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uvby photometry of the magnetic CP stars 45 Leonis, HR 4330, 49 Herculis, and HR 6718⋆

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Abstract. Differential Strömgren *uvby* photometric observations from the Four College Automated Photoelectric Telescope are presented for the magnetic CP stars 45 Leo, HR 4330, 49 Her, and HR 6718. We refined Winzer's periods for 45 Leo and HR 6718 to 1.443820 days and 0.51899 days, respectively. For HR 4330 our period of 3.516 days is quite different from that of Winzer. That for 49 Her, 0.93663 days, is an alias of Winzer's.

Key words: stars: chemically peculiar — stars: individual: 45 Leo, HR 4330, 49 Her, and HR 6718

1. Introduction

The anomalous photospheric abundances of the magnetic Chemically Peculiar (mCP) stars, whose effective temperatures and surface gravities are similar to those of main sequence B, A, and early F stars, are thought to be produced by hydrodynamical processes including radiative diffusion and gravitational settling in radiative envelopes which have strong magnetic fields (Michaud & Proffitt 1993 and references therein). The resulting abundance distributions depend upon the magnetic field, should be patchy, and affect the emergent flux distribution (Shore & Adelman 1974). This is necessary to explain their photometric, magnetic, and spectrum variability. Differential photometric studies with the 0.75-m Four College Automated Photoelectric Telescope (FCAPT) have both improved periods, which are crucial to relating observations taken at different times, and better defined the shapes of their light curves (see, e.g. Adelman & Brunhouse 1998). These results can be used to detect changes in light curves between observing seasons, deduce information concerning the uniformity of the surface abundances, and study the period distribution of mCP stars. An important goal in this research is to derive abundances as a function of photospheric position and then use these abundances to test the theories of chemical differentiation. This permits investigators to learn about hydrodynamical processes at work in mCP (and other hot) star atmospheres.

Table 1. Photometric groups

HD Number	Star Name	Type	V	Spectral Type
90569	45 Leo	v	6.04	A0pSiCr:
89774	42 Leo	c	6.12	A1V
95216	HR 4281	ch	6.53	F5V
96707	HR 4330	v	6.06	F0pSr
97138	HR 4340	c	6.40	A3V
98772	HR 4391	ch	5.98	A3V
152308	49 Her	v	6.52	B9.5pCr:
151862	HR 6246	c	5.91	A1V
150483	HR 6203	ch	6.08	A3Vn
164429	HR 6718	v	6.48	B9pSiSr
162132	HR 6641	c	6.43	A2Vs
165358	HR 6753	ch^a	6.21	A2V
166228	HR 6792	ch^a	6.32	A2V

[a]HD 165358 was used as the check star for 1995-97 and HD 166228 for 1997-98.

This paper presents single-channel differential Strömgren photometry of four mCP stars obtained with the FCAPT, now at Washington Camp, AZ after being on Mt. Hopkins, AZ for six years (September 1990 – July 1996). For these stars Strömgren phtometry yields more astrophysical information than UBV photometry. In part this is due to the λ5200 broad, continuum feature's effect on y values. For each photometric group (Table 1) of variable, comparison, and check stars, the telescope measures the dark count and then the sky-*ch*-*c*-*v*-*c*-*v*-*c*-*v*-*c*-*ch*-sky

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⋆ Tables 2, 3, 4 and 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/Abstract.html in each filter where sky, *ch*, *c*, and *v* are respectively readings of the sky, the check star, the comparison star, and the variable star. The comparison and check stars were selected from supposedly non-variable stars near the variable on the sky that had similar V magnitudes and $B-V$ colors using the Bright Star Catalogue (Hoffleit 1982) and the experience of other photometrists and checked later using photometry from the Hipparcos satellite (ESA 1997). Tables 2-5 contain the data and their yearly means and standard deviations. Corrections were not made for neutral density filter differences among the stars of each group. The standard deviations in Tables 2-5 of the check-comparison star differences indicate that these stars are constant for the period when they were observed.

We plot the *v-c* data for each variable star with the best published period to see if our data approximately confirm this period. Then we use the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986) and/or the clean algorithm (Roberts et al. 1987) with our data. Finally we adjust the period to make our data and any published data coincide as well as possible in phase. In Figs. 1-4 our values are indicated by plus signs, those of Winzer (1974) converted to our zero points as closed circles except for 49 Her where they are closed diamonds, and those of Burke & Barr (1981) by closed diamonds for HR 6718.

2. 45 Leo

Provin (1953) found the sharp-lined star (v sin i = 10 km s^{-1}, Abt & Morrell 1995) 45 Leo (= HR 4101 = HD 90569 = CX Leo) to be photometrically constant, while Burke et al. (1970) thought it was probably variable. Winzer (1974) discovered it was a low amplitude photometric variable with a period of 1.4450 days, a result confirmed by Wolff & Morrison (1975), but not Bonsack (1976). We are looking at a polar region. Leroy (1995) finds its polarization of 0.12% is due in part to interstellar polarization. It is not a star he expects to be usefully studied via broadband polarimetry.

We obtained 60 and 49 differential *uvby* observations of 45 Leo during the 1995-96 and 1996-97 observing seasons, respectively. As 45 Leo is not particularly variable longward of the Balmer jump, we studied the u values and found that the most likely period was 1.4438 days. To bring the U values of Winzer (1974) appropriately rezeroed into best agreement with our data resulted in a slight increase in the period. We also had to adjust the zero point of Winzer's ephemeris. Thus

$$\mathrm{HJD}(u_{\max}) = 2441460.954 \pm 0.002 + (1.443820 \pm 0.000005)\ E.$$

If Wolff & Morrison (1975) had published their data in tabular form, we might have been able to reduce our errors. The amplitudes of variability are 0.042 mag for u, 0.010 mag for b, and 0.005 mag for v and y (Fig. 1). Both u and b vary in phase in a single wave. The marginal variability of v and y are probably also in phase.

3. HR 4330

Winzer (1974) found that HR 4330 (= HD 96707 = EP UMa) (v sin i = 33 km s^{-1}, Abt & Morrell 1995) was a small amplitude light variable with a possible period of 0.8183 days. Its largest amplitude was in V. Burke & Barr (1981) also observed this star, but one of their comparison stars was unfortunately variable. Matthews & Wehlau (1985) did not find HR 4330 to be a rapid variable. According to Leroy (1995), it should show significant polarization, but does not. We obtained 101 sets of differential *uvby* observations of which 35 were from 1995-96, 37 from 1996-97, and 29 from 1997-98. Our periodograms indicated that the most likely period was near 3.516 days. We kept the zero point of Winzer's ephemeris and used

$$\mathrm{HJD}(V_{\max}) = 2441447.19 + (3.5160 \pm 0.0001)\ E.$$

The scatter seen in these light curves (Fig. 2) is greater than that for other mCP stars since these check and comparison stars are not as constant as those used with most mCP stars (Adelman et al. 1998). Hence HR 4330 should be reobserved with less variable check and comparison stars. Light maximum apparently comes near phase 0.9 rather than 0.0 as intended, but the shape of the maximum needs to be better defined. The amplitudes of HR 4330 are 0.02 mag in b and 0.025 mag in y with those for u and v probably smaller. The b and y curves are in phase. The v values show scatter while those for u suggest incipient structure.

4. 49 Her

Winzer (1974) discovered that 49 Her (HR 6268 = HD 152308 = V823 Her) was a moderate amplitude photometric variable. He derived a period of 1.0978 days, but noted that the resonance period near 0.918 days was a possible alternative. Good quality differential *uvby* photometry was obtained with the FCAPT: 56 sets in 1996-97 and 19 sets in 1997-98. A periodogram analysis indicates that the period is close to 0.9366 days. For the best overlap with Winzer's V data rezeroed to the FCAPT y system, the period was lengthened to 0.93663 days. A slight adjustment in the zero epoch was also required. Thus

$$\mathrm{HJD(light\ maximum)} = 2441453.925 \pm 0.003 + (0.93663 \pm 0.00002)\ E.$$

The light curves (Fig. 3) show nearly flat bottomed minima and sharp well defined maxima. The curves for u, v, b, and y are in phase. The minima appear to have two sub-minima with the one near phase 0.37 deeper than the one near phase 0.67. They are of order 0.005 mag fainter than the trend of adjacent values. The amplitudes are 0.055 mag in u, 0.028 mag in v, 0.035 mag in b,

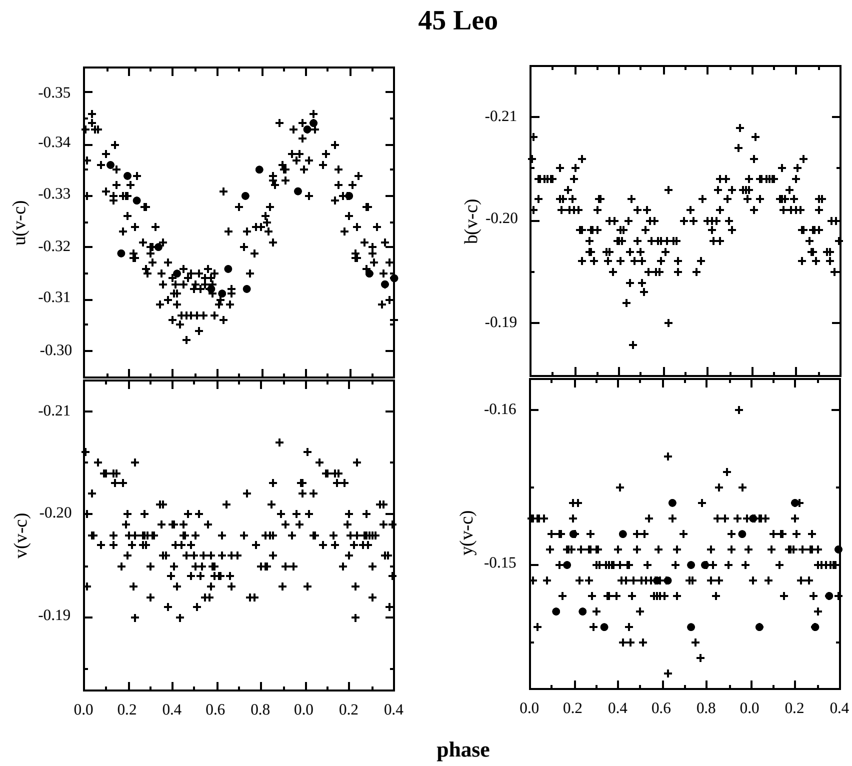

Fig. 1. Photometry of 45 Leo plotted with the ephemeris HJD($u_{\max}$) = 2441460.954 + 1.443820 E. The FCAPT *uvby* values are indicated by + signs while Winzer's U and V values as rezeroed to the u and y scales, respectively, are closed circles

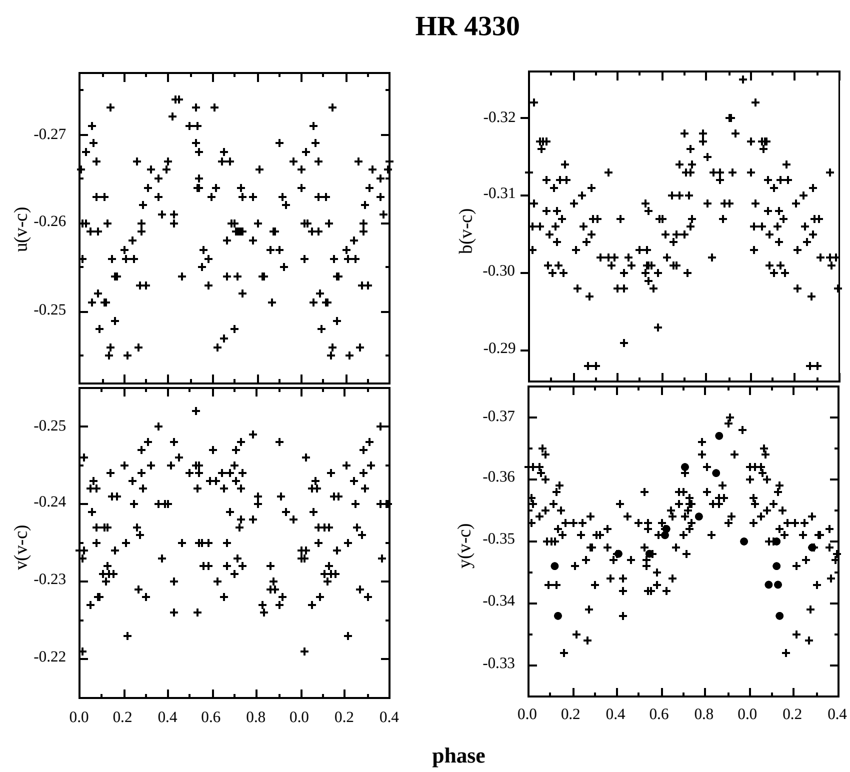

Fig. 2. Photometry of HR 4330 plotted using the ephemeris HJD($y_{\max}$) = 2441447.19 + 3.5160 E. The FCAPT *uvby* values are indicated by + signs while Winzer's V values as rezeroed to the y scale are closed circles

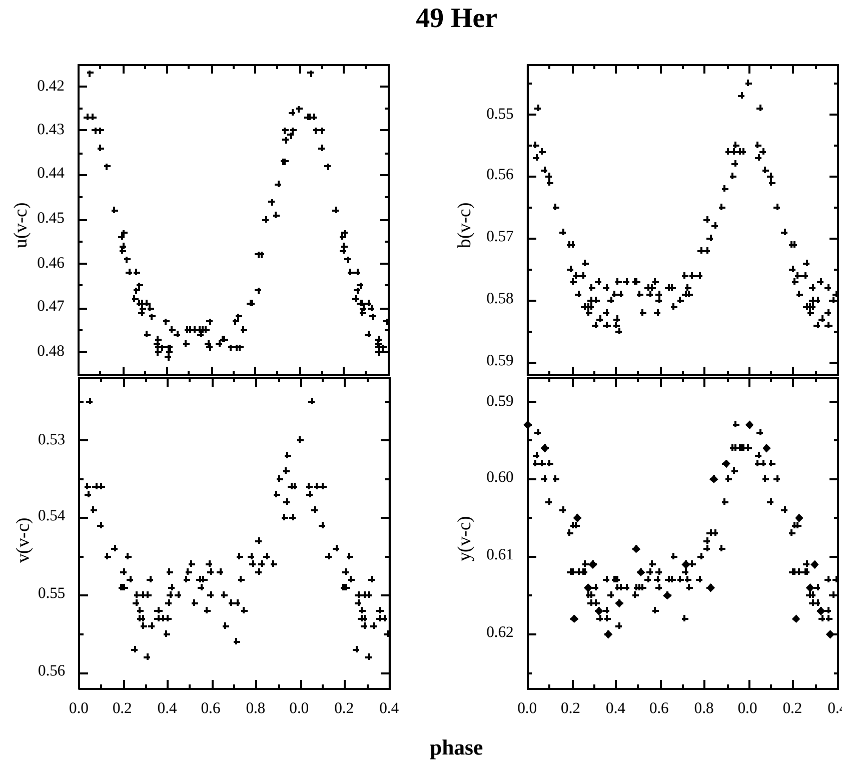

Fig. 3. Photometry of 49 Her plotted according to the ephemeris HJD(light maximum) = 2441453.925 + 0.93663 E. The FCAPT *uvby* values are shown as + signs while Winzer's V values as rezeroed to the y scale are closed diamonds

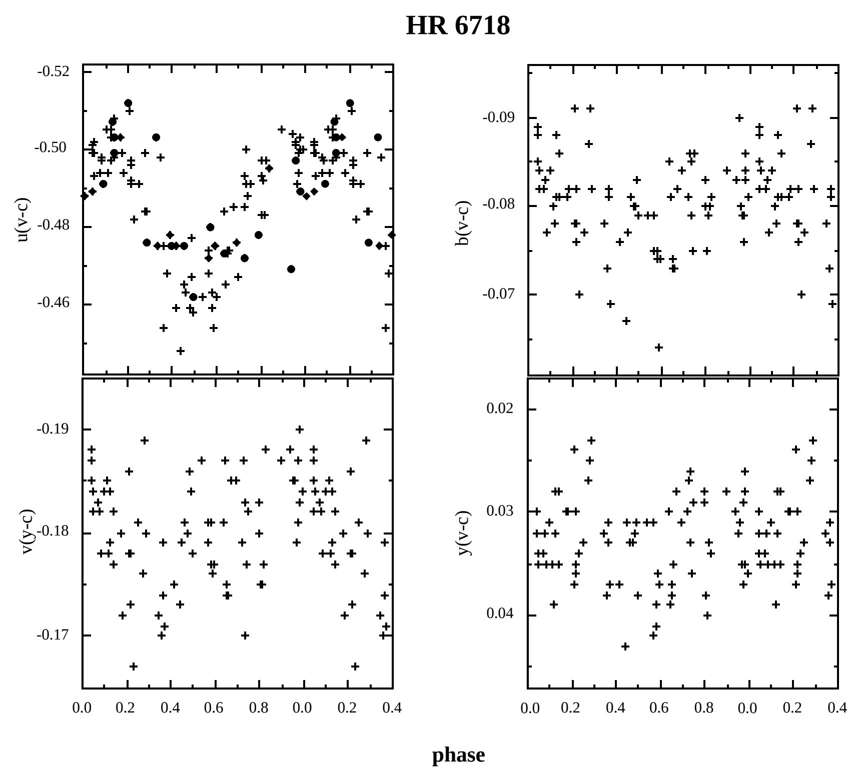

Fig. 4. Photometry of HR 6718 plotted using the ephemeris HJD(u_{max}) = 2441450.808 + 0.51899 E. The FCAPT *uvby* values are shown as + signs while Winzer's and Burke & Barr's U values as rezeroed to the u scale are closed diamonds and closed circles, respectively

and 0.023 mag in y. That the second sub-minimum becomes less easy to see with increasing wavelength indicates that the flux distributions at the two sub-minima are not identical.

Abt & Morrell (1995) find $v \sin i = 95$ km s^{-1}. With a period of order one day, we must be looking at 49 Her with the rotation pole pointing about 20° away from our line of sight. Thus we are seeing differences in the equatorial belt of ±20° latitude which are diminished by limb darkening. Light maximum may coincide with the transit of a magnetic pole across the observable stellar photosphere.

5. HR 6718

Winzer (1974) found that HR 6718 (= HD 164429 = V771 Her) was a relatively low amplitude photometric variable with its largest amplitude of 0.03 mag in U. The variation in B is less than 0.01 mag and is smaller than the V amplitude. His period of 0.51747 days was confirmed by Catalano et al. (1979). Burke & Barr (1981) obtained additional UBV photometry, found slightly larger amplitudes, and essentially the same period of variability. For such a short period variable, its $v \sin i$ value of 85 km s^{-1} (Abt & Morrell 1995) suggests it is seen very close to pole-on which in part explains its low degree of variability. Bohlender et al. (1993) made a measurement of its magnetic field: 640 ± 480 G.

Seventy-seven sets of *uvby* differential values were obtained with the FCAPT, 11 in 1995-96, 35 in 1996-97, and 31 in 1997-98. A periodogram analysis of the u data showed that the period was close to either a half-day or a day. When we used Winzer's (1974) and Burke & Barr's (1981) U data rezeroed to be as consistent as possible with our data we had increase the period slightly and make a slight adjustment to Winzer's zero epoch. Hence

$$\mathrm{HJD}(u_{\max}) = 2441450.808 \pm 0.005 + (0.51899 \pm 0.00004)\ E.$$

The *uvby* photometry plotted with this period (Fig. 4) shows that u is definitely variable with an amplitude of 0.045 mag. Further v, b, and y are probably variable with amplitudes of order 0.015 mag, 0.01 mag, and 0.01 mag, respectively. In addition these light curves are probably shifted in phase by 0.1 with respect to u which indicates a complicated surface distribution of abundances.

6. Final comments

This paper investigated the photometrically variability of four mCP stars studied by Winzer (1974). In most of the observed bandpasses, three of them are low amplitude variables and hence difficult objects to study. According to theory, the rotation of mCP stars is slowed by magnetic braking. Thus it is necessary to study mCP stars with the full range of observed amplitudes to determine the class period distribution. The moderate variable 49 Her is a candidate the further study even though we are observing it close to pole-on. Babcock (1958) notes it is a spectrum variable, but its lines are too broad for effective measurements of the Zeeman effect via photography.

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