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uvby FCAPT Photometry of the Magnetic Chemically Peculiar Stars 36 Aurigae, HR 2722, 13 Andromedae, and HD 220147

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ABSTRACT. Differential Strömgren *uvby* observations obtained with the Four College Automated Photoelectric Telescope (FCAPT) are presented for the magnetic chemically peculiar (mCP) stars 36 Aur, HR 2722, 13 And, and HD 220147. The new data help to better define the light curves. The period for 36 Aur was found to be 14.368 days, close to that for the previous study with FCAPT data. The period for HR 2722 is unchanged, at 2.31523 days. Comparisons between *Hipparcos* and FCAPT photometry were used to refine the periods individually derived by each source to 1.47931 days for 13 And and to 10.983 days for HD 220147.

Online material: extended table

1. INTRODUCTION

The Four College Automated Photoelectric Telescope (FCAPT) at Washington Camp, Arizona, was used to obtain single-channel differential Strömgren *uvby* photometry for the magnetic chemically peculiar (mCP) stars 36 Aur, HR 2722, 13 And, and HD 220147. For 36 Aur and HR 2722, these are the second sets of such values, while these are the first sets for 13 And and HD 220147. The FCAPT 0.75 m automated telescope measures the dark count and then sky-ch-c-v-c-v-c-v-c-ch-sky in the four Strömgren filters for each group of variable (v), check (ch), and comparison (c) stars, where "sky" is a reading of the sky. Neutral-density filters were used to observe stars that otherwise would be too bright for a 10 s integration. For faint stars, the integration time(s) was increased to give a minimum of 10,000 counts in 10 s. Corrections were not made for any neutral density filter differences among the stars of each group.

Using *Hipparcos* photometry (ESA 1997), the comparison and check stars were selected from presumably nonvariable stars close on the sky to variables that had somewhat similar V magnitudes and $B - V$ colors. Table 1 contains information on the three stars of each group (Hoffleit 1982; Hoffleit et al. 1983) and the neutral-density filters used.

The periods of the variable stars were found using the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986). Table 2 contains the photometric values of all four stars (the v − c and the ch − c values). The averages and the standard deviations are given for each filter. As those for ch − c are of an order of 0.005 mag, the errors for v − c are probably similar.

The mCP stars, with their photospheric location-dependent emergent energy distributions, abundances, and magnetic field strengths, often exhibit spectrum, photometric, and magnetic variability when they rotate. Those that exhibit such effects have nonaligned magnetic and rotational axes. Theorists suggest that hydrodynamical processes, in particular radiative diffusion and gravitational settling, in radiative envelopes containing strong magnetic fields produce anomalous photospheric abundances that depend on the local magnetic field strength, the evolution of the field, and the elemental abundances since at least when the star was on the zero-age main sequence (Michaud & Proffitt 1993 and references therein). Differential photometric studies with the FCAPT (see Adelman 2002 for a sumary of this work) have determined and/or refined mCP star periods and light curves to compare observations taken at different times, to detect variable light curves, and to study the period distribution of the stars. For spectrum variables exhibiting moderate rotation, surface maps of the abundances can be derived to serve as tests of mCP star theories. By comparing light curves taken with different filters, one can gain a rough idea about the complexity of the superficial abundances.

2. 36 Aur

Cowley et al. (1969) classified 36 Aur (HR 2101, HD 40394, BD +47°1227) as a B9.5p Si,Fe star. Adelman & Brunhouse (1998) used 83 FCAPT *uvby* observations, along with V values from Winzer (1974), to find a period of 14.366 days. The light curves were found to be in phase. A secondary minimum seen in u might also be present in b and in y.

From fall 2004 through fall 2005 (years 14 and 15 of FCAPT operations), a new set of 72 *uvby* observations were made. Despite that the check star's neutral density filter was changed between the two sets of FCAPT observations and that different photometers were used, the mean v − c values are very close. At worst, they are 0.005 mag different. For u and v, there are no zero-point shifts between the two sets of FCAPT observations. But for b and y, shifts of 0.005 and 0.002 mag, respectively, bring them into better agreement (in Table 2, no shifts are applied

TABLE 1
PHOTOMETRIC GROUPS

HD Number	Name	Type[a]	V	Spectral Type	nd Filter[b]
40394	36 Aur	v	5.73	B9.5pSiFe	2
40626	HR 2112	c	6.05	B9.5 IV	1
43244	42 Aur	ch	6.52	B9 II–III	1
55579	HR 2722	v	6.89	A1pSrCr	1
57744	58 Gem	c	6.02	A1 V	1
55052	48 Gem	ch	5.85	F5 III–IV	2
220885	13 And	v	5.75	B9 III	2
222109	HR 8962	c	5.80	B8 V	2
221756	HR 8947	ch	5.59	A1 III	2
220147	BD +61°2430	v	8.21	B9p	1
217348	HR 8745	c	6.43	B9 III	2
218753	2 Cas	ch	5.70	A5 III	1

[a] Types: v = variable, c = comparison star, ch = check star.
[b] Neutral density (nd) filters: 1 = none, 2 = 1.25 mag.

to the data). Also with the better defined *y* light curve from the two sets of FCAPT values, Winzer's (1974) *V* values do not fit them as well as those given in Adelman & Brunhouse (1998). Thus, they are omitted from the analysis, and

$$\mathrm{HJD}(u_{\min}) = 2450037.0045 \pm 0.01 + 14.368 \pm 0.001E.$$

Figure 1 shows that the four light curves are roughly in phase, with a secondary minimum near phase 0.45 best visible in *u*. The new phases differ by about 0.4 from those of the older ephemeris. The amplitudes are 0.055, 0.020, 0.025, and 0.015 mag, respectively, for *u*, *v*, *b*, and *y*. These estimates are smaller than those of Adelman & Brunhouse (1998), except for *u*. Parts of the light curves are better defined using the values presented in this paper (*open circles*) rather than those of Adelman & Brunhouse (1998; *filled squares*).

A Scargle periodogram of the values from *Hipparcos* photometry (ESA 1997) of 36 Aur is quite noisy. The highest peak corresponds to 14.368 days. Plotting this data with the adopted ephemeris shows a phase shift of the mimimum by an order of 0.01, a number that is affected by an asymmetry in the mimimum. The sense of the correction is to increase the period by an order of 0.001 day. However, adoption of this period change would shift the recent FCAPT values relative to the earlier values and decrease their agreement. Since the FCAPT photometry is of higher quality, I prefer to keep the adopted ephermeris. Additional FCAPT photometry in a few years should help clarify why the phasing is not quite perfect.

3. HR 2722

Winzer (1974) discovered the light variability of HR 2722 (HD 55579, BD +24°1576), whose spectral type is A1pSrCr (Cowley et al. 1969). Adelman & Brunhouse (1998) analyzed 147 FCAPT *uvby* measurements obtained between 1995 and 1998 and found, using Winzer's *V* measurements, that a period of 2.31523 days fit both sets of data. The light curves are best described as being in phase. This is a small-amplitude mCP star, with amplitudes of 0.045 mag for *u*, 0.013 mag for both *b* and *y*, and 0.010 mag for *v*.

Between 2003 and 2005, 78 new FCAPT *uvby* observations were made. As with 36 Aur, both the neutral-density filter for the check star and the photometer of the telescope were changed. The mean *u* and *v* values for both data sets are identical. To bring the *b* and the *y* values into agreement, shifts of 0.004 and 0.003 mag, respectively, were applied to the new values in Figure 2, but not to the data in Table 2. A new periodogram analysis of the Strömgren *u* data yields a period of 2.31522 days, very close to the value given by Adelman & Brunhouse (1998). Since Winzer's (1974) *V* data is also nearly fit with periods close to this value and has a shape similar to that of the Strömgren *y* data, it was used to refine the period. The ephemeris used by Adelman & Brunhouse is retained, as

TABLE 2
uvby PHOTOMETRY FOR 36 AUR, HR 2722, 13 AND, AND HD 220147

HJD	u(v − c)	u(ch − c)	v(v − c)	v(ch − c)	b(v − c)	b(ch − c)	y(v − c)	y(ch − c)
36 Aur:								
2452937.0303	−0.250	0.127	−0.272	0.222	−0.300	0.519	−0.338	0.713
2452938.0276	−0.230	0.120	−0.265	0.216	−0.293	0.516	−0.329	0.711
2452939.0266	−0.224	0.114	−0.263	0.217	−0.290	0.509	−0.332	0.713
2452940.0224	−0.235	0.100	−0.265	0.203	−0.293	0.503	−0.328	0.699
2452942.0175	−0.254	0.118	−0.273	0.217	−0.304	0.516	−0.342	0.709
2452944.0044	−0.270	0.133	−0.285	0.228	−0.311	0.518	−0.346	0.711
2452947.9929	−0.284	0.121	−0.285	0.221	−0.308	0.513	−0.349	0.712
2452948.9982	−0.285	0.121	−0.286	0.221	−0.312	0.513	−0.347	0.710
2452949.9889	−0.272	0.113	−0.282	0.215	−0.307	0.509	−0.344	0.704
2452950.9895	−0.255	0.117	−0.279	0.221	−0.305	0.513	−0.337	0.704

NOTE.—Table 2 is published in its entirety in the electronic edition of the *PASP*. A portion is shown here for guidance regarding its form and content.

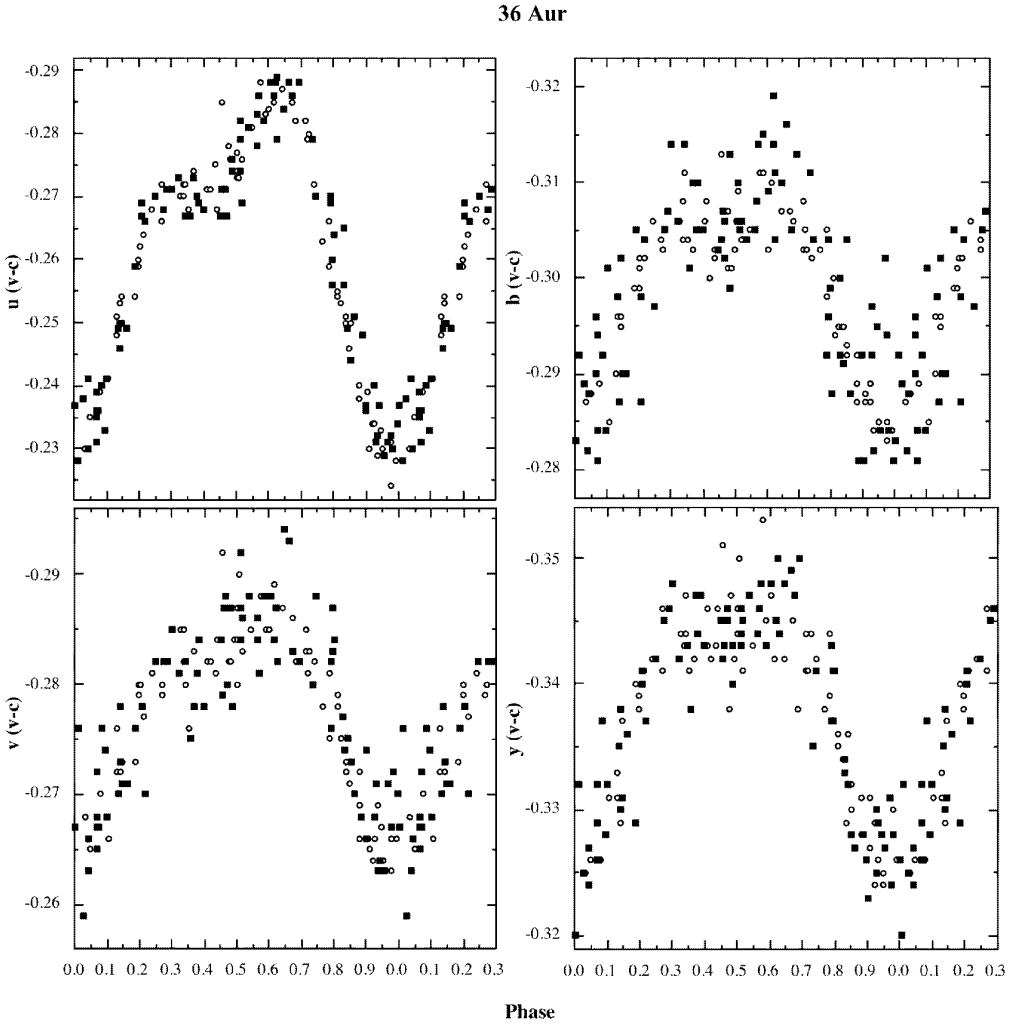

FIG. 1.—*uvby* photometry of 36 Aur using the ephemeris HJD(u_{min}) = 2450037.0045 + 14.368*E*. The filled squares indicate FCAPT photometry from Adelman & Brunhouse (1998), and the open circles show FCAPT observations published with this paper.

it fits all of the data. The error in the period is reduced, giving

$$\text{HJD(maximum light)} = 2441239.73 \pm 0.02 + 2.31523 \pm 0.000015E.$$

The light curves of HR 2722 show something unusual for mCP stars, in that the start of the rising branch apparently shows less scatter than the rest of the data. This is seen for all the filters, and also with Winzer's (1974) data. It is clearly present in all the data sets for each year, except perhaps for the fall 2004 observations. This suggests that HR 2722 might exhibit roAp-type oscillations over part of its period.

4. 13 And

The star 13 And (HR 8913, HD 220885, BD +42°4672, V388 And; Kazarovets et al. 1999) was classified as a B9 III star by Cowley et al. (1969) and as a B9 Mn star by Renson (1991). Typical values of its rotational velocity are 55 km s^{-1} (Renson 1991) and 75 km s^{-1} (Abt et al. 2002). *Hipparcos* photometry (Adelman et al. 2000) shows that its amplitude (0.05 mag) is greater than stars of similar spectral type and that it is a mCP star rather than a HgMn star. In fact, its variability was discovered using these data (see Paunzen & Maitzen 1998), and a period of 1.47946 days was indicated (see Celestia 2000, ESA 1998).

In years 14 and 15, 67 *uvby* differential observations of 13

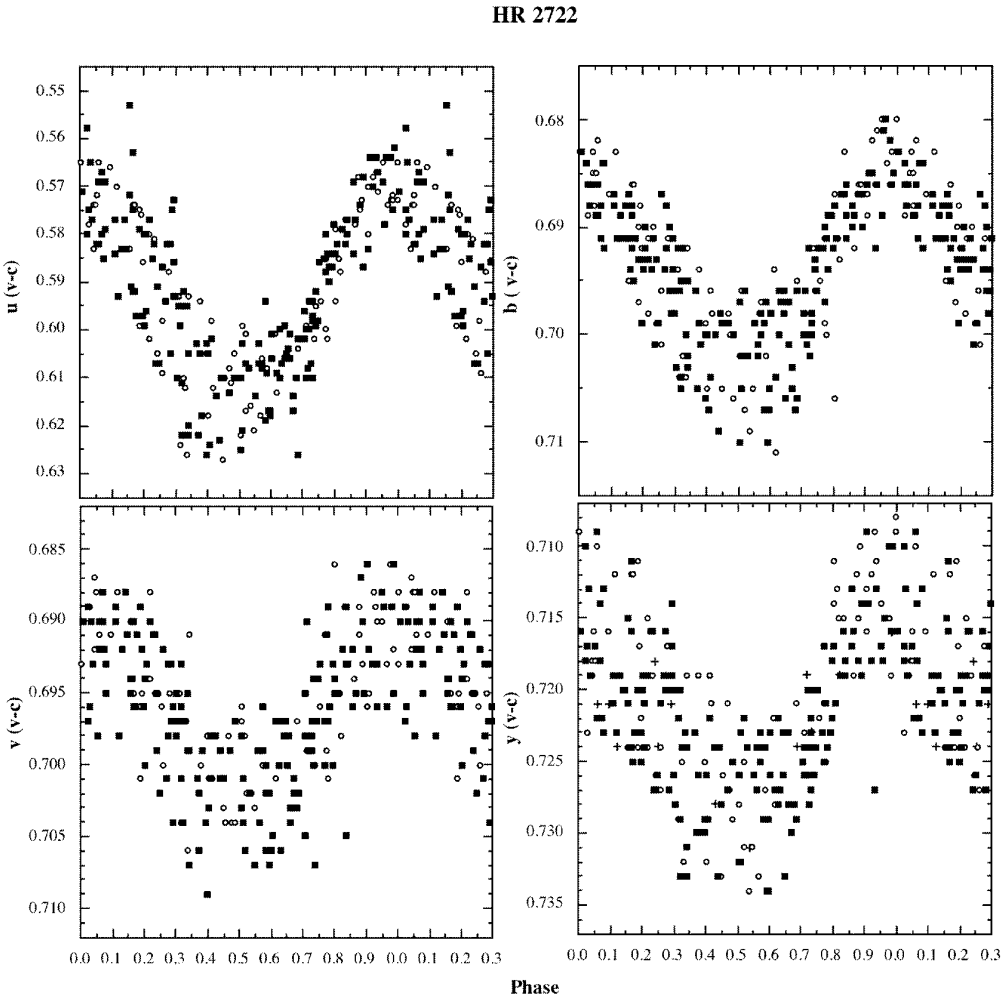

FIG. 2.—*uvby* photometry of HR 2722 using the ephemeris HJD(maximum light) = 2441239.73 + 2.31523*E*. The filled squares indicate FCAPT photometry from Adelman & Brunhouse (1998), the open circles show FCAPT observations published with this paper, and the + signs denote Winzer (1974) *V* values transformed to *y*.

And were obtained with the FCAPT. A period of 1.4794 days was determined using the Scargle periodogram. As the *Hipparcos* values cover a longer period of time than the FCAPT values, I orginally adopted the *Hipparcos* ephemeris. But the *Hipparcos* and the FCAPT data, plotted according to the phases of the *Hipparcos* ephemeris, showed that the FCAPT data had phases offset to smaller values. To bring both into agreement, the period was slightly reduced. Some additional observations made near phase 0.0 would help to better refine the light curves and the ephemeris. I found

$$\mathrm{HJD}(u_{\max}) = 2448500.055 + 1.47931 \pm 0.0001E.$$

The *Hipparcos* photometry shows a triangularly shaped light curve. The FCAPT light curves in Figure 3 are somewhat different, especially for *u*. This indicates that parts of the photosphere do not behave in the same way as the rest of the surface. There is a possible subminium near phase 0.15 whose sharp core needs confirmation. The amplitudes are approximately 0.07, 0.045, 0.04, and 0.03 mag, respectively, in *u*, *v*, *b*, and *y*. The FCAPT data are presented in Table 2.

5. HD 220147

HD 220147 (BD +61°2430, V812 Cas, HIP 115267) is a rather poorly studied B9p mCP star. It was included in a list of previously unpublished magnetic stars by Babcock (Cameron 1967). Three sets of grating scanner spectrophotometry

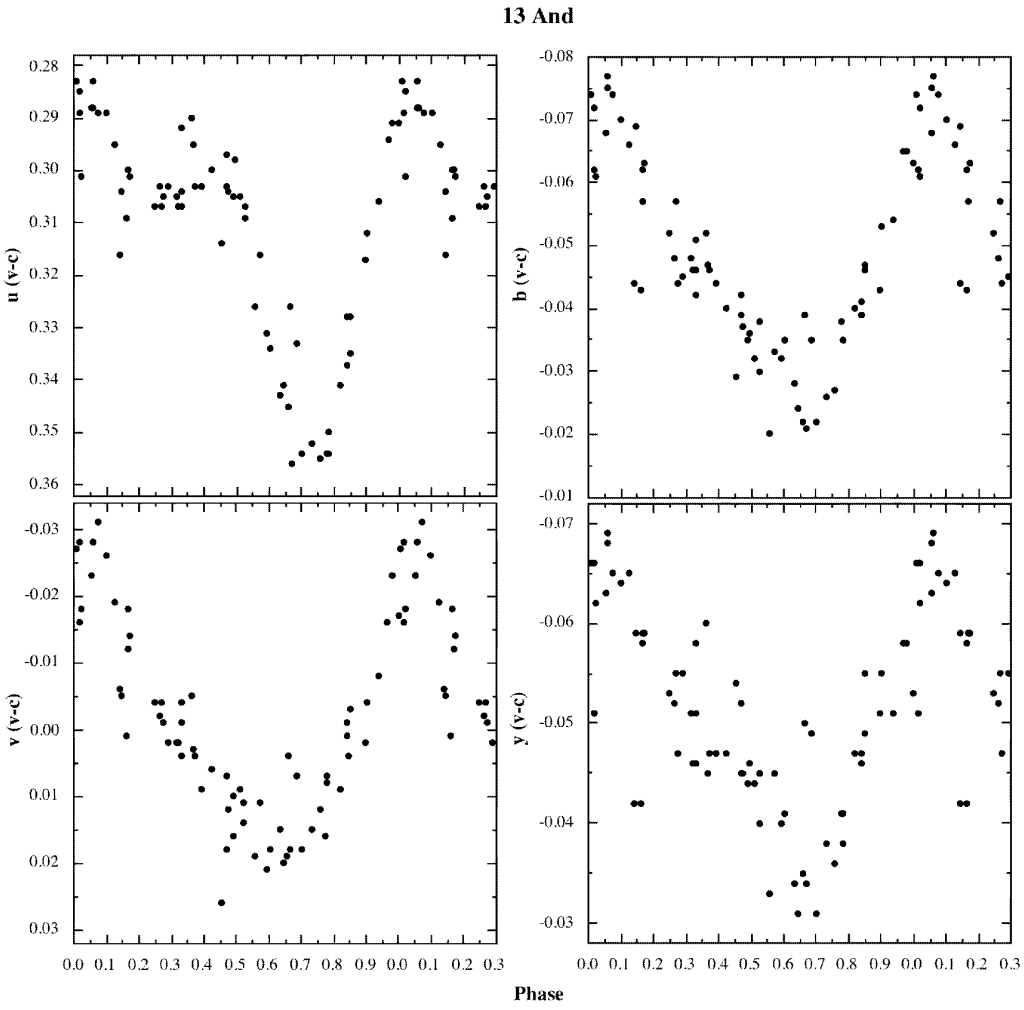

FIG. 3.—*uvby* photometry of 13 And using the ephemeris HJD(u_{max}) = 2448500.055 + 1.47931*E*. The filled circles indicate FCAPT photometry from this paper.

were published by Adelman (1980). HD 220147 has a sharp core to its λ5200 broad continuum feature. *Hipparcos* photometry (Celestia 2000 [ESA 1998] and Paunzen & Maitzen 1998) indicate a period of 10.990 days.

From 2003 September through 2005 January, 73 good FCAPT *uvby* observations were obtained (see Table 2). The in-phase light curves resulted when the data was phased according to the *Hipparcos* ephemeris. However, the FCAPT light maxima were shifted to shorter phases by 0.27. To bring the two light curves into phase agreement requires that the period be reduced to 10.983 days. Thus, the ephemeris used was

$$\mathrm{HJD}(u_{\max}) = 2448501.978 + 10.983 \pm 0.001E.$$

Figure 4 shows the *uvby* photometry as a function of this ephemeris. The amplitudes are 0.09, 0.03, 0.06, and 0.06 mag for *u*, *v*, *b*, and *y*, respectively. The light curves are best described as in phase. Each curve has a single maximum with a broader minimum that has two nearly equal subminima near phases 0.32 and 0.66.

6. FINAL COMMENTS

For 13 And and HD 220147, which are without previous sufficiently extensive *uvby* observations, *Hipparcos* photometry played a major role in determining the adopted periods. For 36 Aur, no period is given in Celestia 2000 (ESA 1998), which reflects the scatter in the values with phase for this star with relatively small amplitudes of variability in *v*, *b*, and *y*. For HR 2722, the use of Winzer's (1974) *V* data were sufficient to refine the period relative to the result for the two epochs of FCAPT *uvby* photometry. For this star, *v*, *b*, and *y* have small

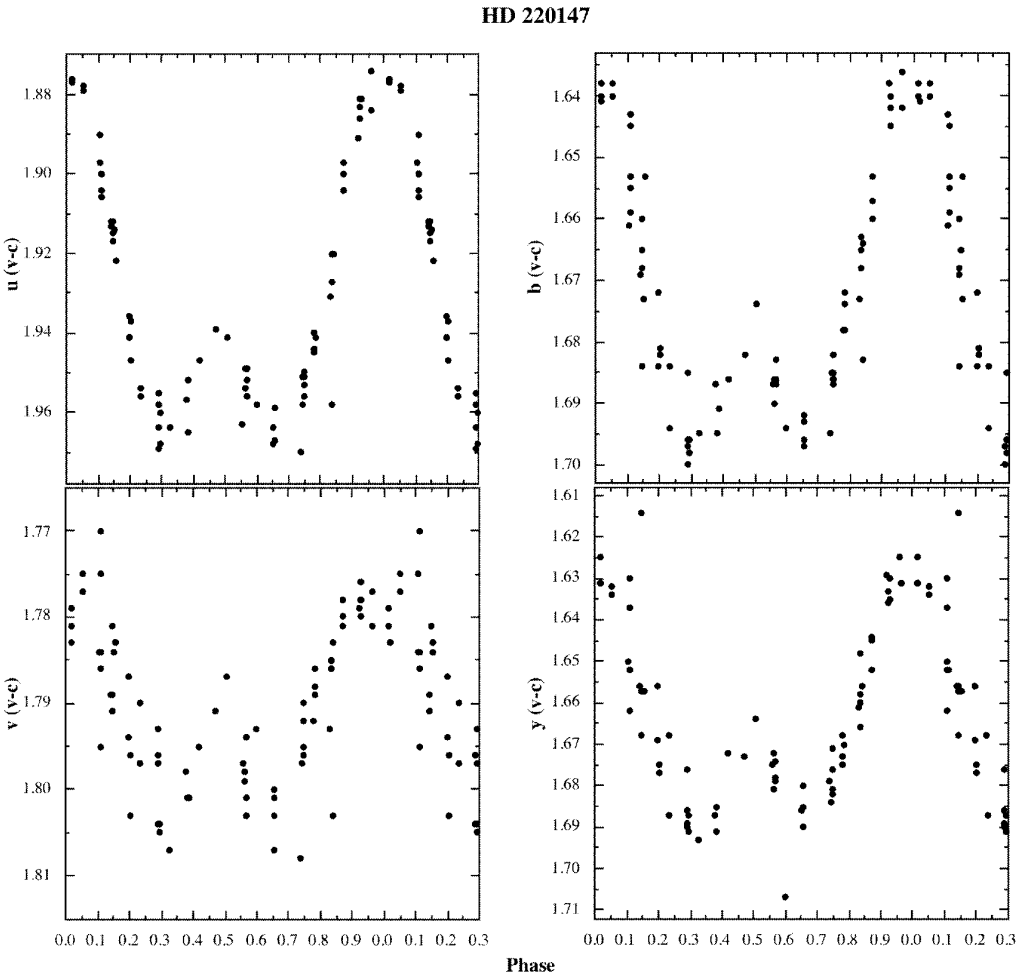

FIG. 4.—*uvby* photometry of HD 220147 using the ephemeris HJD(u_{max}) = 2448501.978 + 10.983*E*. The filled circles indicate FCAPT photometry from this paper.

amplitudes. With an *Hipparcos* photometric amplitude of 0.03 mag compared with 0.04 mag for 36 Aur, it is not surprising that Celestia 2000 does not list any variability.

A comparison of the amplitudes of 13 And and HD 220147 with those of 36 Aur and HR 2722 indicates that those mCP stars for which Celestia 2000 (ESA 1998) lists periods have larger average amplitudes than those that it does not list. Thus, it may be important to obtain *uvby* photometry of those mCP stars found via *Hipparcos* photometry (see Paunzen & Maitzen 1998), as they are likely to be some of the more variable mCP stars. At a given magnitude, it is easier to study those stars with larger amplitudes of variability and to observe any differences among the *uvby* light curves.

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