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uvby FCAPT photometry of the mCP stars HD 32633, θ Aur, 49 Cam, and 3 Hya⋆

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Abstract. Differential Strömgren *uvby* observations from the Four College Automated Photoelectric Telescope are presented for the magnetic Chemically Peculiar (mCP) stars HD 32633, θ Aur, 49 Cam, and 3 Hya. We find for over 30 years, these four stars with stable optical region light curves have had constant periods of 6.4300, 3.61868, 4.28679, and 11.305 days, respectively.

Key words. stars: chemically peculiar – stars: individual: HD 32633 – stars: individual: θ Aur – stars: individual: 49 Cam – stars: individual: 3 Hya

1. Introduction

Single-channel differential Strömgren *uvby* photometry from the Four College Automated Photoelectric Telescope (FCAPT) at Washington Camp, AZ, were recently obtained for the magnetic Chemically Peculiar (mCP) stars HD 32633, θ Aur, 49 Cam, and 3 Hya. These second epoch FCAPT observations of 4 mCP stars were made to improve the periods of light variability and to investigate the stability of their light curves. The 2004−2005 observing season is the 15th year of FCAPT observing whose first year was Fall 1990 through early Summer 1991.

Table 1 contains some important information on our four variables (Hoffleit 1982; Hoffleit et al. 1993). The 0.75-m automated telescope measures the dark count and then in each filter sky-ch-c-v-c-v-c-v-c-ch-sky 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 each group. Using Hipparcos photometry (ESA 1997) the comparison and check stars were selected from presumably non-variable stars that are located near the variables on the sky that had somewhat similar V magnitudes and $B - V$ colors. They are the same as those used for the first epoch FCAPT observations. The periods of the mCP stars were refined with the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986). In Tables 2−5 which contain the photometric values, the standard deviations of v-c and ch-c are given for each filter. Those for ch-c are of order 0.005 mag, which suggests that the errors for v-c are similar.

Table 1. Photometric groups.

HD	Star name	Type	V	Spectral type
32633	HZ Aur	v	7.02	A2pSiCr
32608	HR 1639	c	6.52	A5 V
33704	BD +36° 1047	ch	6.85	A0
40312	θ Aur	v	2.62	A0pSi
39182	HR 2025	c	6.45	A2 V
37339	BD +37° 1275	ch	6.96	B9
62140	49 Cam	v	6.18	F0pSrEu
61497	24 Lyn	c	4.99	A3 IVn
62976	BD +60° 1084	ch	6.78	A2
72968	3 Hya	v	5.72	Ap1SrCrEu
73997	HR 3437	c	6.63	A1 Vn
71766	HR 3342	ch	6.00	F2 III

Note on type of star: v = variable, c = comparison star, and ch = check star.

The mCP stars exhibit photometric, spectrum, and magnetic variability with photospheric location dependent emergent energy distributions, abundances, and magnetic field strengths. Often their magnetic and rotation axes are not aligned. Then a distant observer sees a variety of variable behavior as they rotate. Their anomalous photospheric abundances are thought to be produced by hydrodynamical processes, in particular radiative diffusion and gravitational settling in radiative envelopes containing strong magnetic fields. They depend on the local magnetic field strength and its angle with the vertical as well as the evolution of the field and the elemental abundances since at least when the star was on the Zero

⋆ Tables 2–5 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/435/1099

Age Main Sequence (Michaud & Proffitt 1993, and references therein). Their periods and light curves have been improved by differential photometric studies with the FCAPT by the senior author and his students (see, e.g., Adelman 2002) so that one can better relate observations taken at different times, detect variable light curves, and study the period distribution of the mCP stars. Surface maps of abundances for spectrum variables exhibiting moderate rotation can be derived to serve as tests of mCP star theories.

Two important related questions for the theory of magnetic CP stars are: 1) when do these stars begin to rotate slower than their normal star twins? and 2) how does the distribution of their rotational periods evolve with age? Although there is now a body of somewhat conflicting evidence (see, e.g., Adelman 2002; Zverko et al. 2004), direct evidence for an increase in the rotation period has so far been found only for two rapidly rotating mCP stars, CU Vir (Pyper et al. 1998) and 56 Ari (Adelman et al. 2001). Both show increases of 2 s per century in their periods which if extrapolated to when they will be giants is sufficient to change their rotation periods of 0.5 and 0.7 days, respectively, to those of many days.

Another issue of importance is the percentage of mCP stars whose light curves are (periodically) variable. The cause of this behavior is thought to be connected with the precession of the rotational axis about the magnetic axis (see, e.g. Shore & Adelman 1976; Adelman & Young 2005). Pyper & Adelman (2005) found that of order 10% of those mCP stars with two or more epochs of good photometry showed results consistent with this effect.

Thus obtaining second epochs of FCAPT *uvby* photometry allows one to address both issues. When there is a pre-FCAPT set of photometry, it can possibly be used to strengthen any conclusions. Here we examine new sets of photometry for four typical mCP stars.

2. HD 32633

Adelman (1997a) obtained 91 *uvby* observations of the A2pSiCr star HD 32633 (HZ Aur, BD +33° 953) with the FCAPT during years 2, 4, 5, and 6. He compared these values to Rakosch (1962)'s *uv* photometry. The zero point, the phase of maximum light, was satisfactory. A slight decrease in the period found from a periodogram analysis was necessary to get satisfactory agreement.

In year 14 (2003−2004) of the FCAPT, an additional 77 *uvby* observations were obtained. These observations are very similar to the first FCAPT set except for small zero point shifts, of 0.005 mag in u, −0.005 mag in v, and −0.012 mag in both b and y. Between these two sets of data, the telescope was moved from Mt. Hopkins, AZ, the photometer was replaced, and the filters were changed. Thus these small offsets are probably due to these differences. When a periodogram analysis was run with both sets of FCAPT data, a period of 6.4298 days was found. But the use of Rakosch's data clearly indicates that the 6.4300 day period of Adelman (1997a) is to be preferred. Thus the ephemeris of that paper is also adopted, but with more conservative error estimates.

$$\mathrm{HJD}\ (u_{\max}) = 2\,437\,307.200 \pm 0.005 + 6.43000 \pm 0.00005\ E.$$

Figure 1 compares FCAPT observations of Adelman (1997a) (solid squares) after the zero point shifts were applied with those of this paper (open circles) and the *uv* observations of Rakosch (1962) (×'s) (see u panel). The quite asymmetric light curves vary in phase with one another. There is a suggestion of a subminium near phase 0.25. The amplitudes are 0.06 mag for u, 0.04 mag for v, 0.035 mag for b, and 0.03 mag for y, which are close to the values from Adelman (1997a). The *uv* values of Rakosch do not have quite the amplitude of the FCAPT u values which may due to a slightly different bandpass. The ability to use one ephemeris to represent observations for over a 30 year period suggests that for this time period HD 32633 has had a constant period and light curves.

3. θ Aur

θ Aur (HR 2095, HD 40312, 37 Aur) is an A0p Si Star (Cowley et al. 1969), and the brighter member of the close visual binary ADS 4566. Adelman (1997b) used the V photometry of Winzer (1974) and 47 *uvby* FCAPT observations obtained in years 2−5 to determine a period of 3.6188 ± 0.0001 days. There is a rough in-phase variability among the four Strömgren magnitudes although some details are somewhat different.

Sixty-nine new sets of *uvby* photometry were obtained with the FCAPT during the Fall of 2003 through the Fall of 2004. They usually agree well with the previous FCAPT values although there are parts of the light curves which are suggestive of discrepancies. A few apparent outlyers are found. A Scargle periodogram of the y data indicates a period of 3.61868 days which is slight smaller than that found by Adelman (1997b). This period corresponds to the highest peak in the periodogram. For θ Aur, some investigators have found the alias of this period with less photometry. The amplitudes have not changed appreciably from those found with the early *uvby* photometry. They are now 0.075 mag, 0.035 mag, 0.042 mag, and 0.030 mag, respectively, for u, v, b, and y. For parts of these light curves the scatter is larger than for the regions of best agreement, but still in accord with the photon statistics.

In addition to changing the period slightly, the zero point of the ephemeris, which was taken from Hatzes (1991), also needed a slight modification, corresponding to a change of 0.05 in phase. We chose to use the maximum in u rather than that in y as it was better defined. Still there is some uncertainty as all maxima are somewhat asymmetric with that for u being the narrowest in phase at half amplitude. The phases of maximum light may not be identical for the four Strömgren magnitudes. The new FCAPT photometry fills in the light curves presented in Fig. 2. The ephemeris adopted is

$$\mathrm{HJD}\ (u_{\max}) = 2\,446\,337.972 \pm 0.100 + 3.61868 \pm 0.00002\ E.$$

Doppler imaging techniques provide the distributions of oxygen, silicon, chromium, and iron (Hatzes 1991; Khokhlova et al. 1986; Rice & Wehlau 1990, 1991; Rice et al. 2004).

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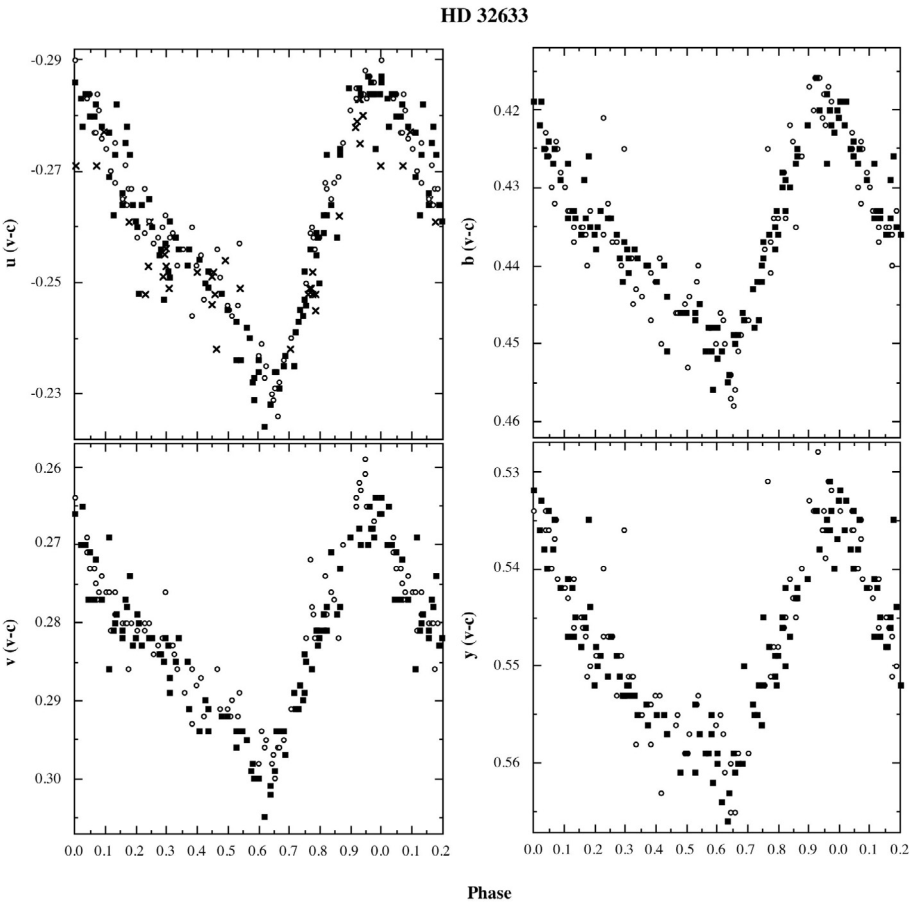

Fig. 1. *uvby* photometry of HD 32633 as a function of the ephemeris HJD ($u_{\rm max}$) = 2 437 307.200 + 6.4300 *E*. The solid squares and the open circles in each panel are, respectively, values from Adelman (1997a) and this paper. In the *u* panel, ×'s indicate *uv* values from Rakosch (1962).

The shapes of the four Strömgren light curves are somewhat different from each other which is indicative of complicated distributions of elemental abundances over the photosphere of θ Aur. Its rotational period has most likely been constant for over 30 years and the light curve amplitudes have been stable.

4. 49 Cam

49 Cam (BC Cam, HR 2977, HD 62140) is a F0p SrEu (Cowley et al. 1969) mCP star. Adelman (1997b) used 89 FCAPT *uvby* observations obtained between 1990 and 1996 as well as 11 *uvby* values from Bonsack et al. (1974) to adjust the ephemeris of Leroy et al. (1994) and Leroy (1995). During the 2003−04 observing season (year 14 for FCAPT observations) 75 new *uvby* observations were made. We found offsets (in magnitudes) from the earlier obtained FCAPT data set mainly due to changing a neutral density filter as −1.369, −1.297, −1.218, and −1.193 for *u*, *v*, *b*, and *y*, respectively. These observations fit the previous ones if the Adelman (1997b) ephemeris is used. This indicates that for some 33 years 49 Cam has had a constant period with stable light curves.

HJD ($v_{\rm max}$) = 2 441 254.08 + 4.28679(±0.000005) *E*.

Figure 3 shows the light curves of 49 Cam with crosses (×'s) being the observations of Bonsack et al. (1974), closed squares those of Adelman (1997b), and open circles those of this paper. The amplitudes are approximately 0.03 mag in *u*, 0.022 mag in *v*, and 0.024 mag in *b* and *y* which are similar to those of Adelman (1997b).

The light curves are different for *u*, *v*, *b*, and *y*, but all have indications of sub-mimima near phases 0.25 and 0.70. They vary in strength among the four color filters. This indicates that the energy distributions of the regions responsible for the two sub-minima are quite different from one another and the background star.

5. 3 Hya

Adelman (1998) published FCAPT *uvby* photometry from years 1−6 of 3 Hya (HR 3398, HD 72968, HV Hya), spectral type A1pSrCrEu (Cowley et al. 1969). Using his data and that of Maitzen et al. (1978) he found that the ephemeris of Maitzen et al. fit both sets of photometry. During the 2003−2004 observing season (year 14), 55 new sets of *uvby* photometry were obtained. The period was essentially the same. The periodogram yields half of the adopted period since 3 Hya has optical light curves which are double waves. Plotting the data shows that the adopted period is better. As this star rotates, each pole points to the Earth during a rotational period. The zero point was slightly modified to reflect a photometric rather than a magnetic determination. The errors have been reduced in these constants. As Maitzen et al. (1978) include data taken by

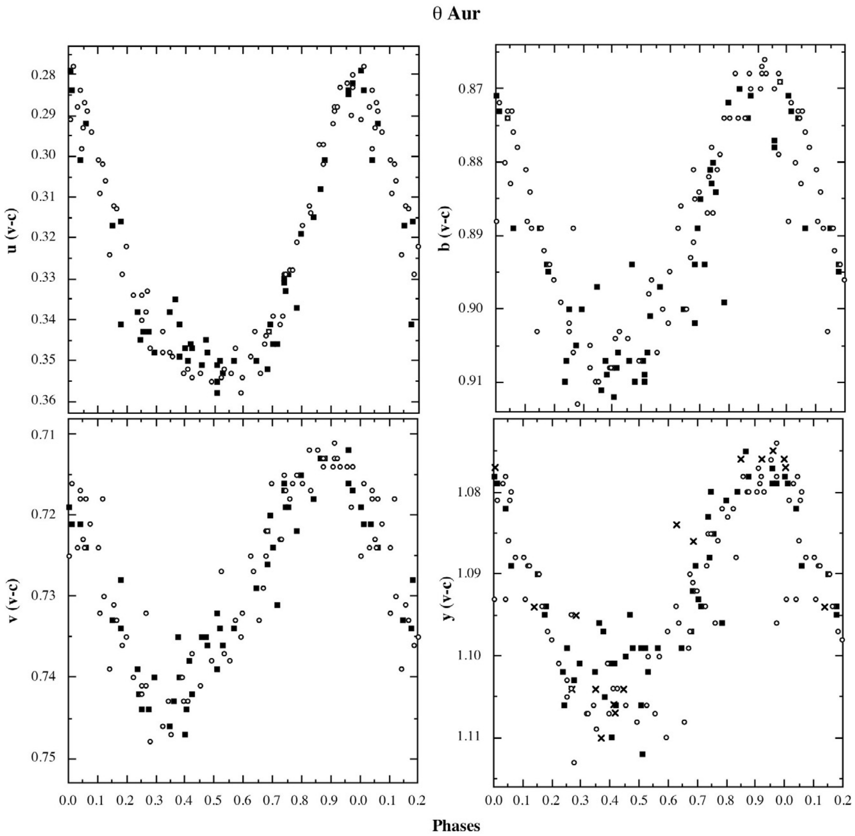

Fig. 2. *uvby* photometry of θ Aur as a function of the ephemeris HJD ($u_{\rm max}$) = 2 446 337.972 + 3.61868 *E*. The solid squares and the open circles in each panel are, respectively, values from Adelman (1997b) and this paper. In the *y* panel, $\times$'s indicate *V* values from Winzer (1974).

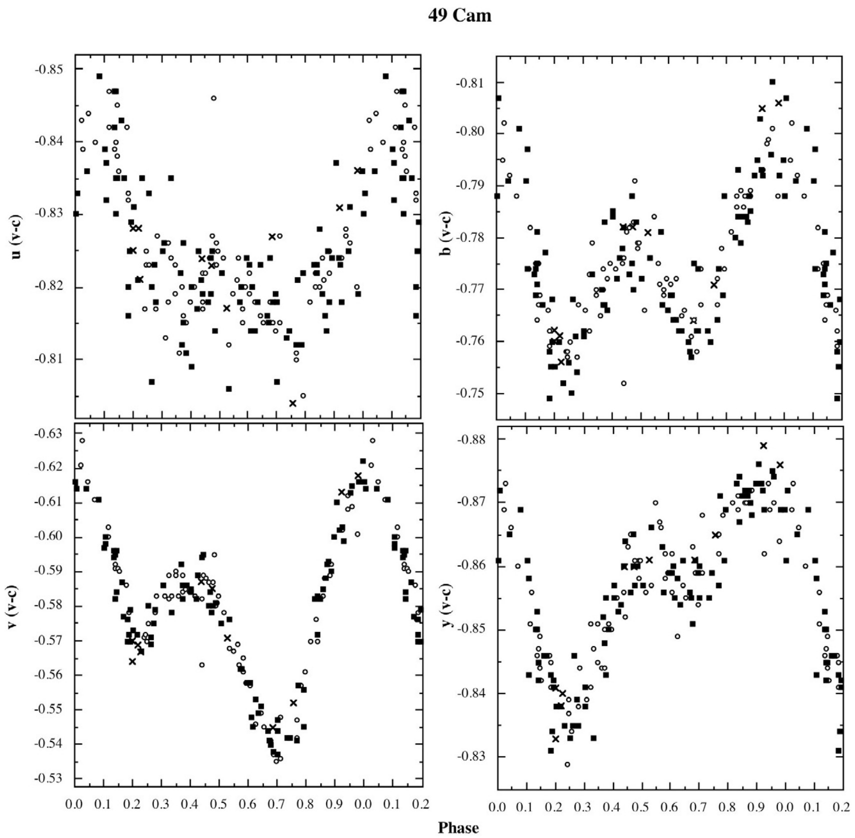

Fig. 3. *uvby* photometry of 49 Cam as a function of the ephemeris HJD ($v_{\rm max}$) = 2 441 254.08 + 4.28679 *E*. The solid squares, the open circles, and the crosses in each panel are, respectively, values from Adelman (1997b), this paper, and Bonsack et al. (1974).

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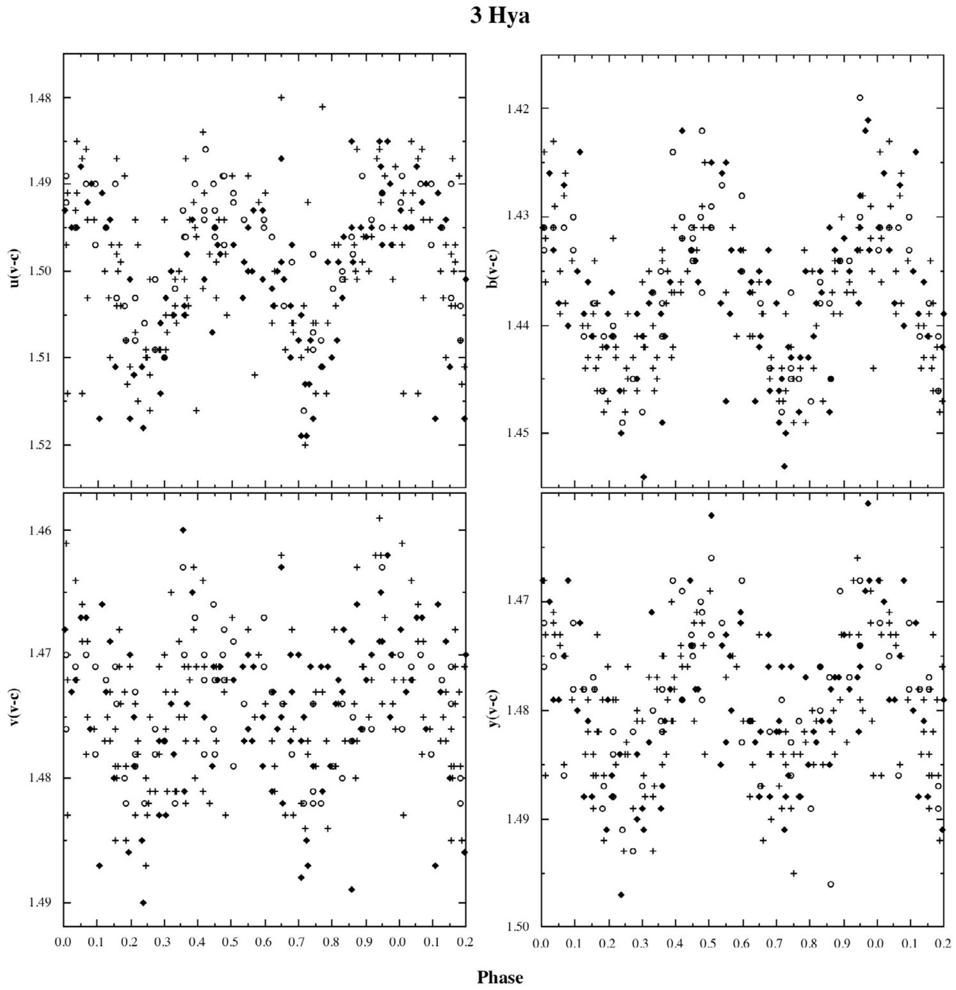

Fig. 4. *uvby* photometry of 3 Hya as a function of the ephemeris HJD (max light) = 2 432 898.245 + 11.305 *E*. The solid diamonds, the plus signs, and the open circles in each panel are, respectively, values from Maitzen et al. (1978), Adelman (1998), and this paper.

Wolff & Wolff (1971) in 1970, 3 Hya appears to have had a constant period for 35 years. The adopted ephemeris is

$$\mathrm{HJD\ (max\ light)} = 2\,432\,898.245(\pm 0.110) + 11.305(\pm 0.001)\,E.$$

Figure 4 shows the light curves of 3 Hya with solid diamonds being the observations of Maitzen et al. (1978), plus (+) signs being those of Adelman (1998), and open circles being those of this paper. The amplitudes are approximately 0.03 mag in u, 0.022 mag in v, and 0.024 mag in b and y which are similar to those of Adelman (1998).

6. Final comments

Thus HD 32633, θ Aur, 49 Cam, and 3 Hya, which have two epochs of FCAPT photometry and a set each of photometry before the FCAPT began operations, show apparent constancy of period and of light curves for 30 or more years. There is still the slight possibility that we have observed each at the same phase of their precessional cycles. Additional sets of observations in a few years will help eliminate any residual chances of precessional cycles as well as help indicate if any periods are increasing. To discover any increases in the rotational periods will likely require observations taken over time periods somewhat greater than we have data. Any increase in the accuracy and the precession of the photometry will also help such determinations.

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