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# PHOTOELECTRIC OBSERVATIONS AND THE WAVE MINIMUM OF RS CVn

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**Abstract.** $B$, $V$ observations of the eclipsing binary RS CVn have been presented. A dip around $0\overset{\mathrm{p}}{.}1$ appears to be a wave minimum which fits well in the 'Wave minimum phase-time' relation, but deviates from the 'Wave aplitude-time' relation, derived for the RS CVn. Either, the 'Wave amplitude-time' relation requires a modification or the amplitude of the wave minmum appears masked by the intrinsic variability of one of the components or by the Sun-spot activity of the system. The colour exhibits variation. The secondary component appears active.

## 1. Introduction

The eclipsing binary RS Canum Venaticorum (Sp: F2–5, G8–K2) was discovered and identified as Algol-type binary by Ceraski (1914). Hoffmeister (1915), Nijland (1920) established the nature of the light curve and determined the light elements. Schneller (1928), Sitterly (1930), Keller and Limber (1951), Popper (1961), Chisari and Lacona (1965), and Catalano and Rodonó (1967) analysed the system. Joy (1930) and Popper (1961) classified the components. Nelson and Duckworth (1968) reported variations in the light curve of RS CVn. Hall (1972) gave a model for explaining the light curve peculiarities of the system. Pfeiffer and Koch (1973, 1977) presented the polarization measures of RS CVn. Weiler (1975) reported correlation between minimum of the wave-like distortion, and H and K line of Ca II and H$\alpha$ emissions. Altenhoff *et al.* (1976) found radio emission from RS CVn. Many investigators initiated period study of the system, the important one belongs to Hall and Kreiner (1980). Recently, Rodonó *et al.* (1986) presented spot-modelling of the system.

## 2. Observations

The eclipsing binary system RS CVn was observed photoelectrically on the 25-cm refractor of the Uttar Pradesh State Observatory, using an unrefrigrated 1P21 photomultiplier tube, $B$ and $V$ filters of the Johnson and Morgan system, and an amplifier $B$ with a power pack. The output is recorded on a strip chart recorder. Two night of observations (24 and 27 April, 1960) have been secured. Two comparison stars BD + 35°2421 and BD + 35°2422 were used to begin with, however, the latter comparison star was finally chosen to obtain the differential magnitudes of the system owing to its better constancy. The average deviations of the individual observations for the comparison star (BD + 35°2422) were $\pm 0\overset{\mathrm{m}}{.}009$ ($B$) and $\pm 0\overset{\mathrm{m}}{.}008$ ($V$). The standard differential magnitudes and colour of each night are listed in Tables I, II, and III, and

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TABLE I

Standard *B* observations of RS CVn

| J.D. (Hel). | Phase | Δ*m* (C–V) | J.D. (Hel.) | Phase | Δ*m* (C–V) |
|---|---|---|---|---|---|
| 2437049.1207 | $2^{d}.1413$ | $0^{m}.022$ | 2437052.2080 | $0^{d}.4308$ | $0^{m}.004$ |
| .1232 | 1.1438 | 0.013 | .2114 | 0.4342 | 0.004 |
| .1232 | 2.1513 | 0.033 | .2144 | 0.4372 | 0.006 |
| .1307 | 2.1546 | 0.053 | .2553 | 0.4781 | 0.012 |
| .1340 | 2.1572 | 0.048 | .2590 | 0.4818 | 0.008 |
| .1366 | 2.1593 | 0.058 | .2623 | 0.4851 | 0.019 |
| .1387 | 2.1760 | 0.055 | .2822 | 0.5050 | 0.016 |
| .1554 | 2.1781 | 0.050 | .2854 | 0.5082 | 0.005 |
| .1575 | 2.1800 | 0.058 | .2891 | 0.5119 | 0.000 |
| .1594 | 2.1846 | 0.052 | .2928 | 0.5156 | 0.001 |
| .1640 | 2.2043 | 0.065 | .3110 | 0.5338 | 0.002 |
| .1827 | 2.2073 | 0.070 | .3147 | 0.5375 | −0.005 |
| .1857 | | | .3183 | 0.5411 | −0.005 |
| 052.1374 | 0.3602 | 0.017 | .3219 | 0.5447 | +0.001 |
| .1409 | 0.3637 | 0.017 | .3472 | 0.5700 | −0.006 |
| .1444 | 0.3672 | 0.021 | .3511 | 0.5739 | −0.026 |
| .1481 | 0.3709 | 0.019 | .3549 | 0.5777 | −0.005 |
| .1671 | 0.3899 | 0.012 | .3698 | 0.5926 | +0.009 |
| .1705 | 0.3933 | 0.018 | .3739 | 0.5968 | 0.021 |
| .1739 | 0.3967 | 0.004 | .3770 | 0.5999 | 0.016 |
| .1781 | 0.4009 | 0.012 | | | |

TABLE II

Standard *V* observations of RS CVn

| J.D. (Hel). | Phase | Δ*m* (C–V) | J.D. (Hel.) | Phase | Δ*m* (C–V) |
|---|---|---|---|---|---|
| 2437049.1195 | $2^{d}.1401$ | $0^{m}.015$ | 2437052.2061 | $0^{d}.4289$ | $-0^{m}.032$ |
| .1217 | 2.1423 | 0.013 | .2098 | 0.4326 | −0.042 |
| .1313 | 2.1524 | 0.029 | .2128 | 0.4356 | −0.034 |
| .1356 | 2.1562 | 0.033 | .2539 | 0.4767 | −0.026 |
| .1375 | 2.1581 | 0.036 | .2570 | 0.4798 | −0.020 |
| .1396 | 2.1602 | 0.026 | .2609 | 0.4837 | −0.025 |
| .1544 | 2.1750 | 0.042 | .2639 | 0.4867 | −0.031 |
| .1566 | 2.1772 | 0.039 | .2839 | 0.5067 | −0.041 |
| .1585 | 2.1791 | 0.035 | .2874 | 0.5102 | −0.038 |
| .1619 | 2.1825 | 0.042 | .2909 | 0.5137 | −0.040 |
| .1657 | 2.1863 | 0.053 | .2945 | 0.5173 | −0.042 |
| .1809 | 2.2055 | 0.064 | .3126 | 0.5354 | −0.044 |
| .1846 | 2.2062 | 0.061 | .3163 | 0.5391 | −0.045 |
| 052.1355 | 0.3583 | −0.036 | .3202 | 0.5429 | −0.043 |
| .1392 | 0.3620 | −0.040 | .3239 | 0.5467 | −0.045 |
| .1426 | 0.3654 | −0.038 | .3491 | 0.5719 | −0.055 |
| .1460 | 0.3688 | −0.039 | .3533 | 0.5761 | −0.045 |
| .1653 | 0.3881 | −0.032 | .3572 | 0.5800 | −0.048 |
| .1688 | 0.3916 | −0.041 | .3682 | 0.5910 | −0.027 |
| .1721 | 0.3949 | −0.039 | .3712 | 0.5940 | −0.022 |
| .1760 | 0.3988 | −0.044 | .3752 | 0.5981 | −0.017 |

TABLE III

Colour indices of RS CVn

| Phase | $\Delta(B-V)$ | Phase | $\Delta(B-V)$ | Phase | $\Delta(B-V)$ |
|---|---|---|---|---|---|
| 2$^{d}$.1407 | 0$^{m}$.007 | 0$^{d}$.3629 | 0$^{m}$.057 | 0$^{d}$.5096 | 0$^{m}$.043 |
| 2.1431 | 0.000 | 0.3663 | 0.059 | 0.5128 | 0.040 |
| 2.1519 | 0.004 | 0.3699 | 0.058 | 0.5165 | 0.043 |
| 2.1554 | 0.020 | 0.3890 | 0.044 | 0.5349 | 0.046 |
| 2.1576 | 0.012 | 0.3925 | 0.059 | 0.5383 | 0.040 |
| 2.1598 | 0.032 | 0.3958 | 0.043 | 0.5420 | 0.038 |
| 2.1755 | 0.013 | 0.3999 | 0.056 | 0.5457 | 0.046 |
| 2.1777 | 0.021 | 0.4299 | 0.036 | 0.5760 | 0.049 |
| 2.1796 | 0.023 | 0.4334 | 0.046 | 0.5800 | 0.019 |
| 2.1836 | 0.010 | 0.4364 | 0.040 | 0.5836 | 0.043 |
| 2.1872 | 0.005 | 0.4771 | 0.038 | 0.5968 | 0.036 |
| 2.2034 | 0.001 | 0.4808 | 0.028 | 0.6004 | 0.043 |
| 2.2068 | 0.009 | 0.4844 | 0.044 | 0.6040 | 0.033 |
| 0.3593 | 0.053 | 0.5059 | 0.057 | – | – |

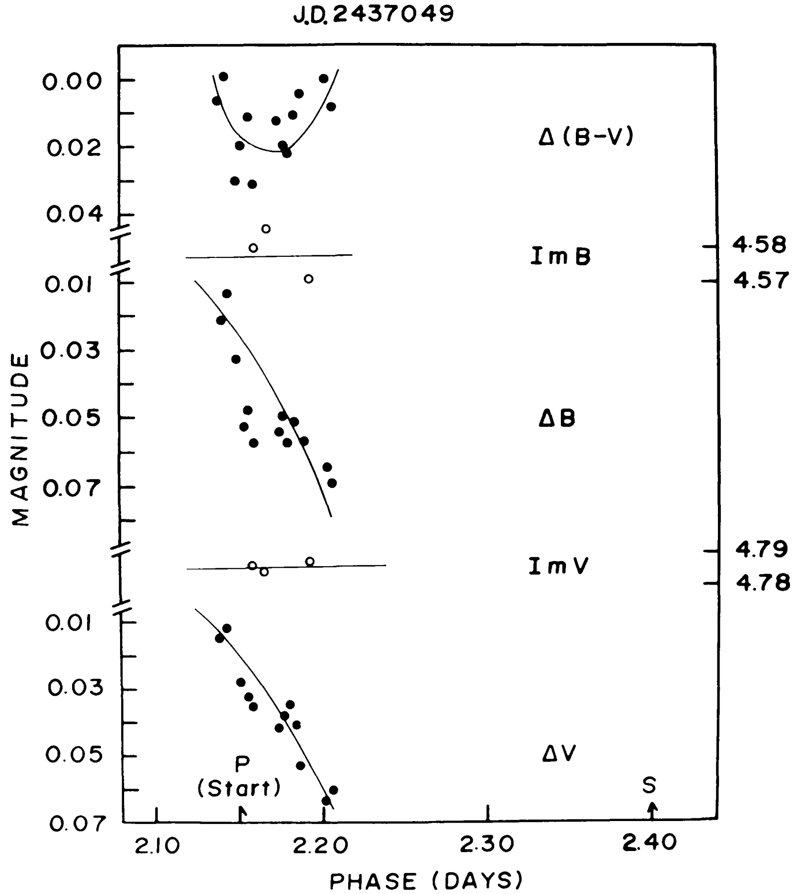

Fig. 1. Light and colour curves of RS CVn on J.D. 2437049. Solid curves represent the smoothened light and colour curves.

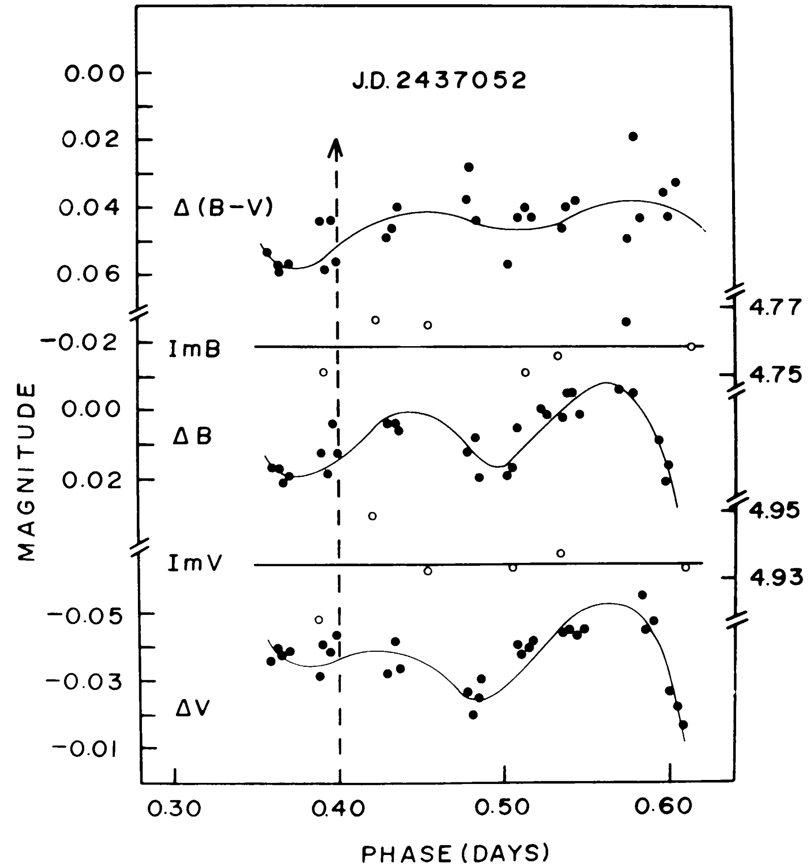

Fig. 2. Light and colour curves of RS CVn on J.D. 2437052. Solid curves represent the smoothened light and colour curves.

are plotted in Figures 1 and 2, alongwith the instrumental magnitudes of the comparison stars.

## 3. Tentative Colours

The $B - V$ colours of the comparison and the variable star have been obtained on both nights, the average colours come out to be $B - V = 0^m.58$ and $B - V = +0^m.64$, respectively, which place these into F9V and G0IV–III spectral-luminosity classes, when compared with the standard colour sequences, given by Golay (1974). The spectral class of the comparison star (F9) is in fair agreement with its spectral class (G0) given earlier, while the spectral class of the variable (G0) appears somewhat different from G8, given by Keller and Limber. Since there are not sufficient number of observations; hence, these colours can not be taken for granted.

## 4. Wave Minimum

A minimum (or dip) of $0^m.025$ ($B$) and $0^m.029$ ($V$) around phase 0.1 is visible on J.D. 2437052. The average amplitude of the wave is nearly $0^m.03$, which is more than

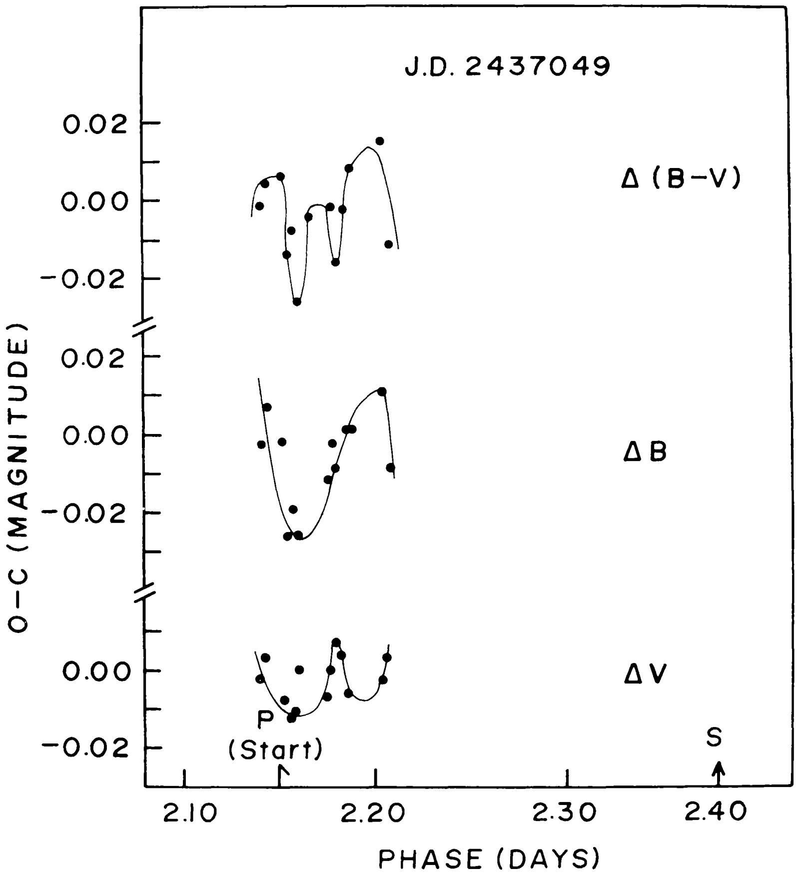

Fig. 3. The O–C residuals (observed minus smoothened values) of the light curves of J.D. 2437049.

$3\sigma$ level of the errors, hence, its existence is important. The position of the dip ($\simeq 0^{\mathrm{d}}.5$) lies well beyond the primary and the secondary minima. This can be caused either by the intrinsic variability of one of the components or due to the distortion wave minimum. If the wave is sinusoidal and symmetric than the maximum amplitude (max. to min.) may be $0^{\mathrm{m}}.06$. Because we did not find it to be fitting in any type of intrinsic variable, as it possesses an amplitude of $0^{\mathrm{m}}.06$ and spectral-type (at maximum) as F9. Moreover, the dip appears stronger in the *V* than in the *B* filter; hence, we feel that it is nothing but a distortion wave minimum which is caused by the stellar spots. It is well known that wave-like distortions are found in the RS Canum Venaticorum-type binaries, which is produced by the movement of spots. The wave minimum is asymmetric as the ascending branch is steeper than the descending branch.

In Figure 2, the first point of the instrumental magnitudes of the comparison star appears to be off than the others, hence, even if we do not consider the points earlier than $0^{\mathrm{d}}.4$ (dashed line), the position of the wave minimum remains unaffected.

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## 5. Intrinsic Variability or Activity

The light and colour curves of J.D. 2437049 and J.D. 2437052 show large scatter around the smoothened light curves. The scatter appears appreciably larger on J.D. 2437049. In order to understand the cause of this scatter, we have obtained the O–C (magnitude) residuals of each observed point from the smoothened (or C) light curves. These residuals are plotted in Figures 4 and 5. The maximum deviations (residuals) are $0\overset{m}{.}038$ (*B*) and $0\overset{m}{.}021$ (*V*) on J.D. 2437049, and $0\overset{m}{.}018$ (*B*) and $0\overset{m}{.}016$ (*V*) on J.D. 2437052. Their average deviations are nearly $0\overset{m}{.}03$ and $0\overset{m}{.}02$, which are appreciable in the light of errors of observations. The observations of J.D. 2437049 lie outside the eclipses, where the spectral type appears to be F9V, and the observations of J.D. 2437052 lie around the descending branch of the secondary minimum, well beyond the totality region of the secondary (annular) eclipse, where the spectral type appears to be G-type (or late G as given earlier). The residuals of the light curves, show continuous variation in both filters, and are indicative of the intrinsic variability of either component. The deviations are seen stronger on J.D. 2437049 than on J.D. 2437052. In the *Catalogue of Graded Photometric Studies of Close Binaries*, the secondary component of RS CVn is quoted as an intrinsic variable. We adopt this contention and

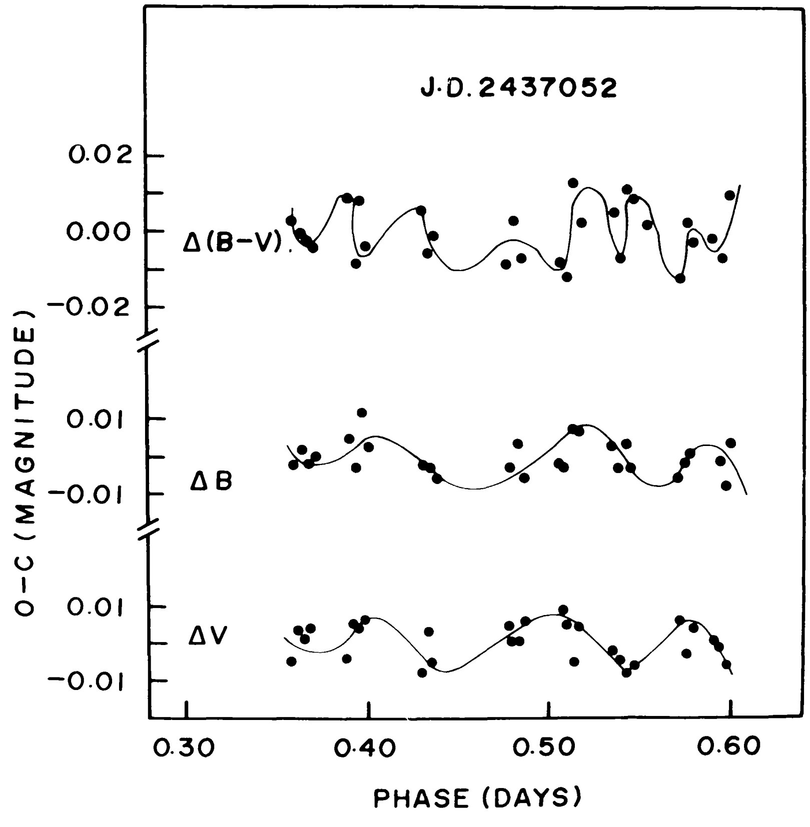

Fig. 4. The O–C residuals (observed minus smoothened values) of the light curves of J.D. 2437052.

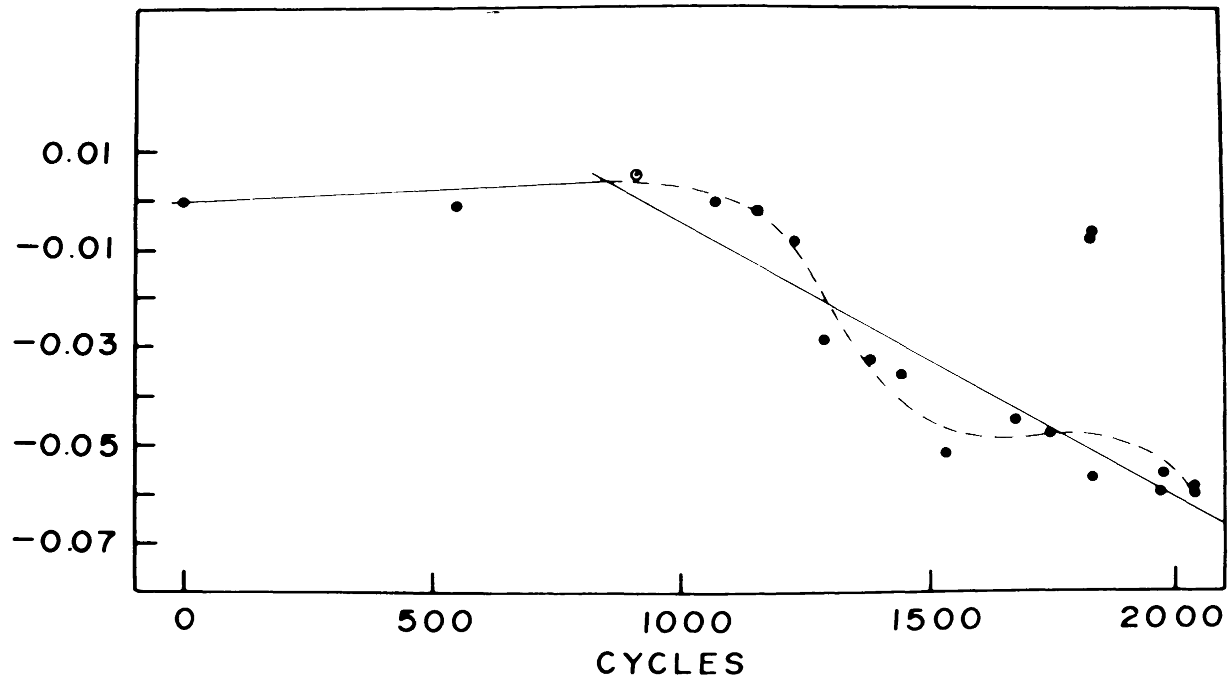

Fig. 5. O–C diagram of the RS CVn. Solid lines represent the period trends, while the dashed curve shows the period fluctuations around the declining trend.

consider the residual changes. These residuals show similar variations in both filters. Adopting the spectral type of the secondary component as late G- or early K-type and the present maximum amplitudes of the residuals as $0\overset{m}{.}03$ (*B*) and $0\overset{m}{.}02$ (*V*), we find that the variability cannot be attributed to any type of intrinsic variables. Thus, we infer, that these superposed light variations are not caused by the intrinsic variability of either component.

Since the variability is seen slightly stronger in *B* filter than in the *V* filter, and the shape of individual dips (Figures 3 and 4) show slightly differing variations, being more steeper in *B* than in *V* on J.D. 2437049, hence, we feel that such variations are due to the spot activity of the secondary component of RS CVn. Weiler (1975) has found that phases of maximum H$\alpha$ and H, K of Ca II emissions coincide with the minimum of the wave-like distortion. Thus, the activity of the secondary component appears reasonable.

## 6. O–C Diagram

Hall (1972) interpreted that the minimum of the wave is caused by large-scale spot activity on the hemisphere of the late type component in RS CVn. We have collected all the photoelectric minima of RS CVn from Hall and Kreiner (1980) alongwith one visual minimum (shown by a point inside the circle in Figure 5), which lies around the epoch of our observations, and have constructed an O–C diagram from ephemeris (Keller and Limber, 1951)

$$\text{Primary Minimum} = \text{J.D. } 2433016.819 + 4\overset{d}{.}79781E\,.$$

The O–C diagram shows a sudden period change at 840 cycles with a tendency to decline. Also, the period shows appreciable fluctuations around the declining trend.

## 7. Supportive Evidence of Wave Migration

Since the variability of RS CVn could not be attributed to any class of the intrinsic variables, hence, we felt that the dip around $0^d.5$ is nothing but a distortion wave minimum. The supporting evidences for this inference is given below.

Hall (1972) explained the nature of the distortion wave minimum of RS CVn and gave 'Wave minimum phase-time' and 'Wave amplitude-time' relations. He has considered both the possibilities that the wave is migrating uniformly as well as non-uniformly. Figure 2 of Hall (1972) has been reproduced here as Figure 6. In the 'Wave minimum phase-time' relation, which is valid for non-uniformly migrating wave (Figure 6). The phase of present wave minimum ($0^p.1$) has been shown by a solid circle in the figure.

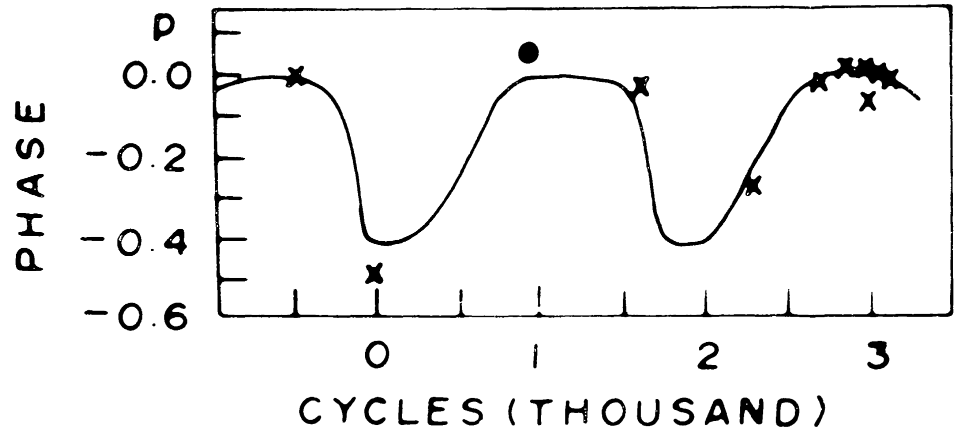

Fig. 6. Wave minimum phase and time-relation of RS CVn valid for non-uniformly migrating wave (cf. Hall, 1972).

The present phase of the minimum fairly conforms to the phase-time relation for non-uniformly migrating wave. However, present results

$$\Delta V \simeq 0^m.06 \text{ (max. to min.)}, \quad \theta(\text{min}) = 0^p.1$$

do not conform to the 'Wave-amplitude-time' relation given by Hall (1972) for the uniformly migrating wave. Thus, we infer that the wave is non-uniform. The present amplitude (which is double of $0^m.03$) appears less than half the predicted one. This may be due to two reasons: (a) either the wave amplitude is masked by the activity of the secondary component; or (b) the 'amplitude-time' relation needs modification, because Hall (1972) has assumed that the Sun-spot cycle is lasting 1800 orbital cycles or $23\frac{1}{2}$ years, which perhaps may not be true. Sahade and Wood (1978) have stated that the amplitude of the travelling wave has varied from $V = 0^m.2$ to amounts difficult to detect with certainty, perhaps this is in the line of the present low-amplitude case.

The other supporting evidence comes from the O–C diagram (Figure 5). A sudden period change (showing a declining tendency) of $\simeq 10^{-5}$ d appears to have occurred nearly at 840 orbital cycles. Our observations of wave minimum phase lie nearly at 841 orbital cycles. Thus, it is evident that a sudden jump of period has occurred around the time of our observations. If the period change is caused by a sudden sporadic mass ejection from RS CVn; it might have probably been caused by the concentration of the spot activity. Such possibility has already been discussed by Hall and Kreiner (1980). Since non-uniform variations are visible (Figures 3 and 4) in the two filters, and which have been attributed to the spot activity of the secondary component of RS CVn, and is also supported by the sudden period change around the wave minimum time in he present observations, which is generated by the maximum spot activity, our inference of possible wave minimum is reasonable. The overall discussions indicate that the present dip on J.D. 2437052 is a distortion wave minimum.

## 8. General Comments

Although our observations were taken in 1960, they are still important on two grounds:

(a) No wave minimum observations are available in the literature (cf. Hall, 1972) around 1960.

(b) These are the supplementary observations, which fill in the gap between Schneller's (1928) and Keller and Limber's (1951) observations. Srivastava (1986) has already emphasized that even a part of observations of the RS CVn binaries are important in considering the distortion wave effect and its migration period, and spot activity.

## 9. Conclusions

Our observation, although taken in 1960, are important as they are supplementary to other observations and bridge the gap between Schneller's and Keller and Limber's observations. In RS CVn systems even a part of observations is important as it provides a clue for understanding the distortion of the light curves and the spot activity. In the present observations, a possible wave minimum is seen around $0\overset{P}{.}1$. The O–C diagram shows a sudden jump in the orbital period of RS CVn, with a tendency to decline, around the time of our wave observations, and this may be correlated with the sporadic mass ejection caused by the spot activity, as suggested by Hall and Kreiner (1980) for the RS CVn systems. Present wave minimum follows 'Wave minimum phase-time' behaviour valid for the non-uniform rate of the wave migration, but does not conform to the 'Wave amplitude-time' relation derived for the 'uniformly' migrrting wave. Our results may necessitate some re-thinking on these relations which are thought to be appropriate for uniformly migrating wave and on the number of orbital cycles of spot activity. In the light curves, appreciable scatter is present which may due to the spot activity of the secondary component as revealed by Weiler (1975). The spectral types, given in this communications, cannot be taken too seriously.

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