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uvby photometry of the magnetic CP stars HD 36668, 36 Lyncis, HD 86592, and HR 8861⋆

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Abstract. Differential Strömgren *uvby* photometric observations from the Four College Automated Photoelectric Telescope (FCAPT) are presented for the magnetic CP stars HD 36668, 36 Lyn, HD 86592, and HR 8861. Using the FCAPT values, North's period for HD 36668 is refined to 2.11884 days. The 3.834 day period of Shore et al. for 36 Lyn, which was found from magnetic field measurements, is confirmed by photometry. The FCAPT observations also support the 2.8867 day period of Babel & North for HD 86592, demonstrate that this star is a large amplitude variable in *v* (0.13 mag.), and show that *y* varies crudely out of phase from *u*, *v*, and *b* which are in phase with one another. The variability of HR 8861 appears to be correlated with the meridional passages of regions of Si over- and underabundance as found by Piskunov et al.

Key words: stars: individual: HD 36668 – stars: individual: 36 Lyn – stars: individual: HD 86592 – stars: individual: HR 8861 – stars: chemically peculiar

Table 1. Photometric groups

HD Number	Star Name	Type	V	Spectral Type
36668	BD +00° 1113	v	8.05	B6Vwp
33647	HR 1690	c	6.67	B9Vn
35640	HR 1896	ch	6.23	B9.5Vn
79158	36 Lyn	v	5.32	B8IIIp
79763	HR 4676	c	5.97	A1V
77327	κ UMa	ch	3.60	A1Vn
86592	BD -12° 3045	v	7.7	Ap
88182	HR 3988	c	6.24	A5m
83754	κ Hya	ch	5.06	B5V
219749	HR 8861	v	6.48	B9pSi
219891	HR 8870	c	6.50	A5Vn
220105	HR 8884	ch	6.13	A5Vn

1. Introduction

Single-channel differential Strömgren *uvby* observations of the magnetic Chemically Peculiar (mCP) stars HD 36668, 36 Lyn, HD 86592, and HR 8861 obtained with the Four College Automated Photoelectric Telescope (FCAPT) are investigated. As these stars are photometric, spectrum, and magnetic variables, their emergent energy distributions, photospheric abundances, and magnetic field strengths depend upon photospheric location. Since their magnetic and rotational axes are not usually aligned, as the stars rotate a distant observer will see variability. Hydrodynamical processes including radiative diffusion and gravitational settling in radiative envelopes which have strong magnetic fields are thought to produce their anomalous photospheric abundances which depend on the local magnetic field strength and the time since the star was on the ZAMS (Michaud & Proffitt 1993 and references therein). FCAPT studies have both improved periods and better defined the shapes of their light curves (see, e.g. Adelman et al. 1999). Using these results astronomers can better relate observations taken at different times, detect variable light curves, and study the period distribution of mCP stars. Using spectra in addition, maps of abundances over the surface can be derived. These results serve as tests for theories of the production of their anomalous abundances.

The FCAPT has operated at Washington Camp, AZ since September 1996. Before that it was on Mt. Hopkins, AZ. For each group of variable, check, and comparison stars, the telescope first measures the dark count. Then in each filter it observes the sky-ch-c-v-c-v-c-v-c-ch-sky 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. Table 1 contains group information (Hoffleit 1982, Hoffleit et al. 1983, SIMBAD database). Corrections were not made for neutral density filter differences among the stars of each group. The comparison and check stars were chosen from supposedly non-variable stars near the variable on the sky that had similar V magnitudes and B-V colors. Adelman et al. (1998) checked their stability using Hipparcos photometry (ESA 1997). To help find periods the Scargle periodogram (Scargle 1982, Horne & Baliunas 1986) and the clean algorithm (Roberts et al. 1987) were used.

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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

2. HD 36668

Borra (1981) obtained six magnetic measurements of HD 36668, a member of the Ori OB 1 association, and proposed three possible periods. North (1984) used 19 sets of Geneva photometry to find a period of 2.11211 days, which is close to one of Borra's values. The light curves show primary and secondary maxima which suggest that we are observing most of the stellar surface including both poles.

Fifteen, 46, and 54 sets of differential Strömgren photometry were obtained with the FCAPT during the 1995-96, 1996-97, and 1997-98 observing seasons, respectively (Table 2). Period analyses of the *u* values suggest a period one-half of that of North. But this was due to the presence of two maxima. Comparison with the B data of North showed a slight shift in phase and the need for a minor adjustment in the zero point of the ephemeris. The following ephemeris fits both sets of data

HJD(u_{max}) = 2444988.375$\pm$0.003 + (2.11884$\pm$0.00004)E.

Fig. 1 shows the FCAPT values plotted with this period. The amplitudes for *u*, *v*, *b*, and *y* are 0.05, 0.035, 0.03, and 0.025 mag., respectively. The zero phase was set by bisecting the *u* primary maximum, which is also seen in the *v*, *b*, and *y* light curves. The secondary maximum is near phase 0.40 which may indicate an off-set dipole magnetic field. For *v* and *b*, the secondary maximum is suggestive and is not seen in *y*. These light curves and those of North show clear wavelength dependences. They may be indicative of a complex magnetic field and distribution of elements in the photosphere.

3. 36 Lyn

Shore et al. (1990) discovered magnetically controlled circumstellar matter around the helium-weak star 36 Lyncis (= HD 79158 = HR 3652), for which no previous period was available. Magnetic field measurements indicated a period of 3.834 days. Their ephemeris is

JD (phase = 0.0) = 2443000.0 + 3.834 E

for which positive crossover is at phase 0.50 $\pm$ 0.03. The C IV line in the ultraviolet is strongest at magnetic null values.

Twenty-three and 38 sets of good Strömgren differential observations were made with the FCAPT during the 1997-98 and 1998-99 observing seasons, respectively (Table 3). The photometry period algorithms yield a period of 3.831 days. But the light curves indicate that a period of 3.834 days gives the best agreement between the *u*, *v*, *b*, and *y* values for the two observing seasons. Thus the ephemeris of Shore et al. (1990) is adopted. However, as there is not a previous set of at least fair quality photometry and as the phenomena are complex, it is not possible to improve the period at this time.

Fig. 2 shows the light curves for *u*, *v*, *b*, and *y* whose amplitudes are, respectively, 0.035, 0.025, 0.015, and 0.010, mag. The light curves appear to be in phase. But for *y* with its small amplitude it is difficult to tell. *u*, *v*, and *b* each show a maximum near phase 0.05 with a minimum near 0.35. Another minimum may be near phase 0.80 which is most clearly seen in *v* and *b*. In comparison the magnetic field has a maximum near phase 0.50 and a minimum near phase 0.0 while the C IV line maxima are at phases 0.35 and 0.80 which are those of the minima if both sets of data are correctly phased together.

4. HD 86592

Bidelman (1981) classified HD 86592 as a SrEu star. Babel & North (1997) discovered a very strong magnetic field of 15 to 16 kG, estimated v sin i = 16$\pm$2 km s^{-1}, and found photometric variability from 24 photometric measurements in the Geneva system:

HJD (max. flux Geneva B mag.)
= 2446896.801 + (2.886669$\pm$0.00030)E.

Forty-five and 77 sets of good Strömgren differential observations were made with the FCAPT during the 1997-98 and 1998-99 observing seasons, respectively (Table 4). The period finding techniques yield the same period as Babel & North whose photometry covers a much long time period, but whose coverage is far sparser. The new photometry defines more subtle variations in the light curves. These values are plotted in Fig. 3. The B light curve of Babel & North shows the same minimum as those of *u*, *b*, and *v* which are in phase. It will require another set of observations to improve the ephemeris.

HD 86582 is a large amplitude variable in *v* (0.13 mag.) while in *u*, *b*, and *y* the amplitudes are 0.04, 0.04, and 0.018 mag., respectively. The variability in *y* is very crudely, but not perfectly in antiphase with those of *u*, *v*, and *b* as its maximum occurs near phase 0.5 rather than 0.35. Thus there must be an approximately non-variable wavelength region between the mean wavelengths of *b* and *y*. The halt in the rise of the rising branch of the light curve near phase 0.75 which is seen in *v* may also weakly occur in *b*.

5. HR 8861

The well studied mCP star HR 8861 (= HD 219749 = ET And) is a single-line spectroscopic binary with a very eccentric orbit (e = 0.5) and an orbital period of 48.3 days (Ouhrabka & Gygra 1979). Leroy (1995) found its polarization is non-variable. Its rotational period is well determined from its photometry (Hildebrandt & Hempelmann 1981):

JD (minimum light) = 2441204.54 + 1.61887 E.

Piskunov et al. (1994) used this ephemeris and spectrograms to map HR 8861's Si and He surface abundances. Much of its photometry is in UBV system from Postdam (Scholz et al. 1985; Hildebrandt et al. 1985). Fig. 4 shows the V photometry from Hildebrandt et al. (1985) (+'s) and Scholz et al. (1985) (o's) and FCAPT *u*, *v*, *b*, and *y* photometry (filled squares) (also given in Table 5). The *u* light curve shows a weak secondary minimum (phase 0.6) and a strong primary minimum (phase 0.0) along with primary (phase 0.3) and secondary maxima (phase 0.7). The *v*, *b*, and *y* light curves are somewhat different. They have their primary maxima at *u* secondary minimum and their minima at phase 0.0. The amplitudes of variations are 0.08 mag. for *u* and 0.025 mag. for *v*, *b*, and *y*. The V data of Hildebrandt et

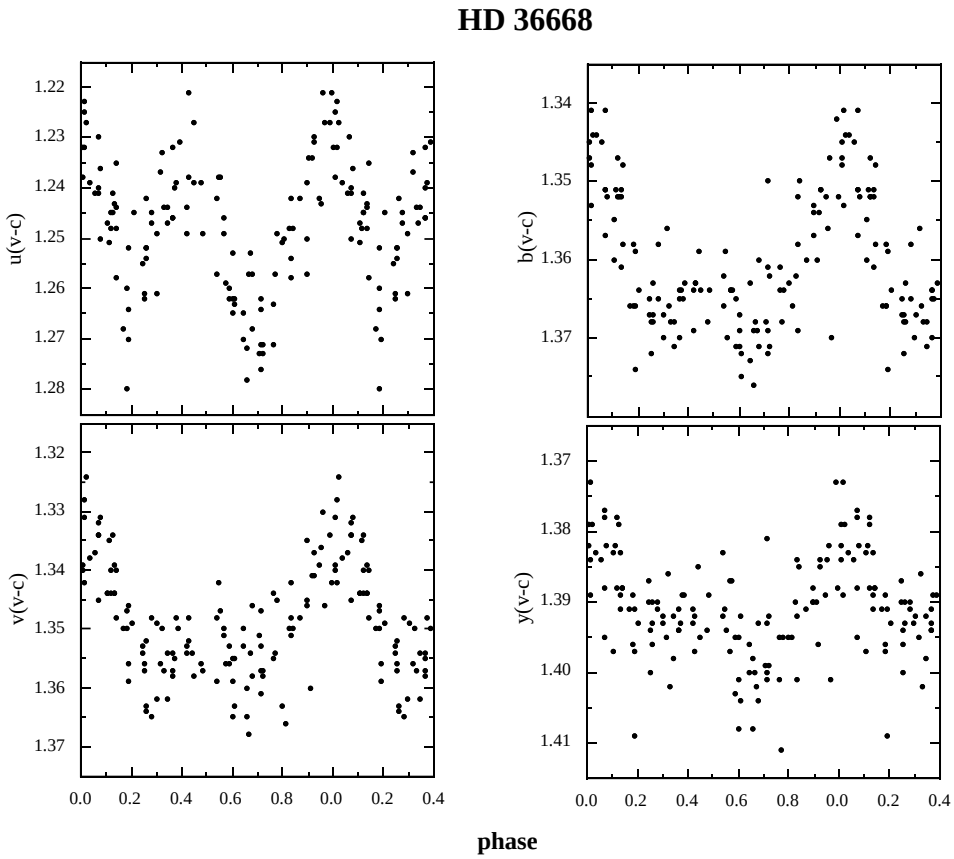

Fig. 1. Differential FCAPT *uvby* photometry of HD 36668 (filled circles) plotted with the ephemeris HJD(u_{max}) = 2444988.375 + 2.11884 E. Note that the secondary maximum in *u* is not seen as well in the other light curves.

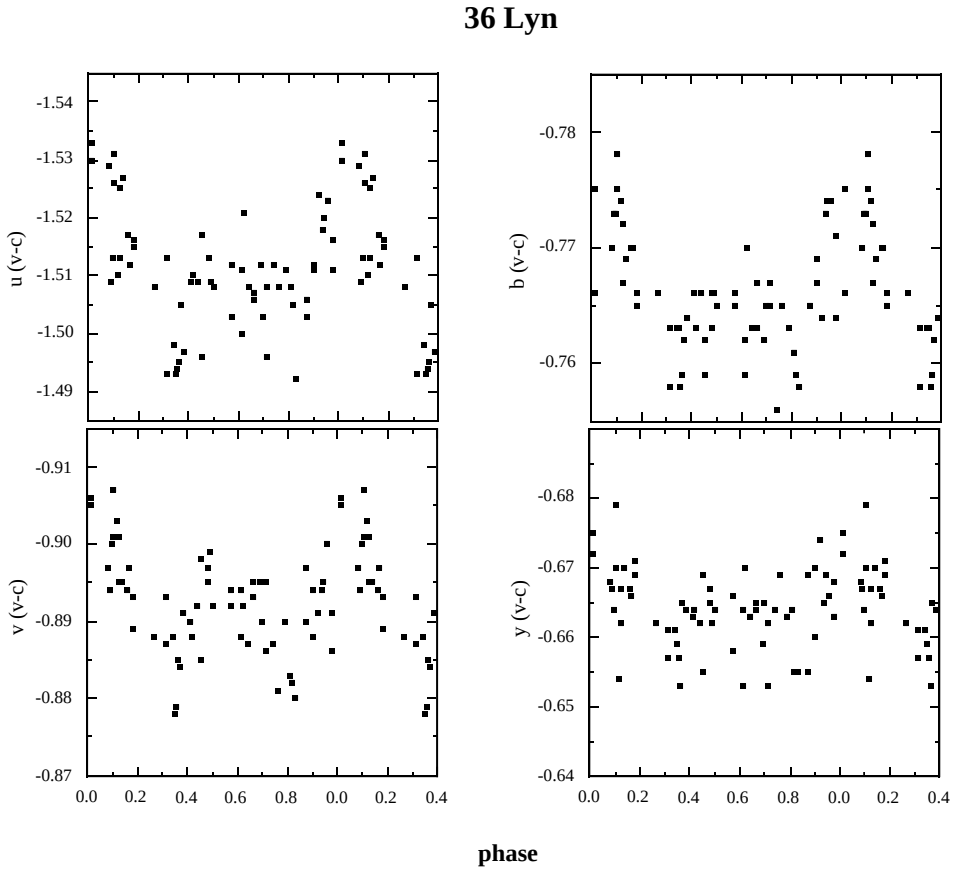

Fig. 2. Differential FCAPT *uvby* photometry of 36 Lyn (filled squares) is displayed using the ephemeris JD (phase = 0.0) = 2443000.0 + 3.834 E.

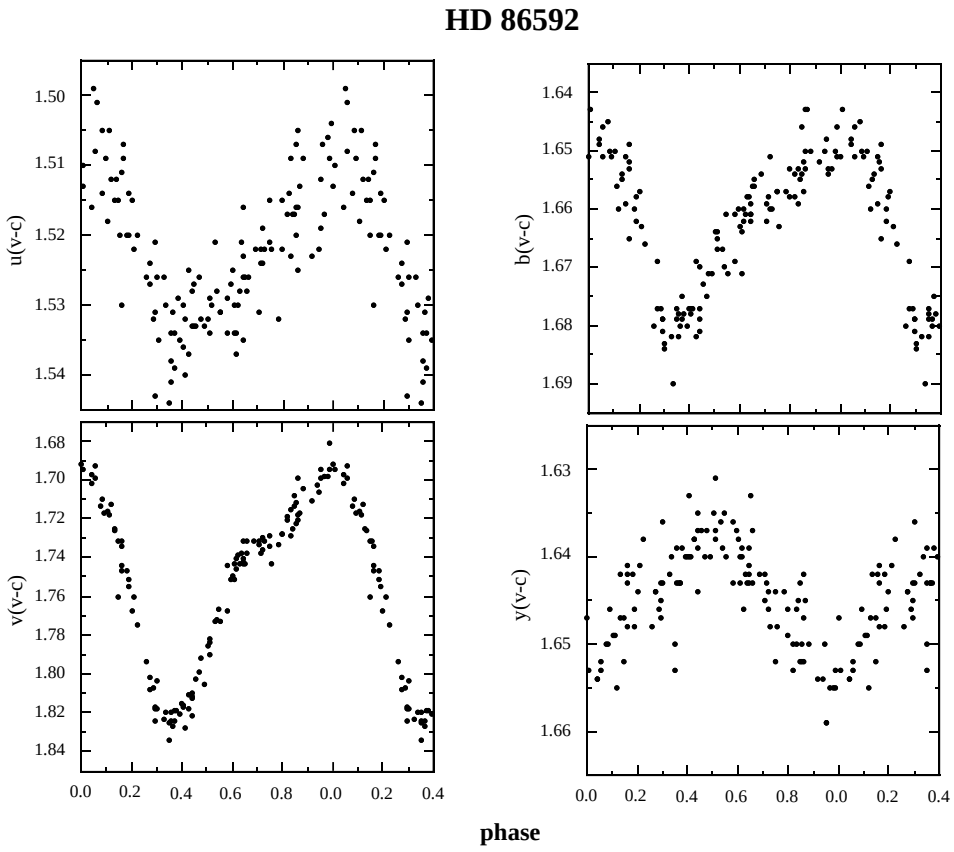

Fig. 3. Differential FCAPT *uvby* photometry of HD 86592 (filled circles) plotted with the ephemeris HJD (max Geneva B mag.) = 2446896.801 + 2.886669 E. Note the variation of *y* is crudely out of phase with those of *u*, *v*, and *b*.

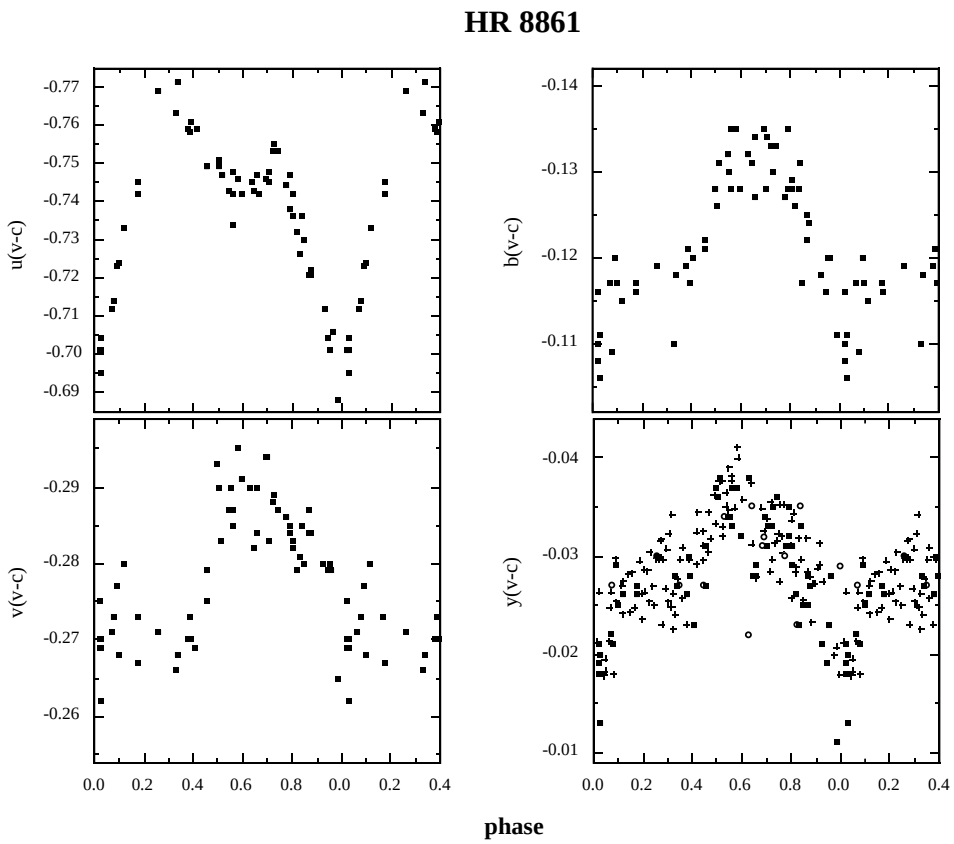

Fig. 4. Differential FCAPT *uvby* photometry of HR 8861 (filled squares) plotted with the ephemeris JD (minimum light) = 2441204.54 + 1.61887E. V photometry normalized to the *y* zero point are shown as +'s for values from Hildebrandt et al. (1985) and as o's from Scholz et al. (1985).

al. (1985) and Scholz et al. (1985) as renormalized to *y* overlay the *y* data quite well and thus improving the ephemeris is not possible at this time.

The model of Piskunov et al. (1994) indicates that the minimum at phase 0.0 coincides with the two largest regions of silicon underabundance crossing the stellar disk. At phase 0.6 the region of greatest silicon overabundance crosses the center of the stellar disk. There are no obvious correlations with the helium abundance variations.

Weiss et al. (1998) recently found a period of 1.618875 days which makes little difference in the photometric results. Further HD 219891, which was used a a comparison star, is a pulsational variable, mostly likely a δ Scuti star with a frequency of 10.0816 d^{-1} and a semi-amplitude of 2.5 mmag. This adds a small source of noise to the v-c data.

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