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PERIOD VARIATION OF SIX RS CVn-TYPE BINARIES WITH POSSIBLE LIGHT-TIME EFFECT

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RESUMEN

Se presentan y discuten las variaciones en el periodo de seis sistemas binarios tipo RS CVn (RT And, SV Cam, WY Cnc, CG Cyg, WW Dra y RT Lac), obtenidas a partir de los tiempos en los que ocurren los mínimos de los eclipses. La explicación más plausible es la presencia de otras componentes no visibles. En todos los casos, los tiempos observados de los mínimos, no cubren mas que un ciclo completo en los diagramas (O−C). Por tanto, la validez de nuestra interpretación en términos de una tercera componente invisible no es definitiva. Sin embargo, las estimaciones de los parámetros orbitales y las masas de las supuestas terceras componentes son físicamente aceptables.

ABSTRACT

Long term period variation of six RS CVn type binaries (RT And, SV Cam, WY Cnc, CG Cyg, WW Dra, and RT Lac) formed by using the observed times of eclipse minima are presented and discussed with regard to the possible causes. The light-time effect due to invisible component stars was found to be the most possible cause. In all cases, the observed times of eclipse minima do not cover more than one complete cycle in the periodic (O−C) diagrams. Thus, the validity of the light-time effect is not definite for our sample stars, although the resulting orbital parameters and masses of the hypothetical third components are physically acceptable.

Key words: **BINARIES: CLOSE — BINARIES: ECLIPSING**

1. INTRODUCTION

A traditional 'observed minus calculated' (O−C) technique for the times of light maxima (or minima) is commonly used in investigating period changes of variable stars. The predicted C times of the zero phase are calculated by assuming that the period P has a constant value. In practice, as pointed out by Sterne (1934), and Lombard & Koen (1993) small random period changes may cause large accumulated changes in the timing of maxima (or minima), and thus may give rise to spurious indications of changes in the mean period. However, it was pointed out that the (O−C) method works if the intrinsic scatter of the period is negligible or very much smaller in comparison to the observational error in determining the times of maxima (or minima). For the eclipsing binaries, this is exactly the case and we think the (O−C) diagrams formed by the times of eclipse minimum provide the basis for studying time dependent period variations of eclipsing binaries. The long-term (O−C) variations reveal actual period changes which, in some cases, are indicative of the existence of unseen third component stars in many eclipsing binary systems (e.g., Frieboes-Condo & Herczeg 1973; Mayer 1990; Chambliss 1992; Demircan 1997).

For the alternating period changes in RS CVn systems, an isotropic wind model was proposed by De Campli & Baliunas (1979). Hall & Kreiner (1980) applied this model to 34 RS CVn systems. The problem with this model is that the mass loss required to produce the observed period changes is unrealisti-

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TABLE 1

SOME PARAMETERS (EXTRACTED FROM THE CABS CATALOG) OF OUR SAMPLE OF RS CVn SYSTEMS

No.	Star	Sp	m_{hot} ($M_\odot$)	m_{cool} ($M_\odot$)	M_v(hot/cool)	i (°)	d (pc)
201	RT And	F8V + K0V	1.50	0.99	5.5/3.9	88.9	95
65	SV Cam	G2–3V + K4	0.93	0.67	5.0/6.74	89.5	74
82	WY Cnc	G5V + M2	0.93	0.53	3.5/3.2	(≈ 90)	160
177	CG Cyg	G9.5V + K3V	0.52	0.52	(5.8/6.65)	81.8	(≈ 63)
136	WW Dra	G2IV + K0IV	1.36	1.34	3.0/3.2	81.4	180
189	RT Lac	G5: + G9IV	0.78	1.66	2.9/3.4	89	205

cally large by one or two orders of magnitude, and more important, the phasing of the observed period changes are not consistent with changing starspot longitudes (Hall 1990).

At present, there are three most plausible models for explaining the cyclic period variations of the eclipsing binaries: *i*) apsidal motion of the elliptical orbit, *ii*) period modulation due to magnetic activity cycle of a component star, and *iii*) light-time effect due to additional objects in the system. The first model is definitely not valid for the RS CVn systems because: *i*) the secondary minima in the light curves display no significant shift from the phase 0.5, *ii*) the radial velocity curves indicate no significant eccentricity for the binary orbits, and *iii*) both the primary and secondary times of minima follow the same trend of (O−C) variation. One or both of the other two models may well be valid for the RS CVn systems. The models can be checked by their predictions in the independent astrometric, spectroscopic and/or infrared CCD imaging observations.

In the present work we shall use all available minima times lists to define the character of long-term period changes of six of the most frequently observed RS CVn systems. The possible causes of these changes will be discussed.

2. DATA

The period variation of a large group of RS CVn systems were studied by Hall & Kreiner (1980). As the observational material has accumulated since then, we thought it appropriate to compile new data and reconsider alternating period changes of some of the most frequently observed RS CVn systems. Six systems with larger data sets in longer time intervals and displaying alternating (O−C) diagrams were chosen based on the Hall & Kreiner's survey. The selected binaries for the present investigation are listed together with some physical parameters in Table 1. The physical parameters, spectral types, masses, visual absolute magnitudes of the component stars, inclination of the orbit, and the distance for each binary in Table 1 were all extracted from the catalogue of Chromospheric Active Binary Systems (CABS) by Strassmeier et al. (1993).

A summary of the collected times of eclipse minimum, including Hall & Kreiner's compilation for our sample stars, are given in Table 2, where n_{pe}, n_{ph}, and n_v stand for the collected number of photoelectric, photographic, and visual times of eclipse minimum. The new data are all available on request from the authors.

3. (O−C) DIAGRAMS

The collected times of eclipse minimum, 1204 altogether, for six systems are used in forming the (O−C) residuals. The linear light elements T_0 and P (see Table 2) from Hall & Kreiner (1980) were used in estimating C values. In order to clarify the character of (O−C) variation, (*i*) we formed and used the seasonal normal points from photographic and visual data, and (*ii*) formed the diagram with horizontal mean axis by adjusting the initial light elements. Thus, the mean light elements valid for the whole time span of observations were obtained. They are listed as $\overline{T}_0$ and $\overline{P}$ in Table 2. The final (O−C) diagrams drawn by using the mean light elements are shown in Figures 1 to 6. It is obviously seen in the figures that the (O−C) diagrams are not formed by linear line segments, but they represent continuous oscillatory variations. The oscillatory nature of the (O−C) diagrams of SV Cam, CG Cyg, WW Dra, and RT Lac are seen to be asymmetric in various degrees. However, it should be noted that for each star only about one cycle of the oscillatory variation is covered by the present observational data.

4. CHARACTER OF THE PERIOD VARIATIONS

Since the orbital period is —by definition— the first time derivative of the (O−C) diagram, the orbital periods of the systems in our sample also follows continuous oscillatory variations. The amplitudes of the oscillatory variations in Figure 1 are between

TABLE 2

SUMMARY OF THE COLLECTED TIMES OF ECLIPSE MINIMA

	RT And	SV Cam	CG Cyg	WY Cnc	WW Dra	RT Lac
n_{pe}	94	140	48	19	4	44
n_{ph}	11	...	3	12	18	81
n_v	240	147	104	93	60	86
n_{total}	345	287	155	124	82	211
T_0	41141.8888	34988.483	44528.5351	26352.3895	28020.3481	40382.891
P	0.6289298	0.593071	0.63114347	0.8293712	4.629617	5.074015
$\overline{T}_0$	41141.8888	41212.763	22967.4248	26352.40467	28020.3481	40382.84
$\overline{P}$	0.6289313	0.5930718	0.63114347	0.82937034	4.6296166	5.073985

≈ 0.008d (for CG Cyg) and ≈ 0.140d (for WW Dra). The periods of the variations however, are between ≈ 44yr (for SV Cam) and ≈ 108yr (for RT And).

5. MOST PLAUSIBLE CAUSE OF THE CYCLIC PERIOD CHANGES

The cyclic magnetic activity effect on the orbital periods of RS CVn systems seems quite possible, since the components of these systems are late type and they display spin-orbit coupling. In the case of the cyclic magnetic activity effect, Applegate (1992) predicts that: *i*) the secular light variation and the (O−C) curve formed by the times of minimum light should have the same cycle length, *ii*) extrema in one should coincide with extrema in the other, and *iii*) the colour of the system should become bluer as the star brightens. Unfortunately, due to insufficient data, these predictions could not be checked for our sample stars. We noted however, that the period estimates of the (O−C) variations (and thus orbital period variations) are too long in comparison to magnetic cycles in solar type single and close binary stars, as compiled by Maceroni et al. (1990) and Bianchini (1990). Moreover, the asymmetries in various degrees of the (O−C) curves in Figures 2, 4, 5, and 6 indicate light-time effects in the eccentric orbits. We, thus, have assumed the light-time effect as the most plausible cause of the cyclic period changes for our sample stars and analysed the (O−C) curves of Figures 1 to 6 under this assumption.

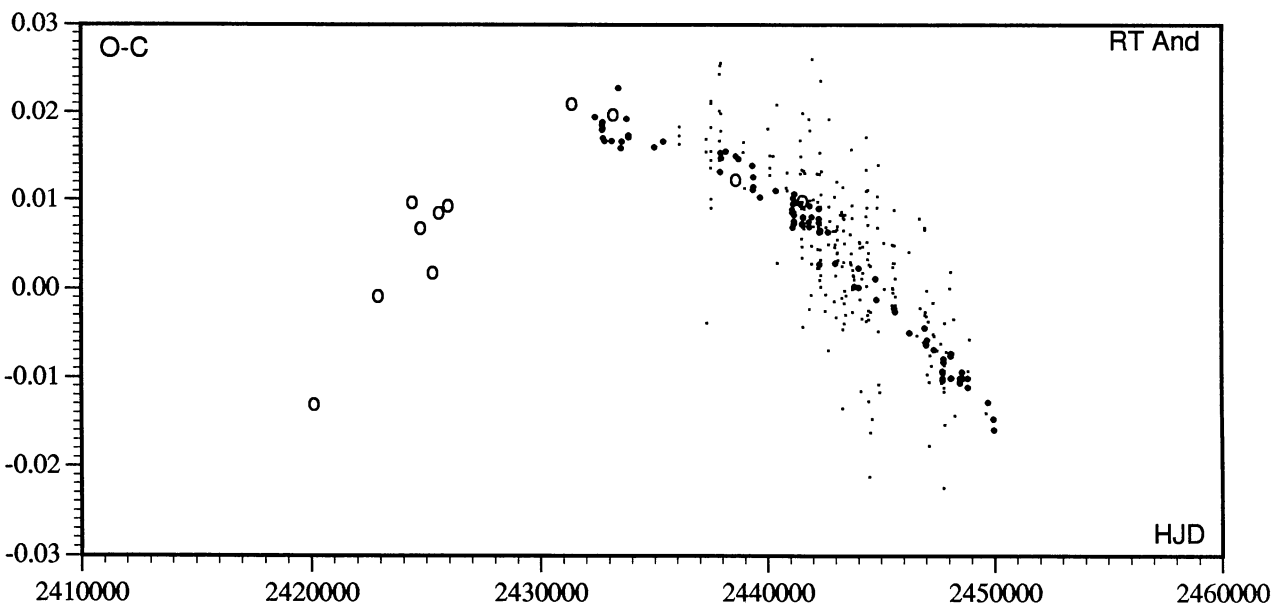

Fig. 1. The (O−C) diagram of RT And (dots are visual, open circles are photographic, filled circles are photoelectric data).

6. LIGHT TIME ORBITS AND INVISIBLE COMPONENT STARS

To derive the light-time orbits and the parameters of the invisible component stars, the analysis of all data set was performed by using the pertinent formulae given by Irwin (1952, 1959). All parameters, except the inclination i of the third body orbit which was assumed to be co-planar with the close binary orbit, were adjusted to approach the best fit with the observational (O−C) diagrams of Figures 1 to 6. The goodness of the fits were checked visually on the observational (O−C) diagrams. Figures 7 to 12 display the best-fitting theoretical curves, superimposed on the observational data. The best-fitting values of the orbital parameters are listed in Table 3. Having the orbital parameters determined, the mass function of the invisible component star can be written as

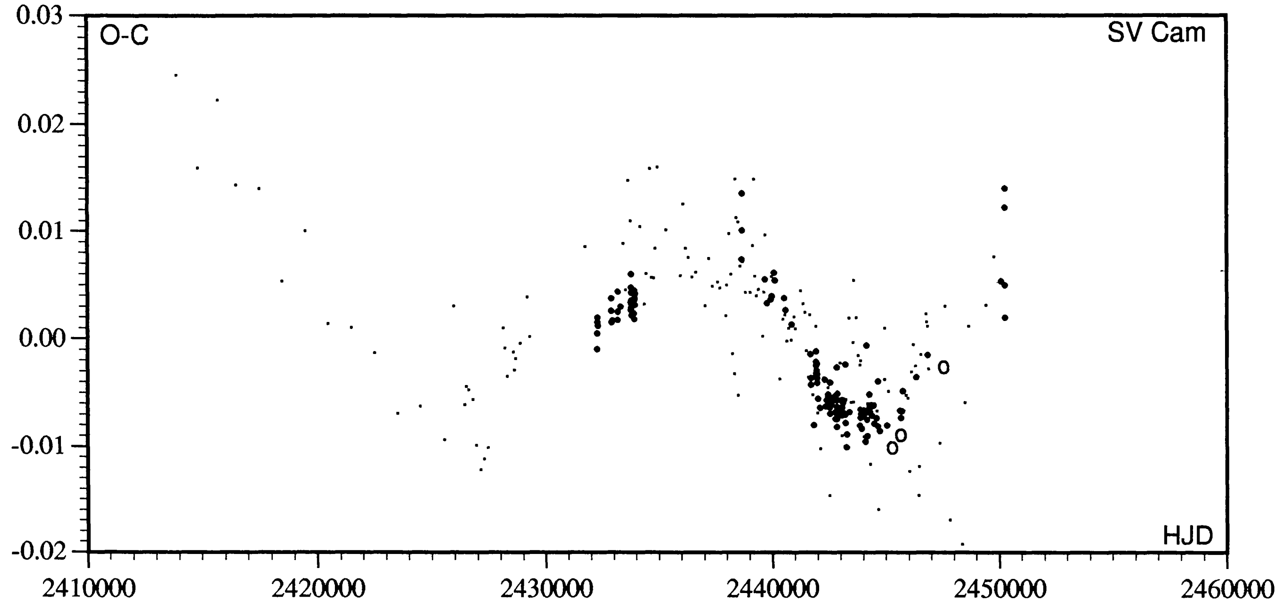

Fig. 2. Same as Figure 1 for SV Cam.

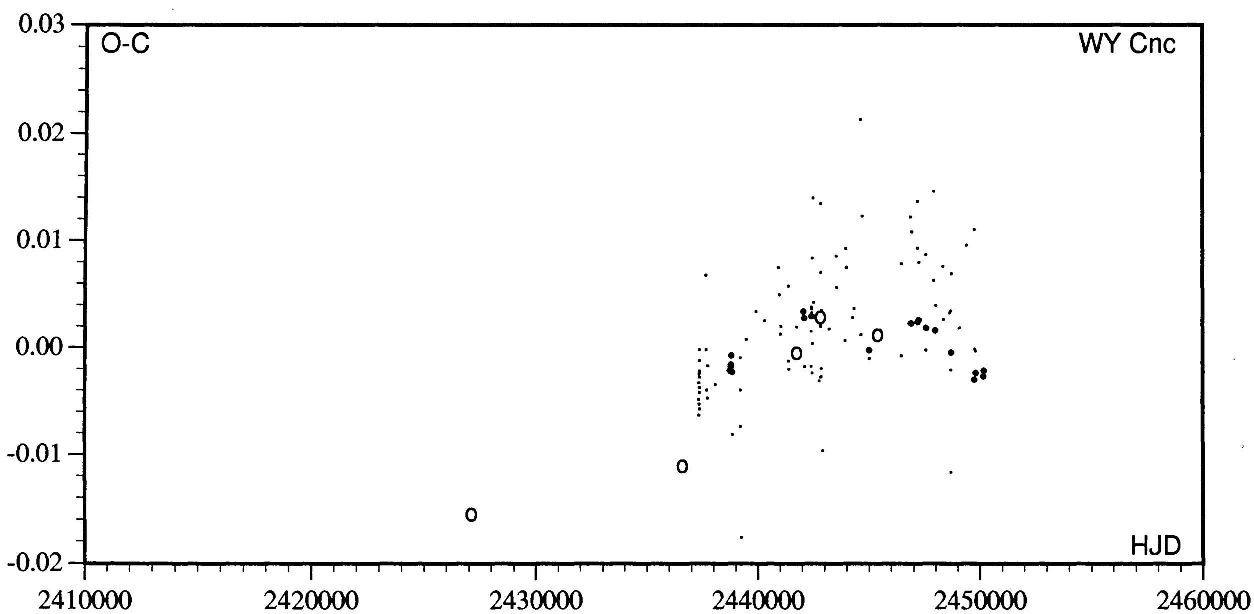

Fig. 3. Same as Figure 1 for WY Cnc.

TABLE 3

PARAMETERS OF THE LIGHT TIME ORBITS AND INVISIBLE COMPONENT STARS AROUND THE SYSTEMS

	RT And	SV Cam	WY Cnc	CG Cyg	WW Dra	RT Lac
e	0	0.3	0	0.12	0.7	0.68
w(o)	...	227	...	272	7	130
A (days)	0.0177	0.0085	0.0101	0.0082	0.1	0.04
P (yr)	108.14	43.81	82.88	46.54	79.4	82.14
a_{12} (AU)	3.067	1.47	1.75	1.44	17.52	6.93
$f(M_3)$ ($M_{\odot}$)	0.0025	0.0017	0.0008	0.0013	2.0536	0.125
M_3 ($M_{\odot}$)	0.27	0.18	0.13	0.12	5.02	1.18
a (AU)	31.8	14.7	22.0	13.6	26.9	21.3
α ($''$)	0.33	0.20	0.14	0.22	0.15	0.10
K (km s^{-1})	0.8	1.1	0.6	0.9	12.0	4.7
Δm (mag)	6.0	6.0	9.0	6.5	4.4	1.7

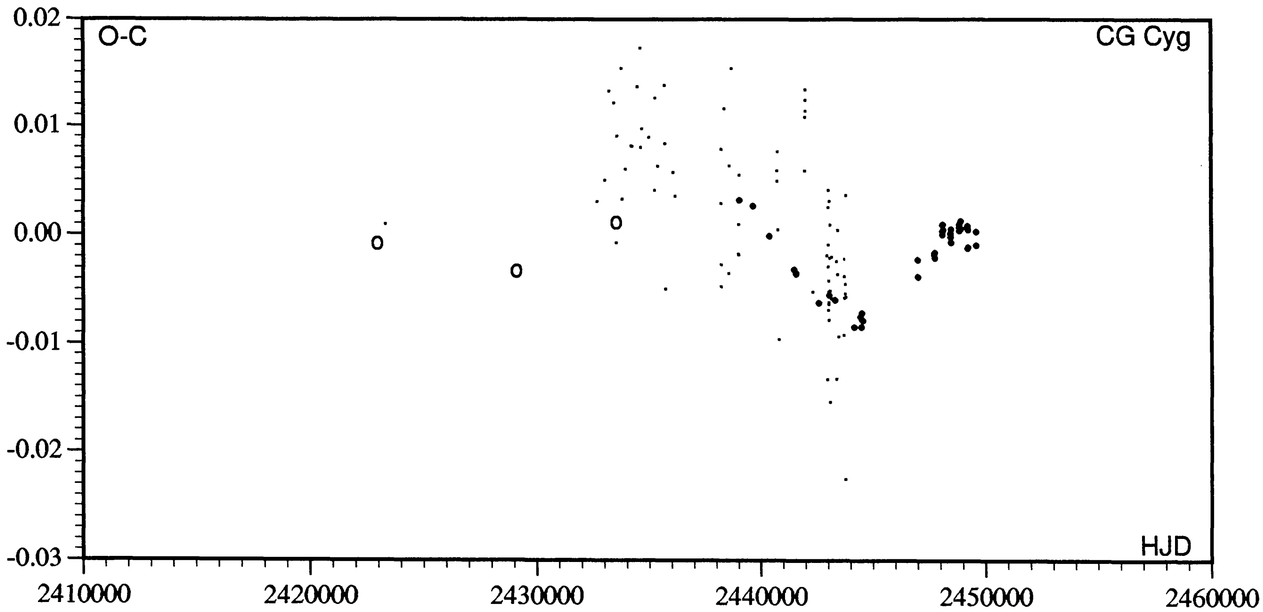

Fig. 4. Same as Figure 1 for CG Cyg.

$$f(M_3) = \frac{(M_3 \sin i)^3}{(M_{12}+M_3)^2} = \frac{(173.262 \times A)^3}{P^2} \quad , \quad (1)$$

where M_{12} and M_3 are the masses (in solar units) of the eclipsing pair and the third body, A is the amplitude in days, and P is the period of (O−C) curve in years. The inclination i of the third body orbit was assumed to be equal to the inclination of the eclipsing binary orbit. Thus the unknown mass M_3 can be derived from a third-order equation, of the form

$$M_3^3 \sin^3 i - M_3^2 f(M_3) - 2M_3 M_{12} f(M_3) - M_{12}^2 f(M_3) = 0 \quad . \quad (2)$$

The systemic radial velocity of the eclipsing pair can be estimated by using the formula

$$V_r = K[\cos(v+w) + e\cos w] \quad , \quad (3)$$

where

$$K = \frac{5156A\sqrt{(1-e^2)}}{P\sqrt{(1-e^2\cos^2 w)}} \quad . \tag{4}$$

Here V_r and K are in km s^{-1}, v is the true anomaly, e is the eccentricity and w is the longitude of periastron for the third body orbit. The distance between the eclipsing pair and third body follows from the simple relations: $a_{12}/a_3 = M_3/M_{12}$ and $a_{12}+a_3 = a$. Then the maximum angular separation of the third body can be estimated as $\alpha(\text{rad}) = a/d$. All these estimates for our sample stars are also listed

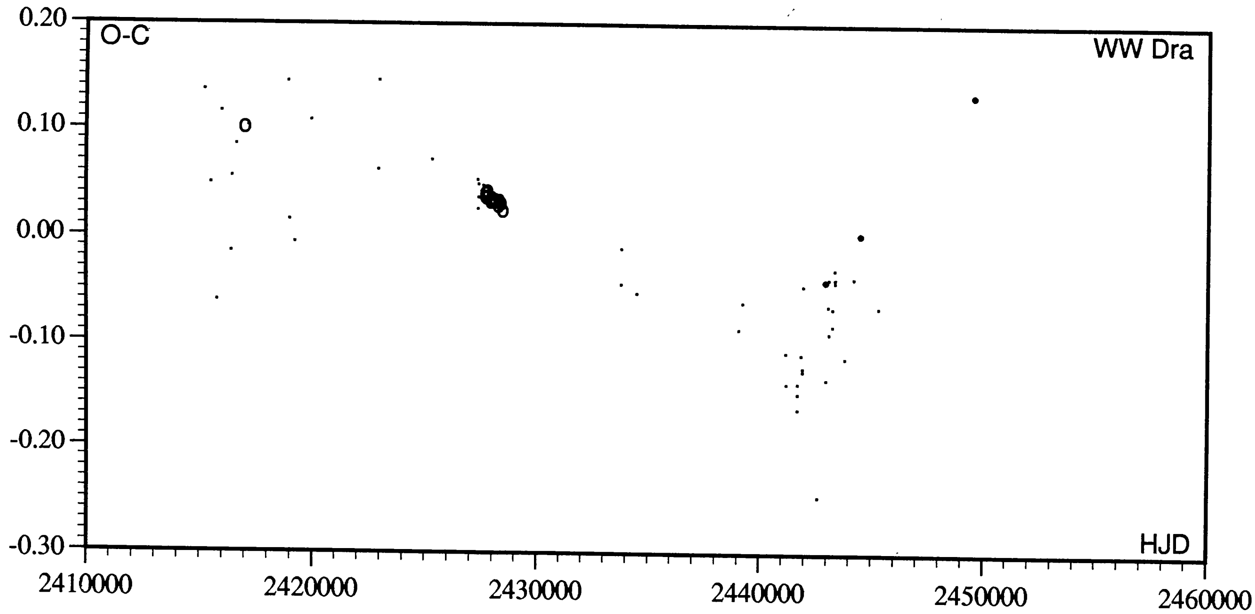

Fig. 5. Same as Figure 1 for WW Dra.

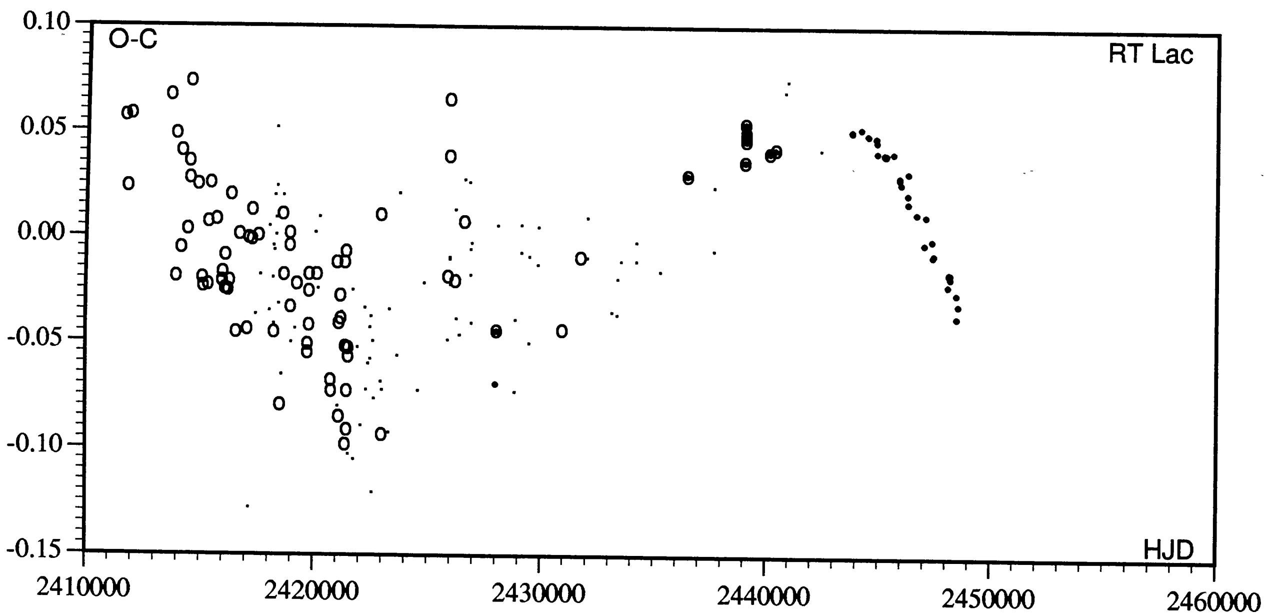

Fig. 6. Same as Figure 1 for RT Lac.

in Table 3, where the estimate of visual magnitude difference Δm between the eclipsing pair and the third body, was obtained by assuming the third body to be a normal star in the main sequence.

7. RESULTS AND DISCUSSION

We studied the period variation of a group of RS CVn systems for which the (O−C) variations (and the orbital period variations) are represented

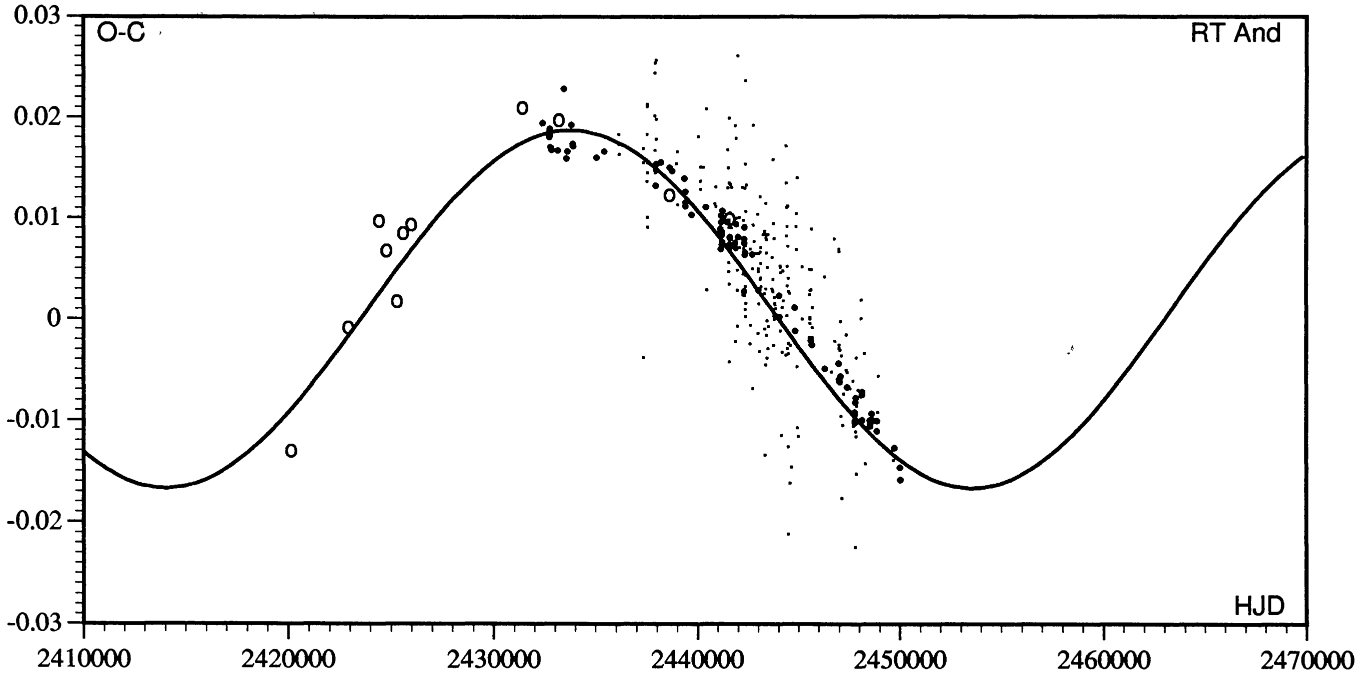

Fig. 7. The best-fitting theoretical curve superimposed on the observational (O−C) data of RT And (dots are visual, open circles are photographic, filled circles are photoelectric data).

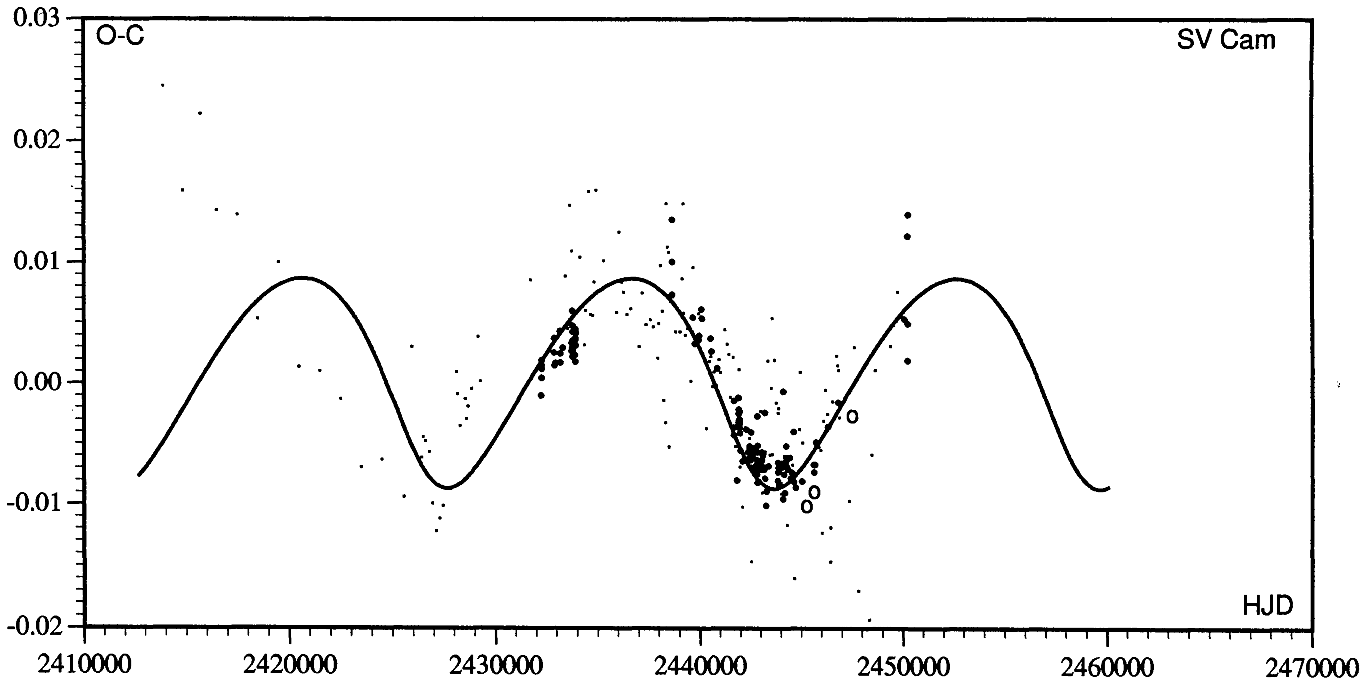

Fig. 8. Same as Figure 7 for SV Cam.

by periodic functions. The significant asymmetry of the cyclic (O−C) variations of SV Cam, CG Cyg, WW Dra, and RT Lac were taken to be the clue for the light-time effect due to invisible component stars in elliptical orbits. The cyclic (O−C) variations most likely are attributed to the light-time effect. The light-time orbits and probable parameters of the invisible component stars were estimated by using a well-known model. For each system, we also predicted the maximum angular separation between

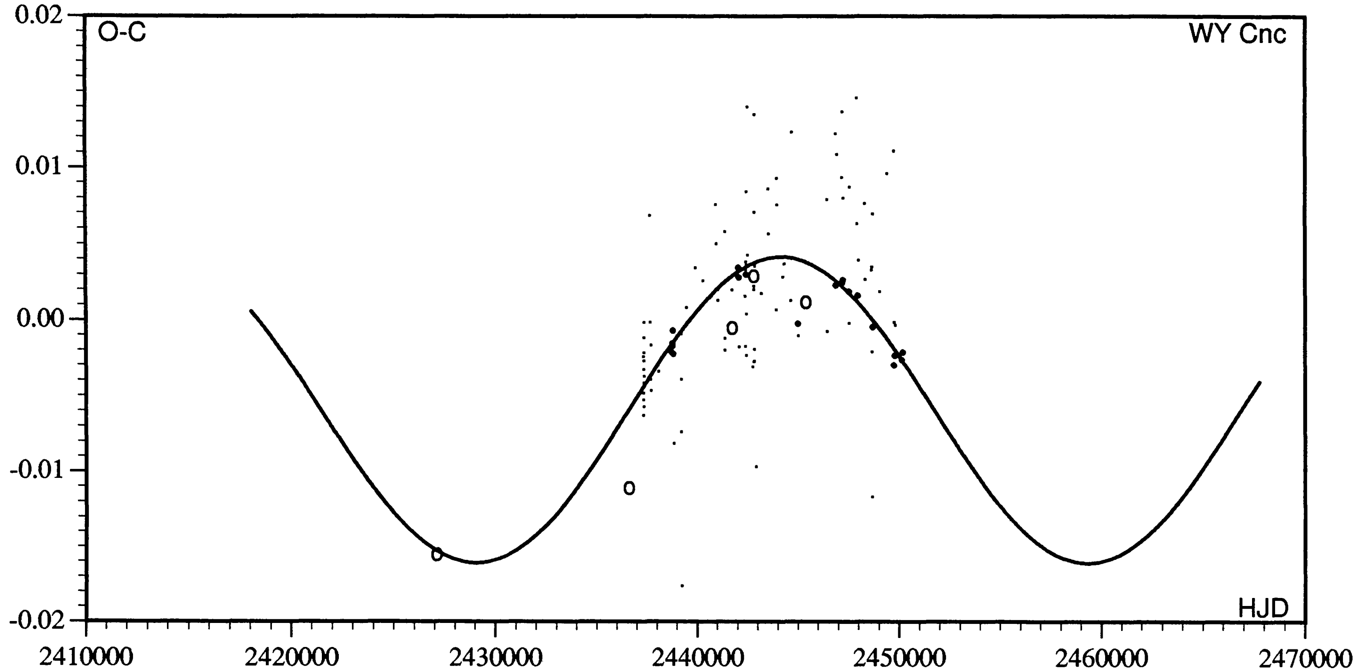

Fig. 9. Same as Figure 7 for WY Cnc.

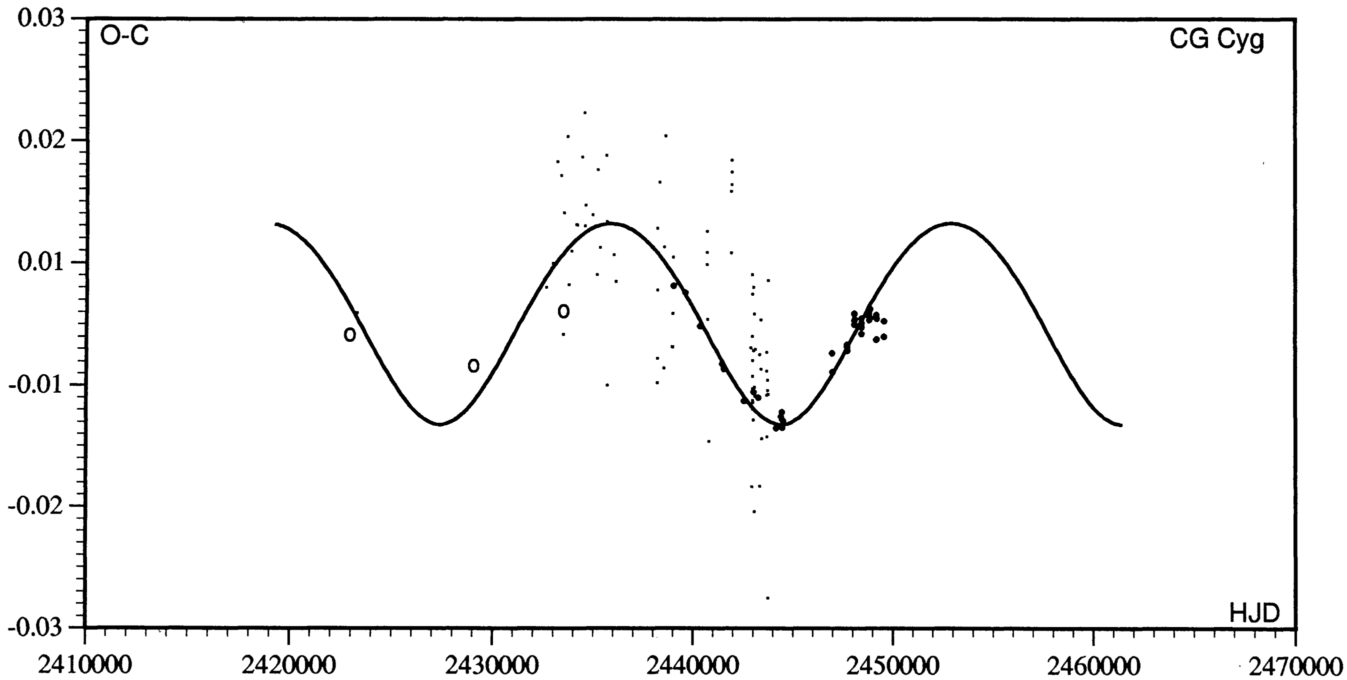

Fig. 10. Same as Figure 7 for CG Cyg.

the binary and the third component, the amplitude K of the systemic radial velocity, and the brightness difference Δm between the binary and the third component. All these results were listed in Table 3. The plausible third components of RT And, SV Cam, WY Cnc, and CG Cyg are too faint for observational detection. However, if the massive third stars of RT Lac and WW Dra are main sequence or evolved stars, they should be bright enough for detection. Since there is no mention about such third compo-

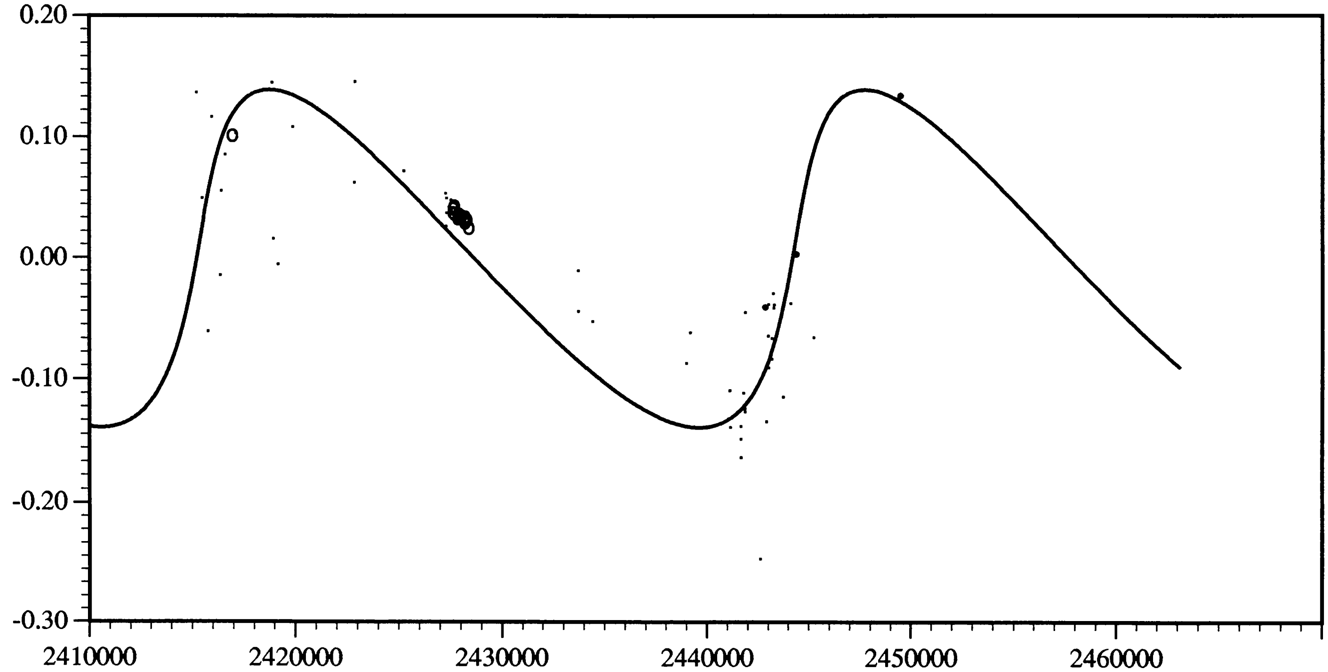

Fig. 11. Same as Figure 7 for WW Dra.

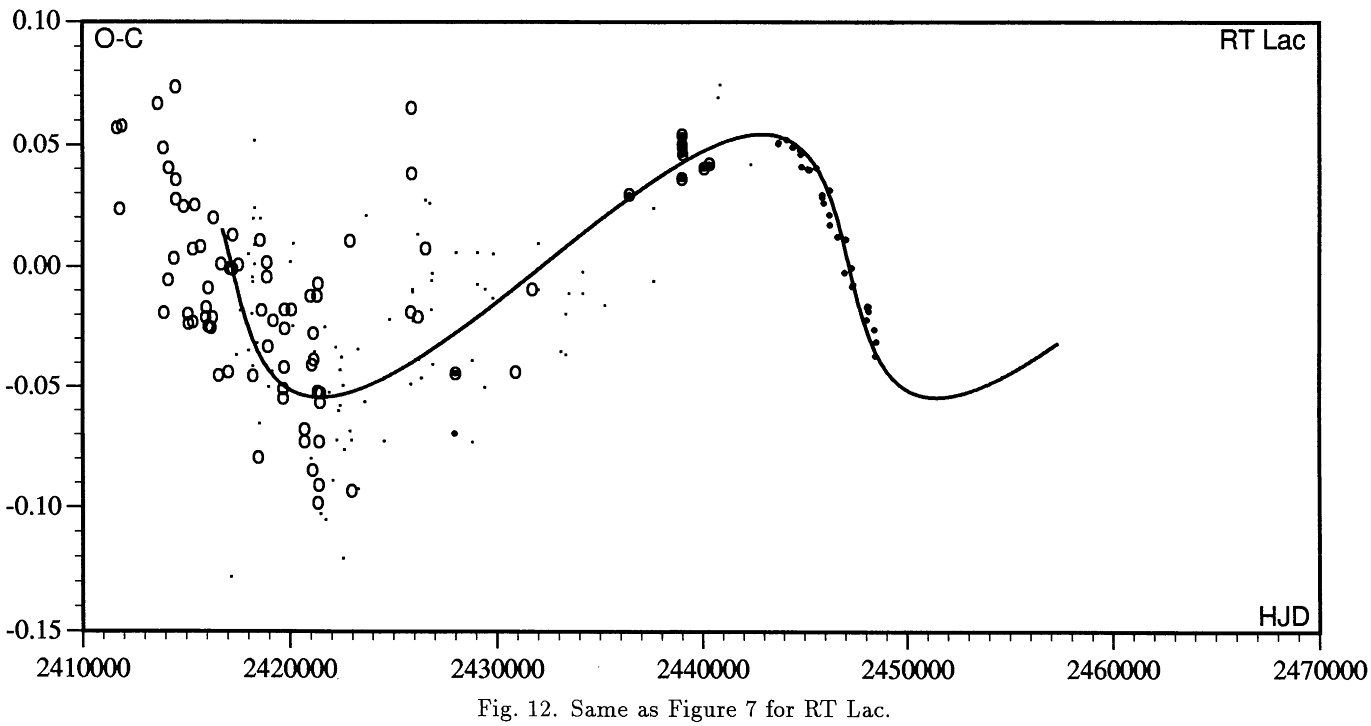

Fig. 12. Same as Figure 7 for RT Lac.

nents, either they are dead stars (WD in the case of RT Lac, and BH in the case of WW Dra) or the third body interpretation is not valid at least for these binaries. The WD third body prediction in the case of RT Lac can be checked on the UV spectra of the system.

Finally, it should be noted that the character of the period variations and their third body interpretation for the present sample of binaries is not definite, because, unfortunately, for each star only about one cycle of the oscillatory variation is covered by the present data. It is, therefore, crucial in each case to obtain new observational data in the future.

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