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PHOTOMETRY OF THREE PECULIAR A-TYPE STARS

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Four-color (*uvby*) photoelectric observations have yielded provisional periods for three peculiar A-type stars. For 108 Aquarii, the period is $3^{d}73$. For HD 184905, the period is either $1^{d}84$ or $2^{d}17$, and for θ^1 Microscopii the most probable periods are $0^{d}941$ and $1^{d}062$.

Key words: photometry — peculiar A-type stars

I. Introduction

We have detected photometric variability in the peculiar A-type stars 108 Aquarii, HD 184905, and θ^1 Microscopii, and we present here the light curves on the *uvby* system. This type of investigation is the most efficient way to obtain periods of Ap stars because it requires only a small telescope. If even a rough value of the period is known, a spectroscopist can time his observations in order to study most efficiently variations in the spectrum and magnetic field.

II. Observations and Results

The observations were made with a 61-cm reflector at the Mauna Kea Observatory. The procedures for observing and for reducing the data were the same as those of Wolff and Wolff (1971). The comparison stars, two for each variable, are listed in Table I.

We list in Table II the magnitude differences, on the *uvby* system, between the variable and the comparison stars. Each observation consists of the sequence: comparison star, variable, variable, comparison star, performed once with each of the two comparison stars. Let V_1 and V_2 represent the values of a color of the variable as derived separately from the two sequences, and let C_1 and C_2, numbered as in Table I, be the corresponding values for the comparison stars. Then the listed color differences are given by

$$\Delta = \tfrac{1}{2}[(V_1 - C_1) + (V_2 - C_2) + \langle C_2 - C_1\rangle]$$

That is, the differences are given as if they had all been measured with respect to comparison number 1. From the scatter of the nightly values of $C_2 - C_1$ about the mean, we find that the standard error in a single differential measurement is about $0^{m}007$. The error in the mean value of $C_2 - C_1$ is, of course, smaller. In Table I, we list the mean colors for each comparison star. These values, being subject to calibration errors that do not enter a differential measurement, have standard errors of about $0^{m}015$ for the color indices and about $0^{m}025$ for the y magnitude. Hence, we have rounded them to the nearest hundredth of a magnitude. Below the colors for each pair of comparison stars are given the mean differences between the two. Because of their higher precision, these values retain the third decimal place.

TABLE I
COMPARISON STARS

Variable Stars	Comparison Stars (HR)		Mean Colors y	b-y	m_1	c_1
108 Aqr	1	8998	5.24	-0.04	0.12	0.79
	2	9002	5.27	0.17	0.20	0.81
	C_2-C_1		0.035	0.202	0.082	0.010
HD 184905	1	7499	6.23	0.10	0.19	0.89
	2	7444	5.35	0.04	0.15	1.18
	C_2-C_1		-0.882	-0.066	-0.031	0.293
θ^1 Mic	1	8104	5.24	0.28	0.17	0.45
	2	8048	5.30	0.27	0.16	0.54
	C_2-C_1		0.060	-0.009	-0.014	0.085

Finally, in Figures 1, 2, and 3, we present differential y, b, v, and u magnitudes as a function of phase for the three variables. The differences were found in the same way as the color differences of Table II. To find the periods, we used essentially the technique of Lafler and Kinman (1965). These authors define the quantity Θ to be proportional to the sum of the squares of the differences between magnitudes at adjacent

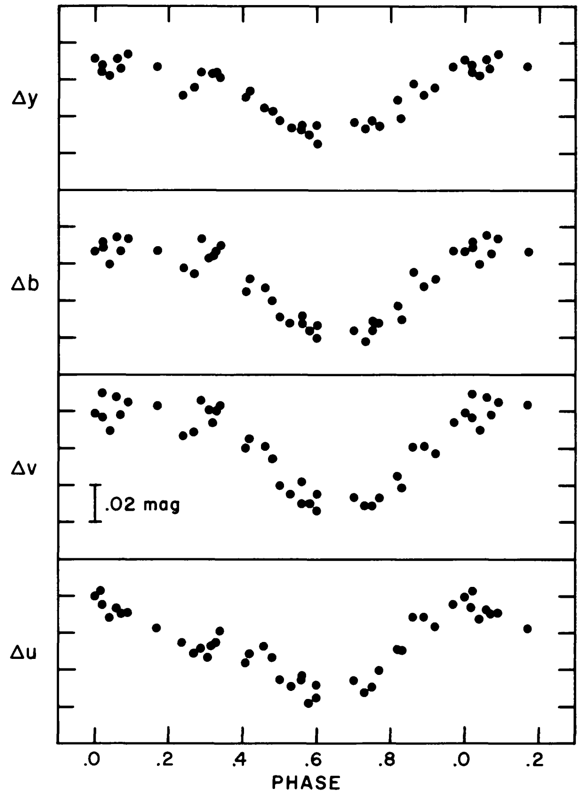

FIG. 1 — The light variations of 108 Aqr plotted according to the ephemeris JD$_\odot$(maximum light) = 2440900.80 + 3.73 E.

values of phase; the correct period is that for which this quantity is minimized. We have assigned to each period an error bar corresponding to the range over which Θ is close to its minimum value. The errors in the epoch of maximum light are derived from inspection of the light curve.

III. Discussion of Individual Stars

A. *108 Aquarii*

The Si star 108 Aqr is of interest because, according to Babcock (1958), a varying magnetic field is present. In addition, lines of Sr II are present and variable (Babcock 1958), and the lines of Ti II vary markedly (Wolff and Wallerstein, unpublished). The present photoelectric observations, which were made in July through November 1970, are plotted in Figure 1 according to the elements

$$\mathrm{JD}_\odot(\text{maximum light}) = \underset{\pm .25}{2440900.80} + \underset{\pm .03}{3.73}\ \mathrm{E}$$

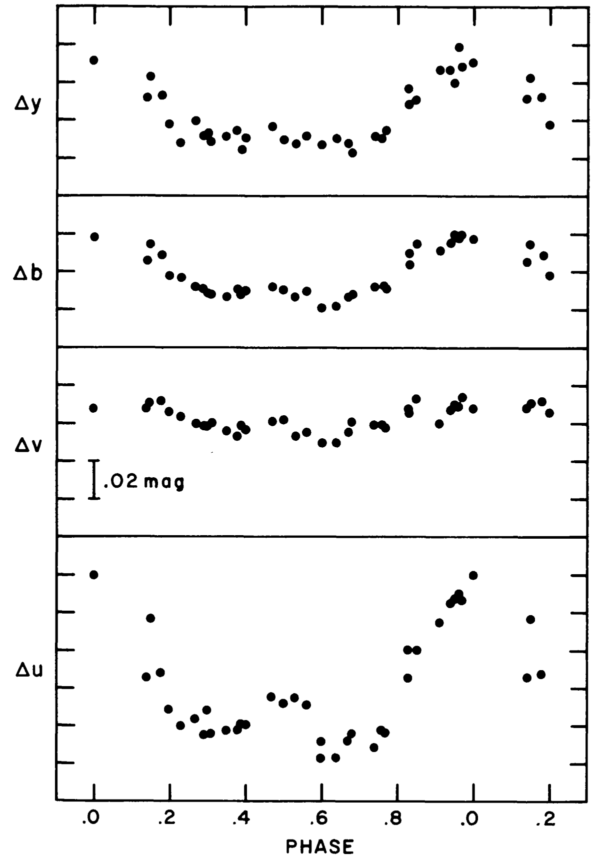

FIG. 2 — The light variations of HD 184905 plotted according to the ephemeris JD$_\odot$(maximum light) = 2440829.81 + 2.17 E.

All four light curves are in phase with each other and have approximately the same shape. There may be a secondary maximum near phase 0.3.

B. *HD 184905*

Figure 2 shows observations of HD 184905, made in June through September 1970. The elements used are

$$\mathrm{JD}_\odot(\text{maximum light}) = \underset{\pm .11}{2440829.81} + \underset{\pm .02}{2.17}\ \mathrm{E}\ .$$

All four light curves are in phase, and the amplitude has a minimum near the wavelength of the *v* filter. Since the Eu II lines in HD 184905 vary conspicuously in strength (Babcock 1958), the large amplitude of the light variation is in keeping with the suggestion (Wolff and Wolff 1971) that the photometric variations in Ap stars are related to variations in the line opacity due to the rare earths.

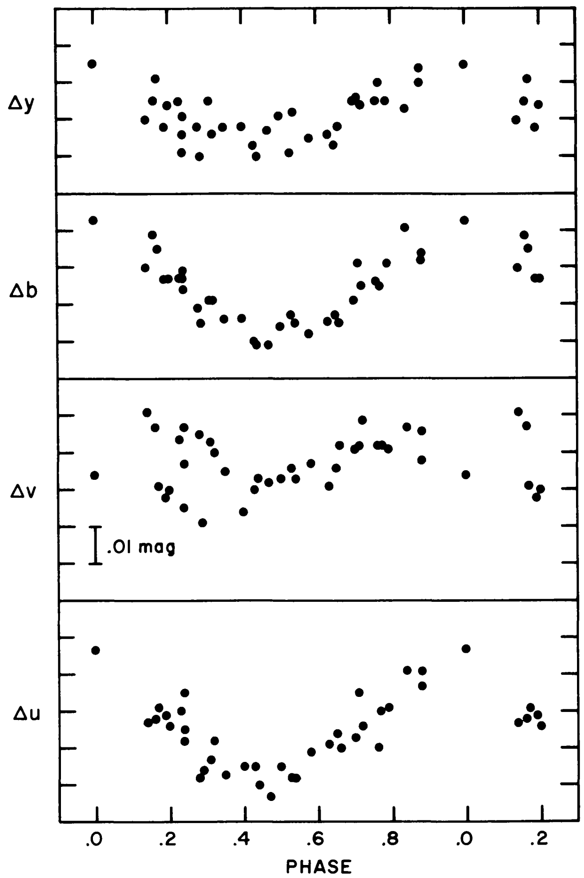

FIG. 3—The light variations of θ^1 Mic plotted according to the ephemeris JD⊙(maximum light) = 2440874.79 + 1.062 E. Note that the scale is twice as large as in the preceding figures.

From *UBV* observations of HD 184905, Burke, Rolland, and Boy (1970) obtained the period 1ᵈ855 ± 0.001. We find, however, that their observations can be equally well represented by the period 2ᵈ17. When our own observations are plotted in the shorter period, they show slightly more scatter than appears in Figure 2, and the secondary maximum in *u* that appears in Figure 2 is absent. We cannot distinguish between the two periods by phasing our observations together with those of Burke et al. because the gap in time between the two is too large. The indeterminacy of the period results from the fact that our observations, like those of Burke et al. were made at nearly the same time each night and extended over at most three months of any one observing season. Future observations should not be limited in the same way.

TABLE II
DIFFERENTIAL COLORS

Julian Date 2440000	Phase	y	b-y	m_1	c_1
		108 Aqr - HR 8998			
784.06	0.70	-0.057	-0.027	+0.017	-0.231
785.05	.97	.087	.040	.033	.235
786.06	.24	.071	.047	.038	.219
787.04	.50	.058	.033	.024	.226
788.05	.77	.055	.033	.028	.242
789.06	.04	.082	.038	.028	.228
790.04	.31	.075	.048	.030	.189
805.00	.32	.083	.041	.031	.210
805.99	.58	.050	.034	.028	.226
810.99	.92	.076	.036	.031	.242
812.98	.46	.065	.042	.028	.218
813.98	.73	.053	.025	.014	.228
818.98	.06	.091	.044	.031	.212
819.97	.33	.083	.044	.031	.202
820.97	.60	.055	.032	.024	.229
821.95	.86	.078	.038	.033	.243
830.00	.02	.088	.044	.039	.233
832.01	.56	.054	.034	.032	.245
833.02	.83	.059	.031	.022	.243
833.92	.07	.086	.041	.030	.222
834.91	.34	.081	.049	.036	.205
835.91	.60	.045	.035	.029	.233
838.92	.41	.070	.035	.020	.209
842.90	.48	.063	.037	.023	.219
843.93	.75	.058	.026	.021	.237
844.93	.02	.084	.045	.024	.212
845.94	.29	.084	.050	.038	.194
846.95	.56	.053	.039	.029	.223
847.91	.82	.069	.028	.020	.239
848.90	.09	.094	.040	.029	.215
851.90	.89	.072	.036	.023	.235
852.95	.17	.087	.040	.024	.204
853.87	.42	.074	.038	.025	.211
900.80	.00	.091	.036	.024	.229
901.82	.27	.076	.039	.025	.206
902.79	0.53	-0.054	-0.034	+0.027	-0.229
		HD 184905 - HR 7499			
758.96	0.35	+0.418	-0.115	-0.034	-0.143
761.98	.74	.418	.120	.027	.133
762.96	.20	.412	.120	.028	.145
763.84	.60	.422	.113	.036	.134
778.94	.56	.418	.118	.028	.159
779.84	.97	.381	.111	.023	.209
781.94	.94	.383	.109	.022	.217
782.90	.38	.415	.116	.026	.153
783.87	.83	.393	.113	.025	.184
784.88	.30	.417	.116	.034	.149
785.91	.77	.415	.116	.031	.142
786.91	.23	.422	.129	.018	.139
787.86	.68	.427	.125	.028	.132
788.88	.14	.398	.114	.028	.166
789.86	.60	.422	.119	.030	.137
804.86	.50	.420	.121	.030	.149
805.85	.96	.371	.099	.032	.220
810.86	.27	.410	.112	.036	.145
812.83	.18	.397	.116	.027	.163
813.84	.64	.419	.111	.037	.135
818.84	.95	.390	.119	.012	.217
819.86	.40	.419	.119	.028	.147
820.79	.85	.399	.124	.014	.179
821.80	.31	.421	.119	.033	.134
828.79	.53	.422	.119	.027	.166
829.81	.00	.379	.107	.023	.232
830.82	.47	.413	.115	.034	.155
831.79	.91	.383	.104	.025	.216
832.82	.39	.425	.123	.028	.141
833.78	.83	.401	.115	.027	.168
834.78	.29	.418	.119	.029	.139
835.80	.76	.419	.121	.027	.140
838.82	0.15	+0.387	-0.112	-0.024	-0.200
		θ^1 Mic - HR 8104			
778.99	0.79	-0.445	-0.286	+0.061	+0.386
782.01	.63	.436	.279	.048	.393
783.99	.50	.441	.273	.059	.390
784.99	.44	.430	.279	.040	.417
786.01	.40	.438	.278	.055	.383
786.97	.32	.436	.285	.051	.402
787.97	.24	.441	.286	.073	.362
789.01	.23	.445	.282	.047	.399
790.01	.17	.451	.284	.073	.363
804.95	.24	.431	.298	.075	.375
805.93	.16	.445	.294	.071	.393
810.95	.88	.450	.284	.057	.384
812.95	.77	.450	.275	.043	.395
813.90	.66	.438	.277	.035	.415
818.88	.35	.438	.278	.044	.408

TABLE II (*Continued*)

Julian Date 2440000	Phase	y	b-y	m_1	c_1
		θ^1 Mic - HR 8104			
819.87	.29	.430	.285	.064	.380
820.89	.24	.436	.288	.050	.412
821.89	.19	.438	.289	.073	.366
829.89	.72	.444	.281	.042	.410
830.88	.65	.433	.284	.050	.403
831.87	.58	.435	.277	.037	.409
832.88	.53	.431	.286	.052	.404
833.87	.47	.437	.272	.032	.415
834.89	.43	.433	.277	.042	.401
835.83	.31	.445	.276	.039	.412
838.89	.20	.444	.283	.065	.371
842.81	.88	.454	.278	.057	.370
843.83	.84	.443	.298	.077	.379
844.80	.76	.445	.281	.050	.401
845.81	.71	.446	.285	.059	.382
846.86	.70	.445	.276	.041	.402
848.81	.54	.442	.273	.040	.403
852.79	.28	.438	.281	.040	.422
871.76	.14	.440	.290	.054	.408
874.79	0.00	-0.455	-0.288	+0.070	.349

C. θ^1 *Microscopii*

Initial examination of the photoelectric measurements of θ^1 Mic yielded a period of $16^d.5$. Such a long period, however, is incompatible with the available spectroscopic data. Babcock (1958) found evidence for a reversal of the magnetic field in one day. He also reported that the lines in θ^1 Mic are typically slightly wider than 0.5 Å; by the period-line width relation, the period of θ^1 Mic must then be less than about seven days (Steinitz 1964). Accordingly, we searched for periods in the vicinity of one day, and found that two values, $1^d.062$ and $0^d.941$, represent the data equally well. Figure 3 is based on the elements

$$JD_{\odot}(\text{maximum light}) = 2440874.79 + 1.062\,E$$
$$\pm .10 \pm .001$$

Since θ^1 Mic is so far south ($\delta = -41°$), its air mass at Mauna Kea is always greater than 1.9, and we can observe the star only close to meridian transit. A definitive period can best be determined from an observatory in the Southern Hemisphere.

The light curves of θ^1 Mic at all four wavelengths are similar in amplitude, shape, and phase. In the v filter, there appears to be unusually large scatter near phase 0.2. We know of no observational effect that might cause a large random error for observations in this filter. The center of the v filter does nearly coincide with Hδ, and it may be that variability in the Balmer lines is responsible for the scatter. In HD 215441 (Wood 1967) and in 73 Draconis (Bonsack and Markowitz 1967), the equivalent widths of the Balmer lines vary rapidly by amounts that range up to 2 Å. A change of 2 Å in the equivalent width of Hδ would change the v magnitude by about $0^m.01$ and would therefore be able to explain the observed scatter.

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