PERIOD STUDY OF THE BINARY STAR SW CYGNI

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Abstract. The O–C curve of SW Cyg between 1880 and 1977 is presented and discussed. It is found that the orbital period undergoes a systematic change, becoming greater with time. In addition, a periodic oscillation of amplitude $0^d.015$ with period of 43.8 years is superimposed on this general trend. It is concluded that the increase in the period is due to a transfer of mass from the secondary star to the primary and the periodic oscillation is due to the light time effect of the third body of mass function $f(m) = 0.006\ M_\odot$.

1. Introduction

The variability of the period of the binary system SW Cygni ($P \simeq 4^d.6$) has been studied by various authors. Dugan and Wright (1939) detected the period of the system to be variable and attributed the variability to the presence of a third body, with $f(m) = 0.05\ M_\odot$. Frieboes-Conde and Herczeg (1973) analysed the available photoelectric minima and pointed out that the star undergoes sudden changes in its period, and thus excluded the presence of a third body as a possible cause of the period variation because of an unacceptable value of $f(m) = 4.0\ M_\odot$. In this paper we shall examine all the available observations of minima between 1880 to 1977, and try to interpret the cause of the variation.

2. Data and Procedures

This study is based on a total of 174 observations of primary minima of SW Cyg reported by Dugan and Wright (1939), Frieboes-Conde and Herczeg (1973) and others, as listed in Table I. All the minima have been grouped into 28 normals, listed in Table II, in which the first column contains the identification number, and the next two columns contain, respectively, the cycle number and the normal O–C values based on the ephemeris (Dugan and Wright, 1939)

$$M(E) = 2\,418\,440.758 + 4^d.572\,792\,3E. \tag{1}$$

The fourth column contains the weight assigned by us. The observations have been weighted taking into account the method of observation and the error in the times of minimum when it was reported. A plot of the normal O–C values against the cycles is presented in Figure 1.

An inspection of Figure 1 enables us to identify two parabolic segments AB and BCD, with the point B corresponding to a sudden period decrease. We have used the

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TABLE I

Times of mid-primary eclipse for SW Cyg

JD (Hel)	E cycles	O–C days	References
2 438 264.160	+4335	+0.347	Kordylewski (1963)
602.601	4409	0.402	Walter (1971)
2 439 640.669	4636	0.446	Baldwin (1973)
704.708	4650	0.466	Baldwin (1973)
2 440 079.715	4732	0.504	Baldwin (1973)
454.685	4814	0.505	Baldwin (1973)
2 441 163.533	4969	0.570	Locher (1973)
849.529	5119	0.647	Locher (1976a)
904.393	5131	0.638	Locher (1976a)
2442 535.500	5269	0.699	Peter (1975)
741.305	5314	0.729	Locher (1975a)
942.517	5358	0.747	Locher (1975b)
974.520	5365	0.731	Peter (1976a)
2 443 029.392	5377	0.730	Locher (1976b)
029.402	5377	0.740	Peter (1976b)
349.521	5447	0.763	Locher (1977)
436.402	5466	0.751	Peter (1977)
459.263	5471	0.758	Peter (1977)

method of least-squares to fit a parabola through the normal points on the segments *AB* and *BCD*. The results of the least-squares quadratic fit are:

Epoch of sudden period decrease = 2 418 440.7073;
Period just after the period decrease = $4^{\mathrm{d}}.572\,626\,875$;
Quadratic terms: $K_1 = 4.1 \times 10^{-8}$; $K_2 = 5.4 \times 10^{-8}$;

where K_1 and K_2 denote, respectively, the parabolic segments *AB* and *BCD* in units of days cycle^{-2}. The residuals from the quadratic fits (in the sense, observed minus computed for the parabolic segment *BCD*) are plotted against cycles in Figure 2.

3. Discussions of the O–C Curve

It is clear from Figure 1 that the period suddenly decreased some time around 1910. After this, the period has been gradually increasing. The change in the period can be explained in terms of the period-change model given by Biermann and Hall (1973). This model has already been used to explain the O–C curve and period variability of U Cep (Hall, 1975), X Tri (Mallama, 1975), RZ Cas (Hall *et al.*, 1976) and TV Cas (Chaubey, 1979).

The simplest scheme consistent with this model uses a sequence of upward-curving parabolic segments to fit the O–C curve. The O–C diagram for SW Cyg appears to

TABLE II

Normal O–C values and their weights

No.	Cycles	O–C	Weights
1	−1131	$-0\overset{d}{.}111$	1
2	−812	−0.073	1
3	−773	−0.068	1
4	−664	−0.044	1
5	−580	−0.037	1
6	−467	−0.030	1
7	−242	−0.010	1
8	+105	−0.001	1
9	+430	−0.007	1
10	+670	−0.040	2
11	+890	−0.060	2
12	+1110	−0.070	2
13	+1330	−0.067	2
14	+1475	−0.060	1
15	+2120	−0.056	1
16	+2210	−0.043	1
17	+3184	+0.091	2
18	+3219	+0.093	2
19	+3676	+0.179	2
20	+3832	+0.218	2
21	+3940	+0.235	2
22	+4012	+0.251	2
23	+4335	+0.347	1
24	+4636	+0.446	2
25	+4814	+0.505	2
26	+5119	+0.647	1
27	+5314	+0.729	1
28	+5447	+0.768	1

consist of such parabolas, curved upwards. The star is thus well suited for the study in the light of B–H model. The gaseous disk around the primary component (Hall and Garrison, 1972), the asymmetry in the light curve (Walter, 1971) and short-lived emission lines near the second and third contacts of the primary eclipse (Struve, 1946) give additional evidence of the mass transfer from the secondary star to the primary. Since the normals in the first parabolic segment are limited and show a large amount of scatter, the results deduced from the parabolic segment *BCD* have been presented and discussed in the sequel.

4. Mass Transfer Rate

In order to calculate the mass transfer rate, we assume that the matter ejected from the cooler star is stored in or around the hotter star within its Roche lobe. The parameters

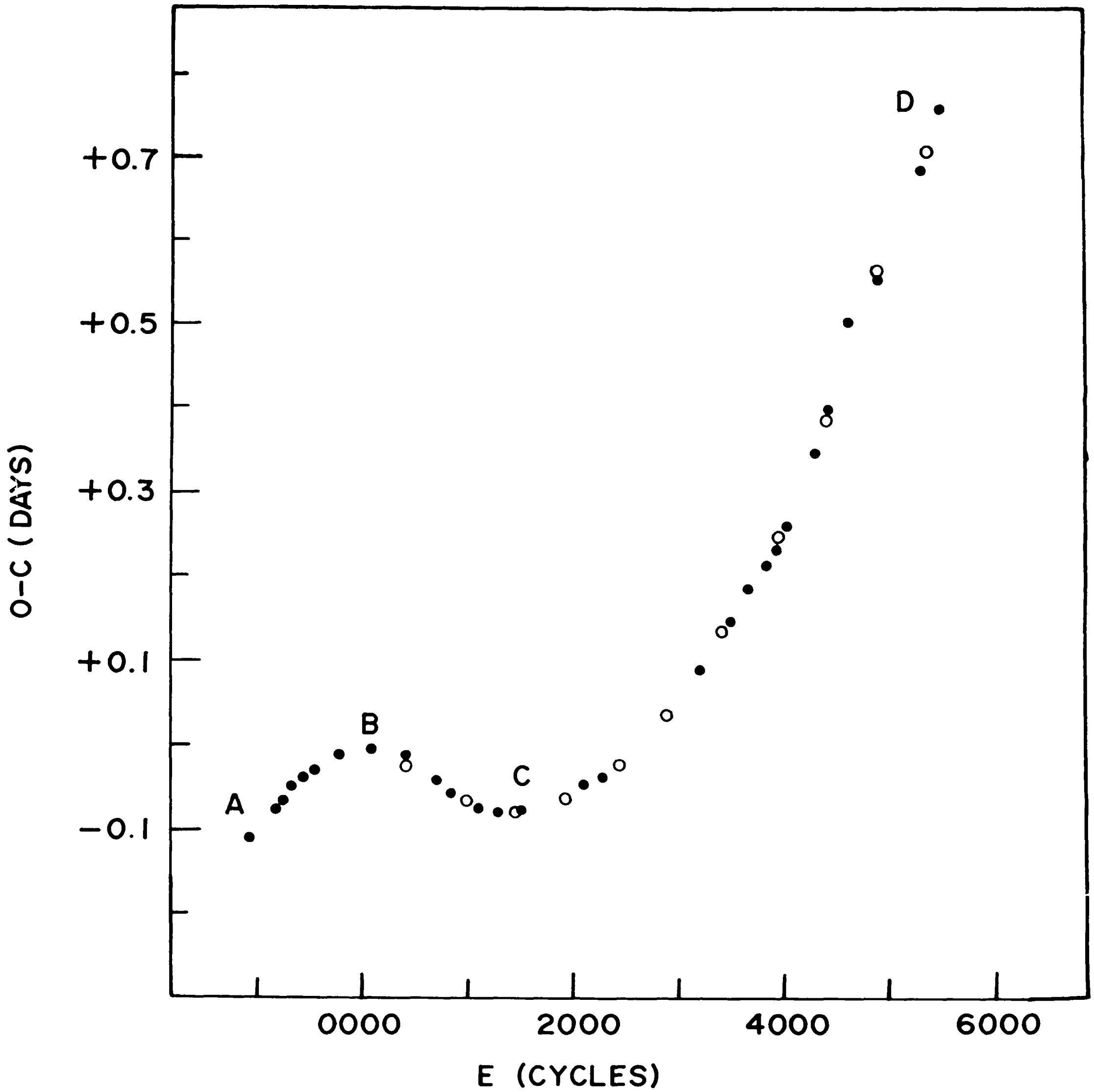

Fig. 1. The O–C curve of SW Cyg between 1880 to 1977. Filled circles denote the observed normal points while the open circles denote the computed points based on the ephemeris: $2\,418\,440.707\,3 + 4^{d}.572\,626\,875E + 5^{d}.4E^2 \times 10^{-8}$.

of this binary star, in all the calculations for this study, are (Kopal, 1959; Hall and Garrison, 1972)

Semi-major axis of the orbit: $A = 17\ R_\odot$,
Masses: $M_h = 2.8\ M_\odot$, $M_c = 0.7\ M_\odot$,
Radii: $R_h = 2.9\ R_\odot$, $R_c = 4.4\ R_\odot$,

where subscripts h and c indicate the hotter and cooler components, respectively. In the case where the subsequent period increase is observed, one can use the relation

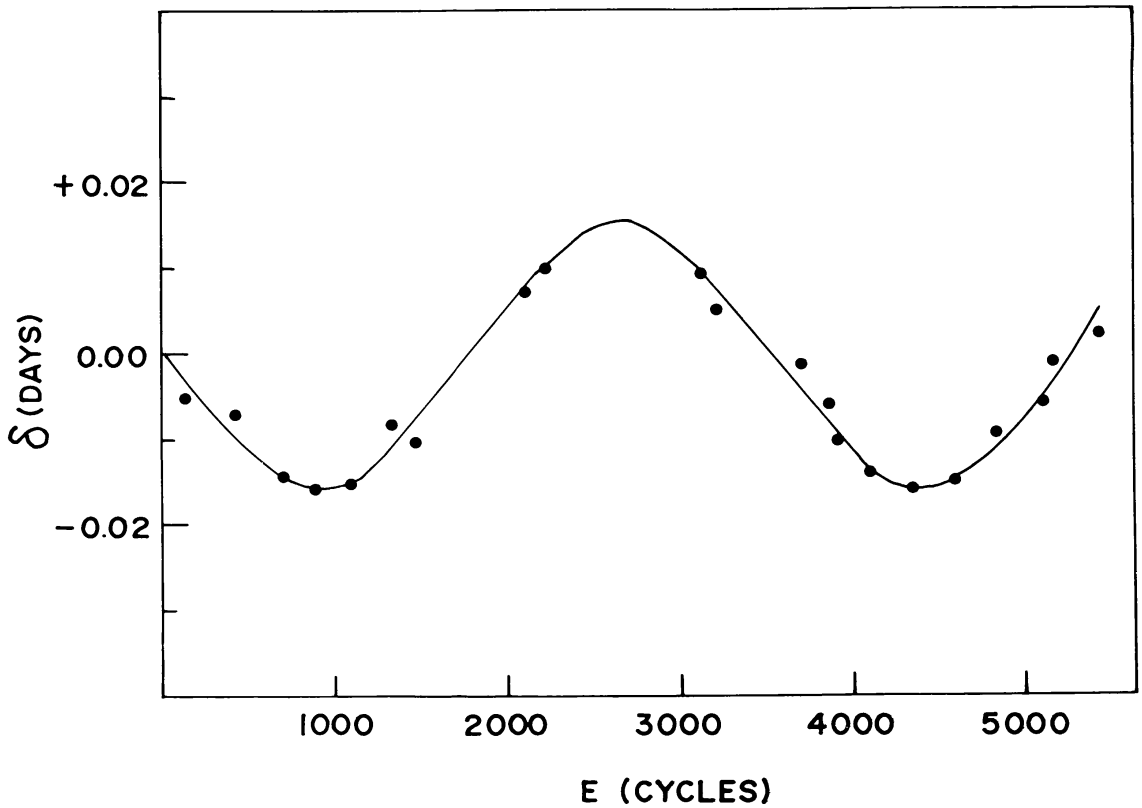

Fig. 2. Residuals from the representation in Figure 1.

(Chaubey, 1979)

$$\frac{\Delta P}{P} = 3\left\{\frac{M}{M_c}\left(\frac{M}{M_h}\right)^{1/2}\left(\frac{R_h}{A}\right)^{1/2}\right\}\frac{\Delta M_c}{M} \tag{2}$$

to calculate the amount of mass accreted by the primary star. Inserting appropriate quantities in the above equation, we find that $4.6 \times 10^{-7}\ M_\odot$ of mass is transferred from the secondary star to the primary in one year.

5. Presence of a Third Body

An inspection of Figure 1 reveals that the times of minimum light between 1910 to 1977 can be represented by a relation

$$M(E) = 2\,418\,440.707\,3 + 4^{\mathrm{d}}.572\,626\,875E + 5^{\mathrm{d}}.4E^2 \times 10^{-8}. \tag{3}$$

The residuals, after allowing for the trend established by this ephemeris, have been plotted in Figure 2. These can be fitted with a sine curve of semi-amplitude $0^{\mathrm{d}}.015$ and period 43.8 years. From the theory of regular period variations of eclipsing binary systems, two possible causes are admissible (Kruszewski, 1966): (1) apsidal motion, or (2) presence of a third body.

If the residuals are due to the apsidal motion within the binary system, we find that the eccentricity of the orbit should be $e = 0.01$ and that the phase for the secondary minima for the year 1964 would be 178°. However, the photoelectric observations give the phase as 180° for the secondary minima for the same year 1964 (Walter, 1971). Thus, we may exclude this hypothesis as a possible cause of the regular period variation.

Turning to the alternative hypothesis of the light-time effect of a third body, by use of the previously adopted masses the mass function becomes 0.006 $M_\odot$ and the mass of the third body 0.56 $M_\odot$ for $i' = 80°$. This value of the mass for the third body is quite acceptable. On the other hand, the radial velocity of the centre of mass of the SW Cyg binary pair for the year 1945 is the same as that deduced spectroscopically by Struve (1946). Thus a third body is suggested to be the possible cause of the regular period variation of the system.

6. Conclusions

From the analysis of the O–C curves of SW Cygni, we conclude that the orbital period changes are due to a transfer of mass from the secondary to the primary star and to the presence of a third body.

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