A STUDY OF THE ORBITAL PERIODS OF 22 ECLIPSING BINARIES

T. Panchatsaram and K.D. Abhyankar
Centre of Advanced Study in Astronomy
Osmania University, Hyderabad, India

1. INTRODUCTION

Investigation of the variability of the orbital periods of eclipsing binaries is important not only from the evolutionary point of view but also for detecting additional components in them. Systematic study of the period changes in binary stars was started by Plavec (Plavec et al 1960) more than twenty years ago. Work on the same lines for 20 detached systems was reported by Herczeg (1980) at the I.A.U. Symposium No. 88 held in Toronto two years ago. Here we describe the study of 22 systems carried out by us at Hyderabad.

It is a common experience that the large errors in the visual and photographic minima obscure the real nature of period variations. Hence, in order to have accurate and homogeneous data it was decided to use only photoelectric times of minima. Only those systems for which such data was available for at least a decade were considered. Our sample includes all three kinds of systems: detached, semi-detached and contact, having periods up to 4 days. It has been possible to divide them into four groups: (i) Systems with constant periods, (ii) Periodic systems, (iii) Secular systems and (iv) Peculiar systems.

Group (i) contains the four systems: CM Lac, AB And, YY Eri (Panchatsaram and Abhyankar 1981 c) and Z Her (Panchatsaram and Abhyankar 1981 b). The constancy of the period for the detached system CM Lac was already pointed out by Herczeg (1980). The constant period of the RS CVn type system Z Her found by us agrees closely with the period derived by Plavec et al (1961) on the basis of all types of minima. The remaining two binaries of this group are contact systems.

Z. Kopal and J. Rahe (eds.), Binary and Multiple Stars as Tracers of Stellar Evolution, 47–60.

https://doi.org/10.1017/S025292110010034X Published online by Cambridge University Press

2. PERIODIC SYSTEMS

Group (ii) contains the four systems: U Oph, AK Her, SW Lac and RT Per. Sinusoidal variation of the detached system U Oph was earlier pointed out by Herczeg (1980). Now Panchatsaram (1981 a) has derived the following light time orbit for this system:

$a_{12} \sin i = 1.08$ AU, $P_3 = 27.55$ yrs, $e = 0$, $f(m) = 0.0017$; giving a mass of the third body equal to 0.57 to 0.66 solar masses for i greater than 60 degrees. In the case of AK Her he (Panchatsaram 1980) had obtained a third body period of 41.55 years with a circular orbit of size

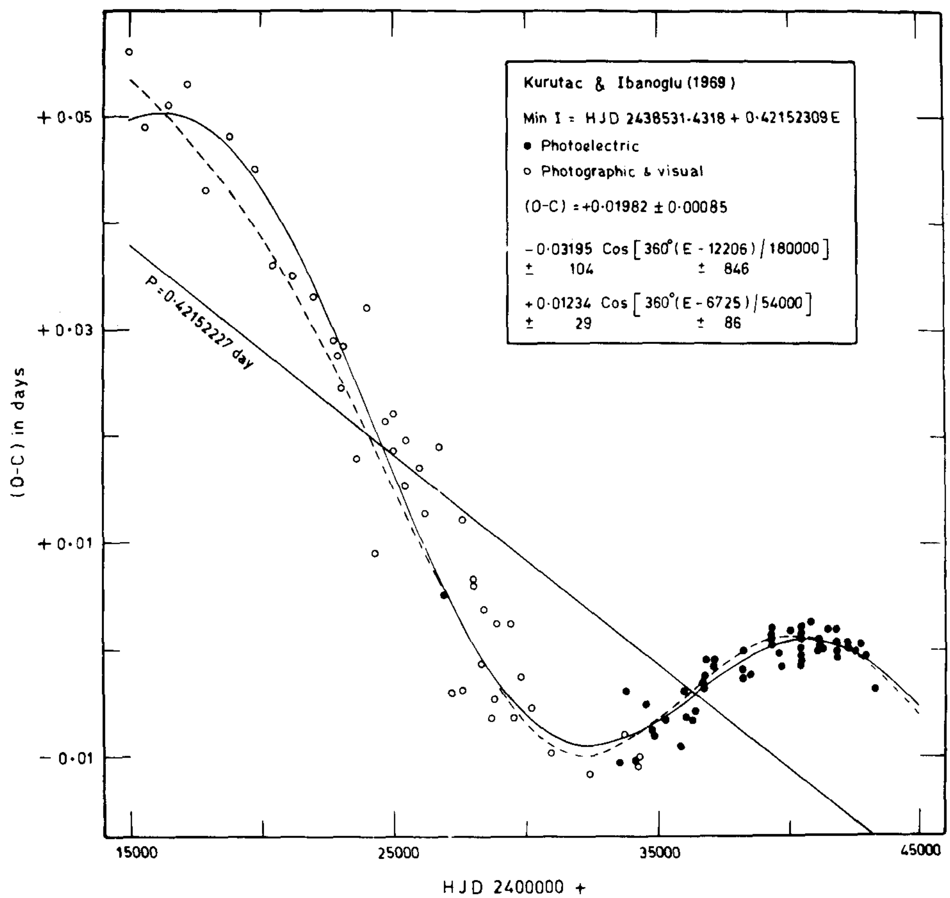


Figure 1. (O-C) diagram for AK Herculis based on the ephemeris of Kurutac and Ibanoglu (1969).

$a_{12} \sin i = 0.92$ AU. However in this case we have tried to see whether the earlier photographic and visual minima fit the postulated orbit, particularly because the residuals are large compared to observational errors. Figure 1 shows the (O-C) diagram for all available primary minima of AK Her based on the period of 0.42152309 day given by Kurutac and Ibanoglu (1969). It is obvious that we have here a double sinusoid pointing to the existence of a third as well as a fourth body. The best fit for a four body solution is shown by the continuous line in the figure. Barker and Herczeg (1979) have however used a different period of 0.42152227 day as indicated by the straight line in Figure 1. On that basis they have obtained an eccentric third body orbit represented by the dashed curve. The two models which follow are given in Table I and shown schematically in Figure 2. It is clear from Figure 1 that the choice between them depends critically on the assumed period of the binary. It should be possible to remove this ambiguity by astrometric measurements in addition to future observations of the minima.

TABLE I - TWO INTERPRETATIONS OF PERIOD CHANGES IN AK Her.

Period	P = 0.42152227 day	P = 0.42152309 day	
Parameter	3rd body	3rd body	4th body
$a_{12} \sin i$	2.74 AU	2.13 AU	5.52 AU
e	0.3	0	0
P	78 yrs	62 yrs	207 yrs
$f(m)/M_\odot$	0.00336	0.00252	0.00392
$m_{12(3)}/M_\odot$	1.5	1.5	1.5 + m_3
$m_{3(4)}/M_\odot$			
$i = 90^o$	0.21	0.20	0.24
$i = 60^o$	0.25	0.22	0.31
$i = 30^o$	0.47	0.43	0.58

https://doi.org/10.1017/S025292110001034X Published online by Cambridge University Press

Two other binaries: the contact system SW Lac and the semi-detached system RT Per, show double sinusoids in their (O-C) diagrams. They have been interpreted by us (Panchatsaram and Abhyankar 1981 a, Panchatsaram 1981 b) as light

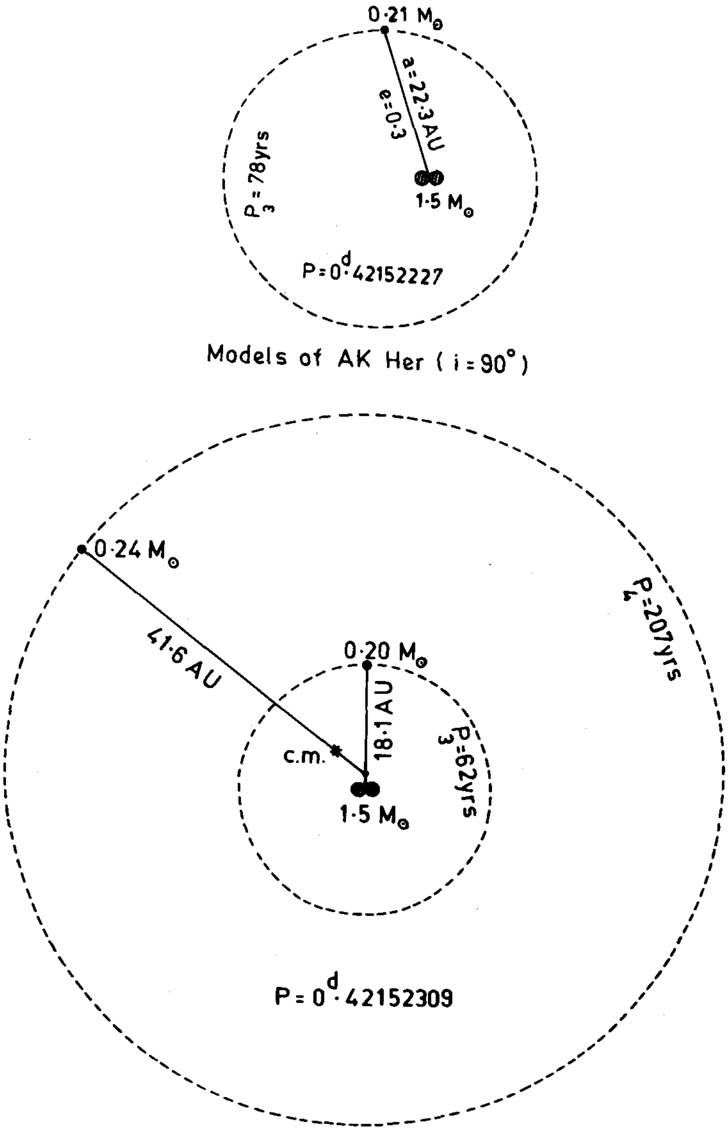


Figure 2. Two alternate models of the system AK Herculis.

https://doi.org/10.1017/S025292110010034X Published online by Cambridge University Press

time effects in quadruple systems. The possible third and fourth masses are given in Table II. They are small enough to infer that they might be white dwarfs. Again it should be possible to detect them by astrometric measurements and also by uv observations from satellites.

TABLE II - POSSIBLE QUADRUPLE SYSTEMS

Parameter	RT Per	SW Lac
a_{12} sin i (AU)	3.10	3.51
P_3 (yrs)	41.86	19.67
$f(m)/M_\odot$	0.017	0.112
$m_3/M_\odot(i \geqslant 60^\circ)$	0.49 - 0.58	0.99 - 1.19
a_{123}sin i (AU)	3.94	7.11
P_4 (yrs)	100	70.25
$f(m)/M_\odot$	0.006	0.073
$m_4/M_\odot(i \geqslant 60^\circ)$	0.40 - 0.48	1.05 - 1.26

3. SECULAR SYSTEMS

We, now, come to Group (iii) containing systems which show secular variation of period. Here we have two sub-groups: one with secularly increasing periods and the other with secularly decreasing periods; each group contains five systems. Details of their period studies will be published elsewhere.

Figure 3 shows the (O-C) diagrams for two contact systems V 566 Oph and AH Vir and two semi-detached systems KO Aql and AG Vir, all showing secular increase of period as indicated by the fitted parabolas. Figure 4 shows the (O-C) diagram for the contact system 44 i Boo B. Since it is a member of a visual binary we have removed the effect of its motion in the visual binary orbit on the basis of the elements given by Heintz (1963), in the lower part of the figure.

Figures 5 and 6 show the (O-C) diagrams of three detached systems: RT And, SV Cam and AR Lac, one semi-detached system TV Cas and one contact system U Peg, which

https://doi.org/10.1017/S025292110001034X Published online by Cambridge University Press

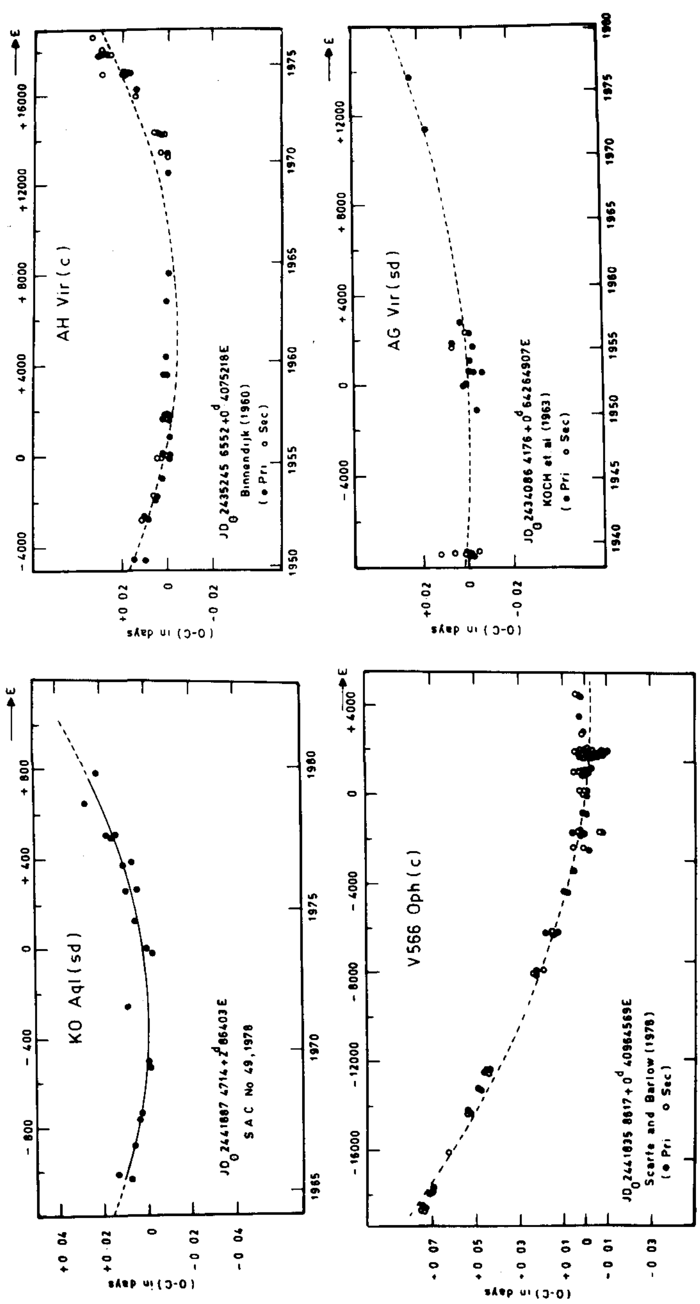
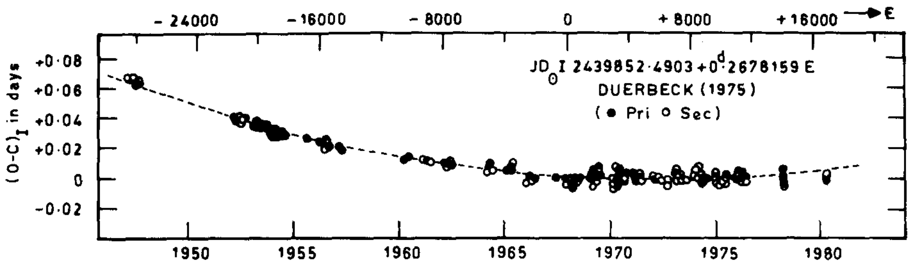


Figure 3. Secular variation of period for KO Aql, AH Vir, V 566 Oph and AG Vir.



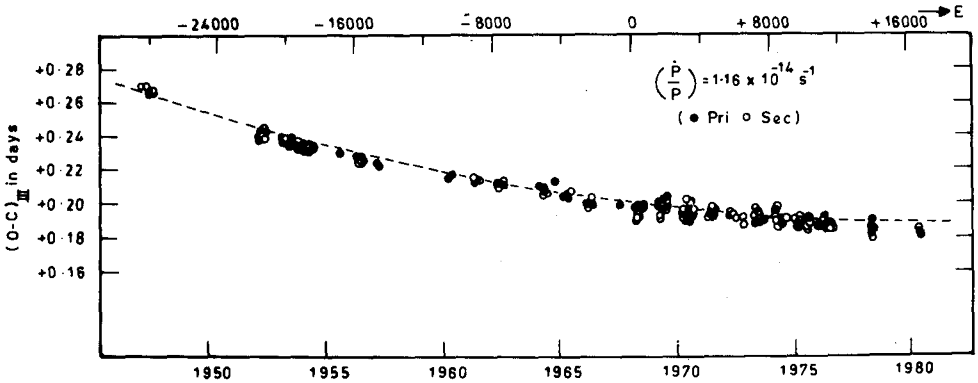


Figure 4. Secular variation of period of 44 i Bootis B; lower part indicates variation after removing the light time effect of the visual companion according to the elements given by Heintz.

exhibit secular decrease of period. It is to be noted that the phenomenon of secular variation of period is common to detached, semi-detached and contact systems which are at different stages of evolution. Hence the commonly assumed mechanisms of mass-exchange and mass-loss may not account for the variations of period in all cases. Light time effect due to the presence of additional components could be another common cause for such variations.

Correct interpretation of the (O-C) diagrams by light time effect in cases where the sinusoidal variation is not apparent becomes difficult in the absence of the knowledge of the true period of the binary. Even where sinusoidal

https://doi.org/10.1017/S025292110001034X Published online by Cambridge University Press

variation is seen we can have ambiguity as we have seen in the case of AK Her. Hence we should look for another parameter which is not critically dependent on the period.

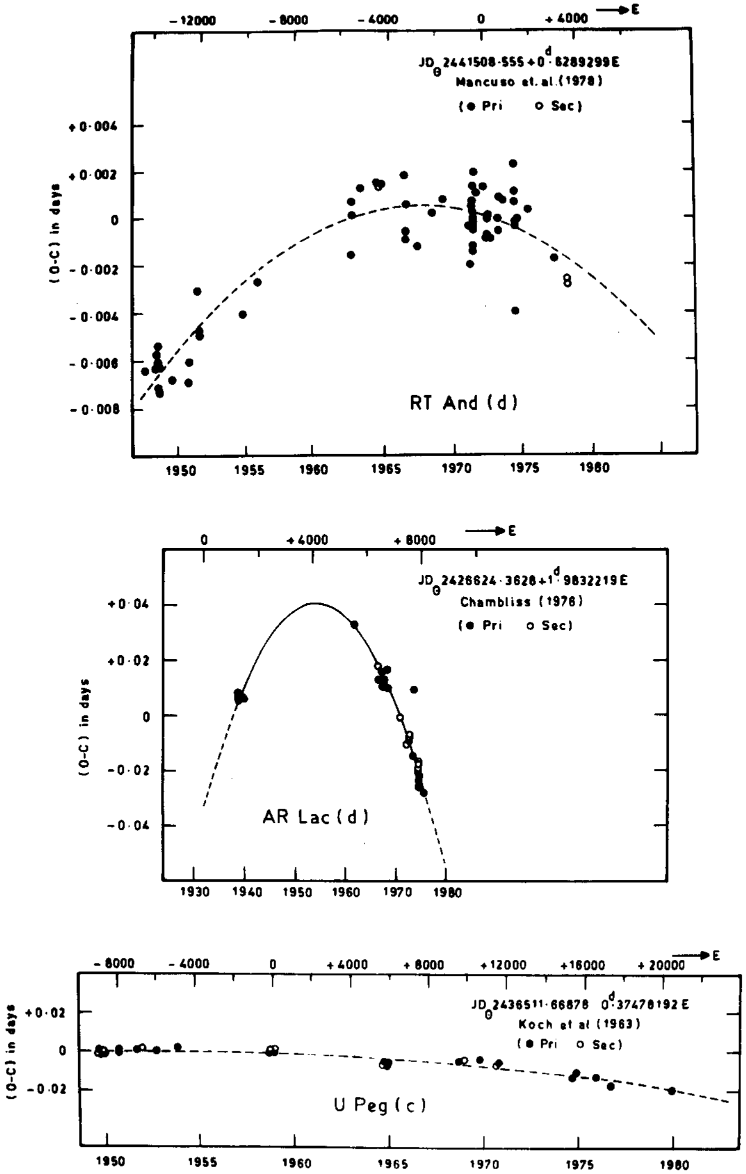


Figure 5. Secular variation of period in RT And, AR Lac and U Peg.

Abhyankar (1981) has tried to identify one such parameter which could give information about the third body if it exists.

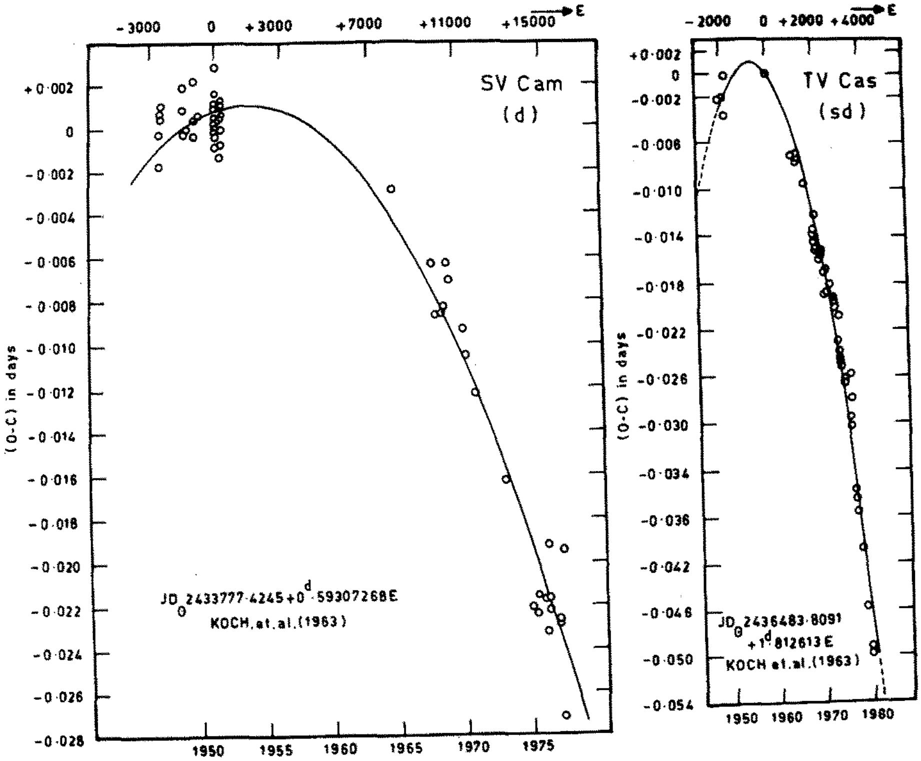


Figure 6. Secular variation of period for SV Cam and TV Cas.

First we note that the quadratic representation of (O-C)'s gives us (1/P).dP/dt which, when multiplied by the velocity of light c, has the dimensions of acceleration. The quadratic representation indicates that the system is experiencing a constant acceleration for considerable length of time. It is easy to see that (c/P).dP/dt represents the acceleration of Z_{12}, the distance of the centre of mass of the binary along the line of sight. Measuring this distance from the sky plane passing through the centre of mass of the triple system it is found that the acceleration of Z_{12} remains constant for a large fraction of the period of the third body near $M \approx v \approx 180$ degrees when $\omega = \pm 90$ degrees for large values of e. The magnitude of the constant acceleration decreases with increasing eccentricity, hence the probability of observing a system in this phase of light time orbit is largest for e = 0.4 to 0.7 which is

https://doi.org/10.1017/S025292110001034X Published online by Cambridge University Press

also the modal range for the eccentricities of visual binary orbits. In this case the constant acceleration lasts for about half the length of period. Hence we can obtain a tentative value of the mass function from

$$f(m)/M_{\odot} = (d^2 Z_{12}/dt^2)^3 P_3^4 (1+e)^6 / 64\pi^6$$

where the acceleration is in AU/yr^2 and P_3 in years, by putting e = 0.6 and P_3 equal to twice the observed duration of constant acceleration. The known mass of the binary can then give us an estimate of the mass of the third body.

Table III gives the results obtained in the above manner for the secular systems considered by us. We get reasonably small values for the mass of the third body to make it normally undectable in the case of 6 systems: SV Cam, U Peg, AG Vir, RT And, V 566 Oph and 44 i Boo B. For the remaining four systems the third body interpretation may not be acceptable.

TABLE III - ESTIMATED MASSES FOR THIRD COMPONENTS FROM SECULAR PERIOD CHANGES

System	(1/P).dP/dt sec^{-1}	P_3 years	$f(m)/M_{\odot}$	$m_3/M_{\odot}$ ($i \geqslant 60^{\circ}$)
SV Cam	7.90×10^{-15}	62	1.58×10^{-2}	0.4 to 0.5
AR Lac	2.52×10^{-14}	76	1.16	3.5 to 4.6
TV Cas	1.44×10^{-14}	60	8.38×10^{-2}	1.4 to 1.7
KO Aql	6.12×10^{-14}	28	3.05×10^{-1}	2.1 to 2.6
U Peg	5.14×10^{-15}	64	4.94×10^{-3}	0.3 to 0.4
AG Vir	5.44×10^{-15}	78	1.29×10^{-2}	0.5 to 0.6
RT And	3.28×10^{-15}	66	1.45×10^{-3}	0.2 to 0.3
AH Vir	2.62×10^{-14}	54	3.32×10^{-1}	1.6 to 2.0
V 566 Oph	2.04×10^{-14}	54	1.57×10^{-1}	1.1 to 1.3
44i Boo B (Heintz elements)	1.16×10^{-14}	68	7.27×10^{-2}	0.6 to 0.8

https://doi.org/10.1017/S025292110001034X Published online by Cambridge University Press

We can arrive at the same conclusion by an alternative approach. If we make the other extreme assumption that the third body motion can be represented by a long period circular orbit we can proceed as follows. In this case we can get

$$(a^2/m_3 \sin i) = 4\pi^2/(d^2 Z_{12}/dt^2).$$

Then for a small third mass of the order of one solar mass we can obtain an estimate of 'a' and calculate period P_3 by putting the total mass of the system equal to $m_{12}+M_\odot$. Since in this case the acceleration will be continuously changing the observed duration of secular variation of period should come out to be a small fraction of the third body period. From Table IV, which shows such calculations for the ten secular systems considered by us, we again find that the same six systems as before qualify for possible presence of a small third body. Hence we feel that many systems showing secular variation of period might be triple. It is interesting to note that Hilditch et al (1979) have found for SV Cam a third body period of 64 years in an orbit with e = 0.6 and ω = 90 degrees in agreement with the tentative values given in Table III.

TABLE IV - CIRCULAR THIRD BODY ORBIT REPRESENTATIONS FOR SECULAR SYSTEMS

System	a (m_3 sin i = 1) $M_\odot$	$m_{12}+m_3$ (i = 90°)	P_3 years	Observed fraction	Small 3rd body
SV Cam	50 AU	2.70 $M_\odot$	215	1/7	Possible
AR Lac	28	3.70	77	1/2	?
TV Cas	37	5.49	96	1/3	?
KO Aql	18	4.49	36	1/2.5	?
U Peg	62	3.40	265	1/8	Possible
AG Vir	60	3.83	239	1/6	Possible
RT And	78	3.52	365	1/11	Possible
AH Vir	28	2.96	84	1/3	?
V 566 Oph	31	2.74	105	1/4	Possible
44i Boo B (Heintz elements)	41	2.24	177	1/5	Possible

https://doi.org/10.1017/S025292110010034X Published online by Cambridge University Press

4. PECULIAR SYSTEMS

Finally we come to Group (iv) containing four contact systems which are put under peculiar category. Most prominent among them is the prototype W UMa itself. From Figure 7 we see that in addition to showing a secular decrease of period the (O-C) diagram indicates a discontinuity in 1964 which coincides remarkably with the flare observed in that system by Kuhi (1964). Relation of the

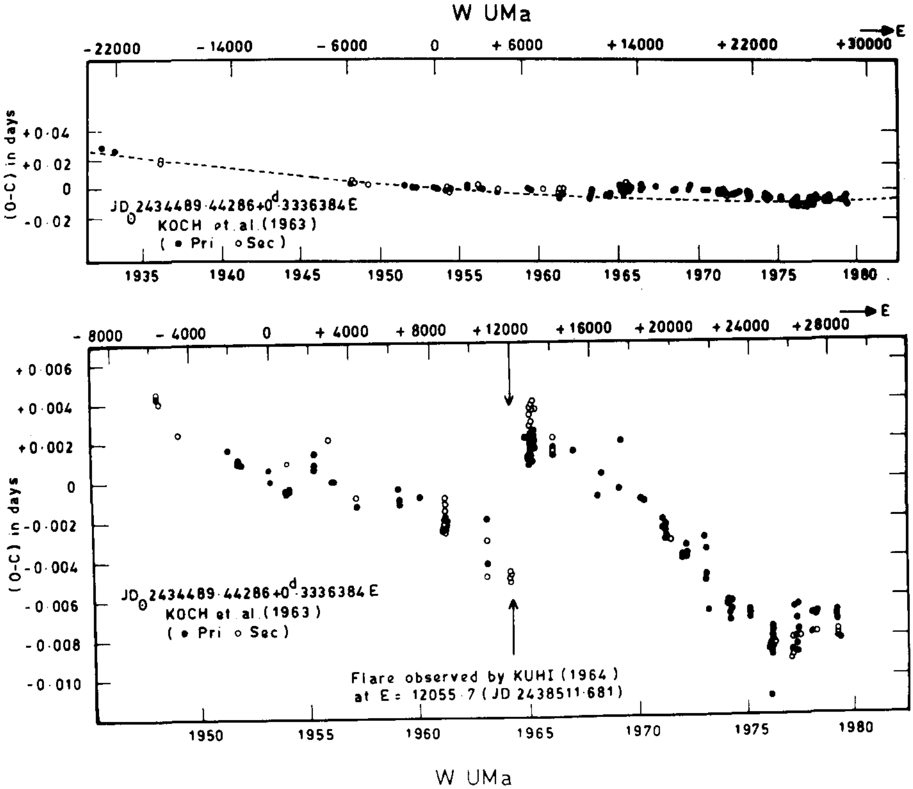


Figure 7. The (O-C) diagram for W UMa, lower part on expanded scale to bring out discontinuity.

flare to the period discontinuity is not clear, but we can observe the Kwee (1966) effect of separation of primary and secondary minima which occurs immediately after the flare. Discontinuities similar to W UMa are also observed in three other systems VW Cep, UV Leo and XY Leo, whose (O-C) diagrams are shown in Figure 8. However, the existence of third bodies in W UMa and VW Cep cannot be ruled out. The periods used for VW Cep and UV Leo are those due to Koch et al (1963) while that for XY Leo is obtained in the present study.

Concluding, it is commonly assumed that period changes in binary systems are mostly caused by mass exchange between components or loss of mass by the system during the course of its evolution. However, light time effects due to the presence of additional components may be equally important

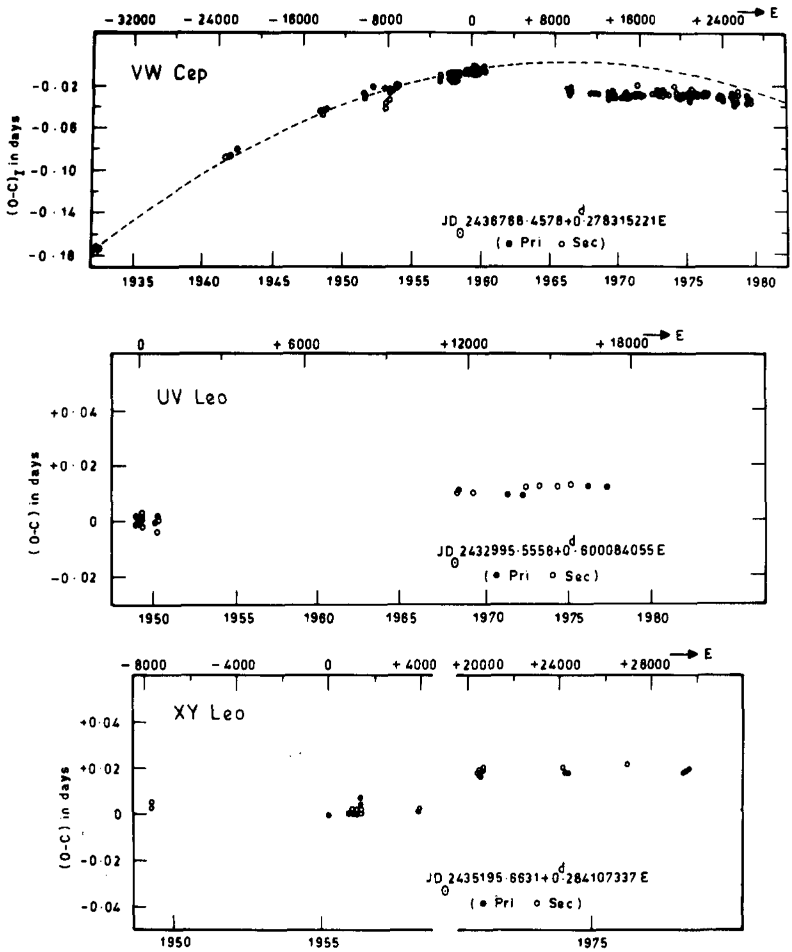


Figure 8. (O-C) diagrams for VW Cep, UV Leo and XY Leo.

in many cases. We would also like to suggest making regular astrometric measurements of all such eclipsing binaries.

REFERENCES

Abhyankar, K.D.: 1981, Bull. Astron. Soc. India, 9, 99.
Barker, L.A. and Herczeg, T.J.: 1979, Pub. Astron. Soc. Pacific, 91, 247.
Binnendijk, L.: 1960, Astron. J., 65, 88 and 358.
Chambliss, C.R.: 1976, Pub. Astron. Soc. Pacific, 88, 762.
Duerbeck, H.W.: 1975, Inform. Bull. Var. Stars, No. 1497.
Heintz, W.D.: 1963, Veroff. der Sternwarter Munchen, 5, 257.
Herczeg, T.J.: 1980, I.A.U. Symposium No. 88, 89.
Hilditch, R.W.; Harland, D.M. and Mclean, B.J.: 1979, Mon. Not. Roy. Astron. Soc., 187, 797.
Koch, R.H., Sobieski, S. and Wood, F.B.: 1963, Pub. Univ. Pa. Astron. Ser. No. 9.
Kuhi, L.V.: 1964, Pub. Astron. Soc. Pacific, 76, 430.
Kurutac, M. and Ibanoglu, C.: 1969, Inform. Bull. Var. Stars, No. 369.
Kwee, K.K.: 1966, Bull. Astron. Inst. Nether., 18, 448.
Mancuso, S., Milano, L., Russo, G. and Sollazzo, C.: 1978, Inform. Bull. Var. Stars, No. 1409.
Panchatsaram, T.: 1980, Thesis, Osmania Univ. Hyderabad.
Panchatsaram, T.: 1981 a, Bull. Astron. Soc. India, 9, 139.
Panchatsaram, T.: 1981 b, Astrop. Space Sc., 77, 179.
Panchatsaram, T. and Abhyankar, K.D.: 1981 a, Bull. Astron. Soc. India, 9, 31.
Panchatsaram, T. and Abhyankar, K.D.: 1981 b, J. Astrop. and Astron., 2, 29.
Panchatsaram, T. and Abhyankar, K.D.: 1981 c, Bull. Astron. Soc. India, 9, (in press).
Plavec, M., Pekny, Z. and Smetanova, M.: 1960, Bull. Astron. Inst. Czechosl., 11, 180.
Plavec, M., Smetanova, M. and Pekny, Z.: 1961, Bull. Astron. Inst. Czechosl., 12, 117.