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Photoelectric photometry of chemically peculiar stars at the Catania astrophysical observatory. I. Observatory of HD 2453, HD 71866, HD 72968 and HD 126515

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Abstract. — Photoelectric observations of four CP stars are presented which were carried out from 1969 through 1975 at the Catania Astrophysical Observatory in the *UBV* natural system. For the star HD 2453 a revised value (546.87) of the period is derived from the magnetic field data available in the literature which satisfies the photometric observations. The periods of the stars HD 71866 and HD 72968 are confirmed to be 6.80054 and 11.305 days respectively. For the long period variable HD 126515 Preston's 130.0 days value, deduced from the magnetic field variations, is shown to be the period of the light variations too.

Key words : CP stars — Light variability — HD 2453 — HD 71866 — HD 72968 — HD 126515.

1. Introduction.

Knowledge of the period of variability of the chemically peculiar (CP) stars of the upper main sequence is fundamental to understand the complex phenomenology presented by these stars, which is currently interpreted in terms of the oblique rotator model (Babcock, 1949; Stibbs, 1950; Deutsch, 1958; Preston, 1971a).

Photoelectric photometry is well-suited in this respect because it necessitates relatively small telescopes and gives a relatively high accuracy in short observing times.

A long-term programme of period determination of CP stars by photoelectric photometry was undertaken in 1967 at the Catania Astrophysical Observatory and the stars were mainly chosen among those for which magnetic observations were available in the literature.

In referring to the various subgroups of CP stars we will use Preston's (1974) nomenclature, according to which, for example, CP2 refers to the stars in which lines of Si, Cr, Sr, Eu, etc. are enhanced (these are also known in the literature as magnetic stars).

2. Observations, reduction and analysis of the data.

The photoelectric observations presented here have been carried out at the stellar station of the Catania Astrophysical Observatory from 1969 through 1975 in our natural *UBV* system with the telescopes, equipments and procedures decribed in Blanco *et al.* (1978).

The programme stars and the used comparison stars are listed in table I: the spectral types and peculiarities for the programme stars are taken from the "General Catalogue of the Ap and Am Stars" by Renson *et al.* (in preparation), while the data for the comparison stars are taken from the 41th revised edition of "The Bright Star Catalogue" (Hoffleit and Jaschek, 1982) or from the Smithsonian Astrophysical Observatory Star Catalog (Smithsonian Institution Publ. N. 4652, Washington, 1971).

TABLE I. — *Data on programme stars and comparison stars. The spectrum and peculiarity type for the programme stars are from "The General Catalogue of Ap and Am Stars" (Renson et al., in preparation). The data for the comparison stars are from "The Bright Star Catalogue" (Hoffleit and Jaschek, 1982) or from the Smithsonian Astrophysical Observatory Star Catalogue.*

Programme	stars	Comparison	stars	
HD2453	A1 Sr Eu Cr	HD1439 =	HR71	A0IV
		HD 952 =	HR44	A1V
HD71866	A1 Eu Sr Si	HD71844 =	GC11633	A3
		HD70273 =	GC11397	F0
HD72968	A0 Sr Cr	HD73451 =	HR3416	A1V+G
		HD73997 =	HR3437	A1Vn
HD126515	A2 Cr Sr	HD127167 =	HR5418	A5IV
		HD125489 =	HR5368	A7V

At least two comparison stars were used during the various runs in order to secure ourselves against the possibility that some of them could be variable. The magnitude differences in each filter between the programme and the comparison stars were computed by means of the formula:

$$\Delta m = \frac{1}{2}[(CP - C_1) + (CP - C_2) + \langle C_2 - C_1 \rangle] \quad (1)$$

where $\langle C_2 - C_1 \rangle$ is the annual average value of the magnitude differences between the comparison stars: this term has been introduced in formula (1) in order to take into account possible systematic differences in the instrumental photometric system due to alterations of the reflectivity of the telescope mirrors, transparency of the filters, and so on. Moreover the standard deviation of this term has been found to be very useful to have an estimate of the behavior of the comparison stars. In any case the changes of $\langle C_2 - C_1 \rangle$ for all the stars presented here never exceeded 0.015 magnitudes.

Search for periodicity has been carried out by means of the Fourier analysis of unequally spaced data technique as suggested by Deeming (1975). To distinguish if a peak in the periodogram was noise or signal we looked for peaks present simultaneously in all three filters. In the case more than one significant peak was present we choose the one that minimized the scatter of the observations around the function:

$$\Delta m = A_0 + A_1 \sin(2\pi(t - t_0)/P + \phi_1))$$

$$+ A_2 \sin(4\pi(t - t_0)/P + \phi_2)) \quad (2)$$

where:
- Δm is the magnitude difference in each filter computed by (1);
- t is the JD time of observation;
- t_0 is the initial epoch (given as J.D.$_0$ in Tab. II);
- P is the period in days;
- A_i and ϕ_i are the amplitudes and the phases.

When a reliable value of the period was found the data were phased by means of the simple formula:

$$\phi = (\mathrm{J.D.} - \mathrm{J.D.}_0)/P \quad (3)$$

where J.D.$_0$ is the assumed initial epoch and P is the period (in days). The assumed phase is of course the fractional part of the right-hand side of equation (3). For each programme star the initial epoch (J.D.$_0$), the adopted values of the period and the empirically estimated errors in these quantities are summarized in table II.

The parameters of the least-squares fit of the light curves are reported in table III.

3. Results for individual stars.

Here we present the observations of the individual stars and the results obtained.

TABLE II. — *The ephemeris elements for the programme stars used to compute the phase by means of formula (3).*

Star	Assumed initial epoch JD_o	Instant of	Period
HD2453	2442288.00 ±0.50	H_{eff} minimum	546.87 ±0.25
HD71866	2432957.90 ±0.02	Positive Crossover	6.80054 ±0.00002
HD72968	2432897.68 ±0.23	H_{eff} maximum	11.305 ±0.002
HD126515	2437015.00 ±1.00	H_s maximum	130.0 ±0.1

TABLE III. — *Parameters of the least-square fit of the hight curves according to formula (2) in the text. In the last column the standard deviation σ (in magnitudes) is given.*

Star	Filter	A_0	A_1	A_2	ϕ_1	ϕ_2	σ
HD2453	U	+1.17503	−.00709	−.00138	−.089	−.025	0.0010
	B	+1.11216	−.00536	−.00150	−.150	−.075	0.0008
	V	+1.01617	+.00593	−.00483	−.244	+.037	0.0010
HD71866	U	−0.58553	+.01418	+.00496	−.008	+.332	0.0012
	B	−0.46827	+.01262	+.00575	+.047	+.131	0.0013
	V	−0.35757	−.00682	−.00587	+.434	+.062	0.0011
HD72968	U	−1.47371	+.00829	−.00868	−.291	+.156	0.0012
	B	−1.37510	−.00220	+.01418	−.011	−.273	0.0018
	V	−0.92191	−.00859	−.01493	+.174	+.213	0.0012
HD126515	U	+0.85968	−.00872	+.00862	−.064	+.063	0.0012
	B	+0.98596	−.01763	+.00735	−.825	+.082	0.0015
	V	+1.11946	−.02265	+.00911	−.905	+.053	0.0019

3.1 HD 2453 = GC 553 = GR And. — The possible variability of the spectrum and of the effective magnetic field of the star HD 2453 (A1, Sr Eu Cr) was firstly pointed out by Babcock (1958a) who also suggested a general similarity (spectral and magnetic) to the long period magnetic variable star HD 188041 (HR 7575).

Photoelectric observations of HD 2453 in *UBV* have been carried out by Stepien (1968) and Winzer (1974a, b). Both these authors found HD 2453 to be constant on a short time baseline, although a periodicity of at least several months was not excluded by Stepien. No spectral variations were also evident on a ten years baseline (Winzer, 1974a). On the other hand, Preston (1970a) included HD 2453 into a list of suspected long period variables, giving evidence in support of this hypothesis. On the basis of *uvby* observations Wolff and Morrison (1973) suggested HD 2453 to be definitely variable but on a time scale of the order of two years. This result was later confirmed by Wolff (1975) who derived a period of 525 days for the variability of the magnetic field intensity and the c_1 photometric index.

Photoelectric observations of HD 2453 were carried out from 1970 to 1974 using the comparison stars listed in table I. First reduction of the observations confirmed the results of Wolff (1975), showing that HD 2453 has a definite variation in V, but no improvement of the period was obtained (Catalano and Vaccari, 1985).

To check the reliability of the 525 days period we decided to use the magnetic data by Wolff (1975) together with those by Babcock (1958a) because of the larger time lag between these two sets, both sets as a whole covering a 24 years time interval, i.e. about 16 times the 525 days period. However, as it has been pointed out by Hensberge *et al.* (1979), it is of basic importance to correct the published effective magnetic field values for inconsistencies introduced by the use of different instrumentations, if one wants to compare various sets of data. Hence we transformed the Mt. Wilson and Mt. Palomar measurements by Babcock (1958a) into the Lick system, by applying the linear transformation formula and the suitable coefficients given in the paper by Hensberge *et al.* (1979). Plots of all the magnetic data *versus* the phase computed by means of the 525 days period gave no satisfactory representation. Performing the search for the period by the method and the procedure described above and including also our photometric observations, we obtained a final value of 546.87 days for the period which gave the best phase diagrammes for all sets of data.

In figure 1 the magnetic field measurements and the photometric c_1 index (Wolff, 1975) are plotted *versus* the phase computed by means of the adopted ephemeris elements:

$$\mathrm{JD}\ (H_{\mathrm{eff}}\ \mathrm{minimum}) = 2442288.0 + 546.87\,E \qquad (4)$$

The magnitude differences between HD 2453 and the comparison stars, computed by means of formula (1), are listed in table IV and are plotted in figure 2 *versus* the phase computed according to the ephemeris elements (4). Each point in figure 2 represents the nightly average of multiple observations, mainly 2 to 3 observations per night, with a typical standard deviation of ±0.008 magnitudes.

TABLE IV. — *Observations of HD 2453. The magnitude differences HD 2453 minus the comparison stars HD 1439 and HD 952 are computed by means of formula (1) in the text.*

JD 2440000+	ΔU	JD 2440000+	ΔB	JD 2440000+	ΔV
838.5825	1.173	838.5825	1.106	838.5825	1.012
854.6154	1.174	854.6154	1.105	854.6154	1.031
860.5930	1.160	860.5930	1.113	860.5930	1.028
864.5332	1.167	864.5332	1.106	864.5332	1.019
870.5368	1.172	870.5368	1.115	870.5368	1.033
886.4930	1.176	886.5930	1.106	886.5930	1.028
894.4591	1.181	894.4591	1.107	894.4591	1.036
896.4609	1.171	896.4609	1.108	896.4609	1.020
1177.5607	1.185	1177.5607	1.116	1177.5607	1.004
1187.5816	1.179	1187.5816	1.128	1187.5816	1.002
1190.5712	1.180	1190.5712	1.119	1190.5712	1.005
1206.4917	1.181	1206.4917	1.125	1206.4917	1.005
1215.5343	1.177	1215.5343	1.122	1215.5343	1.003
1218.5235	1.176	1218.5235	1.118	1218.5235	1.014
1233.4823	1.178	1233.4823	1.112	1233.4823	1.005
1236.4893	1.186	1236.4893	1.117	1236.4893	1.009
1246.4177	1.179	1246.4177	1.117	1246.4177	1.020
1261.3055	1.174	1261.3055	1.108	1261.3055	1.002
1264.4380	1.180	1264.4380	1.122	1264.4380	1.008
1503.5679	1.172	1503.5679	1.115	1503.5679	1.013
1506.5615	1.177	1506.5615	1.105	1506.5615	1.004
1516.5599	1.170	1516.5599	1.110	1516.5599	1.010
1518.5624	1.185	1518.5624	1.110	1518.5624	1.022
1530.5916	1.176	1530.5916	1.101	1530.5916	1.002
1531.5553	1.170	1531.5553	1.100	1531.5553	1.013
1539.5818	1.176	1539.5818	1.111	1539.5818	1.020
1543.5755	1.175	1543.5755	1.114	1543.5755	1.018
1560.5882	1.168	1560.5882	1.113	1560.5882	1.010
1571.5747	1.176	1571.5747	1.117	1571.5747	1.025
1594.4968	1.179	1594.5968	1.117	1594.5968	1.022
1600.4730	1.182	1600.4730	1.116	1600.4730	1.024
1607.4664	1.187	1607.4664	1.115	1607.4664	1.018
1608.3989	1.176	1608.4989	1.112	1608.4989	1.022
1636.4341	1.198	1636.4341	1.116	1636.4341	1.021
1645.3800	1.180	1645.3800	1.118	1645.3800	1.009
2004.3320	1.159	2004.3320	1.111	2004.3320	1.020
2281.5929	1.177	2281.5929	1.115	2281.5929	1.018
2287.5001	1.173	2287.5001	1.114	2287.5001	1.000
2300.5474	1.171	2300.5474	1.111	2300.5474	1.006
2301.5801	1.166	2301.5801	1.109	2301.5801	1.010
2314.5036	1.172	2314.5036	1.097	2314.5036	1.003
2328.3917	1.175	2328.3917	1.118	2328.3917	1.016
2399.2953	1.155	2399.3953	1.103	2399.3953	1.006

3.2 HD 71866 = GC 11639 = TZ Lyn. — The magnetic field variations of the stars HD 71866 (A1, Eu Sr Si) have been studied by Babcock (1956; 1958a, b) and by Preston and Pyper (1965).

Photoelectric observations of HD 71866 have also been extensively carried out both in *UBV* and *uvby* photometric systems and are published in the literature (for complete references see Catalano and Renson, 1984 and 1988) with values of the period which have been progressively and slightly improved from the initial value of 6.7976 days established by Babcock (1956) to the currently assumed value of 6.80054 days (Hildebrandt *et al.*, 1985). It is important to note that all observers always used the same comparison star HD 71844.

Our photoelectric observations were performed in 1971 with HD 71844 and HD 70273 as comparison stars. Since the value of the period is well established we did not perform a complete search, but we only checked its reliability, which was confirmed indeed. The magnitude differences HD 71866 minus the comparison stars, computed by means of formula (1), are listed in table V and are plotted in figure 3 *versus* the phase computed on the basis of the ephemeris elements:

$$\text{JD (positive crossover)} = 2432957.9 + 6.80054\,E \qquad (5)$$

where the initial epoch is taken from Babcock (1956).

3.3 HD 72968 = HR 3398 = 3 Hya = HV Hya. — HD 72968 (A0, Sr Cr) is the first star for which an estimate of the intensity of the surface magnetic field has been carried out on the basis of the study of the Zeeman intensification of spectral lines on the saturated part of the curve of growth (Hensberge and de Loore, 1974).

Photoelectric observations of HD 72968 have been carried out in *uvby* by Wolff and Wolff (1971) who derived a period of 5.57 days, which indeed did not satisfy too well the magnetic field observations by Babcock (1958a). From the analysis of extensive photoelectric photometry performed at ESO-La Silla, Maitzen *et al.* (1978) were able to evidence

TABLE V. — *Observations of HD 71866. The magnitude differences HD 71866 minus the comparison stars HD 71844 and HD 70273 are computed by means of formula (1) in the text.*

JD 2440000+	ΔU	JD 2440000+	ΔB	JD 2440000+	ΔV
1036.4247	-0.585	1036.4295	-0.460	1036.4342	-0.356
1036.4473	-0.595	1036.4429	-0.469	1036.4381	-0.356
1036.4520	-0.590	1036.4572	-0.466	1036.4617	-0.353
1036.4754	-0.606	1036.4701	-0.466	1036.4662	-0.355
1043.3555	-0.582	1043.3610	-0.474	1043.3666	-0.361
1043.3719	-0.600	1043.3776	-0.483	1043.3834	-0.360
1056.3162	-0.589	1056.3257	-0.476	1056.3327	-0.354
1060.3152	-0.576	1060.3280	-0.450	1060.3359	-0.340
1060.3435	-0.568	1060.3503	-0.475	1060.3580	-0.359
1060.3673	-0.568	1060.3768	-0.469	1060.3846	-0.347
1060.3930	-0.583	1060.4019	-0.481	1060.4104	-0.343
1060.4194	-0.583	1060.4268	-0.467	1060.4346	-0.346
1062.4059	-0.598	1062.4134	-0.498	1062.4220	-0.350
1062.4293	-0.595	1062.4392	-0.493	1062.4472	-0.366
1062.4568	-0.607	1062.4650	-0.509	1062.4715	-0.364
1063.4080	-0.593	1063.4184	-0.472	1063.4261	-0.362
1066.3095	-0.573	1066.3170	-0.465	1066.3240	-0.353
1066.3316	-0.564	1066.3399	-0.464	1066.3470	-0.341
1066.3559	-0.568	1066.3643	-0.457	1066.3712	-0.348
1066.3782	-0.571	1066.3851	-0.462	1066.3927	-0.360
1068.3408	-0.590	1068.3484	-0.469	1068.3559	-0.377
1068.3638	-0.598	1068.3707	-0.469	1068.3774	-0.363
1068.3844	-0.599	1068.3912	-0.473	1068.3977	-0.376
1068.4046	-0.595	1068.4111	-0.475	1068.4189	-0.360
1071.3177	-0.580	1071.3274	-0.449	1071.3344	-0.373
1071.3413	-0.567	1071.3483	-0.453	1071.3580	-0.367
1071.3650	-0.572	1071.3726	-0.467	1071.3803	-0.361
1071.3879	-0.580	1071.3949	-0.459	1071.4017	-0.368
1071.4087	-0.584	1071.4150	-0.454	1071.4209	-0.361
1072.3121	-0.576	1072.3191	-0.454	1072.3302	-0.350
1072.3372	-0.571	1072.3441	-0.457	1072.3517	-0.342
1072.3588	-0.586	1072.3655	-0.453	1072.3725	-0.358
1072.3802	-0.594	1072.3872	-0.459	1072.3982	-0.349
1072.4055	-0.582	1072.4123	-0.461	1072.4187	-0.358
1089.3339	-0.596	1089.3413	-0.470	1089.3489	-0.365
1089.3566	-0.606	1089.3656	-0.466	1089.3746	-0.370
		1089.3900	-0.474	1089.3976	-0.363
1090.3295	-0.616	1090.3385	-0.485	1090.3469	-0.359

TABLE VI. — *Observations of HD 72968. The magnitude differences HD 72968 minus the comparison stars HD 73451 and HD 73997 are computed by means of formula (1) in the text.*

JD 2440000+	ΔU	JD 2440000+	ΔB	JD 2440000+	ΔV
1631.6329	-1.479	1631.6346	-1.385	1631.6362	-0.920
1631.6674	-1.481	1631.6695	-1.383	1631.6715	-0.921
1636.6437	-1.494	1636.6451	-1.404	1636.6463	-0.943
1636.6690	-1.496			1636.6715	-0.944
1639.6568	-1.472	1639.6580	-1.380	1639.6591	-0.999
1640.6641	-1.468	1640.6657	-1.374	1640.6669	-0.924
1641.6397	-1.461	1641.6314	-1.388	1641.6429	-0.919
1641.6650	-1.470	1641.6664	-1.380	1641.6676	-0.914
1655.6372	-1.482	1655.6386	-1.375	1655.6398	-0.901
1662.6375	-1.464	1662.6389	-1.362	1662.6404	-0.908
2423.4492	-1.468	2423.4511	-1.371	2423.4532	-0.917
2423.4780	-1.460	2423.4800	-1.374	2423.4818	-0.918
2423.5087	-1.461	2423.5106	-1.403	2423.5121	-0.929
2427.4582	-1.476	2427.4594	-1.382	2427.4528	-0.934
2427.4857	-1.474	2427.4881	-1.381	2427.4905	-0.925
2427.5215	-1.482	2427.5193	-1.380	2427.5175	-0.927
2431.4788	-1.460	2431.4770	-1.384	2431.4755	-0.913
2431.5128	-1.463	2431.5145	-1.371	2431.5163	-0.911
2433.4702	-1.478	2433.4687	-1.391	2433.4669	-0.935
2433.4918	-1.486	2433.4933	-1.390	2433.4946	-0.938
2433.5170	-1.486	2433.5153	-1.394	2433.5137	-0.933
2434.4792	-1.471	2434.4776	-1.380	2434.4760	-0.921
2434.5051	-1.469	2434.5064	-1.385	2434.5076	-0.927
2455.4119	-1.472	2455.4106	-1.376	2455.4091	-0.928
2455.4384	-1.462	2455.4400	-1.374	2455.4414	-0.926
3524.5202	-1.493	3524.5317	-1.397	3524.5202	-0.952
3524.5316	-1.495	3524.5400	-1.407	3524.5400	-0.945
3524.5400	-1.491	3524.5478	-1.402	3524.5479	-0.960
3524.5478	-1.499			3524.5550	-0.950
3850.6253	-1.476	3850.6287	-1.358	3850.6424	-0.923
3850.6424	-1.471	3850.6424	-1.350	3850.6501	-0.922
3850.6685	-1.465	3850.6435	-1.354	3850.6804	-0.913
3853.5967	-1.482	3853.5967	-1.373	3853.5967	-0.932
3853.6009	-1.487	3853.6088	-1.365	3853.6328	-0.928
3853.6454	-1.480	3853.6248	-1.366	3853.6454	-0.933
		3853.6289	-1.367		

a double wave variation in all filters with a periodicity of 11.305 days. This value of the period has been very recently confirmed by Heck *et al.* (1987).

Our photoelectric observations of HD 72968 were carried out from 1972 to 1975 using HD 73451 and HD 73997 as comparison stars (see Tab. I). HD 73451 was also one of the comparison stars used by Wolff and Wolff (1971), while HD 73997 was the comparison star used by Maitzen *et al.* (1978) and by Heck *et al.* (1987). As in the case of HD 71866, also for HD 72968 the period appears to be fairly well established and with far more observations than ours, so that we did not carry out the search for periodicity, but we only checked it.

The magnitude differences, HD 72968 minus the comparison stars, computed by means of formula (1), are listed in table VI and are plotted in figure 4 *versus* the phase computed on the basis of the ephemeris elements taken from Maitzen *et al.* (1978):

$$\text{JD}\ (H_{\text{eff}}\ \text{Maximum}) = 2432897.68 + 11.305\ E \qquad (6)$$

From figure 4 a slight difference in the heights of the maxima in all three filters is evident, in good agreement with the results of Maitzen *et al.* (1978).

3.4 HD 126515 = GC 19462 = FF Vir. — The star HD 126515 (A2, Cr Sr) is one of the very few CP stars in which the spectral lines split in the Zeeman components have been observed. This fact allowed Preston (1970b) to succeed in measuring the average surface field H_s which resulted to vary between 10 and 17 kG with a periodicity of 130 days. With the same period of the magnetic field and in phase with of the elements Si, Cr, Fe, Ti, Sr, and Eu.

No photometric observations of HD 126515 are available in the literature apart from a Δa study of the λ5200 continuum depression carried out by Hensberge *et al.* (1986). In this study the association of the surface region, in which the high peculiarity values originate, with the regions of enhanced spectral lines strength was inferred, rather than with the local magnetic field strength.

The observations of HD 126515 were carried out from 1972 to 1975 using HD 127167 and HD 125489 as comparison stars (see Tab. I). Search for periodicities with the procedure outlined above confirmed the 130 days value, which, on the other hand, was found by Preston (1970b) by analyzing observations obtained in a time interval longer than 12 years since he included in his work the measurements based on plates taken by Babcock (1958a). Hence we assumed the Preston's (1970b) ephemeris elements:

$$\text{JD}\ (H_s\ \text{Maximum}) = 2437015.0 + 130.0\ E \qquad (7)$$

The magnitude differences HD 126515 minus the comparison stars, computed by means of formula (1), are listed in table VII and are plotted in figure 5 *versus* the phase obtained using the ephemeris (7). It has to be noted that in figure 5 each point represents the nightly average of multiple observations (from a minimum of three to a maximum of six observations per night) with a typical standard deviation of ±0.005 magnitudes.

TABLE VII. — *Observations of HD 126515. The magnitude differeces HD 126515 minus the comparison stars HD 127167 and HD 126489 are computed by means of formula (1) in the text.*

JD 2440000+	ΔU	JD 2440000+	ΔB	JD 2440000+	ΔV
1417.4518	0.856	1417.4546	0.969	1417.4546	1.103
1422.4884	0.854	1422.4919	0.960	1422.4944	1.097
1428.4548	0.866	1428.4576	0.973	1428.4600	1.095
1431.3755	0.864	1431.3779	0.984	1431.3802	1.110
1469.4210	0.842	1469.4228	0.968	1469.4248	1.101
1470.3837	0.847	1470.3865	0.980	1470.3891	1.095
1478.4271	0.843	1478.4295	0.977	1478.4300	1.094
1775.6278	0.870	1775.6265	1.002	1775.6253	1.154
1794.5355	0.869	1794.5357	0.992	1794.5361	1.143
1803.4511	0.856	1803.4527	0.984	1803.4550	1.133
1808.4576	0.871	1808.4600	0.982	1808.4626	1.125
1816.4668	0.856	1816.4683	0.976	1816.4694	1.120
1824.3732	0.862	1824.3750	0.979	1824.3765	1.109
1828.3941	0.865	1828.3947	0.977	1828.3955	1.122
1835.3566	0.873	1835.3573	0.975	1835.3579	1.104
2131.6163	0.845	2131.6190	0.987	2131.6223	1.110
2170.4636	0.862	2170.4637	1.012	2170.4636	1.158
2176.4512	0.867	2176.4490	1.003	2176.4497	1.144
2178.3937	0.863	2178.3942	0.991	2178.3933	1.134
2180.3862	0.869	2180.3870	0.983	2180.3876	1.131
2194.4045	0.857	2194.4066	0.989	2194.4066	1.131
2205.4218	0.877	2205.4235	0.960	2205.4252	1.115
2206.4049	0.855	2206.4058	0.959	2206.4066	1.099
2562.4123	0.877	2562.4123	1.006	2562.4122	1.132

From figure 5 it is evident that the largest amplitude of the variations occurs in the V filter, where it amounts to about $0^{\text{m}}05$, and decreases to $0^{\text{m}}04$ in B and to $0^{\text{m}}03$ in U. From the same figure a different behavior is also evident for the light curves in the three colours: while in V and B the minimum of light is sharp and quite well defined, in U it appears quite shallow and not so well defined. Interesting enough, the instant of minimum in V and B (where it can be better appreciated) occurs at around the phase 0.6, just when the surface magnetic field attains its lowest intensity and all the line intensities are at their minimum (see Figs. 3 and 7 in: Preston, 1970b).

4. Conclusion.

Interpreting the observed light variations as due to an oblique rotating star, the equatorial rotational velocity v_e of the star can be computed by means of the simple formula:

$$v_e = 2\pi R/P = 50.613\ R/P \qquad (8)$$

where R is the radius in solar units and P is the period in days. When measurements of the projected rotational

velocity ($v_e \sin(i)$) are available in the literature, from the simple ratio $(v_e \sin(i))/v_e$ it is possible to estimate the angle i the rotational axis of the star forms with the line of sight. But this is possible only in principle, since, as stressed by Maitzen *et al.* (1978), in doing this we are facing the problem of determining the radii of the CP stars.
The radius of a star can be evaluated by using the formula:

$$\log(R/R_\odot) = 0.2\,[42.361 - M_{\rm bol} - 10\log(T_{\rm eff})] \qquad (9)$$

which implies the knowledge of the bolometric magnitude and of the effective temperature. The choice of the values of these quantities is a complicated task because of the special atmospheric structure of the CP stars. As it is well known, enhanced line blocking and backwarming may significantly alter the overall flux distribution. This means that a straightforward application to the CP stars of the usual calibrations appropriate for normal stars may lead to noticeable differences.
Valuable efforts have been done in recent years by many authors to establish reliable empirical and theoretical calibrations of the fundamental parameters of the CP stars. From a statistical analysis of the apparent rotational velocities and rotational periods of 78 CP2 stars having periods shorter than 10 days, Hensberge and Van Rensbergen (1990) have evaluated the distribution of the radii of these stars. Grouping them into three subsamples: Si stars, Si and other peculiarities or other plus Si, and other CP2 (i.e. the Cr, Sr and the rare earths CP2 stars) Hensberge and Van Rensbergen found the mean radii to be:

3.18 $R_\odot$ for Si stars
2.84 $R_\odot$ for Si plus other peculiarities
2.24 $R_\odot$ for the other (cooler) CP2 stars

Out our four stars, only HD 71866 is in the sample studied by Hensberge and Van Rensbergen, and, more precisely, in the second subsample. The stars HD 2453 and HD 126515 share the peculiarities of the third subsample, the one of the cooler CP2 stars. As far as it concerns the spectral peculiarities, HD 72968 should be considered as belonging to the third subsample, but, as Maitzen *et al.* (1978) have pointed out, HD 72968 is a hotter CP2 star, so that, as far as the value of the radius is concerned, it seems to be more appropriate to assign it the value typical of the subsample "Si plus other peculiarities". On the other hand the 2.84 $R_\odot$ value of the radius proper to this subsample is in good agreement with the range (2.75 - 3.0) estimated by Maitzen *et al.* (1978) by means of formula (9).

TABLE VIII. — *Observed and computed quantities necessary to compute the inclination angle i. The rotational velocity v_e is computed by means of formula (8) in the text. The reference codes for the values of $v_e \sin(i)$ are the following: P71 = Preston, 1971b; HL74 = Hensberge and de Loore, 1974; HV89 = Hensberge and Van Rensbergen, 1989.*

Star	Period (days)	$R/R_\odot$	v_e (Km/s)	$v_e sini$ (*Refer.*)	i
HD2453	546.87	2.24	0.2	< 6 (P71)	-
HD71866	6.80054	2.84	21.1	12 (HV89)	35
HD72968	11.305	2.84	12.7	11 (HL74)	60
HD126515	130.0	2.24	0.9	< 6 (P71)	-

Projected rotational velocity measurements or estimates for all our programme stars are available in the literature and are reported in column 5 of table VIII together with the references.
Introducing into formula (8) the appropriate mean value of the radius we obtain the rotational velocity. From the ratios $(v_e \sin(i))/v_e$ we can evaluate the i angle values which are reported in table VIII. For the two longest period stars (i.e. HD 2453 and HD 126515) only upper values are given for the $v_e \sin(i)$, which are so high with respect to the v_e we got that they do not even allow upper limit estimates of i.
In conclusion we would like to stress the importance of determining the light curves of CP2 stars. The fact that they are quite satisfactorily represented by a sinusoid and its first harmonic strongly supports the presence of only two patches, or conversely a unique ring, with anomalous abundances on the surface of these stars (Mathys *et al.*, 1989) and might have remarkable consequences on the comprehension of the link between the light and spectral variations and the magnetic field structure.

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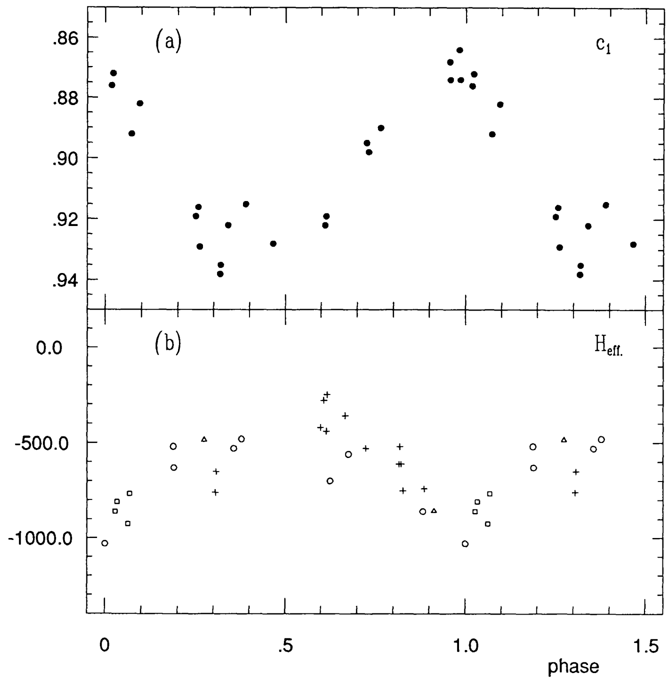

FIGURE 1. — The Wolff (1975) Strömgren index c_1 (a) and the magnetic field (b) variations of HD 2453 *versus* the phase computed according the ephemeris elements (4). In (b) the symbols represent the various sets of observations, transformed into the Lick system as outlined in the text, with the meaning: (△) Mt. Wilson and (□) Mt. Palomar (Babcock, 1958a), (+) Lick and (o) Mauna Kea (Wolff, 1975).

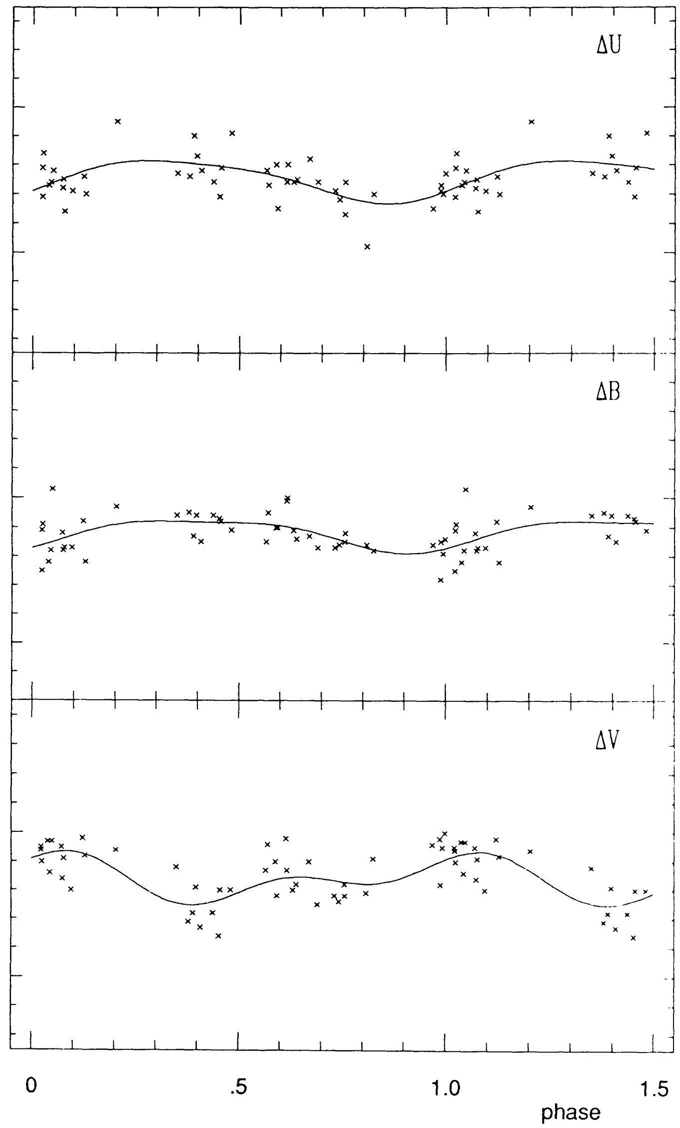

FIGURE 2. — Light curves of HD 2453. The magnitude differences between HD 2453 and the comparison stars HD 1439 and HD 952 are computed by means of formula (1) in the text. The phases are computed according to the ephemeris elements (4). The solid line is a least-square fit of the observations by formula (2). In the magnitude axis one subdivision is 0.01 mag.

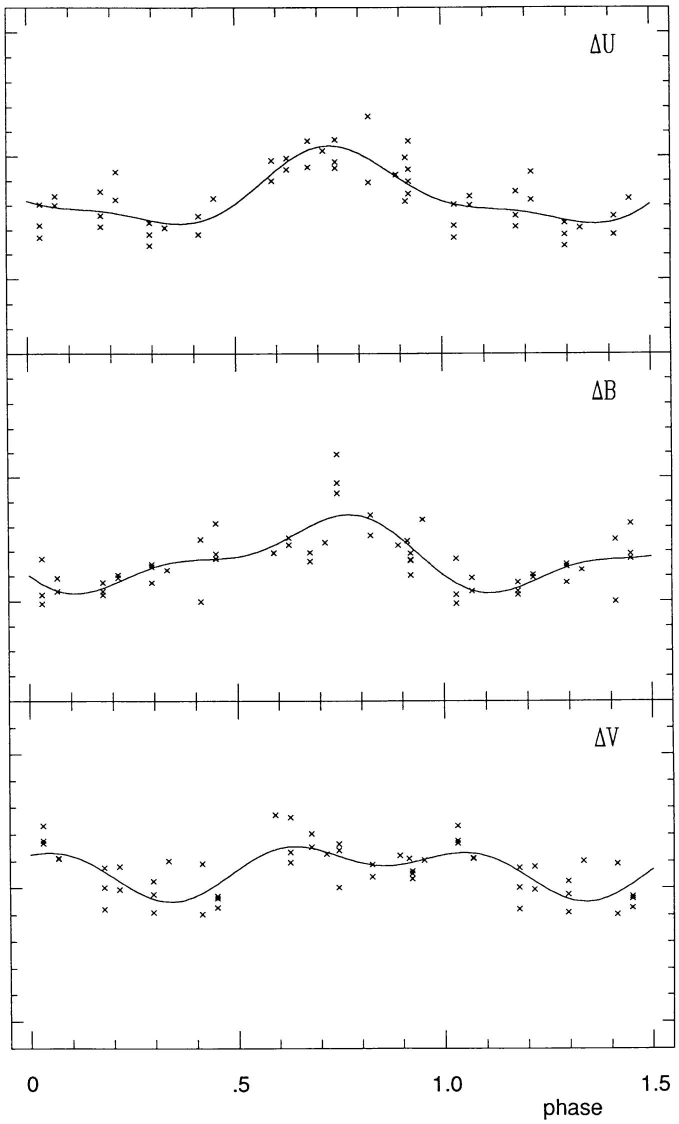

FIGURE 3. — Light curves of HD 71866. The magnitude differences between HD 71866 and the comparison stars HD 71844 and HD 70273 are computed by means of formula (1) in the text. The phases are computed according to the ephemeris elements (5). The solid line is a least-square fit of the observations by formula (2). The magnitude scale is the same as in figure 2.

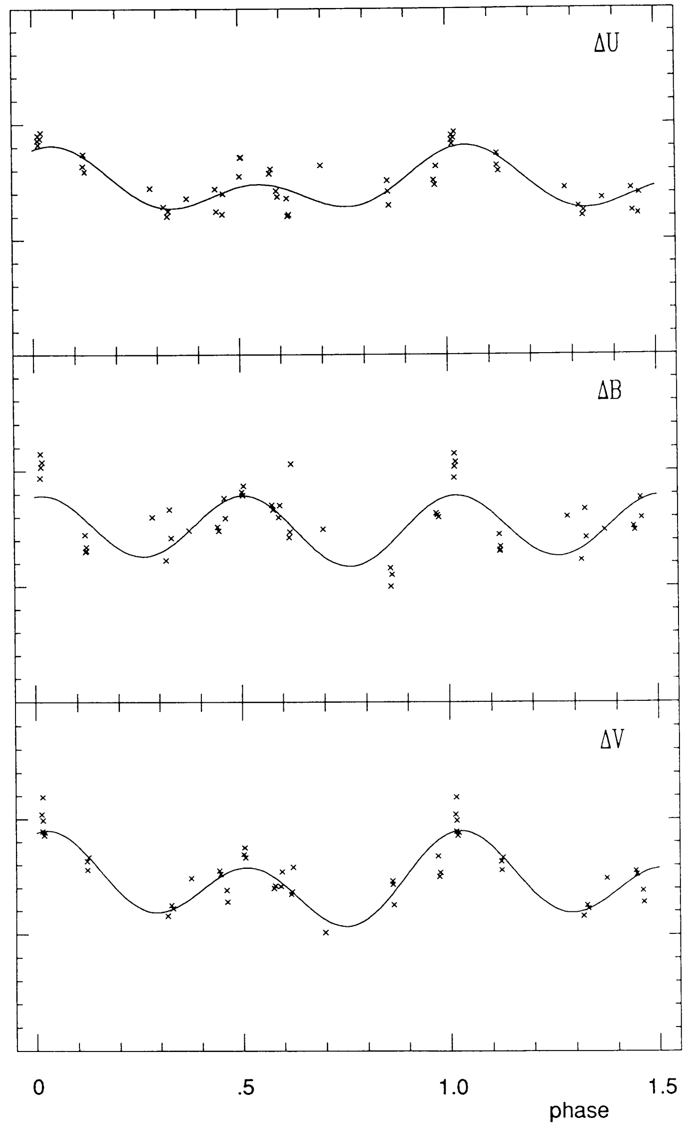

FIGURE 4. — Light curves of HD 72968. The magnitude differences between HD 72968 and the comparison stars HD 73451 and HD 73997 are computed by means of formula (1) in the text. The phases are computed according to the ephemeris elements (6). The solid line is a least-square fit of the observations by formula (2). The magnitude scale is the same as in figure 2.

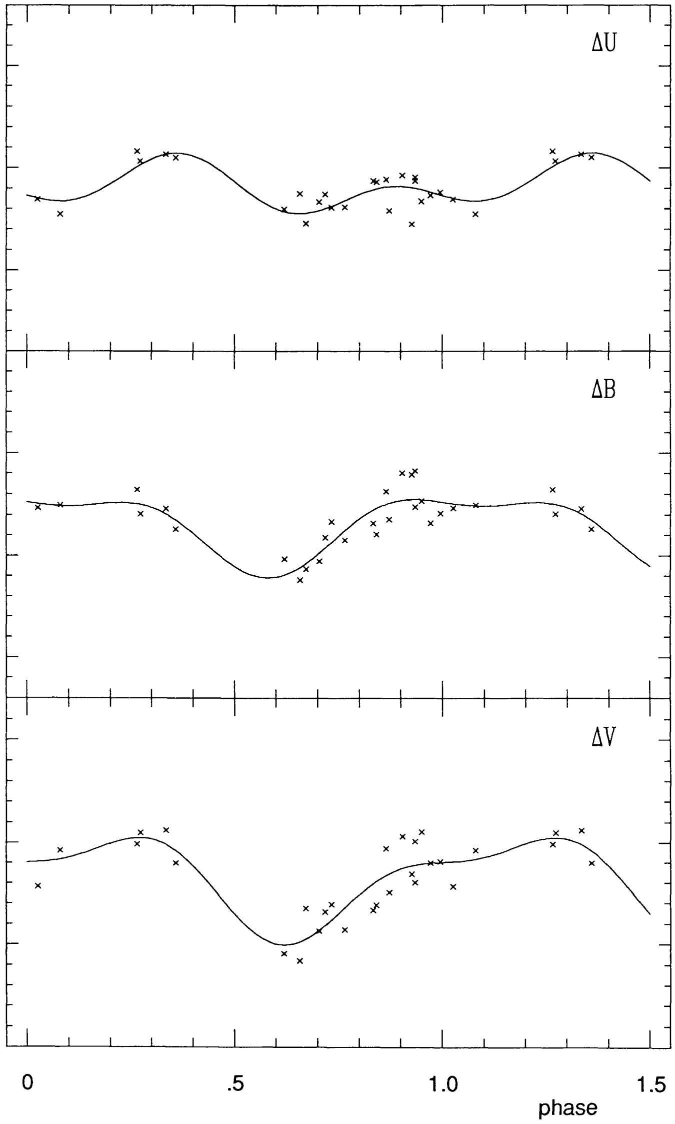

FIGURE 5. — Light curves of HD 126515. The magnitude differences between HD 126515 and the comparison stars HD 127167 and HD 125489 are computed by means of formula (1) in the text. The phases are computed according to the ephemeris elements (7). The solid line is a lest-square fit of the observations by formula (2). The magnitude scale is the same as in figure 2.