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uvby photometry of the magnetic chemically peculiar stars HD 37776, HR 2258, HR 6958, and 108 Aquarii⋆

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Abstract. Differential Strömgren *uvby* photometric observations from the Four College Automated Photoelectric Telescope are presented for four magnetic chemically peculiar stars. Comparison with *uvby* photometry of Pedersen & Thomsen for HD 37776 yields an improved period of 1.538675 days. New periods of 15.0305 days and 18.065 days are found for the sharp-lined stars HR 2258 and HR 6958, respectively, rather than one of their aliases. For HR 6958 each color shows a slightly different time of maximum. Comparison of the four color photometry of 108 Aqr taken during the fall of 1995 which well covers the period shows the presence of a secondary minimum near primary maximum in u, v, and b. Comparison with published photometry indicates indicates that subtle changes in the shapes of the light curves have occurred suggesting that this star might be precessing.

Key words: stars: individual: HD 37766 — stars: individual: HR 2258 — stars: individual: HR 6958 — stars: individual: 108 Aqr — stars: chemically peculiar — stars: variable

1. Introduction

During the first six years (September 1990 - July 1996) of operation of the 0.75-m Four College Automated Photoelectric Telescope (FCAPT) on Mt. Hopkins, AZ, I obtained differential Strömgren *uvby* photometry of several magnetic Chemically Peculiar stars. The dark count and then in each filter the following measurements were obtained: 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. This paper presents observations of HD 37776, HR 2258, HR 6958, and 108 Aquarii. Table 1 gives information on the stars (Hoffleit 1982 and Hoffleit et al. 1983) of each group which consists of a variable along with two supposedly non-variable stars, the comparison and check, against which the brightness of the variable is compared. The data are given in Tables 2-5 along with their means and their standard deviations. No corrections have been made for neutral density filter differences among the stars of each group. The comparison and check stars were selected from those stars in the vicinity of the variable on the sky that had similar V magnitudes and $B-V$ colors. Known variables were not selected. The standard deviations in Tables 2-5 of the check-comparison star differences indicate that these stars are constant at least for the period when they were observed.

Table 1. Photometric groups

Star	Type	V	$B-V$	Spectral Type
HD 37776	v	6.96	−0.14	B2IV/V
HR 1861	c	5.35	−0.19	B1IV
HR 2109	ch	6.63	−0.07	B8IIIn
HR 2258	v	6.32	−0.07	B9IIIpSiCr:
72 Ori	c	5.30	−0.14	B7V
64 Ori	ch	5.14	−0.11	B8III
HR 6958	v	6.43	−0.04	A0pSiCr
HR 6900	c	6.74	+0.02	B9V
HD 172046	ch	6.64	−0.04	B8
108 Aqr	v	5.18	−0.10	B9pSiSrCr
106 Aqr	c	5.24	−0.08	B9Vn
2 Cet	ch	4.55	−0.05	B9.5Vn

For each variable I plotted the data using the best published period to see if the data approximately confirmed this period. Then I used the Scargle periodogram (Scargle 1982; Horne & Baliunas 1986) and considered my data and those of other observers separately in calculating

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⋆ Tables 2-5 will be 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

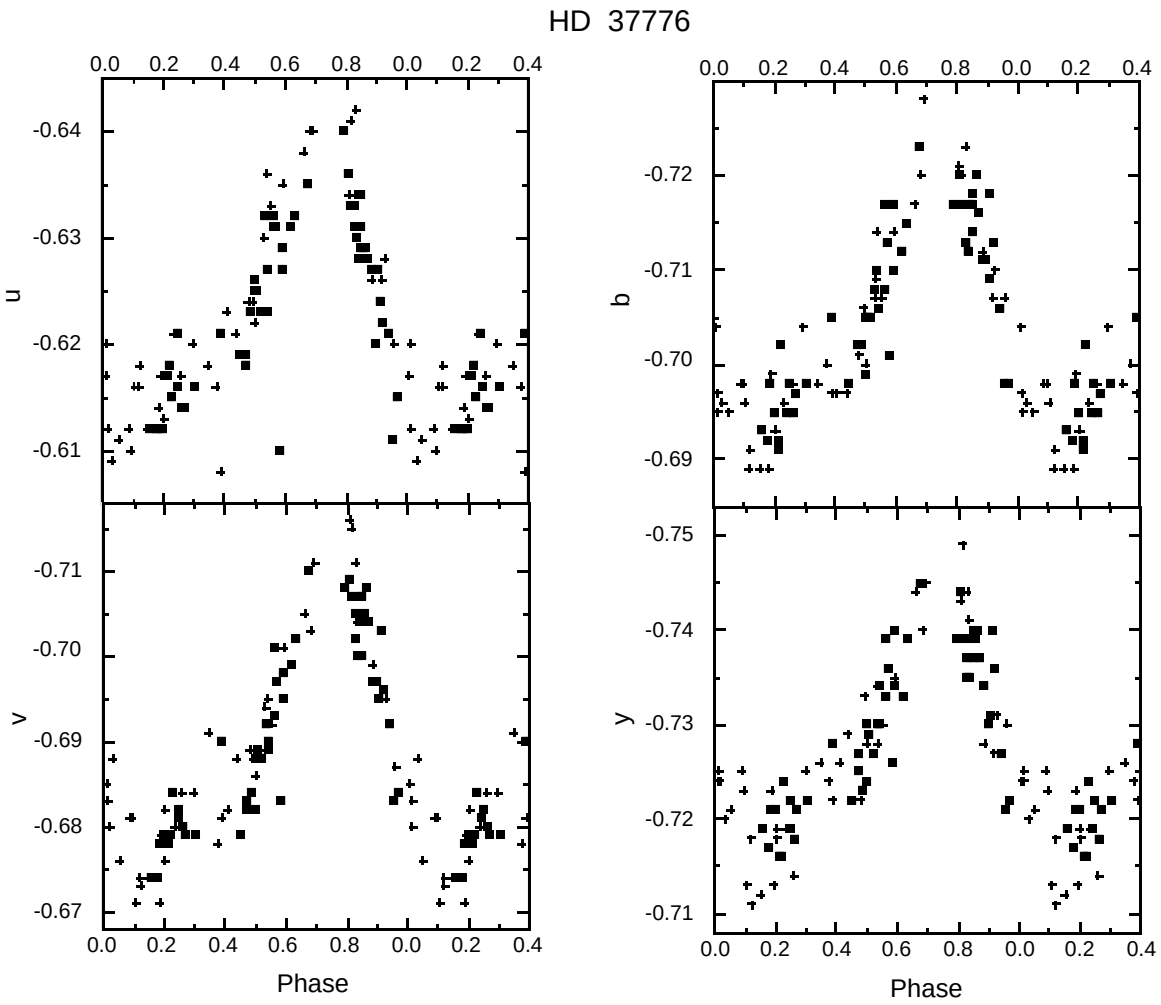

Fig. 1. The *uvby* photometry of HD 37776 using the ephemeris JD(B_1^+) = 2445724.669 ($\pm$0.02) + 1.538675 ($\pm$0.000005) E. The closed squares are data from Pedersen & Thomsen and the plus signs are FCAPT data

periodograms. If the periodograms confirmed the published period, then I adjusted the period to make all data coincide as well as possible in phase.

2. HD 37776

Nissen (1976) classified HD 37776 as a helium-strong star. Pedersen & Thomsen (1977) and Pedersen (1979) discovered it was both a low amplitude spectrum and light variable with a period of 1.5385 $\pm$ 0.003 days. Walborn (1982) observed that its Si and perhaps Mg lines also vary. Thompson & Landstreet (1985) found an extraordinary double-wave magnetic curve with a period of 1.53869 days and argued that this star has a quadrupole-like field geometry. Shore & Brown (1990) reported on its ultraviolet variability.

In years 5 and 6 of the FCAPT, I obtained 42 *uvby* observations of HD 37776. Periodograms of this data agree with the above period. When I plotted them and that of Pedersen & Thomsen with similar zero points, I found that a slight adjustment was needed in the period. I adopted the zero phase of Thompson & Landstreet

$$\mathrm{JD}(B_1^+) = 2445724.669(\pm 0.02) + 1.538675(\pm 0.000005)\ E.$$

The error in the period is reduced by a factor of 10 compared to Thompson & Landstreet.

Figure 1 shows the photometry with closed squares being the data of Pedersen & Thomsen and plus signs being FCAPT data. Both sets of data agree reasonably well. HD 37776 has a single maximum which occurs at approximately the same time in each color near phase 0.75. Better coverage of its peak is desirable. There is a minimum near phase 0.1. The photometric variation amplitudes are 0.03 mag in u, 0.04 mag in v, and 0.035 mag in b and y.

3. HR 2258 (= HD 43819)

Winzer (1974) discovered HR 2258 was a photometric variable and derived a period of 1.0785 days. It is a sharp-lined star with $v \sin i$ = 14 km s^{-1} (Wolff & Preston 1978).

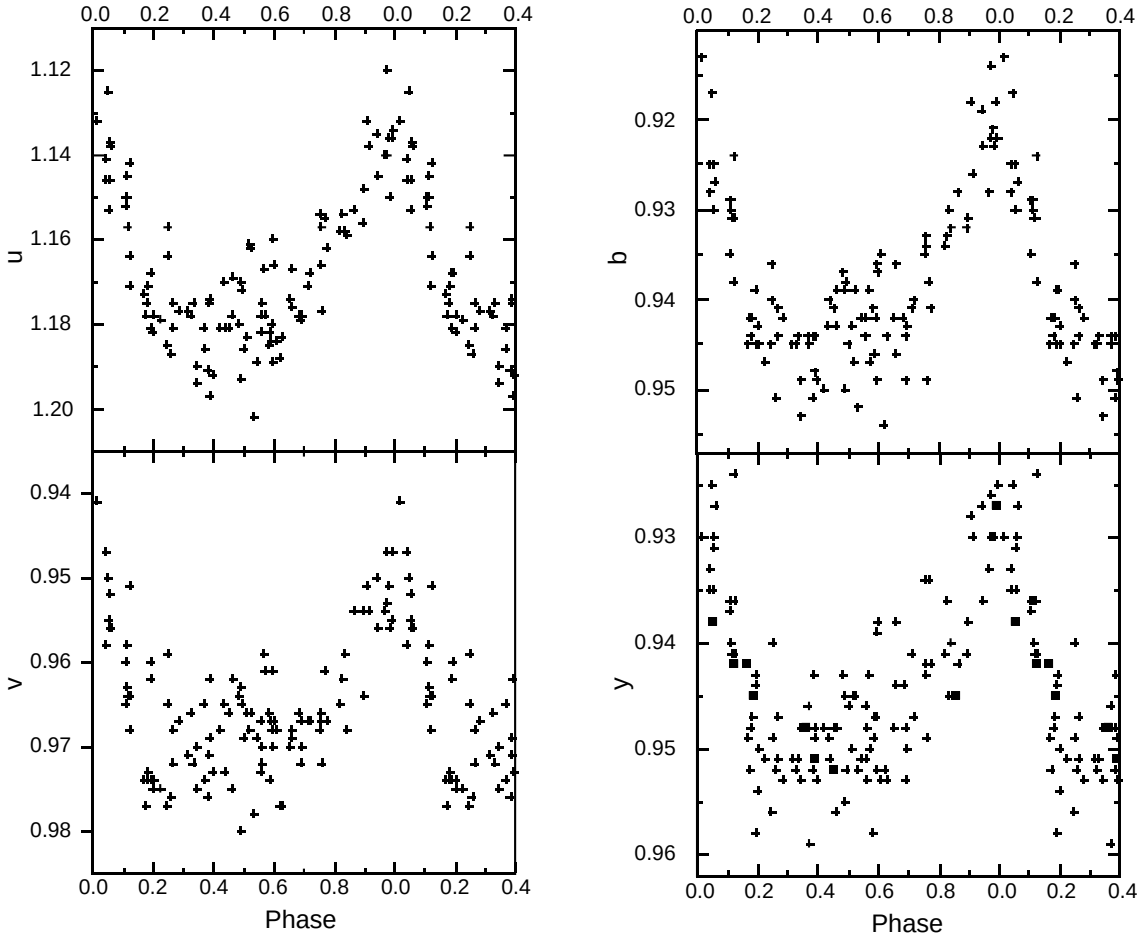

Fig. 2. The *uvby* photometry of HR 2258 with the ephemeris HJD (maximum light) = 2441254.16 + 15.0305 E. The closed squares are V photometry of Winzer transformed to y and the plus signs are data from the FCAPT

Adelman (1975, 1982) discovered it has a definite λ 5200 broad, continuum feature as well as modest λ 4200 feature. An abundance analysis by Lopez-Garcia & Adelman (1994) showed that most of its iron peak elements are 10 times solar while its rare earths are typically 1000 times solar.

I obtained 110 observations of HR 2258 (10 in year 2, 12 in year 3, 8 in year 4, 34 in year 5, and 46 in year 6). A periodogram analysis of the y values shows that the period is 15.033 days. Winzer's period is an alias of this period. Examination of the u data shows that the extrema of the values occur with this period which is also much more consistent with the sharp-lined nature of the star. Adding a constant to Winzer's V data and comparing it to the y data indicates that the period should be 15.0305 days. The scatter in the *uvby* data with this period is slightly greater than found for the correct periods of many magnetic CP stars with FCAPT data.

The zero point was found by adjusting Winzer's value. It is an average of those for the four colors and needs to be better defined by obtaining additional photometry with phases close to it.

The adopted ephemeris is

$$\begin{aligned} \text{JD (maximum light)} &= 2441254.16\ (\pm 0.05) \\ &\quad +15.0305\ (\pm 0.0003)\ E. \end{aligned}$$

Figure 2 show that the variability is roughly in phase in all four colors with amplitudes of 0.06 mag in u, 0.035 mag in b, and 0.03 mag in v and y. The light curves are asymmetric with the fall from maximum being faster than the rise from minimum.

4. HR 6958 (= HD 170973 = MV Ser)

Winzer (1974) found HR 6958 was a photometric variable. He used HR 6985 as the comparison star and found a period of 0.9451 days. Burke & Barr (1981) obtained additional UBV photometry with HD 1702999 and HD 171802 (= HR 6985) as the comparison stars and found a similar period. Spectrograms show it is relatively

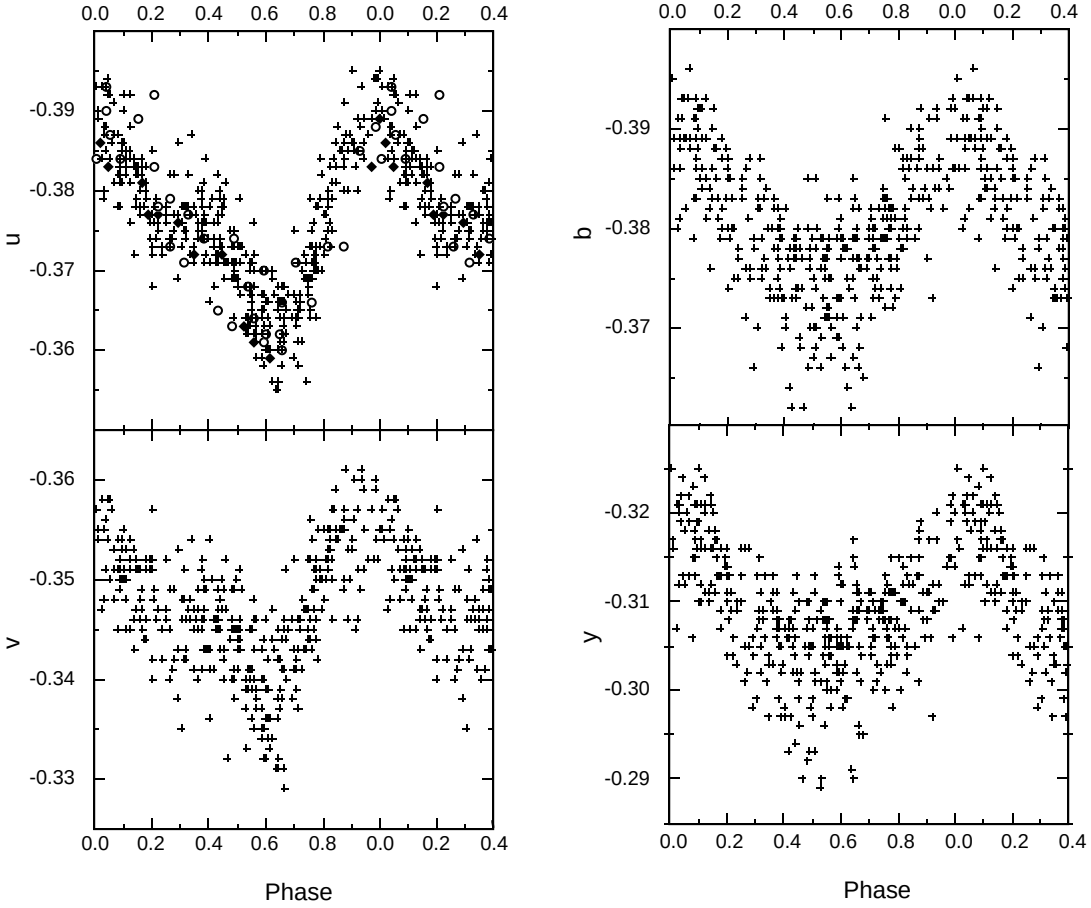

Fig. 3. The *uvby* photometry of HR 6958 plotted according to HJD $(u_{\max}) = 2441459.136 + 18.065\ E$. The FCAPT values are plotted as plus signs and the transformed U values of Winzer (1974) and Burke & Barr (1981) as solid diamonds and open circles, respectively

sharp-lined which is inconsistent with a photometric period of this length.

In a first attempt at using FCAPT data, I could not determine which period was significant and so began to obtain at least two observations per night. A total of 379 *uvby* observations (Table 4) were obtained during the first five years of observations. A periodogram analysis of the u values indicated that the most likely period was 18.072 days. Winzer's period corresponds to the frequency of this period plus 1.0. Examination of photometry obtained on the same night and the sharp-lined nature of this star argued for the longer period. As the amplitude of HR 6958 is greatest in u, constants were added to the U photometry of Winzer (1974) and of Burke & Barr (1981) so that their mean values were the same as that for u. When these values were plotted with the u data, small adjustments in both the period and the epoch of the maximum value for u are needed. Thus

HJD $(u_{\max}) = 2441459.136\ (\pm 0.007) + 18.065\ (\pm 0.001)\ E.$

As both the maxima and minima are asymmetric there is no advantage of selecting one over the other for determining the zero phase.

Figure 3 shows the *uvby* values plotted according to the adopted ephemeris. In the panel for u, the transformed U values of Winzer (1974) and Burke & Barr (1981) are plotted as close diamonds and open circles, respectively. The FCAPT values are always plotted as plus signs. Maxima in different colors appear to occur at slightly different phases with that for v occurring earlier than that for u and those for b and y occurring slightly later than that for u. The amplitudes of variation are 0.03 mag, 0.02 mag, 0.02 mag, and 0.015 mag, respectively for u, v, b, and y. The light curve for u is quite asymmetric with the rising branch of the light curve taking about 40% of the period. That for v is somewhat similar to that for u. But those of b and y are nearly symmetric.

5. 108 Aqr (= HR 9031 = HD 223640)

North et al. (1992) derived a precise rotational period from Geneva photometry and previously published y photometry especially that of Morrison & Wolff (1971) for the cool magnetic CP star 108 Aquarii. Their ephemeris was

HJD (phase origin) = 2444696.820 + 3.735239 E.

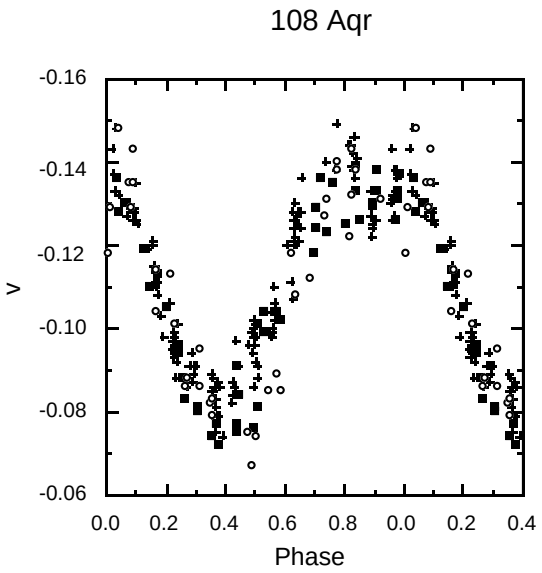

Fig. 4. The v photometry of 108 Aqr plotted according to HJD (phase origin) = 2444696.820 + 3.735239 E. Data from Morrison & Wolff (1971) transformed to the Four College APT system are shown as open circles, from Adelman & Knox (1994) as closed squares, and from this paper as plus signs. Differences between these data sets are seen, especially in the rising branch of the light curves

Adelman & Knox (1994) obtained 48 *uvby* values with the FCAPT. When they used North et al.'s ephemeris and compared their data with that of Morrison & Wolff corrected for zero point shifts, they found generally good, but not perfect agreement. Although they were not able to improve the above ephemeris, comparison of their data with that of Morrison & Wolff indicated some changes in the shapes of the light curves especially a phase shift in the rising branch of the u curve which is less evident in v and b and a perhaps slightly greater amplitude in y. As this was similar to the changes in the shape of the light curves of 56 Ari reported by Adelman & Fried (1993) who interpret this type of behavior as due to free body precession of the magnetic CP star, additional photometric FCAPT observations of this star were made in the fall of 1995 using the same comparison and check stars. Almost all the 146 new observations observations were made during one month with many observations per night. Due to the stellar period and the telescope's observing window, only about 5% of the light curve could be covered each night.

The agreement of the average ch-c values with those of Adelman & Knox (1994) is good except for u which has a 0.010 mag offset. The ephemeris of North et al. (1992) also satisfies the new observations. These fall 1995 observations show clearly new features, especially a secondary minimum near phase 0.90 in u, v, and b in the midst of the broad maximum. Possibly it is now seen due to the superior definition of the light curve, which is a complicating factor in the entire analysis as are slight shifts in the ch-c star values.

Figure 4 shows the v magnitudes from Morrison & Wolff (1971) (open circles), Adelman & Knox (1994) (closed squares), and this paper (pluses). The newly found secondary minimum is seen well only in this paper's data. The falling branch values are in good agreement while the rising branch values are offset from one another, which was previously noted by Adelman & Knox. The new values suggest a narrower core for the secondary than do the previous photometry and near phase 0.6 a broader maximum.

As in Adelman & Knox a careful comparison with the Morrison & Wolff data is given, here I present a comparison between the current data and that published by Adelman & Knox (see Fig. 5), which cover a period of 470 days. Slight adjustments in the values are made to correct offset in the data.

For u the rising branch near the primary maximum is now well defined. The rising branches are in reasonable agreement while the fall branches may be offset. For v and b the greatest differences are between phases 0.7 and 0.0, near the primary maximum and secondary minimum. For y the greater scatter of the Adelman & Knox (1994) data makes it difficult to come to any conclusions. The improved coverage of the light curve and reduction in scatter are important for future studies of 108 Aqr. To establish that the differences in the light curves are real requires additional data of the type presented in this paper.

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References

Adelman S.J., 1975, ApJ 195, 397
Adelman S.J., 1982, A&AS 49, 668
Adelman S.J., Fried R., 1993, AJ 105, 1103
Adelman S.J., Knox J.R. Jr., 1994, A&AS 103, 1
Burke E.W., Barr T.H., 1981, PASP 93, 344
Hoffleit D., 1982, The Bright Star Catalogue, 4th edition, New Haven, Yale University Observatory
Hoffleit D., Saladyga M., Wlasuk P., 1993, A Supplement to the Bright Star Catalogue, New Haven, Yale University Observatory

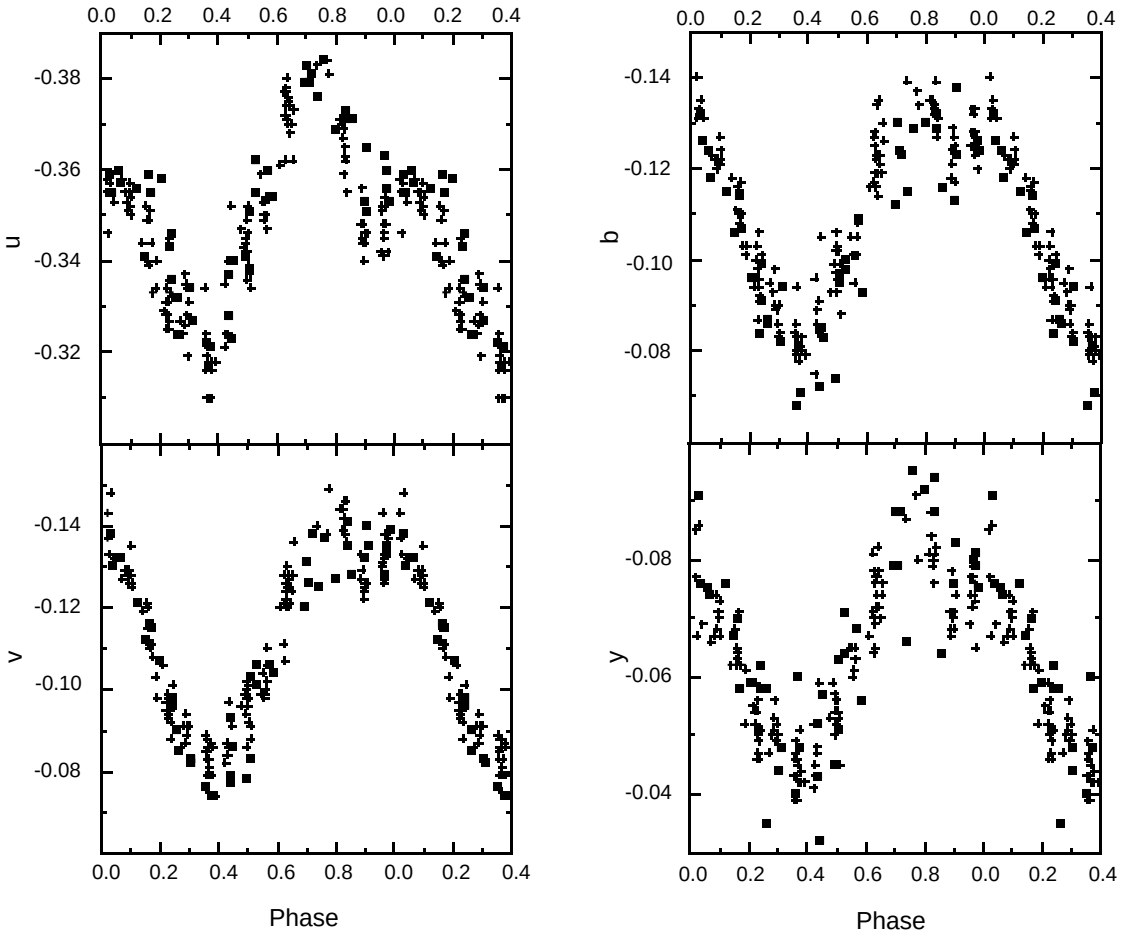

Fig. 5. The *uvby* photometry of 108 Aqr plotted according to HJD (phase origin) = 2444696.820 + 3.735239 E with values from Adelman & Knox (1994) as closed squares and from this paper as plus signs

Horne J.H., Baliunas S.L., 1986, ApJ 302, 757
Lopez-Garcia Z., Adelman S.J., 1994, A&AS 107, 353
Morrison N.D., Wolff S.C., 1971, PASP 83, 474
Nissen P.E., 1976, A&A 50, 343
North P., Brown D.N., Landstreet J.D., 1992, A&A 258, 389
Pedersen H., 1979, A&AS 35, 313
Pedersen H., Thomsen B., 1977, A&AS 30, 11
Scargle J.D., 1982, ApJ 263, 835
Shore S.N., Brown D.N., 1990, ApJ 365, 665
Thompson I.N., Landstreet J.D., 1985, ApJ 289, L9
Winzer J.E., 1974, Ph. D. Thesis, University of Toronto
Wolff S.C., Preston G.W., 1978, ApJS 37, 371