THE ASTRONOMICAL JOURNAL VOLUME 104, NUMBER 1 JULY 1992

PHOTOMETRY OF EIGHT MAGNETIC PECULIAR A STARS[1]

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Received 6 November 1991

ABSTRACT

Differential U,B,V observations of the magnetic Ap stars CU Vir, β CrB, χ Ser, and HD 173650 obtained with the Phoenix 10 in. telescope of the Fairborn Observatory are analyzed along with *uvby* data taken with the 0.4 m telescope of Kitt Peak National Observatory. Our refined periods, 0.520 680 days for CU Vir, 1.595 83 days for χ Ser, and 9.975 48 days for HD 173650, differ only slightly with those in the literature. For CU Vir the shapes of the light curves vary from observer to observer suggesting that this star may be precessing. For β CrB the 18.487 day period of Preston & Sturch [*The Magnetic and Related Stars* (1967)] appears adequate. We also analyzed differential U,B,V observations of the magnetic Ap stars 63 And, HD 111133, HD 147010, and 52 Her obtained with the Phoenix 10 in. telescope. The star 63 And has a period of 4.2190 days of which Winzer's [Ph.D. thesis, University of Toronto (1974)] period is an alias. The period of HD 111133 is 16.3047 days, which is marginally longer than found by Buchholz & Maitzen [A&A, 73, 222 (1979)] and by Wolff & Wolff [ApJ, 176, 433 (1972)]. Our data validates North's [A&AS, 55, 259 (1984)] period for HD 147010 of 3.9210 days, but we are not able to confirm the variability of 52 Herculis below the Balmer jump.

1. INTRODUCTION

Many B and A stars have spectra which do not fit easily into the normal scheme of spectral classification. Among these are the magnetic peculiar A stars, which are the only group of upper main sequence stars which possess detectable magnetic fields. Many are known spectrum, light, and magnetic variables (see, Wolff 1983). Their properties can be understood with the rigid rotator model first proposed by Babcock (1949) and championed by Stibbs (1950) in which the magnetic field axis is often substantially inclined to the rotational axis. The field is assumed to be locally constant or frozen in. To a distant observer, the magnetic field intensity varies as the star rotates. The spectrum and light variations can be explained by assuming that the variable elements are concentrated nonuniformly on the stellar surface. Radiative diffusion processes are the most likely cause of the chemical segregation (Michaud 1970). To combine spectral, light, and magnetic information taken at different epochs it is necessary to accurately know the rotational periods. These can be determined by extended photometric observations.

This paper discusses photometry of eight stars most of which was obtained with the Phoenix 10 in. Automated Photoelectric Telescope (APT). An APT is very useful, in principle, for obtaining observations to monitor the performance of a variable. But when working with APT observations of small amplitude variables such as the ones discussed in the present paper, adequate care must be taken to include only those observations obtained on photometric nights. Hall and his associates (Strassmeier & Hall 1988a,b; Strassmeier *et al.* 1989; Houten & Hall 1990) have demonstrated that APTs can produce photometry whose quality at least equals that produced manually by astronomers.

We also include *uvby* observations of these stars obtained by Pyper with the 0.4 m telescope of Kitt Peak National Observatory. Table 1 is a list of corrected HJD values for the *uvby* data of CU Vir and β CrB published in Pyper & Adelman (1985) which were later found to contain errors. Tables 2 and 3 are the *uvby* photometry and HJD values at the midpoints of the observations for χ Ser and HD 173650, respectively.

2. QUALITY OF APT OBSERVATIONS

The APT Service of Fairborn Observatory sends data to its subscribers whenever the rms deviation of the individual measurements making up an observation is smaller than 0.020 mag. We tried to verify this ad-hoc rule concerning the cutoff for the acceptability of APT observations (Genet & Boyd 1985). In doing so, we concluded it is prudent to only analyze data for which all six values are present (variable-comparison and check-comparison values for U, B, and V). In Table 4 we give the number of data values in

[1]Based on the SIMBAD data retrieval system, database of the Strasbourg, France, Astronomical Data Center.

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 0004-6256/92/070314-13$00.90

TABLE 1. Corrected JDs for β CrB and CU Vir.

β CrB JD 244+	CU Vir JD 244+
5440.916	4338.898
5441.892	4339.861
5443.870	4340.882
5444.888	4341.896
5471.903	4342.846
5472.871	4742.790
5474.782	4743.680
5475.775	4743.751
5476.774	4745.680
5477.763	4745.738
5782.963	4746.684
5783.942	4746.751
5785.914	5441.834
5787.866	5443.814
	5444.847
	5471.831
	5472.740
	5472.847
	5474.744
	5475.741
	5476.734
	5476.805
	5477.725

the group measurements for the data of the eight Ap stars we studied. By this criteria, 20% of the values which were sent to us had to be discarded. Some of this to be discarded data was taken by the APT observing too early in the evening or too late in the morning. Other values represent groups for which it was clear when the APT started to observe and clouds came in during the observations. The greatest percent of data to be discarded for a group was for that of HD 147010, the most southerly star at a declination of $-20°$.

For the remaining 80% of the data, we calculated the mean and standard deviation of the data for each check-comparison star value and color. Only a few data points were much more than 3σ from the mean. Based on this criterion, we discarded a small amount of data: 1 observation each for HD 111133, CU Vir, and χ Ser, and 4 for HD 147010. This is 0.8% of the data which passed the 6 values for the group test and confirms that this test excludes most of the bad data.

Table 5 gives the mean check-comparison *UBV* values and the standard deviations for the eight groups. The mean σ values are 0.011 mag for *U*, 0.007 mag for *B*, and 0.009 mag for *V*, with a rms scatter of 0.002 mag. For some groups the scatter is somewhat less. The largest scatter is again for HD 147010. In Table 6 we compare the APT differential magnitudes with those extracted from the SIMBAD database. The agreement, in general, is quite good and is what is acceptable for *UBV* photometry. We did not include ΔU values from the third quarter of 1989 in our analysis, as a blocking filter was not present which was present for previous data. In all eight datasets there was no indication of variability of either the comparison or the check star. Table 7 shows the number of observations obtained within the ranges of Julian Dates. We have indicated substantial breaks in the datasets due to the shutdown in the summer or to when the star was not observable.

3. PERIOD DETERMINATIONS

Many published papers concerning the periods of Ap stars are based on less than a desirable number of data

TABLE 2. *uvby* photometry for χ Serpentis (star$-$comparison).

JD 244+	Phase*	$b-y$	$u-b$	y	b	v	u
4338.974	0.738	−0.053	0.006	−0.397	−0.450	−0.485	−0.443
4339.922	0.332	−0.047	0.006	−0.377	−0.424	−0.461	−0.418
4340.938	0.968	−0.042	−0.004	−0.393	−0.435	−0.469	−0.438
4341.951	0.603	−0.050	−0.004	−0.386	−0.435	−0.479	−0.439
4342.913	0.206	−0.053	0.016	−0.393	−0.446	−0.480	−0.429
4343.890	0.818	−0.039	−0.001	−0.400	−0.439	−0.482	−0.440
4742.889	0.844	−0.038	0.007	−0.401	−0.439	−0.459	−0.432
4743.845	0.443	−0.038	0.002	−0.379	−0.416	−0.447	−0.415
4745.834	0.690	−0.054	0.008	−0.403	−0.457	−0.462	−0.449
5440.944	0.268	−0.047	0.009	−0.381	−0.428	−0.463	−0.420
5441.912	0.875	−0.050	0.010	−0.400	−0.450	−0.491	−0.439
5443.897	0.119	−0.046	0.010	−0.399	−0.445	−0.473	−0.435
5444.908	0.752	−0.050	0.007	−0.401	−0.451	−0.495	−0.445
5472.922	0.307	−0.042	0.000	−0.388	−0.430	−0.457	−0.430
5474.830	0.503	−0.029	−0.007	−0.377	−0.406	−0.442	−0.413
5475.839	0.135	−0.041	0.008	−0.394	−0.436	−0.460	−0.427
5476.860	0.775	−0.057	0.007	−0.395	−0.452	−0.483	−0.445
5477.814	0.372	−0.050	0.011	−0.380	−0.430	−0.453	−0.420
5782.938	0.573	−0.043	0.000	−0.386	−0.429	−0.456	−0.429
5783.892	0.171	−0.048	0.007	−0.392	−0.440	−0.463	−0.434
5787.904	0.685	−0.049	0.006	−0.393	−0.442	−0.471	−0.436
6120.952	0.384	−0.039	0.005	−0.377	−0.416	−0.446	−0.411

Note to TABLE 2

*JD=2434134.06+1.59583*E*.

TABLE 3. *uvby* photometry for HD 173650 (star−comparison).

JD 244+	Phase*	$b-y$	$u-b$	y	b	v	u
4339.976	0.612	−0.067	−0.262	−0.367	−0.434	−0.473	−0.696
4342.976	0.913	−0.064	−0.220	−0.327	−0.390	−0.431	−0.610
4343.944	0.010	−0.066	−0.191	−0.324	−0.390	−0.441	−0.580
4742.935	0.007	−0.062	−0.211	−0.331	−0.393	−0.444	−0.604
4743.926	0.106	−0.062	−0.184	−0.329	−0.391	−0.431	−0.575
4745.908	0.305	−0.044	−0.202	−0.343	−0.387	−0.431	−0.589
5441.939	0.079	−0.067	−0.192	−0.337	−0.404	−0.451	−0.596
5443.923	0.278	−0.067	−0.204	−0.328	−0.395	−0.449	−0.598
5444.931	0.379	−0.057	−0.229	−0.348	−0.405	−0.452	−0.634
5471.947	0.087	−0.065	−0.200	−0.327	−0.392	−0.446	−0.592
5474.878	0.381	−0.073	−0.215	−0.341	−0.414	−0.465	−0.629
5475.858	0.479	−0.050	−0.252	−0.359	−0.410	−0.455	−0.661
5476.879	0.582	−0.064	−0.265	−0.369	−0.433	−0.472	−0.699
5477.853	0.679	−0.066	−0.244	−0.360	−0.427	−0.472	−0.671
5620.625	0.992	−0.063	−0.202	−0.323	−0.386	−0.441	−0.588
5621.624	0.092	−0.064	−0.191	−0.335	−0.399	−0.454	−0.590
5622.599	0.189	−0.062	−0.198	−0.326	−0.387	−0.446	−0.585
5782.992	0.268	−0.049	−0.209	−0.344	−0.393	−0.443	−0.602
5783.993	0.369	−0.055	−0.234	−0.347	−0.402	−0.450	−0.636
5787.980	0.768	−0.062	−0.231	−0.347	−0.402	−0.438	−0.640
5986.656	0.685	−0.058	−0.262	−0.360	−0.417	−0.446	−0.679
5987.631	0.782	−0.062	−0.231	−0.339	−0.401	−0.453	−0.633

Note to TABLE 3

*JD=2437121.6+9.97548*E*.

values. Table 5 shows that this is not the case for our data, except perhaps for HD 147010. Furthermore, as Ap stars typically have periods of a few days in length, inspection of Table 7 demonstrates that we have obtained at least one data point for each cycle for a reasonably consecutive observing run.

Our basic philosophy for each star was to plot our data using the best published period to see if the data approximately confirmed this period. Then we used an IDL implementation of the Scargle periodogram (Scargle 1982, Horne & Baliunas 1986) by Fullerton. We usually adopted the moderately conservative rule that we should consider our data and those of other observers separately in calculating periodograms. If our data and the periodograms confirmed the published period, then we adjusted the period so that our data and the published data coincide as well as possible in phase. However, if a new period as needed, we used all the data in our periodogram analysis.

TABLE 4. Group completeness statistics.

	Values within Groups of Given Size					
Variable	1	2	3	4	5	6
HD 14392	9	14	45	20	85	690
HD 111133	8	26	48	84	125	1188
HD 124224	21	48	135	100	275	2721
HD 137909	1	14	18	24	45	474
HD 140160	3	18	15	16	70	366
HD 147010	6	12	57	24	40	144
HD 152107	4	6	33	28	60	486
HD 173650	3	8	15	16	40	456
Total	55	146	366	312	740	6525

4. 63 ANDROMEDAE

Winzer (1974) discovered the light variability of 63 Andromedae (=HR 682=HD 14392) when he performed differential *U*, *B*, *V* photometry (19 measurements) with respect to 62 And. He found a variability of about 0.05 mag in *U*, 0.035 mag in *B*, and of about 0.025 mag in *V*. His epochs of *U* light maxima are given by

$$\mathrm{JD}(U_{\max})=2441619.66+1.3040E.$$

This star is a moderately large amplitude variable (0.05 mag. in *U*) with a somewhat larger scatter than normal for other Ap stars, especially a strange dip near phase 0.8.

As our observations used 62 And (=HD 14212) as our comparison star and 66 And (=HD 15138) as our check star, we can directly compare our results with Winzer's. Our data consists of 115 observations taken over a period of some 22 months. On some night we obtained two observations of 63 And.

We initially plotted the data according to Winzer's ephemeris. We found the mean differences for ΔU, ΔB, and ΔV between our data and Winzer's and then applied these corrections to Winzer's data. Figure 1 shows the ΔB photometry as an example. Winzer's data (open circles) and the APT data (closed circles) overlay one another, but there is a range of phases where the scatter is far greater than expected. Small changes in the period could not reduce the scatter.

That Winzer's data fell within the scatter of our data at a given phase given his ephemeris and that he made only one observation per night of this star, suggested that he might have found an alias to the true period. We examined

TABLE 5. Differential check-comparison magnitudes.

Variable (HD)	Comparison (HD)	Check (HD)	ΔU	ΔB	ΔV	Number of Values
14392	14212	15138	1.148 ± 0.010	1.257 ± 0.007	0.850 ± 0.011	116 (108)
111133	109860	110951	-0.724 ± 0.011	-0.812 ± 0.009	-1.115 ± 0.010	197
124224	122408	121607	1.759 ± 0.011	1.779 ± 0.010	1.671 ± 0.009	356
137909	135502	136849	-0.281 ± 0.007	-0.013 ± 0.005	0.103 ± 0.007	79 (75)
140160	141187	141458	0.920 ± 0.011	1.003 ± 0.007	1.082 ± 0.007	62 (61)
147010	146952	146416	-1.031 ± 0.016	-0.689 ± 0.009	-0.455 ± 0.012	20
152107	152951	149081	-0.558 ± 0.011	-0.511 ± 0.007	-0.434 ± 0.007	81 (71)
173650	175427	174262	1.023 ± 0.012	0.600 ± 0.006	0.487 ± 0.007	75 (65)

Note to TABLE 5

The number of values in parentheses are those for ΔU when observations for ΔB and ΔV include those for values taken in the third quarter of 1989.

the U, B, and V values both for our data alone and for our data and Winzer's. For all the data, U and V suggest a frequency of 0.238 55 cycles/day while B a frequency of 0.23854 cycles/day. This corresponds to a period of 4.1920 days, which indicates Winzer found an alias to the true period. The periodograms show peaks corresponding to his period and to the rotational frequency plus 1.0 and 2.0 cycles/day. We show in Fig. 2 the U, B, and V differential photometry plotted using

$$\mathrm{JD}(U_{\max})=2441619.66+4.1920E.$$

The scatter about the mean curves is now of the same order as that for other stars of this paper. The light curve is asymmetric with the falling branch lasting longer than the rising branch. The variability in all three colors is almost in phase with amplitudes similar to that found by Winzer (1974). The zero point needs to be shifted about 0.1 of a period, with U, B, and V giving slightly different results. Further and higher quality photometry is needed to improve the period and the zero epoch. It might be more appropriate to give the ephemeris in terms of minimum rather than maximum light.

5. HD 111133

Wolff & Wolff (1972) discovered the light variability of HD 111133 (=HR 4854) using *uvby* photometry. The amplitude of variability is 0.04, 0.05, 0.05, and 0.03 mag in *u*, *v*, *b*, and *y*, respectively. Buchholz & Maitzen (1979) obtained Δa photometry which makes use of the Stromgren *y* filter and two other filters to measure the strength of the λ5200 broad continuum feature. Their revised ephemeris is

$$\mathrm{JD(light\ maximum)}=2440640.20\pm0.41 + 16.304\pm0.003E.$$

TABLE 6. Comparison of differential magnitude values.

Variable	ΔU	ΔB	ΔV	Source
HD 14392	...	1.25	0.85	This Paper
	...	1.25	0.82	SIMBAD
HD 111133	...	−0.81	−1.12	This Paper
	...	−0.80	−1.11	SIMBAD
HD 124224	1.76	1.78	1.67	This Paper
	1.77	1.75	1.65	SIMBAD
HD 137909	−0.28	−0.01	0.10	This Paper
	−0.28	−0.01	0.11	SIMBAD
HD 141458	0.92	1.00	1.08	This Paper
	0.95	1.04	1.11	SIMBAD

TABLE 7. APT photometry.

Star	Number of Observations	JD 244+ Start	JD 244+ End
63 And	31	7144	7221
	77	7419	7555
	6	7779	7800
HD 111133	178	7497	7618
	19	7659	7702
CU Vir	41	6905	6985
	179	7158	7261
	112	7520	7618
	24	7654	7701
β CrB	1	7419	7420
	56	7536	7618
	18	7659	7696
	4	7779	7790
HD 147010	20	7569	7610
	4	7673	7696
χ Ser	47	7540	7618
	14	7654	7694
	1	7780	7781
52 Her	15	7415	7447
	29	7568	7618
	27	7654	7696
	10	7779	7798
HD 173650	36	7415	7484
	7	7601	7616
	22	7664	7702
	11	7779	7798

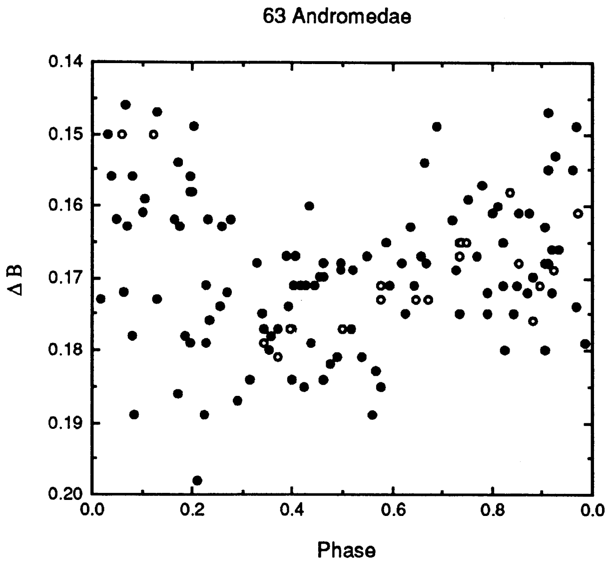

FIG. 1. The ΔB values for 63 And plotted using Winzer's ephemeris. Closed circles are the APT values while open circles are Winzer's values less -0.009 mag.

Our measurements used the same comparison star HD 109860 as Wolff & Wolff (1972). We combined their Δy values with our ΔV values to improve the period. We have 197 *UBV* observations taken over a 10 month period. When we plot our ΔV data according to the Buchholz and Maitzen ephemeris, we find that their period is essentially correct. There are a few outlying values, which are less important in our ΔB data than for ΔV and ΔU. Although Δy values are often assumed to be the same as ΔV values, this is not necessarily correct for magnetic Ap star photometry due to the λ5200 broad, continuum features of such stars. As the mean value of Wolff & Wolff's Δy values are 0.006 mag more negative than that for our ΔV values (excluding values for which $\Delta V > 0.02$ mag), we added 0.006 mag to their data for our phase comparisons. A small period adjustment to bring the Δy and ΔV values into better coincidence results in a period of 16.3047 (± 0.002) days in accord with our periodogram analysis. There is no justification for changing the epoch of light maximum. Our data indicates a variability of 0.04 mag in *U* and *B* and a 0.025 mag variability in *V*. Figures 3(a)–3(c) show the resultant light curves for ΔU, ΔB, and ΔV, respectively, with our derived period. The data of Wolff and Wolff are indicted in Fig. 3(c) with plus signs to differentiate them from our data.

6. CU VIRGINIS

CU Virginis (HR 5313=HD 124224) is a well-known spectrum variable with relatively large light variations. Deutsch (1952a) discovered the spectrum variations and found a period of 0.520 67 days, which is the shortest of any Ap star. Hardie (1958) found that the light variations occurred with the same period as the spectral variations with maximum light corresponding to Si II maximum and minimum light to He I maximum. Blanco & Catalano (1971) obtained *UBV* photometry and improved the period. Their ephemeris is

$$\mathrm{HJD(Light\ Minimum)} = 2439995.4413 + 0.52067688E.$$

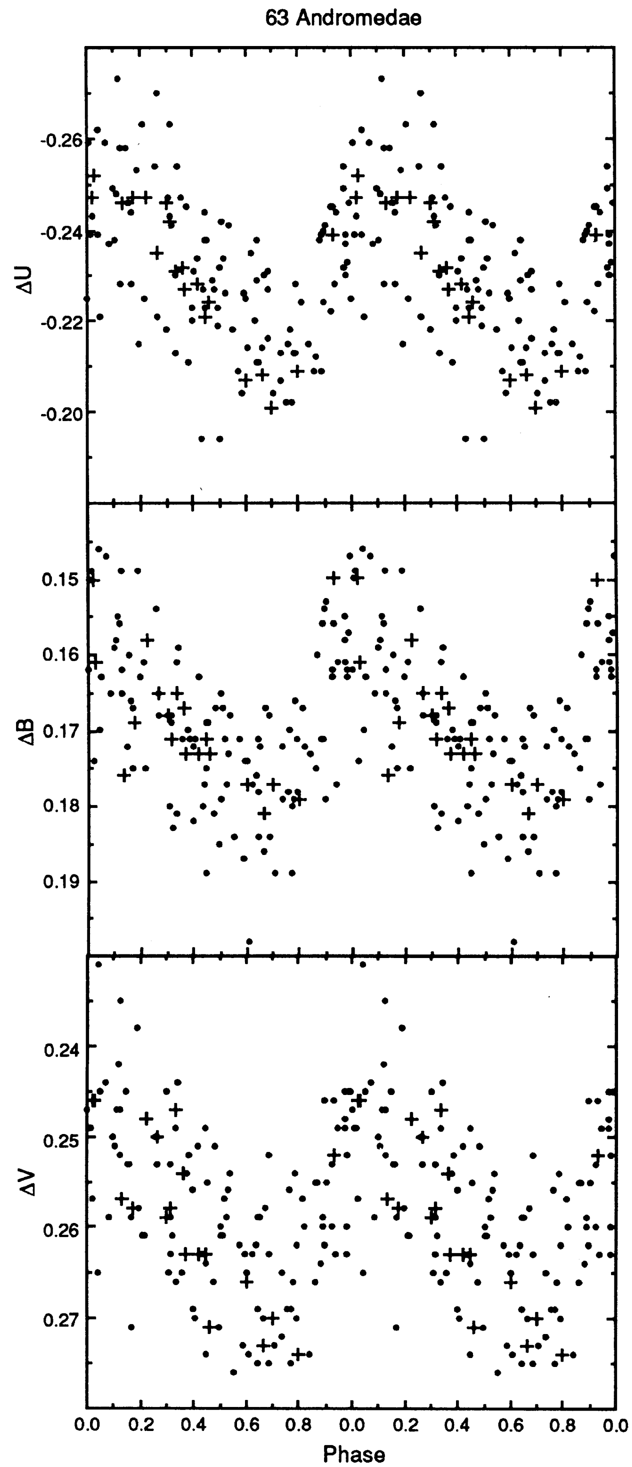

FIG. 2. The ΔU, ΔB, and ΔV values for 63 And assuming a period of 4.2190 days and Winzer's initial epoch of maximum light in *U*. Winzer's (1974) data with slight adjustments (-0.013 mag for *U*, -0.009 mag for *B*, and $+0.001$ mag for *V*) are shown as +'s while our data is shown as closed circles.

Winzer (1974) obtained a few U, B, V measurements using τ Vir(=HD 122408) as the comparison star. Weiss *et al.* (1976) and Pyper & Adelman (1985) published *uvby* photometry. The current *UBV* data consists of 357 values obtained over a span of some 26 months. Our comparison star was HD 122408 and our check star HD 121607. The periodogram for our data has maximum power for a frequency of 1.9205 cycles/day (0.520 70 days). That for the data of Blanco & Catalano (1971) is essentially the same. Hardie's data was not published in an appropriate form for period determination and thus we have excluded it.

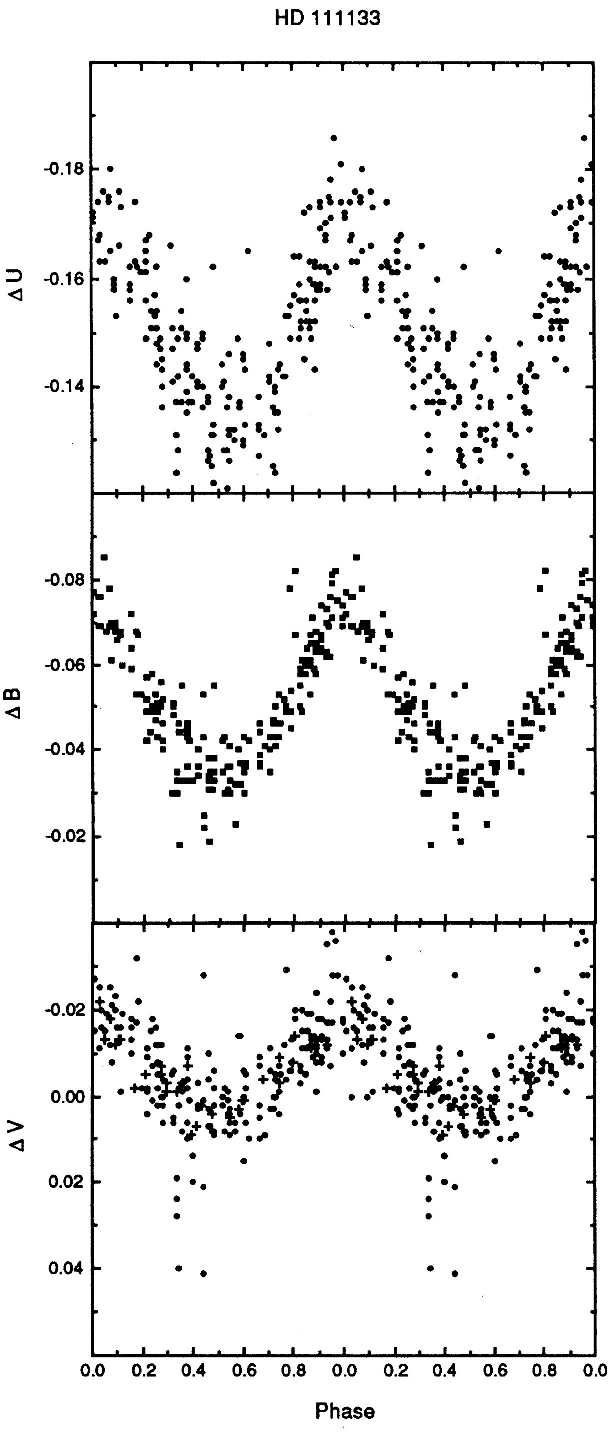

FIG. 3. The ΔU, ΔB, and ΔV values for HD 111133 assuming a period of 16.3047 days and an initial JD (light max) = 24406240.20 days. Our APT data are represented by closed circles for ΔU and ΔY and by filled rectangles for ΔB while Wolff & Wolff's (1972) Δy values plus 0.006 mag are indicated by +'s in part c.

To verify and further refine the period we used our V photometry, that of Hardie (1958), that of Blanco & Catalano (1971), that of Winzer (1974), and the y photometry of Pyper & Adelman (1985). When the light curve for each dataset is plotted using Blanco and Catalano's period, the light curves have similar ranges of variation with some differences in shape. Light curve shape differences can be produced by either the star or the different photometric systems. The star spots might be changing their location relative to the magnetic axis, which is highly unlikely for stars with radiative atmospheres, or the star might be precessing (Shore & Adelman 1976). As the stellar rotational period is constant for these possibilities, we matched light minima.

When the light minima of our APT data and that of Hardie are brought into agreement, we find a period of 0.5206800 ± 0.0000005 days. The minima of the photometry of Blanco & Catalano (1971) also coincide when this period is used. We examined alternative periods assuming that an integral number of rotational periods was overcounted or undercounted between our results and those of Hardie, but this does not make either Winzer's data or the y data agree with the other three sets. CU Vir has a definite λ5200 broad, continuum feature (Pyper & Adelman 1985). We need simultaneous V and y photometry to see if the variability of this feature might be causing the y magnitudes and the V magnitudes to behave differently.

Figures 4 and 5, respectively, show the *UBV* and the *uvby* photometry of CU Vir using our period and zero epoch of Blanco & Catalano (1971). The B and V light curves are more similar to one another than the U curve. There are differences in the light-curve data among the Blanco and Catalano, the Hardie, and the APT data, which are consistently seen in each filter. The epoch of minimum light is not quite at zero phase and appears to be about 0.03. The v, b, and y light curves have similar shapes and are different from that for u. The shapes of the u and the mean U light curves are similar, but are slightly phase shifted. This is also true of mean B and V compared with v, b, and y.

As the light curves of CU Vir taken at different epochs by various investigators show clear differences, additional observations are needed. The same telescope, photometer, and filter set should be used for several years. The quality of the photometry needs to be better than that obtained to date. Investigations of the Balmer line variability also would be desirable. If we are observing the free body precession of CU Vir, its precessional period should be of the order of a few years (Shore & Adelman 1976). The photometry of the rapidly rotating Ap star 56 Ari shows more dramatic changes of the type described here (Adelman & Fried 1991).

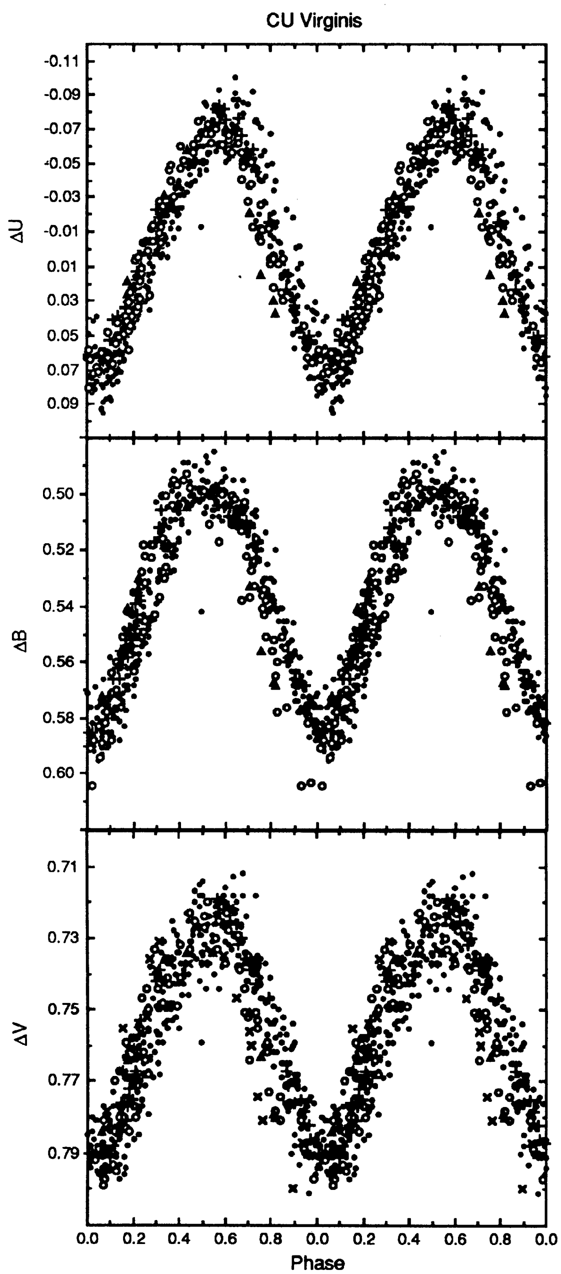

FIG. 4. The U, B, and V photometry of CU Vir plotted according to the ephemeris HJD=2439995.4413+0.5206800E days. Zero point values for other observers have been adjusted to overplot U, B, and V data. Our APT results are closed circles, Blanco & Catalano's (1971) values open circles. Hardie's (1958) are +'s, Winzer's (1974) are closed triangles, and Pyper & Adelman's (1985) are ×'s.

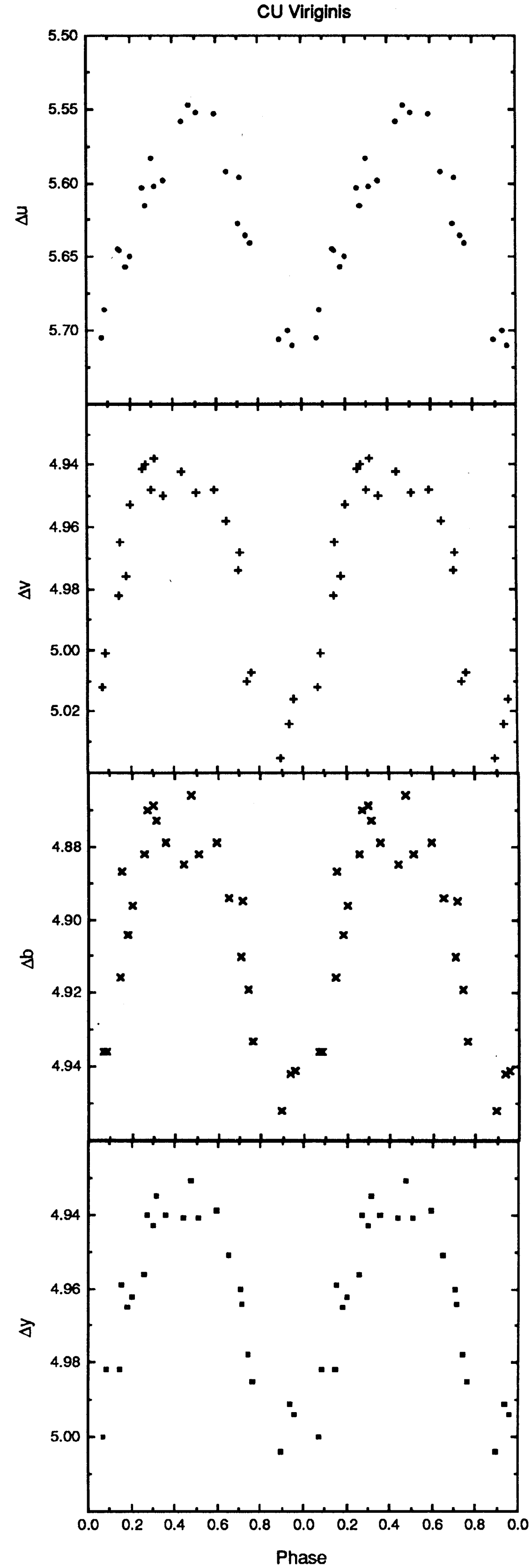

FIG. 5. The u, v, b, and y photometry of CU Vir from Pyper & Adelman (1985) plotted as for Fig. 4.

7. BETA CORONAE BOREALIS

Babcock (1958) found that β Coronae Borealis (=HR 5747=HD 137909) possessed a large, variable magnetic field. Steinitz (1964) derived a period of 18.5 days from these measurements of the longitudinal magnetic field. Preston & Sturch (1967) confirmed this period and found

$$\text{HJD(positive crossover)}=2434217.50+18.487E.$$

The mean surface field varied with the same period (Wolff & Wolff 1970). β CrB is a binary with a period of 10.55 yr (Kamper *et al.* 1990). Depending on the phase angle, the companion can be detected visually or by speckle interferometry. During the binary period there may be a long-term variation in the average magnetic field of the primary (Preston & Sturch 1967). Four-color (*uvby*) photometry by Wolff & Wolff (1971) and Pyper & Adelman (1985) demonstrated that light variations occur with the same period as the magnetic variations. Our data and that of Burke *et al.* (1970) correspond to the same orbital phases, while those of Pyper & Adelman (1985) are approximately 0.4 of a period later. For the present, we plot the photometry according to the 18.487 day period which appears to be adequate.

UBV photometry by Brodskaya (1970) and Burke *et al.* (1970) show that the variations in *U*, *B*, and *V* are in phase, with *B* having the largest range. When we examined our 79 *UBV* observations taken during a year, the most evident variability is in *B* with a range of 0.035 mag, compared with 0.025 mag in *U* and at most 0.015 mag in *V* [Figs. 6(a)–6(c)]. Our comparison star was HD 135502 and our check star was HD 136849.

The ranges of the observed light curves with the *u*, *b*, and *y* filters are quite small, order 0.02 mag, but are apparently in phase with that of the *v* filter, 0.03 mag. Figures 7(a)–7(d) show the variations of *u*, *v*, *b*, and *y* from Pyper & Adelman (1985). The values for *v*, *b*, and *y* are variable in phase with *U*, *B*, and possibly *V*, while those for *u* as a function of phase yield a scatter diagram. This is slightly different from the photometry of Wolff & Wolff (1971) in which *y* is essentially constant, *b* and *v* are definitely variable, and *u* shows suggestions of variability. The differences between the *V* and *y* variability might be due to how these filters sample the energy distribution of this star.

8. CHI SERPENTIS

Deutsch (1947) discovered the spectrum variability of χ Serpentis (=HR 5843=HD 140160) and later (Deutsch 1952b) revised the period. His ephemeris was

$$\mathrm{JD(Sr\ II\ max)} = 2434134.06 + 1.59584E.$$

Provin (1953) established that this star was also a light variable with this period, which was confirmed by van Genderen (1971) with five-color photometry and by Blanco & Catalano (1971) with *UBV* photometry. Musielok *et al.* (1980) performed 10-color photometry. We obtained 61 *UBV* observations over a 9 month period. Our comparison star was HD 141187 and our check star was HD 141458.

Comparison of the *V* values of Provin (1953) and van Genderen (1971) and of our *y* values with our *V* magnitudes indicated that only a slight change of period was needed for optimal agreement. This decreased the period to 1.595 83 days. A periodogram analysis of this data shows the strongest peak at 1.595 81 days. This is in good agreement with our corrected period.

Figures 8 and 9 show the photometry as a function of our period and the initial epoch of Deutsch. The amplitudes of *u*, *U*, *B*, *V*, and *y* are about 0.025 mag, while that of *b* and *v* are about 0.03 mag. In all of these magnitudes the star appears to vary in phase.

9. HD 147010

North (1984) found that Geneva photometry of HD 147010 (=DM −19° 4359), a member of the Upper Scor-

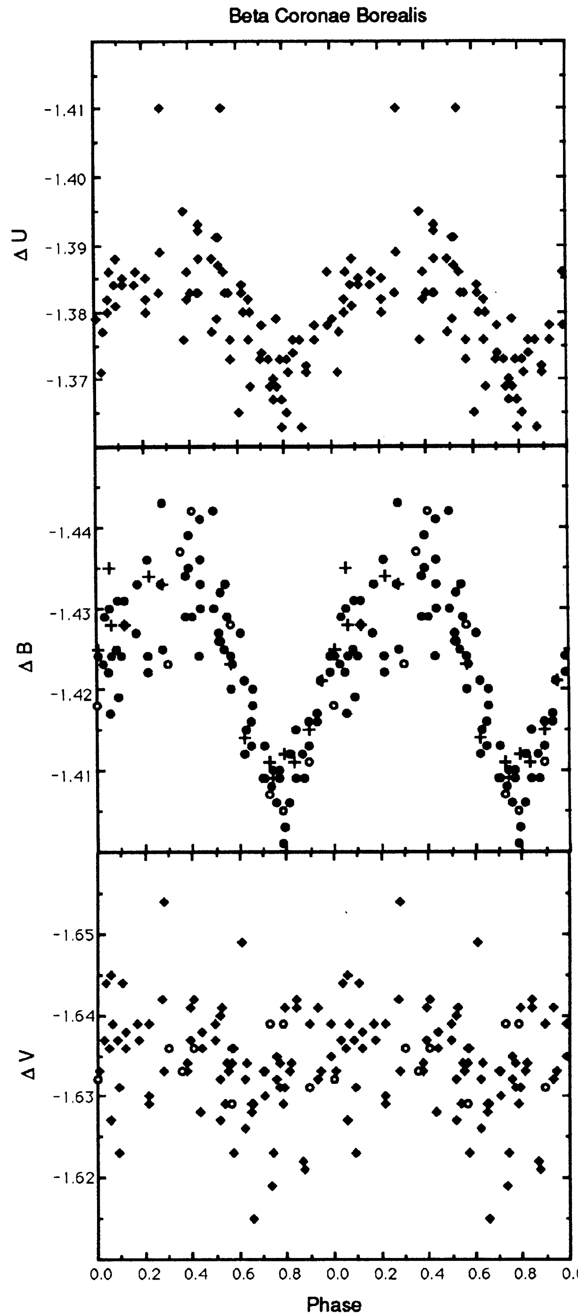

FIG. 6. The *U*, *B*, and *V* photometry of β CrB plotted according to the ephemeris HJD (positive crossover) = 243217.50 + 18.487*E* days. Solid symbols represent our APT data, open circles the data of Burke *et al.* (1970), and the +'s are the *b* photometry of Pyper & Adelman (1985). Zero point values for non-APT data have been adjusted to overplot our *U*, *B*, and *V* data.

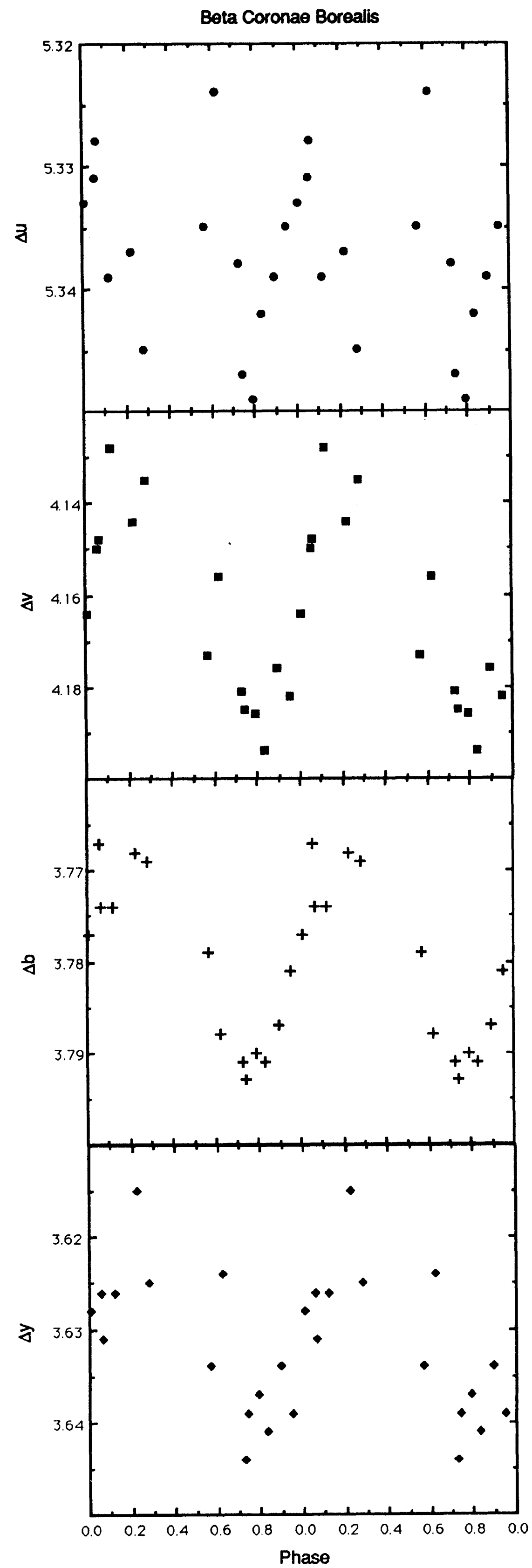

FIG. 7. The u, v, b, and y photometry of β CrB from Pyper & Adelman (1985) plotted as for Fig. 6.

pius Association, showed this star was a photoelectric variable. The amplitudes of variability are 0.09, 0.08, and 0.045 mag in [U], [B], and [V], respectively. He found

$$\mathrm{HJD}(U\ \mathrm{minimum}) = 2444808.447 + 3.9210 \pm 0.0001E.$$

Borra *et al.* (1985) obtained Stromgren *vby* photometry of HD 147010 and derived a period of 3.998 27 days. Un-

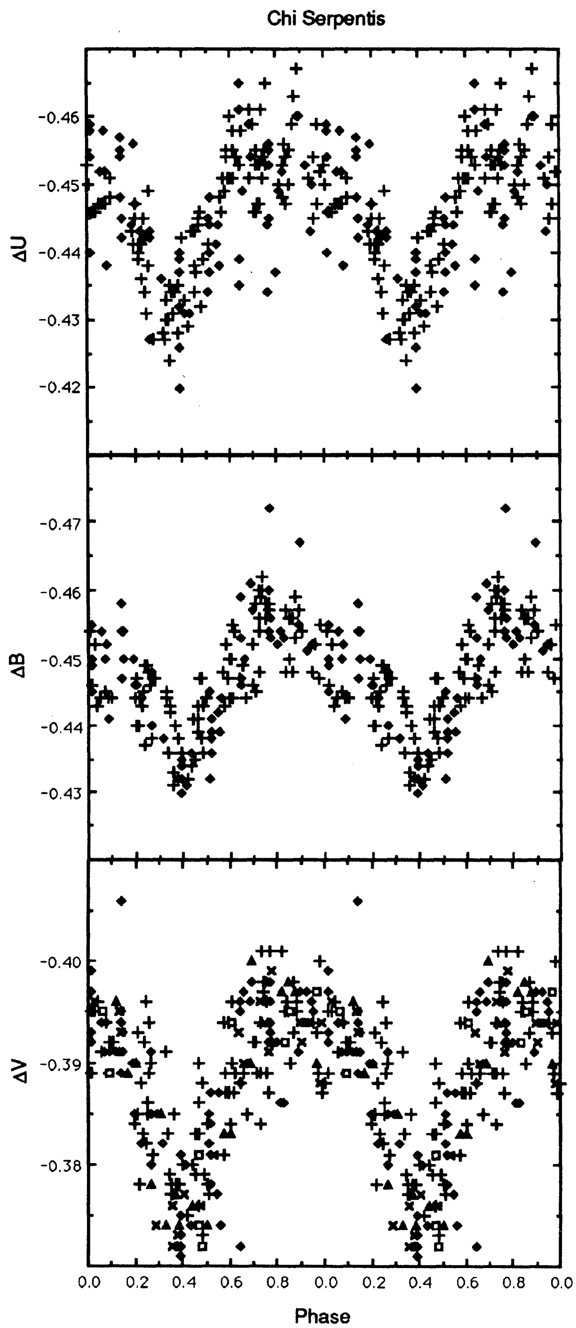

FIG. 8. The U, B, and V and photometry of χ Ser plotted according to the ephemeris HJD ($\mathrm{Sr\ II_{max}}$) = 2434134.06 + 1.59583E days. Filled diamonds are our APT values, open squares values from Provin (1953), +'s values from Blanco & Catalano (1971), ×'s values from van Genderen (1971), and closed triangles our y photometry. Zero point values for non-APT data have been adjusted to overplot our U, B, and V data.

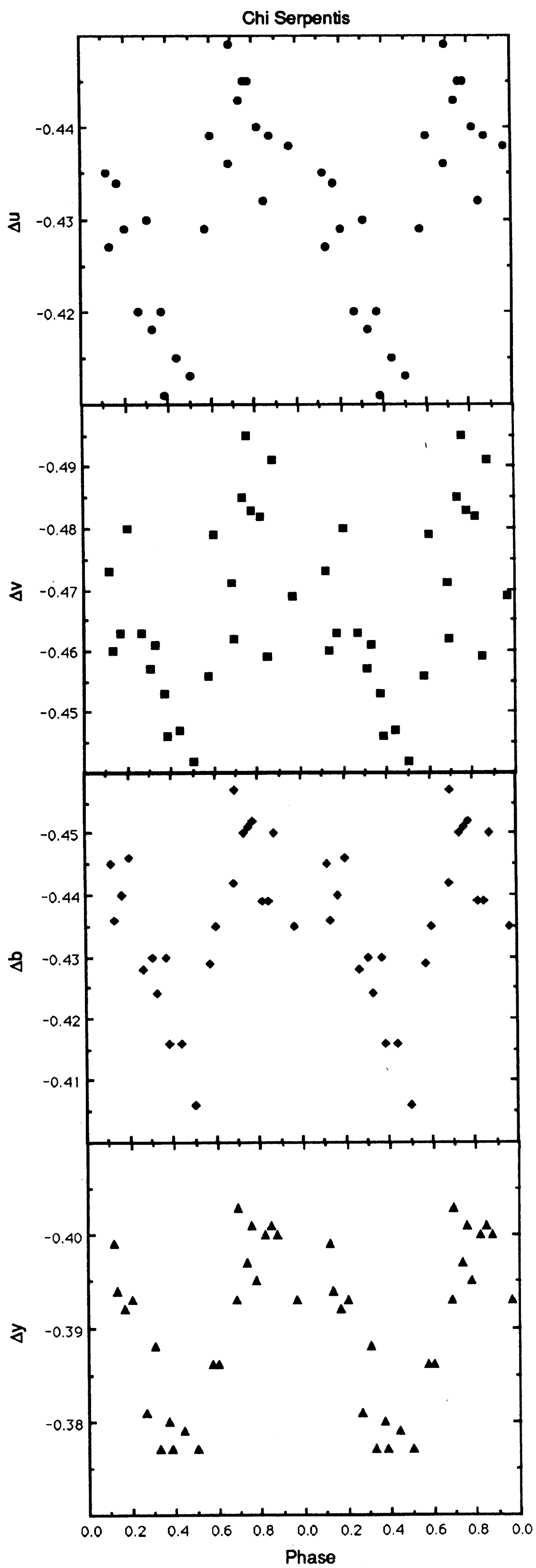

FIG. 9. The u, v, b, and y photometry of χ Ser plotted as for Fig. 8.

fortunately, we did not use the comparison or the check star of either dataset. Examining our data using both ephemerides showed that the period was more likely to be close to that of North. Recently, Lanz & Mathys (1991) reported that 20 new values obtained in 1987 allowed them to improve the period to 3.920 76 days.

Figure 4(c) shows that our ΔV data (filled circles), the y data of Borra *et al.* (+'s), and North's [V] data ($\times$'s) reasonably overlay one another when a period of 3.9210 days is used and the average values of the later two sets is made to coincide with our mean. Both our data and that of North have 20 values, while that of Borra *et al.* has 19 values. The scatter of the Borra *et al.* data is greater than our data which, in turn, is greater than the North data, which are high quality Geneva photometry. Our data was obtained under unfavorable conditions since $V=7.40$ mag for HD 147010 which, at best, is 52° from the zenith. Our comparison star was HD 146952. The amplitudes of variability (see Fig. 10) are about 0.10 mag for U, 0.08 mag for B, and 0.05 mag for V, which are similar to those given by North, whose photometry was based on different bandpasses. A periodogram analysis confirms the period is close to 3.9210 days.

10. 52 HERCULIS

Wolff & Preston (1978) found that the Ca II K line, the magnetic field intensity, and the brightness of 52 Herculis (=HR 6254=HD 152107) vary periodically. They found

$$\mathrm{HJD}(K\text{-line maximum})=2439247.7\pm0.05+3.8575E \pm0.0005.$$

Their Stromgren photometry with 14 observations shows a variability of 0.03 mag in m_1 and 0.05 mag in c_1. The average values are $V=4.803\pm0.003$ mag, $b-y=0.028 \pm0.004$ mag, $m_1=0.228\pm0.010$ mag, and $c_1=0.951 \pm0.017$ mag.

Our Phoenix 10 data consists of 81 sets of values taken over a 13 month period with HD 152951 as the comparison star. The V and B data, when plotted against phase using the Wolff and Preston ephemeris, are scattered diagrams [Figs. 11(b) and 11(c)]. We find $\Delta B=-2.085 \pm0.007$ mag and $\Delta V=-2.067\pm0.007$ mag, which are indicative of very little or no variability, in agreement with the photometry of Wolff and Preston. The mean ΔU value is -2.097 ± 0.010 mag. These values, when plotted against a period of about 3.8575 days, show a vaguely suggestive pattern [Fig. 11(a)], whose scatter cannot be reduced by changing the trial period by a few times the errors of the spectroscopic period. The lack of definite variability compared to that found by Wolff & Preston is most likely due to the poorer quality of our data or less likely to the inclusion of features in the U bandpass which are not included in the u bandpass.

The periodogram of our U data is very noisy with no frequency exceeding the S/N level for 1% significance. There are several peaks which indicate more than a one day period. But these are inconsistent with the spectroscopic results. The nearest spike to 3.8575 days is at 3.9217 days, but plotting the data with that period does not result in definite variability.

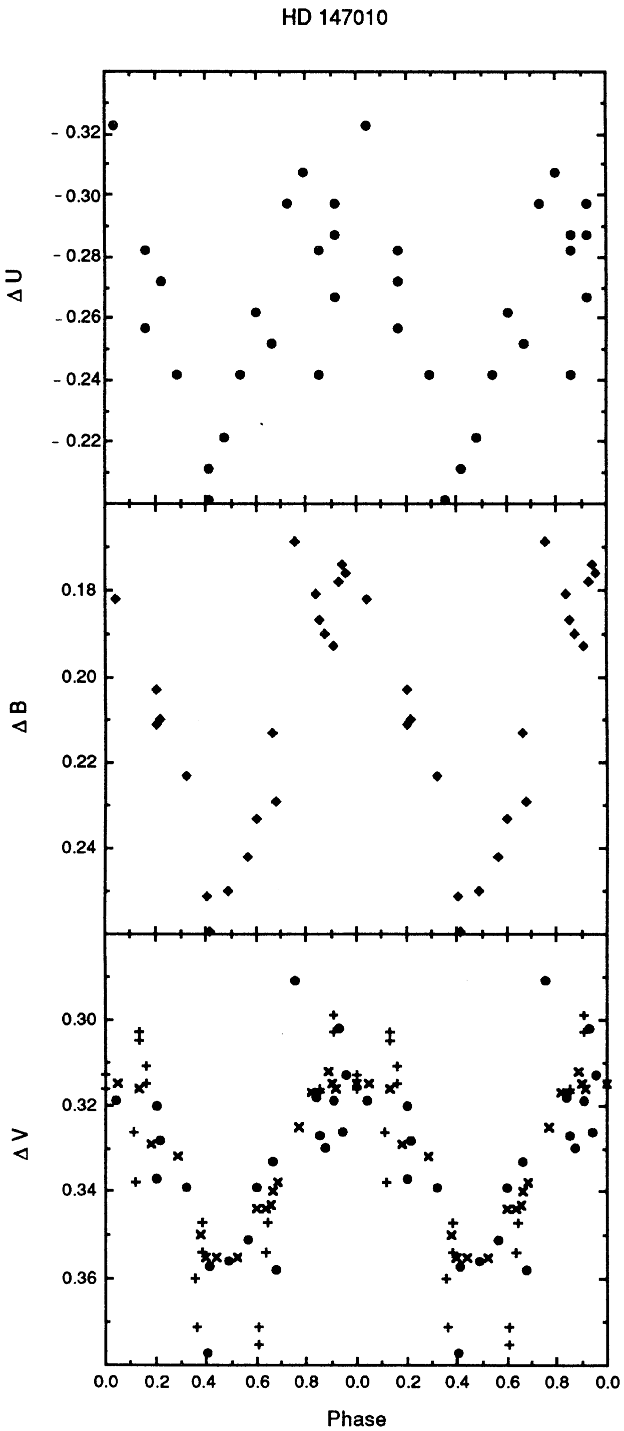

FIG. 10. The ΔU, ΔB, and ΔV values for HD 147010 assuming North's (1984) period of 3.9210 days and starting Julian Date. Our APT values are shown as closed circles for ΔU and ΔV and filled diamonds for ΔB. In part (c) $\times$'s are North's (1984) values plus 0.023 mag. and +'s are Borra *et al.* (1985)'s values minus 0.642 mag.

11. HD 173650

Babcock (1958) found HD 173650 (=HR 7058) was a magnetic variable. Wehlau (1962) first discovered its photometric variability. Other studies are by Blanco & Catalano (1968), Burke *et al.* (1969), Rice (1969), van Gen-

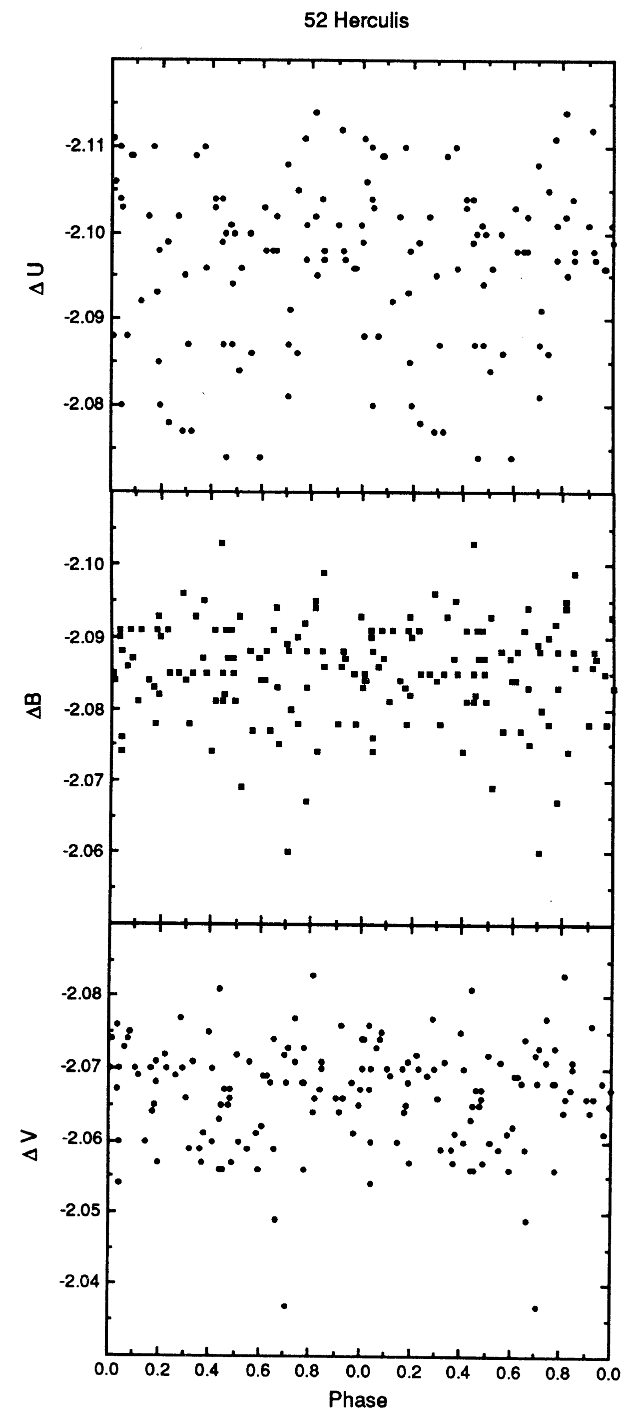

FIG. 11. The ΔU, ΔB, and ΔV values for 52 Her assuming a period of 3.8575 days. The first plot is possibly suggestive of variability while the other two plots indicate constancy.

deren (1971), and Rakosch & Fiedler (1978). Rice (1969) discussed the magnetic field, spectrum, and photometric variations in an attempt to map the magnetic field and elemental peculiarities on the stellar surface. Musielok *et al.* (1980) and Hildebrant *et al.* (1985) performed 10-color photometry. The latter's ephemeris is

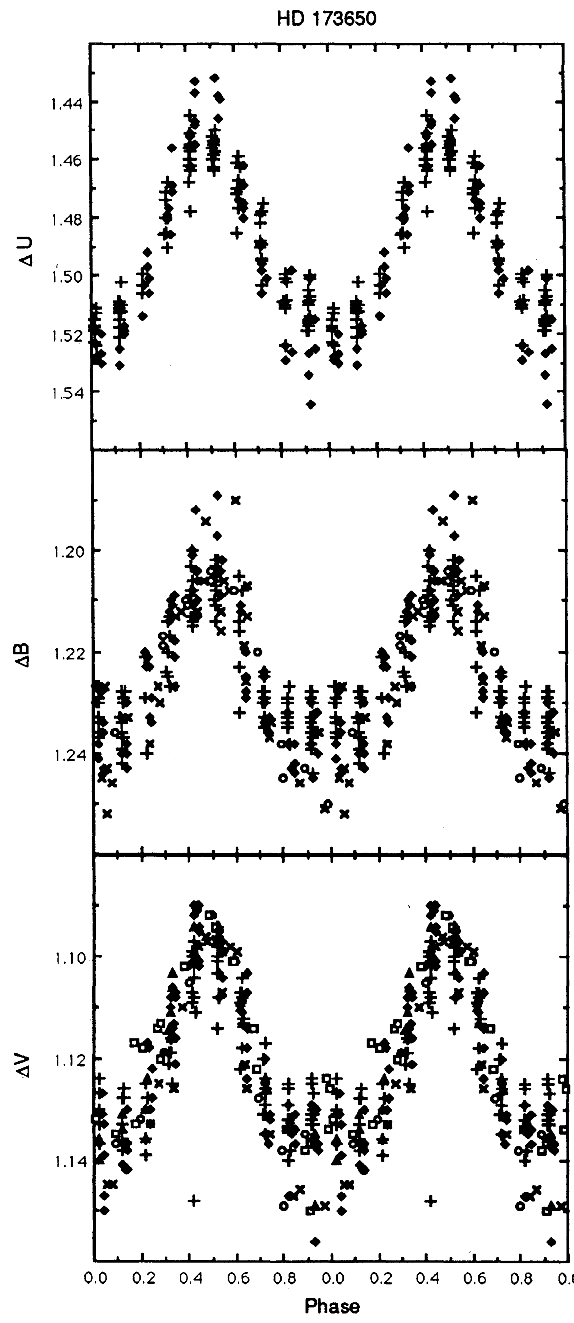

FIG. 12. The U, B, V photometry of HD 173650 plotted according to the ephemeris HJD $(U_{min})=2437122.60+9.97548E$ days. Zero point values for other observers have been adjusted to overplot U, B, and V data. Our APT data is shown as filled diamonds, the UBV photometry of Blanco & Catalano (1968) as +'s, the BV photometry of Burke *et al.* (1969) as ×'s, the BV photometry of Rakosch & Fiedler (1978) as O's, the V photometry of van Genderen (1971) as filled triangles, and our y photometry as open squares.

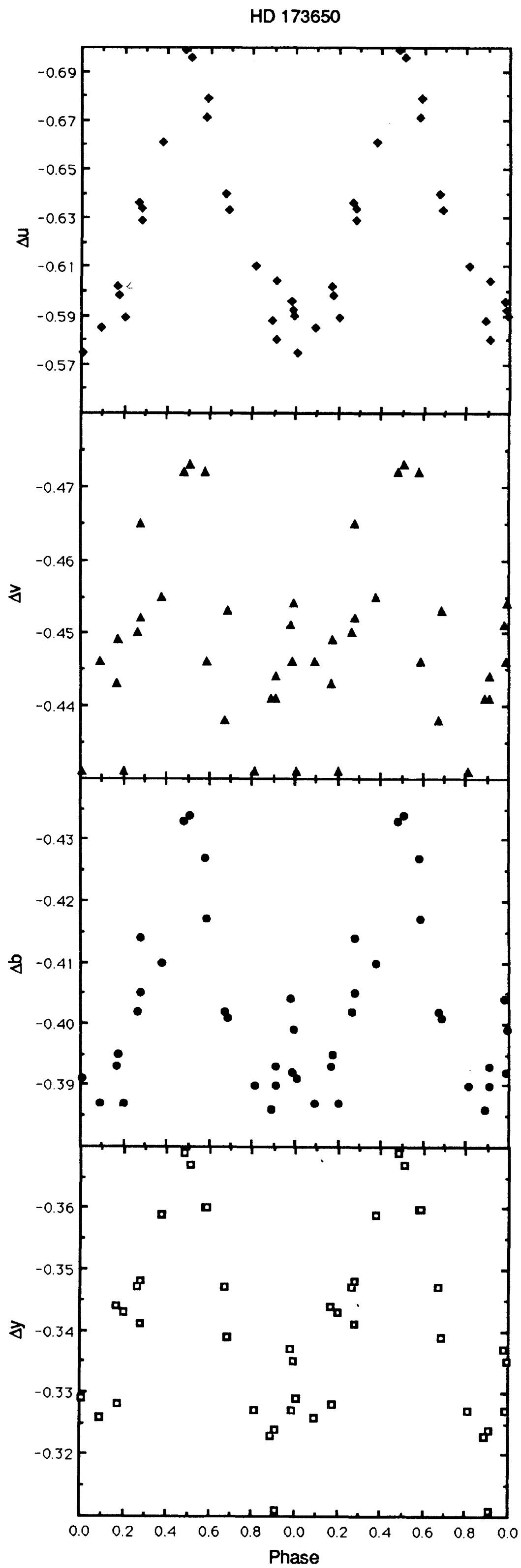

FIG. 13. The u, v, b, and y photometry of HD 173650 plotted as for Fig. 12.

$$\mathrm{JD}(U_{\max}) = 2443317.51 + 9.9754E.$$

The period of HD 173650 creates a nasty problem. With observations obtained at only one observing site during one observing season, one obtains photometry of essentially ten different phases. To obtain observations well distributed over its period requires observations taken over a period of several years or the use of several observing sites well distributed in longitude. Our 76 *UBV* observations, which were taken only over a 13 month period, used HD 175427 as the comparison star and HD 174262 as the check star.

Comparison of our photometry with that of other observers, especially Blanco & Catalano (1968), indicates a slight increase in the period. Our ephemeris is

$$\mathrm{JD}(U_{\min}) = 2437122.60 + 9.975\,48E.$$

Our zero epoch value is that given by Burke *et al.* (1969) plus one day. A periodogram analysis of our *V* data and those of Blanco and Catalano shows the maximum is at 0.100 25 cycles/day or 9.975 06 days. The next lowest frequency has almost as much power. This result is in accord with the adopted period.

Figure 12 shows the *U*, *B*, *V* observations. These light curves have a somewhat similar shape. The zero points of the observations of other observers have been adjusted to equal that of our values. Our *UBV* values are given as filled diamonds, the *UBV* values of Blanco & Catalano (1968) as +'s, the *BV* values of Burke *et al.* (1969) as ×'s, the *BV* values of Rakosch & Fiedler (1978) as ○'s, the *V* values of van Genderen (1971) as closed diamonds, and our *y* values as open squares. Our photometry seems to show HD 173650 as having a greater range of variability than that of Blanco and Catalano. The *U* range is about 0.08 mag while those of *B* and *V* are about 0.045 mag.

Figure 13 illustrates the four-color photometry. The character of the light curves is similar, although the *v* photometry shows more scatter. The range of variation is greatest in *u* (0.11 mag), which shows a greater range than *U*. That for *v* is perhaps 0.025 mag while those for *b* and *v* are about 0.045 mag. It is very difficult to say anything about possible asymmetries in the light curves as there is a considerable amount of scatter. The energy distribution of HD 173650 is definitely changing as the star rotates.

12. DISCUSSION

Major causes of our not being able to establish better periods are the inaccuracies and gaps in the photometry. Often the published photometry is just able to establish the period and there have been long gaps between datasets. In some cases, e.g., CU Vir, there is also the potential for substantial differences in the photometry due to the use of slightly different bandpasses or the star precessing. Going to the Stromgren system, which is better defined than Johnson photometry, and to a larger telescope will lead to better periods with somewhat shorter base lines as well as help resolve the problems seen in the CU Vir photometry.

The data used in this paper is being submitted to the IAU Commission No. 27, Archives of Unpublished Observations of Variable Stars as File No. 224.

We thank Louis Boyd, Russell M. Genet, and Michael Seeds for useful discussions, Franco Catalano for providing numerical values of his photometry published with Blanco, and Alex Fullerton for his IDL implementation of the Scargle periodogram. We also acknowledge the use of the SIMBAD data bank of the CDS. This research was supported in part by NSF Grant No. AST-8616362 to the College of Charleston of which The Citadel and the University of Nevada Las Vegas are subgrantees and by grants to SJA from The Citadel Development Foundation.

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