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Orbital period behaviour of three semi-detached binaries: AI Cru, V1898 Cyg and Z Vul

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ABSTRACT

In this research, orbital period variation of three semi-detached binaries AI Cru, V1898 Cyg and Z Vul investigated using all published eclipse times. O-C analysis method has preferred as the method and the orbital periods of all systems are determined to increase. The changing rate of their period has been determined to be 0.8, 4.1 and 0.8 s/century for AI Cru, V1898 Cyg and Z Vul, respectively. Mass transfer between components has proposed as the cause of orbital period increase. For AI Cru, V1898 Cyg and Z Vul, mass transfer from less massive component to more massive and mass transfer rate was found to be 2.9×10^{-7}, 1.5×10^{-7} and 5.3×10^{-8} $M_{\odot}$/yr, respectively. Cyclic change has also seen in AI Cru and V1898 Cyg with increasing parabolic change. Cyclic periodic changes can be explained as being the result of a light-travel time effect via a tertiary body around the eclipsing pair. The minimum mass of probable tertiary components around AI Cru and V1898 Cyg were found to be 0.38 $M_{\odot}$ and 0.26 $M_{\odot}$, respectively.

1. Introduction

One of the most important classifications of binary stars was made by Kopal (1955) according to Roche lobes, and this classification also provides information about the evolutionary states of stars. The radii of stars change during their evolution, but the expansion of binary stars it is limited to their Roche lobes. Semi-detached binaries (also known as classical Algols) is a classification made according to Roche classification, and one of the components filled the Roche lobe and the other did not. Classical Algols are semi-detached star systems and the primary component usually B or early A (rarely spectral type F) composed of spectral type, the second component is of the G, K, M spectral type of giant or sub-giant that filled the Roche lobe. Except for eclipsing systems, they do not show any significant change in their light curves. This the most important feature of the systems is that both eclipse depths are quite different from each other. The orbital periods of the vast majority are between one day and several days.

Orbital period analysis provides information about the evolution of such stars. So in this paper, the orbital period changes of three semi-detached systems (AI Cru, V1898 Cyg and Z Vul) are examined. Some basic physical parameters and data information of target systems collected in the literature have given in Tables 1 and 2.

1.1. AI Cru

The eclipsing binary AI Crucis (GSC 08974-00877, TYC 8974-877-1, Gaia DR2 6058510765049380096, V=9.69 mag) was discovered by Oosterhoff (1933) and determined the orbital period as P = 1.4177073 day. Then the photometric solutions of the system were made by several authors (Ollongren 1956, Giuricin et al. 1980, Russo 1981). It was reported by Russo (1981) that the second component is a semi-detached system filling the Roche lobe. Both photometric and spectroscopic observations of AI Cru were carried out by Bell et al. (1987). The spectral type of the primary component was determined as B 1.5 by Bell et al. (1987) and the masses of the components in the same study were reported as 9.8±0.5 $M_{\odot}$ and 5.8±0.3 $M_{\odot}$. The orbital period analysis study of the system was performed by Zhao et al. (2010) and Zhao & Qian (2012). In both studies, it was determined that the orbital period of the system is increased. The last orbital period analysis study of the system was made by Zhao & Qian (2012) and the period increase rate was determined as dP/dt =+1.00 (± 0.04) $\times10^{-7}$ days/yr.

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Table 1. Basic physical parameters of systems used in analysis.

Parameters	AI Cru	V1898 Cyg	Z Vul
Spectral type	B2IV[3]	B2IV+GIII[4]	B3-5V+A2-3III[5]
Orbital period (day)	1.41771076[1]	1.51312433[1]	2.45492774[1]
T_o (HJD+ 2400000)	33466.3382[1]	45960.6717[1]	25456.118[1]
M_1-M_2 ($M_\odot$)	9.8-5.8[2]	6.05-1.16[4]	5.29-2.33[5]
R_1-R_2 ($R_\odot$)	4.9-4.4[2]	3.53-2.64[4]	4.93-4.67[5]

References: 1: Kreiner et al. (2001); 2: Bell et al. (1987), 3: Wesselink (1969), 4: Dervişoğlu et al. (2011), 5: Lazaro et al. (2009).

1.2. V1898 Cyg

V1898 Cyg (GSC 03588-04247, TYC 3588-4247-1, Gaia DR2 2163574661395444864, *V*=7.82 mag) was discovered by Abt et al. (1972). Photometric observations on *B* and *V* filters were made by Halbedel (1985) and, contrary to spectroscopic observations, it was found that both eclipses were similar and the orbital period was determined as P = 3.0239 days. The new light curve was made by Caton & Smith (2005) and the orbital period of the system was determined as P = 1.5131273 days and it is half the value found by Halbedel (1985). Both photometric and spectroscopic observations of the V1898 Cyg system was carried out by Dervişoğlu et al. (2011) and in the same study, basic physical parameters such as mass, radius of the system were determined. The orbital period analysis study of the system was also carried out by Dervişoğlu et al. (2011) and it has been determined that the period has increased. They are the orbital period increase rate P'/P = 6.68 (± 0.63) × 10^{-7} yr^{-1}.

1.3. Z Vul

The eclipsing binary system Z Vul (GSC 02128-00966, TYC 2128-966-1, Gaia DR2 2023954311223665536, *V*=7.33 mag) was discovered by Herschel (it has been reported by Astbury, 1909). The radial velocity study was made by Popper (1957) and the mass ratio of the Z Vul system was determined as q = 0.42. The spectral type of the system was determined as B5 by Levato (1975) and the rotational velocity in the same study was determined as $v\sin i$ = 195 km/s. Light curve analysis simultaneously with radial velocity was carried out by Ghoreyshi et al. (2008) and in the same study, basic astrophysical parameters such as mass and radius have determined. Light curve and spectroscopic observations of Z Vul were made by Lazaro et al. (2009). Light and radial velocity curve analysis were also performed in the same study. The orbital period analysis study of the system was conducted by Kreiner & Ziolkowski (1978) and it has been stated that the orbital period has increased.

2. Material and Method

In this study, collected all visual, photographic, photoelectric and CCD data from the literature. The following equations have applied to the minimum times collected (most of which are taken from the O-C Gateway (Paschke and Brat; 2006)). Some information about the O-C data has given in Table 2.

Table 2. Data information used in the orbital period analysis of systems.

System	Data Range (year)	The total number of data	Type Min.I/Min.II
AI Cru	~90	29	26/3
V1898 Cyg	~30	13	13/-
Z Vul	~120	466	444/22

The orbital periods of binary star systems can change over time. These changes are it may be in the form of an increase or decrease. In the literature, the change in the periods of binary stars is explained by four different mechanisms. These are conserved mass transfer between components or nonconservative mass loss, magnetic activity, the effect of a third body in the system and axis rotation. From these four effects, mass transfer/mass loss and magnetic activity are it literally changes its period. The axis rotation and the third body do not literally change the orbital period. To determine the cause of the period change of a system (O: observed and C: calculated minima times) the change of the difference of O-C with respect to time it is based on interpretation. O-C analyzes of binary stars are often complex. These often involve one or more cyclical changes superimposed on an increasing or decreasing parabolic change. Parabolic changes are generally explained by mass transfer between components. However, decreased parabolic changes can also be explained by possible angular momentum loss from the system if at least one of the components is behind the F5 spectral type. Although sinus-like changes are generally accepted to be caused by possible components revolving around the binary system, in addition, the source of this change. There may also be magnetic cycles of cold and magnetic active components in the system (Applegate, 1992). In O-C graphs, interstellar mass and energy transfer or mass loss of the system appear as parabolic change. In this case, equation 1 is used for O-C data.

$$MinI = T_0 + E.P + Q.E^2 \tag{1}$$

where T_0 and P are the starting minimum time and orbital period, respectively, E is the number of cycles and Q is the coefficient of the parabolic term. If the period of the system is increasing, Q is positive, if it is decreasing, it is negative. Equation 2 is used to express the change in unit time, period.

$$\frac{\Delta P}{P} = \frac{2.Q}{P} \tag{2}$$

In order to model the sine-like changes seen in O-C graphs using the light-time effect (LITE) caused by the possible third object, the most basic expression was first given by Irwin (1959) with equation 3.

$$\Delta t = \frac{a_{12}\sin i'}{c}\left\{\frac{1-e'^2}{1+e'\cos v'}\sin(v'+w')+e'\cos w'\right\} \tag{3}$$

The value given in the equation is the time delay caused by the possible third object. In the equation 3; a_{12}, i', e', v' and w' are the semi-major axis, inclination, eccentricity, true anomaly of the position of the binary system's mass center of orbit and the longitude of the periastron of the orbit of the eclipsing binary around the third component, respectively.

O-C changes due to magnetic cycle are cyclical and can be represented by equation 4.

$$MinI = T_0 + E.P + A_{mod} \sin\left[\frac{2\pi}{P_{mod}}(E - T_s)\right] \quad (4)$$

where A_{mod}, P_{mod}, and T_s represent the amplitude, period and minimum moment of the cyclic change, respectively. Conservative mass transfer between components can be recommended as the cause of orbital period increase. The following equation is used for mass transfer between components (Kwee, 1958).

$$\frac{\Delta P}{P} = \frac{3\dot{m}_1(m_1 - m_2)}{m_1.m_2} \quad (5)$$

where it is represented by the period change (ΔP) and the transferred mass amount ($\dot{m}_1$).

3. Results and Conclusion

In this study, the orbital period analysis study of three semi-detached systems has been done in detail and O-C method has used in the analysis. Semi-detached systems generally the second component filled the Roche lobe while the first component did not fill the Roche lobe. Therefore, the orbital period change of the systems is expected to increase since there will be a mass transfer from the second component filling the Roche lobe to the first component from Lagrange 1 point. It has been observed that the orbital periods of all systems increase.

O-C analysis of AI Cru has performed with a total of 29 minima times collected from the literature (an update of about 8 years has been made). Both cyclical change and increasing parabolic change has seen in AI Cru's O-C analysis (see Figure 1 and Figure 2). So equation 1 showing parabolic change and light time effect has used. Equation 2 has used to calculate the period change rate of AI Cru and the orbital period increase rate of the system has determined as dP/dt=9.3×10^{-8} days/ yr. In the last period analysis study conducted by Zhao & Qian (2012) for the AI Cru system, the rate of increase of the period has calculated as dP/dt=1.00(0.04) ×10^{-7} days/yr. It was also noted in the same study that the conservative mass transfer between components would not be sufficient as the reason for the period increase of the system and it has been suggested that the loss of mass from the first component by the stellar wind may be the reason for the period increase. Therefore, in this study, both the conservative mass transfer rate and the mass loss ratio are calculated and given in Table 3. With the increase of the AI Cru system period, cyclical change was also observed and it has suggested that a possible third object could be the cause of cyclical change. The mass of the possible third component has calculated to be 0.38 $M_\odot$.

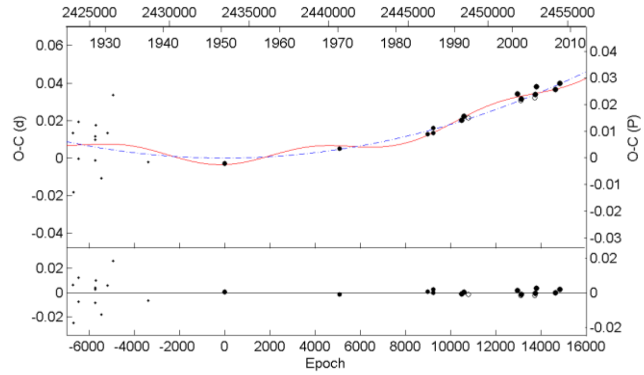

Figure 1. Representation of AI Cru system with O-C graph and theoretical curves. On the top panel; dashed line represents parabola, continuous line represents parabola + cyclical fit, bottom panel shows differences from theoretical curve.

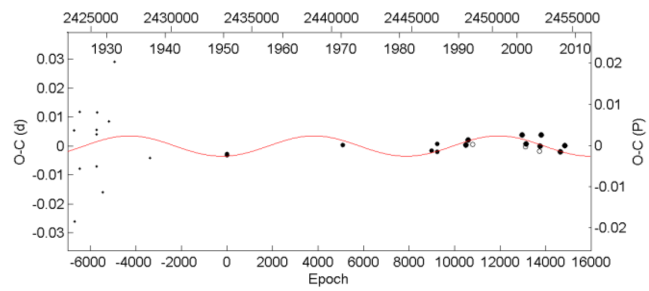

Figure 2. Cyclical O-C change and theoretical representation of AI Cru system.

Approximately 10 years of update has been made for the V1898 Cyg system and an orbital period analysis study has been performed with 13 minima times collected in the literature. As a result of O-C analysis of V1898 Cyg system, cyclic change has observed with parabolic change (see Figure 3 and Figure 4). Using the equations in section 2, the orbital period rate of change has calculated as dP/dt=4.73×10^{-7} days/yr (3.13×10^{-7} yr^{-1}). The last orbital period analysis study of the system was made by Dervişoğlu (2011) and the period increase rate was calculated as dP/P=6.68×10^{-7} days/yr. In this study, it has proposed that the orbital period change for V1898 Cyg can be a mass transfer between components with the assumption of conservative mass. Mass transfer between components has calculated as dM/dt=1.5×10^{-7} $M_\odot$/yr from second component to primary component. In the analysis, it was seen that there was a cyclical change with the increase of the period. It has been suggested that there may be a third object as the cause of cyclical change and the minimum mass of this object has been calculated as 0.38$M_\odot$.

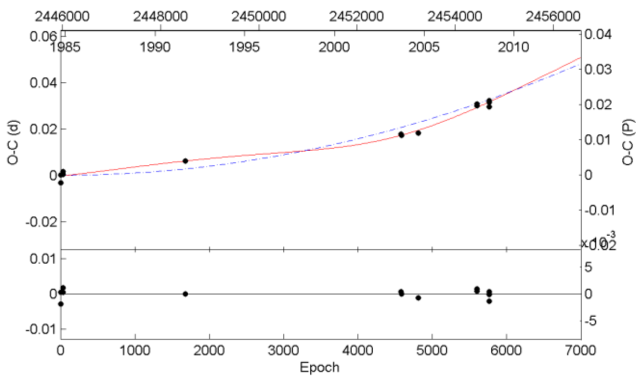

Figure 3. O-C values of V1898 Cyg (description is the same as fig. 1).

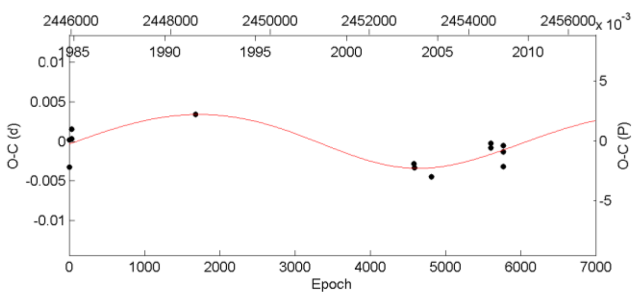

Figure 4. Sinusoidal fit on the O-C diagram of V1898 Cyg.

A detailed orbital period analysis study has been conducted for the Z Vul semi-detached system. The orbital period analysis of the system has made by Kreiner & Ziolkowski (1978) and it has reported that the period increased. Analysis has conducted with more sensitive data of about 40 years (with minima times 466 collected in the literature). It is seen that the period of the Z Vul system has increased and this rate of increase has been determined as dP/P=9.37×10^{-8} days/yr. Mass transfer from the first component to the second component has been proposed as the cause of orbital period increase. The mass transfer ratio has calculated as dM/dt=5.3×10^{-8}$M_\odot$/yr with the conservative mass assumption.

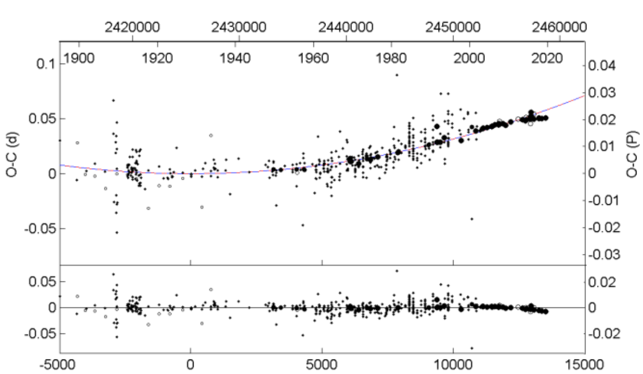

Figure 5. O-C values of the Z Vul system and the theoretical curve used to represent it and its differences.

Table 3. Parameters derived from O-C analysis of three systems in this study.

Parameters	AI Cru	V1898 Cyg	Z Vul
T_0(HJD+2400000)	33466.3389 (37)	45960.6755 (13)	25456.1147 (24)
P_{orb} (day)	1.4177092 (4)	1.5131199 (18)	2.4549259 (7)
Q (day)(×10^{-10})	1.8(1)	9.8(2)	3.1 (5)
dP/dt (s/century)	0.8	4.1	0.8
dM/dt ($M_\odot$/yr) (conservative)	2.9×10^{-7}	1.5 ×10^{-7}	5.3 ×10^{-8}
dM/dt ($M_\odot$/yr) (estimated mass loss)	1.3×10^{-7}	1.7 ×10^{-7}	5.9 ×10^{-8}
A (day)	0.0035 (3)	0.0034 (9)	---
$a_{12} \sin i$ (AB)	0.61 (18)	0.59 (16)	---
e	0.12 (1)	0.10 (5)	---
ω (deg)	80 (19)	246 (48)	---
T'(HJD+2400000)	37010(626)	51226(533)	---
P_{12} (yr)	31 (4)	24 (4)	---
$f(m_3)$ ($M_\odot$)	0.00023 (1)	0.00033 (8)	---
m_3 ($M_\odot$) for i=90 deg.	0.38	0.26	---

A second way of explanation for cyclical variations is if one or both of the components are cold and the outer parts have a convective envelope, the magnetic cycle of the active components can also cause the cyclical period change. Therefore, with the parabolic term, the cyclic changes Applegate (1992), equation 4 was applied to the O-C data to explain the model and the Applegate parameters found were listed in table 4.

Table 4. Some parameters related to Applegate model for AI Cru and V1898 Cyg.

Parameters	AI Cru	V1898 Cyg
P_{mod} (yr)	31 (4)	24 (4)
$\Delta P/P$	3.88×10^{-6}	4.87×10^{-6}
ΔJ (erg s^{-1})	-1.2×10^{49}	-1.2×10^{49}
$\Delta\Omega/\Omega$	0.016	0.032
ΔE (erg)	9.9×10^{42}	1.8 ×10^{43}
I_s (g cm^2)	1.42×10^{55}	7.95 ×10^{54}
ΔL_{rms} ($L_\odot$)	8	20
B (kG)	8	2

As a result; the orbital period analysis study of three semi-detached systems has been done in detail. It has been observed that the orbital periods of all systems increase. This is what is expected of such systems. The changing rate of their period have been determined to be 0.8, 4.1 and 0.8 s/century for AI Cru, V1898 Cyg and Z Vul, respectively. Conservative mass between components have assumed as the orbital period reason. For AI Cru, V1898 Cyg and Z Vul, mass transfer from less massive component to more massive and mass transfer rate was found to be 2.9×10^{-7}, 1.5×10^{-7} and 5.3×10^{-8} $M_\odot$/yr, respectively. Cyclic change has also seen in AI Cru and V1898 Cyg with increasing parabolic change. Cyclic periodic changes can be explained as being the result of a light-travel time effect via a tertiary body around the eclipsing pair. The minimum mass of probable tertiary components around AI Cru and

V1898 Cyg were found to be 0.38 $M_{\odot}$ and 0.26 $M_{\odot}$, respectively.

In order to better understand the nature of such systems, more minima times and data accumulated over longer years are needed.

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