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uvby Photometry of the Magnetic Chemically Peculiar Stars HR 1297, 36 Aurigae, and HR 2722 and the Nonmagnetic Chemically Peculiar Stars HR 1576 and α Cancri

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ABSTRACT. Differential Strömgren *uvby* photometric observations from the Four College Automated Photoelectric Telescope are presented for the magnetic CP stars HR 1297, 36 Aur, and HR 2722 and the nonmagnetic CP stars HR 1576 and α Cnc. Both the moderately rotating HR 1576, a mercury-manganese star, and α Cnc, a metallic-line star, are nonvariable. For HR 1297 we refined Winzer's period to 1.06457 days. Our period of 14.366 days for 36 Aur is an alias of Winzer's period and is in keeping with the sharp-lined nature of this star. We found a more accurate period of 2.31523 days for the low-amplitude variable HR 2722.

1. INTRODUCTION

The anomalous photospheric abundances of the chemically peculiar (CP) stars except for the λ Boo stars are thought to be produced by hydrodynamical processes including radiative diffusion in radiative atmospheres that are extremely quiescent (the nonmagnetic CP stars: the mercury-manganese and the metallic-line stars) and that have strong magnetic fields (the magnetic CP stars). The envelope and photospheric abundances in the magnetic stars should be patchy, while those of the nonmagnetic stars should be uniform. Hence, only the magnetic types should be photometric, light, and spectrum variables (see Michaud & Proffitt 1993 and references therein).

We present differential Strömgren photometry of two nonmagnetic and three magnetic chemically peculiar (mCP) stars obtained with the 0.75 m Four College Automated Photoelectric Telescope (FCAPT) which was on Mount Hopkins, Arizona, for 6 yr (1990 September–1996 July) and on nearby Washington Camp, Arizona, for the last two observing seasons (1996 October–1998 July). For each photometric group (Table 1) (the variable and two constant stars, the comparison and check, against which the brightness of the variable is compared) the telescope measures the dark count and then the sky-ch-c-v-c-v-c-v-c-ch-sky in each filter, where sky is a reading of the sky, ch that of the check star, c that of the comparison star, and v that of the variable star. The comparison and check stars were chosen from supposedly nonvariable stars near the variable on the sky that had similar V magnitudes and $B - V$ colors using the Bright Star Catalogue (Hoffleit 1982) and other catalogs. For α Cnc we include our original comparison star oc, which was later replaced. Table2[1] presents 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 Table 2of 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 confirmed this period. Then we used the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986) with our data and those of other observers separately in calculating periodograms. If the periodograms confirm the published period, then we adjust the period to make all data coincide as well as possible in phase.

2. THE NONMAGNETIC CP STARS HR 1576 AND α CNC

The literature contains claims of low-amplitude variability for some nonmagnetic CP stars. If the possible intrinsic variability of such stars (which are not also δ Scuti stars) were demonstrated, it would require a new theoretical understanding of these stars. Adelman (1997a and references therein) found that several sharp-lined HgMn and Am stars for which there are such claims are in fact constant. As these stars might be rotating with their poles nearly toward the Earth, two faster rotating nonmagnetic CP stars were observed whose visible hemispheres would likely show larger fractions of their photospheres. HR 1576 (=HD 31373) was classified as B9 V by

[1] A sample of Table 2A illustrates the data in Table 2, which are contained in the electronic version of this paper.

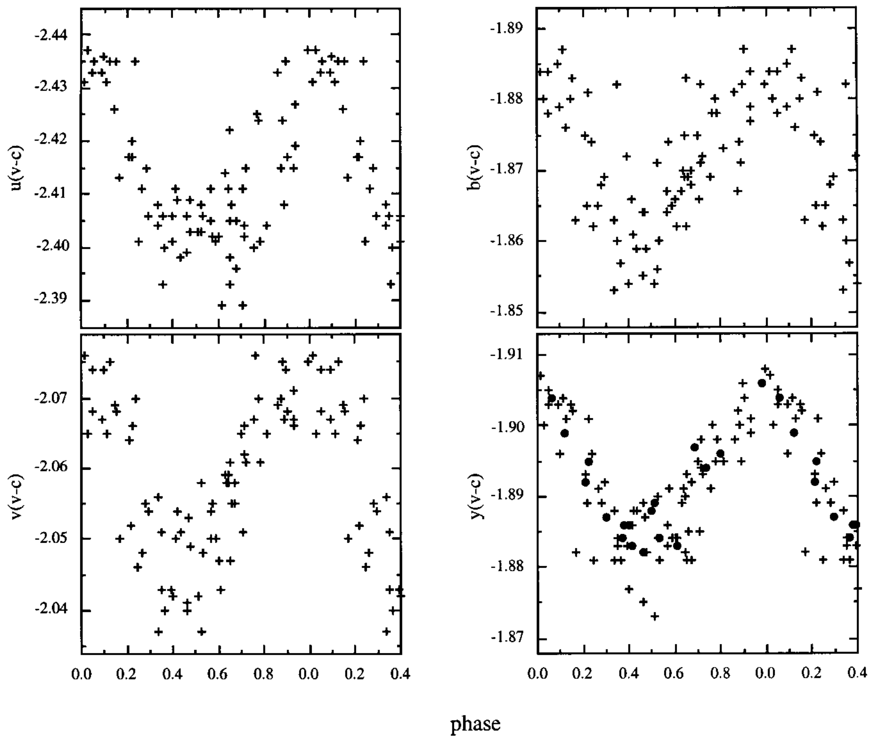

FIG. 1.—*uvby* photometry of HR 1297 according to the ephemeris HJD(y_{max}) = 2,441,246.876 + 1.06457E. FCAPT observations are shown as plus signs, and Winzer's V magnitudes rezeroed as closed circles.

TABLE 1
PHOTOMETRIC GROUPS

HD Number	Star Name	Type	V	Spectral Type
26571	HR 1297	v	6.16	B9 IIIp:Si:
27176	51 Tau	c	5.65	F0 V
24740	32 Tau	ch	5.63	F2 IV
31373	HR 1576	v	5.81	B9 V
33276	15 Ori	c	4.82	F2 IV
31764	HR 1600	ch	6.09	B7 V
40394	36 Aur	v	5.73	B9.5pSiFe
40626	HR 2112	c	6.05	B9.5 IV
43244	42 Aur	ch	6.52	B9 II–III
55579	HR 2722	v	6.89	A1pSrCr
57744	58 Gem	c	6.02	A1 V
55052	48 Gem	ch	5.85	F5 III–IV
76756	HR 3572	v	4.25	A5m
76543	HR 3561	c	5.20	A5 III
80064	HR 3689	ch	6.41	A2 IV
74873	50 Cnc	oc	5.87	A1 V

NOTE.—α Cnc is HR 3572.

Cowley (1972) and as an HgMn star with $v \sin i$ = 90 km s^{-1} by Wolff & Preston (1978). α Cnc (=HR 3572 = HD 76756) is an Am (A5/A9/F0) star with $v \sin i$ = 65 km s^{-1} (Abt & Morrell 1995).

Table 2A shows that for HR 1576 (51 *uvby* values) the standard deviations of the mean v − c and c − ch values are about 0.004 and 0.005 mag, respectively. For α Cnc (60 total *uvby* values) with the second comparison star, these values are about 0.003 and 0.005 mag, respectively. Since the errors for the individual stars add in quadrature, the standard deviations of the typical mean magnitude for the v, c, and ch stars must be about 0.003 mag, which reflects the scatter expected due to photon statistics.

3. THREE MAGNETIC CP STARS

3.1. HR 1297

Gulliver (1971) (see also Gulliver & MacRae 1975) first identified HR 1297 (=HD 26571) as an mCP star, classifying it as B8p[Si] and also found it was a marked spectrum variable. Winzer (1974) noted that it was the reddest bright silicon star known to him with $B - V = +0.18$ and found a period of 1.0646 days.

The y periodogram based on 79 *uvby* observations from the 1995–1996, 1996–1997, and 1997–1998 observing seasons

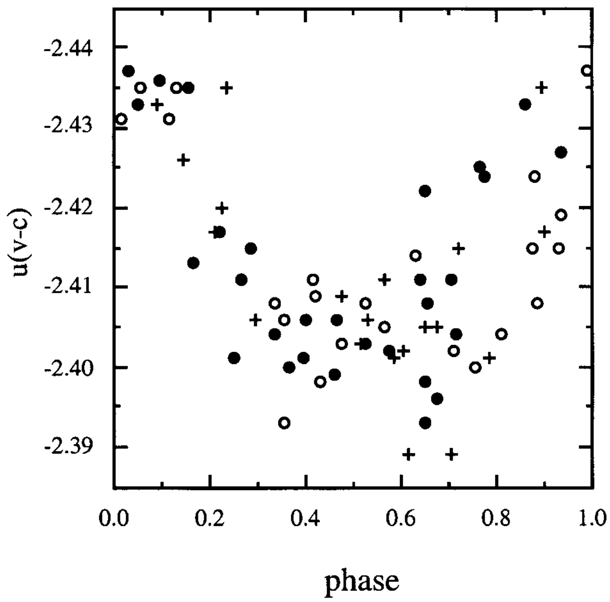

FIG. 2.—u photometry of HR 1297 with the same ephemeris as Fig. 1, but showing the values separately for each of three seasons of observations (1995–1996, *filled circles*; 1996–1997, *plus signs*; 1997–1998, *open circles*).

(Table 2C) shows maxima at frequencies of 0.939350 and 0.06056 cycles s^{-1}. The higher frequency results in a smoother light curve and corresponds to a period of 1.06459 days. Using the V values of Winzer (1974) rezeroed to our y mean, we found best agreement for

$$\mathrm{HJD}(y_{\max}) = 2{,}441{,}246.876 \pm 0.005 + 1.06457 \pm 0.00003E.$$

The amplitudes of variation are 0.035 mag in u, 0.03 mag in v, 0.035 mag in b, and 0.025 mag in y (Fig. 1). The light curves show asymmetries. The y minimum near phase 0.4 is defined by values close to it. The v and b light curves are similar. But the u light curve has a broader minimum centered close to phase 0.5 and is more symmetric. These differences suggest a complicated surface abundance geometry. Compared with other mCP stars of similar brightness studied with FCAPT *uvby* photometry, the scatter at many phases is greater. Figure 2 shows the u values with those for each year indicated by different symbols. There are apparent differences between each year. The v, b, and y light curves show similar effects.

3.2. 36 Aur

Cowley et al. (1968) classified 36 Aur (=HR 2101 = HD 40394) as a B9.5p Si, Fe star. Optical spectrophotometry (Adelman & Pyper 1983) indicates only mild peculiarities with weak λ4200 and λ5200 broad, continuum features. According to Abt & Morrell (1995) its rotational velocity is 10 km s^{-1} and its spectral type A1 Vp (Si st, CaMg wk). Winzer (1974) found that 36 Aur was variable with a relatively large amplitude variation of 0.05 mag in U and a period that is most likely 1.0853 days. However, he was not able to eliminate the resonance period near 0.927 days.

Table 2Dcontains the 83 *uvby* observations of 36 Aur made during the 1995–1996, 1996–1997, and 1997–1998 observing seasons. Our periodograms showed two possible periods, near 1.0717 days and 14.374 days. The sharp-lined nature of the star and the relative scatter of the light curves lead to the later value as the more probable. When we rezeroed the V values of Winzer (1974) values so that they were comparable with our y values, we found a period of 14.366 days. As the light minimum was sharper and better defined than the maximum, we used it to set the zero point of our ephemeris, which we selected to be within Winzer's observations; thus

$$\mathrm{HJD}(y_{\max}) = 2{,}441{,}252.18 \pm 0.02 + 14.366 \pm 0.002E.$$

TABLE 2
A. PHOTOMETRY OF HR 1576

Heliocentric Julian Date	u(v − c)	u(ch − c)	v(v − c)	v(ch − c)	b(v − c)	b(ch − c)	y(v − c)	y(ch − c)
2,450,396.7795	−0.223	−0.509	0.463	−0.942	0.789	−1.186	0.994	−1.291
2,450,397.8330	−0.221	−0.510	0.465	−0.948	0.786	−1.180	0.997	−1.284
2,450,400.7723	−0.229	−0.517	0.463	−0.969	0.772	−1.198	0.988	−1.289
2,450,434.8729	−0.219	−0.503	0.469	−0.946	0.783	−1.174	0.986	−1.276
2,450,437.8506	−0.225	−0.505	0.465	−0.941	0.783	−1.185	0.996	−1.284
2,450,439.8101	−0.224	−0.505	0.467	−0.941	0.786	−1.181	0.995	−1.280
2,450,441.8426	−0.209	−0.503	0.478	−0.947	0.792	−1.171	1.004	−1.276
2,450,443.8303	−0.221	−0.509	0.471	−0.943	0.783	−1.184	0.993	−1.278
2,450,450.8333	−0.219	−0.511	0.474	−0.950	0.783	−1.179	0.997	−1.284
2,450,457.8130	−0.219	−0.509	0.469	−0.951	0.782	−1.177	0.992	−1.284
2,450,458.8135	−0.220	−0.516	0.474	−0.944	0.788	−1.185	0.992	−1.278
2,450,396.7795	−0.223	−0.509	0.463	−0.942	0.789	−1.186	0.994	−1.291
2,450,397.8330	−0.221	−0.510	0.465	−0.948	0.786	−1.180	0.997	−1.284

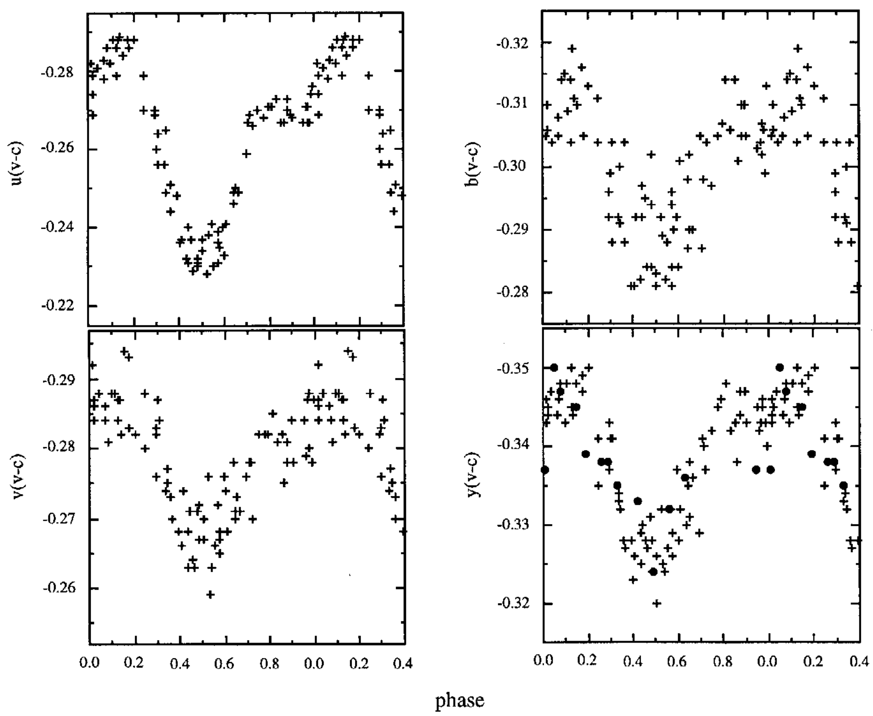

FIG. 3.—*uvby* photometry of 36 Aur plotted with the ephemeris HJD (y_{max}) = 2,441,252.18 + 14.366*E*. FCAPT observations are indicated by plus signs, and Winzer's *V* magnitudes rezeroed as closed circles.

The light curves (Fig. 3) in all four magnitudes are in phase. The amplitudes are 0.05 mag in *u*, 0.035 mag in *v*, and 0.03 mag in *b* and *y*. The *u* light curve shows a secondary minimum near phase 0.95, which is also suggested by the *v* and *b* light curves and in maximum light occurring near phase 0.15. These curves indicate possible complex surface elemental abundance distributions.

3.3. HR 2722

Winzer (1974) discovered that HR 2722 (=HD 55579) was a low-amplitude variable in *V* and *B* and a moderate-amplitude variable star in *U* using 58 Gem as the companion star. His best estimate for the period was 2.2297 days. The light curves show a relatively sharp maximum and broad minimum.

We analyzed 147 *uvby* observations (Table 2E) obtained during the 1995–1996, 1996–1997, and 1997–1998 observing seasons. A periodogram analysis of the *u* photometry suggested a period of 2.315 days. The alias near 1.76 days yields a much poorer light curve. To improve the period, we rezeroed the *V* magnitudes of Winzer and compared them with our *y* values. We derived the followed ephemeris:

$$\text{HJD(maximum light)}$$
$$= 2{,}441{,}239.73 \pm 0.02 + (2.31523 \pm 0.00002)E.$$

Figure 4 shows the *uvby* light curves, which are all approximately in phase. The amplitudes are 0.04 mag for *u*, 0.015 mag for *v*, and 0.02 mag for *b* and *v*. The minima are broader than the maxima, which show suggestions of structure. There is an offset in the *b*(c − ch) values between those taken during the 1997–1998 observing season and those for the previous two seasons that does not affect the *b*(v − c) values and thus not the analysis of HR 2722.

4. DISCUSSION

Before these observations were completed, photometry from the *Hipparcos* satellite became available. Adelman (1998) finds that after the known variables are excluded, almost all of the observed HgMn and Am stars are constant. Several HgMn and Am stars, whose variability need to be checked, are likely to be eclipsing binaries rather than intrinsic variables. The data for HR 1576 and α Cnc are important as the FCAPT and the *Hipparcos* satellite obtained photometry with different time samplings and their data sets are in some sense complementary. That both show that these two stars are nonvariable provides independent confirmation and indicates constancy for timescales of several hours to several years. The second comparison star for α Cnc is more constant than the first in accord with *Hipparcos* photometry.

FCAPT studies of the mCP stars have both improved periods

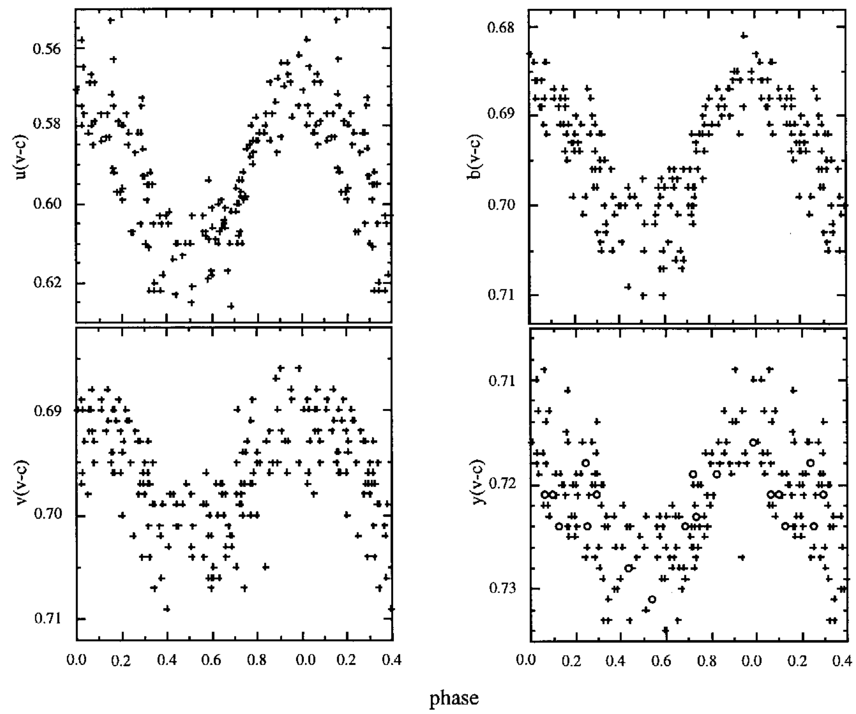

FIG. 4.—*uvby* photometry of HR 2722 using the ephemeris HJD (maximum light) = 2,441,239.73 + 2.31523*E*. FCAPT observations are indicated by plus signs, and Winzer's *V* magnitudes rezeroed as open circles.

and better defined the shapes of their light curves (see, e.g., Adelman 1997b). From such studies one can relate observations taken at different times, check whether such stars have variable light curves, gain some information on the uniformity of the surface abundances, and study the distribution of periods. These aspects provide important information on the evolution of such stars.

The apparent differences between the light curves of HR 1297 using observations made in different observing seasons is suggestive of precession of the axis of rotation with a constant period of rotation (Shore & Adelman 1976). Alternatively, the scatter might be the result of rapid variability sampled once a night. To check such behavior, it is best to obtain the light curves in a few nights of observing with continuous observations at least once per observing season for several years as one can then minimize the effects of minor extinction changes.

For some mCP stars we have good knowledge of their periods. But often their published periods are not well established as for 36 Aur. If there is a good initial set with at least of order 25 observations, then with FCAPT observations one can check the period and improve its known value as this paper did for HR 1297 and HR 2722. As mCP stars are supposed to undergo magnetic braking during their lifetimes, their period distribution measures this process. Unfortunately, temperatures and surface gravities determinations of such stars are still a challenge (Adelman et al. 1995), but once this problem is resolved, we should gain an improved understanding of their evolution with *Hipparcos* parallaxes.

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