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FCAPT *uvby* Photometry of the mCP Stars HR 1297, 25 Sex, BX Boo, and 49 Her

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ABSTRACT. I obtained additional differential Strömgren $uvby$ observations of four magnetic CP stars HR 1297, 25 Sex, BX Boo, and 49 Her with the Four College Automated Photoelectric Telescope (FCAPT). The seasonal light curves of 25 Sex do not show definite differences. The period of Manfroid & Renson of 4.37900 days is confirmed. The other three stars usually have light curves in phase or nearly so, but there are differences between observing seasons. As the local properties of the photosphere change very slowly with time for these stars that have radiative atmospheres and strong magnetic fields, we are viewing slightly different hemispheres at the same phase. To produce this result, their rotational axes precess about their magnetic axes. For HR 1297, which has moderate amplitudes of variation, the period of Adelman is refined to 15.7505 days. The additional observations of BX Boo do not change the best estimate of its period, 2.88756 days. Although its amplitudes of variation are less than those of HR 1297, there are similar differences between observing seasons. For 49 Her the period of 0.93663 days of Adelman et al. is verified. There are probably small season-to-season light curve differences. Of the mCP stars for which I have FCAPT Strömgren observations, at least 13% exhibit variability among their light curves for different years.

Online material: color figures, extended table

1. INTRODUCTION

Studies of magnetic chemically peculiar (mCP) stars, which used data from the 0.75-m Four College Automated Photoelectric Telescope (FCAPT) at Fairborn Observatory, Washington Camp, AZ, determined periods and light curves to relate observations taken at different times and in some cases detected variable light curves (see, e.g., Adelman 2006). According to theory, hydrodynamical processes, especially radiative diffusion and gravitational settling in radiative envelopes with strong magnetic fields, produce their anomalous photospheric abundances, which are functions of 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). Thus the mCP stars have emergent energy distributions, abundances, and magnetic field strengths dependent on photospheric location.

This paper provides at least second epoch FCAPT single-channel differential Strömgren $uvby$ photometry in the instrumental system of HR 1297, 25 Sex, BX Boo, and 49 Her. I studied this data and my published FCAPT data to improve both the periods and the light curve shapes. The FCAPT automatically 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. I chose comparison and check stars from the least variable stars of *Hipparcos* photometry (ESA 1997), which are close on the sky to the variables and also had similar V magnitudes and $B - V$ colors. Table 1 presents some basic information on each group from Hoffleit (1982), Hoffleit et al. (1983), and SIMBAD. I used the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986) to find the mCP star periods.

Table 2 lists the photometric values, their averages, and the standard deviations of v-c and ch-c for each filter of the new data. As those for ch-c are of order 0.005 mag, the errors for v-c are probably similar. The first observing season for the FCAPT was Fall 1990 through Spring 1991. The current 18th observing season is 2007 September through 2008 July. If a mCP star exhibits in-phase optical region variability and good older photometry has not been obtained, then *Hipparcos* photometry (ESA 1997) may be useful in refining the period.

For spectrum variables exhibiting moderate rotation, surface abundance maps obtained from spectra and Doppler Imaging techniques when derived can serve as tests of mCP star theories. Simple comparisons of light curves taken with different filters may provide some indications 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, can be used to improve periods. When there are sufficient observations from two or more observing seasons, one can also 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).

TABLE 1
PHOTOMETRIC GROUPS

HD	Name	Type[a]	V	Spectral Type	Filter[b]
26571 ……	HR 1297	v	6.12	B9IIIp:Si:	1
27176 ……	51 Tau	c	5.65	F0V	3
24740 ……	32 Tau	ch	5.63	F2 IV	3
90044 ……	25 Sex	v	5.97	B9p	2
90882 ……	29 Sex	c	5.21	B9.5 V	2
88372 ……	HR 4000	ch	6.25	A2 Vn	2
133029 …..	BX Boo	v	6.37	B9p	1
133962 …..	47 Boo	c	5.57	A1 V	2
130945 …..	38 Boo	ch	5.74	F7 IV	2
152308 …..	49 Her	v	6.52	B9.5pCr:	1
151862 …..	HR 6246	c	5.91	A0 V	2
150483 …..	HR 6203	ch	6.08	A3 Vn	2

[a] Type of Star: v = variable, c = comparison star, and ch = check star.
[b] Filters: 1 = no neutral density filter and 2 = 1.25 mag neutral density filter.

2. HR 1297

Gulliver (1971) and Gulliver & MacRae (1975) identified HR 1297 (= HD 26571 = BD + 22649) as a B8p[Si] star and marked spectrum variable. Adelman & Brunhouse (1998) and Adelman (2000) obtained 78 and 117 sets of FCAPT data of HR 1297, respectively, in seasons 6, 7, and 8 and in season 9. To supplement this data, an additional 30, 26, and 47 sets were obtained in seasons 14, 15, and 16, respectively. Adelman (2000) found the period was 15.7490 days. The ephemeris has now been refined to HJD (light maximum: $\phi = 0.95$) $= 2441247.475 \pm 0.005 + (15.7505 \pm 0.0004)$ E. The change in the zero point did not result in light maximum at phase 0.00.

The data of Adelman & Brunhouse (1998), Adelman (2000), and this paper have different zero points and so were normalized to a common scale for comparison in plotting. The data from the four Strömgren filters suggest (see Fig. 1) that there may be slight differences in the phasing of light maximum. The full amplitudes of variation are 0.042, 0.030, 0.027, and 0.022 mag. for u, v, b, and y, respectively. These are similar to, but not identical to those of Adelman & Brunhouse (1998) and Adelman (2000).

Data from the most complete seasonal data sets do not lie exactly on top of one another. Thus, HR 1297 shows slightly different hemispheres at the same phase, an effect that is produced by the precession of the rotational axis about the magnetic axis (Adelman et al. 2001). The amplitudes of variability are smaller than some other similar stars. The complex light curves suggest a complicated surface distribution of abundances. More complete light curves obtained in different observing seasons are needed to reveal the details and the changes. For HR 1297 it is desirable to get 60 or more observations per season.

3. 25 SEX

The photometric variability of 25 Sex (= HD 90044 = HR 4082 = BD − 03 2911), spectral type B9p Si (Sr,Cr) (Cowley et al. 1969) was studied by Manfroid & Renson (1994) and Adelman (1997). Both used the ephemeris HJD(t_o) $= 2445659.000 + (4.37900 \pm 0.00004)$ E.

Adelman (1997) and this paper contain 160 and 123 sets of $uvby$ values, respectively. The origin of the ephemeris is that for u light minimum. The b, v, and y light curves are in phase. Their minimum agrees with that of u, their secondary maximum with u maximum, and their maximum with a change of slope in the falling u branch. There are at least two spots with different energy distributions. The amplitudes of 0.066, 0.034, 0.040, and 0.026 mag. for u, v, b, and y, respectively, are similar to those of Adelman (1997),

The observations reported in Adelman (1997) were from seasons 2, 3, 4, and 5. There are also 37 observations from season 1 that I have included, as well as 25 and 37 observations, respectively, from seasons 11 and 15. An additional 23, 11, 5, and 63 observations were made in seasons 12, 13, 14, and 17, respectively, but were not used. Those from season 12 were divided among 3 choices of filters, those from seasons 13 and 14 did

TABLE 2
uvby NEW PHOTOMETRY FOR HR 1297, 25 SEX, BX BOO, AND 49 HER

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)
HR 1297								
2452984.8604 …..	−2.144	0.043	−1.857	−0.067	−1.821	−0.021	−1.877	0.022
2452991.8432 …..	−2.171	0.044	−1.862	−0.062	−1.817	−0.023	−1.877	0.024
2452992.6734 …..	−2.171	0.045	−1.872	−0.066	−1.821	−0.027	−1.872	0.016
2452994.7109 …..	−2.193	0.054	−1.879	−0.062	−1.832	−0.018	−1.893	0.023
2452995.7116 …..	−2.187	0.047	−1.876	−0.080	−1.825	−0.027	−1.887	0.014
2452998.7074 …..	−2.165	0.038	−1.858	−0.079	−1.813	−0.040	−1.863	0.010
2452999.7076 …..	−2.159	0.038	−1.858	−0.077	−1.810	−0.037	−1.865	0.011
2453000.7476 …..	−2.148	0.039	−1.852	−0.074	−1.814	−0.027	−1.865	0.017
2453007.7045 …..	−2.159	0.041	−1.845	−0.069	−1.807	−0.022	−1.862	0.019
2453009.7234 …..	−2.177	20.055	−1.865	−0.059	−1.820	−0.021	−1.869	0.024

NOTES.—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.

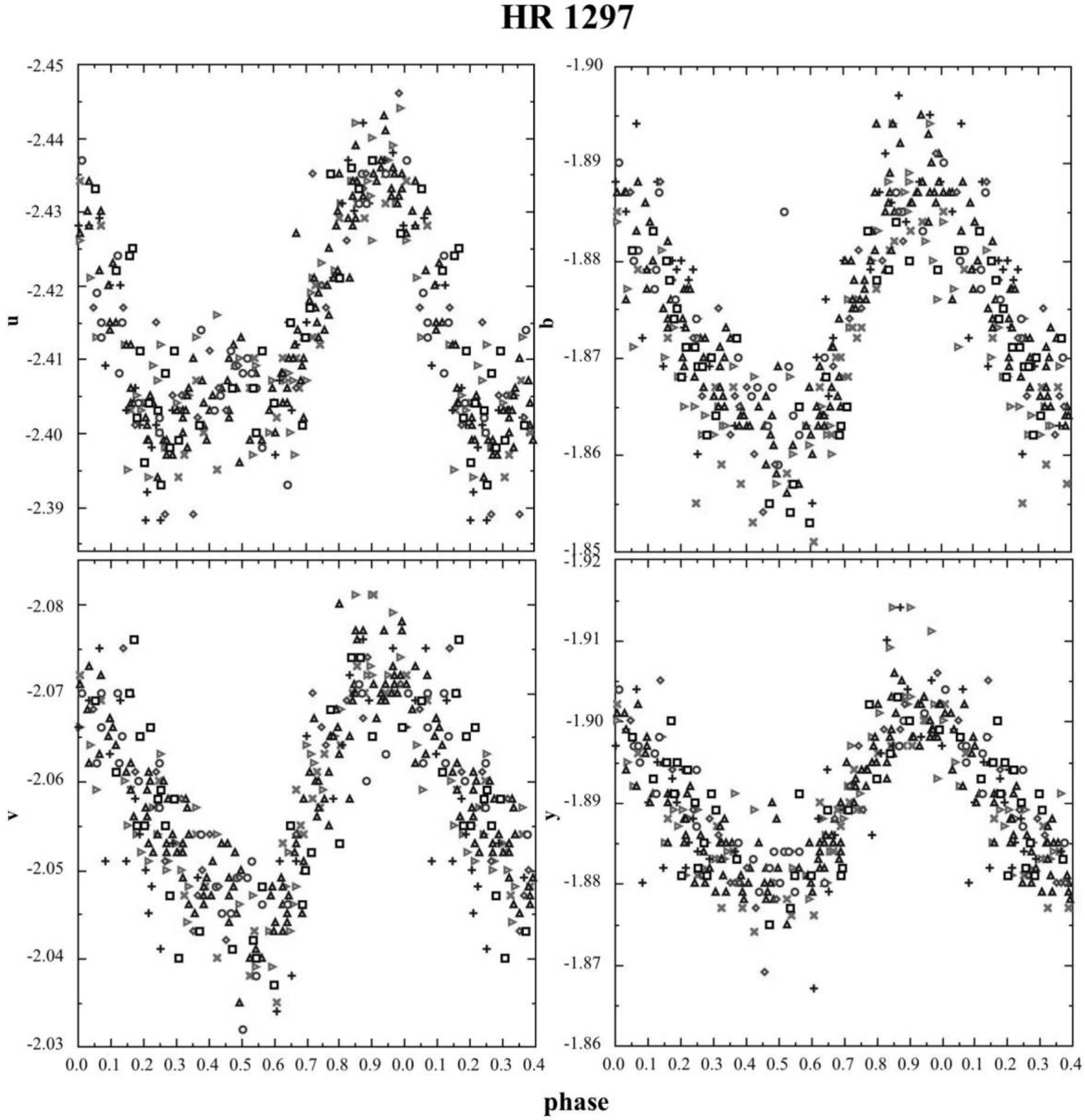

FIG. 1.—*uvby* photometry of HR 1297 for observing seasons 6 (*squares*), 7 (*diamonds*). 8 (*circles*), 9 (*upward-pointing triangles*), 14 (*plus signs*), 15 (*crosses*), and 16 (*right-facing triangles*) plotted using HJD(light maximum: $\phi = 0.95$) $= 2441247.475 \pm 0.005 + (15.7505 \pm 0.0004)$ E. The photometry is best described as in phase, but with small season to season differences. See the electronic edition of the PASP for a color version of this figure.

not use the same set of neutral density filters as other seasons, and those from season 17 were relatively noisy. For some seasons and filters, small global changes were made to improve interseasonal agreement: $u + 0.005$ for season 17, $v - 0.005$ for seasons 4 and 5, $b - 0.005$ for seasons 4 and 5, $y - 0.005$ for seasons 3, 11, and 15 and $y - 0.010$ for seasons 4 and 5. Table 2 has the results from seasons 1, 11, and 15, which have not been published before. For these values no correction factors were applied.

There are no significant differences seen among the seasonal light curves. As the new observations are in good agreement with the previous FCAPT observations (see Fig. 2), the ephemeris of Manfroid & Renson (1994) was used. The earliest data used in its construction were taken in 1980. That the same ephemeris works throughout some 25 years of data suggests that 25 Sex had stable light curves during this period.

4. BX BOO

Winzer (1974) and Wolff & Morrison (1975) found that BX Boo (= HD 133029 = HR 5597) was a magnetic CP star with a period of 2.8881 days. Rakosh & Fielder (1978) and Borra & Landstreet (1980) found similar periods. Adelman (1998) refined the period with 90 FCAPT observations from

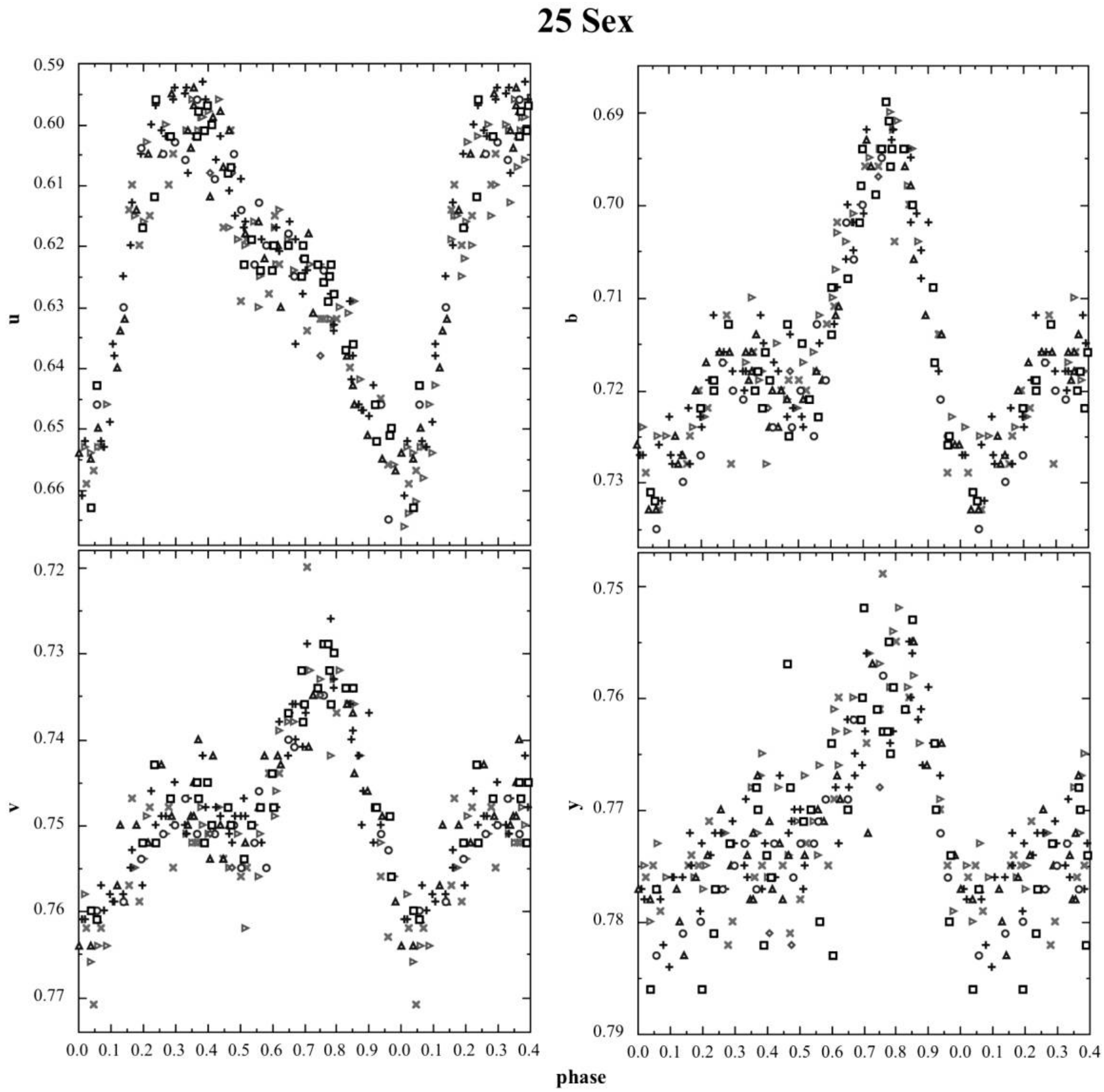

FIG. 2.—*uvby* photometry of 25 SEX for observing seasons 1 (*squares*), 2 (*diamonds*). 3 (*circles*), 4 (*upward-pointing triangles*), 5 (*plus signs*), 11 (*crosses*), and 15 (*right-facing triangles*) plotted using $\mathrm{HJD}(to) = 2445659.000 + (4.37900 \pm 0.00004)$ E The photometry is best described as in phase without seasonal differences. See the electronic edition of the PASP for a color version of this figure.

seasons 2, 3, 4, and 5 and found $\mathrm{HJD(light\ minimum)} = 2448720.181 \pm 0.025 + (2.88756 \pm 0.00004)$ E.

Here 57, 32, and 45 observations from seasons 1, 14, and 15, respectively, were also used (see also Table 2). A reassessment showed that most observations from season 1 were good. Observations from season 13 showed considerable scatter and were not used in the period analysis. As the period derived was the same as the last study using FCAPT data, the ephemeris was not modified. The amplitudes are 0.016, 0.022, 0.024, and 0.014 mag for u, v, b, and y, which are similar to those of Adelman (1998).

Figure 3 shows that the photometry from the four Strömgren filters appear nearly in phase. Light maximum occurs near phase (ϕ) 0.5 and light minimum between phases 0.95 and 1.00. Thus in the ephemeris cited in the first paragraph of this section, light minimum is changed to light maximum: $\phi = 0.50$. Further there are minor differences between data of each season that are similar to those of HR 1297.

5. 49 HER

Winzer (1974) found that 49 Her (HR $6268 =$ HD $152308 =$ V823 Her) was a moderate amplitude photometric variable. He adopted a period of 1.0978 days, but noted that the resonance period of 0.918 days was a possible alternative. Adelman et al. (1999) obtained 56 sets in season 7 and 19 sets in season 8 of FCAPT $uvby$ photometry and used it with Winzer's V data to find $\mathrm{HJD(light\ maximum)} = 2441453.925 \pm 0.003 + (0.93663 \pm 0.00002)$ E. The photometry data are almost in

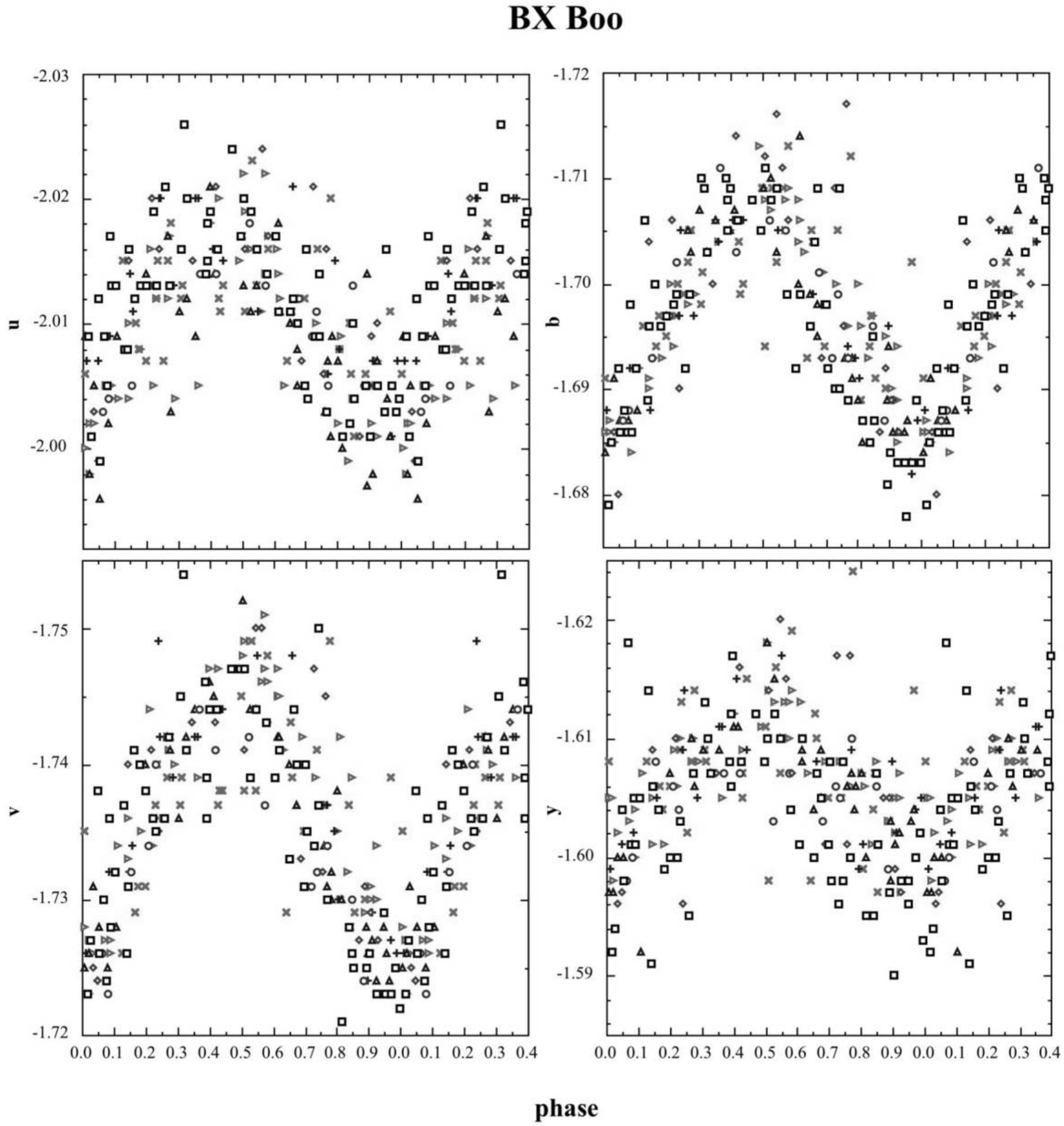

FIG. 3.—*uvby* photometry of BX Boo for observing seasons 1 (*squares*), 2 (*diamonds*). 3 (*circles*), 4 (*upward-pointing triangles*), 5 (*plus signs*), 14 (*crosses*), and 15 (*right-facing triangles*) plotted using HJD(light maximum: $\phi = 0.50) = 2448720.181 \pm 0.025 + (2.88756 \pm 0.00004)$ E. The v, b, and y photometry is best described as in phase and partially out of phase with the u photometery. There might be some small season-to-season differences. See the electronic edition of the PASP for a color version of this figure.

phase but the details for the different filters were not quite the same.

New FCAPT photometry obtained in seasons 15, 16, and 17 have 62, 38, and 46 values, respectively. The new data zero points were modified to agree with the pervious zero points for Figure 4, while for the data in Table 2 no such adjustment were made. A Scargle periodogram suggested a slightly different period. But as it produced light curves for each season slightly offset from one another, it was wrong. Thus, I kept the Adelman et al. (1999) ephemeris.

The four light curves had apparent slight differences in light maxima over the phase range 0.98 to 1.02. The maxima are far narrower in phase than the light minimum, which has two subminima or suggestions thereof. This makes judging differences somewhat difficult, see, e.g., the u light curves for seasons 7 and 13. They are probably different. The amplitudes found for u, v, b, and y, which are, respectively, 0.055, 0.023, 0.030, and 0.021 mag, tend to be less than those found by Adelman et al. (1999). The differences are to a large degree due to having better defined light curves.

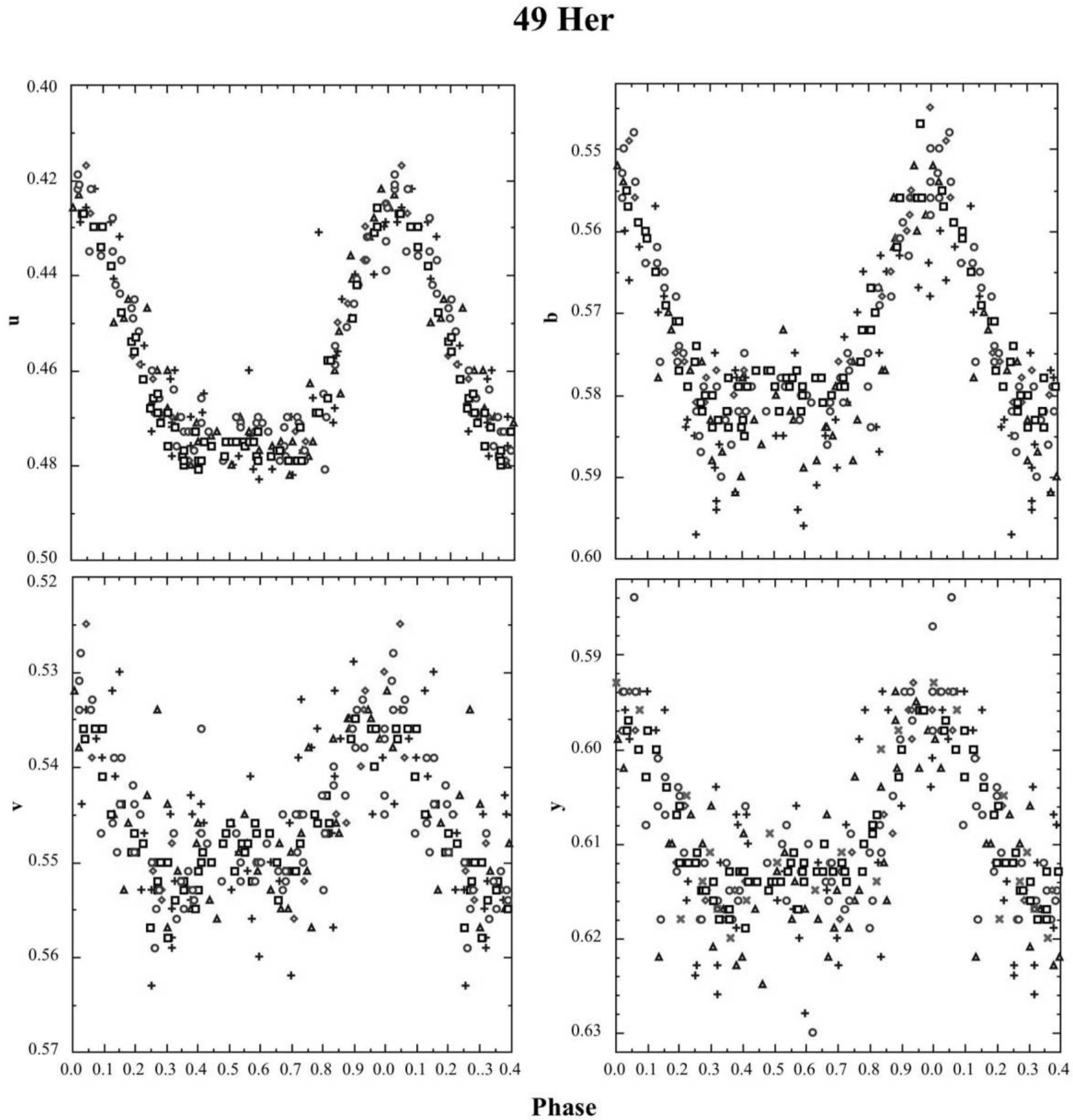

FIG. 4.—*uvby* photometry of 49 Her for observing seasons 7 (*squares*), 8 (*diamonds*). 15 (*circles*), 16 (*upward-pointing triangles*), and 17 (*plus signs*), and Winzer (1974)'s V data converted to y (*crosses* only for y) plotted using HJD(light maximum) $= 2441453.925 \pm 0.003 + (0.93663 \pm 0.00002)$ E. The photometry is best described as in phase, but with possible small season to season differences. See the electronic edition of the PASP for a color version of this figure.

6. SOME FINAL COMMENTS

In this paper, making small (order 0.005 mag.) adjustments in magnitude to all the data in an observing season lead to the light curves with data from several season exhibiting reduced scatter and simultaneously has helped resolve whether there are differences between seasons. There are many stars whose light curves show apparent small differences between seasons. In trying to see if these are significant, good coverage at the extrema is especially important when the data are limited in number. At the beginning of this series of FCAPT papers, the goal was to obtain a total of 50 or more observations compared to the norm in 1990, on the order of 30 observations. With complicated light curves, even more observations were desirable per season. Obtaining one per clear night when the star is observable is the current goal. For those stars with periods of 4 days or less, it is a good idea to get two observations per night during part of the observing season. For those stars for which seasonal differences are seen, the number of observations per season are often greater than for those that do not show this behavior.

Recently two studies confirmed long-held ideas about the mCP stars. Aurière et al. (2007) found that all their firmly classified mCP stars show detectable surface fields and that there is a magnetic threshold for such stars. Adelman & Woodward (2007) discovered that their cohort of mCP stars and by inference the entire class are photometric variables. Thus their magnetic and rotation axes are not aligned. Without photometric "spots" due to abundance inhomogeneities there would not be any photometric variability. Class members are also magnetic and spectrum variables at least to a minimum extent. A distant observer may see variability of fluxes, spectrum, and/or magnetic field as a mCP star rotates. Many, if not all, mCP stars should also show the precession of their rotational axes around their magnetic axes (see Shore & Adelman 1976). Thus, the observed light curves should periodically change from one observing season to the next, although for many stars the changes produced may be insufficient to detect with 5 millimagnitude photometric errors.

Pyper & Adelman (2004) summarized what was known about variable light curves in mCP stars. Only two of the fastest rotators: CU Vir (Pyper et al. 1998) and 56 Ari (Adelman et al. 2001) exhibited measurable long-term period changes. HR 7224 (Adelman 2004) went from being a well-behaved mCP star to one whose variability was nonperiodic. Stars with variable light curves indicating the precession of the rotational axis about their magnetic axis include 108 Aqr (Adelman 1999), 20 Eri (Adelman 2000), 56 Ari (Adelman et al. 2001), MW Vul (Adelman & Young 2005), and V1093 Ori (Pyper & Adelman 2004). Recently other similar mCP stars were found: EP Vir (Adelman & Sutton 2007), HR 7786 (Adelman 2008), and, in this paper, HR 1297, BX Boo, and probably 49 Her. Thus, my FCAPT *uvby* photometry indicates that at least 13% of mCP stars show differences among their seasonal light curves. This is a lower limit, because for many stars proper searches for light curve variability still need to be performed. However, there are also many mCP stars whose light curves have been shown to be stable for 25 to 30 years in this series of papers. This difference in behavior requires careful study.

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