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uvby FCAPT photometry of the metallic-lined stars 60 Tau and HR 1528 and the magnetic CP stars HR 8216 and HR 8770*

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Abstract. Differential Strömgren *uvby* observations from the Four College Automated Photoelectric Telescope (FCAPT) are presented for the metallic-lined stars 60 Tau and HR 1528 and the magnetic Chemically Peculiar stars HR 8216 and HR 8770. The first star, which is a δ Scuti variable, was found not to change its mean magnitudes. HR 1528 is best described as constant. A decade of photometry of HR 8216 shows that its b and y values have changed by -0.016 and -0.010 mag, respectively, over this time and now can be considered a photometric variable. For HR 8770 a period of 5.3923 days is derived with the photometric variability being generally in phase. The light curves also suggest possible surface abundance inhomogeneities.

Key words. stars: chemically peculiar – stars: individual: 60 Tau – stars: individual: HR 1528 – stars: individual: HR 8216 – stars: individual: HR 8770

1. Introduction

Single-channel differential Strömgren *uvby* photometry from the Four College Automated Photoelectric Telescope (FCAPT) at Washington Camp, AZ, obtained in recent years is presented for the metallic-line (Am) spectroscopic binaries 60 Tau and HR 1528 and the magnetic Chemically Peculiar (mCP) stars HR 8216 and HR 8770. These investigations are part of a series of continuing studies of the stability of single non-magnetic CP stars and of the photometric variability of magnetic CP stars to determine both their rotational periods and the shapes of their light curves. This 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. Photometric information on the variables of this paper is summarized in Table 1 (Hoffleit 1982; Hoffleit et al. 1993). No corrections were made for any neutral density filter differences among the stars of each group. The comparison and check stars were chosen from presumably non-variable stars near the variables on the sky that had similar V magnitudes and $B-V$ colors. Adelman et al. (1998) checked their stability using Hipparcos photometry (ESA 1997). The Scargle periodogram (Scargle 1982; Horne & Baliunas 1986) and the clean algorithm (Roberts et al. 1987) were used to help find the period of HR 8770.

* Tables 2, 3, 4 and 6 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/401/357`

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2. The metallic-lined stars 60 Tau and HR 1528

For the mercury-manganese (HgMn) and metallic-lined (Am) stars, which constitute the non-magnetic CP stars, a question of particular importance is whether there exist any class members, which are not located in the variability strip, that are not intrinsically constant. On the basis of their Hipparcos photometry Adelman (1998) noted that four Am stars are possible variables including 60 Tau (HD 27628, HR 1368, HIP 20400) and HR 1528 (HD 30453, HIP 22407). Abt & Morrell (1995) classified them as Am (A6/F0/F2) and Am (A7/F0/F2), respectively, and noted that $v \sin i$ for both is 14 km s^{-1}. As Celestia 2000 (ESA 1998) did not note the kind of variability for 60 Tau, the author mistakenly assumed that it was unknown or the star was really constant.

Kurtz (1978) confirmed that 60 Tau was a spectroscopic binary Am star (Cowley et al. 1969) of the classical Am variety. Horan (1979) discovered its δ Scuti nature. In three observing seasons, 1998–99, 1999–2000, and 2000–2001, 4, 29, and 52 sets of *uvby* measurements were made with the FCAPT. The mean and values standard deviations in Table 2 are not particularly suggestive of variability. However, Li (2000) found that this δ Scuti variable in 5 nights of observations covering 30 hours had two frequencies of 13.0364 and 11.8521 d^{-1}, and amplitudes of 6.01 and 3.95 mmag in v and of 3.35 and 1.99 mmag in y, respectively. He claims a measuring error of 4.0 mmag. As our data was obtained in a one observation per photometric night mode, its δ Scuti nature is not particularly evident. The mean *uvby* magnitudes of 60 Tau appear to remain constant, but within the data set are some values which are suggestive of variability.

Table 1. Photometric groups.

HD number	Star name	Type	V	Spectral type
27628	60 Tau	v	5.72	A3m
27397	57 Tau	c	5.59	F0 IV
28867	HR 1442	ch	6.25	B9 IVn
30453	HR 1528	v	5.86	A8m
28459	HR 1419	c	6.21	B9.5 Vn
32608	HR 1639	ch	6.49	A5 V
204411	HR 8216	v	5.13	A6pCrEu:
205314	HR 8246	c	5.75	A0 V
203746	BD +48° 3360	ch	6.84	A1 V
217833	HR 8770	v	6.50	B9 IIIHewk
217348	HR 8745	c	6.43	B9 III
218753	2 Cas	ch	5.70	A5 III

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

Harper (1932) discovered HR 1528 was a spectroscopic binary. Stockton & Fekel (1992) found lines of the secondary in the red. Both components appear to be synchronously rotating. Its photometry in Table 3 indicates that it is a constant star.

Of the two other potentially variable Am stars listed by Adelman (1998), HR 5341 was found to be constant by Adelman (2001) and HR 9044 is too far South to be properly observed by the FCAPT. As no Am stars which are located outside the variability strip are known to be intrinsic photometric variables, the constancy of such Am stars is now well established.

3. The magnetic CP stars HR 8216 and HR 8770

The mCP stars are photometric, spectrum, and magnetic variables with their emergent energy distributions, photospheric abundances, and magnetic field strengths dependent upon photospheric location. As their magnetic and rotational axes are not usually aligned, a distant observer sees a variety of variability as they rotate. Their anomalous photospheric abundances, which are thought to be produced by hydrodynamical processes especially radiative diffusion and gravitational settling in radiative envelopes containing strong magnetic fields, are functions of the local magnetic field strength and the time since the star was on the Zero Age Main Sequence (Michaud & Proffitt 1993 and references therein). Differential photometric studies with the FCAPT have improved their periods and light curves (see, e.g., Adelman et al. 1999) so that they can be used to better relate observations taken at different times, detect variable light curves, and study the period distribution of the mCP stars. Using spectra, surface maps of abundances for some stars which exhibit moderate rotation can be derived to serve as tests of mCP star theories.

3.1. HR 8216

Due to discrepancies in various published descriptions of its spectra and its *UBV* colors Preston (1970) suggested that the cool mCP star HR 8216 (HD 204411) might be a very long period photometric and/or spectroscopic variable. Caliskan's (1995) comparison of overlapping regions of spectra taken at the Dominion Astrophysical Observatory at a reciprocal dispersion of 2.4 Å mm^{-1}, resolution = 0.072 Å, and S/N = 200+ between 1988 and 1993 provide strong evidence for constancy within this period. Adelman et al. (1994) presented 67 *uvby* FCAPT observations taken over four observing seasons which also strongly indicated constancy. Later Adelman & Rice (1999) published data for four additional observing seasons. At least 24 values were obtained during four of these eight seasons. At best one could suggest possible small long term variability due to minor discrepancies between the mean averages. In this paper 35, 52, and 29 sets of *uvby* FCAPT photometry of HR 8216 obtained during the 1998–99, 1999–2000, and 2000–01 observing seasons, respectively, (Table 4) are summarized in Table 5. Between the 1997–98 and 1998–99 data, a neutral density filter was changed for the ch star so that it became approximately 2.5 mag brighter and slightly decreased the standard deviations in the ch-c values.

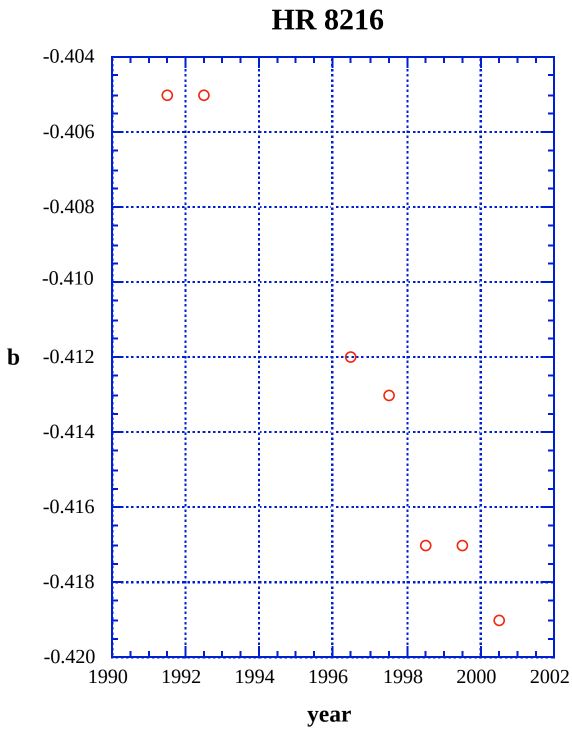

Fig. 1. The mean b magnitudes of the mCP star HR 8216 as a function of year of observation.

When the mean v-c magnitudes for u, v, b (see Fig. 1), and y are plotted against the midpoint of the observing season and linear fits are made, the slopes are 0.00057, −0.00035, −0.00164, and −0.00098 mag y^{-1}, respectively, with the relations for b and y being the most convincing. Thus in 10 years, the changes in u and v are about the same order as the yearly standard deviations while those for b and y of −0.016 and −0.010 mag, respectively, are larger and significant. The complete dataset implies that the variability period is probably at least 20 years with a longer period being more likely. If similar observations are subsequently obtained every few years,

Table 5. Summary of latest photometry of HR 8216.

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
1998–99								
35 values								
average	0.033	−1.316	−0.300	−1.189	−0.417	−1.134	−0.472	−1.095
std. dev.	0.003	0.007	0.004	0.007	0.002	0.005	0.002	0.004
1999–2000								
52 values								
average	0.032	−1.314	−0.299	−1.188	−0.417	−1.134	−0.470	−1.095
std. dev.	0.003	0.007	0.003	0.005	0.002	0.005	0.008	0.007
2000–2001								
29 values								
average	0.030	−1.316	−0.300	−1.189	−0.419	−1.136	−0.473	−1.095
std. dev.	0.005	0.005	0.004	0.004	0.003	0.003	0.002	0.003

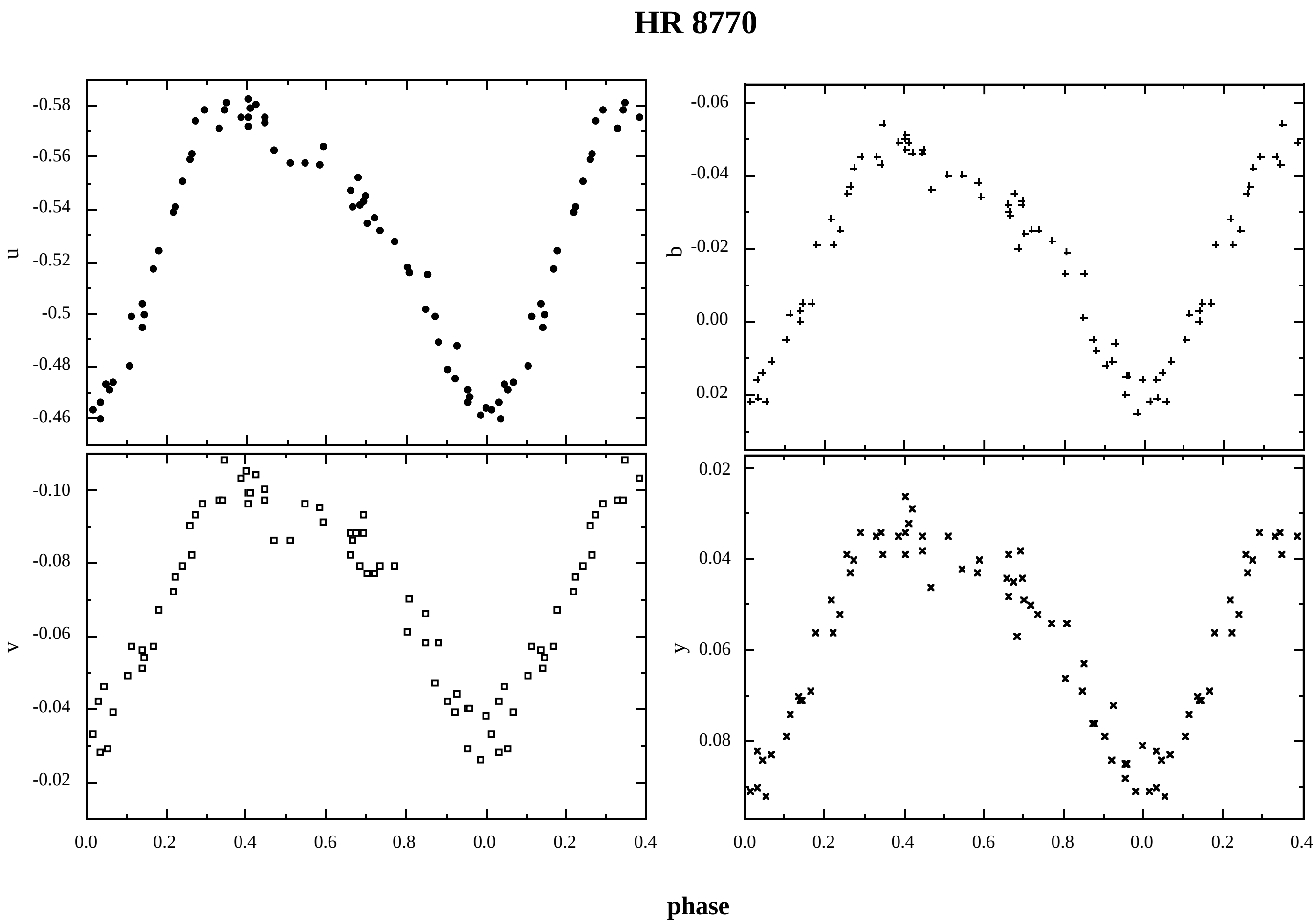

Fig. 2. Differential *uvby* photometry of the mCP star HR 8770 with the ephemeris HJD (light minimum) = 2451427.9203 + 5.3923 *E*.

eventually they should lead to the determination of its rotational period. The amplitudes in each color depend both on the surficial abundance inhomogeneities and the aspect at which HR 8216 is viewed. The existence of photometric changes also suggests those in the spectra. But their small sizes and the study by Caliskan (1995) indicates that those in the spectra are likely to be minimal except perhaps for lines of some trace element which is distributed over the surface in a manner quite different than most of the more common metals. This type of search requires obtaining spectra with high resolution and S/N ratios. As it is virtually non-rotating, any information about its spectral variability provides some evidence concerning the magnetic field of this star which is nearing the end of its main sequence lifetime.

3.2. HR 8770

HR 8770 (HD 217833, HIP 113797, V638 Cas) is classified as B9 III weak. Veto et al. (1980) detected photometric variability and found a period of 5.4 days. Celestia 2000 (ESA 1998) gives a period of 5.3933 days. Using 29 and 32 FCAPT *uvby* observations from the 1999–2000 and the 2000–2001 observing seasons, respectively, I found a period of 5.3923 days. The ch-c values indicate constancy, but the mean values from the two years are slightly offset. This could be real or due to some minor change in differential extinction which is not evident in other data sets between the two observing seasons. It is important to obtain additional photometric observations to determine the most probable cause of the discrepancies in the v-c values. In Table 6 the photometric values have not been adjusted for this effect. However, in displaying the light curves the 2000–2001 values were adjusted by 0.005 mag for *uby* and 0.010 mag for y.

From this data the derived ephemeris was

$$\text{HJD (light minimum)} = 2451427.9203 \pm 0.0010 + 5.3923 \pm 0.0005\,E.$$

Figure 2 shows the light curves with amplitudes of 0.12 mag in u, 0.07 mag in v and b, and 0.055 mag in y. They appear to be in phase with some light curves suggesting a secondary minimum near phase 0.50. These minor differences indicate possible complexities in the distribution of elemental abundances in the stellar photosphere. The zero point of the ephemeris was determined from the nearly symmetric light minimum.

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