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HD 81410: a new RS CVn binary

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Summary. *B* and *V* photometry of HD 81410 obtained on 34 nights during 1981 January 3–March 14 is presented. The amplitudes are found to be ~ 0.15 mag both in *B* and *V*. It is found that a 12.86833 day period satisfies all the available photometric data. Orbital elements of the system have been derived from the published radial velocity measurements. The orbital period, strong Ca II H and K emission and the spectral types of the components indicate that HD 81410 is a member of the RS CVn group. It is seen that the star becomes redder at fainter visual magnitudes. We attribute this to the relatively cooler temperatures of the 'darker regions' present on the visible hemisphere.

1 Introduction

HD 81410 is listed by Bidelman & MacConnell (1973) as a star with a K1 III spectrum displaying strong Ca II H and K emission and 'filled Balmer lines'. The radial velocity observations by Wayman and Jones (Eggen 1973) showed HD 81410 to be a single lined spectroscopic binary. Wayman classified the spectrum as K1 IV and found that the strong Ca II H and K emission lines yielded the same velocity as the absorption lines. The suspected light variability of HD 81410 (Cousins & Stoy 1963) was confirmed by Eggen (1973), whose observations of 1971 and 1972 showed an amplitude of about 0.5 mag in the visible region. He found that a period of 25.4 day, though satisfying the observations of each season separately, could not bridge the gap between them since the light curves obtained during the two observing runs differed appreciably.

HD 81410 was observed as part of our photometric programme on late-type emission binaries to study their photometric behaviour and chromospheric activity. In this paper we report the results of our photometric observations of HD 81410 in *B* and *V* and an analysis of all the available information about the system.

2 Observations

HD 81410 was observed on 34 nights between 1981 January 3 and March 14 with the 34-cm reflector of the Kavalur Observatory through standard *B* and *V* filters. The comparison stars observed were HD 81904 and 80991 of spectral types K0 and K2 respectively. All observations were made differentially with respect to HD 81904 and transformed to the Johnson's system. The mean magnitudes and colours of the comparison stars are given in Table 1. Table 2 gives the results for the variable star. On the average each value given in the Table is a mean of three independent measurements. The probable errors of the differential magnitude and colour of the variable star are ±0.007 and ±0.008 mag respectively. The total uncertainty of a V value given in Table 2 is ±0.014 mag and that of a $(B-V)$ value is ±0.010 mag.

Table 1. Magnitudes and colours of the companion stars.

Star	V	$B-V$
HD 81904	8.055 ± 0.012	+0.967 ± 0.006
HD 80991	8.551 ± 0.012	+1.024 ± 0.006

Table 2. Magnitudes and colours of HD 81410.

JD	V	$B-V$	JD	V	$B-V$
2 444 600.+			2 444 600+		
08.4447	7.554	1.015	61.2215	7.610	1.028
09.4424	7.584	1.036	61.3040	7.632	—
10.4310	7.607	1.045	61.3818	7.615	—
11.4287	7.608	1.038	62.1603	7.650	—
22.3951	7.588	1.068	62.2648	7.649	1.047
32.3775	7.617	—	62.3552	7.653	—
33.2986	7.594	1.043	63.1442	7.640	—
34.4475	7.568	—	63.2655	7.639	1.037
35.2928	7.609	1.051	63.3917	7.635	—
36.3914	7.653	1.056	64.1259	7.612	—
37.3606	7.622	1.043	64.2365	7.582	1.054
38.4171	7.584	—	64.2583	7.579	1.055
42.2988	7.561	1.040	64.3891	7.604	—
42.3326	7.576	1.050	65.2125	7.541	1.052
43.2602	7.612	1.066	65.3642	7.519	—
43.3472	7.623	1.067	66.2163	7.513	1.039
43.4253	7.623	—	66.3522	7.496	—
45.2275	7.618	—	67.1634	7.540	—
45.2433	7.616	—	67.2585	7.519	1.045
45.2924	7.616	—	68.1530	7.575	—
45.3049	7.607	—	68.2033	7.578	—
45.3767	7.621	—	69.3203	7.644	—
46.2171	7.580	—	69.3398	7.628	—
46.2613	7.587	—	69.3580	7.626	—
46.3095	7.591	—	70.1336	7.635	—
47.2017	7.571	—	70.2523	7.637	1.051
47.2525	7.580	—	71.1385	7.614	—
47.3342	7.579	—	71.2502	7.609	1.029
47.3976	7.594	—	72.1175	7.601	—
59.2064	7.578	—	72.1691	7.592	1.029
59.2825	7.565	1.043	73.1219	7.580	—
59.3944	7.568	—	73.1822	7.599	1.014
60.1670	7.571	—	74.2415	7.621	1.049
61.1620	7.618	—	78.1458	7.523	—

3 Period determination

It was obvious that the period derived by Eggen did not fit the present set of observations and we decided to have a fresh look at the period of light variation. To determine the period of light variation we adopted a method very similar to the one described by Bopp *et al.* (1970). For each trial period the observations were ordered in phase; and the quantity Q, taken as the measure of goodness of fit, was calculated from

$$Q = \sum_{i=1}^{N-1} |m_i - m_{i+1}| + |m_N - m_1|$$

The period which gave the least value of Q was taken as the best approximation.

The present set of observations and the 1972 observations of Eggen when subjected to the above method of period determination yielded the periods 12.89 and 12.75 day respectively. Due to the poor phase coverage of Eggen's observations and the small number of the photometric cycles covered by the two sets of observations the determination of the photometric periods are not sufficiently accurate to decide definitely whether the difference in the derived periods is real.

4 Orbital elements

Eggen (1973) lists eight radial velocity measurements of HD 81410 which are supplied by Wayman and Jones. From the giant–subgiant nature of the visible primary component of HD 81410, we assume that the system is sufficiently old and that the tidal coupling effects have brought about orbit circularization and near spin synchronization.

The observations show that the maximum of radial velocity occurs at ~ JD 2 441 466.0, the systemic velocity is ~ – 5.0 km s^{-1} and the amplitude of variation is ~ 40.0 km s^{-1}. These were taken as the preliminary values for T_0, γ, and K for the orbital solution. Sterne's (1941) method for orbits of small eccentricity was used for the least squares solution. A preliminary value of the period was varied between 12.7 and 13.1 day in steps of 0.001 day. Each time the radial velocity residual was calculated using the resulting elements. It was found that the minimum residual occurs when the period P = 12.86833 day. The final orbital elements thus derived are presented in Table 3. Fig. 1 shows the radial velocity curve computed with these elements along with the individual measurements.

5 Photometric results

The Julian days of observation given in Table 2 are converted to orbital phases using the ephemeris:

Phase = JD 2 441 466.213 + $12^{\mathrm{d}}.86833E$,

Table 3. Orbital elements of HD 81410.

p	12.86833 ± 0.00088 day
e	= 0.0 (assumed)
ω	–
κ	38.0 ± 2.1 km s^{-1}
γ	– 4.2 ± 2.2 km s^{-1}
T_0	JD 2 441 466.213 ± 0.211
$a \sin i$	(6.72 ± 0.37) × 10^6 km
$f(m)$	0.073 ± 0.012$M_\odot$

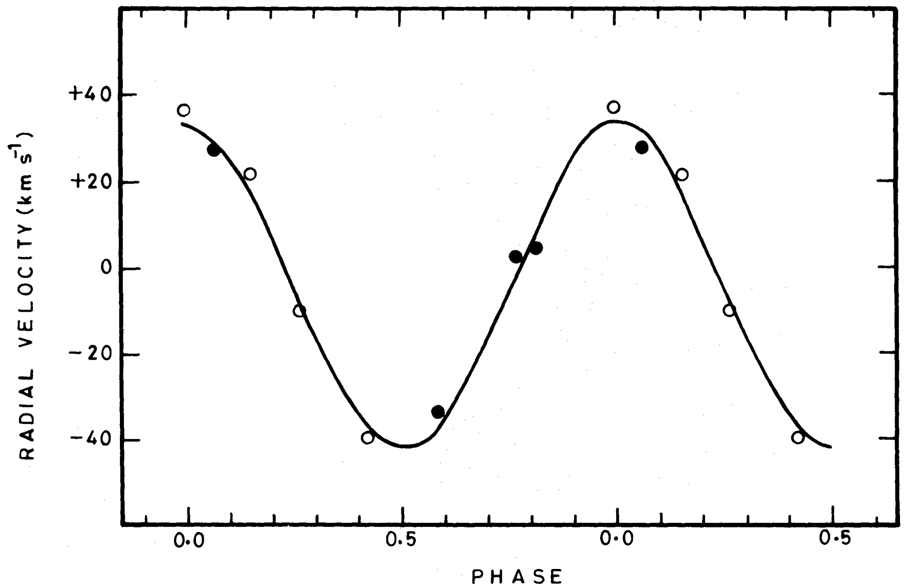

Figure 1. Radial velocity curve of HD 81410. Filled and open circles denote measurements by Wayman and Jones respectively (Eggin 1973).

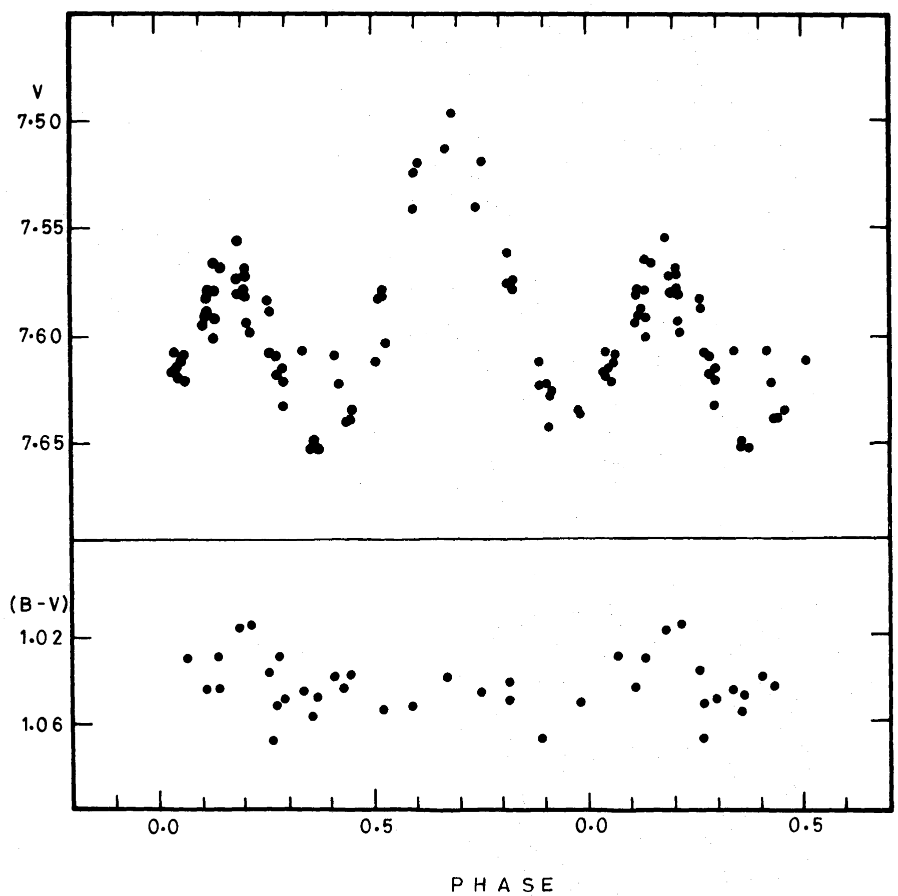

Figure 2. New V and $(B-V)$ light curves of HD 81410.

where the initial epoch corresponds to the maximum of the radial velocity curve. Fig. 2 is the plot of the observations contained in Table 2. From the figure it is clear that the light curve exhibits two unequal humps, one centred around phase 0.18 and the other around 0.70. The extension over the photometric phase of the first hump, which is smaller of the two, is less than the second. The minima which occur at phases 0.35 and 0.95 too are unequal.

In Fig. 3 observations of Eggen are plotted with the same ephemeris given above. It is seen that the 1971 observations lie systematically below the 1972 observations. The minimum and the maximum in both cases occur roughly at the same phases and the amplitudes of variation are almost equal. The difference between the light curves of 1971–72 and of the present study is very striking. The amplitude of light variation has decreased from 0.45 to 0.15 mag and the mean brightness of the system has gone up by ~ 0.10 mag.

Fig. 4 is the plot of colour indices $(U\!-\!B)$, $(B\!-\!V)$ and $(R\!-\!I)$ against the corresponding visual magnitudes V. It clearly shows that at fainter visual magnitudes HD 81410 appears redder and that the colour variation depends on the wavelength. $(U\!-\!B)$ shows very little variation whereas a change of about 0.10 mag occurs in $(R\!-\!I)$ for a change of half a magnitude in the brightness of the system. The solid lines shown in the figure represent the least square solutions of assumed linear relationships. The corresponding slopes are 0.023 ± 0.021, 0.112 ± 0.017 and 0.158 ± 0.015.

The nature and the phasing of the minima of light curves show that geometrical eclipses are not the cause of light variation. We are in fact seeing the 'distortion-like wave' exhibited by late-type emission binaries with a giant–subgiant component. Hall (1976) has shown that these are related to the well-known binary systems like RS CVn and AR Lac. The photometric variation shown by these systems are attributed to the presence of large scale 'star spots' on the giant–subgiant component which rotationally modulate the observed flux (Eaton & Hall 1979; Bopp & Noah 1980). The spectral type K1 III (Bidelman & MacConnell 1973) of the visible primary and the orbital period of HD 81410 satisfy the criteria proposed by Hall for membership in the RS CVn group of binaries.

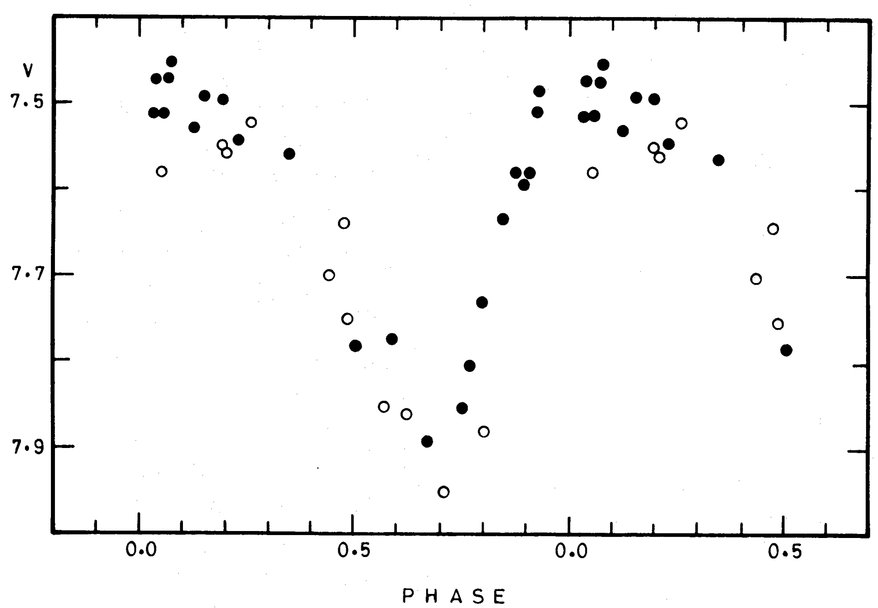

Figure 3. *V* observations of Eggen. Open and filled circles denote the 1971 and 1972 observations.

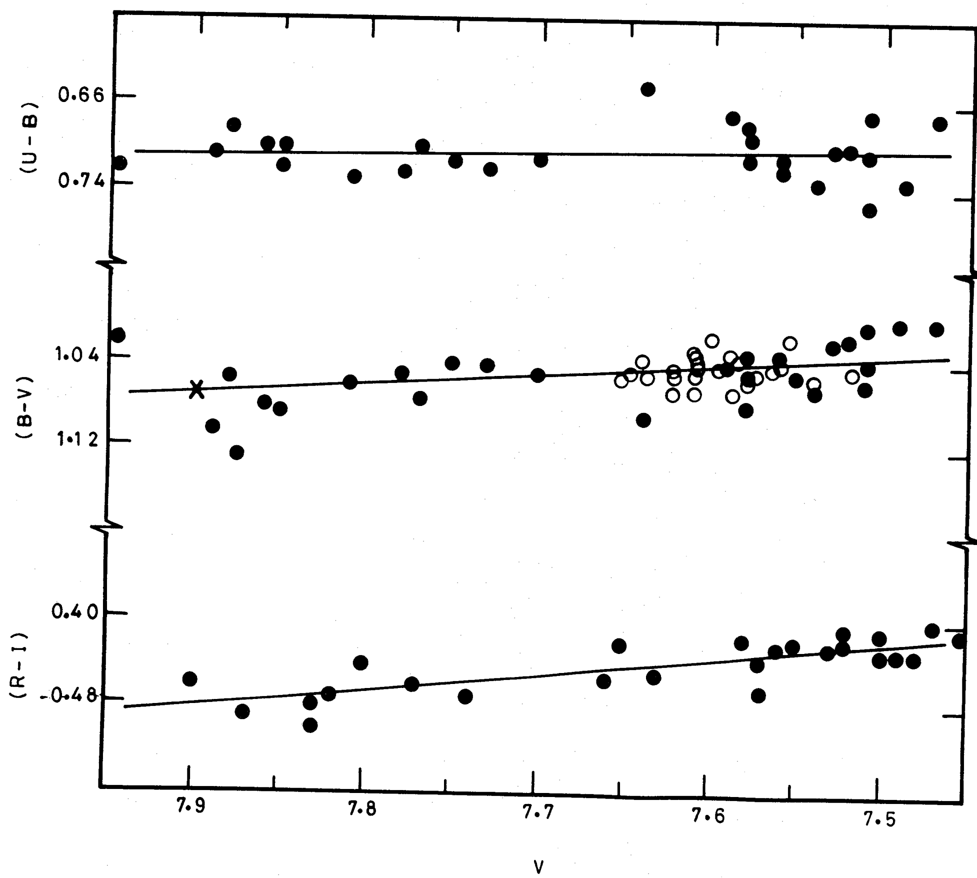

Figure 4. Plots of $(U-B)$, $(B-V)$ and $(R-I)$ colour indices against the V magnitude. Open circles, filled circles and cross denote the present study, Eggen (1973) and Cousins & Stoy (1963) respectively.

The asymmetric light curves indicate a highly non-uniform brightness distribution on the surface of the visible primary. The present study indicates that the 'areas of activity' are centred around two regions separated in longitude. No major changes in the brightness distribution occur over a span of a few orbital periods as indicated by the rather stable light curves of each season. However, the scatter seen in Figs 2 and 3 points out the small changes taking place in the brightness distribution on smaller time-scales. A study by Parthasarathy, Raveendran & Mekkaden (1981) shows that similar short-term fluctuations are exhibited by the well-known RS CVn binary HR 1099.

Any inhomogeneity in the circumpolar region of the star would be presented to the observer throughout the period of rotation. This implies that the amplitude of light variation depends only on the brightness distribution of the equatorial zone. If we take the exteme unphysical situation that the dark regions (say, spots) do not radiate at all (corresponding to spot temperature = 0 K) an amplitude of ~ 0.5 mag observed in the case of HD 81410 indicates that a fraction = 0.37 of the visible disc of the star is covered by spots. In order to have the maximum amplitude for the light variation, the extent of spots should be less than or equal to the area occupied by the equatorial zone of the visible disc. For an orbital inclination $i = 30°$, the equatorial zone occupies only a fraction $(1-\cos^3 i) = 0.35$ of the visible disc, which is less than the area of the spots should occupy for the observed amplitude of variation. If the spots also radiate (corresponding to spot temperature $\gg$ 0 K) the extent of the spots and hence the equatorial zone should be correspondingly larger which suggests that the orbital inclination is considerably greater than 30°. This, together

Table 4. Comparison of colours

Colour	K0 III	(K0 III + F5 V)	HD 81410
$U-B$	0.89	0.75	0.70
$B-V$	1.04	0.99	1.02
$V-R$	0.77	0.75	0.79
$R-I$	0.53	0.52	0.55

with the spectral type K1 III assigned to the primary by Bidelman & MacConnell and the derived mass function $f(m) = 0.073 M_\odot$, indicates that the secondary is probably an F dwarf. The suggestion that the invisible companion probably belongs to an earlier spectral type is further strengthened by the fact that $(U-B)$ of HD 81410 is brighter by ~ 0.2 mag than a typical K giant with the observed $(B-V)$ and $(R-I)$ colours.

Table 4 gives the colours predicted for a binary with K0 III and F5 V components along with the observed colours of HD 81410. The $(V-R)$ and $(R-I)$ colours are derived from Eggen's observations and transformed to the system defined by Johnson, MacArthur & Mitchell (1966). The colours correspond to the maximum observed brightness $V = 7.4$ mag of HD 81410. The agreement is most striking and shows that the spectral type of the secondary is close to F5 V and that of the primary at the maximum observed brightness is ~ K0 III. The contamination of the observed $(V-R)$ and $(R-I)$ colours by the F-type secondary is almost negligible. Hence the $(R-I)$ variation shown by HD 81410 could be attributed to the primary alone, which means that a change in brightness is followed by a colour change of the primary. We interpret the colour change as due to a change in the effective temperature and conclude that the 'darker regions' present on the visible hemisphere at the light minimum are relatively cooler. Spectroscopic studies of HR 1099 by Ramsey & Nations (1980) have shown that a difference of ~ 1000 K exists between the spot and the photosphere. Similar studies in the case of HD 81410 would be fruitful.

Table 4 also shows that the maximum effect of the F-type secondary is felt in the $(U-B)$ colour and to a lesser degree in the $(B-V)$. As primary becomes fainter, the increased fractional contribution to the composite $(U-B)$ and $(B-V)$ colours by the secondary partly compensates the colour changes that occur in the primary. This explains why $(U-B)$ shows less variation as the brightness changes. If we assume that $V = 7.40$ mag, which is the maximum observed brightness, corresponds to the 'quiescent state' of the primary, then on subtraction of the colours of an F5 V component from the observed colours of HD 81410, we find when $V = 7.90$ mag, which is the minimum observed brightness, $(U-B) = 1.18$, $(B-V) = 1.17$ and $(R-I) = 0.62$. This tallies well with the colours of a K2 III star (Johnson 1966). We have already seen that the colours of the primary at maximum observed brightness agree well with those of a K0 III star.

6 Conclusion

Photometry of HD 81410 obtained between 1981 January 3 and 1981 March 14 shows that the amplitudes of light variation are close to 0.15 mag. This is considerably less than the 0.45 mag variation observed by Eggen during 1971–72. It is found that the period 12.86833 day satisfies all the available photometric and radial velocity observations. The orbital elements for the case of zero eccentricity are derived. We find that the spectral types K0 III and F5 V for the components tally well with the observed colours of HD 81410 when it is at its maximum brightness. The system is seen to be redder at light minimum and we interpret this as due to the relatively cooler temperatures of the 'darker regions' present on the visible hemisphere.

The orbital period, spectral types of the components and the strong Ca II H and K emission indicate that HD 81410 is a member of the RS CVn group of binaries. Three image tube spectrograms of HD 81410 at Hα taken on 1981 March 14.83, 15.79 and 16.77 at 66 Å mm^{-1} dispersion with the 102-cm reflector of the Kavalur Observatory show that the line is completely filled in by emission. This confirms the earlier observations of Bidelman & MacConnell (1973). The strong H and K emission, filled Hα line and the photometric peculiarities indicate that HD 81410 has an active chromosphere. Several members of the RS CVn group are known to be variable X-ray and radio sources (Walter *et al.* 1980; Spangler, Owen & Hulse 1977). It wold be interesting to know whether HD 81410 is also an X-ray and a radio emitter.

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