807 ± 0.088	0.635 ± 0.013
98088	u	0.0197 ± 0.0006	0.0045 ± 0.0010	-0.0047 ± 0.0010	-0.358 ± 0.029	-0.110 ± 0.026
	v	-0.0538 ± 0.0007	0.0163 ± 0.0010	0.0139 ± 0.0011	-0.260 ± 0.010	-0.059 ± 0.011
	b	-0.0526 ± 0.0008	0.0033 ± 0.0010	0.0017 ± 0.0012	-0.258 ± 0.049	-0.567 ± 0.088
	y	0.0206 ± 0.0007	0.0013 ± 0.0010	-0.0049 ± 0.0009	-0.450 ± 0.012	-0.212 ± 0.030
111133	u	-0.1792 ± 0.0005	-0.0053 ± 0.0007	0.0020 ± 0.0007	-0.099 ± 0.022	-0.057 ± 0.091
	v	-0.0354 ± 0.0004	-0.0179 ± 0.0007	0.0043 ± 0.0007	-0.766 ± 0.006	-0.214 ± 0.022
	b	-0.0553 ± 0.0005	-0.0237 ± 0.0007	0.0034 ± 0.0007	-0.794 ± 0.005	-0.274 ± 0.024
	y	-0.0013 ± 0.0005	-0.0085 ± 0.0007	0.0021 ± 0.0008	-0.749 ± 0.011	0.740 ± 0.055
118022	u	-1.3031 ± 0.0006	0.0166 ± 0.0010	-0.0044 ± 0.0010	0.219 ± 0.008	0.062 ± 0.029
	v	-1.1774 ± 0.0006	0.0082 ± 0.0010	-0.0046 ± 0.0010	0.169 ± 0.017	-0.003 ± 0.029
	b	-1.0931 ± 0.0006	0.0139 ± 0.0010	-0.0038 ± 0.0009	0.193 ± 0.010	0.063 ± 0.032
	y	-0.9729 ± 0.0006	0.0115 ± 0.0010	-0.0034 ± 0.0009	0.185 ± 0.011	-0.027 ± 0.039
153882	u	-1.0861 ± 0.0010	0.0153 ± 0.0137	0.0061 ± 0.0011	0.063 ± 0.001	0.202 ± 0.033
	v	-1.0564 ± 0.0010	-0.0648 ± 0.0014	-0.0063 ± 0.0011	-0.086 ± 0.030	0.194 ± 0.034
	b	-1.0286 ± 0.0008	-0.0032 ± 0.0011	0.0099 ± 0.0011	0.074 ± 0.057	0.221 ± 0.021
	y	-0.9786 ± 0.0009	-0.0010 ± 0.0013	0.0072 ± 0.0013	-0.038 ± 0.184	0.186 ± 0.028
164258	u	1.8780 ± 0.0009	0.0070 ± 0.0010	—	0.677 ± 0.026	—
	v	1.4561 ± 0.0008	0.0068 ± 0.0012	—	0.750 ± 0.003	—
	b	1.5854 ± 0.0009	0.0060 ± 0.0013	—	0.769 ± 0.033	—
	y	1.7457 ± 0.0009	0.0037 ± 0.0014	—	0.712 ± 0.049	—

2.2. *HD 83368 = HR 3831 = IM Vel*

The late type CP2 star HD 83368 is a visual double with a magnitude difference $\Delta V = 2.85$ and a separation of 3.3 arcsec, which implies that both components are measured in the photometric observations.

The photometric variability of HD 83368 has been detected by Renson & Manfroid (1978). Kurtz (1982) discovered that HD 83368 shows pulsations with periods of ~6 and 12 min modulated within a period of about 2.85 d. Thompson (1983) measured a magnetic field symmetrically variable from +800 to −800 gauss within a period of 2.857 d. This value of the period has been confirmed by Mathys & Manfroid (1985), Heck et al. (1987), and Kurtz & Marang (1988). Recently Kurtz et al. (1992) have shown that the period of the pulsation amplitude modulation is equal to the period of the mean-light variation and have refined the rotation period to the value 2.851982±0.000005 d. This value represents quite well our observations, hence no further refinement was necessary. The light curves of HD 83368 are plotted in Fig. 2 versus the phase computed by means of ephemeris elements (Kurtz et al. 1992):

$$\mathrm{JD}(-B_e\ \mathrm{extr.}) = 2444576.169 + 2.851982\,E \qquad (3)$$

From Fig. 2 we see that the light curves show a double wave behavior with nearly equal amplitudes in both the extrema. The amplitudes in u and v are of the order of 0.06 mag. peak to peak. In b the variation is barely evident, while in y the amplitude is of the order of 0.03 mag. and the variation is in antiphase with the one in u and v. Because of the light dilution due to the presence of the close companion, the amplitude should be considered about 8 percent larger (Renson et al. 1984).

2.3. *HD 98088 = HR 4369 = SV Crt*

HD 98088 is the brightest component of a visual binary (ADS 8115) whose components are separated by 57.2 arcsec and the secondary is 3.8 mag. fainter. It is also a double-lined spectroscopic binary with a quite well-known orbit (Abt 1953; Abt et al. 1968; Wolff 1974) and a period of 5.90513 d.

The magnetic field of HD 98088 has been measured by Babcock (1958a,b), who showed it varies with the same

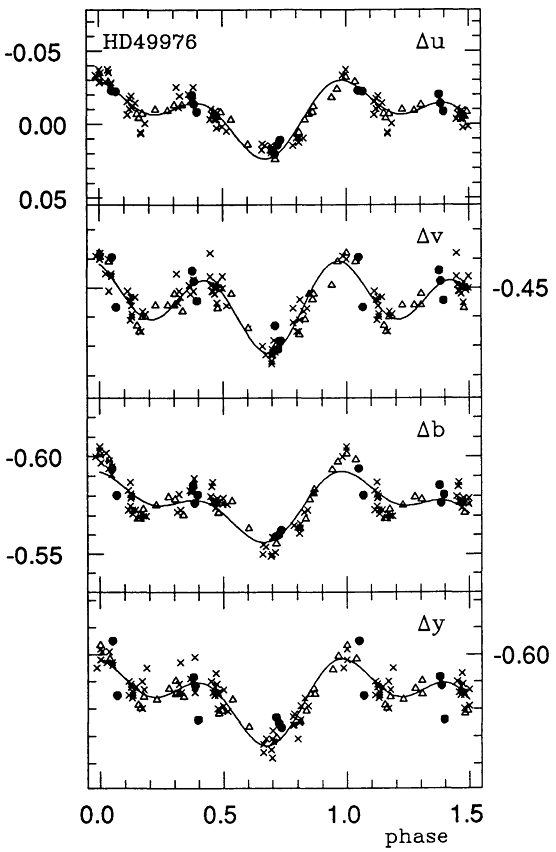

Fig. 1. Lightcurves of HD 49976. The phases are computed according to the ephemeris elements (2). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.. Codes: △ Pilachowski et al. (1974), × Maitzen & Albrecht (1975), • present paper

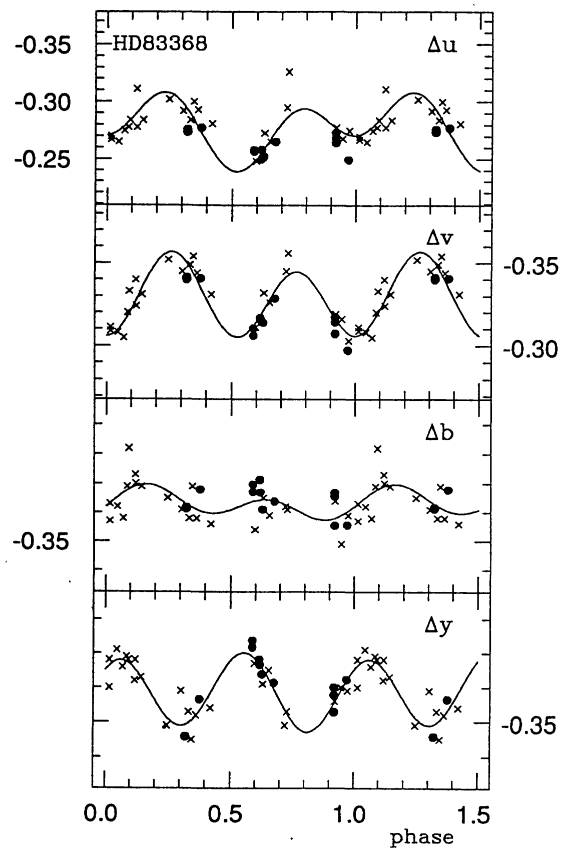

Fig. 2. Lightcurves of HD 83368. The phases are computed according to the ephemeris elements (3). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.. Codes: × Heck et al. (1987), • present paper

period as the orbital motion.

The light variations of HD 98088 have been studied by Maitzen (1973) and Wolff & Morrison (1975). Using the data of these authors, together with our observations, we found that the period of this star is very well defined and it still adequately represents observations carried out many years apart. The observations of HD 98088 are plotted in Fig. 3 versus the phase computed by means of the ephemeris elements of Abt et al. (1968):

$$\mathrm{JD(periastron)} = 2434419.130 + 5.905130\,E \qquad (4)$$

The light variation of HD 98088 is clearly evident in the v filter only, where it is double-waved and has an amplitude of the order of 0.06 mag. peak to peak. In the u filter the amplitude is of the order of 0.02 mag., while in b and y it is of the order of 0.01 mag..

Two observations of HD 98088 are not plotted in Fig. 3, since the Δm shows a very large value, ≈ 0.12 mag. in all filters, occurring between phases 0.40 and 0.50, where the v minimum is located. Careful check of the observations led to the conclusion that such a large dispersion is real, in fact it is partially present in Maitzen's (1973) Δv and ΔB curves, and could be an evidence of a (very sharp) eclipse: according to assumed epoch of periastron the primary minimum should occur at phase 0.45 ± 0.10. If confirmed, such an event would be extremely important, since very few CP stars show eclipsing binary phenomenology. However, we have planned further observations, hence we have excluded these two observations from the present discussion.

2.4. *HD 111133 = HR 4854 = EP Vir*

Babcock (1958a) found the presence of a fairly strong magnetic field in HD 111133.

The first photometric investigation by Stepien (1968) in the UBV system gave indication of a period of the order of 11 d.

The magnetic variation has been studied by Wolff & Wolff (1972), who found it occurs within a period of 16.31 d. The same period was found for the spectral line intensity of CrI, CrII, FeI, and FeII, and the light variations. Further magnetic field measurements have been carried out

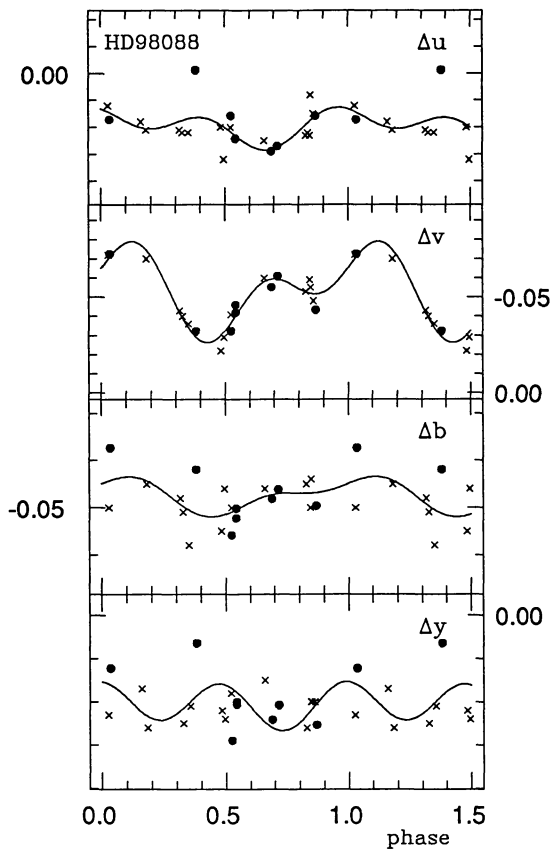

Fig. 3. Lightcurves of HD 98088. The phases are computed according to the ephemeris elements (4). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.. Codes: × Maitzen (1973), • present paper

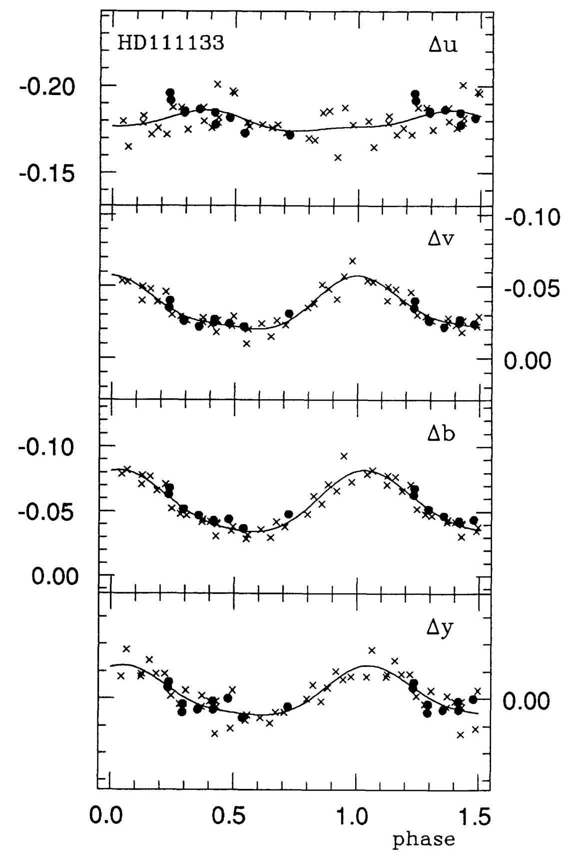

Fig. 4. Lightcurves of HD 111133. The phases are computed according to the ephemeris elements (5). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.. Codes: × Wolff & Wolff (1972), • present paper

by Glagolevsky et al. (1982).

The spectrum variations have been later studied by Engin (1974), while the Δa peculiarity index and $b-y$ variations have been studied by Buchholz & Maitzen (1979).

Since only $b-y$ data were available from dr. Maitzen, the value of the period has been refined by combining these observations with those of Wolff & Wolff (1972) and ours. In such a way we got five sets of data. The best representation of all photometric observations was obtained with the period 16.48281($\pm$0.00040) d.

The *uvby* light curves of HD 111133 are shown in Fig. 4, where they are plotted versus the ephemeris elements:

$$\mathrm{JD}(uvby\,\mathrm{max.}) = 2439253.78 + 16.48281\,E \qquad (5)$$

The analysis of the light curves shows that all of them are in phase with each other; the amplitudes amount to 0.03 mag. in the u filter, 0.02 mag. in v, 0.04 mag. in b, and 0.03 mag. in y. It is interesting to note that in all light curves the minimum is broader than the maximum, indeed the ascending branch is steeper than the descending one, where an incipient double-wave might be present.

2.5. *HD 118022 = HR 5105 = 78 Vir = CW Vir*

HD 118022 is the first star in which a magnetic field has been detected (Babcock 1947).

The magnetic field variation has been subsequently studied by Preston (1969), who first determined the correct period to be 3.7220 d from the analysis of the crossover effect. Several authors have provided further magnetic measurements (Wolff & Wolff 1971; Wolff & Bonsack 1972; Wolff 1978; Borra 1980; Borra & Landstreet 1980), all of them confirming the period found by Preston.

The light variability has been studied in *UBV* by Stepien (1968) and Winzer (1974), in the Walraven system by van Genderen (1971), and in *uvby* by Wolff & Wolff (1971). These studies have confirmed the 3.722 d value of the period.

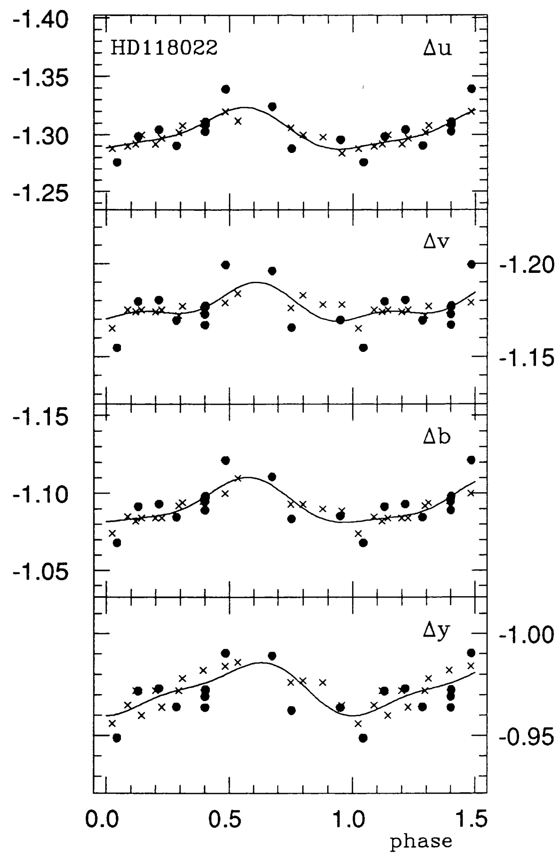

Fig. 5. Lightcurves of HD 118022. The phases are computed according to the ephemeris elements (6). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.. Codes: × Wolff & Wolff (1971), • present paper

Combining Wolff & Wolff (1971) observations with ours, we found that the light curves show the minimum dispersion when the period: P = 3.722084(±0.000042) d is used.
The resulting light curves are plotted in Fig. 5 with the following ephemeris elements:

$$\mathrm{JD}(y\ \mathrm{min.}) = 2434816.90 + 3.722084\, E \quad (6)$$

As it is evident from Fig. 5 the light curves of HD 118022 show essentially single-waved trend and are in phase with each other, with amplitudes of about 0.04 mag. in u, and 0.03 mag. in v, b and y.

2.6. *HD 137949 = ζ^2 Lib = GZ Lib*

The unusual strength of the lines of SrII in the spectrum of HD 137949 has been noted by Adams et al. (1935). Babcock (1958a) also noted the unusual intensity of the EuII lines and found evidence of a rather strong magnetic field (≈ 1 kgauss). Further magnetic measurements were carried out by van den Heuvel (1971), who suggested that the magnetic field variation occurs within 18.4 d. This value of the period was not confirmed by Wolff (1975), who instead supported evidence of a magnetic variation occurring within a period of 23.26 d, but did not detect light variations larger than 0.01 mag.
From photometric observations Kurtz (1982) suggested that the rotation period of HD 137949 could be 7.194 d. However, the light variability of this late CP star, if ever exists, is controversial. Essentially, no variability was evident from photometric observations carried out by Wolff (1975) and by Deul & van Genderen (1983). No variations have also been found in the UV by van Dijk et al. (1978). Our *uvby* measurements are consistent with no light variation in excess of 0.01 mag.

2.7. *HD 153882 = HR 6326 = V451 Her*

The star HD 153882 has been discovered to be magnetic variable by Gjellestad & Babcock (1953) who found the period to be 6.005 d.
The light variability of this star has been studied by Jarzebowski (1960), Chugainov (1961), Stepien (1968), van Genderen (1971), Panov & Schöneich (1975), Schöneich et al. (1976), Rakosch & Fiedler (1978) and Hempelmann (1981). All these authors have confirmed the value 6.009 d of the period as given by Babcock (1958a).
Further magnetic observations of HD 153882 have been carried out by Hockey (1971), Preston & Pyper (1965) and very recently by Mathys (1991).
Taking into account all magnetic data, relative to a time interval of more than forty years, Mathys (1991) refined the value of the period to 6.00890(±0.000015) d. Mathys confirmed the quite sinusoidal character with polarity reversal of the magnetic variation, occurring with the same period as the photometric one, and extrema in the range −1600 to +1600 gauss. Mathys also studied the equivalent width of the FeII λ5961 line and found large anharmonic variations whose extrema coincide in phase with the light variations but show no simple phase relation with the extrema of the magnetic field.
Since the period of HD 153882 is well-defined, we did not perform any search. The light curves of HD 153882 are shown in Fig. 6, where they are plotted versus the phase computed by means of the ephemeris elements:

$$\mathrm{JD}(\mathrm{pos.\ crossover}) = 2432752.730 + 6.00890\, E \quad (7)$$

From Fig. 6 we see that all light variations are double-waved and in phase with each other. The amplitude is 0.04 mag peak to peak in u, of the order of 0.02 mag. in v and b, and slightly less than 0.02 mag. in y.

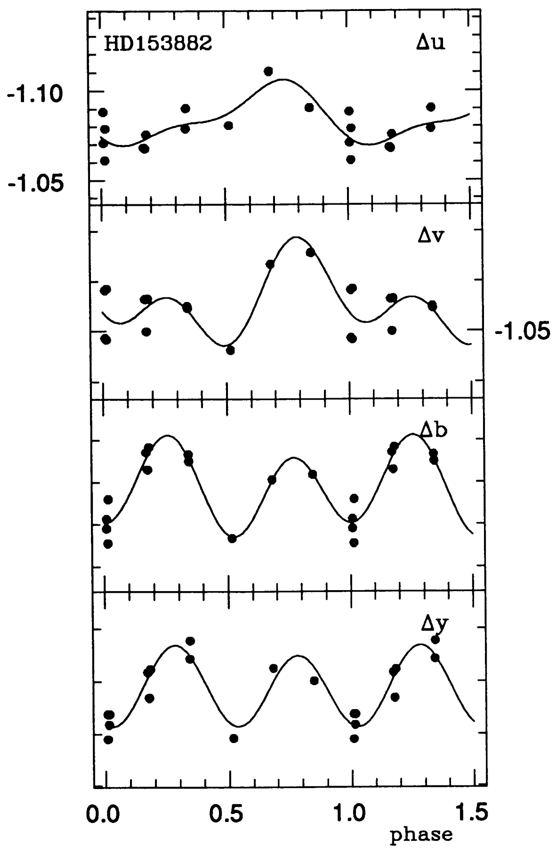

Fig. 6. Lightcurves of HD 153882. The phases are computed according to the ephemeris elements (7). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.

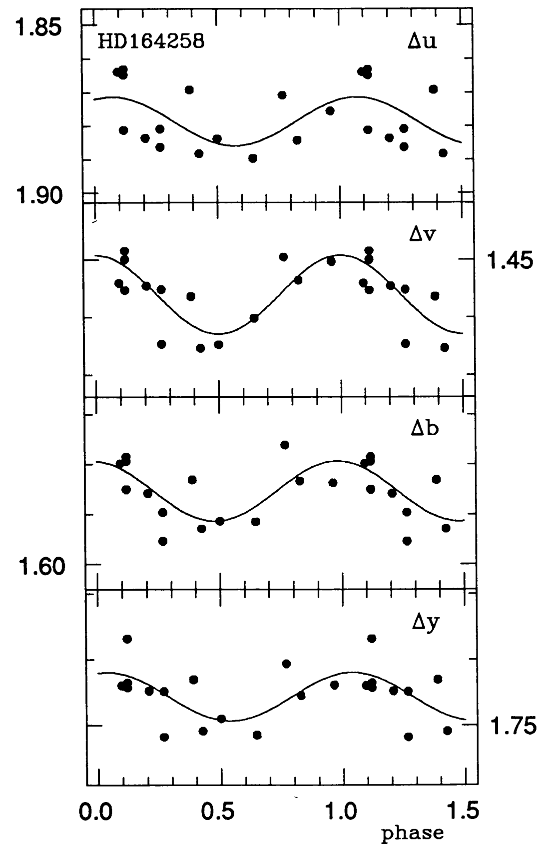

Fig. 7. Lightcurves of HD 164258. The phases are computed according to the ephemeris elements (8). The solid line is a least-square fit of the observations by formula (1) as described in the text. In the magnitude axis one subdivision is 0.01 mag.

2.8. *HD 164258 = HR 6709 = V2126 Oph*

Babcock (1958a) included HD 164258 in the list of the stars with probable magnetic fields and noted the unusual strength of the SrII lines. Bonsack (1974) found indication of variability in the lines of EuII but did not determined any period.

The star HD 164258 has been found to be variable in light by Renson & Manfroid (1980) who gave indication of a period of about 2.41 d.

However, Manfroid & Mathys (1985) suggested shorter periods as 0.719 or 0.359 d.

The search for periodicity led to the value 0.829 (±0.005) d, which gives quite a good representation of the observations.

The light curves of HD 164258 are shown in Fig. 7, where they are plotted versus the phase computed by means of the ephemeris elements:

$$\mathrm{JD}(uvby\ \mathrm{max.}) = 2448339.77 + 0.829\,E \qquad (8)$$

From Fig. 7 we see that all light variations are single-waved and in phase with each other. The amplitudes are almost low and amount to about 0.02 mag peak to peak in u, 0.015 mag. in v and b, and 0.01 mag. in y.

3. Conclusions

We have presented new photometric observations of the CP2 stars HD 49976, HD 83368, HD 98088, HD 111133, HD 118022, HD 137949, HD 153882, and HD 164258.

To refine the period values for the stars HD 49976, HD 111133, HD 118022, and HD 164258 we have used our observations and those available in the literature. In the cases of the stars HD 83368, HD 98088, and HD 153882 the period values available in the literature still represent quite well all data.

HD 137949 has been confirmed to be constant within 0.01 mag..

From the analysis of the light variations we see that the amplitudes shown by CP2 of the SrCrEu subgroup are in the average smaller than those of hotter CP stars, but they show almost the same very complicated morphology of different behavior in different filters, in the sense that the shape of the variations and the phases at which their extrema occur do change with the wavelength. This result has to be taken into consideration when looking for the interpretation of the observed variations.

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