J. Astrophys. Astr. (1983) **4**, 161–169

The Distortion Wave on the Light Curve of the RS CVn Binary UV Piscium

P. Vivekananda Rao and M. B. K. Sarma
Centre of Advanced Study in Astronomy, Osmania University, Hyderabad 500007

Received 1983 March 7; accepted 1983 July 4

Abstract. The eclipsing binary UV Piscium was observed with the standard *UBV* filters during 1976–77, 1977–78 and 1978–79 observing seasons with the 1.22-m reflecting telescope of the Japal-Rangapur Observatory. A wave-like distortion on the light curve noticed by Carr (1969), Oliver (1974), Sadik (1979) and Zeilik *et al.* (1982a) is confirmed by the present observations. Combining our observations with those of Carr, Oliver and Sadik, it is found that the distortion wave is moving towards decreasing orbital phase with a period of about 1200 days. The source of the observed distortion wave is found to be the hotter component.

Key words: *UBV* photometry—RS CVn variables—stars, individual.

1. Introduction

The short-period eclipsing binary UV Piscium (BD 6° 197; G2, P = 0.861d) was classified by Oliver (1974)—from its spectroscopic and photometric properties—as a member of the group of stars exhibiting RS CVn type characteristics. Hall (1976) listed this star as a member of the short-period (< 1 d) group of RS CVn systems. The most intriguing photometric feature of the RS CVn binaries is the presence of a wave-like distortion in their outside-of-eclipse light curves (Rodono 1981; Hall 1981). In most of these variables the wave migrates towards decreasing or increasing orbital phase over a time interval that is long compared to the orbital period. Spectroscopically, these binaries exhibit strong H and K emission lines outside of eclipses (Hall 1981; Rodonò 1981). Several competing explanations have been put forth to explain the photometric and spectroscopic characteristics of these binaries (Oliver 1974; Popper 1977). Of all the theories presented so far, the starspot model (Hall 1972; Eaton & Hall 1979) seems to be the most promising one. According to this model, the distortion wave arises due to the presence of spots on the surface of any one component. Moreover, the wave migrates on the light curve because the rotation of the spotted star is not synchronous with the orbital motion (Hall 1981). Variations in the wave migration rate would result from the latitudinal migration of spots over a non-uniformly rotating stellar photosphere.

A distortion wave as discussed above was found to be present in the RS CVn type binary UV Psc from the photoelectric observations of Carr (1969), Oliver (1974), Sadik (1979), Rao & Sarma (1981b) and Zeilik *et al.* (1982a), though Zeilik *et al.* (1981) failed to detect it in 197980. The studies of Carr, Oliver and Sadik had mainly dealt with the solution of light curves. No information was available regarding the effect of the distortion wave on the observed times of minima. Furthermore, the nature of the distortion wave, its migration period and the component responsible for the wave are also not known.

The effect of the distortion wave on the derived times of minima, and the period variations of this system are discussed by us elsewhere (Rao & Sarma 1983). We now discuss the properties of the distortion wave that is present on the light curves of UV Psc, using the photoelectric observations obtained by us in the three consecutive observing seasons 1976–77, 1977–78 and 1978–79 and those made by Carr (1969), Oliver (1974) and Sadik (1979).

2. Observations

UV Psc was observed by us on 47 nights in 17 filter and on 54 nights in *B* and *V* filters of the Johnson & Morgan system, during 1976 October 23–1977 January 18, 1977 October 28–1978 February 5,1978 October 18–1978 December 24. These observations were made using an unrefrigerated EMI 6256B photomultiplier attached to the 1.22-m reflector telescope of the Japal-Rangapur Observatory. The photocurrent was amplified by means of a GR 1230A DC amplifier and was recorded on a Honeywell Brown chart recorder. HD 7542 and HD 7918 were used as comparison and check stars respectively. The observations of the comparison star were used for determining the nightly extinction coefficients. The rms error of Δm (check – comparison) was found to be ~ 0.02 mag in the three colours which indicates that the comparison was constant in brightness within this error during the period of observations. The differential magnitudes Δm (variable–comparison) were corrected for atmospheric extinction and transformed to the Johnson & Morgan standard *UBV* system using the transformation coefficients obtained from observations of a number of standard stars and using the transformation relations given by Hardie (1962). A total of 1110 observations in *V*, 1107 observations in *B* and 942 observations in *U* were obtained during the entire period of observations and have been published elsewhere (Rao & Sarma 1981a).

3. The distortion wave

In order to establish the nature of the wavelike distortion in the RS CVn type eclipsing binaries, outside of eclipse observations should be obtained for several years. We were successful in obtaining complete light curves in *V* and *B* during 1976–77 and 1978–79, and in *U* during 1978–79. Partial light curves (of about 75 per cent) were obtained in *V* and *B* during 197778, and in *U* during 197677 and 1977–78.

To determine the properties of the distortion wave, the average of the outside-of-eclipse observations was used to normalize the light curves. A preliminary (graphical) study of our light curves yielded a value of 27° for the angle of external tangency, θ_e. This value agrees well with the value of 26.°5 reported by Carr (1969) and Sadik (1979).

In most of the RS CVn binaries, the distortion wave is generally approximated to be sinusoidal in shape, suggesting a single grouping of spots on the star's surface (Eaton & Hall 1979; Sarma & Ausekar 1980; Vogt 1981). This is because the Fourier expression used for fitting the outside-of-eclipse light variations is terminated at B_1 only. In reality, one should use a Fourier expression with a larger number of terms (say, n = 4) and determine the limiting value of η for which the coefficients are significant. When the assumed Fourier expression has significant terms up to B_2 and beyond, the distortion wave has two or more minima, which would indicate the presence of more than one spot

Table 1. UV Psc: Fourier coefficients for the points outside the eclipse.

Year (Reference)	Colour	A_0	A_1	A_2	B_1	B_2
1966 (Carr 1969)	*V*	0.97052	−0.00093	−0.00266	+0.01853	−0.00174
	B	0.97255	+0.00258	−0.00238	+0.01989	−0.00203
	U	0.96932	+0.01256	−0.00771	+0.02041	−0.00467
1969 (Oliver 1974)	*V*	1.0023	−0.0087	−0.0196	+0.0005	−0.0028
		±0.0018	±0.0023	±0.0039	±0.0032	±0.0020
	B	1.0043	−0.0123	−0.0142	+0.0011	−0.0083
		±0.0013	±0.0017	±0.0029	±0.0023	±0.0015
	U	1.0048	−0.0185	−0.0166	+0.0044	−0.0077
		±0.0030	±0.0038	±0.0065	±0.0053	±0.0033
1977 (Sadik 1979)	*V*	0.9899	−0.0087	−0.0250	+0.0246	−0.0144
		±0.0015	±0.0022	±0.0024	±0.0015	±0.0016
	B	0.9902	−0.0023	−0.0221	+0.0263	−0.0143
		±0.0015	±0.0022	±0.0024	±0.0015	±0.0016
1976–77 (Rao & Sarma 1981a)	*V*	0.9996	−0.0383	−0.0071	−0.0070	+0.0043
		±0.0014	±0.0020	±0.0021	±0.0015	±0.0015
	B	0.9989	−0.0377	−0.0059	+0.0019	−0.0003
		±0.0014	±0.0021	±0.0023	±0.0016	±0.0016
	U	0.9985	−0.0382	−0.0138	+0.0043	+0.0044
		±0.0020	±0.0030	±0.0031	±0.0022	±0.0022
1977–78 (Rao & Sarma 1981a)	*V*	0.9924	+0.0180	−0.0078	+0.0022	−0.0120
		±0.0031	±0.0053	±0.0041	±0.0028	±0.0037
	B	0.9905	−0.0039	−0.0116	+0.0125	+0.0083
		±0.0029	±0.0049	±0.0039	±0.0027	±0.0034
	U	0.9775	+0.0156	−0.0264	+0.0334	−0.0050
		±0.0047	±0.0088	±0.0062	±0.0042	±0.0065
1978–79 (Rao & Sarma 1981a)	*V*	0.9967	−0.0013	−0.0092	−0.0157	−0.0047
		±0.0010	±0.0014	±0.0015	±0.0009	±0.0010
	B	0.9947	−0.0014	−0.0071	−0.0211	−0.0059
		±0.0012	±0.0016	±0.0018	±0.0010	±0.0011
	U	0.9886	+0.0031	−0.0155	−0.0300	−0.0153
		±0.0022	±0.0031	±0.0034	±0.0020	±0.0022

groups on the surface of the star. For UV Psc, we fitted the outside-of-eclipse light variations to a Fourier series and found that the terms for n= 3 and 4 were not significant. Hence, the light outside of the eclipses is fitted to a Fourier expression of the from

$$l^{\mathrm{obs}} = \sum_{n=0}^{2} A_n \cos n\theta + \sum_{n=1}^{2} B_n \sin n\theta. \tag{1}$$

The values of the Fourier coefficients determined from our own observations and those of Carr (1969), Oliver (1974) and Sadik (1979), along with their probable errors are given in Table 1.

The Fourier coefficients A_1 and A_2 given in Table 1 include the effects (i) of the reflection and ellipticity and (ii) of the wave; *i.e.*,

$$A_{1,2} — A_{1,2}\,(\text{reflection}) + A_{1,2}\,(\text{ellipticity}) + A_{1,2}\,(\text{wave}). \tag{2}$$

Theoretical values of the reflection and ellipticity coefficients in the above equations were obtained from Merrill's (1970) equations using the orbital and light elements determined by Carr (1969), Popper (1976) and Sadik (1979). The derived values are – 0.0032, – 0.0015 and 0.0000 for A_1 (reflection + ellipticity) and – 0.0211, – 0.0265 and – 0.0325 for A_2 (reflection + ellipticity) in V, B and U bands, respectively.

4. Period of the distortion wave

Using the above values of $A_{1,2}$ (reflection + ellipticity), the quantities $A_{1,2}$ (wave) were obtained from Equation (2) for the data given in Table 1. From these derived values of $A_{1,2}$ (wave), and the observed values of B_1 and B_2, the shape of the distortion wave superposed on the light curve of UV Psc can be obtained for each year of observation by the following equation:

$$l = A_0 + A_1\,(\text{wave}) \cos\theta + A_2\,(\text{wave}) \cos 2\theta + B_1 \sin\theta + B_1 \sin 2\theta. \tag{3}$$

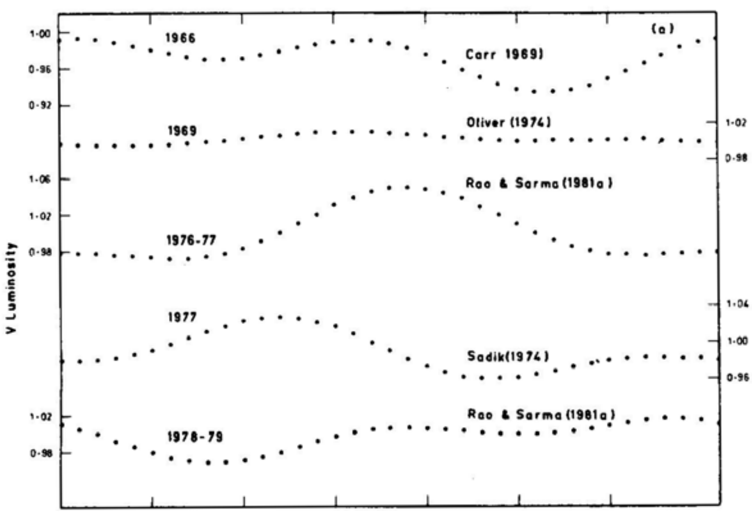

Figure 1. Distortion wave of UV Psc in (a) V, (b) B and (c) U bands based on the observations of Carr (1969), Oliver (1974), Sadik (1979) and Rao & Sarma (1981a). The 1977–78 observations of Rao & Sarma are not plotted as the data for that year is discontinuous.

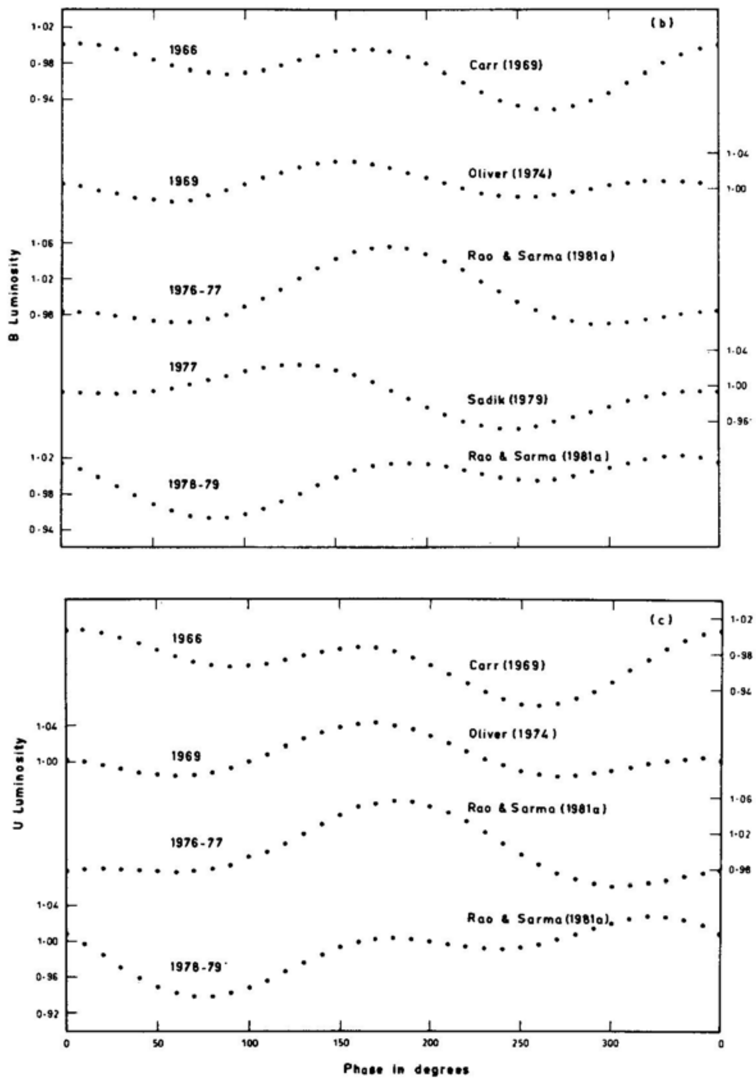

Figure 1. Continued.

From the above equation, the value of l for various values of θ gave us two minima ($\theta^{1}_{\min}$ and $\theta^{11}_{\min}$) of the distortion wave for each year. Fig. 1 shows the shapes of the photometric wave and the position of the two minima $\theta^{1}_{\min}$ and $\theta^{11}_{\min}$ in V, B and U for the observations made by Carr (1969), Oliver (1974), Sadik (1979) and by us. This double-peaked distortion wave as observed in Fig. 1 indicates that there are two cool regions separated in longitude located on the surface of any one of the components. Such waves have been reported for the non-eclipsing RS CVn binaries like II Peg (Nations & Ramsey 1981), V711 Tau (Blanco *et al.* 1981; Bartolini *et al.* 1983) and HD 185151 (Bopp *et al.* 1982).

The semi-amplitudes .K_1 and K_2 of the distortion wave for each year of observation were calculated using the equation

$$K_{1,2} = [A^2_{1,2}\,(\text{wave}) + B^2_{1,2}]^{1/2}. \qquad (4)$$

Table 2. UV Psc: Wave amplitudes and wave minima for the data given in Table 1.

Year	Colour	K_1 (light units)	K_2 (light units)	$\theta^{\mathrm{I}}_{\mathrm{min}}$	$\theta^{\mathrm{II}}_{\mathrm{min}}$	$\langle\theta^{\mathrm{I}}_{\mathrm{min}}\rangle$	$\langle\theta^{\mathrm{II}}_{\mathrm{min}}\rangle$	Mean HJD
1966	V	0.019	0.018	0.7389	0.2472			
	B	0.020	0.024	0.7361	0.2500	0.7324	0.2509	2439404.3
	U	0.024	0.025	0.7222	0.2556			
1969	V	0.006 ± 0.002	0.003 ± 0.004	0.1111 ± 0.0687	0.7472 ± 0.0492			
	B	0.011 ± 0.002	0.015 ± 0.003	0.1750 ± 0.0187	0.7306 ± 0.0083	0.1518	0.7454	2440472.4
	U	0.020 ± 0.005	0.018 ± 0.007	0.1694 ± 0.0373	0.7583 ± 0.0027			
1977	V	0.025 ± 0.002	0.015 ± 0.002	0.6556 ± 0.0115	0.0222 ± 0.0145			
	B	0.026 ± 0.002	0.015 ± 0.002	0.6806 ± 0.0089	0.0750 ± 0.0109	0.6681	0.0486	2443457.9
1976–77	V	0.036 ± 0.002	0.015 ± 0.002	0.8833 ± 0.0347	0.1806 ± 0.0235			
	B	0.036 ± 0.002	0.021 ± 0.002	0.8194 ± 0.0092	0.1722 ± 0.0171	0.8472	0.1741	2443118.7
	U	0.039 ± 0.003	0.019 ± 0.004	0.8389 ± 0.0161	0.1694 ± 0.0365			
1977–78	V	0.021 ± 0.006	0.018 ± 0.006	0.6528 ± 0.0173	0.2417 ± 0.0333			
	B	0.013 ± 0.004	0.017 ± 0.005	0.7861 ± 0.0053	0.2917 ± 0.0212	0.7083	0.2667	2443495.1
	U	0.037 ± 0.007	0.008 ± 0.009	0.6861 ± 0.0267	...			
1978–79	V	0.016 ± 0.001	0.013 ± 0.002	0.2306 ± 0.0094	0.6972 ± 0.0228			
	B	0.021 ± 0.001	0.020 ± 0.002	0.2306 ± 0.0010	0.7167 ± 0.0160	0.2241	0.6907	2443833.7
	U	0.030 ± 0.002	0.023 ± 0.004	0.2110 ± 0.0130	0.6583 ± 0.0173			

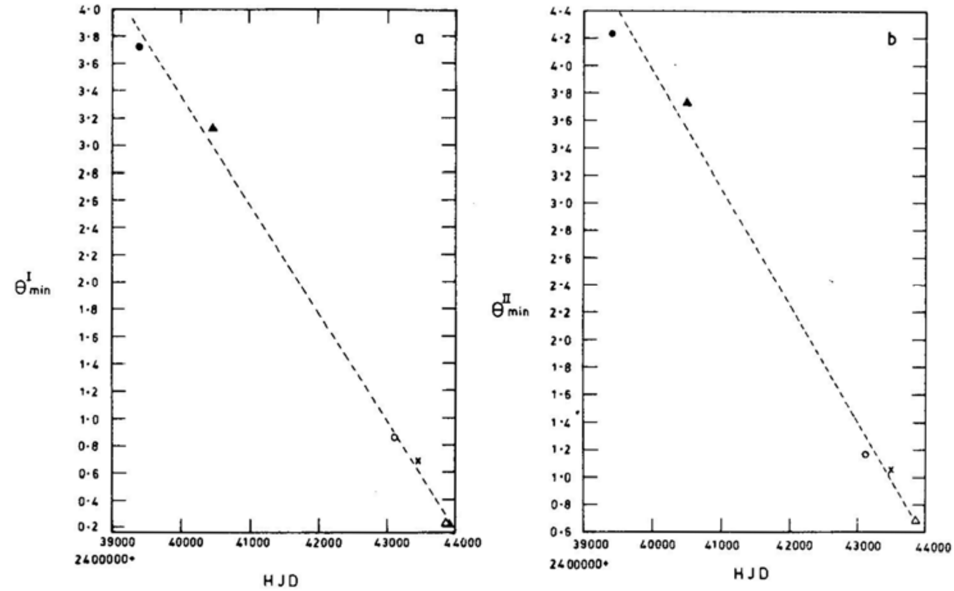

Figure 2. Plots of (a) $\theta^{1}_{\mathrm{min}}$ (deeper minimum) and (b) $\theta^{11}_{\mathrm{min}}$ (shallower minimum) versus heliocentric Julian day. Filled circle: Carr (1969); filled triangle: Oliver (1974); cross: Sadik (1979); open circle and open triangle: Rao & Sarma (1981a) data for the years 197677 and 1978–79, respectively.

The derived values of the semi-amplitudes (K_1 and K_2), and of $\theta^{1}_{\mathrm{min}}$ and $\theta^{11}_{\mathrm{min}}$ are listed in Table 2. The mean heliocentric Julian day (HJD) for the period of observations is also given. Fig. 2 shows the plots of the mean $\theta^{1}_{\mathrm{min}}$ and $\theta^{11}_{\mathrm{min}}$ for *UBV* colours against the mean HJD. It is clear from these plots that during 1966–1979, both the wave minima ($\theta^{1}_{\mathrm{min}}$ and $\theta^{11}_{\mathrm{min}}$) migrated towards decreasing orbital phase completing one cycle of migration in nearly 1200 days or 1394 orbital cycles. This period and direction of wave migration is a preliminary result since it is based on the limited data available. In fact, most RS CVn systems, in particular RS CVn itself which has been observed systematically for many years, do show variable migration rates and even migration reversal (Blanco *et al.* 1982).

It can be seen from Table 2 that the semi-amplitudes (K_1 and K_2) of the wave are the same in *UBV* colours indicating no colour dependence for the wave. This is similar to the result obtained for the systems Z Her (Oliver 1974) and HR 1099 (Bartolini *et al* 1983; Sarma & Ausekar 1980) but is in variance with the result obtained for the systems RS CVn, SS Boo, SS Cam and RW UMa (Oliver 1974) in which the wave amplitudes were found to decrease with decreasing wavelength. From Table 2 it is found that the semi-amplitude K_1 of the wave is larger than K_2 This Indicates that the spot region responsible for the semi-amplitude K_1 of the wave is approximately two times more intense than the spot region responsible for K_2.

5. Source of the distortion wave

In order to determine which component of the binary is responsible for the wave, we have proceeded in the following way. The light curves obtained by us for each year

Table 3. UV Psc: percentage of light contributed by the wave in terms of L_h and L_c

Year	Component star	P_1*			P_2*		
		V	B	U	V	B	U
1966	hotter star	2.3	2.4	2.7	2.2	2.9	2.8
	cooler star	10.4	12.4	22.8	9.9	14.9	23.8
1969	hotter star	0.7 ± 0.2	1.3 ± 0.2	2.2 ± 0.6	0.4 ± 0.5	1.8 ± 0.4	2.0 ± 0.8
	cooler star	3.3 ± 1.1	6.8 ± 1.2	19.0 ± 4.8	1.6 ± 2.2	9.3 ± 1.5	17.1 ± 6.7
1977	hotter star	3.0 ± 0.2	3.1 ± 0.2	···	1.8 ± 0.2	1.8 ± 0.2	···
	cooler star	13.7 ± 1.1	16.1 ± 1.2	···	8.2 ± 1.1	9.3 ± 1.2	···
1976–77	hotter star	4.4 ± 0.2	4.3 ± 0.2	4.4 ± 0.2	1.8 ± 0.2	2.5 ± 0.2	2.1 ± 0.4
	cooler star	19.8 ± 1.1	22.4 ± 1.2	37.1 ± 2.8	8.2 ± 1.1	13.0 ± 1.2	18.1 ± 3.8
1977–78	hotter star	2.6 ± 0.7	1.5 ± 0.5	4.1 ± 0.8	2.2 ± 0.7	2.0 ± 0.6	0.9 ± 1.0
	cooler star	11.5 ± 3.3	8.1 ± 2.5	35.2 ± 6.7	9.9 ± 3.3	10.6 ± 3.1	7.6 ± 8.6
1978–79	hotter star	2.0 ± 0.1	2.5 ± 0.1	3.4 ± 0.2	1.6 ± 0.2	2.4 ± 0.2	2.5 ± 0.4
	cooler star	8.8 ± 0.5	13.0 ± 0.6	28.6 ± 1.9	7.1 ± 1.1	12.4 ± 1.2	21.9 ± 3.8

* P_1 and P_2 are the percentages of light contributed by semi-amplitudes K_1 and K_2 of the wave, respectively.

during 1976–79, were independently corrected for the distortion wave in *UBV* colours and the observations were later combined to get one light curve for each colour. These combined light curves in *UBV* colours were solved for the orbital and light elements using the modified Wellmann's method. The solution of the light curves and the elements so obtained will be published elsewhere. Using the contributions of individual components L_h and $L_c = (1 - L_h)$ obtained from the combined solution for each colour, the percentages of light (P_1 and P_2) contributed by the wave amplitudes with respect to the hotter and cooler components are calculated and are given in Table 3. The adopted values of L_h are 0.818, 0.839 and 0.895 in *V, B* and *U* bands, respectively. It is very clear from Table 3 that the wave amplitudes contribute nearly the same percentage of the light of the hotter star in all the three colours. Hence it is concluded that the hotter star is responsible for the wave in UV Psc. In this respect, UV Psc is similar to the systems XY UMa (Geyer 1979) and AR Lac (Popper 1977) where the hotter star is found to be responsible for the wave; but it is in variance with the general conclusion that the cooler component is responsible for the wave in a majority of RS CVn systems (Eaton & Hall 1979, Arnold *et al.* 1979).

6. Conclusions

Like other members of the RS CVn group, UV Psc exhibits a distortion wave outside the eclipse. The present photoelectric studies and the studies by Carr (1969), Oliver (1974) and Sadik (1979) indicate that this system exhibits a double-peaked distortion wave thereby suggesting the presence of two cool dark regions. The wave minima in UV Psc migrated towards decreasing orbital phase completing one cycle in 1200 days or 1394 orbital cycles during the period 1969–1979. The source of the distortion wave is found to be the hotter star of spectral type G4-6 V. The amplitudes of the distortion wave are found to be independent of wavelength *(UBV* colours). It is desirable to study this system further to see whether the distortion wave continues to migrate in the retrograde direction or reverses like UX Ari (Zeilik *et al.* 1982b) and RS CVn (Blanco *et al.* 1982). Further, it is also essential to study this binary systematically for many years to investigate whether the rate of migration of the distortion wave is constant or varies like the wave in RS CVn (Blanco *et al.* 1982). Observations in *RI* bands would help in ascertaining the wavelength dependence of the distortion wave in the near-infrared and also in understanding the nature of the secondary component (K1 V).

Acknowledgements

The authors wish to thank Professor K. D. Abhyankar for useful discussions. One of us (PVR) would like to thank the University Grants Commission, New Delhi for providing financial assistance during the tenure of this work.

References

Arnold, C. K, Hall, D. S., Montle, R. E, Stuhlinger, T. W. 1979, *Acta Astr.,* **29**, 243.

Bartolini, C, Blanco, C, Catalano, S., Cerruti-Sola, M., Eaton, J. A., Glarier, A., Hall, D. S., Henry, G. W., Hopkins, J. L., Landis, H. J., Louth, H., Marilli, E., Piccioni, A., Renner, T. R., Rodonò, M., Scaltriti, F. 1983, *Astr. Astrophys.,* **117**, 149.

Blanco, C, Catalano, S., Marilli, E., Rodonò, M. 1982, *Astr. Astrophys.,* **106**, 311.

Blanco, C, Catalano, S., Marilli, E., Rodonò, M., Scaltriti, F. 1981, *Inf. Bull Var. Stars,* No. 2000.

Bopp, B. W., Fekel, F. C, Hall, D. S., Henry, G. W., Noah, P. V., Africano, J., Wilkerson, M. S., Beavers, W. I. 1982, *Astr. J.,* **87**, 1035.

Carr, R. B. 1969, *PhD Thesis,* University of Florida.

Eaton, J. A., Hall, D. S. 1979, *Astrophys. J.,* **227**, 907.

Geyer, E. H. 1979, in *IAU Symp.* 88: *Close Binary Stars: Observations and Interpretation,* Eds M. J. Plavec, D. M. Popper and R. K. Ulrich, D. Reidel, Dordrecht, p. 423.

Hall, D. S. 1972, *Publ. astr. Soc. Pacific,* **84**, 323.

Hall, D. S. 1976, in *IAU Coll.* 29: *Multiple Periodic Variable Stars,* Part I, Ed. W. S. Fitch, D. Reidel, Dordrecht, p. 287.

Hall, D. S. 1981, *Solar Phenomena in Stars and Stellar Systems,* Eds A. K. Dupree and M. Bonnet, D. Reidel, Dordrecht, p. 431.

Hardie, R. H. 1962, in *Astronomical Techniques,* Ed. W. A. Hiltner, University of Chicago Press, p. 178.

Merrill, J. E. 1970, *Vistas in Astronomy,* **12**, 43.

Nations, H. L., Ramsey, L. W. 1981, *Astr. J.* **86**, 433.

Oliver, J. P. 1974, *PhD Thesis,* University of California.

Popper, D. M. 1976, *Inf. Bull. Var. Stars,* No. 1083.

Popper, D. M. 1977, *Highlights in Astronomy,* Vol. 4, Part II, p. 397.

Rao, P. V., Sarma, M. B. K. 1981a, *Contr. Nizamiah Japal-Rangapur Obs.,* No. 14.

Rao, P. V., Sarma M. B. K. 1981b, *in Photometric and Spectroscopic Binary Systems,* Eds E. B. Carling and Z. Kopal, D. Reidel, Dordrecht, p. 305.

Rao, P. V., Sarma, M, B. K. 1983, *Bull astr. Soc. India,* **11**, 75.

Rodonò, M. 1981, in *Photometric and Spectroscopic Binary Systems,* Eds E. B. Carling and Z. Kopal, D. Reidel, Dordrecht p. 285.

Sadik, A. R. 1979, *Astrophys. Space Sci.,* **63**,319.

Sarma, M. B. K., Ausekar, B. D. 1980, *Acta Astr.,* **30**, 101.

Vogt, S. S. 1981, *Astrophys.* J., **250**, 327.

Zeilik, M., Elston, R., Henson, G., Schmolke, P., Smith, P. 1982a. *Inf. Bull. Var, Stars,* No. 2089.

Zeilik, M., Elston, R., Henson, G., Smith, P. 1981, *Inf. Bull Var. Stars,* No. 2006.

Zeilik, M., Elston, R., Henson, G., Smith, P. 1982b, *Inf. Bull. Var. Stars,* No. 2168.