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Secular period changes in ten eclipsing binaries

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Abstract. The photoelectric times of minima, available for the eclipsing binaries KO Aql, V566 Oph, AH Vir, AG Vir, 44i Boo B, RT And, SV Cam, TV Cas, AR Lac and U Peg have been analysed to study their orbital periods. KO Aql, V566 Oph, AH Vir, AG Vir and 44i Boo B show increase in their periods while RT And, SV Cam, TV Cas, AR Lac and U Peg exhibit decrease of period. Quadratic ephemeris for the primary times of minima for all the systems have been derived. The cause for the apparent secular change is conjectured to be the light-time effect, as no other mechanism seems appropriate to interpret the observed variations without difficulty. The need for future photoelectric observations of the times of minima and astrometric work for these systems is emphasized.

Key words : binaries-eclipsing—light-time effect

1. Introduction

An appreciable number of close binary systems have increasing or decreasing periods; this can be clearly seen if the minimum-time residual diagram is drawn usigng photoelectric times of minima. This is because on most occasions the observed period changes are many times smaller than the accuracy with which other types of minima (visual or photographic) are usually determined.

The available photoelectic times of minima for the following ten eclipsing binaries have been analysed by us : KO Aql, V566 Oph, AH Vir, AG Vir, 44i Boo B, RT And, SV Cam, TV Cas, AR Lac, and U peg. It is found that the first five show an increase in period while the later five, a decrease.

2. Systems with increasing period

First we discuss individually the systems KO Aql, V566 Oph, AH Vir, AG Vir and 44i Boo B which show secular increase of periods.

(i) *KO Aql* : The components of this eclipsing system have been suspected to be in the pre-main-sequence contraction phase of evolution (Roxburgh 1966, Field 1969).

The photoelectric light curve analysis by Hayasaka (1979) leads to the conclusion that the secondary component is smaller than its Roche limit, supporting Kopal's (1959) inclusion of this system in his classification of close binary systems containing undersize subgiant components. Panchatsaram & Abhyankar (1981b) have investigated the expected nature of period variations in such types of close binary systems. They feel that the cause for the observed period changes in KO Aql may be light-time effect. From all the published photoelectric times of minima, a least squares fitting gives the following quadratic ephemeris for the primary times of minima :

$$\text{Min } I = \text{JD}_{\odot}\ 244\ 1887.4731 + 2^{d}.8640440\ E + 0.217 \times 10^{-7}\ E^2. \quad \ldots(1)$$
$$\pm 13 \qquad \pm 18 \qquad \pm 32$$

(ii) *V566 Oph* : It is a W UMa-type eclipsing binary, undergoing complete eclipses. Bookmyer (1969, 1976), Dowson & Narayanaswamy (1977) and others have made period studies of this system. The above authors have found that the period has increased since 1966 after having remained constant for more than a decade. The study by Maddox (1978) also has disclosed the increase in the period of V566 Oph since 1966. But we find that the system is undergoing a secular increase of period. All the available photoelectric times of minima are listed in table 1 and the time residuals shown in figure 1 have been computed through the ephemeris given by Scarfe & Barlow (1978). The times of primary minima are given by the following quadratic ephemeris obtained through least squares method :

$$\text{Min } I = \text{JD}_{\odot}\ 244\ 1835.86198 + 0^{d}.40964428\ E + 0.148 \times 10^{-9} E^2. \quad \ldots(2)$$
$$\pm 43 \qquad \pm 17 \qquad \pm 11$$

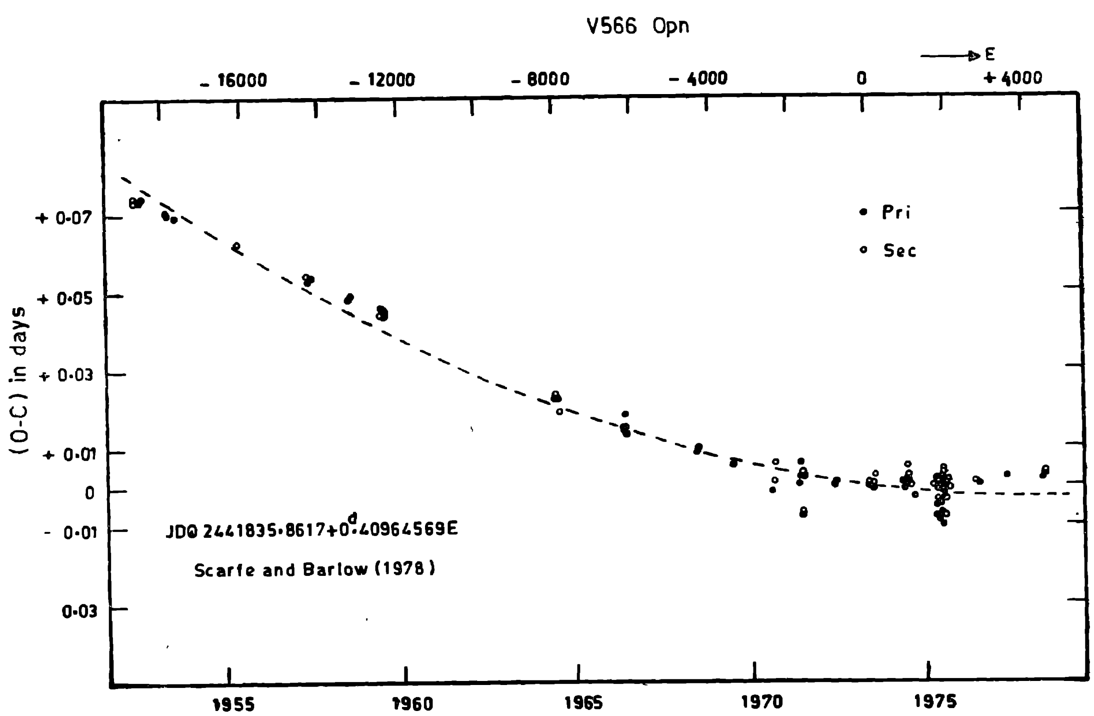

Figure 1. $(O - C)$ diagram for V566 Oph.

Table 1. Photoelectric times of minima of V566 Oph

No.	JD⊙		E	(O − C)	Notes
1	243 4179.45335	II	−18690	+0.07441	1
2	4181.50086	II	−18685	+0.07369	1
3	4226.35716		−18576	+0.07379	1
4	4237.41773		−18549	+0.07395	1
5	4515.56393		−17870	+0.07071	1
6	4515.56423		−17870	+0.07101	2
7	4593.39559		−17680	+0.06968	1,2
8	5245.74938	II	−16087	+0.06271	1
9	5968.76551	II	−14322	+0.05420	1
10	5987.81291		−14276	+0.05308	1
11	6010.75340		−14220	+0.05341	1
12	6395.40561		−13281	+0.04831	3
13	6404.41857		−13259	+0.04907	3
14	6725.3717	II	−12475	+0.04480	3
15	6728.4452		−12468	+0.04596	3
16	6744.41947		−12429	+0.04405	3
17	6755.48104		−12402	+0.04518	3
18	8556.4671	II	−8005	+0.02396	3
19	8557.4900		−8003	+0.02275	3
20	8589.4423		−7925	+0.02269	3
21	8590.4633	II	−7922	+0.01957	3
22	9289.72402	II	−6215	+0.01510	3
23	9289.92881		−6215	+0.01507	3
24	9294.4382		−6204	+0.01836	4
25	9297.71126		−6196	+0.01425	3
26	9297.9170	II	−6195	+0.01516	3
27	9319.4218		−6143	+0.01357	4
28	244 0047.358		−4366	+0.00938	5
29	0049.4057		−4361	+0.00885	5
30	0418.4931		−3460	+0.00548	5
31	0820.3490		−2479	−0.00104	6
32	0846.3686	II	−2415	+0.00606	7
33	0853.328	II	−2398	+0.00148	7
34	1119.8018		−1748	+0.00076	8
35	1119.807		−1748	+0.00596	8
36	1135.780		−1709	+0.00278	9
37	1136.3852	II	−1707	−0.00649	10
38	1139.4564		−1700	−0.00763	10
39	1145.8170	II	−1684	+0.00346	9
40	1165.684		−1636	+0.00264	9
41	1479.4702		−870	+0.00025	11
42	1479.4704		−870	+0.00045	11
43	1835.8616		0	−0.00010	8
44	1843.8498	II	+20	+0.00001	8
45	1845.489	II	+24	+0.00063	11
46	1850.6089		+36	−0.00004	9
47	1851.4283		+38	+0.00007	11
48	1851.6327	II	+39	−0.00036	9
49	1851.8381		+39	+0.00022	9
50	1858.5968	II	+56	−0.00023	9
51	1861.6690		+63	−0.00037	9
52	1862.6934	II	+66	−0.00009	9
53	1863.7179		+68	+0.00030	9
54	1866.5848		+75	−0.00032	9
55	1877.8508	II	+103	+0.00042	8
56	1895.468	II	+146	+0.00285	11
57	2193.4828		+873	+0.00042	12
58	2203.723		+898	−0.00052	9
59	2215.8078	II	+928	−0.00028	13
60	2216.8320		+930	−0.00019	13
61	2225.4170		+951	−0.01775	14
62	2230.3329		+963	−0.01759	14
63	2241.8201		+991	−0.00047	13
64	2243.4608		+995	+0.00164	15

Continued

Table 1—*Continued*

No.	JD⊙		E	(O−C)	Notes
65	244 2248.7844		+1008	−0.00015	13
66	2251.4448	II	+1015	−0.00245	12
67	2256.3680	II	+1027	+0.00500	15
68	2257.3880		+1029	+0.00089	15
69	2258.4165	II	+1032	+0.00527	15
70	2265.7848	II	+1050	−0.00005	13
71	2268.4474		+1056	−0.00014	12
72	2268.448		+1056	+0.00046	12
73	2307.3612		+1151	−0.00268	15
74	2532.4640	II	+1701	−0.00002	15
75	2537.5770		+1713	−0.00776	15
76	2549.4593		+1742	−0.00519	15
77	2555.4039	II	+1757	−0.00045	15
78	2563.3940		+1776	+0.00156	15
79	2565.4320		+1781	−0.00867	15
80	2567.4800		+1786	−0.00890	15
81	2572.8131		+1799	−0.00119	13
82	2576.4964		+1808	−0.00470	15
83	2579.779		+1816	+0.00073	16
84	2580.8014	II	+1819	−0.00099	16
85	2581.8262		+1821	−0.00030	13
86	2581.8263		+1821	−0.00020	16
87	2588.3797		+1837	−0.00113	15
88	2590.4300		+1842	+0.00094	15
89	2590.8385		+1843	−0.00020	16
90	2591.4547	II	+1845	+0.00155	15
91	2595.5490	II	+1855	−0.00063	15
92	2601.4860		+1869	−0.00349	15
93	2605.3790	II	+1879	−0.00213	15
94	2608.4600		+1886	−0.00653	15
95	2609.4740	II	+1889	−0.00358	15
96	2609.4785	II	+1889	+0.00092	15
97	2610.5010	II	+1891	−0.00069	15
98	2614.8044	II	+1902	+0.00142	13
99	2617.4555		+1908	−0.01017	15
100	2618.4945	II	+1911	+0.00471	15
101	2620.5300	II	+1916	−0.00802	15
102	2620.5350	II	+1916	−0.00302	15
103	2621.3892*	II	+1918	+0.03189	15
104	2623.4060	II	+1923	+0.00046	15
105	2624.4277		+1925	−0.00195	15
106	2666.4175	II	+2028	−0.00083	15
107	2938.8340	II	+2693	+0.00128	13
108	2987.7861		+2812	+0.00072	13
109	3281.5037		+3529	+0.00236	17
110	3671.8964		+4482	+0.00272	18
111	3676.4026		+4493	+0.00282	19
112	3677.4272	II	+4496	+0.00330	19

Notes : 1. Binnendijk (1959), 2. Kwee (1958), 3. Bookmyer (1969), 4. Popovici (1966), 5. Kizilirmak and Pohl (1970), 6. Popovici (1971), 7. Pohl and Kizilirmak (1971), 8. Scarfe *et al.* (1973), 9. Bookmyer (1976), 10. Pohl and Kizilirmak (1972), 11. Pohl and Kizilirmak (1974), 12. Kizilirmak and Pohl (1975), 13. Scarfe and Barlow (1978), 14. Popovici (1974), 15. Pop and Todoran (1977), 16. Dawson and Narayanaswamy (1977), 17. Kizilirmak and Pohl (1978), 18. Maddox (1978), 19. Niarchos (1979).

*Not used in the analysis.

In this connection it may be remembered that none has so far speculated on the cause for the period changes in KO Aql and V566 Oph, even though the period variations in these systems have been known for quite a long time.

(iii) *AH Vir* : This W UMa-type system shows peculiar light curve anomalies. Binnendijk (1960) interprets these features in terms of sub-luminous regions on the greater star. He attributes the period decrease found by him in 1953 to such 'explosion-like prominance' on the advancing side of the greater star as hypothesized by Wood (1950). Further, according to Binnendijk (1960) the period increase in 1955 is interpreted in terms of outflow of matter from the greater star to the circum-stellar space. Bakos (1977) also finds that the period variation in AH Vir is caused by mass transfer among the components. The above conclusions are based on rather imprecise data. It is true that the light curve of this system is very active. This is also well indicated in its $(O - C)$ diagram shown in figure 2 which is constructed from accurate photoelectric times of minima listed in table 2. We can easily find secularly

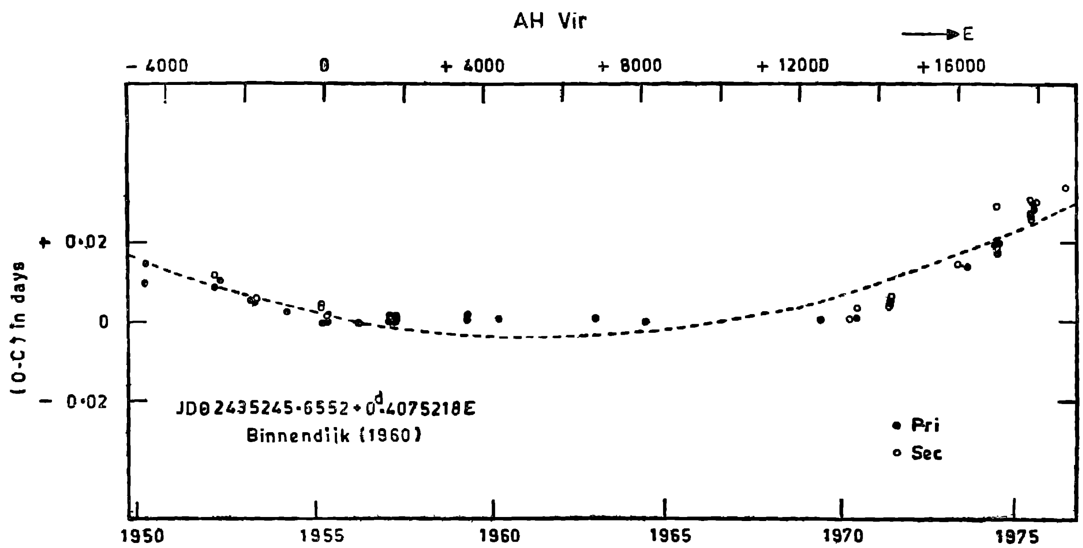

Figure 2. $(O - C)$ diagram for AH Vir.

Table 2. Photoelectric times of minima of AH Vir

No.	JD⊙		E	$(O-C)$	Notes
1	243 3389.811		—4554	+0.01007	1
2	3389.816		−4554	+0.01507	2
3	4094.41509		−2825	+0.00897	11
4	4094.4151		−2825	+0.00898	3
5	4105.2169	II	−2798	+0.01145	2
6	4105.2170	II	−2798	+0.01155	12
7	4157.990		−2669	+0.01048	12
8	4486.44716		−1863	+0.00507	11
9	4486.4471		−1863	+0.00501	3
10	4508.45296		−1809	+0.00469	11
11	4508.4530		−1809	+0.00473	3
12	4530.664	II	−1754	+0.00580	4
13	4841.39628		−992	+0.00270	11
14	4841.3963		−992	+0.00272	3
15	5197.7756	II	−117	+0.00421	5
16	5197.7762	II	−117	+0.00481	2
17	5207.7554		−93	−0.00028	3
18	5207.7555		−93	−0.00018	5
19	5207.75545		−93	−0.00023	2
20	5243.6173		−5	−0.00030	3
21	5243.61733		−5	−0.00027	2
22	5243.6175		−5	−0.00010	5

Continued

Table 2—*Continued*

No.	JD⊙		E	(O−C)	Notes
23	243 5344.63855	II	−2	+0.00215	2
24	5344.6380	II	−2	+0.00160	5
25	5244.6386	II	−2	+0.00200	3
26	5245.6552		0	0	2
27	5245.6555		0	+0.00030	5
28	5573.7102		+803	−0.00004	5
29	5573.70997		+805	−0.00027	2
30	5573.7100		+805	−0.00024	3
31	5901.76578		+1610	+0.00049	2
32	5901.7658		+1610	+0.00051	3
33	5901 7675		+1610	+0.00221	5
34	5907.675	II	+1625	+0.00064	5
35	5907.67557	II	+1625	+0.00121	2
36	5907.6756	II	+1625	+0.00124	3
37	5910.7309		+1632	+0.00013	3
38	5910.73091		+1632	+0.00014	2
39	5921.7339		+1659	+0.00004	3
40	5921.73391		+1659	+0.00005	2
41	5921.7340		+1659	+0.00014	5
42	5938.6462	II	+1701	+0.00018	5
43	5938.64646	II	+1701	+0.00044	2
44	5938.6465	II	+1701	+0.00048	3
45	5958.6149	II	+1750	+0.00031	3
46	5958.61491	II	+1750	+0.00032	2
47	5958.615	II	+1750	+0.00041	5
48	5959.6320		+1752	−0.00139	5
49	5959.63316		+1752	−0.00023	2
50	5959.6332		−1752	−0.00019	3
51	5961.6700		+1757	−0.00100	5
52	5961.67108		+1757	+0.00008	2
53	5961.6711		+1757	+0.00010	3
54	5962.6900	II	+1760	+0.00020	3
55	5962.69001	II	+1760	+0.00021	2
56	6697.6560		+3563	+0.00063	5
57	6697.65698		+3563	+0.00161	2
58	6697.657		+3563	+0.00163	3
59	7017.5609		+4348	+0.00092	3
60	8026.9925		+6825	+0.00102	3
61	8534.3559		+8070	—0.00022	3
62	244 0349.4590		+12324	+0.00078	10
63	0652.8587	II	+13269	+0.00050	3
64	0652.85873	II	+13269	+0 00053	6
65	0717.6567	II	+13428	+0.00353	3
66	υ718.6742		+13430	+0.00123	3
67	1059.7738		+14267	+0.00508	3
68	1061.8110		+14272	+0.00468	3
69	1062.8285	II	+14275	+0.00337	3
70	1067.7220	II	+14287	+0.00661	3
71	1765.4077	II	+15999	+0.01499	8
72	1859.3405		+16229	+0.01401	8
73	2155.6146		+16956	+0.01976	3
74	2157.6499		+16961	+0.01746	3
75	2158.6673	II	+16964	+0.02962	3
76	2162.7464	II	+16974	+0.01993	3
77	2171.7109	II	+16996	+0.01895	3
78	2501.408	II	+17805	+0.03092	9
79	2516.6870		+17842	+0.02785	3
80	2519.7418	II	+17850	+0.02623	3
81	2529.7267		+17874	+0.02685	3
82	2532.5828		+17881	+0.03030	3
83	2546.6422	II	+17916	+0.03020	3
84	2549.6949		+17923	+0.02848	3
85	2858.4003	II	+18681	+0.03412	7

Notes : 1. Nason and Moore (1951), 2. Binendijk (1960), 3. Bakos (1977), 4. Fitch (1964), 5. Szafraniec (1962), 6. Landolt (1972), 7. Kizilirmak and Pohl (1977), 8. Kizilirmak and Pohl (1974), 9. Kizilirmak and Pohl (1976), 10. Kizilirmak and Pohl (1970), 11. Kwee (1958), 12. Kitamura *et al.* (1957).

increasing period for AH Vir from its $(O - C)$ diagram. The light-elements given by Binnendijk (1960) have been used in the $(O - C)$ computations. A least squares solution gives the following quadratic ephemeris for the primary times of minima :

$$\text{Min } I = \text{JD}_\odot\, 243\,5245.65708 + 0^d.40715973\, E + 0.188 \times 10^{-9} E^2 \quad \ldots(3)$$
$$\pm 45 \qquad\qquad \pm 19 \qquad\qquad \pm 12$$

(iv) *AG Vir* : The primary of AG Vir is believed to fill its Roche lobe (Blanco & Catalano 1970) while the secondary is still an unevolved main-sequence star. Hill & Barnes (1972) expect this system to be a prototype of a most elusive class of eclipsing variables, wherein the primary is filling the Roche lobe and secondary is on the main-sequence. If the primary transfers matter to the secondary and if the mass is conserved, the period will decrease secularly. However what we observe is a secular increase of period in AG Vir. This kind of system is never found in the catalogues of eclipsing binaries. However, Kopal (1978) comments that the probability of finding such types of systems would be greater than of any other types. Binnendijk (1969) found an abrupt period change in 1944 whereas Blanco & Catalano (1970) suspected apsidal motion or the presence of a third body to be the cause of the period changes in AG Vir. Apsidal motion can be safely ruled out as the primary and the secondary points in the $(O - C)$ diagram are in phase.

The photoelectric times of minima available to us are presented in table 3. Using the ephemeris given by Koch *et al.* (1963) the $(O - C)$ values have been computed. A plot of these residuals shown in figure 3 indicates secular increase of period. This change depends entirely upon the last two photoelectric minima times. If they were not considered, no change in the period would be obvious. A least squares solution gives the following ephemeris for the primary times of minima :

$$\text{Min } I = \text{JD}_\odot\, 243\,4086.4171 + 0^d.64264956\, E + 0.97 \times 10^{-10} E^2 \quad \ldots(4)$$
$$\pm 10 \qquad\qquad \pm 13 \qquad\qquad \pm 17$$

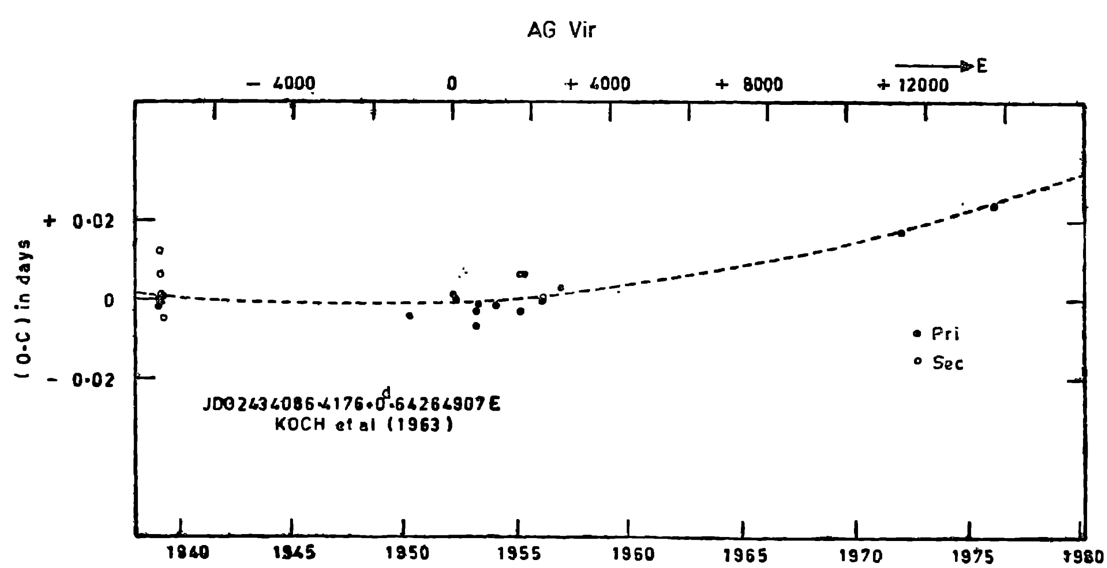

Figure 3. $(O - C)$ diagram for AG Vir.

Table 3. Photoelectric times of minima of AG Vir

No.	JD$_\odot$		E	(O−C)	Notes
1	242 9329.851	II	−7402	+0.00049	1
2	9334.993	II	−7394	+0.00130	1
3	9335.956		−7392	+0.00032	1
4	9337.884		−7389	+0.00037	1
5	9338.851	II	−7388	+0.01240	1
6	9339.811		−7386	−0.00057	1
7	9346.879		−7375	−0.00171	1
8	9353.635	II	−7365	+0.00648	1
9	9359.734		−7355	+0.00030	1
10	9363.910	II	−7349	−0.00090	1
11	9368.732		−7341	+0.00122	1
12	9374.831	II	−7332	−0.00494	1
13	243 3387.854		−1087	−0.00407	2
14	4086.41948		0	+0.00188	3
15	4120.47868		+53	+0.00068	3
16	4455.2919		+574	−0.00626	4
17	4458.5090		+579	−0.00241	4
18	4487.42968		+624	−0.00093	3
19	4776.62146		+1074	−0.00124	3
20	5197.5551		+1729	−0.00274	4
21	5198.5286	II	+1731	+0.00678	4
22	5219.4146		+1763	+0.00669	4
23	5561.2974		+2295	+0.00019	4
24	5562.2619	II	+2297	+0.00071	4
25	5548.5649		+2742	+0.00356	4
26	244 1391.427		+11367	+0.01743	5
27	2501.408*		+13094	+0.14348	6
28	2892.6620		+13703	+0.02420	7

Notes : 1. Wood (1946), 2. Nason and Moore (1951), 3. Kwee (1958), 4. Szozepanowska (1958), 5. Pohl and Kizilirmak (1974), 6. Kizilirmak and Pohl (1976), 7. Mallama *et al.* (1977).

*Not used in the analysis.

(v) *44i Boo B* : 44i Bootis is a visual binary both primary 44i Boo A and secondary 44i Boo B being of the same spectral type G2V. The secondary is a W UMa-type eclipsing spectroscopic binary. The primary of the visual pair also exhibits a slight light variation (Binnendijk 1955). Van't Veer (1971) gives a different spectral type F5 V for the primary of the visual binary. Strand (1937) has improved Duerbeck's (1909) elements of this visual binary orbit (see also Heintz 1963). According to Binnendijk (1966) the masses of the primary and secondary are about 1.17 $M_\odot$ and 1.24 $M_\odot$ respectively. The individual masses of the eclipsing system are about 0.76 $M_\odot$ and 0.48 $M_\odot$.

A number of studies of the orbital period of the eclipsing system 44i Boo B, have been made (Plaut 1939, Eggen 1948, Binnendijk 1955, Schmidt & Schrick 1957). Schneller's (1965) finding of the nonlinearly increasing period from 1916 to 1964 and the random nature of its variation was supported by Scarfe & Brimacombe (1971). Abrami & Cester (1956) analysing the available times of minima arrived at the conclusion that in addition to effects due to the visual double system, there must be at least partly actual variations intrinsic to the eclipsing system. Bergeat *et al.* (1972) found that 44i Boo B undergoes periodic changes in its orbital period; once in ten years there is a sudden change in the period accompanied by disturbed light curve. They attribute this phenomenon to a periodic outflow of matter from the envelope of the system through the outer Lagrangian point L_2. Differing conclusions regarding the nature of the period variation in 44i Boo B, have been reached by others (Herczeg 1962; Purgathofer & Prochazka 1967; Karetnikov 1965; Brown & Pinnington 1969; and Breinhorst 1978). Most of these authors do not agree upon the point that the orbital period of 44i Boo B has been secularly increasing since 1930, showing practically no abrupt discontinuities in the period. This is surely because the above authors used rather imprecise data. If the period analysis is made using only photoelectrically determined minimum-period as we have been doing, the picture one gets is entirely different. It is therefore clear from the above discussion that it is generally believed the period changes in the eclipsing system of 44i Boo B are due to either mass transfer among the components or mass loss from the system. Plaut's idea (Breinhost 1978) that the period change in 44i Boo B is purely on account of its orbital motion in the visual binary system for positive value of the angle of inclination of the visual binary orbit has completely been abandoned in recent times.

The photoelectric $(O - C)$ diagram, shown in figure 4a, for the light elements given by Duerbeck (1975) using the minima listed in table 4, clearly indicates that the period has been secularly increasing since 1945. The points in figure 4a were fitted with a parabola by least squares method to get the following representation :

$$(O - C)_{\rm I} = \underset{\pm 2}{0.0004} - \underset{\pm .1}{6.2} \times 10^{-7} E + \underset{\pm .2}{5.5} \times 10^{-11} E^2. \qquad \ldots(5)$$

Let us now eliminate the effect due to the eclipsing pair's motion in the visual orbit. The minimum time residuals shown in column 4 of table 4 were corrected for visual motion using Heintz's (1963) orbital elements and are plotted in figure 4b. We note that even the corrected residuals again show the presence of secularly increasing tendency of the period at the present time. The points in figure 4b were further fitted with a quadratic expression by least squares method to get :

$$(O - C)_{\rm II} = \underset{\pm 1}{0.1988} - \underset{\pm 3}{1.28} \times 10^{-6} E + \underset{\pm .2}{3.6} \times 10^{-11} E^2. \qquad \ldots(6)$$

It is thus obvious that the observed period variations in 44i Boo B are not entirely due to the motion of the eclipsing pair in the visual orbit. There is an additional part present in the period changes.

3. Systems with decreasing periods

Let us now consider individually the systems RT And, SV Cam, TV Cas, AR Lac and U Peg—which show secular decrease of period.

(i) *RT And* : Kopal & Shapley (1956) classified this system as a semi-detached binary, but later analysis has identified it as a detached system with unevolved main-sequence components (Giannone & Giannuzzi 1974; Batten *et al.* 1978). Asymmetric eclipse light curve and both diurnal and annual variations in the levels of maxima and in the depths of minima have been reported by Gordon (1956), Dean (1974) and Mancuso *et al.* (1978). Kristenson (1967) expected reflection of the effect of varying asymmetry in the light curve causing fluctuations in the epochs of times of minima. It is true that the time dependent asymmetry in the light curve will cause a large random scattering of points in the $(O - C)$ diagram. But in the case of

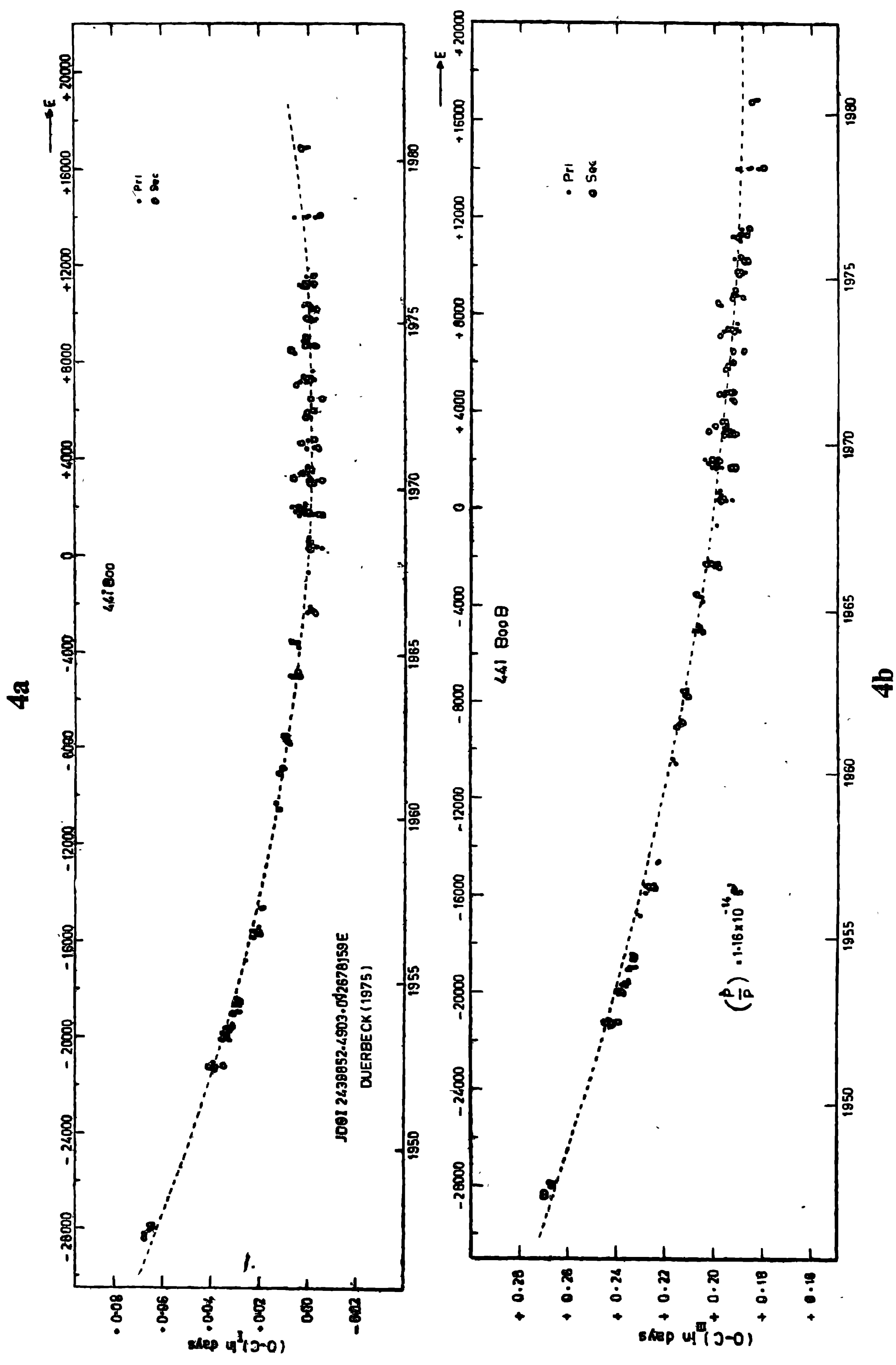

Figure 4(a). (*O* — *C*) diagram for 44i Boo B.
Figure 4(b). (*O* — *C*) diagram for 44i Boo B after applying light-time correction for visual binary orbit due to Heintz (1963).

Table 4. Photoelectric times of minima of 44i Bootis B

No.	JD⊙		*E*	$(O-C)_{I}$	$(O-C)_{II}$	Notes
1	243 2244.8455	II	—28407	+0.06756	—0.24536	1
2	2262.7892	II	—28340	+0.06759	—0.24511	1
3	2339.7838		—28052	+0.06512	—0.24668	1
4	2361.7221*		—27970	+0.04252	...	1
5	2369.7788		—27940	+0.06374	—0.24771	1
6	2373.7953		—27925	+0.06400	—0.24740	1
7	2374.7332	II	—27922	+0.06454	—0.24685	1
8	2380.7585		—27899	+0.06399	—0.25033	1
9	4132.51692		—21358	+0.03861	—0.25224	2
10	4132.5173		—21358	+0.03899	—0.25186	3
11	4139.2130		—21333	+0.03929	—0.25148	4
12	4145.2380	II	—22311	+0.03843	—0.25227	4
13	4156.2205	II	—21270	+0.04048	—0.25010	4
14	4169.0705	II	—21222	+0.03531	—0.25511	4
15	4199.4715		—21108	+0.03921	—0.25086	3
16	4199.47151		—21108	+0.03922	—0.25085	2
17	4459.7820		—20136	+0.03266	—0.25437	5
18	4478.53146		—20066	+0.03500	—0.25180	2
19	4778.5315		—20066	+0.03504	—0.25176	3
20	4501.5618		—19980	+0.03318	—0.25336	3
21	4501.56168		—19980	+0.03306	—0.25348	2
22	4503.7047		—19972	+0.03353	—0.25296	3
23	4505.7144	II	—19965	+0.03463	—0.25186	3
24	4506.7848	II	—19961	+0.03376	—0.25271	3
25	4513.7490	II	—19935	+0.03475	—0.25165	3
26	4558.6055		—19767	+0.03209	—0.25378	3
27	4568.5152		—19730	+0.03260	—0 25315	3
28	4583.5141		—19674	+0.03381	—0.25177	3
29	4586.7256		—19662	+0.03152	—0.25402	3
30	4688.6009		—19655	+0.03211	—0.25341	3
31	4595.5646		—19629	+0.03206	—0.25284	3
32	4597.7056		—19621	+0.03107	—0.25434	3
33	4750.6288		—19050	+0.03139	−0.25224	3
34	4750.62786		—19050	+0.03045	—0.25318	2
35	4764.5541		—18998	+0.03026	—0.25320	2
36	4764.5543		—18998	+0.03046	—0.25300	3
37	4768.57067		—18983	+0.02959	—0.25382	2
38	4768.5712		—18983	+0.03012	—0.25329	3
39	4775.53238		—18957	+0.02809	—0.25524	2
40	4775.5324		—18957	+0.02811	—0.25522	3
41	4845.7017		—18695	+0.ᵈ02965	− 0.ᵈ25287	3
42	4853.7347		−18665	+0.02817	—0.25425	3
43	4876.4988		−19580	+0.02792	—0.25424	6
44	5893.6389		—18516	+0.02780	—0.25416	3
45	4893.7739	II	—18516	+0.02889	—0.25307	3
46	4901.6743		—18486	+0.02872	—0.25314	3
47	4913.7265		—18441	+0.02921	—0.25251	3
48	5341.4252		—16844	+0.02591	—0.25081	6
49	5601.4725		—15873	+0.02398	—0.24971	6
50	5663.4681	II	—15642	+0.02019	—0.25277	7
51	5663.4689	II	—15642	+0.02099	—0.25197	7
52	5667.4858	II	—15627	+0.02063	—0.25526	7
53	5667.4881	II	—15627	+0.02295	—0.24996	7
54	5627.4429		—15608	+0.02316	—0.24969	7
55	6694.4010		—15526	+0.02036	—0.25224	6
56	2927.3997		—14656	+0.01923	−0.25065	6
57	5932.4875		—14637	+0.01852	—0.25129	6
58	7026.5090		−10552	+0.01207	—0.24496	8
59	7082.4840		−10343	+0.01355	—0.24282	8
60	7439.6151	II	—9010	+0.01214	—0.24006	9
61	7443.6322	II	—8995	+0.01201	—0.24015	9
62	7443.7660		—8994	+0.01190	—0.24025	9
63	7449.6577		—8972	+0.01165	—0.24043	9
64	7449.7917	II	—8972	+0.01194	—0.24034	9

Continued

Table 4—*Continued*

No.	JD⊙		E	$(O-C)_I$	$(O-C)_{II}$	Notes
65	243 7472.6889		—8886	$+0^d.01068$	$-0^d.24113$	9
66	7472.8228	II	—8886	+0.01067	—0.24114	9
67	7779.4695	II	—7741	+0.00817	—0.24006	10
68	7780.4080		—7737	+0.00931	—0.23890	10
69	7826.4719		—7565	+0.00838	—0.23880	10
70	7835.4445	II	—7532	+0.00964	—0.23792	10
71	7855.3959		—7457	+0.00876	—0.23858	10
72	8241.4390*	II	—6016	—0.00476	...	11
73	8512.3470		—5004	+0.00746	—0.23220	12
74	8512.4770	II	—5004	+0 00355	—0.23611	12
75	8513.4165		—5000	+0.00570	—0.23395	13
76	8513.4170		—5000	+0.00620	—0.23345	12
77	8540.4649		—4899	+0.00469	—0.23464	14
78	8560.4170	II	—4825	+0.00450	—0.23460	12
79	8663.3890		—4440	+0.01203	—0.23661	12
80	8675.3020*	II	—4396	—0.00352	...	12
81	8833.4550	II	—3805	+0.00419	—0.23172	12
82	8882.4660		—3622	+0.00488	—0.23045	12
83	8882.4663		—3622	+0.00518	—0 23015	13
84	8902.4200	II	—3548	+0.00660	—0.22851	12
85	9210.3994	II	—2398	—0.00229	—0.23379	15
86	9224.4624		—2345	+0.00038	—0.23096	15
87	9242.4050		—2278	—0.00068	—0.23181	16
88	9243.3465	II	—2275	+0.00346	—0.22766	16
89	9245.3520		—2267	+0.00034	—0.23076	16
90	9245.4865	II	—2267	+0.00093	—0.23017	16
91	9247.3600	II	—2260	—0.00028	—0.23135	16
92	9248.4310	II	—2256	—0.00054	—0 23161	16
93	9252.4480	II	—2241	—0.00078	—0.23180	15
94	9290.3855*		—2099	+0.04077	...	15
95	9261.4198		—2207	—0.00081	—0.23172	13
96	9671.4470		—676	+0.00024	—0.22587	13
97	9922.9250		+263	—0.00088	—0.22405	17
98	9935.9136	II	+312	—0.00135	—0.22437	17
99	9945.4222		+347	—0.00021	—0.22313	18
100	9948.3630		+358	—0.00539	—0.22827	19
101	9952.9210		+375	—0.00026	—0.22308	17
102	9956.4000		+388	—0.00286	—0.22565	19
103	9959.3490		+399	+0.00016	—0.22259	19
104	9959.4810	II	+400	—0.00175	—0.22449	19
105	9968.4530		+433	+0.00158	—0.22422	19
106	9977.2920		+466	—0.00050	—0.22305	19
107	244 0005.8141	II	+573	—0.00080	—0.22300	20
108	0007.8230		+580	—0.00052	—0.22270	20
109	0029.7844		+662	—0.00002	—0.22195	20
110	0040.7647		+703	—0.00017	—0.22197	20
111	0312.4583	II	+1718	—0.00580	—0.22442	21
112	0312.4595	II	+1718	—0.00460	—0.22322	21
113	0312.5966		+1718	—0.00141	—0.22003	21
114	0312.5978		+1718	—0.00021	—0.21883	21
115	0313.4034		+1721	+0.00194	—0.21647	21
116	0313.4051		+1721	+0.00364	—0.21497	21
117	0316.3460		+1732	—0.00343	—0.22001	19
118	0319.2960		+1743	—0.00259	—0.21595	19
119	0325.4556		+1766	+0.00243	—0.21605	22
120	0331.3460		+1788	+0.00088	—0.21753	19
121	0333.3541	II	+1796	+0.00036	—0.21802	22
122	0339.3816		+1818	+0.00200	—0.21631	22
123	0339.6493		+1819	+0.00188	—0.21642	23
124	0346.6161		+1845	+0.00547	—0.21276	23
125	0346.7482	II	+1846	+0.00366	—0.21456	23
126	0363.4840		+1908	+0.00097	—0.21706	19
127	0382.7676		+1980	+0.00182	—0.21598	24
128	0390.8020		+2010	+0.00175	—0.21596	24

Continued

Table 4—*Continued*

No.	JD⊙		E	$(O-C)_{\mathrm{I}}$	$(O-C)_{\mathrm{II}}$	Notes
129	244 0392.5449	II	+2017	+0ᵈ.00384	—0ᵈ.21384	23
130	0392 6820		+2017	+0.00703	—0.21065	23
131	0420.7971		+2122	+0.00147	—0.21589	24
132	0661.4273	II	+3021	—0.00092	—0.21546	25
133	0675.4871		+3073	—0.00146	—0.21584	21
134	0675.4878		+3073	—0.00076	—0.21514	21
135	0675.6193	II	+3074	—0.00316	—0.21754	21
136	0675.6207	II	+3074	—0.00176	—0.21614	21
137	0678.5655	II	+3085	—0.00314	—0.21748	21
138	0678.5669	II	+3085	—0.00154	—0.21588	21
139	0679.3664	II	+3088	—0.00548	—0.21982	21
140	0679.3704	II	+3088	—0.00148	—0.21582	21
141	0679.5034		+3088	—0.00239	—0.21673	21
142	0679.5040		+3088	—0.00179	—0.21613	21
143	0681.3774		+3095	—0.00311	—0.21742	21
144	0681.5119	II	+3096	—0.00251	—0.21682	21
145	0682.4518		+3099	+0.00003	—0.2 427	21
146	0682.4485		+3099	—0.00327	—0.21757	21
147	0686.4668		+3114	—0.00221	—0.21646	21
148	0700.3943		+3166	—0.00113	—0.21522	26
149	0714.5891		+3219	—0.00058	—0.21450	23
150	0714.7299	II	+3220	—0.00632	—0.20760	23
151	0753.4231		+3364	+0.00022	—0.21335	25
152	0769.6286	II	+3425	+0.00276	—0.21052	23
153	0759.7628		+3425	+0.00305	—0.21023	23
154	0780.4710		+3465	—0.00139	—0.21454	25
155	0801.7627	II	+3545	—0.00105	—0.21395	27
156	0812.7448	II	+3586	+0.00060	—0.21218	27
157	1055.3820	II	+4492	—0.00341	—0.21335	21
158	1055.5165		+4492	—0.00282	—0.21276	21
159	1102.6556		+4668	+0 00068	−0.20871	23
160	1110.8264	II	+4699	+0.00310	—0.20619	27
161	1131.8469		+4777	+0.00005	—0.20900	27
162	1138.4060	II	+4802	—0.00234	—0.21131	28
163	1139.3450		+4805	—0.00070	−0.20965	28
164	1141.4886		+4813	+0.00037	—0.20856	28
165	1147.7804	II	+4837	—0.00149	—0.21035	27
166	1384.5323	II	+5721	+0.00115	—0.20494	29
167	1392.4320		+5750	+0.00028	—0.20572	29
168	1435.4166	II	+5911	+0.00043	—0.20507	29
169	1462.4640	II	+6012	− 0.00158	—0.20676	29
170	1585.3920	II	+6471	—0.00107	—0.20482	29
171	1599.3140	II	+6523	—0.00550	—0.20908	29
172	1758.4070	II	+7117	+0.00485	—0.19687	29
173	1798.4440		+7266	+0.00338	—0.19788	29
174	1814.7746		+7327	—0.00279	—0.20386	27
175	1816.7854	II	+7335	—0.00061	—0.20165	27
176	1818.7946		+7342	—0.00003	—0.20105	27
177	1819.4640	II	+7345	—0.00017	—0.20118	29
178	1827.7662	II	+7376	+0.00174	—0.19918	27
179	1829.7737		+7383	—0.00138	—0.20228	27
180	1900.7444		+7648	—0.00190	—0.20196	30
181	2095.4540		+8375	+0.00554	—0.19224	31
182	2122.3710	II	+8476	+0.00705	—0.19042	31
183	2187.4400	II	+8719	+0.00322	—0.19993	31
184	2196.8176	II	+8754	+0.00083	—0.19577	30
185	2218.7782	II	+8836	+0.00052	—0.19582	30
186	2219.4470		+8838	—0.00022	—0.19656	31
187	2228.8212		+8873	+0.00042	—0.19580	30
188	2268.3240	II	+9021	+0.00038	—0.19538	31
189	2449.5010		+9697	—0.00008	—0.19373	32
190	2450.5712		+9701	−0.00114	—0.19478	33
191	2450.7059	II	+9702	—0.00035	—0.19398	33
192	2453.5168		+9712	—0.00152	—0.19512	33

Continued

Table 4—*Continued*

No.	JD⊙		E	$(O-C)_I$	$(O-C)_{II}$	Notes
193	244 2453.6511	II	+9713	—0ᵈ.00112	—0ᵈ.19472	33
194	2465.4365	II	+9757	+0.00038	—0.19308	32
195	2465.5670		+9757	—0.00303	—0.19649	32
196	2581.3970	II	+10190	—0.00341	—0.19551	32
197	2600.4137	II	+10261	—0.00163	—0.19352	32
198	2619.8345		+10333	+0.00251	—0.18915	34
199	2635.7667	II	—10393	—0.00033	—0.19180	30
200	2828.4615		+11112	+0.00092	—0.18830	35
201	2841.5850		+11161	+0.00145	—0.18762	35
202	2849.3540	*	+11190	+0.00378	—0.18519	35
203	2849.4860	II	+11191	+0.00188	—0.18709	35
204	2869.4358		+11265	—0.00061	—0.18935	35
205	2969.5685	II	+11266	—0.00181	—0.19055	35
206	2886.4420	II	+11239	+0.00072	—0.18926	35
207	2886.5780		+11329	+0.00137	—0.18717	35
208	2937.4620		+11519	+0.00036	—4.18759	35
209	2947.7702	II	+11558	—0.00236	—0.19018	30
210	3604.5880		+14010	—0.00305	—0.18320	36
211	3607.5379		+14021	+0.00087	—0.17924	36
212	3607.8107		+14022	+0.00586	—0.17426	36
213	3614.3611	II	+14047	—0.00523	—0.18527	37
214	3614.5000		+14047	—0.00024	—0.18028	37
215	3615.5710		+14051	—0.00051	—0.18053	37
216	4345.50670	II	+16777	+0.00296	—0.16853	38
217	4365.45694		+16851	+0.00091	—0.17034	38
218	4366.52904		+16855	+0.00175	—0.16949	38

Notes : *Minima not included in the analysis.

1. Eggen (1948), 2. Kwee (1958), 3. Binnendijk (1955), 4. Huruhata *et al.* (1957), 5. Fitch (1964), 6. Schmidt and Schrick (1957), 7. Abrami and Cester (1956), 8. Plavec and Mayer (1962), 9. Wehlan and Leung (1962), 10. Semeniuk (1963), 11. Pohl and Kizilirmak (1964), 12. Pohl and Kizilirmak (1966), 13. Pohl (1967), 14. Schneller (1964), 15. Popovici (1966), 16. Schnellor (1966), 17. Brown and Pinnington (1969), 18. Popovici (1968), 19. Kizilirmak and Pohl (1970), 20. Breinhorst (1978), 21. Bergeat *et al.* (1972), 22. Popovici (1970), 23. Rudnick (1973), 24. Scarfe and Brimacombe (1971), 25. Pohl and Kizilirmak (1971), 26. Popovici (1971), 27, Scarfe *et al.* (1973), 28. Pohl and Kizi.irmak (1972), 29. Kizilirmak and Pohl, 1974, 30. Scarfe and Barlow (1978), 31. Pohl and Kizilirmak (1975), 32. Pohl and Kizilirmak (1976), 33. Gieseking (1977), 34. Margrave *et al.* (1978), 35. Kizilirmak and Pohl (1977), 36. Duerbeck *et al.* (1978), 37. Rovithis and Rovithis-Livaniou (1978), 38. Mikolajewska and Mikolajewski (1980).

RT And it is found that although the observed change is much larger than the spread of points arising out of asymmetric minima, the scattering in the photoelectric $(O - C)$ diagram based on the photoelectric minima listed in table 5 and on the light elements given by Mancuso *et al.* (1978) shown in figure 5 is about $0^d.004$. Therefore, the variation is real and not due to asymmetric minima.

Earlier authors found abrupt period chages in RT And when they analysed mostly visual and photographic times of minima. As the true variation in the period of the system is many times smaller than the error involved in the determination of the time of minimum using visual or photographic techniques, the real variation becomes apparent only if the $(O - C)$ diagram is constructed using photoelectric minima. The $(O - C)$ curve of RT And shows a secular decrease of period right from about 1950 when photoelectric observations were first started on this system. We may note that in a detached system like RT And mass transfer will hardly take place. Even if we assume that the secondary fills its Roche lobe so that it may transfer

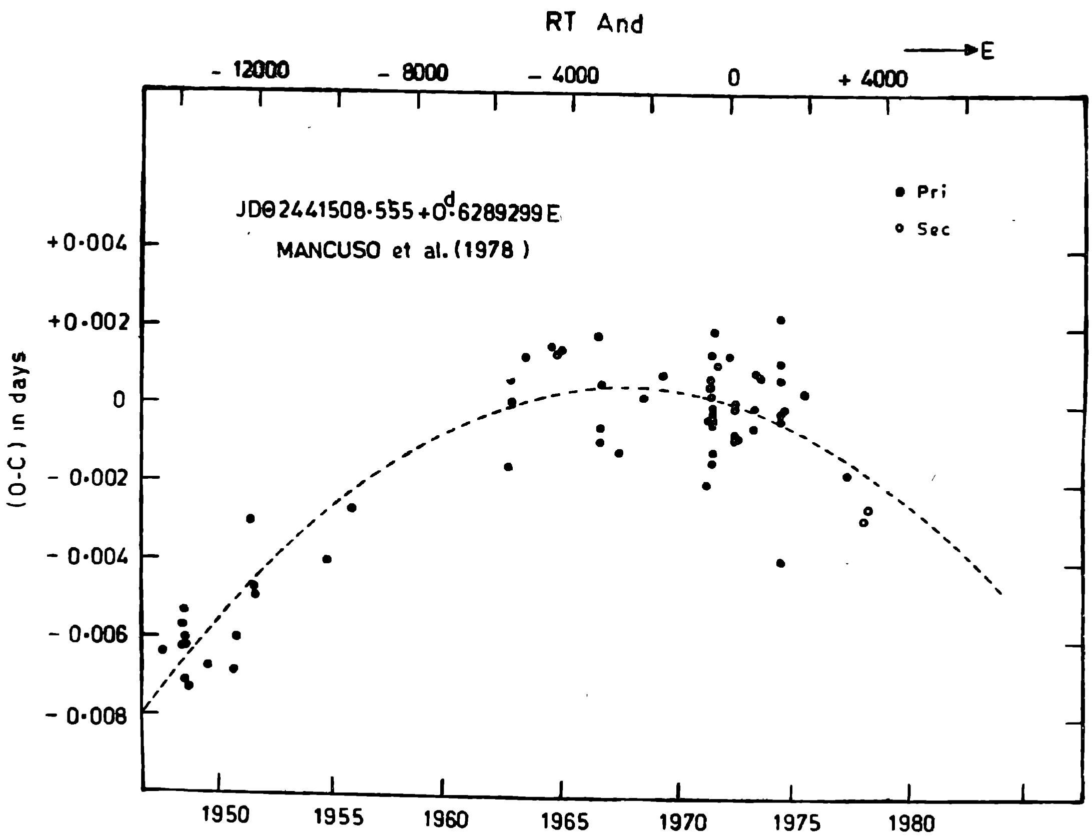

Figure 5. ($O - C$) diagram for RT And.

Table 5. Photoelectric times of minima of RT And

No.	JD⊙		E	$(O-C)$	Notes
1	243 2443.782		—14413	—0.00636	1
2	2758.876		—13912	—0.00624	1
3	2763.908		—13904	—0.00568	1
4	2775.858		—13885	—0.00534	1
5	2787.807		—13866	—0.00601	1
6	2804.787		—13839	—0.00712	1
7	2821.769		—13812	—0.00623	2
8	2865.793		—13742	—0.00732	1
9	3175.856		—13249	—0.00676	1
10	3587.805		—12594	—0.00684	1
11	3627.4284		—12531	—0.00603	1
12	3837.494		—12197	—0.00301	1
13	3918.624		—12068	—0.00497	1
14	3920.511		—12065	—0.00476	1
15	5066.422		—10243	—0.00404	1
16	5454.4731		—9626	—0.00269	1
17	7958.8731		—5644	—0.00155	3
18	7987.8061		—5598	+0.00068	3
19	7999.7552		—5579	+0.00011	3
20	8227.429		—5217	+0.00128	1
21	8651.328		—4543	+0.00153	1
22	8728.6862		—4420	+0.00136	3
23	8778.6862	II	—4341	+0.00142	4
24	9390.3209		—3368	+0.00180	1
25	9422.3936		—3317	—0.00093	1
26	9429.3122		—3306	—0.00056	1

Continued

Table 5—*Continued*

No.	JD⊙		*E*	(*E*−*C*)	Notes
27	243 9441.2630		—3287	+0.00058	1
28	9739.374		—2813	—0.00120	1
29	244 0115.4755		—2215	+0.00022	1
30	0439.375		—1700	+0.00083	1
31	1141.8885		—583	—0.00037	1
32	1143.7753		—580	—0 00036	1
33	1167.673		—542	—0.00200	1
34	1176.795	II	—528	+0.00052	1
35	1194.7197		—499	+0.00072	1
36	1197.865		—494	+0.00137	1
37	1198.8073	II	—493	+0.00028	1
38	1218.6181		—461	—0.00022	1
39	1220.8192	II	—458	—0.00038	1
40	1222.7063	II	—455	—0.00007	1
41	1227.4219		—447	—0.00144	1
42	1230.5675		—442	—0.00049	1
43	1232.4536		—439	—0.00118	1
44	1261.3875		—393	+0.00195	1
45	1300.3803		—331	+0.00109	9
46	1508.5563		0	+0.00130	5
47	1598.4911		+143	—0.00087	5
48	1598.4912		+143	—0.00077	6
49	1619.2458		+176	—0.00086	7
50	1627.4227		+189	—0.00005	6
51	1627.4228		+189	+0.00005	5
52	1886.5418		+601	—0.00006	5
53	1905.4092		+631	—0.00056	10
54	1924.2795		+661	+0 00184	7
55	2011.3852	II	+800	+0.00075	5
56	2317.3611		+1286	+0.00225	8
57	2329.3092		+1305	+0.00069	5
58	2330.5675		+1307	+0.00113	5
59	2338.4240	II	+1320	−0.00400	5
60	2339.3710		+1321	—0.00039	5
61	2367.3586	II	+1366	—0.00018	5
62	2385.2832		+1394	—0.00008	5
63	2717.3586		+1922	+0.00034	11
64	3044.3992		+2442	—0.00262	12
65	3381.5065		+2978	—0.00174	13
66	3725.5303		+3525	—0.00260	4
67	3732.4483		+3536	—0.00283	4

Notes : 1. Williamon (1974), 2. Kristenson (1967), 3. Dean (1974), 4. Mancuso *et al.* (1979), 5. Mancuso *et al.* (1978), 6. Mancuso and Milano (1974), 7. Kizilirmak and Pohl (1974), 8. Baldinelli and Ghedini (1976), 9. Pohl and Kizilirmak (1972), 10. Baldinelli *et al.* (1973), 11. Pohl and Kizilirmak (1976), 12. Patkos (1980), 13. Ebersberger *et al.* (1978).

matter to primary this process will lead to increase in the period contrary to what we observe today. The secondary points in the $(O - C)$ diagram follow clearly the primary points. Moreover, Williamon (1974) finds the occurrence of secondary minimum close to 0.5 phase. Hence, the possibility of apsidal notion is also ruled out.

The following quadratic ephemeris was obtained from the available photoelectric times of minima listed in table 5 by the least squares method :

$$\text{Min } I = \text{JD}_\odot\ 244\ 1508.55504 + 0.62892960\, E - 0.561 \times 10^{-10} E^2. \qquad \ldots(7)$$
$$\pm 17 \qquad\qquad \pm 8 \qquad\qquad \pm 64$$

(ii) *SV Cam* : Sommer (1956) represented the minimum time residuals of SV Cam by a sine term with long-term period equal to 57.7 yr. Van Woerden (1957) found random variations in the period resulting mainly from irregular chages in the light curves. Frieboes-Conde & Herczeg (1973) re-established the sine term keeping the long-term period as 72.8 yr and obtained lower estimates for the third body mass. Almost all observers of this system have found highly disturbed light curves. This was ascribed to the supposed instabilities in the primary component nearly filling its Roche lobe. In a recent study of this system, Hilditch *et al.* (1979) have proposed a revised light-time hypothesis to explain the period variation. Further, the latter authors have found the secondary of SV Cam as a BY Dra variable. According to them, the observed erratic behaviour of the light curve is attributed to the intrinsic variability of the secondary component. Moreover they find SV Cam as a detached system.

As the light curve is subject to transient changes it may be intuitively expected that the points in the $(O - C)$ diagram will also show wide scattering, particularly if the minimum time analysis is made using all types of minima. This can be well seen in the $(O - C)$ diagram published by Hilditch *et al.* (1979). To get a good idea of the actual process responsible for the period variations it is highly advantageous to take only reliable determinations of the epochs of minima. Even forming normal points will mask the true changes. The photoelectric $(O - C)$ diagram shown in figure 6 is based on the times of minima listed in table 6 using the linear ephemeris given by Koch *et al.* (1963). In spite of the wide scattering even among photoelectric minima, it is clear that the period of the system has been secularly decreasing at least for the last three decades.

The following quadratic ephemeris obtained through the photoelectric minima listed in table 6 represents the times of primary minima :

$$\text{Min } I = \text{JD}_\odot\ 243\ 3777.42528 + 0^d.59307304\ E - 0.120 \times 10^{-9}\ E^2. \quad \ldots(8)$$
$$\pm 24 \qquad\qquad \pm 12 \qquad\qquad \pm 9$$

(iii) *TV Cas* : It is an Algol-type system consisting of a B9 star of 3.1 $M_\odot$ and a F9 star of 1.39 $M_\odot$. Many authors have discussed the period changes occurring in this system. Analysing all the times of minima available till 1959, Chou (1959) found only one sudden period increase around 1935, following which the period has remained constant. The next detailed period analysis by Plavec *et al.* (1961) established that there was no change in the period of the system. It should be noted that the above authors mostly relied on the visual and photographic times of minima for their analysis because the then available photoelectric minima were relatively few in number. Kristenson (1966) suspected changes in the period while Walter (1979) recognised a clear shortening of the period. Bakos & Tremko (1973) found the period variations to be sinusoidal with long-term period equal to 40 yr. Frieboes Conde & Herczeg (1973) attributed the changes to light-time effect with third body orbital period equal to 39.2 yr. and the third mass equal to 0.42 $M_\odot$, for the third body orbital inclination of 60°. The latter authors based their analysis mainly on a few photoelectric times of minima then available. Grauer *et al.* (1977) revised the above value for third body orbital period to 28.8 yr. It may be noted here that none of the light-time ephemeris available in the literature represents adequately

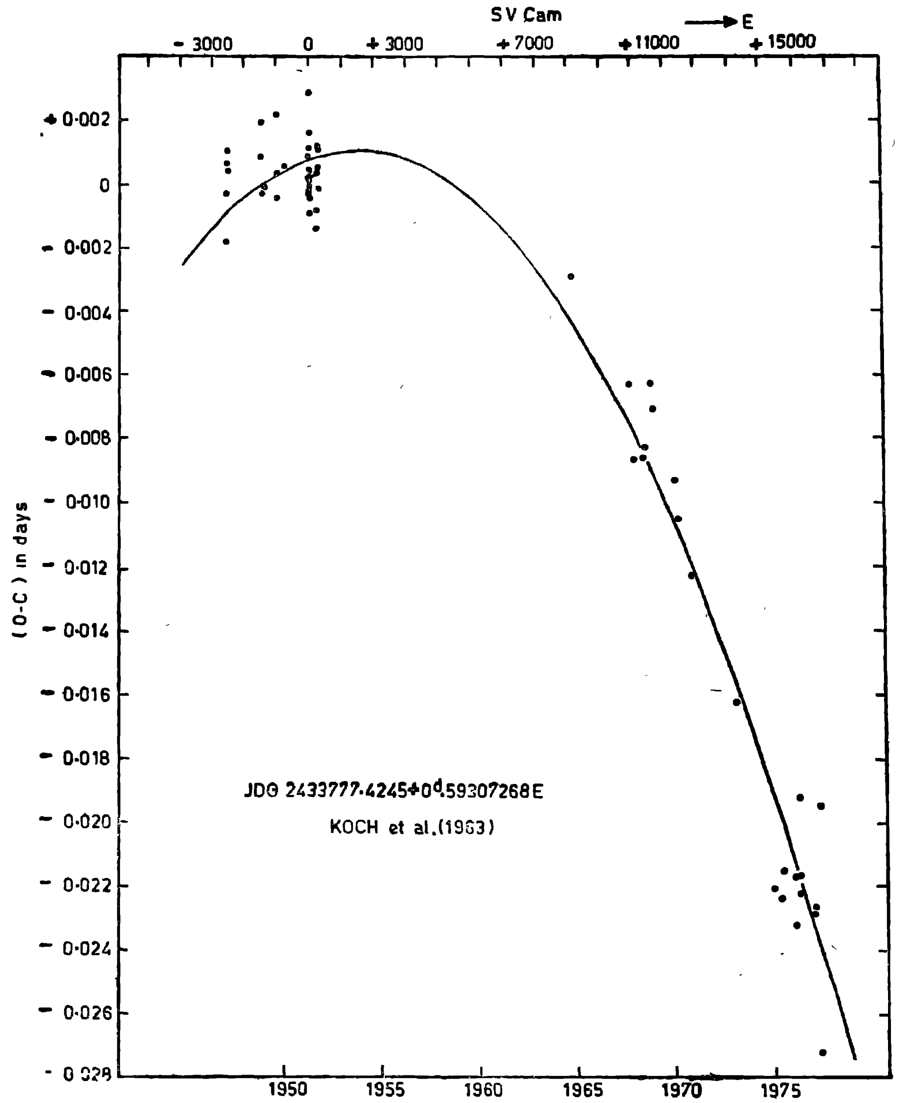

Figure 6. (*O* — *C*) diagram for SV Cam.

Table 6. Photoelectric times of minima of SV Cam

No.	JD⊙	*E*	(*O*−*C*)	Notes
1	243 2253.81897	—2569	—0.00182	1
2	2265.68193	—2549	—0.00031	1
3	2268.64828	—2544	+0.00067	1
4	2281.66927	—2522	+0.00106	1
5	2287.62634	—2512	+0.00041	1
6	2878.92135	—1515	+0.00196	1
7	2883.66482	—1507	+0.00084	1
8	2911.53810	—1460	—0.00029	1
9	2949.49493	—1396	—0.00011	1
10	3179.60942	—1008	+0.00218	1
11	3180.79374	—1006	+0.00035	1
12	3183.75833	—1001	—0.00042	1
13	3314.82840	—780	+0.00059	1
14	3741.83983	—60	—0.00031	1
15	3741.84052	—60	+0.00038	1

Continued

Table 6—*Continued*

No.	JD⊙	E	(O−C)	Notes
16	243 3761.41135	−27	−0.00019	1
17	3762.59789	−25	+0.00020	1
18	3768.52885	−15	+0.00044	1
19	3769.71441	−13	−0.00015	1
20	3769.71745	−13	+0.00289	1
21	3775.64646	−3	+0.00117	1
22	3775.64696	−3	+0.00167	1
23	3777.42408	0	−0.00042	1
24	3784.54045	+12	−0.00092	1
25	3791.65787	+24	−0.00037	1
26	3791.65817	+24	−0.00007	1
27	3803.52001	+44	+0.00032	1
28	3844.44204	+113	+0.00033	1
29	3895.44313	+199	−0.00083	1
30	3911.45753	+226	−0.00139	1
31	3921.54153	+243	+0.00037	1
32	3923.32090	+246	+0.00053	1
33	3927.47308	+253	+0.00120	1
34	3928.65913	+255	+0.00110	1
35	3931.62431	+260	+0.00092	1
36	3943.48472	+280	−0.00013	1
37	8652.479	+8220	−0.00292	2
38	8667.312*	+8245	+0.00326	2
39	8671.460*	+8252	−0.00025	2
40	9681.4567	+9955	−0.00632	2
41	9776.346	+10115	−0.00865	2
42	9945.3718	+10400	−0.00857	6
43	9977.3980	+10454	−0.00829	6
44	244 0092.4561	+10648	−0.00629	6
45	0127.4466	+10707	−0.00708	6
46	0528.3615	+11383	−0.00931	3
47	0593.5983	+11493	−0.01051	4
48	0857.5139	+11938	−0.01225	5
49	1681.2879	+13327	−0.01620	7
50	2366.281	+14482	−0.02205	8
51	2517.5142	+14737	−0.02238	9
52	2545.3895	+14784	−0.02150	9
53	2771.350	+15165	−0.02169	9
54	2777.2792	+15175	−0.02321	9
55	2836.5905	+15275	−0.01918	10
56	2852.601	+15302	−0.02164	10
57	2855.5458	+15307	−0.02221	10
58	3115.3310	+15745	−0.02284	4
59	3138.461	+15784	−0.02268	13
60	3222.384 II	+15926	−0.01946	11
61	3263.5948	+15995	−0.02722	12

Notes : 1. Van Woerdon (1957), 2. Frieboes-Conde and Herczeg (1973), 3. Muthsam (1972), 4. Hilditch *et al.* (1979), 5. Kizilirmak and Pohl (1971), 6. Pohl and Kizilirmak (1970), 7. Kizilirmak and Pohl (1974), 8. Pohl and Kizilirmak (1975), 9. Pohl and Kizilirmak (1976), 10. Mallama *et al.* (1977), 11. Budding *et al.* (1977), 12. Mallama (1979), 13. Pohl and Kizilirmak (1977).

*Not used in the analysis.

all the available photolectric times of minima. This is either because of inaccurate data or of the treatment of a small arc, as a part of the sinusoid arising out of light-time effect. Whether or not the arc is a part of the sinusoid is to be decided by future accurate photoelectric observations of times of minima for a decade or more. Any attempt at the solution of the third-body orbit at present might prove to be an exercise in vain. Any interpretation based on light-time effect should therefore be viewed critically.

However, Tremko & Bakos (1977) have invoked the process of steller wind flowing from the hotter star and falling on the cooler star to explain the observed secular period decrease in TV Cas. Conservative mass transfer equation reveals that the period of a binary system decreases as the more massive component transfer matter to the less massive component. Since stellar wind is mostly an isotropic emission phenomenon not confined to any particular region on the surface of the star, mass may be lost isotropically from the surface of the star rather than as directional flow of matter to the other star. This isotropic emission of matter clearly corresponds to the Jeans mode of mass flow (Huang 1956, 1963) leading to only secular increase in the period contrary to what is being observed in TV Cas. Moreover the fraction of matter the secondary is likely to capture from this stellar wind would be so small that the orbital period changes due to this capture will be practically zero. Furthermore, it is very doubtful whether stellar wind is so powerful a mechanism in TV Cas that the lost mass carries away a major fraction of the angular momentum thereby leading to secular period decrease.

An alternative approach is to interpret the period variation in terms of Biermann-Hall period-change model (Chaubey 1979). The so-called sequence of parabolas found by Chaubey in his $(O - C)$ diagram constructed out of normal points formed from mostly inaccurate times of minima obtained either visually or photographically (*cf.* Frieboes-Conde & Herczeg 1973) appears to be nothing more than spurious 'wiggles' arising out of observational scatter of points. This statement is fully confirmed if one compares the $(O - C)$ curve constructed using only the photoelectric times of minima with that obtained from all types of minima. One may therefore conclude that the idea of mass transfer between the components will not be appropriate for the behaviour of the change in the orbital period of TV Cas. Even the pre-main sequence status for this star is ruled out as discussed by Panchatsaram & Abhyankar (1981a). Their period study of the sytem gave the following ephemeris for the primary times of minima from a least squares analysis of all the available photoelectric times of minima :

$$\text{Min } I + \text{JD}_\odot\ 2436483.8094 + 1^d.8126107\, E - 0.204 \times 10^{-8}\, E^2. \qquad \ldots(9)$$
$$\pm 5 \qquad\qquad \pm 3 \qquad\qquad \pm 9$$

(iv) *AR Lac* : This system is similar to RS CVn in many respects. It is a detached system, consisting of two late type subgiant components of spectral types G2 and K0 (Chambliss 1974). Dugan & Wright (1939) found a constant period for this system. But later investigators such as Wood (1950), Plavec *et al.* (1961) and Chambliss (1976) are of the opinion that the system undergoes abrupt period changes. The photoelectric $(O - C)$ curve shows none of changes so far reported. A secular decrease of the orbital period can be seen from figure 7 drawn using the minima listed in table 7 and the light-elements provided by Chambliss (1976). The following quadratic ephemeris for the primary times of minima is obtained through the least squares solution of the available photoelectric times of minima listed in table 7 :

$$\text{Min } I = \text{JD}_\odot\ 242\,6624.3301 + 1^d.9832573\, E - 0.429 \times 10^{-8}\, E^2. \qquad \ldots(10)$$
$$\pm 21 \qquad\qquad \pm 13 \qquad\qquad \pm 14$$

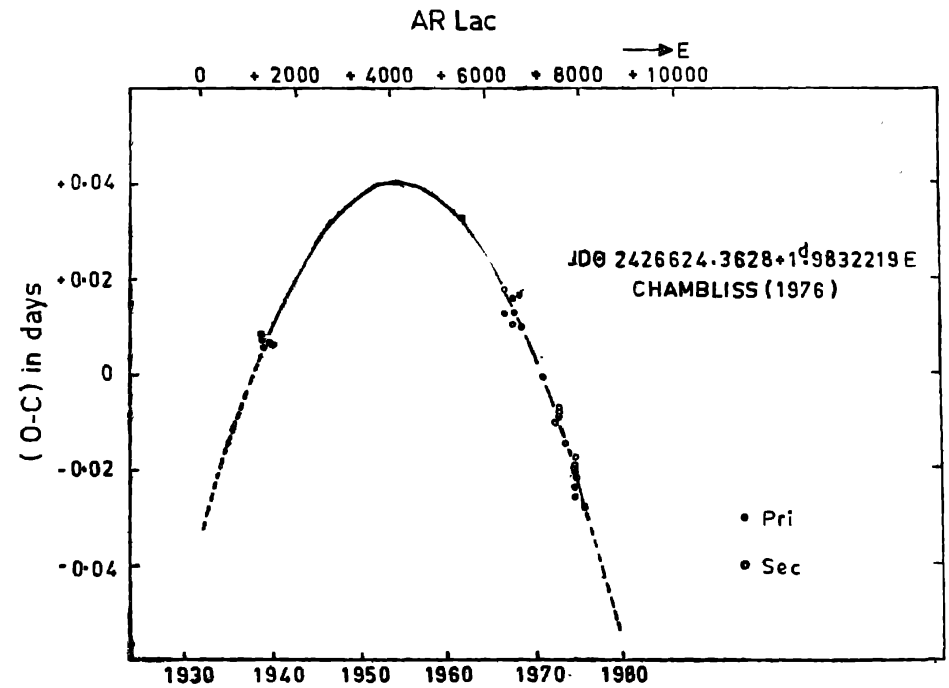

Figure 7. (O — C) diagram for AR Lac.

Table 7. Photoelectric times of minima of AR Lac

No.	JD⊙		E	(O—C)	Notes
1	242 9178.761		+1288	+0.00840	1
2	9186.693		+1292	+0.00751	1
3	9188.675		+1293	+0.00629	1
4	9404.847		+1402	+0.00710	1
5	9535.739		+1468	+0.00646	1
6	243 7569.7977		+5519	+0.03324	2
7	9376.4926		+6430	+0.01299	2
8	9383.4386	II	+6434	+0.01771	2
9	9691.8224		+6589	+0.01051	3
10	9695.7941		+6591	+0.01576	3
11	9699.7590		+6593	+0.01422	3
12	9701.7410		+6594	+0.01300	3
13	9876.268		+6682	+0.01647	4
14	244 0046.8186		+6768	+0.00999	3
15	0932.3168	II	+7215	—0.00039	5
16	1513.391	II	+7508	—0.01021	6
17	1592.7219	II	+7548	—0.00819	2
18	1593.7124		+7548	—0.00930	2
19	1604.6224	II	+7554	—0.00704	2
20	1936.8022*		+7721	+0.00964	2
21	1938.7874		+7722	—0.01491	2
22	2285.8406		+7897	—0.02554	3
23	2287.8257		+7898	—0.02366	3
24	2287.8275		+7898	—0.02186	7
25	2288.8215	II	+7899	—0.01947	7
26	2288.8231	II	+7899	—0.01787	3
27	2289.8120		+7899	—0.02058	3
28	2292.7872	II	+7901	—0.02022	3
29	2634.8850		+8073	—0.02819	3

Notes : 1. Plavec *et al.* (1961), 2. Chambliss (1976), 3. Karle *et al.* (1977), 4. Kizilirmak and Pohl (1970) 5. Battistini *et al.* (1973), 6. Pohl and Kizilirmak (1974), 7. Scarfe and Barlow (1978).
*Not used in the analysis.

(v) *U Peg* : All the available photoelectric times of minima of this W UMa-type eclipsing system are listed in table 8. The photoelectric $(O - C)$ curve, based on the light elements of Koch *et al.* (1963) is shown in figure 8. It indicates that the system undergoes secular decrease of period confirming earlier finding by Kwee (1958). A flare activity in U Peg in 1951 December has been reported by Huruhata (1952). This would have been a mild activity as compared to that in W UMa, as the $(O - C)$ curve does not seem to have been affected to any marked degree. However, Huruhata's suspicion of apsidal motion is invalid because the primary and the secondary points in the $(O - C)$ diagram follow in steps. The following quadratic ephemeris has been obtained by least squares method analysing the minima in table 8 :

$$\text{Min } I = \text{JD}_\odot\ 2436511.66872 + 0.37478164\,E - 3.12 \times 10^{-11}\,E^2. \qquad \ldots(11)$$
$$\pm 42 \qquad \pm 4 \qquad \pm .39$$

Table 8. Photoeletric times of minima of U Peg

No.	JD⊙		E	(O — C)	Notes
1	243 3182.8561		—8882	+0.00033	1
2	3190.7262		—8861	+0.00001	1
3	3190.9132	II	—8860	—0.00038	1
4	3202.7181		—8829	—0.00111	1
5	3230.6408	II	—8754	+0.00033	1
6	3244.5075	II	—8717	+0.00010	1
7	3255.5630		—8688	—0.00046	1
8	3558.7624		—7679	+0.00036	1
9	3561.7592		—7871	—0.00109	1
10	3924.54967		—6903	+0.00048	2
11	3958.9448	II	—6704	+0.00193	3
12	4303.4545		—5892	+0.00079	2
13	4685.3586		—4873	+0.00211	2
14	6481.68639		—80	+0 00016	3
15	6483.74902	II	—74	+0.00149	3
16	6484.68389		—72	—0.00060	3
17	6508.67015		—8	—0.00038	3
18	6511.66878		0	0	3
19	6515.60569	II	+11	+0.00170	3
20	8689.7081	II	+5812	—0.00580	4
21	8691.7693	II	+5817	—0.00590	4
22	8692.7072		+5820	—0.00496	4
23	8703.388		+5848	—0.00544	5
24	244 0096.4534		+9565	—0.00444	6
25	0205.328	II	+9856	—0.00399	6
26	0511.338		+10672	—0.00343	7
27	0835.3337	II	+11537	—0.00670	7
28	0867.3784		+11622	—0.00585	7
29	2291.543		+15422	—6.01255	8
30	2347.3879		+15571	—0.01015	9
31	2741.281		+16622	—0.01285	9
32	3021.6134		+17370	—0.01733	10
33	4185.3093		+20475	—0.01929	8

Notes : 1. Lafara (1952), 2. Kwee (1958), 3. Binnendijk (1960), 4. Gordon (1975), 5. Pohl and Kizilirmak (1966), 6. Kizilirmak and Pohl (1970), 7. Pohl and Kizilirmak (1971), 8. Patkos (1980), 9. Patkos (1976), 10. Mallama *et al.* (1977).

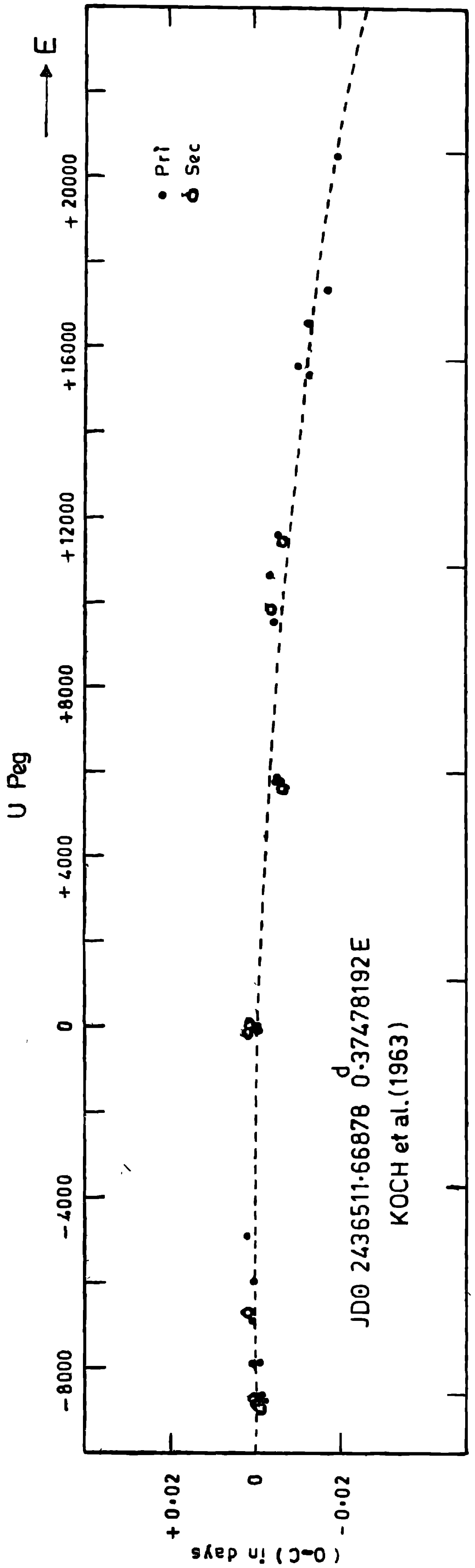

Figure 8. (*O* — *C*) diagram for U Peg.

4. Discussion

Usually the secular period changes observed in the eclipsing systems are attributed to mass transfer between the components, but this interpretation poses many difficulties as discussed above. Besides, we find that the secular increase or decrease of period is not at all characteristic of any special kind of binary systems; because we detect secular changes in detached, semi-detached and contact systems. Therefore, it is possible to invoke a common agency for these variations and assume that the observed changes are due to light-time effect. The currently available segment in the $(O - C)$ diagrams could then be a part of their periodic variations due to gravitational interaction from a third or a fourth body in the system; getting the long term orbital elements of either third or fourth component from the available portion of the light-time curve will be out of question. But if it is assumed that the observed secular change is due to the presence of a third body, the question is : is it possible to get relevant parameters, either geometrical or physical, of the so called triple configuration from the available parabolic light-time curve? Recently Abhyankar (1981) has described a statistical method to derive probable masses for the third components from the available parabolic segment of the light-time curves of secular systems. We have applied this method to all the above secular systems and the results are given in Panchatsaram & Abhyankar (1981b). They show that the masses of the third companion are comparatively smaller for six systems, but the computed third-body masses in the case of AR Lac, AH Vir, TV Cas and KO Aql are very high. This could be due to the uncertainty involved in the long-term period and the orbital eccentricity, for which we have used some plausible values. Finally, if the observed secular changes are most probably due either to a third or a fourth component in the systems, then periodicity in the light-time curve should be anticipated if there are no abrupt discontinuities in future. Astrometric studies can be planned wherever possible for these eclipsing systems.

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