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Photometry of Peculiar A Stars

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Summary. The results of uvby-photometry of 4 Ap-stars observed during 1975 at the ESO, La Silla, are presented. One of the stars, HD 81009, was also observed during 1971 in the *UBV* system. Periods are proposed for the silicon stars HD 63401 ($P=2^{d}.41\pm.02$) and HD 92664 ($P=1^{d}.668\pm.004$ or $0.624\pm.002$). The three silicon stars in our sample (the two previous ones and HD 73340) are variable in the four channels showing their largest amplitude in *u*. HD 81009 shows at least variability in the *u*-channel.

Key words: Ap-stars – photometry

1. Introduction

Bidelman and MacConnell's (1973) list of southern peculiar stars contains a number of newly discovered ones. Among these, we found three silicon stars which might be of some interest. They are bright enough to allow accurate photometry; furthermore, until now 41 Tau and HD 215441 were the hottest silicon stars to have been observed in some detail in *ubvy* in order to determine the character of the light variations. According to Megessier (1971), $u-b$ is a relevant effective temperature indicator for silicon stars. As HD 92664, HD 73340 and HD 63401 all have smaller $u-b$ indices ($.45<u-b<.55$) than 41 Tau and HD 215441 ($u-b>.6$), they must be significantly hotter. Only HD 34452, observed in *B* and *V* by Rakos (1962) is as hot as HD 92664. HD 81009 has been observed in *UBV* by De Loore in 1971. The star shows no variability with amplitudes larger than $0^{m}.005$ (in *V*, $B-V$ and $U-B$) during the 10 day interval that we observed it. However, the c_1 value of this star in the catalogue of Grönbech *et al.* (1975) was quoted with an unusually large standard deviation. Since this star has very sharp lines (van den Heuvel, 1971), we suspected it to be a long period

Table 1. Information about the observation runs

Star	Peculiarity type	Comparison stars	Observing times (1975)	Number of nights (number of obs.)	Observer/ telescope[a]
HD 63401	Si	HD 62712	Jan, 14–28	9(18)	HH/ESO
(HR 3032)		and			
		HD 63215	Feb, 26	1(2)	GH, EZ/Dan
HD 73340	Si	HD 74071	Jan, 14–28	8(9)	HH/ESO
(HR 3413)			March, 2–14	7(7)	EZ/Dan
HD 81009	Sr–Cr	HD 80447	May, 11–21 (1971)	7(7) *UBV*	CDL/Dan
(HR 3724)		and			
		HD 82428	Jan, 14–19	4(4)	HH/ESO
		HD 81728			
		(in 1971)			
HD 92664	Si	HD 93163	Jan, 15–18	4(5)	HH/ESO
(HR 4185)		and			
		HD 93194	Feb, 16-March, 1	12(12)	GH, EZ/Dan

[a] Abbreviations: HH = H. Hensberge; GH = G. Hammerschlag-Hensberge; EZ = E. J. Zuiderwijk; CDL = C. De Loore; ESO = ESO 50 cm telescope; Dan = Danish 50 cm telescope.

variable. Thus, we decided to reobserve this star in our 1975 runs, which should permit us to have observations over a much longer time interval.

2. Observations

Information about the observation runs is listed in Table 1. In 1971, each *UBV* observation sequence was performed as follows: first comparison star – second comparison star—program star—second comparison star—first comparison star. Each measurement of a star was followed by one of the sky. We continued our observations in 1975 in the *uvby* system. Furthermore each observation sequence was extended in the sense that the program star was observed also between the two comparison stars in order to ensure higher accuracy. After a few nights, one of the comparison stars for HD 73340, i.e. HD 74196, was omitted as it was suspected to be slightly variable and only the remaining comparison star was used.

The standard deviation determined by two brightness measurements of the same star in one sequence is less than $0\overset{m}{.}004$. However m_1 and c_1 indices have systematically larger standard deviations of about $0\overset{m}{.}007$ for the January 1975 runs. Observations with the Danish telescope do not show the same effect; this is probably due to the fact that this telescope is equipped with a simultaneous multi-channel photometer while the ESO telescope is not. This could suggest that short-term extinction variations enhance the experimental error by the combination of non-simultaneous measurements in different filters. The standard deviation of the differential brightness (first comparison star relative to the second one, as determined by the observations of one sequence) increases from $0\overset{m}{.}004$ in y to $0\overset{m}{.}008$ in u. Differential colors ($b-y$, $v-b$, $u-v$) show very low scatter however, resulting in standard deviations smaller than $0\overset{m}{.}003$. Therefore y, $b-y$, $v-b$ and $u-v$ were used to select possible periods by the technique described by Lafler and Kinman (1965).

3. Reductions

The extinction corrections were computed in the usual way, defining average coefficients per night; transformation to the standard system was done by fitting comparison stars and extinction stars to the *uvby* system of the catalogue of bright southern stars (Grönbech *et al.*, 1975). The mean colours of the comparison stars are given in Table 2. The present observations confirm the catalogue values up to $0\overset{m}{.}005$ in two third of all cases. Only two of the colour indices differ by more than $0\overset{m}{.}011$, the m_1-index of HD 82428 ($0\overset{m}{.}016$) and the c_1-index of HD 63215 ($0\overset{m}{.}018$). Table 3 gives the approximate magnitude range of the four peculiar stars. However transformation from y to V is rather tentative for Ap stars since

Table 2. Colours of the comparison stars

Star	(V)	$b-y$	m_1	c_1
HD 62712	6.430	−.064	.117	.503
HD 63215	5.884	−.048	.100	.508
HD 74071	5.461	−.070	.113	.428
HD 80447	6.631	+.045	.170	1.131
HD 82428	6.139	+.156	.168	.835
HD 93163	5.755	+.051	.054	.342
HD 93194	4.805	−.057	.101	.359

Table 3. Approximate observed colour ranges of the program stars

Star	(V)	$b-y$	m_1	c_1
HD 63401	6.30–6.36	−.10– −.07	.11–.16	.41–.48
HD 73340	5.78–5.81	−.07– −.055	.11–.14	.40–.41
HD 81009[a]	6.528	.098	.297	.732
HD 92664	5.48–5.52	−.09	.13–.14	.34–.39

[a]) For HD 81009 we give the mean colours as it was constant during the observation time. Grönbech *et al.* (1975) give $(V)=6.530$, $b-y=.088$, $m_1=.288$, $c_1=.787$.

wavelength dependence is quite complicated in this part of the visible spectrum [e.g. there are pronounced differences between y and V lightcurves of HD 125248 (Maitzen and Moffat, 1972)]. Therefore we denote the resulting visual magnitude as (V). It should be noticed that differences between instrumental y magnitudes and transformed (V) never exceed .003. No attempt was made to obtain standard values from the observations with the Danish Telescope since the reductions reveal important zero-point changes. So Tables 2 and 3 are obtained from transformation of the ESO telescope observations. However the difference between the *uvby* system of the ESO 50 cm and that of the Danish telescope is rather small: differential magnitudes obtained in both instrumental systems are intrinsically the same. Thus we did not adopt a transformation from one instrumental system to the other.

A complete list of the observations and the transformation formulae adopted are available from the authors upon request.

4. Results

For those cases in which the data enabled us to propose a period only a plot is given; otherwise the observations are tabulated. The plots were made after transformation to the *uvby* system of the catalogue of bright southern stars (Grönbech *et al.*, 1975). Phase zero is chosen arbitrarily as the time of the first observation.

A. HD 63401

All observations are plotted in Figure 1; phase zero corresponds to J.D. 2442427.56. The phases are computed according to a period of $2\overset{d}{.}41$. Considering

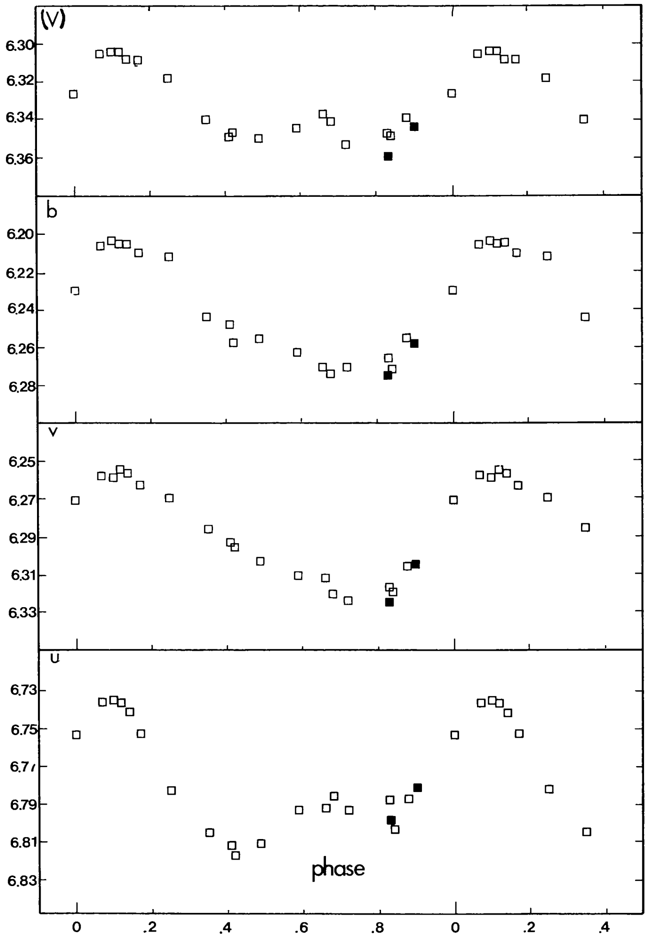

Fig. 1. Light variations of HD 63401. Phases are computed according to $P=2^{\mathrm{d}}41$. Open squares denote ESO telescope observations, filled squares denote observations with the Danish telescope

the uncertainty induced by the method used for the determination of the period and by the neglect of a transformation between both instrumental systems, one may rely on this period up to $\pm 0^{\mathrm{d}}02$.

This star exhibits a rather complicated photometric character. The y and u lightcurves show secondary extrema while b and v show an almost identical and single wave. The primary maximum occurs at the same phase for all curves, but u reaches its secondary minimum when the brightness at longer wavelengths is minimum. Minimum brightness in u corresponds in phase to the other minimum in y. This characteristic—i.e. that the importance of the secondary extrema can change rather drastically with wavelength—has also been found for other silicon stars i.e. HD 19832≡56 Ari (Wolff and Morrison, 1974) and HD 224801 (Stepien, 1968).

B. HD *73340*

The Lafler-Kinman (1965) technique cannot distinguish between several periods, all of them showing definitely larger scatter than in the other cases. The loss of

Table 4. Observations of HD 73340: final results

J.D. 2442400+	(V)	b	v	u
27.59	5.797	5.742	5.799	6.254
28.60	5.781	5.716	5.778	6.235
29.59	5.813	5.744	5.815	6.286
30.58	5.804	5.747	5.801	6.262
30.84	5.788	5.731	5.785	6.248
31.59	5.788	5.719	5.775	6.234
32.59	5.810	5.757	5.819	6.294
38.66	5.792	5.735	5.792	6.258
41.71	5.792	5.725	5.789	6.258
74.64	5.791	5.726	5.791	6.257
78.60	5.802	5.743	5.804	6.264
79.60	5.788	5.720	5.781	6.248
80.60	5.795	5.741	5.797	6.253
81.59	5.802	5.736	5.800	6.267
85.60	5.794	5.733	5.795	6.264
86.60	5.794	5.738	5.797	6.255

accuracy can partially be due to the fact that we had to omit one of the comparison stars. It should be noticed that if the lightcurves have really double waves and if the number of observations is rather limited as in our case, the true period can be masked by erroneous single wave periods. As we are unable to select a period, we listed our observations in Table 4. The values suggest a period of the order of a few days or less, since the star changes its brightness from maximum to minimum in one day.

C. HD *81009*

Our *UBV* photometry of 1971 reveals that this star remained essentially constant during the 10 day observing run. The probability is very low that this is caused by observing the star always at the same phase but while one or more cycles have elapsed, since HD 81009 has very sharp lines (van den Heuvel, 1971) so that periods of the order of one day are very unlikely. The attempt to collect observations covering a longer time interval during our 1975 observing runs was abandoned at the end of January because bad wheather conditions obliged us to reduce our program. Although no *uvby*-variability could be detected in this observing run, some remarks of interest for further investigations can be made. First, y and earlier V measurements relative to HD 80447, and the agreement between our standard (V), $b-y$ and m_1 values and those of Olsen *et al.* (1975) seem to lend support to the non-variability of this star in the blue and in the visible. However c_1 assures that this star is at least variable at lower wavelengths: there is a disagreement of $0^{\mathrm{m}}055$ between the catalogue value of c_1 and our mean c_1 index (see Table 3). So we feel that further investigations should concentrate on measurements below 4000 Å during an extended time interval.

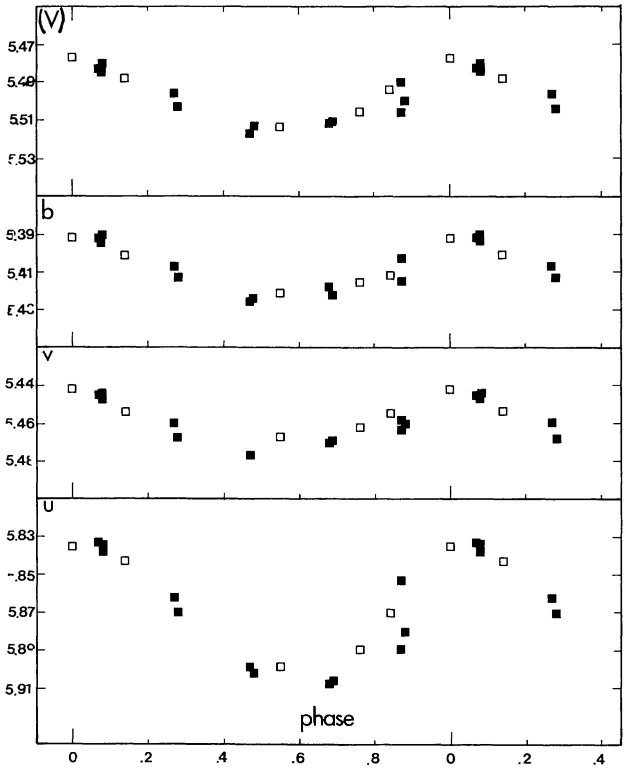

Fig. 2. Light variations of HD 92664. Phases are computed according to $P=1^d.664$. Symbols as in Fig. 1

D. HD 92664

Two possible periods remain between which it is difficult to choose. These periods are derived from y and $u-v$ measurements only, $b-y$ and $v-b$ being approximately constant. In Fig. 2 we have plotted the results for a $1^d.668$ period. The uncertainty is about $\pm 0^d.004$. Zero phase is J.D. = 2442428.81. However periods in the interval $P=0^d.624\pm 0^d.002$ cannot be excluded at this moment. In both cases all the lightcurves are in phase. A final choice can be made if this star will be observed during two successive nights with intervals of a few hours.

5. Discussion

With our three silicon stars included, we know of 16 Si stars studied in some detail in *UBV* and 10 in *uvby*; here the term "silicon star" is used in its broader sense, i.e. all stars showing enhanced Si, even if this does not seem to be the most prominent spectral peculiarity. Six of these stars were studied in both systems and two of them in the ultraviolet, i.e. α^2CVn (Molmar, 1973) and HD 215441 (Leckrone, 1974a).

Table 5 lists these stars with references. The three Si stars which we observed are the hottest Si stars studied in *uvby*; photometrically they behave just like the cooler members of the list. When the photometric properties in the wavelength region 3500–5500 Å of this sample of

Table 5. List of Silicon stars. The meaning of the references is the following: (a) this paper; (b) Kodaira (1973) and references therein; (c) Wolff (1973); (d) Wolff and Morrison (1975). The $(u-b)$-values are from Lindemann and Hauck (1973)

Star	$u-b$	References
HD 92664	.45	a
HD 34452	.46	b
HD 73340	.49	a
HD 63401	.51	a
HD 25823 ≡ 41 Tau	.62	b, c
HD 215441	.65	b
HD 215038	.69	b
HD 223640	.71	b
HD 19832	.71	b, d
HD 124224	.75	b
HD 32633	.77	b
HD 224801	.87	b
HD 112413 ≡ α^2 CVn	.88	b
HD 30466	.92	b
HD 133029	1.01	d
HD 184905	1.01	b
HD 18296	1.01	b
HD 74521	1.02	b
HD 68351	1.23	b
HD 173650	1.26	b

20 hot Ap stars are compared with the cooler ones, it is obvious that the cool group presents more diversity. We can summarize the main differences in overall photometric character in the blue-visible by two statements:

a) The light curves of Si stars between 3500 Å and 5500 Å are always in phase with each other; this is not the case for cool Ap stars: in the case of 53 Cam (Wolff and Wolff, 1971; Preston and Stepien, 1968), HD 188041 (Jones and Wolff, 1973) and HD 125248 (Maitzen and Rakosch, 1970; Wolff and Wolff, 1971; Maitzen and Moffat, 1972) maximum brightness in one channel corresponds in phase with minimum brightness in some of the others.

Of course, satellite observations point out that both Si stars observed in the UV have in this wavelength range a null region (i.e. without photometric variability) and lightcurves on different sides of this region are in anti-phase. This null region occurs near 2500 Å in HD 215441 and near. 3000 Å in α^2 CVn. Molnar (1973) suggested that two mechanisms of backwarming are responsible for the variations, one dominant at lower wavelengths, the other at longer wavelengths and compensating each other in the null region. From model atmosphere calculations with arbitrarily enhanced metal opacities, Leckrone *et al.* (1974b) suggested that this null region may be temperature dependent in the sense that hotter stars have their null region at lower wavelengths. If this is true, we expect that no silicon star (not much cooler than α^2 CVn) shows lightcurves in antiphase in *uvby* or *UBV*; moreover, in stars as hot as α^2 CVn, no null variation in u or U should occur if their variation at longer wavelengths is large because the null region is, in that case, situated well below 3500 Å. Therefore, this suggestion is consistent with the observations.

b) None of the silicon stars shows the strong variability in the *v* band (relative to the *u* band) which occurs in a number of cool Ap stars [e.g. HD 24712 (Wolff and Morrison, 1973), 49 Cam (Bonsack *et al.*, 1974), HD 71866 (Wolff and Wolff, 1971), HD 98088 (Maitzen, 1973), HD 119213 (Wolff and Morrison, 1974), HD 125248 (Wolff and Wolff, 1971; Maitzen and Moffat, 1972) and HD 188041 (Wolff and Wolff, 1971)]. Blanketing measurements by Pilachowski and Bonsack (1975) show that local line blanketing in the *v* band is not responsible for this strong variability in the case of HD 125248.

Our conclusive remark is that ultraviolet observations of silicon stars add substantial new information. HD 63401 or HD 92664 deserve further attention, because they are expected to be very suitable for testing the temperature dependence of the null region by far ultraviolet photometry.

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Note Added in Proof. Recently Wolff (1975) published data of HD 81009 (comparison star HD 80447); she proposed a period of 69^d or 34^d5. Her data reveal that we measured the star around minimum brightness. Combination of her data with the observations of Grönbech and Olsen at JD 2441324.77 and JD 2441368.68 (the last one also near minimum brightness) and with our data favorises strongly the possibility of the shorter period. All data are well represented with a period of $34^d.1 \pm 0^d.2$.

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