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Period Studies of Some Neglected Close Binaries: EP Andromedae, V724 Aquilae, SS Comae, AM Eridani, FZ Orionis, BY Pegasi, EQ Tauri, and NO Vulpeculae

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ABSTRACT. Orbital period changes of eight neglected short-period close binaries, EP And, V724 Aql, SS Com, AM Eri, FZ Ori, BY Peg, EQ Tau, and NO Vul, are presented based on the analysis of their $O-C$ observations. It is found that the periods of BY Peg and EQ Tau are decreasing at rates of $dP/dt = -1.67 \times 10^{-7}$ and -1.72×10^{-7} day yr^{-1}, respectively, while the orbital periods of SS Com and AM Eri show secular increase at rates of $dP/dt = +5.91 \times 10^{-7}$ and $+4.39 \times 10^{-7}$ day yr^{-1}. Weak evidence also indicates that the orbital period of EP And is increasing. For FZ Ori, the decrease rate of orbital period is revised. For the other two systems, V724 Aql and NO Vul, their $O-C$ curve can be described by a sudden period decrease or a continuous period decrease; further investigation is needed. The period changes of the eight systems can be explained by mass transfer between the two components and/or mass and angular momentum loss from these binaries. A strong mass-radius relation for observed contact binaries is formed based on the parameters given by Maceroni & Van't Veer. It is shown that the parameters of SS Com and EQ Tau given by Brancewicz & Dworak do not agree with the mass-radius relation. This may suggest that the two systems are not yet in contact. In order to understand the physical properties of these binaries, complete photoelectric or CCD light curves and radial velocity observations are needed.

1. INTRODUCTION

Short-period close binary systems are important objects for study since they contain the phenomena of contact, near contact, or virtual contact. Orbital period study of this type of system is very useful to understand their structure and evolution. It can provide estimates of mass transfer and angular momentum loss (AML) which are predicted by some theoretical work, e.g., the thermal relaxation oscillation (TRO) models and the AML theory. Recently, with the times of light minimum collected at the Eclipsing Binaries Minimum Database[3] and those compiled from other literature, the orbital period changes of some neglected short-period close binaries have been surveyed. Here we report period variations of eight such systems (EP And, V724 Aql, SS Com, AM Eri, FZ Ori, BY Peg, EQ Tau, and NO Vul). According to the fourth edition of the General Catalogue of Variable Stars (GCVS; Kholopov 1985), they are close binaries with EW-type light curves for which it is impossible to specify the moments of the beginning and the end of the eclipses; the depths of the two minima are almost equal or differ by less than ~0.1 mag. The EB-type light curve shows a continuous light variation, but, in general, the difference of the depths of the two minima is slightly larger than that of EW type. The general properties of these systems are shown in Table 1.

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[3] The Eclipsing Minimum Database is available at http://www.oa.uj.edu.pl/ktt/ktt.html.

2. ORBITAL PERIOD CHANGES OF THE SAMPLE STARS

2.1. EP And

EP And was a neglected close binary system with an EW-type light curve. Its spectral type is unknown. Apart from two photoelectric times of minima by Hoffmann (1983), no photoelectric or CCD times of minima have been published. Based on all times of light minimum collected at the Eclipsing Binaries Minima Database, the ephemeris given by the fourth edition of the GCVS (Kholopov 1985),

$$\min I = 2{,}442{,}638.522 + 0.40410755E, \qquad (1)$$

has been revised as

$$\min I = 2{,}442{,}638.5109 + 0.40411057E. \qquad (2)$$

The $O-C$ curve computed from the ephemeris (2) is plotted in Figure 1, where open circles refer to visual or photographic observations and the two solid dots to the two photoelectric

TABLE 1
GENERAL PROPERTIES FOR EIGHT CLOSE BINARIES

Star	Type	P (days)	Spectral Type	M_1 ($M_\odot$)	M_2 ($M_\odot$)	R_1 ($R_\odot$)	R_2 ($R_\odot$)	Reference
EP And	EW/KW	0.40410755	...	...	...	...	...	1
V724 Aql	EW/KW	0.51752	A1	1.19	0.81	1.20	1.02	1, 2
SS Com	EW/KW	0.4128093	F5	1.56	0.94	1.16	1.16	1, 2
AM Eri	EW/KW	0.316576	...	...	...	...	...	1
FZ Ori	EW/KW	0.3999866	G0	...	...	...	...	1
BY Peg	EW/KW	0.3419372	...	...	...	...	...	1
EQ Tau	EW/KW	0.34134848	A3+K0 IV	1.20	0.80	1.01	1.01	1, 2
NO Vul	EW/KW	0.3707685	...	...	...	...	...	1

REFERENCES.—(1) Kholopov 1985 (GCVS); (2) Brancewicz & Dworak 1980.

data. With the method of least squares, the quadratic ephemeris

$$\min I = 2{,}442{,}638.5134(9) + 0.404110940(1)E + 6.44(9) \times 10^{-11}E^2 \quad (3)$$

is obtained. This ephemeris tells us that the orbital period of the system is continuously increasing at a rate of $dP/dt = +1.16 \times 10^{-7}$ day yr^{-1}. However, as displayed in Figure 1, since the $O-C$ values show large scatter, this conclusion needs further investigation.

2.2. V724 Aql

V724 Aql was discovered to be a short-period variable by Hoffmeister (1934a). Ahnert et al. (1949) classified the variable as a Cepheid and gave 11 times of maximum light and elements for maxima. Later, in the course of a photoelectric survey of northern Cepheids, the variable was proved to be a W UMa type eclipsing binary by Oosterhoff (1960). He obtained a normal light curve and an ephemeris

$$\min I = 2{,}436{,}818.672 + 0.51752E. \quad (4)$$

Since the period is slightly large for a W UMa type binary, the system may be not in contact; further investigation is needed. Recently, Agerer & Lichtenknecker (1991) published complete B and V light curves and five times of light minimum. From their new timings and the normal one by Oosterhoff, they derived a new ephemeris,

$$\min I = 2{,}436{,}818.6721 + 0.51760028E. \quad (5)$$

Agerer & Lichtenknecker (1991) also calculated 11 times of light minimum by adding $P/4$ to the maximum timings given by Ahnert et al. (1949), but the $O-C$ values of these timings showed large scatter (up to 0.13 days).

After Agerer & Lichtenknecker's study, two photoelectric times of light minimum were published by Agerer & Hubscher (1997, 1998). All the photoelectric timings are listed in Table

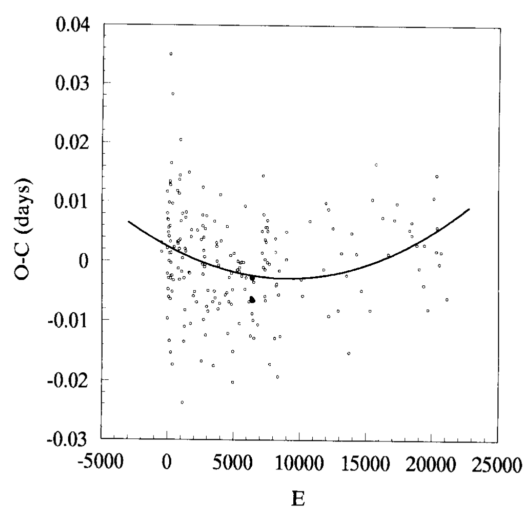

FIG. 1.—$O-C$ curve of EP And based on the revised ephemeris (2). Solid dots refer to photoelectric data and open circles to visual or photographic observations.

TABLE 2
PHOTOELECTRIC TIMINGS FOR V724 AQL

HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)	Reference (5)
36,818.672	I	0	−0.0001	1
47,912.3980	I	20467	+0.0009	2
47,913.9320	I	20469	−0.0003	2
48,097.4913	II	21790.5	+0.0002	2
48,098.4744	II	21792.5	−0.0019	2
50,301.3793	II	26048.5	−0.0037	3
50,711.3160	II	26840.5	−0.0064	4

REFERENCES.—(1) Oosterhoff 1960; (2) Agerer & Lichtenknecker 1991; (3) Agerer & Huebscher 1997; (4) Agerer & Huebscher 1998.

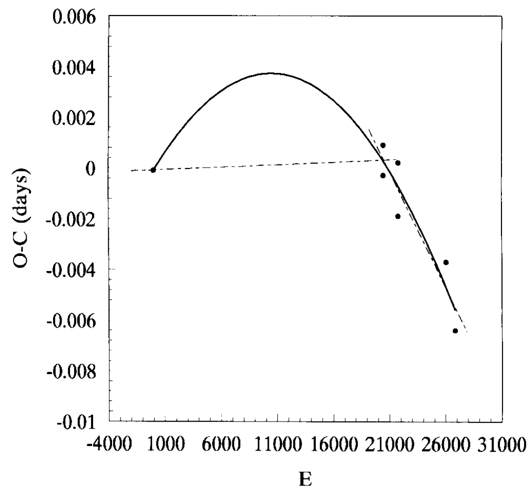

FIG. 2.—$O-C$ observations of V724 Aql. Dashed lines refer to a sudden period decrease and solid line to a continuous period decrease.

2, and with ephemeris (5) their $O-C$ values are computed and are plotted in Figure 2. As displayed in Figure 2, the orbital period is variable. Although before $E = 20{,}000$ there is only one point, it is the mean value by Oosterhoff. Since there are no observations between $E = 0$ and $E = 20{,}000$, the character of the variation is not clear. If the $O-C$ curve shows a sudden change, using the method of least squares, we derive the linear ephemeris

$$\min I = 2{,}436{,}818.6720(8) + 0.51760030(5)E \quad (6)$$

for the $O-C$ values before $E = 21{,}000$. As for the $O-C$ values after $E = 20{,}000$, with the same method we obtain the ephemeris

$$\min I = 2{,}436{,}818.6912(40) + 0.51759936(18)E \quad (7)$$

and a sudden period decrease of $\Delta P = -9.4 \times 10^{-7}$ day. If all the photoelectric timings have a parabolic $O-C$ variation, a least-squares solution leads to the quadratic ephemeris

$$\min I = 2{,}436{,}818.6720(1) + 0.51760101(1)E - 3.49(2) \times 10^{-11}E^2 \quad (8)$$

and a period decrease rate of $dP/dt = -4.93 \times 10^{-8}$ day yr^{-1}. As we can see from Figure 2, both the linear ephemerides and the quadratic ephemeris (*dashed lines and solid line*) can describe the general trend of the $O-C$ curve.

TABLE 3
PHOTOELECTRIC TIMINGS FOR SS COM

HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)	Reference (5)
45,026.532	I	0	+0.0010	1
45,027.563	I	2.5	−0.00002	1
45,079.367	I	128	−0.0036	2
48,013.419	II	7235.5	+0.0063	3
48,683.6200	I	8859	+0.0114	4
49,446.500	I	10707	+0.0198	5
50,140.4327	I	12388	+0.0201	6
50,199.4782	I	12531	+0.0339	7
50,570.3924	II	13429.5	+0.0389	8
50,944.4045	II	14335.5	+0.0457	9
51,271.3552	II	15127.5	+0.0516	10
51,298.3957	I	15193	+0.0530	10

REFERENCES.—(1) Hoffmann 1983; (2) BBSAG Bull. 60; (3) BBSAG Bull. 95; (4) BAV-M 60; (5) BAV-M 68; (6) Agerer & Hubscher 1996; (7) Agerer & Hubscher 1997; (8) Agerer & Hubscher 1998; (9) Agerer & Hubscher 1999; (10) Agerer & Hubscher 2000.

2.3. SS Com

SS Com is a short-period close binary system with a spectral type of F5. All published photoelectric times of light minimum of the star were collected and are listed in Table 3. The $O-C$ values of these timings are computed with the ephemeris

$$\min I = 2{,}445{,}026.531 + 0.4128093E \quad (9)$$

and are plotted in Figure 3. We can conclude on the basis of

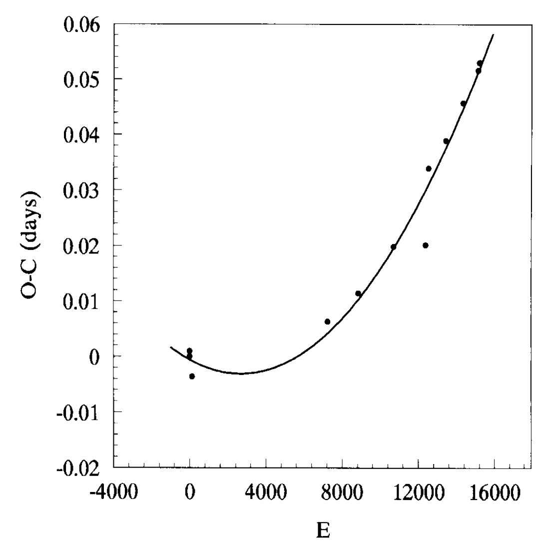

FIG. 3.—$O-C$ diagram of SS Com based on all photoelectric or CCD timings.

TABLE 4
Times of Light Minimum for the Contact Binary AM Eri

HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)	$(O-C\text{?pentaplus-kern})_1$ (5)	HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)	$(O-C\text{?pentaplus-kern})_1$ (5)
43,852.468	II	−119.5	+0.0032	+0.0042	44,885.603	I	3144	−0.0139	−0.0033
43,888.240	II	−6.5	−0.0043	−0.0030	44,910.621	I	3223	−0.0054	+0.0054
43,890.302	I	0	0.0000	+0.0013	44,965.230	II	3395.5	−0.0058	+0.0055
43,899.495	I	29	+0.0123	+0.0137	44,989.275	II	3471.5	−0.0206	−0.0090
44,195.470	I	964	−0.0113	−0.0071	45,004.317	I	3519	−0.0159	−0.0042
44,206.404	II	998.5	+0.0009	+0.0052	45,225.593	I	4218	−0.0266	−0.0128
44,206.562	I	999	+0.0006	+0.0049	45,257.574	I	4319	−0.0197	−0.0056
44,244.392	II	1118.5	−0.0003	+0.0043	45,285.581	II	4407.5	−0.0297	−0.0154
44,253.247	II	1146.5	−0.0094	−0.0047	45,285.582	II	4407.5	−0.0287	−0.0143
44,253.404	I	1147	−0.0107	−0.0060	45,370.282	I	4675	−0.0128	+0.0023
44,267.345	I	1191	+0.0001	+0.0049	45,379.294	II	4703.5	−0.0232	−0.0080
44,281.271	I	1235	−0.0024	+0.0026	45,621.636	I	5469	−0.0201	−0.0026
44,289.344	II	1260.5	−0.0020	+0.0030	45,635.572	I	5531	−0.0135	+0.0041
44,489.583	I	1893	+0.0020	+0.0089	45,641.574	I	5532	−0.0264	−0.0088
44,497.650	I	1918.5	−0.0031	+0.0039	45,701.417	I	5721	−0.0163	+0.0019
44,501.596	I	1931	−0.0143	−0.0072	45,725.304	II	5796.5	−0.0308	−0.0124
44,504.609	II	1940.5	−0.0087	−0.0016	45,995.501	I	6650	−0.0314	−0.0105
44,527.570	I	2013	+0.0005	+0.0078	46,046.484	I	6811	−0.0171	+0.0043
44,528.515	I	2016	−0.0042	+0.0031	47,157.334	I	10320	−0.0323	−0.0005
44,566.501	I	2136	−0.0073	+0.0003	47,451.593	II	11249.5	−0.0307	+0.0038
44,586.435	I	2199	−0.0176	+0.0061	47,566.355	I	11612	−0.0257	+0.0087
44,604.493	I	2256	−0.0045	+0.0035	47,804.559	II	12364.5	−0.0470	−0.0092
44,629.333	II	2334.5	−0.0157	−0.0075	47,825.467	II	12430.5	−0.0330	+0.0047
44,636.312	II	2356.5	−0.0013	+0.0070	48,162.610	II	13495.5	−0.0434	−0.0023
44,644.379	I	2382	−0.0070	+0.0014	48,248.420	II	13766.5	−0.0255	+0.0164
44,844.617	II	3014.5	−0.0034	+0.0068	48,532.530	I	14664	−0.0425	+0.0021
44,854.587	I	3046	−0.0055	+0.0048					

Figure 3 that the orbital period of the system is variable. Since the general trend of the $O-C$ diagram may show a roughly parabolic distribution indicating a long time increase in the orbital period, a second-order least-squares solution of the $O-C$ values yields the ephemeris

$$\min I = 2{,}4450{,}26.5304(7) + 0.41280741(2)E + 3.52(2) \times 10^{-10}E^2 \quad (10)$$

where the coefficient of the square term represents the rate of change of the period. This ephemeris can be used to estimate future times of light minimum. A continuous period increase of $dP/dE = +7.04 \times 10^{-10}$ day cycle^{-1} $= +6.23 \times 10^{-7}$ day yr^{-1} is calculated, which is equivalent to a period increase of 5.4 s century^{-1}.

2.4. AM Eri

According to the fourth edition of the GCVS, AM Eri is a neglected short-period close binary with an EW-type light curve. Its spectral type is unknown. Although no photoelectric or CCD observations were published, many times of light minimum observed by various amateurs have been compiled at the Eclipsing Binaries Minima Database. These timings are listed in column (1) of Table 4. The $O-C$ values based on the ephemeris given in the fourth edition of the GCVS,

$$\min I = 2{,}443{,}890.302 + 0.316576E, \quad (11)$$

are calculated and are listed in column (4) ofTable 4. With these $O-C$ values this ephemeris has been revised as

$$\min I = 2443890.3007(15) + 0.31657305(25)E. \quad (12)$$

The $(O-C)_1$ values computed from the ephemeris (12) are displayed in Figure 4. As shown in this figure, the orbital period of the system is variable. With the method of least squares, the quadratic ephemeris

$$\min I = 2{,}443{,}890.3054(3) + 0.316570450(3)E + 1.90(2) \times 10^{-10}E^2 \quad (13)$$

can be derived. The quadratic term of this ephemeris tells us that the orbital period of the system is continuously increasing at the rate of $dP/dt = +4.39 \times 10^{-7}$ day yr^{-1}. However, as displayed in Figure 4, since the $O-C$ values show large scatter, the property of the period change needs further investigation.

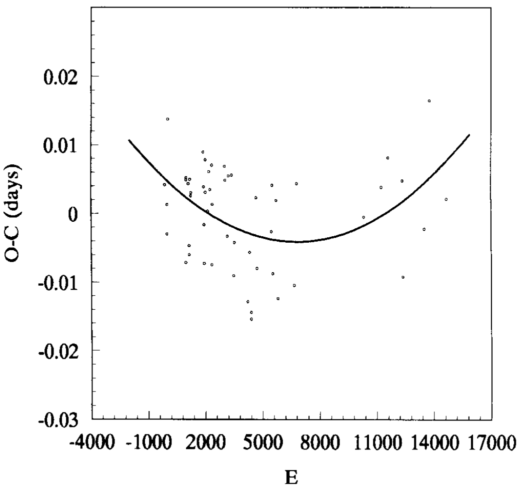

FIG. 4.—$O-C$ residuals of AM Eri calculated from the revised ephemeris (12)

2.5. FZ Ori

FZ Ori was discovered to be a variable by Hoffmeister (1934b). Kippenhahn (1953) classified the light variation of the system as that of β Lyrae–like stars and estimated the orbital period as 1.597 days. The W UMa type light curve was suspected by Soloviev (1945) and has been confirmed by Figer (1983) and Le Borgne, Figer, & Dumont (1984), who pointed out that the orbital period of the system was about 0.4 day. Complete *UBV* light curves of FZ Ori have been published by El-Bassuny Alawy (1993), who studied the period change of the system and derived the ephemeris

$$\min I = 2{,}444{,}034.9697 + 0.4001528E - 1.43 \times 10^{-8}E^2. \quad (14)$$

The quadratic term of the ephemeris indicates a continuous period decrease at a rate of $dP/dt = -2.61 \times 10^{-5}$ day yr^{-1}, which is rather large for a contact binary.

In order to study the period change of FZ Ori, many times of light minimum have been compiled. A total of 14 photoelectric times of light minimum have been published by Figer (1983), Le Borgne et al. (1984), El-Bassuny Alawy (1993) and Agerer, Dahm, & Hubscher (1999), and 30 visual and photographic observations have been collected at the Eclipsing Binaries Minima Database. The $O-C$ values of these timings are computed with the ephemeris

$$\min I = 2{,}444{,}024.4583 + 0.3999866E. \quad (15)$$

The corresponding $O-C$ diagram is shown in Figure 5, where open circles refer to visual or photographic observations and dots to photoelectric data. As we can see from this figure, recently the orbital period has decreased. Assigning a weight of 1 to visual or photographic data and 8 to photoelectric observations, we find that a least-squares solution yields the quadratic ephemeris

$$\min I = 2{,}444{,}024.4431(3) + 0.39998961(5)E - 2.85(3) \times 10^{-10}E^2 \quad (16)$$

and a period decrease rate of $dP/dt = -5.20 \times 10^{-7}$ day yr^{-1}, which is a typical value for W UMa type contact binary.

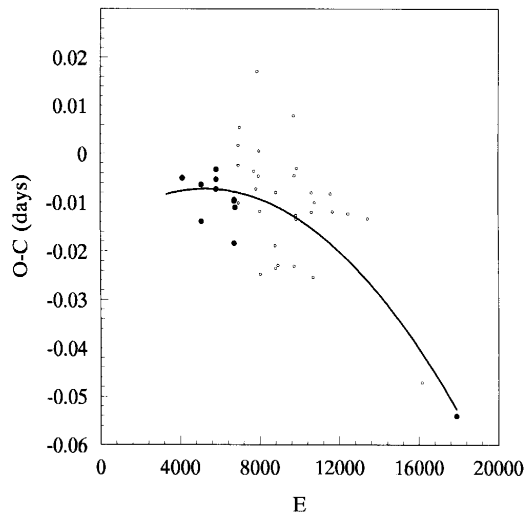

FIG. 5.—$O-C$ curve of FZ Ori. Solid dots refer to photoelectric observations and open circles to visual or photographic data.

2.6. BY Peg

BY Peg is another short-period ($P = 0.3419372$ day) close binary with an EW-type light curve. A total of 80 visual or photographic times of light minimum have been collected at the Eclipsing Binaries Minima Database. These times of light minimum are listed in column (1) of Table 5. With the ephemeris given in the fourth edition of the GCVS,

$$\min I = 2{,}445{,}565.518 + 0.3419372E, \quad (17)$$

the $O-C$ values are computed. During the computation, timings with the same epoch have been averaged, and only the mean values are listed inTable 5. Four times of light minimum, 2,443,668.576, 2,444,737.443, 2,444,932.326, and 2,445,277.234, are discarded since their $O-C$ values show large deviations from the general trend formed by other points.

TABLE 5
TIMES OF LIGHT MINIMUM FOR THE CONTACT BINARY BY PEG

HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)	HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)
41,900.464	II	−10718.5	−0.0001	43,845.230	I	−5031	−0.0019
41,901.481	II	−10715.5	−0.0089	44,028.509	I	−4495	−0.0013
42,402.268	I	−9251	+0.0110	44,133.493	I	−4188	+0.0080
42,403.304	I	−9248	+0.0212	44,135.383	II	−4182.5	−0.0173
42,414.235	I	−9216	+0.0102	44,194.346	I	−4010	−0.0038
42,417.312	I	−9207	+0.0098	44,375.565	I	−3480	−0.0115
42,424.306	II	−9186.5	−0.0059	44,516.452	I	−3068	−0.0027
42,435.272	II	−9154.5	+0.0181	44,569.296	II	−2913.5	+0.0120
42,571.524	I	−8756	+0.0081	44,575.271	I	−2896	+0.0031
42,572.550	I	−8753	+0.0083	44,582.269	II	−2875.5	−0.0086
42,576.483	II	−8741.5	+0.0090	44,793.424	I	−2258	+0.0002
42,596.480	I	−8683	+0.0027	44,874.294	II	−2021.5	+0.0020
42,597.502	I	−8680	−0.0011	44,878.393	II	−2009.5	−0.0022
42,638.362	II	−8560.5	−0.0026	44,897.374	I	−1954	+0.0013
42,669.312	I	−8470	+0.0021	44,927.285	II	−1866.5	−0.0072
42,681.287	I	−8435	+0.0093	45,116.542	I	−1313	−0.0125
42,682.303	I	−8432	−0.0005	45,169.530	I	−1158	−0.0247
42,713.246	II	−8341.5	−0.0028	45,224.438	II	−997.5	+0.0024
42,740.268	II	−8262.5	+0.0061	45,231.450	I	−977	+0.0046
42,774.276	I	−8163	−0.0086	45,236.415	II	−962.5	+0.0116
42,937.557	I	−7685.5	−0.0026	45,238.463	II	−956.5	+0.0079
42,950.558	II	−7647.5	+0.0047	45,263.406	II	−883.5	−0.0105
42,997.582	I	−7510	+0.0124	45,519.538	II	−134.5	+0.0106
43,012.602	I	−7466	−0.0129	45,561.421	I	−12	+0.0062
43,036.374	II	−7396.5	−0.0055	45,565.518	I	0	0.0000
43,040.309	I	−7385	−0.0028	45,579.377	II	40.5	+0.0105
43,393.372	II	−6352.5	+0.0101	45,604.326	II	113.5	−0.0019
43,420.382	II	−6273.5	+0.0070	45,887.460	II	941.5	+0.0081
43,451.320	I	−6183	−0.0003	45,890.527	II	950.5	−0.0023
43,510.307	II	−6010.5	+0.0025	45,934.461	I	1079	−0.0072
43,703.503	II	−5445.5	+0.0040	46,291.424	I	2123	−0.0267
43,732.556	I	−5360.5	−0.0076	49,677.283	I	12025	−0.0298
43,734.438	II	−5355	−0.0063	49,999.387	I	12967	−0.0307
43,746.414	I	−5320	+0.0019	49,999.541	II	12967.5	−0.0476
43,833.257	I	−5066	−0.0071	50,646.484	II	14859.5	−0.0498

The corresponding $O-C$ curves are plotted in Figure 6. As shown in this figure, the orbital period of the system is decreasing. Based on the method of least squares, the ephemeris

$$\min I = 2{,}445{,}565.5143(8) + 0.34193579(19)E - 7.8(22) \times 10^{-8}E^2 \quad (18)$$

and a period decrease rate of $dP/dt = -1.67 \times 10^{-7}$ day yr^{-1} are obtained.

2.7. EQ Tau

In order to study the orbital history of EQ Tau, all published eclipse timings were collected. Many visual and photographic times of light minimum observed by many amateurs have been collected at the Eclipsing Minimum Database, and two photoelectric timings, 2,449,687.607 and 2,450,396.9250, were published by Benbow & Mutel (1995) and Buckner, Nellermoe, & Mutel (1998). These timings are listed in column (1) ofTable 6. Timings with the same epoch numbers have been averaged, and some times of light minimum listed inTable 6 are the mean values of these timings. With the ephemeris given in the fourth edition of the GCVS,

$$\min I = 2{,}440{,}213.325 + 0.34134848E, \quad (19)$$

the $O-C$ values of these timings are calculated. These values are listed in column (4) ofTable 6 and are plotted in Figure 7, where circles refer to photographic and visual times of light minimum and dots to photoelectric observations. Three timings, 2,441,972.509, 2,446,825.249, and 2,447,847.584, show large deviation from the general $O-C$ trend formed by other points in Figure 7. These points were not considered further in the discussion of the period variation.

As shown in Figure 7, although the visual and photographic

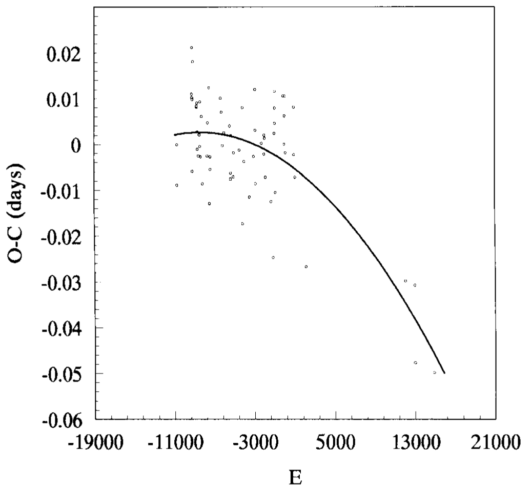

FIG. 6.—Linear residuals of BY Peg, for all times of light minimum.

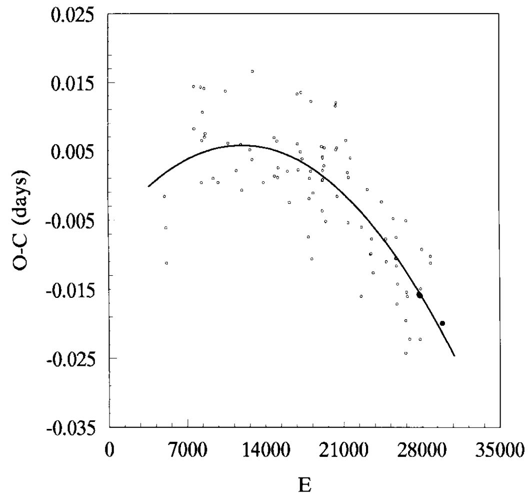

FIG. 7.—Same as Fig. 5, but for EQ Tau.

times of light minimum show large scatter, the general trend of the $O-C$ curve suggests that the orbital period of the system is variable. Since the $O-C$ values may show a roughly parabolic distribution indicating a long time decrease in the orbital period, with the weight 1 for visual and photographic data and 8 for photoelectric observations, the ephemeris

$$\min I = 2{,}440{,}213.3185(3) + 0.34135052(1)E - 8.51(2) \times 10^{-11}E^2 \quad (20)$$

is obtained by a least-squares solution. Using the coefficient of the square term, we calculate a continuous period decrease of $dP/dE = -1.82 \times 10^{-7}$ day yr^{-1}, which is equivalent to a period decrease of 1.6 s century^{-1}.

2.8. NO Vul

According to the fourth edition of the GCVS, NO Vul is also a close binary with an EW-type light curve. A total of 71 visual or photographic times of light minimum have been compiled at the Eclipsing Minimum Database. Recently, six CCD times of light minimum have been published by Safar & Zejda (2000a, 2000b). Based on these times of light minimum, and with the weight 1 for visual or photographic observations and weight 8 for CCD data, a revised linear ephemeris,

$$\min I = 2{,}446{,}346.2997(12) + 0.37076561(19)E, \quad (21)$$

is obtained. The residuals from this ephemeris are plotted in Figure 8. As we can see in the figure, the orbital period of NO Vul is variable. Since there are no observations in the time interval between $E = 0$ and $E = 10{,}000$, more times of light minimum are needed to ascertain the period changes in the system. Considering a continuous $O-C$ variation, a least-squares solution leads to the quadratic ephemeris

$$\min I = 2{,}446{,}346.3070(4) + 0.37076620(12)E - 1.06(17) \times 10^{-10}E^2 \quad (22)$$

and a period decrease rate of $dP/dE = -2.09 \times 10^{-7}$ day yr^{-1}.

3. DISCUSSIONS AND CONCLUSIONS

In the previous sections, the $O-C$ curves of eight close binaries, EP And, V724 Aql, SS Com, AM Eri, FZ Ori, BY Peg, EQ Tau, and NO Vul, are formed and period changes in these systems are found. As in many cases, the periods of BY Peg and EQ Tau are decreasing, while the orbital periods of SS Com and AM Eri show secular increase. Weak evidence also indicates that the orbital period of EP And is increasing. For FZ Ori, the period decrease rate of $dP/dt = -2.61 \times 10^{-5}$ day yr^{-1} given by El-Bassuny Alawy (1993) is revised as $dP/dt = -5.20 \times 10^{-7}$ day yr^{-1}. For the remaining two systems, V724 Aql and NO Vul, their $O-C$ curves can be described by a sudden period decrease or a continuous period decrease. The rates of period change of these systems are listed in Table 7. However, the secular period changes may be part of a long-term periodic change, and in some cases the period change needs to be investigated further.

Increases and decreases of the period are not unusual among W UMa type stars. This is a well-known property of contact binaries. Other examples that show period increases (or as a component in the period changes) are CK Boo (Qian & Liu 2000a), YY Eri (Kim et al. 1997), V839 Oph (Akalin & Derman

TABLE 6
TIMES OF LIGHT MINIMUM FOR THE CONTACT BINARY EQ TAU

HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)	HJD (2,400,000+) (1)	Minimum (2)	E (3)	$O-C$ (4)
41,932.525	II	5036.5	−0.0016	46,769.606	I	19207	+0.0014
41,972.629	I	5154	−0.0061	46,770.291	I	19209	+0.0031
41,974.672	I	5160	−0.0112	46,773.364	I	19218	+0.0039
42,832.677	II	7673.5	+0.0144	46,814.666	I	19339	+0.0028
42,844.618	II	7708.5	+0.0082	46,821.325	II	19358.5	+0.0054
43,045.849	I	8298	+0.0143	46,857.668	I	19465	−0.0052
43,066.828	II	8359.5	+0.0004	47,159.266	II	20348.5	+0.0115
43,085.779	I	8415	+0.0065	47,174.279	II	20392.5	+0.0051
43,098.925	II	8453.5	+0.0106	47,176.334	II	20398.5	+0.0120
43,154.739	I	8617	+0.0141	47,205.342	II	20483.5	+0.0054
43,165.655	I	8649	+0.0070	47,212.674	I	20505	−0.0016
43,190.574	I	8722	+0.0075	47,481.494	II	21292.5	+0.0065
43,420.807	II	9396.5	+0.0010	47,530.3021	II	21435.5	+0.0018
43,577.656	I	9856	+0.0004	47,539.682	I	21463	−0.0054
43,802.618	I	10515	+0.0137	47,558.292	II	21517.5	+0.0011
43,876.683	I	10732	+0.0061	47,615.300	II	21684.5	+0.0039
44,132.861	II	11482.5	+0.0021	47,919.763	II	22576.5	−0.0160
44,271.623	I	11889	+0.0059	47,950.665	I	22667	−0.0060
44,300.631	I	11974	−0.0007	48,135.852	II	23209.5	−0.0006
44,544.701	I	12689	+0.0051	48,210.598	II	23428.5	−0.0099
44,614.676	I	12894	+0.0037	48,232.615	I	23493	−0.0098
44,623.564	I	12920	+0.0166	48,251.562	II	23548.5	−0.0077
44,958.752	I	13902	+0.0004	48,295.591	II	23677.5	−0.0126
45,294.304	I	14885	+0.0069	48,568.680	II	24477.5	−0.0024
45,298.736	I	14898	+0.0013	48,679.613	II	24802.5	−0.0077
45,373.667	II	15117.5	+0.0064	48,694.629	II	24846.5	−0.0110
45,401.311	II	15198.5	+0.0011	48,922.656	II	25514.5	−0.0048
45,407.286	I	15216	+0.0025	48,976.754	I	25673	−0.0105
45,697.261	II	16065.5	+0.0020	49,005.601	II	25757.5	−0.0075
45,753.579	II	16230.5	−0.0025	49,007.645	II	25763.5	−0.0116
45,991.344	I	16927	+0.0133	49,012.589	I	25778	−0.0171
46,005.332	I	16968	+0.0060	49,036.657	II	25848.5	−0.0142
46,023.249	II	17020.5	+0.0022	49,270.812	II	26534.5	−0.0242
46,091.692	I	17221	+0.0048	49,283.788	II	26572.5	−0.0195
46,095.267	II	17231.5	−0.0043	49,311.612	I	26654	−0.0154
46,114.571	I	17288	+0.0135	49,311.793	II	26654.5	−0.0051
46,119.333	I	17302	−0.0034	49,333.799	I	26719	−0.0160
46,144.600	I	17376	+0.0038	49,397.625	I	26906	−0.0222
46,321.578	II	17894.5	−0.0074	49,679.585	I	27732	−0.0160
46,355.377	II	17993.5	−0.0019	49,687.607	II	27755.5	−0.0157
46,373.642	I	18047	+0.0010	49,713.543	II	27831.5	−0.0222
46,409.826	I	18153	+0.0020	49,725.6672	I	27867	−0.0159
46,413.591	I	18164	+0.0122	49,743.589	II	27919.5	−0.0149
46,416.299	I	18172	−0.0106	49,779.607	I	28025	−0.0092
46,472.631	I	18337	−0.0011	50,043.639	II	28798.5	−0.0102
46,742.303	I	19127	+0.0056	50,044.662	II	28801.5	−0.0112
46,756.801	II	19169.5	−0.0037	50,396.9250	II	29833.5	−0.0199
46,763.291	II	19188.5	+0.0007				

1997), AB And (Kalimeris et al. 1994), DK Cyg (Awadalla 1994), V401 Cyg (Herczeg 1993), V566 Oph (Maddox & Bookmyer 1981), and others; some systems that show period decreases (or as a component in the period changes) are TZ Boo (Qian & Liu 2000b), Y Sex (Qian & Liu 2000b), V502 Oph (Derman & Demircan 1992), U Peg (Zhai et al. 1984), VW Cep (Kaszas et al. 1998), V781 Tau (Liu & Yang 2000) and others. An extensive statistical study of the period changes for contact binaries is in progress. However, for the present studied neglected systems, as far as we know, no photometric and spectroscopic solutions were published, we do not know whether they are type W (for which the primary minimum of the light curve corresponds to the occultation of the eclipse of the smaller, less massive component) or type A (for

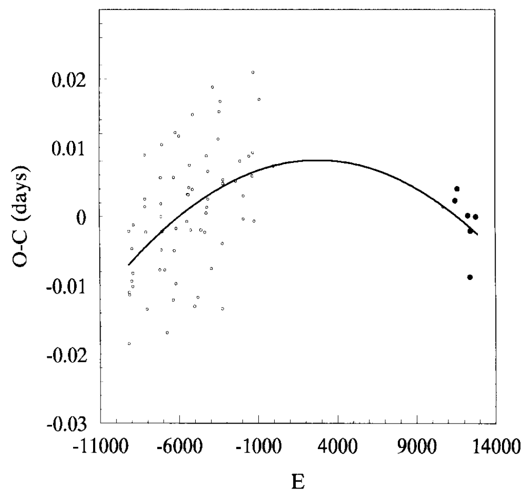

FIG. 8.—Same as Figs. 5 and 7, but for NO Vul.

which the primary minimum of the light curve corresponds to the transit of the eclipse of the large, massive component), and their physical properties are not clear.

The secular period changes of these systems can be explained by mass transfer between the components. If we assume that the mass and angular momentum are conservative, then the period increase corresponds to a mass transfer from the less massive to the more massive components (i.e., the mass ratio is decreasing), in the case of period decrease, the direction of mass transfer is reversed (i.e., the mass ratio is increasing). The TRO models of contact binaries predicted that a system is oscillating around a marginal contact state and being alternatively in contact and noncontact stages. In this picture, as discussed by Kiss et al. (1999), the systems with increasing period (EP And, SS Com, and AM Eri) may be in the expanding TRO stage, while the systems with decreasing period (V724 Aql, FZ Ori, BY Peg, EQ Tau, and NO Vul) may be in the shrinking TRO stage. On the other hand, the period change, especially the period decrease, can also be explained by AML via magnetic breaking.

Recently, a large self-consistent sample of absolute parameters for contact binaries has been published by Maceroni & Van't Veer (1996). With these elements, the ratio of radii $k = R_2/R_1$ and mass ratio $q = M_2/M_1$ were obtained and a k-q diagram was formed (plotted in Fig. 9). As shown in Figure 9, the values of q and k are strongly correlated for the observed contact binaries. A least-squares solution yields (Fig. 9, *solid line*)

$$q = 1.1901(9)k^2 - 0.251(1)k + 0.045(6), \qquad (23)$$

TABLE 7
THE RATES OF PERIOD VARIATION FOR EIGHT CLOSE BINARIES

Star	Type	P (days)	dP/dt (day yr^{-1})
EP And	EW/KW	0.40410755	$+1.16 \times 10^{-7}$
V724 Aql	EW/KW	0.51752	-4.93×10^{-8}
SS Com	EW/KW	0.4128093	$+6.23 \times 10^{-7}$
AM Eri	EW/KW	0.316576	$+4.39 \times 10^{-7}$
FZ Ori	EW/KW	0.3999866	-5.20×10^{-7}
BY Peg	EW/KW	0.3419372	-1.67×10^{-7}
EQ Tau	EW/KW	0.34134848	-1.82×10^{-7}
NO Vul	EW/KW	0.3707685	-2.09×10^{-7}

which is slightly different from that given by Selam & Demircan (1994) of $q = 1.12k^2 - 0.14k + 0.01$. As mentioned by Selam & Demircan (1994), the strong correlation is imposed by the common-envelope nature of the component stars. This relation can be used to check the parameters for contact binaries; the parameters of the three systems V724 Aql, SS Com, and EQ Tau, given by Brancewicz & Dworak (1980) are checked. As we can see from Figure 9, the positions of SS Com and EQ Tau show slight large deviations from the general mass-radius relation. Since the k-q relation reflects the equipotential configurations of contact binaries, the deviations of SS Com and EQ Tau from this relation may suggest that the

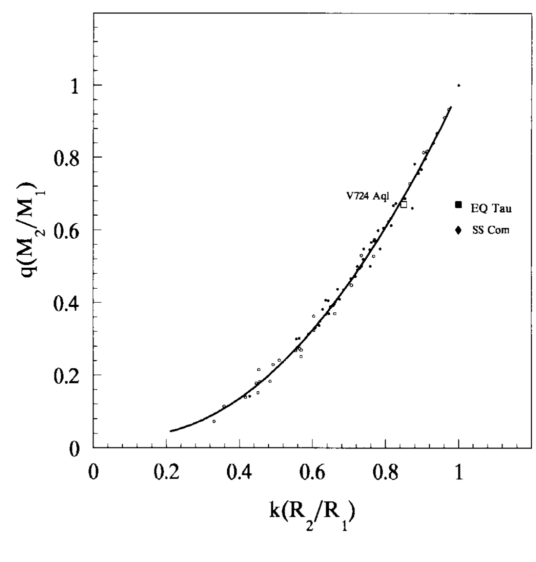

FIG. 9.—Mass-radius relation for 78 observed contact binaries. Small dots and circles refer to W-type and A-type, respectively. The three systems, V724 Aql, SS Com, and EQ Tau, are distinguished from the others.

two systems are not yet in contact and maybe they are near-contact systems; further study is needed. The spectral types of the two systems are F5 and A3, respectively, which is not unusual among near-contact binaries. In order to understand the physical properties of these binaries, complete photoelectric or CCD light curves and radial velocity observations are needed. Moreover, further eclipse timings will be required to ascertain the predictions of period changes of these neglected systems.

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