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UBV photometry of four magnetic stars

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Differential *UBV* observations of four magnetic Ap stars are presented. No significant variations are detected for HD 2453 over a 14-month interval. A possible period of $10^{d}.61$ is suggested for 9 Tau=HD22374, although this period gives a poorly defined light curve. Well-defined light curves have been obtained for the other two stars, HD171586 and HD192913, which have periods of $2^{d}.1436$ and $16^{d}.478$, respectively.

INTRODUCTION

SINCE Abt and Golson (1962) showed statistically that most of the magnetic Ap stars [those listed by Babcock (1958)] were small amplitude photometric variables, about half of these stars have been reported as periodic variables while relatively few have been found to be constant. This present paper presents observations of four magnetic stars. They are: HD2453 (A0p [Sr-Cr-Eu]), 9 Tau=HD22374 (A0p [Cr-Sr]), HD171586 (A0p [Sr-Cr]), and HD192913 (A0p [Si 4012]). The spectral types are those of Osawa (1965).

OBSERVATIONS

All observations were obtained either at Palomar Observatory using the 20-in. reflector and pulse-counting data system, or at Kitt Peak National Observatory using one of the 16-in. reflectors and charge-integration data system. In all cases, standard UBV filters and a refrigerated 1P21 photomultiplier were used.

For each program star, two nearby comparison stars were selected. The spectral types, magnitudes, and color indices of these are summarized in Table I. In general, only one set of observations (comparison-program-comparison) was obtained nightly, although on one or more nights, several sets of observations were obtained over an interval of several hours to search for short period pulsations such as those described by Rakos (1963), and to guard against spurious periods arising from observations obtained at an interval of one day.

The differential measurements were corrected for extinction using mean extinction coefficients. A small color term between different observing runs was removed differentially. Each observation should be accurate to better than 0.005 mag. For each magnetic star, the observations are presented as differential magnitudes, ΔV, ΔB, and ΔU, with respect to one of the comparison stars.

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DESCRIPTION OF INDIVIDUAL STARS

HD2453: Spectroscopic observations by Babcock (1958) show this star to have a magnetic field varying between extreme values of −710 and −425 G, a total variation of less than 300 G. Photometric observations by Stępień (1968) suggest that HD2453 is constant or, if variable, has a period of at least several months. Wolff and Morrison (1973) suggest that it is variable and has a period longer than one year.

The differential observations, HD2453−HR71, are listed in Table II. The second comparison star, π And, was suspected of being slightly variable. Over an interval of several weeks, these data show that HD2453 was constant, in agreement with the results of Stępień, and Wolff and Morrison. Over the longer interval of 14 months, the average magnitudes seem to have become brighter by 0.004 mag in V, 0.003 mag in B, and 0.005 mag in U. However, as this is on the same order of magnitude as possible errors, it is probably not a significant variation.

As a further check for long period variability, a comparison can be made between the present magnitudes: $V=6.88$, $B-V=+0.08$, $U-B=+0.04$, and the magnitudes found by Abt and Golson (1962): $V=6.92$, $B-V=+0.05$, $U-B=+0.03$, and Stępień (1968): $V=6.88$, $B-V=+0.08$, $U-B=+0.03$. There seems to be no significant difference in these values.

A number of 33 Å/mm spectra of this star were available in the David Dunlap Observatory plate files covering the interval from 1935 to 1945. With these, it was possible to search for spectrum variability over a ten year baseline. The star does not appear to be a spectrum variable on the basis of the plates available.

9 Tau=HD22374: Spectroscopic observations of 9 Tau by Babcock (1958) indicate a small magnetic field of +140 G (from 1 plate measured). Wolff and Morrison (1971) find a period of light variability of $10^{d}.6$.

The differential observations, 9 Tau–11 Tau, are listed in Table III. The second comparison star, 7 Tau, may be slightly variable. The data seem best fit by a period of $10^{d}.61$, in agreement with the Wolff and Morrison result. The light curves (Fig. 1) were plotted for this period with epochs of U light maxima

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TABLE I. Spectral types, magnitudes, and color indices of comparison stars.

Magnetic star	Comparison stars	Spectral type	V (mag)	$B-V$ (mag)	$U-B$ (mag)
HD2453	HR71=HD1439	*A0 IV*	5.87	−0.02	−0.03
	π And=HD3369	*B5 V*	4.33	−0.13	−0.54
9 Tau=HD22374	7 Tau=HD22091	*A2 V*	5.95	+0.12	+0.15
	11 Tau=HD22805	*A2 IV*	6.11	+0.09	+0.12
HD171586	HR6985=HD171802	*F1 V*	5.47	+0.35	−0.03
	HR7048=HD173495	*A1 V*	5.85	+0.03	+0.01
HD192913	18 Vul=HD191747	*A3 V*	5.50	+0.09	+0.12
	21 Vul=HD192518	*A7 IVn*	5.19	+0.19	+0.16

being given by

$$JD(U_{\max})=2441252.12+10.61E. \quad (1)$$

The complexity of these curves, with double maxima in V and U but a single poorly defined maximum in B, is somewhat unusual, and suggested that the period might be incorrect. However, no satisfactory alternative period was found.

HD171586: The differential observations, HD171586–HR7048, are listed in Table IV. Both comparison stars were found to be constant and were used to determine the final magnitudes. The data seem best fit by a period of $2^{\mathrm{d}}.1436$, although periods $2^{\mathrm{d}}.1308$ and $2^{\mathrm{d}}.1565$ are also possible. The light curves (Fig. 2) were plotted for this period, with epochs of U light maxima being given by

$$JD(U_{\max})=2441460.79+2.1436E. \quad (2)$$

There is a moderately large variation in U (0.03 mag amplitude) with a possible secondary maximum. Any variation in B has an amplitude of less than 0.005 mag.

HD192913: The differential observations, HD192913–18 Vul, are listed in Table V. The second comparison star, 21 Vul, was found to be a δ Scuti type variable. The data, from two widely separated observing runs, are satisfied by periods of $16^{\mathrm{d}}.148$, $16^{\mathrm{d}}.478$, and $16^{\mathrm{d}}.821$. All of these seem equally satisfactory. The final selection was made after plotting the Abt and Golson (1962) observations to these different periods. The best fit was found for the $16^{\mathrm{d}}.478$ period, hence, this was assumed to be the correct period. Note that this result is questionable as Stępień (1968) has reported a general lack of correlation between his results and those of Abt and Golson. An attempt to plot the Zeeman measurements of Babcock (1958) gave negative results for all three periods. The light curves (Fig. 3) are plotted with epochs of U light maxima being given by

$$JD(U_{\max})=2441617.165+16.478E. \quad (3)$$

They show almost equal amplitudes (0.07 mag) in V, B, and U, with a single, sharply-defined maximum.

DISCUSSION

The fact that three magnetic Ap stars out of a sample of four such stars show photometric variability emphasizes the conclusion initially drawn by Abt and Golson (1962), and more recently by Stępień (1968) as well as others, that most of the magnetic Ap stars are low

TABLE II. Differential observations, HD2453–HR71.

JD (2440000+)	ΔV	ΔB	ΔU
0805.972	1.012	1.103	1.174
0814.997	1.011	1.107	1.182
0819.962	1.011	1.105	1.182
0821.001	1.015	1.099	1.182
1238.637	1.002	1.098	1.176
1239.640	1.008	1.098	1.171
1240.639	1.011	1.107	1.172
1244.643	1.012	1.099	1.175
1245.682	1.005	1.101	1.176
1246.592	1.010	1.100	1.170
1247.680	1.009[a]	1.102[a]	1.179[a]
1251.644	1.007	1.102	1.175
1254.643	1.007	1.100	1.177
1256.628	1.010	1.100	1.179

[a] Average of multiple observations.

TABLE III. Differential observations, 9 Tau–11 Tau.

JD (2440000+)	Phase ($P=10^{\mathrm{d}}61$)	ΔV	ΔB	ΔU
0918.758	0.580	0.606	0.629	0.646
0919.692	0.668	0.604	0.626	0.641
0925.729	0.237	0.618	0.637	0.647
0928.661	0.513	0.603	0.627	0.642
1236.828	0.559	0.601	0.625	0.638
1237.796	0.650	0.609	0.622	0.643
1238.823	0.747	0.620	0.632	0.648
1239.776	0.837	0.619	0.628	0.644
1243.818	0.218	0.619	0.643	0.645
1245.845	0.409	0.614	0.640	0.657
1247.840	0.597	0.608[a]	0.625[a]	0.644[a]
1252.757	0.060	0.607	0.634	0.633
1254.724	0.245	0.625	0.646	0.650
1256.748	0.436	0.606	0.631	0.652

[a] Average of multiple observations.

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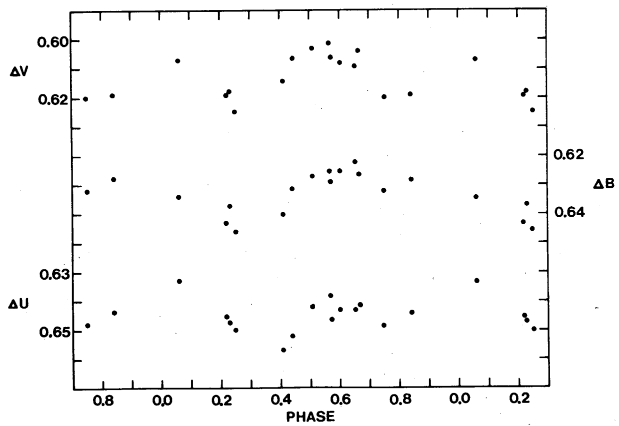

FIG. 1. Light curves for 9 Tau–11 Tau. A period of 10ᵈ61 is assumed with U light maxima given by $JD(U_{max})=2441252.12+10.61E$.

amplitude photometric variables. Also well illustrated by the selection of stars presented here is the fact that each Ap variable seems to possess a unique photometric variability.

HD2453 appears to be constant to better than 0.01 mag. Unfortunately, it is not possible to verify absolute constancy as the star may be variable below the limits of this investigation or with a period of several years. However, it should not be surprising if a few constant magnetic stars are found, as presumably some Ap stars would be observed pole on. This star may be such an example. In any event, further UBV observations should be made over the next few years to verify whether or not this star is a long period variable.

9 Tau is somewhat unusual in the complexity of the light curves. Except for this, it seems similar to other Cr-Sr variables such as HD10783 (van Genderen 1971).

HD171586 is one of the shorter period magnetic stars. Its light curves are unusual for a Sr–Cr star in the almost complete absence of variations in B. This can be contrasted to the light curves of HD15144 or 78 Vir (van Genderen 1971) both of which have amplitudes in B similar to those in U.

TABLE IV. Differential observations, HD171586–HR7048.

JD (2440000+)	Phase (P=2ᵈ1436)	ΔV	ΔB	ΔU
1097.907	0.713	0.669	0.704	0.746
1106.875	0.897	0.667	0.694	0.737
1107.925	0.387	0.670	0.703	0.750
1110.845	0.749	0.664	0.700	0.738
1116.850	0.550	0.664[a]	0.702[a]	0.742[a]
1119.850	0.950	0.658[a]	0.697[a]	0.721[a]
1120.884	0.432	0.669	0.698	0.750
1121.871	0.893	0.660	0.697	0.735
1122.876	0.361	0.662	0.701	0.746
1444.867	0.572	0.670	0.700	0.749
1445.864	0.037	0.656	0.697	0.718
1449.887	0.914	0.661	0.699	0.727
1451.906	0.856	0.670	0.699	0.740
1452.892	0.316	0.666	0.698	0.742
1459.880	0.575	0.665[a]	0.700[a]	0.745[a]
1460.789	0.000	0.660	0.702	0.715
1461.794	0.468	0.667	0.704	0.744

[a] Average of multiple observations.

TABLE V. Differential observations, HD192913–18 Vul.

JD (2440000+)	Phase (P=16ᵈ478)	ΔV	ΔB	ΔU
0805.781	0.760	1.140[a]	0.999[a]	0.638[a]
0806.814	0.822	1.120	0.984	0.620
0816.759	0.426	1.153	1.005	0.647
0819.793	0.610	1.158	1.015	0.651
1604.642	0.240	1.145	0.987	0.628
1605.627	0.300	1.140	0.992	0.633
1606.631	0.361	1.150	1.001	0.639
1607.669	0.424	1.148	1.007	0.644
1612.615	0.724	1.146	1.002	0.643
1613.620	0.785	1.135	0.989	0.628
1616.660	0.969	1.100	0.953	0.583
1619.573	0.146	1.121	0.973	0.613

[a] Average of multiple observations.

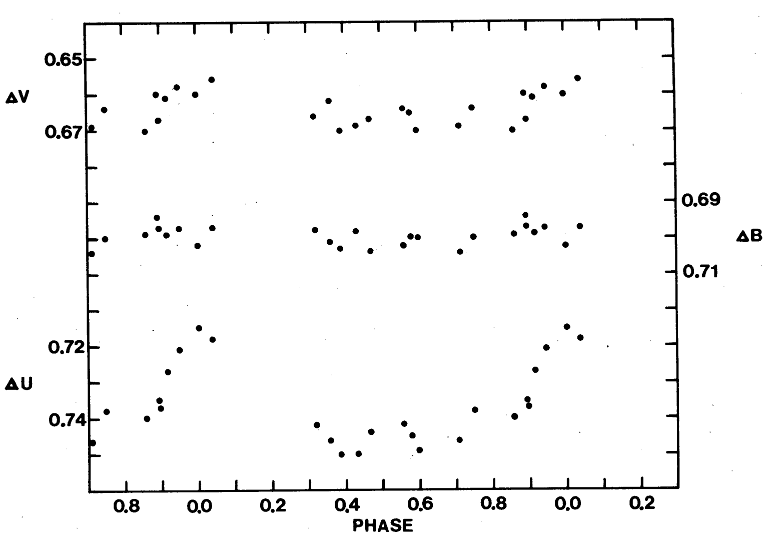

FIG. 2. Light curves for HD171586–HR7048. A period of 2ᵈ1436 is assumed with U light maxima given by $JD(U_{max})=2441460.79+2.1436E$.

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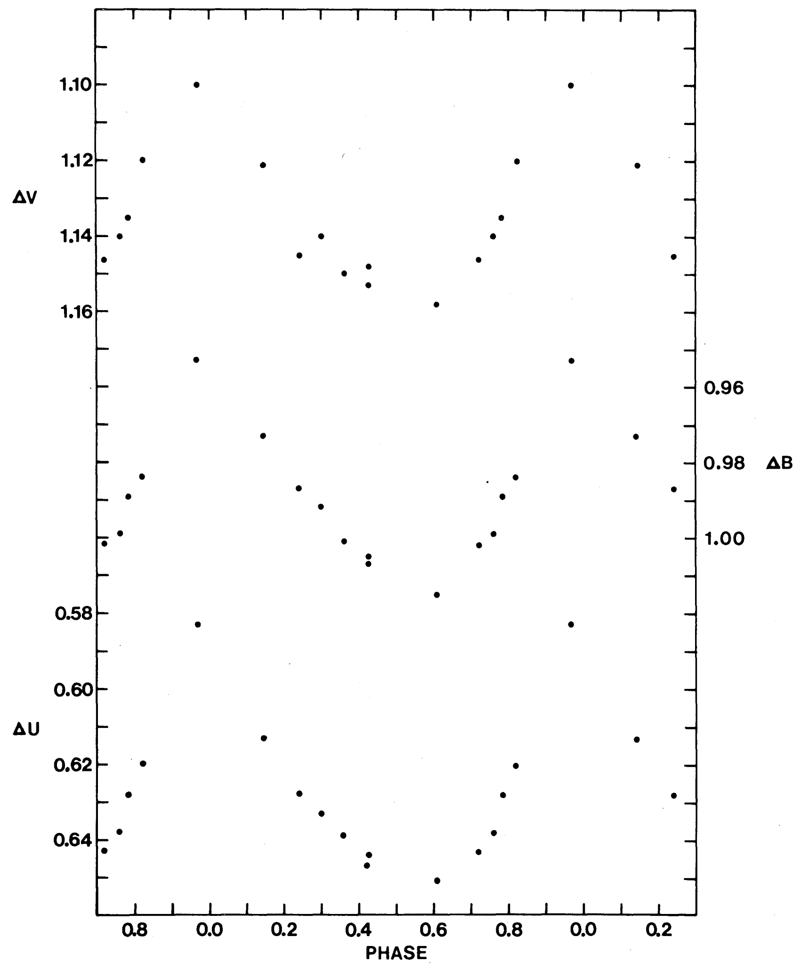

FIG. 3. Light curves for HD192913–18 Vul. A period of 16ᵈ478 is assumed with U light maxima given by $JD(U_{\max})=2441617.165+16.478E$.

HD192913 is unique in two respects. First, it is the longest period silicon star known. Although there are several magnetic stars with longer periods, the silicon stars in general tend to have shorter periods. Second, there is an almost complete lack of any color variation. Most silicon stars have definite color variations, becoming bluest at maximum light, as exemplified by HD215441 and HD215038 (Stępień 1968).

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