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PERIOD VARIATION STUDY OF THE NEGLECTED ALGOL ECLIPSING BINARY SYSTEM V346 CYGNIUS

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Abstract: We present the first period variation study for the Algol eclipsing binary V346 Cyg by constructing the $(O-C)$ residual diagram using all the available precise minima times. We conclude that the period variation can be explained by a sine–like variation due to the presence of a third body orbiting the binary in about 68.89 ± 4.69 years, together with a long-term orbital period decrease ($dP/dt = -1.23 \times 10^{-7}$day/yr) that can be interpreted to be due to slow mass loss from the δ–Scuti primary component. The sinusoidal variation may also be explained by using the the Applegate (1992) mechanism involving cyclic magnetic activity due to star–spots on the secondary component. The present preliminary solution needs more precise photometric observations to be confirmed.

Key words: binaries: close; eclipsing; Algol; semi-detached — stars: triple — stars: individual: V346 Cyg

1. INTRODUCTION

The system V346 Cyg (HIP 100198, TYC 2684-1000-1, $\alpha_{2000} = 20^{\rm h}\,19^{\rm m}\,24^{\rm s}.7244$, $\delta_{2000} = +36^\circ\ 20'\ 24.2092$, $\pi = 2.57$ (mas), and Sp. type A5 according to the SIMBAD database) is an eclipsing binary system. Its changeability was discovered by Beljawsky (1932), and confirmed by Parenago (1933) who determined the first three photographic times of minimum and suggested its Algol type configuration. Florja (1934) monitored the system visually covering the time interval from Aug 8, 1932 to Aug 31, 1933. From the observations, he derived 10 minima times and obtained the first linear ephemeris:

$$\mathrm{HJD(Min.I)} = 2\,427\,300.411 + 2^{\rm d}.74322 \cdot E\ . \qquad (1)$$

Florja also combined his visual observations to those photographic minima given by Parenago and deduced the linear ephemeris:

$$\mathrm{HJD(Min.I)} = 2\,427\,300.411 + 2^{\rm d}.743358 \cdot E\ . \qquad (2)$$

According to this ephemeris, he also obtained the first (mean) visual light curve for V346 Cyg.

The first photographic light curve was observed by Petrow (1946) who used the linear elements of Florja (1934) and deduced the linear elements:

$$\mathrm{HJD(Min.I)} = 2\,435\,686.7191 + 2^{\rm d}.7432997 \cdot E\ . \qquad (3)$$

The system was recorded as a semi-detached Algol eclipsing binary by many authors (e.g., Brancewicz & Dworak 1980; Budding et al. 2004; Samus et al. 2004; Kim et al. 2005; Soydugan et al. 2006a,b), while it was mentioned as a detached system by the current SIMBAD database.

The system was partially observed photometrically in the B-passband by Kim et al. (2005). They used 2K CCD camera attached to 1.0m telescope of the Mt. Lemmon Optical Astronomy Observatory. Their observations were performed for six nights in November 2004, about 2 hours per night. They obtained some parts of the phase diagram, combined them to a primary minimum of depth $1^m.7$, used the light curve solution of Surkova & Svechnikov (2004) and considered the semi-detached Algol binary configuration to apply the Wilson & Devinney (1971) code. They then concluded that the primary component of V346 Cyg has δ Scuti character.

As V346 Cyg is of maximum $\mathrm{mag_B} = 11.8$, and a relatively short period $P = 2.^d743310$ (Brancewicz & Dworak 1980), Budding (1984) has listed it among a relatively neglected group of binaries. Since then, many observers have monitored this system and determined about 20 photoelectric (pe) and CCD minima times. Later, the general properties of V346 Cyg were given by Soydugan et al. (2006b) and are listed in Table 1. They deduced that the system is an eclipsing binary with pulsating component and A5+G4IV Sp. Type.

The aim of the present paper is to discuss the possible mechanisms that could be causing the changes in the period of V346 Cyg and to determine the LITE due to the presence of a third body, as well as to apply the Applegate mechanism to test the magnetic activity which is nearly a common characteristic among late–type low–mass stars similar to our sun.

2. PERIOD VARIATION STUDY

No period variation studies of this system have been conducted till now. An essential method to study the period variation in eclipsing binary systems is the analysis of the $O-C$ diagram, by the use of minima times determined throughout the observational history of the

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Table 1
Physical Parameters of V346 Cyg in literature

	$M_1/\mathrm{M}_\odot$	$M_2/\mathrm{M}_\odot$	$R_1/\mathrm{R}_\odot$	$R_2/\mathrm{R}_\odot$	$L_1/\mathrm{L}_\odot$	$L_2/\mathrm{L}_\odot$	T_1(K)	T_2(K)
Surkova & Svechnikov (2004)	1.86	0.56	2.21	3.01	-	-	-	-
Soydugan et al. (2006b)	2.34	1.83	3.75	4.74	61.76	38.94	8353	6620

binary. For this purpose, a total of 71 minima times are gathered and listed in the self-explanatory Table 4. We construct the $O-C$ diagram (Figure 1) by using Kreiner's (2004a) light elements:

$$\mathrm{HJD(Min.I)} = 2\,435\,686.7191 + 2^{\mathrm{d}}.7432997 \cdot E\ . \quad (4)$$

For minima time detection, we used the last 18 photoelectric and CCD minima of Table 4 (the upward branch of Figure 1) starting from JD 24 48500.6600, and obtained the new linear ephemeris:

$$\mathrm{HJD(Min.I)} = 2\,435\,686.42843 + 2^{\mathrm{d}}.743347163 \cdot E\ , \quad (5)$$

with standard deviation SD=0.0039, and regression r = 0.955. All the linear elements given by various authors, together with the linear elements obtained in this work are listed in Table 2.

The $(O-C)$ diagram of V346 Cyg (Figure 1) shows a sine-like variation which is usually attributed to be a result of light time effect (LITE) caused by the presence of a third body orbiting the binary system, or it may be a result of cyclic magnetic activity due to star spot(s) on the late G4 Sp. type secondary component of the binary. Beside this, the semi-detached Algol type configuration usually suggests a transfer of matter from the less massive evolved component to the more massive primary one. However, this does not agree with the system under study as we shall see below.

To analyze the $O-C$ diagram we use the standard approach (Mayer 1990) assuming that the time of minima follow a quadratic ephemeris and are modulated by LITE (Irwin 1959). The time of mid eclipse is computed as follows:

$$\begin{aligned}\mathrm{Min.I} \quad = \quad & JD_0 + P \cdot E + Q \cdot E^2 + \frac{a_{12}\ \sin i}{c} \times \quad (6)\\ & \left[\frac{1-e_3^2}{1+e_3\ \cos\nu}\ \sin(\nu+\omega_3) + e_3\ \sin\omega_3\right]\ ,\end{aligned}$$

where e_3, ω_3, ν, $a_{12}\ \sin i$ and c are the eccentricity, longitude of the periastron, true anomaly of the binary orbit around the center of mass of the triple system, projected semi-major axis, and the speed of light, respectively. We used the weighted least squares computer programme written by Zasche et al. (2009). We exclude the first three photographic (pg) minima (listed in Table 4) due to the big gap ($\approx$ 34 years) between them and the other data. We gave weights 1, 3 and 10 for visual (v), pg, and photoelectric (pe) &CCD minima, respectively.

The quadratic ephemeris of the minima is captured by the first three terms of Equation (6), and shown by the dashed line in Figure 1, while the solid line fit represents the LITE. The lower panel in Figure 1 shows the residuals after the subtraction of the solution.

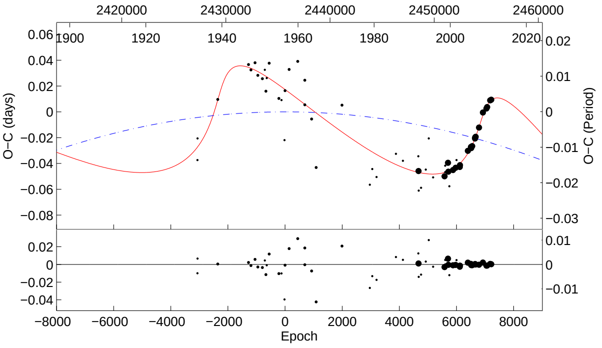

Figure 1. Raw $O-C$ diagram for V346 Cyg based on Kreiner's ephemeris (upper panel). The individual observations are shown as dots. The size of the dot is proportional to the statistical weight assigned to the minima (visual - 1; photographic - 3; photoelectric & CCD measurement - 10). The lower panel represents the residuals after the subtraction of the solution.

2.1. Mass Loss

Many semi-detached Algol binary systems exhibit either long–term parabolic increase or decrease in their orbital periods during their evolution depending on whether the process of matter transfer is conservative or non-conservative; for examples see Hanna & Amin (2013). However, in case of binaries that show orbital period decrease many authors, e.g., Kreiner et al. (1994b) and Pribulla (1998) have attributed such orbital period decrease to non–conservative mass loss from the primary component.

As one can see from the obtained quadratic term coefficient of Equation (6) (see Table 2 or 3), there is a decreasing parabolic long–term evolution of the orbital period represented by the dashed line in Figure 1. It may be identified as a period decrease caused by slow mass loss $dP/dt = -9.27 \times^{-10}$ day/cycle (= -1.23×10^{-7}day/yr $\simeq$ 1 Second/Century) from the more massive δ Scuti pulsating primary component.

2.2. Third Body Hypothesis

The $O-C$ residuals show a sine-like variation with an amplitude $\simeq 0^d.068\pm0.01$. This value is above the lower limit, $0^d.030$, suggested by Frieboes-Conde and Herczeg (1973) for detecting a third component orbiting a close binary system. Anyhow, the LITE due to the presence of the third body is clearly visible in the upper panel of

Table 2
The ephemerids of V346 Cyg found by different authors

JD+240000	Period	Quadratic term	Cubic term	Reference
27300.41100	2.743220			Florja (1934)
27300.41100	2.743358			Florja (1934)
27300.40000	2.743370			Petrow (1946)
33283.62879	2.7432956	-1.51×10^{-8}	0.10×10^{-11}	Wood & Forbes (1963)
35686.71910	2.7432997			Kreiner (2004a)
52500.39800	2.743305			Kreiner (2004b)
35686.63000	2.7433200			Paschke & Brát (2013)
35686.42843	2.743347163			Present work †
35686.73570	2.743316124	-4.6371×10^{-10}		Present work ‡

† Light elements from the last 18 pe and CCD minima times. ‡ Light elements obtained from the solution approach of section IIa.

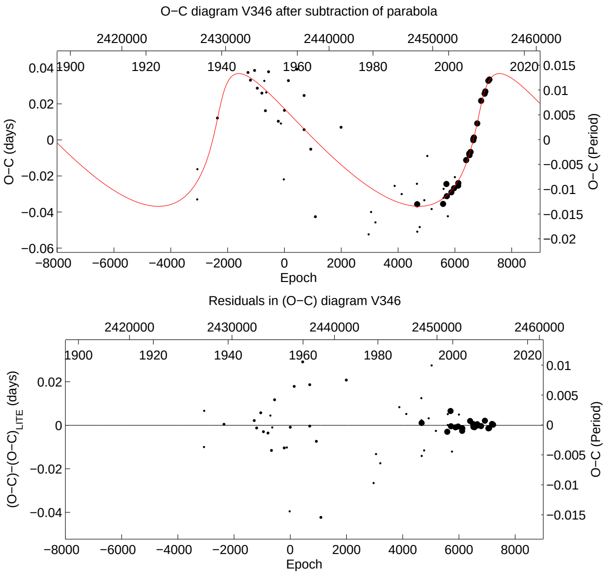

Figure 2. LITE solution made after the removal of a parabola (upper panel) and residuals (lower panel) for V346 Cyg.

Figure 2 after the removal of the parabola. The residuals are also presented in the lower panel of Figure 2. In this analysis we have considered the physical parameters obtained by Soydugan et al. (2006b) (see Table 1). The final solution of the orbital parameters are listed in Table 3. The solution shows a third body of mass $M_3 = 1.45\ \mathrm{M}_\odot$ that can be observed photometrically.

2.3. Magnetic Activity

Magnetic activities seen in low–mass late–type stars may produce cyclic period variation because of their rapid rotation and outer convective layers (Richards & Albright 1993). Changes of the magnetic field distribution result in changes of angular momentum distribution. Gravitational quadrupole coupling produces changes in the internal structure of the active star which results in a period variation.

Zavala et al. (2002) studied the cause of period changes for the Algol binary WW Cyg whose orbital period undergoes a 56 yr cyclic variation with an amplitude ≈ 0.02 days. In their study they rejected the hypotheses of mass transfer, mass loss, apsidal motion, and the gravitational influence of an unseen companion as causes for these changes. They invoked the Applegate (1992) model which involves variations of the subsurface magnetic field. Such subsurface magnetic field may be compared to solar activity cycles. The model can give a plausible explanation of the observed cyclic period variations of such late type active stars.

Star-spots are expected to be present on the cooler member i.e., the secondary less massive star (Sp. Type G4IV) was considered as the active component when applying the Applegate (1992) mechanism. For more details about the mechanism see Applegate and Patterson (1987), Applegate (1992) and references therein.

To compute the amplitude of the period oscillation of V346 Cyg shown in Figure 1, one could use the following equation (Rovithis-Livaniou et al. 2000),

$$\Delta P = A\sqrt{2[1-\cos(2\pi P_e/P_{cycle})]}\ , \tag{7}$$

as $\Delta P = 2.33 \times 10^{-5}$ with $P_{cycle} = 25162$ days. Thus, the rate of period variation is found to be $\Delta P/P = 8.491 \times 10^{-6} \simeq 10^{-5}$, which is in agreement to the amplitude proposed by Lanza and Rodonò (1999) for Algols.

Following Lanza & Rodonò (2002),

$$\frac{\Delta P}{P} = -9\frac{\Delta Q}{Ma^2}\ , \tag{8}$$

the variation in the quadrupole moment can be estimated to be $\Delta Q = 4.7 \times 10^{51}\,\mathrm{g\cdot cm^2}$ for the secondary evolved late type component; where M is the mass of the active star and the separation a between both components can be determined with the Kepler's third low,

$$a = [74.5 \cdot P^2(M_1 + M_2)]^{1/3}\ . \tag{9}$$

Assuming conservation of the orbital angular momentum, Lanza and Rodonó (1999, 2004) have argued that magnetic variation could be detectable if the quadrupole moment ΔQ is of the order $10^{51} - 10^{52}\,\mathrm{g\ cm^2}$ for Algol–type binaries, which indicating that the obtained ΔQ value of the secondary component of V346 Cyg is a typical value for the close binaries. Therefore, the magnetic activity proposed by Applegate is a possible mechanism to explain the cyclic variation of V346

Table 3
A light–time effect solution and the corresponding ephemeris of the binary system V346 Cyg

Parameter	Unit	Value
P_3 (period)	[yr.]	68.89 ± 4.69
A (semi-amplit.)	[day]	0.068 ± 0.0119
e_3 (eccentricity)		0.692 ± 0.25
ω_3 long. preias. pass.	[deg]	22.187 ± 33.3
T_0 (Time of periastron passage)	[HJD]	$24\,29458.878 \pm 2362.53$
$a_{12} \sin i$ (projection of semi–major axis)	[AU]	8.305 ± 2.68
$f(M_3)$	[M$_\odot$]	0.1208 ± 0.079
$M_{3,min}$	[M$_\odot$]	1.450 ± 0.46
a_3 angular distance of 3^{rd} component	[mas]	77.410
JD_0	[HJD]	$24\,35686.73357 \pm 0.00292$
P_{binary}	[day]	$2.743303847 \pm (2.13 \times 10^{-6})$
$Q \quad (\times 10^{-10})$	[day]	-4.6371 ± 0.0146
Sum of the square residuals $\sum (O-C)^2$	[days^2]	0.0180

Cyg. However, it is worth pointing out that the conservative angular momentum assumption for the system is in contrast to the result obtained in section IIa which concerns the loss of matter out of the system. In addition, magnetic activity cycle of about 70 years is considerably longer than expected in such low mass solar type stars in comparison to our sun.

2.4. δ Scuti Light Time Effect

Soydugan et al. (2006a) performed a study by considering a sample of 20 eclipsing binary systems with δ–Scuti type primaries. They discovered that there is a possible linear relation among the pulsation periods of the primaries and the orbital periods of the system governed by $P_{\rm puls} = 0.020(2)P_{\rm orb} - 0.005(8)$. It is clearly seen that the longer the orbital period systems have longer pulsational periods. Also, they indicated and reported that the orbital motion of the pulsating component around the center-of-mass of the binary produces a light time effect, hence the observed period of variation will decrease and increase. They suggested that this effect is very small for the short period systems. However, more similar systems with δ–Scuti component have to be studied in order to confirm their new detection.

3. DISCUSSION

Pribulla (1998) derived the efficiency of mass transfer and mass outflow in close binaries. He concluded that, in case of conservative mass transfer the relative period change is

$$\frac{\Delta P}{P} = \frac{3(1-q^2)}{q} \times \frac{\Delta m}{m} \,, \tag{10}$$

where q is the mass ratio and m is the total mass $M_1 + M_2$. And, if the matter is being transferred from the less to the more massive component, the period increases and the efficiency of the mass transfer is

$$\alpha = \frac{3(1-q^2)}{q} \,, \tag{11}$$

i.e., the efficiency of this process is zero if the mass ratio is unity. In other words, the efficiency of transferring matter from the less to the more massive component monotonically decreases for increasing mass ratio. Accordingly, for V346 Cyg in which high mass ratio ($q = 0.78$, Soydugan et al. 2006b) is seen, the efficiency of the transfer of matter from the secondary to the primary massive star is low.

A δ Scuti variable (sometimes termed dwarf Cepheid) is a variable star which exhibits variations in its luminosity due to both radial and non-radial pulsations of the star's surface. Recent infrared and radio observations show that the prototypical Cepheid, δ Cephei, is undergoing mass loss (Marengo et al. 2010; Mathews et al. 2012). Neilson (2013) reported that this result was surprising and raises important questions about the role pulsation and mass loss in these stars. It is worthy to note that this result has been obtained for classical Cepheids. However, δ Scuti stars are, in general, main sequence or slightly evolved post main-sequence stars with masses between 1.4 and 3 $M_\odot$. They are located near the bottom part of the classical Cepheid instability strip and are burning hydrogen either in a convective core, or in a shell outside the H-depleted core (Guzik 2000; Soydugan et al. 2006a). This may be explanation for the coefficient of the quadratic term in Equation (6) being negative implying the unexpected direction of flow of matter (from the primary to the secondary less massive component which filling its Roche lobe). The interpretation of this contradiction may be due to:

1. Inaccuracy in specifying the evolutionary status of this system and the system is not specifically semi-detached, i.e., the secondary component is pre-contact its Roche lobe limit and the matter escape from the system isotropically from the δ Scuti primary component obeying the non–conservative assumption case. Also, in his catalogue of classical Algol–Type binaries, Budding (1984) reported that the high mass ratio $q_{sd} = 0.78$ for V346 Cygni as a semi–detached system suggests faulty solution.

Table 4
Times of minima

HJD (+2400000)	K	E	$(O-C)$	Ref.
14431.400	pg	-7748	0.01336	[1]
14933.270	pg	-7565	-0.14420	[1]
15162.400	pg	-7481.5	-0.08142	[1]
26930.119	v	-3192	0.16644	[2]
26951.988	v	-3184	0.08888	[2]
26982.198	v	-3173	0.12236	[2]
26990.400	v	-3170	0.09440	[2]
27270.240	v	-3068	0.11576	[2]
27281.230	v	-3064	0.13248	[2]
27300.412	v	-3057	0.11124	[2]
27303.156	v	-3056	0.11192	[2]
27311.376	v	-3053	0.10196	[2]
27314.112	v	-3052	0.09464	[2]
29220.776	pg	-2357	0.15124	[3]
32172.598	pg	-1281	0.16092	[4]
32408.518	pg	-1195	0.15540	[4]
32800.816	pg	-1052	0.15864	[4]
33069.65	pg	-954	0.14728	[4]
33508.576	pg	-794	0.14208	[4]
33744.507	vis	-708	0.14756	[5]
33848.736	pg	-670	0.13040	[4]
33928.302	vis	-641	0.14012	[5]
34158.751	pg	-557	0.15024	[4]
35091.447	pg	-217	0.11744	[4]
35346.573	vis	-124	0.11468	[5]
35626.359	vis	-22	0.08204	[6]
35686.750	pg	0	0.12000	[4]
36070.829	pg	140	0.13420	[4]
36899.313	pg	442	0.13556	[7]
37582.362	pg	691	0.09788	[7]
37582.381	pg	691	0.11688	[7]
38232.514	pg	928	0.08304	[7]
38671.405	pg	1088	0.04284	[7]
41151.400	pg	1992	0.07656	[7]
43820.573	vis	2965	-0.00080	[7]
44053.766	vis	3050	0.01000	[7]
44470.742	vis	3202	0.00136	[7]
46330.720	vis	3880	0.00840	[7]
47002.824	vis	4125	-0.00100	[7]
48478.725	vis	4663	-0.00616	[7]
48489.688	vis	4667	-0.01644	[7]
48500.660	V Hipp	4671	-0.01772	[7]
48511.618	vis	4675	-0.03300	[7]
48744.801	vis	4760	-0.03220	[7]
49194.717	vis	4924	-0.02068	[7]
49482.788	vis	5029	0.00172	[7]
49899.740	vis	5181	-0.03092	[7]
50999.8057	ccd	5582	-0.03654	[7]
51054.675	vis	5602	-0.03364	[7]
51054.680	vis	5602	-0.02864	[7]
51323.526	ccd	5700	-0.02800	[7]
51364.6687	ccd	5715	-0.03510	[7]
51460.673	vis	5750	-0.04700	[7]
50999.8057	ccd	5582	-0.03654	[7]
51054.675	vis	5602	-0.03364	[7]
51054.680	vis	5602	-0.02864	[7]
51323.526	ccd	5700	-0.02800	[7]
51364.6687	ccd	5715	-0.03510	[7]
51460.673	vis	5750	-0.04700	[7]
51806.3419	ccd	5876	-0.03642	[7]
52061.47091	ccd	5969	-0.03617	[8]
52143.776	vis	5999	-0.03068	[7]
52456.5073	(-Ir)	6113	-0.03786	[9]
52475.7118	ccd	6120	-0.03660	[7]
53232.8748	ccd	6396	-0.02992	[7]
53531.8979	ccd R	6505	-0.02870	[10]
53553.8434	ccd R	6513	-0.02976	[10]
53655.3472	pe (-Ir)	6550	-0.02880	[11]
53921.4536	pe (-Ir)	6647	-0.02444	[11]
53932.4276	pe V	6651	-0.02372	[12]
53981.8076	V	6669	-0.02348	[7]
54302.7813	ccd	6786	-0.01822	[7]
54681.3689	BVR	6924	-0.00878	[13]
55018.7984	ccd	7047	-0.00764	[7]
55084.6388	ccd	7071	-0.00692	[14]
55375.4342	pe (-Ir)	7177	-0.00344	[15]
55479.6802	V	7215	-0.00360	[7]

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2. Data is not enough and more minima times are needed.

3. Mass transfers from the δ Scuti primary pulsating star to the secondary component, even if partial.

4. CONCLUSIONS

The period variation study of V346 Cyg leads us to the following conclusions:

1. The nonexistence of the apsidal motion in the system V346 Cyg is confirmed by the 0.5 secondary minimum phase position (see, Florja 1934).
2. If the secular period decrease exists, it needs mass flow (in the case of conservative mass transfer) from the more massive primary component, filling its Roche lobe, to the less massive secondary component. This is not valid for the system configuration as recorded by various authors. (e.g., Kim et al. 2005; Soydugan et al. 2006a,b). Instead one may consider mass transfer and/or loss from the δ Scuti primary component.
3. Beside the secular decrease due to mass transfer and/or loss from V346 Cyg, the sine-like variation seen in the $O-C$ diagram may also be attributed to:

(a) LITE due to the presence of a third body of mass 1.45 $M_\odot$ orbiting the binary with about 69 years period and orbital eccentricity $e_3 \simeq 0.69$,
(b) a magnetic activity cycling due to star spots on the late type secondary star, or
(c) LITE due to the orbital motion of the pulsating component around the center-of-mass of the binary suggested before by Soydugan et al. (2006). However, this cause seems to be disfavoured until new evidence is obtained supporting their new detection.

Finally, it can be concluded that the $O - C$ residual diagram shows a long term orbital period decrease superimposed on a sine–like variation behavior which may be interpreted as a result of periodic or cyclic variation due to the presence of a third body or star spots on the late type secondary star, respectively. However more precise minima times and high dispersion spectroscopic observation are needed in order to confirm the results obtained for this elusive Algol V346 Cyg.

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