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FCAPT *uvby* Photometry of the mCP Stars HD 16545, HD 93226, HR 7575, and HR 8206

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ABSTRACT. The Four College Automated Photoelectric Telescope (FCAPT) obtained differential Strömgren *uvby* observations of the magnetic CP (mCP) stars HD 16545, HD 93226, HR 7575, and HR 8206. These are the first reported from the FCAPT. HD 16545, with its largest amplitudes (0.06 mag) being those in *v* and in *b*, has a period of 1.61926 days, close to its period from *Hipparcos* photometry. The HD 93226 photometry exhibits a period of 1.72907 days, with the *v*, *b*, and *y* light curves in phase. The *u* light curve is shifted by 0.05 to 0.10 in phase. Its *u* amplitude is a relatively large 0.10 mag. The *v* photometry of HR 7575 is consistent with the 223.826 day period of Mikulasek et al. HR 8206 is a small-amplitude variable with a period of 1.5849 days.

Online material: color figures, extended tables

1. INTRODUCTION

Most magnetic chemically peculiar (mCP) stars are photometric, spectrum, and/or magnetic variables, as their emergent energy distributions, abundances, and magnetic field strengths depend on photospheric location. Usually, the magnetic and rotation axes are not aligned, so as mCP stars rotate, a distant observer may see variability of several types. According to theory, hydrodynamical processes, especially radiative diffusion and gravitational settling in radiative envelopes with strong magnetic fields, produce their anomalous photospheric abundances, which depend on the local magnetic field strength and the evolution of the field and elemental abundances since at least the time when the stars were on the zero-age main sequence (Michaud & Proffitt 1993 and references therein).

Studies using data from the Four College Automated Photoelectric Telescope (FCAPT) at Fairborn Observatory, Washington Camp, Arizona, determined the periods and light curves of mCP stars to relate observations taken at different times and to detect variable light curves (see, e.g., Adelman 2006). For spectrum variables exhibiting moderate rotation, surface abundance maps obtained from Doppler imaging techniques can serve as tests of mCP star theories. Comparison of light curves taken with different filters may provide some idea of the complexity of the surficial abundances and/or the magnetic field geometry. With complete phase coverage, data from different observing seasons, especially those separated by several years, are useful to improve periods. With sufficient observations from two or more observing seasons, one can check for changes in the shapes of the light curves, which have been interpreted as evidence for the precession of the rotational axis about the magnetic axis (Adelman et al. 2001). If a mCP star exhibits in-phase variability, then results from the *Hipparcos* satellite may be useful in refining the period.

For the first time, we study the mCP stars HD 16545, HD 93226, HR 7575, and HR 8206 with FCAPT single-channel differential Strömgren *uvby* photometry in the instrumental system. The FCAPT 0.75 m automated telescope obtains the dark count and then sky-ch-c-v-c-v-c-v-c-ch-sky values 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. Corrections were not made for any neutral-density filter differences among the stars of a group.

With the aid of *Hipparcos* photometry (ESA 1997), I chose comparison and check stars from the least variable stars close on the sky to the variables that had somewhat similar *V* magnitudes and $B - V$ colors. Table 1 presents basic information on each group (Hoffleit 1982; Hoffleit et al. 1983; SIMBAD). The mCP star periods were found using the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986). Table 2 gives the photometric values, their averages, and the standard deviations of v-c and ch-c for each filter. With those for ch-c of order 0.005 mag, the errors for v-c are probably similar. The first observing season for the FCAPT was from fall 1990 through spring 1991. This paper includes data taken from many observing seasons, including season 17 (fall 2006 through early summer 2007).

2. HD 16545

HD 16545 (VV 557 Per, BD +43 551, HIP 12478) is a poorly studied A0p star. Celestia 2000 (ESA 1998) and Paunzen & Maitzen (1998) give a period of 1.61942 days and indicate an amplitude of 0.05 mag. Fifty-nine and sixty sets of good FCAPT *uvby* photometry of HD 16545 were respectively obtained during observing seasons 16 (2005–2006) and 17 (2006–2007). Using a Scargle periodogram, I determined a period of 1.61938 days and adopted the initial *Hipparcos* epoch. How-

TABLE 1
PHOTOMETRIC GROUPS

HD	Name	Type	*V*	Spectral Type	Filter
16545	BD +43 551	v	7.30	A0p	1
16004	HR 746	c	6.34	B9HgMn	1
14212	62 And	ch	5.31	A1 IV	1
93226	BD −09 3134	v	7.45	A0p	1
92245	HR 4172	c	6.04	A0 Vn	1
91992	HR 4160	ch	6.52	F0 V	1
188041	HR 7575	v	5.63	A5p	2
189359	BD −02 5159	c	6.60	A2	1
188350	58 Aql	ch	5.63	A0 III	2
204131	HR 8206	v	6.58	B9	1
205314	HR 8246	c	5.75	A0 V	2
203746	BD +48 3360	ch	6.84	A1 V	1

NOTES.—(1) Type of star: v = variable, c= comparison star, and ch = check star; and (2) filters: 1 = no neutral-density filter and 2 = 1.25 mag neutral-density filter.

ever, I found that a small period correction to 1.61926 days was needed to bring the FCAPT and the *Hipparcos* photometry into phase. The error in the zero point is from ESA (1998). Thus,

$$\text{HJD(light maximum)} = 2{,}448{,}500.6802 \pm 0.001 + (1.61926 \pm 0.00006)E.$$

Figure 1 shows the FCAPT values plotted with this ephemeris. The light curves are probably in phase and look similar to the *Hipparcos* values with the same initial epoch. The amplitudes of variability are 0.05, 0.06, 0.06, and 0.035 mag for *u*, *v*, *b*, and *y*, respectively. The *b* and the *y* values for season 17 are shifted upward by 0.004 and 0.010 mag, respectively for better agreement. The scatter is less for the season 16 values (*open squares*) than for the season 17 values (*solid circles*).

3. HD 93226

HD 93326 (BD −09 3134, HIP 52461), like HD 16545, is a poorly studied mCP star. Bidelman (1981) classified it as a Si star from objective-prism observations. Celestia 2000 (ESA 1998) and Paunzen & Maitzen (1998) give a period of 1.72901 days and indicate an amplitude of 0.04 mag. In observing seasons 16 and 17, 45 and 60 good *uvby* observations were made, respectively. The use of the Scargle periodogram on the *u* data yields 1.72896 days, in good agreement with the previous determination. When the data are plotted using the Celestia 2000 zero point, there is a minimum near phase 0.60. However, the maximum is near phase 0.30 for *u* and near phase 0.20 for *v*, *b*, and *y*. Looking at the light curve plotted in Celestia 2000 (ESA 1998), the maximum is at phase 0.0 and the minimum is at phase 0.4. This suggests that the period be adjusted. An adjustment to 1.72907 days brings the *vby* light curves, on average, into phase agreement with the *Hipparcos* data. The *u* maximum and minimum are shifted by 0.05 to 0.10 in phase with respect to the other three filters. Thus, I adopted an ephemeris of

$$\text{HJD(light maximum of } v, b, \text{ and } y) = 2{,}448{,}500.597 \pm 0.003 + (1.72907 \pm 0.00005)E.$$

The measured amplitudes are 0.10 mag for *u*, 0.05 mag for *v*, 0.045 mag for *b*, and 0.04 for *y*. The *u* amplitude is relatively large for a mCP star. Figure 2 shows data from seasons 16 (*plus signs*) and 17 (*open circles*) and differences of the shape of the *u* light curve from those for *v*, *b*, and *y*.

TABLE 2
uvby PHOTOMETRY FOR HD 16545, HD 93326, HR 7575, AND HR 8206

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)
HD 16545								
2453648.9446	0.898	−0.576	1.039	−0.169	1.027	−0.154	1.044	−0.150
2453651.9284	0.877	−0.573	1.003	−0.159	0.995	−0.145	1.012	−0.139
2453652.9475	0.863	−0.580	0.997	−0.168	0.986	−0.150	1.022	−0.158
2453653.9698	0.892	−0.577	1.046	−0.166	1.032	−0.160	1.048	−0.150
2453666.9101	0.903	−0.582	1.040	−0.170	1.031	−0.155	1.042	−0.152
2453668.9065	0.885	−0.585	1.011	−0.167	1.011	−0.155	1.031	−0.153
2453670.9064	0.856	−0.580	0.983	−0.168	0.977	−0.155	1.009	−0.153
2453671.9065	0.900	−0.581	1.036	−0.164	1.028	−0.152	1.043	−0.155
2453672.9013	0.865	−0.581	0.993	−0.165	0.990	−0.152	1.016	−0.153
2453673.9002	0.878	−0.581	1.000	−0.167	0.999	−0.156	1.030	−0.155
2453674.8989	0.901	−0.581	1.043	−0.167	1.032	−0.158	1.048	−0.158
2453680.8835	0.862	−0.579	0.991	−0.169	0.981	−0.150	1.009	−0.154

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.

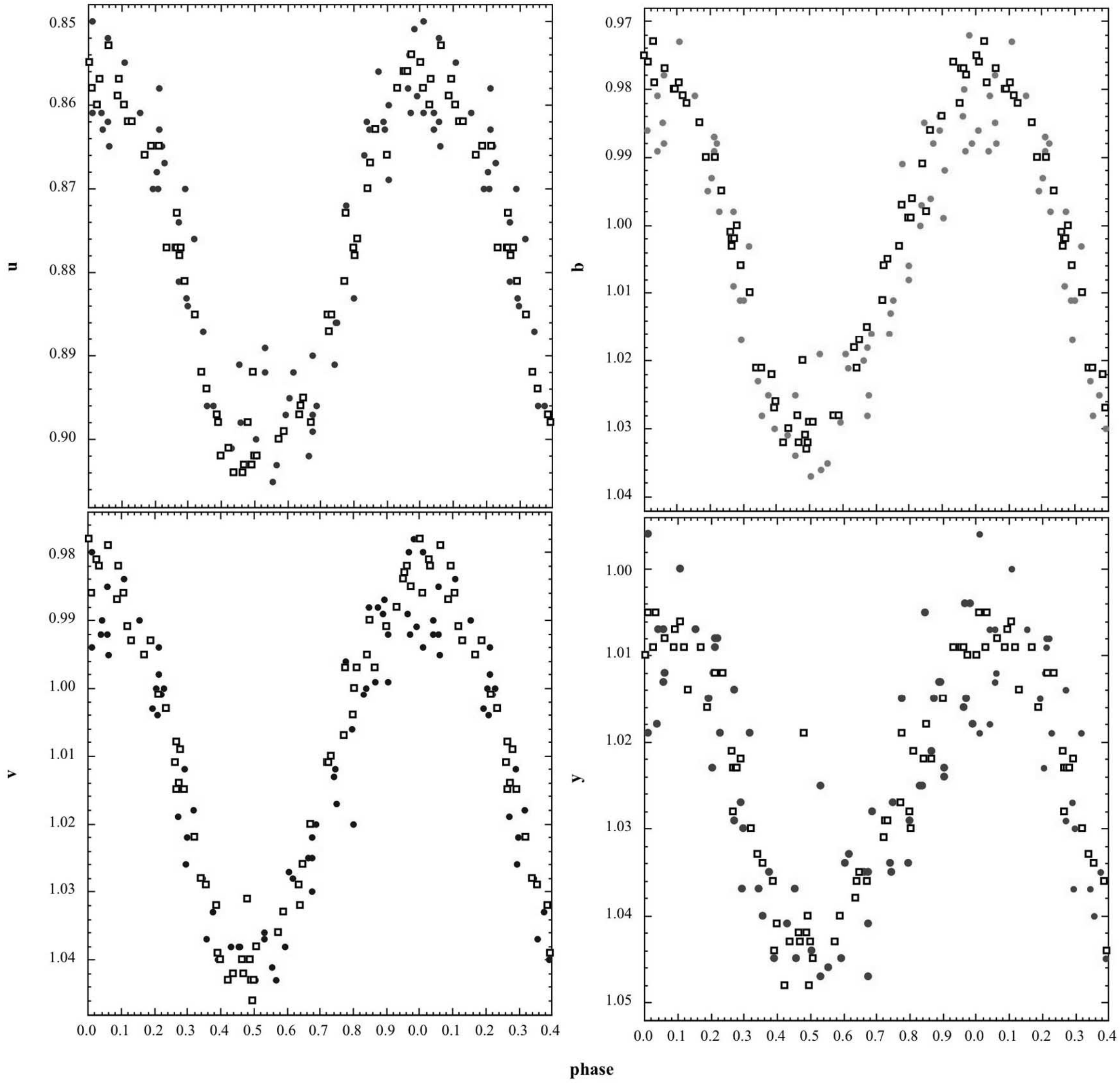

FIG. 1.—*uvby* photometry of HD 16545 for observing seasons 16 (*open squares*) and 17 (*filled circles*), plotted using HJD (*Hipparcos* inital epoch) = 2,448,500.6802 + (1.61926 ± 0.00006)*E*. The photometry is best described as in phase. [*See the electronic edition of PASP for a color version of this figure.*]

4. HR 7575

HR 7575 (HD 188041, V1291 Aql) was one of the first magnetic CP stars discovered with a period over 100 days (Babcock 1953). Jones & Wolff (1973) found it had large amplitude (0.10 mag.) in *v*, while the *u* and *y* amplitudes are of order 0.01 mag, and *b* is constant. The periods of the photometric and magnetic variability were the same, 224.5 days. The rare earth maximum occurs slightly ahead of the magnetic maximum. The iron-peak elements vary in phase with them, but with smaller amplitude (Wolff 1969). Mathys (1991) slightly decreased the period to best fit all the magnetic data. Hensberge (1993), using observations collected at the European Southern Observatory for the project on the Long-Term Photometry of Variables, refined the period to 223.9 ± 0.2 days. Later, Mikulasek et al. (2003) revised the period of variability and set the zero phase at the center of the *v* light minimum. Thus,

$$\mathrm{HJD}(v_{\min}) = 2{,}440{,}981.8 \pm 0.6 + (223.826 \pm 0.040)E.$$

The derivation of this ephemeris and the contributions of many studies are discussed in some detail by them. The FCAPT comparison star is the same as that used by Hensberge (1993). During the first five observing seasons of operation, 46, 10, 32, 34, and 31 sets of observations were obtained. More recently, 34 and 20 observations were obtained in observing seasons 16 and 17, respectively. Hensberge (1993) notes some

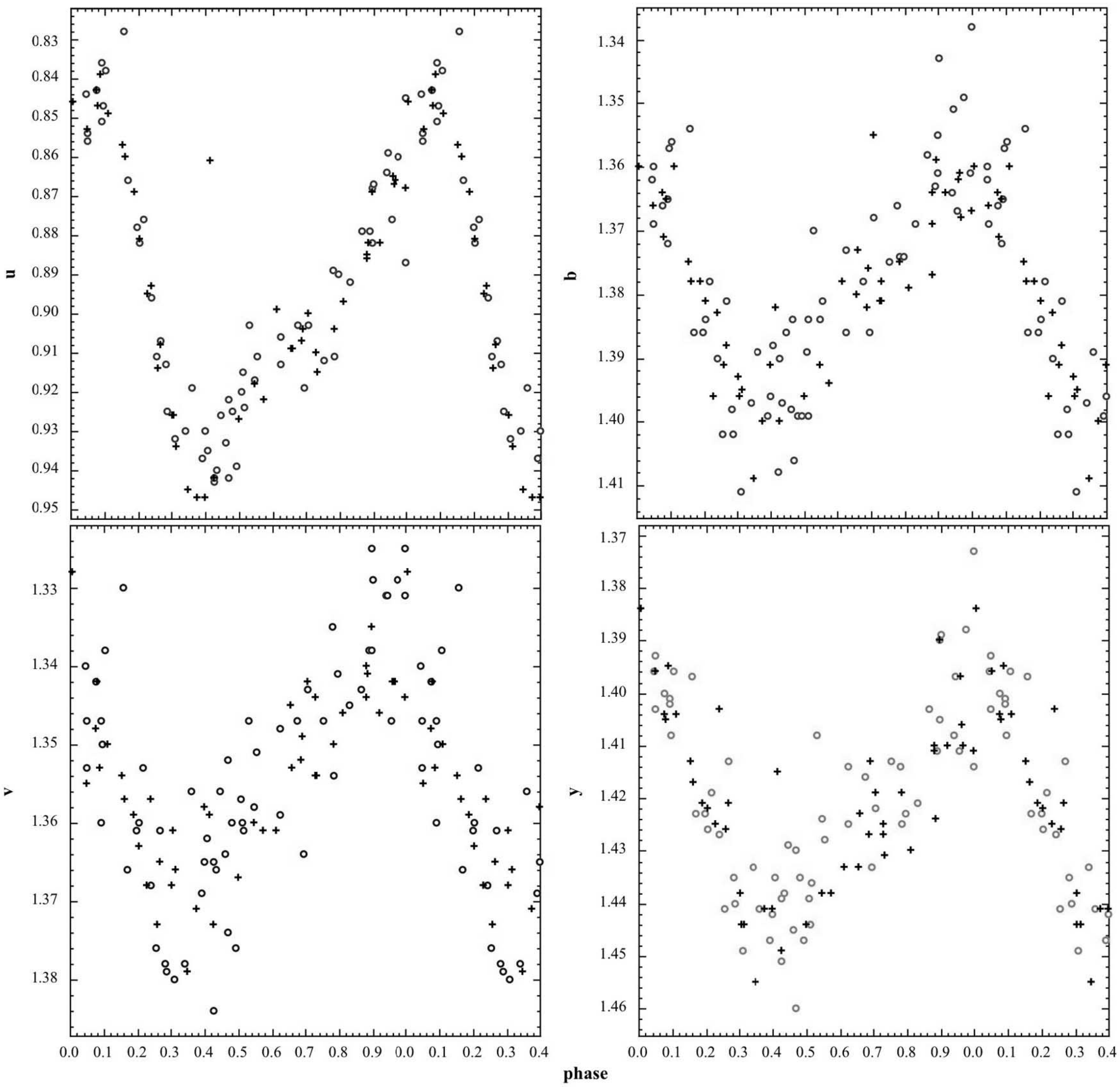

FIG. 2.—*uvby* photometry of HD 93326 for observing seasons 16 (*plus signs*) and 17 (*open circles*), plotted using HJD(light maximum) = 2,448,500.597 ± 0.003 + (1.72907 ± 0.00005)*E*. The photometry is best described as in phase for *v*, *b*, and *y*, with these light curves being offset from that for *u*, which has the largest amplitude of variability. [*See the electronic edition of PASP for a color version of this figure.*]

differences in the variability of his *u* data relative to that of Jones & Wolff (1973), which may be due to the transformation to the standard system. The FCAPT observations began about a year after those from the ESO project ended.

There are suggestions of structure in the *v* light curve, whose amplitude is 0.095 mag. When the *u*, *b*, and *y* v-c FCAPT data are plotted according to the above ephemeris, they exhibit greater scatter than those of Jones & Wolff (1973) and Hensberge (1993). This is due to the use of HD 189359 as a comparison star, whose *Hipparcos* data (ESA 1997) show is more variable than HR 7575. Although the scatter seen in the v-ch data is less than that for the v-c data for these three filters, it is still more than those of the published photometry. Ideally, the declination difference of the variable and check star for the observed altitude should be smaller. *Hipparcos* data show that the check star 58 Aql is very constant. To better define the variability requires new observations using more constant and appropriate comparison and check stars. The variability in *v* was seen simply because it was so much greater than that of the comparison star.

In Figure 3, I plot the v-ch *v* values as a function of the Mikulasek et al. (2003) ephemeris. As this FCAPT light curve is similar to that of Mikulasek et al., it is consistent. Some minor vertical shifts might make the curve tighter. Filled

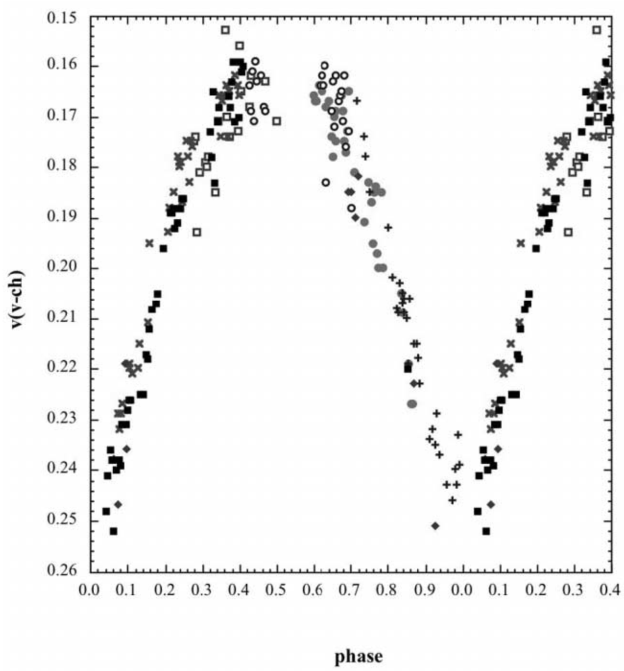

FIG. 3.—v photometry of HR 7775 with the ephemeris of Mikulasek et al. (2003): $\mathrm{HJD}(v_{\min}) = 2{,}440{,}981.8 \pm 0.6 + (223.826 \pm 0.040)E$. Data from observing seasons 1 (*filled squares*), 2 (*filled diamonds*), 3 (*open circles*), 4 (*crosses*), 5 (*plus signs*), 16 (*filled circles*), and 17 (*open squares*) are plotted. [*See the electronic edition of PASP for a color version of this figure.*]

squares, filled diamonds, open circles, crosses, plus signs, filled circles, and open squares represent values from observing seasons 1, 2, 3, 4, 5, 16, and 17, respectively.

5. HR 8206

HR 8206 (HD 204131, V1934 Cyg, BD +48 3376) is poorly studied, with spectral class B9pSi:Cr:Sr: (Cowley et al. 1968). SIMBAD lists $v \sin i$ values between 35 and 50 km s^{-1}. Winzer (1974) suggests low-amplitude variability from seven *UBV* observations that were insufficient for a good period determination.

Forty and fifty-two good *uvby* FCAPT observations were made in observing seasons 15 (fall 2004–spring 2005) and 16 (fall 2005–spring 2006), respectively. As among the (v-c) sets of data, the u values showed the largest standard deviation about their mean values, I selected them for analysis. Using a Scargle periodogram, the most likely period was 1.5849 days. My zero point was adjusted to have the maximum light for u correspond to phase = 0.50. So the adopted ephemeris is

$$\mathrm{HJD} = 2{,}452{,}894.8946 \pm 0.005 + (1.5849 \pm 0.0005)E.$$

Figure 4 shows the data plotted according to the adopted ephemeris. The data from observing seasons 15 and 16 are shown as filled squares and open circles, respectively. Small offsets of −0.007, −0.005, and 0.003 mag were added to the observing season 16 u, v, and y values, respectively, to make them better agree with the corresponding observing season 15 values. The amplitudes are 0.035, ≤0.01, 0.01, and ≤0.01 mag for u, v, b, and y, respectively. All of the light curves may be in phase with that of u. Note that the u light curve maximum is at phase 0.50, but minimum is near phase 0.95. This is suggestive of a decentered dipole.

6. SOME FINAL COMMENTS

This paper concerns the first sets of FCAPT observations for four mCP stars. Those for HR 7575, a known 224 day variable, fit well with the data from other observers. If additional FCAPT observations are made, the comparison star needs to be replaced. HR 8206, a poorly studied star, shows its largest amplitude for u.

The variability of both HD 16545 and HD 93226 was discovered when their *Hipparcos* satellite photometry was examined. These stars have relatively large amplitudes for their *Hipparcos* photometry and were later found to have good sized Strömgren photometry amplitudes. These stars are good candidates for additional observations to check the stability of their light curves. Observations are in progress for several other mCP stars from Paunzen & Maitzen (1998) with similarly sized *Hipparcos* amplitudes that can be observed from the Fairborn Observatory. The amplitudes of their *Hipparcos* photometry are reflected in those seen in their Strömgren data, which further suggests that their optical fluxes vary in phase.

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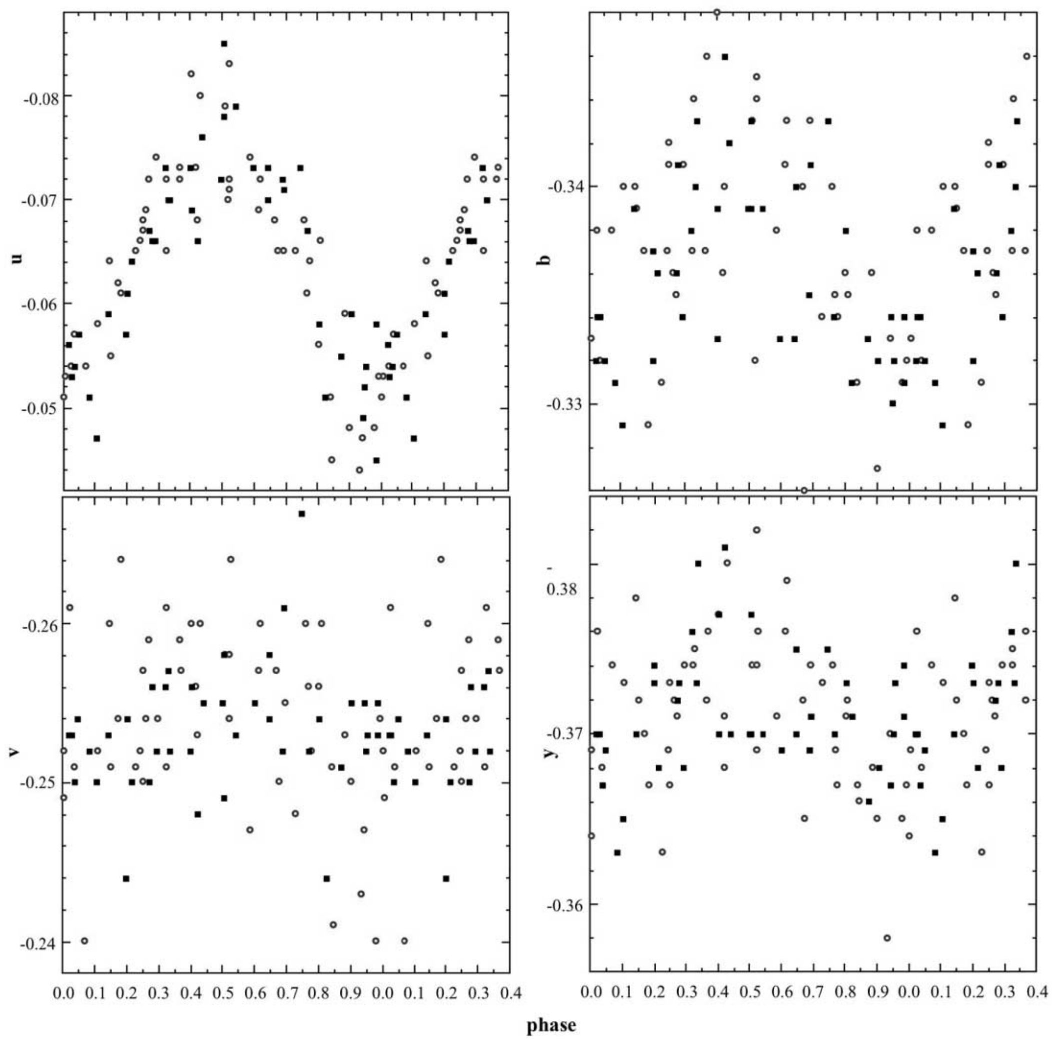

FIG. 4.—*uvby* photometry of HR 8206, plotted with the ephemeris HJD = 2,452,894.8946 ± 0.10 + (1.5849 ± 0.0005)*E*. The FCAPT observations are from seasons 15 (*filled squares*) and 16 (*open circles*). The light curves may all be in phase. [*See the electronic edition of PASP for a color version of this figure.*]

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