OUT-OF-ECLIPSE LIGHT VARIATION OF RS CVn STARS

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ABSTRACT

The photoelectric observations of the close binary RS CVn carried out at Catania Observatory from 1963 to 1973 are presented. A new period of 9.48 years for the retrograde migration of the wave-like distortion on the light-curve has been determined. The wave amplitude is found to undergo cyclic changes with a period of about 4.74 years.

Possible correlation between the wave amplitude and the inclination of the rotational axis and the spectral type of the spotted component for several RS CVn and BY Dra binaries is investigated.

1. INTRODUCTION

One of the outstanding features of the binary system RS CVn is the retrograde migration on the light-curve of a wave-like distortion which was discovered in the very first years of observations carried out at Catania Observatory (Catalano and Rodonò 1967). Owing to this peculiar out-of-eclipse variability, RS CVn binaries need to be observed carefully for decades in order to ascertain and interpret correctly their physical characteristics.

In the present paper we present the results of Catania observations covering a complete cycle of variability of RS CVn and we analyze the main light-curve features, also for other RS CVn and BY Dra stars.

2. THE LIGHT CURVE OF RS CVn AND ITS VARIATIONS

Eleven out-of-eclipse V-band light-curves of RS CVn obtained at Catania Observatory from 1963 to 1973 are shown in Figure 1. The 1963 light-curve shape is repeated between 1972 and 1973. The retrograde migration of the wave-like distortion is better represented by the decreasing phase of the wave-light minimum as shown in Figure 2. A

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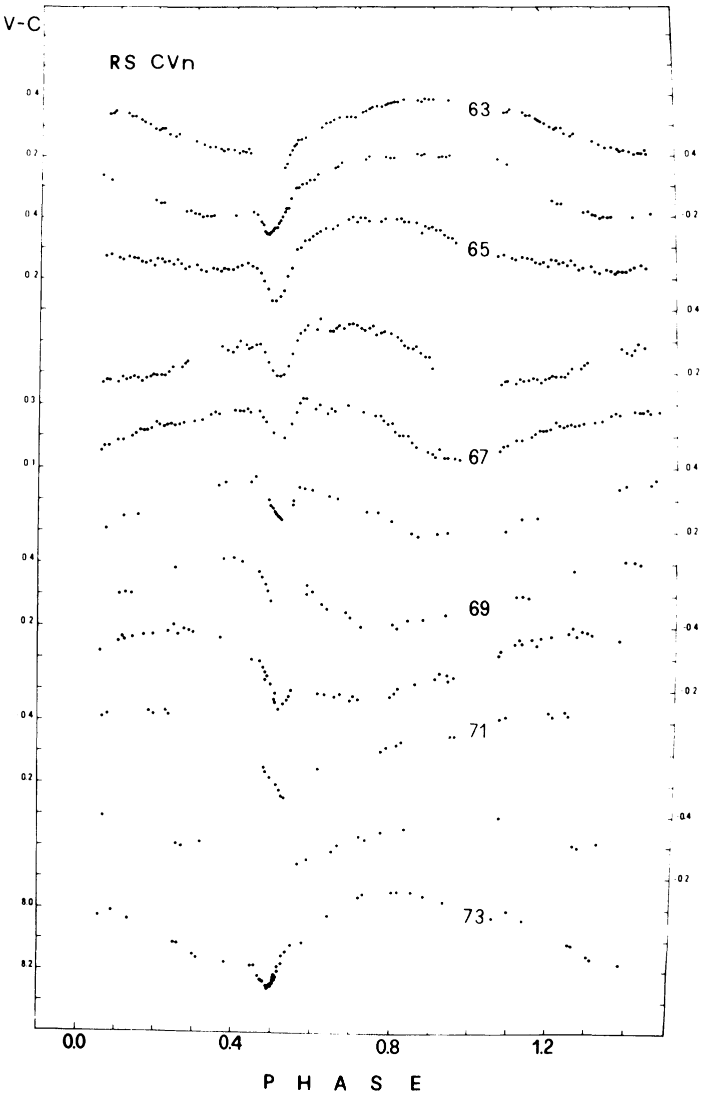

Figure 1. Out-of-eclipse light-curve of RS CVn from 1963 to 1973.

least square fit to the data gives an almost linear migration of the distortion wave with a period $P_W = 9.48$ years or 722 orbital periods. This indicates that the period of variability of the secondary component is $P_{orb} \times (1-1/722)$.

As before (Catalano and Rodonò 1969), each out-of-eclipse

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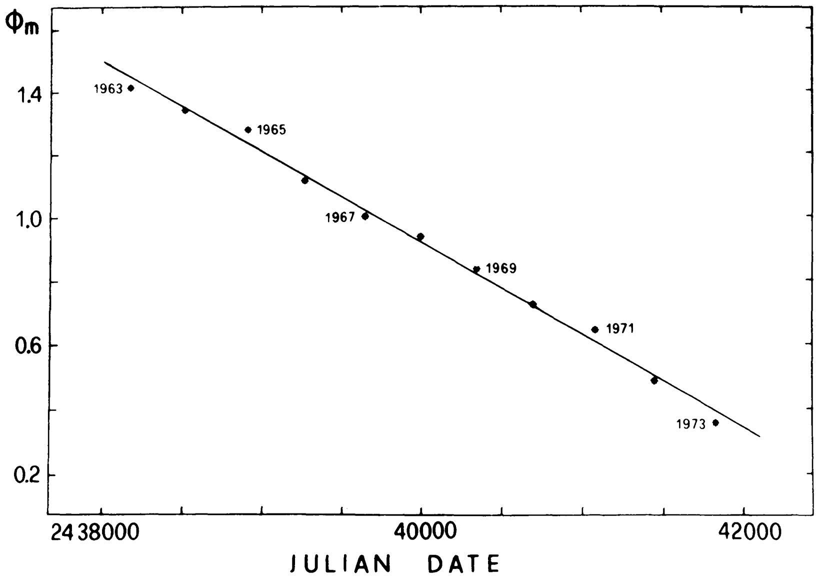

Figure 2. Phase of RS CVn wave distortion minimum versus Julian date. The continuous line represents a linear migration of the wave with a period P_w of 9.48 years or 722 orbital period.

light curve has been represented by a cosine curve in a least square fit to the data in order to determine the phase of the wave minimum (ϕ_{min}), its amplitude (Δ_{min}), and the mean light level (Δm_o). However, since in some light curves the distortion wave is not truly sinusoidal, the adopted least square fit gives a wave amplitude which is underestimated relative to the amplitude obtained as the difference between the maximum and the minimum of the out-of-eclipse light. The resulting data for each year and colour are listed in Table 1. The amplitude of the wave distortion fluctuates almost periodically in about 4.74 years around the mean value of $0\overset{m}{.}088$ with a half amplitude $0\overset{m}{.}013$

A previous analysis of the wave amplitude variation, including old visual and photographic observations (Hall 1972) has led to a considerably larger amplitude variation, from about 0.05 to 0.20, and a period of 23.5 years, much longer than the present one. Additional Catania observations and the 1975 Ludington light-curve shown in Zeilik et al. (1979) are consistent with our present result of a shorter period and a smaller amplitude variation.

3. VARIABILITY OF THE SECONDARY STAR

As already recognized (Catalano and Rodonò 1969) the out-of-eclipse light variation is due to the secondary star. Since the primary minimum

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TABLE 1

Year	Δm_o			Δm_w			ϕ_{min}
	V	B	U	V	B	U	
1963	-0.304	-	-	0.089	-	-	0.413
1964	-0.309	-	-	0.101	-	-	0.339
1965	-0.310	-	-	0.081	-	-	0.278
1966	-0.257	-	-	0.085	-	-	0.118
1967	-0.236	-0.165	-	0.072	0.061	-	0.994
1968	-0.268	-0.171	-0.083	0.084	0.062	0.053	0.943
1969	-0.310	-0.199	-0.096	0.097	0.097	0.062	0.829
1970	-0.278	-0.171	-0.080	0.103	0.082	0.064	0.724
1971	-0.343	-0.222	-0.110	0.074	0.063	0.049	0.645
1972	-0.324	-0.210	-0.096	0.075	0.062	0.040	0.480
1973	-0.371	-0.234	-0.116	0.104	0.083	0.057	0.370

is total, by observing in different seasons, we get magnitude determinations of the secondary star at different phases of its variability. The available V, B-V and U-B at the totality in the standard system from 1967 to 1973 are presented in Figure 3 versus Julian date. The V magnitude covers the period of the intrinsic light variation of the secondary star from phase 1.00 to 0.36. The observed 0.6 magnitude increase of the secondary star is consistent with the observed average out-of-eclipse wave amplitude of the combined light of the entire system.

No large colour variations are observed. The B-V values show a little scatter around the value 0.93. The U-B values give some indication that the secondary star is redder by 0.07 magnitude at minimum relative to the maximum light. This reddening at minimum is not strong enough to be detectable in the combined light of the system. In fact it appears to be even bluer at the minimum of the distortion wave (Catalano and Rodonò 1969) due to the relatively low contribution of the redder star to the combined light of the system at this phase.

We have attempted to find solutions of the best covered light-curves following the Russell-Merrill method (1952) after removing the out-of-eclipse distortion wave. The radius of the primary star turns out to be constant while that of the secondary star shows a variation of about 20%, phase locked with the position of the distortion wave on the light-curve. However, to detect possible residual effects of the distortion-wave on the photometric eclipse, we have treated separately the descending and the ascending branches of the primary minimum, and an average of both. The three solutions show the largest disagreement when the minimum of the distortion wave falls at one of the quadratures, i.e. when the minimum suffers the maximum asymmetry. This would indicate that a residual effect of the distortion wave is still present on the rectified curves. Hence, the variation of the secondary star radius is likely to be a spurious photometric effect.

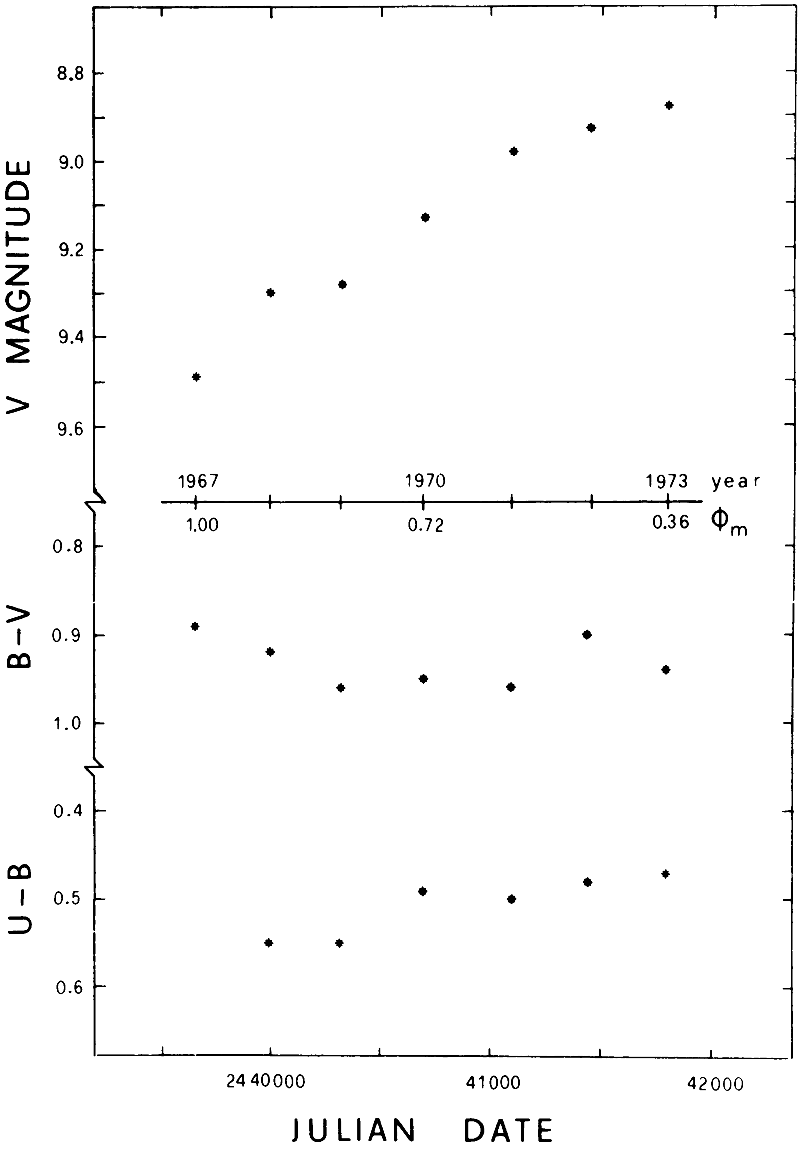

Figure 3. UBV magnitudes and colour indices of the secondary component determined at totality. Orbital phases ϕ_{min} of the wave distortion minimum and reference years are indicated in the middle scale.

Light-curve solutions of another RS CVn star (AR Lac) carried out by Theokas (1977) using Kopal's method also lead to variations of the fractional radii whose reality the author considered doubtful. Our Fourier analysis of the eclipses of RS CVn following Kopal's method have not led to meaningful solutions.

4. WAVE AMPLITUDES IN RS CVn AND BY DRA STARS

Slow periodic light variations of the stars are interpreted as uneven distribution of surface brightness, or starspots, in a rotating star which is not seen pole-on. This interpretation, reviving the early suggestion by Kron (1950), has been successfully applied to reproduce the observed out-of-eclipse light variations of RS CVn (Hall 1972) and BY Dra stars (see Kunkel 1975). However it is difficult to obtain unique solutions for the latitude, relative temperature, extent of the spotted area, and inclination of the rotational axis from the observed light curves. We have explored the possibility of the wave amplitude being statistically correlated with the angle between the rotation and the line of sight. Since this angle is not generally known, the orbital inclination readily gives the required angle by assuming the star rotation axis to be perpendicular to the orbital plane. The observed average wave amplitudes have been corrected by the light contribution of the unspotted companion for the purpose of extracting the actual light variation of the spotted star. No correlation between the average wave amplitude $(\Delta m_W)_C$, corrected by the light contribution of the unperturbed star, and the orbital inclination is apparent. All $(\Delta m_W)_C$ amplitudes are randomly distributed around the mean value of 0.18 (.09 s.d.) but for RS CVn which has the exceptionally large average wave amplitude of 0.82 magnitude. The lack of correlation between $(\Delta m_W)_C$ and $\underline{i}$ results from a random distribution in latitude and/or a wide range of the admissible fractional extent of the spotted region for the stars in our sample. This result has to be compared with that almost invariably found for both RS CVn and BY Dra stars, namely that the spotted regions are concentrated around 30-40 degrees latitude (Eaton and Hall 1979, Chugainon 1973, Torres and Ferraz Mello 1973, Bopp and Evans 1973, Vogt 1975).

Bearing in mind that numerous parameters affect the actually observed periodic brightness variation, we could expect different upper limits of the wave amplitude $(\Delta m_W)_C$ for different spectral types. In Figure 4 the average wave amplitude $(\Delta m_W)_C$ of RS CVn and BY Dra stars is plotted versus the spectral type of the spotted star. Although not well defined, a maximum is apparent at spectral type KO.

Chromospheric activity inferred from the absolute flux of the Ca II K emission line shows also a relative maximum at spectral type KO (Blanco et al. 1974).

These two concurrent results might indicate, as in the solar analogue, a close connection of the photospheric and chromospheric activity in late type stars.

According to Mullan (1974) starspots are convection cells penetrating throughout the entire depth of the convection zone and their size is expected to grow as the convection zone depth does, i.e. the later the spectral type is. However, as the convection zone thickens,

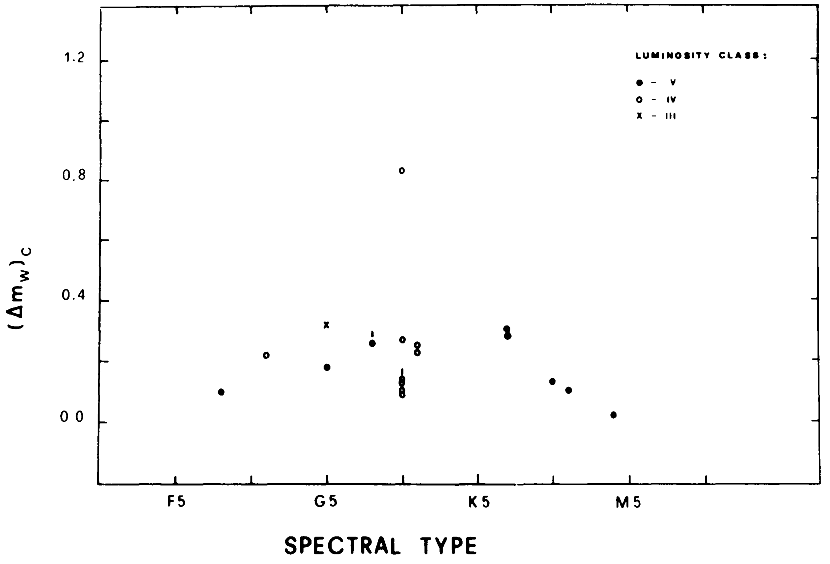

Figure 4. Average wave amplitudes, corrected for the light contribution of the unperturbed component, versus the spectral type of the variable component.

a low order multipole of the magnetic fields generated by dynamo action becomes more favoured. In stars of the latest spectral type, dipole fields would be more prominent. If it is aligned with the rotation axis, the largest field strength, and also the spots, should be confined to the rotation poles so that no periodic rotational modulation of the star brightness should result. Therefore, periodic brightness variations due to spots would be expected for stars with spectral types from F5-G0 (Mullan 1972), where the transition from shallow to deep convection zone occurs, to earlier than M5.5, i.e. before the star becomes completely convective (Mullan 1976). This picture is consistent with our result shown in Figure 4: the maximum periodic variations occur around spectral type K0.

Even if the various hypotheses postulated by Mullan (1976) are not entirely met, no rotational modulation of the star's brightness should result in late type stars because the spotted areas become so extended that they cover almost entirely the stellar photosphere.

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DISCUSSION FOLLOWING CATALANO, FRISINA AND RODONO

Leung: Have you looked at the "wave" phenomena in the system of SV Cam?

Rodono: No, we haven't.

Oswalt: Have RS CVn or any similar systems on your observing program exhibited a constant light level during any phase interval between wave maximum and wave minimum?

Naftilan: On your graph of the wave amplitudes vs. spectral type, you had one point which was much larger than all the rest. Which system is this?

Rodono: It is RS CVn. The wave amplitude we actually observe on its light curve is about 0.20 magn. However you must take into account the light contribution of the primary star in order to get the intrinsic light variation of the secondary one, i.e. the quantity plotted in the figure vs. spectral type.

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