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Research article

Period Change Analysis of a W UMa-type Binary: V417 Aquilae

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Abstract: Light curve analysis investigated the orbital period variations of the short period, overcontact eclipsing binary system, and V417 Aquilae (V417 Aql). The system was observed using a 0.70-meter telescope with a CCD photometric system using B and V filters at the Regional Observatory for the Public, Songkhla, Thailand, on 2 July 2021 UT. The light curve constructed by the photometric method for each filter was analyzed to find the period change of the system. It is found that the V417 Aql system is undergoing a long-term decrease of rate 0.00251 seconds/year. The reduction in the period showed that the distance between the stars was decreased according to Angular Momentum Loss (AML) theory. V417 Aql residuals tend to be periodic, indicating there might be a third body in the system. The calculation shows that the third body's distance, period, and mass function are about 1.97 AU, 47.7 years, and 0.19MΘ, respectively.

Keywords: Binary stars; V417 Aql

1. Introduction

V417 Aql [$\alpha(2000) = 19^h\ 35^m\ 24.1219^s$, $\delta(2000) = +05° 50' 17.656''$] are classified as W Ursae Majoris (W UMa) binaries. They are over-contact eclipsing binary stars with short orbital periods. The effective temperatures of both components are very similar. The depth of the primary eclipse and the second one are close. There are two types of W UMa: A-type (the brighter and hotter star has a smaller size and mass) and W-type (the brighter and hotter star has a bigger size and mass). Some binary star systems can return between A-type and W-type.

The V417 Aql system has a short period that constantly changes. The eclipsing binary V417 Aql system was discovered by Hoffmeister [1]. In 1937, Soloviev [2-3] classified it as W UMa type with a period of 0.37 days. Koch [4] identified it as a strongly interacting solar-type binary system. Many studies indicate that their period is decreasing and a third body may be in the system. Samec [5] concluded that V417 Aql was a W-type W UMa system with a 25-minute time of constant light in the primary minimum. The system consisted of a GO V spectral type primary component and an F9 V spectral type secondary component with a mass ratio of $q \approx 0.37$ and might evolve into an A-type W UMa binary. Lu et al. [6] found that the spectroscopic mass ratio value q equals 0.362. By combining the photometric solution of Samec et al. with their radial velocity solution, the following absolute parameters could be derived: $a=2.68R_\odot$, side radii $R_1=1.29\ R_\odot$, and $R_2=0.80\ R_\odot$, and mass $M_1=1.40M_\odot$, $M_2=0.50M_\odot$.

The degree of contact was 19%. According to the study of Qian [7], a long-term period of V417 Aql was decreased with the value of dP/dt equal to -5.50×10^{-8} days/year. The long-term period variation was consistent with the study of Qian [8]. There is a suggestion of no third body in the system. The asymmetries in the light curve may be caused by the components' solar-type magnetic activity, and V417 Aql is an A-type in a deep contact configuration [9].

The objective of this study is to analyze the change in the period of V417 Aql. In this paper, the light curve is obtained from photometric observations in B and V wavelength bands.

2. Materials and Methods

2.1 Light curve analysis

An eclipsing binary normally consists of stars orbiting each other in space concerning the Earth. The light of one can be obscured behind the other. The total light observed from the earth could be decreased when the eclipse occurs. The light curve is temporal data that records a decrease or increase in light from the binary system over a complete light cycle. It has been widely used to study the characteristics of the binary star. The curve indicates the orbital orientation of the system observed on the Earth. If the brighter star orbits behind the lesser one, there will be a significant decrease in minimum light, called the primary minimum: Min I. Likewise, if a less brightness star is obscured, the light curve will reduce to minimum light with less volume than the primary minimum. This minimum is called the secondary minimum: Min II. For the W UMa binary, in which the depth of the primary and secondary eclipse is close to each other, Min I and Min II are not much different.

2.2 O-C

The time of the minimum of the light curve will vary according to the number of periods according to the Linear Ephemeris equation as follows:

$$HJD = HJD_0 + PE \tag{1}$$

The period change is achieved from the analysis of the O-C diagram, which can be described as follows:

$$O\text{-}C = (P - P_{est})\, E \tag{2}$$

O and C are observed, and the time of minimum light. At the same time, Pest and P are the orbital periods of a binary star system calculated from the ephemeris linear equation and observation, respectively. If the O-C diagram has a parabolic distribution, then

$$O\text{-}C = aE^2 + bE + c = (P - P_{est})E \tag{3}$$

$$\frac{dP}{dE}E + (P - P_{est}) = 2aE + b \tag{4}$$

So, the change in period dP/dE is equal to 2a. The value of "a" can be obtained from the quadratic polynomial fitting method.

2.3 Third body

Some binary star systems consist of more than two members, known as "multiple star systems." The third object could be a star or a planet. The existence of the third member affects some properties of the system. For example, the total mass comprises the masses of binary stars and the third body. The amount of light observed consists of the light from the three objects.

(The third body's light is considered constant). The small mass of the third body function can be calculated using the following equation.

$$f(m)=\frac{m_3^3}{m_1+m_2+m_3}\sin^3 i' = \frac{1}{P'^2}(a' \sin i')^3 \quad (5)$$

When m_1, m_2, and m_3 are the masses of the first, the second, and the third component, respectively. The i' is the inclination, a' is the distance of the third body from the binary system, and P' is the orbital period of it.

3. Results and Discussion

V417 Aql was observed using a 0.70-meter telescope with a CCD photometric system using the standard B and V filters at the Regional Observatory for the Public, Songkhla, Thailand, on 2 July 2021 UT. The exposure time for each filter was 60 seconds.

The temporal flux of the binary archived from the observation using the standard B and V filters was plotted, as shown in Figure 1.

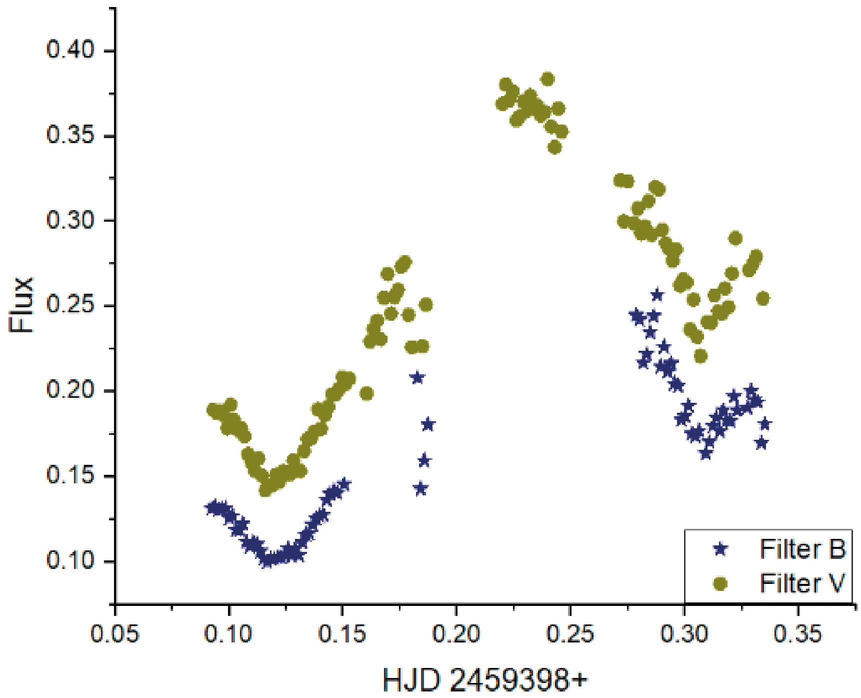

Figure 1. The light curve of V417 Aql in V filter (green dots) and B filter (blue dots)

The minimum time of V417 Aql can be obtained from the second-order ordinary differential equations. Each minimum is the average value of the minimum of B and V filters. The fittings of the light curve obtained from the observations using B and V filters considering only the first and secondary eclipse parts are shown in Figure 2.

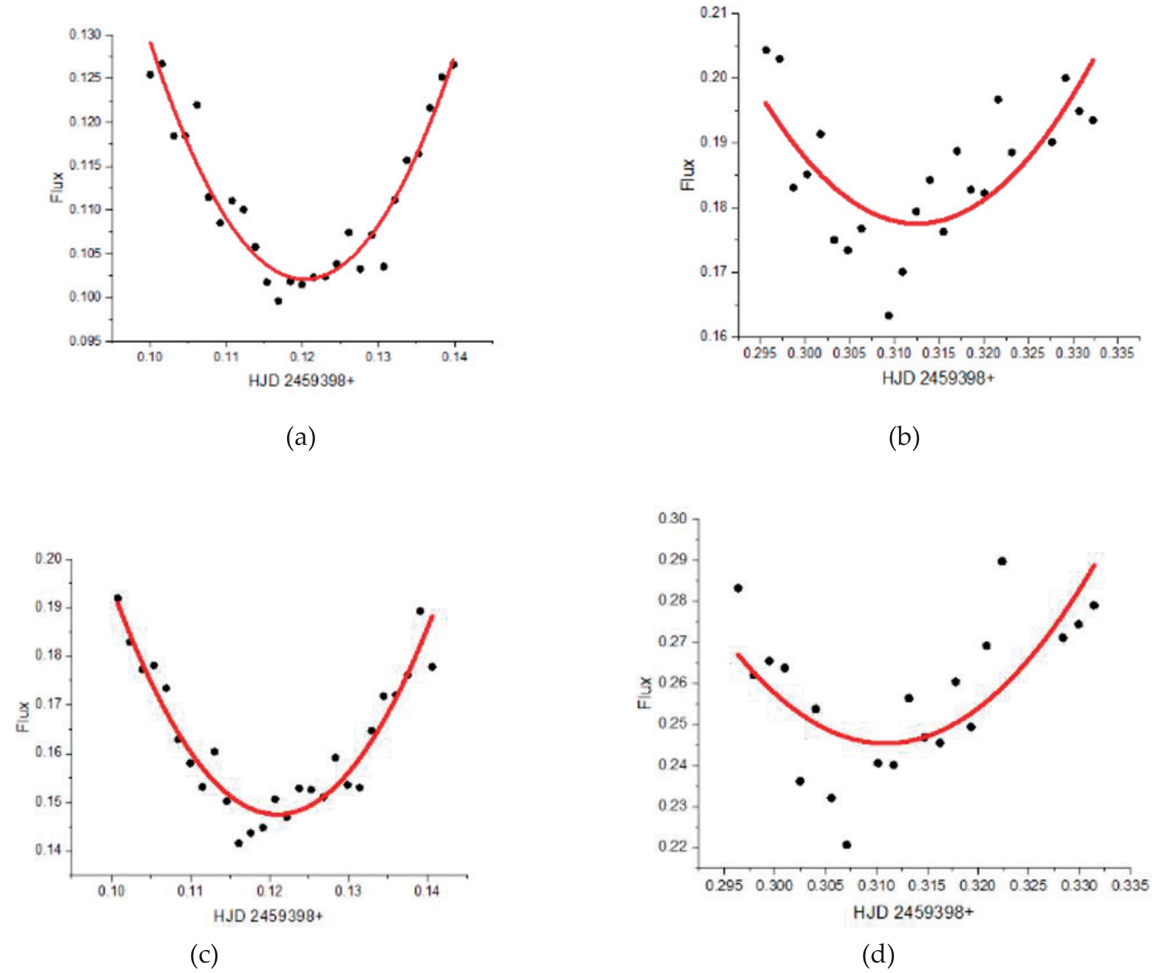

Figure 2. The ODE fits show the primary and secondary minimum eclipse depths obtained from the observation with B [(a) and (b)] and V [(c) and (d)] filters, respectively.

In the ordinary differential equation (ODE) from Figure 2, we got the average of the first time of minimum is equal to 0.120641822 and 0.311703 for the second one.

The following linear ephemeris (Eq.6) derived by Qian [7-8] along with the database of eclipsing binary O-C Files by Bob Nelson, AAVSO [10] was used to calculate the O–C values of all the times of minimum light.

$$\text{HJD Min} = 2449546.4983+0.37031178E \quad (6)$$

The corresponding O-C diagram is shown in Figure 3. The data during the secondary minimum seems to be very scattered; this could result from the existence of clouds along with the low transparency of the sky on the day of the observation.

The times of minimum light of V417 Aql are displayed in Table 1, and the O-C diagram is shown in Figure 3.

Table 1. The times of minimum light of V417 Aql.

HJD Min	Epoc	O-C	Source
2428427.127	-57031	-0.12017	CTAD 22
2428427.132	-57031	-0.11517	IBVS 6091
2428428.241	-57028	-0.11711	CTAD 22
2428429.165	-57025.5	-0.11889	Samec 1997
2428429.344	-57025	-0.12505	CTAD 22
2428430.266	-57022.5	-0.12882	Samec 1997
2428431.196	-57020	-0.1246	CTAD 22
2428460.253	-56941.5	-0.13708	Samec 1997
2428775.223	-56091	-0.11725	PZ 6.287
2428776.146	-56088.5	-0.12003	PZ 6.287
2430583.266	-51208.5	-0.12151	PZ 6.287
2430583.46	-51208	-0.11267	PZ 6.287
2431328.352	-49196.5	-0.10282	IODE 1.1.38
2431329.27	-49194	-0.11059	IODE 1.1.38
2431340.2	-49164.5	-0.10479	IODE 1.1.38
2431342.229	-49159	-0.11251	IODE 1.1.38
2431344.271	-49153.5	-0.10722	IODE 1.1.38
2431345.2	-49151	-0.104	IODE 1.1.38
2431346.306	-49148	-0.10894	IODE 1.1.38
2431347.232	-49145.5	-0.10872	IODE 1.1.38
2432385.409	-46342	-0.10079	IODE 1.1.41
2432392.441	-46323	-0.10472	IODE 1.1.41
2432415.399	-46261	-0.10605	IODE 1.1.41
2434922.819	-39490	-0.06711	AJ 61.47
2441135.405	-22713.5	-0.01668	BBSAG Bull...31
2441135.405	-22713.5	-0.01668	BBSAG Bull...31
2442990.498	-17704	-0.00055	BBSAG Bull.29
2443016.404	-17634	-0.01637	GCVS 4
2443016.414	-17634	-0.00637	BBSAG Bull.29
2443765.379	-15611.5	0.003053	BBSAG Bull.39
2444476.35	-13691.5	-0.02456	BBSAG Bull.49
2444486.367	-13664.5	-0.00598	BBSAG Bull.50
2444815.397	-12776	0.002001	BBSAG Bull.56
2444852.43	-12676	0.003823	BAVM 34
2444875.384	-12614	-0.00151	BAVM 34
2444878.347	-12606	-0.001	BAVM 34
2444885.383	-12587	-0.00093	BAVM 34
2445196.447	-11747	0.00128	Samec 1997
2445225.333	-11669	0.002861	BAVR 33.152
2445225.35	-11669	0.019861	IBVS 2344
2445542.689	-10812	0.002065	IBVS 2439
2445550.651	-10790.5	0.001762	IBVS 2439
2445554.723	-10779.5	0.000933	IBVS 2439
2445558.438	-10769.5	0.012415	BAVM 38
2445575.647	-10723	0.001717	IBVS 2439
2445583.434	-10702	0.01237	BAVR 33.157
2445605.642	-10642	0.001263	IBVS 2439
2445892.447	-9867.5	0.000189	BBSAG Bull.73
2445911.518	-9816	0.000132	BAVM 39

HJD Min	Epoch	O-C	Source
2445935.404	-9751.5	0.000623	Samec 1997
2445945.399	-9724.5	-0.0024	BAVM 39
2445962.622	-9678	0.001207	Samec 1997
2446263.13	-8866.5	0.001097	VSB 47
2446676.379	-7750.5	-0.01785	BBSAG Bull.81
2446679.347	-7742.5	-0.01234	BAVM 46
2446696.39	-7696.5	-0.00369	BBSAG Bull.82
2446702.311	-7680.5	-0.00767	BBSAG Bull.82
2446977.454	-6937.5	-0.00603	Samec 1997
2446982.457	-6924	-0.00304	BAVM 50
2447407.397	-5776.5	0.004697	BBSAG Bull.89
2447412.397	-5763	0.005488	BBSAG Bull.89
2447432.386	-5709	-0.00235	BBSAG Bull.90
2448163.382	-3735	-0.0018	BBSAG Bull.96
2448448.522	-2965	-0.00217	Samec 1997
2448476.49	-2889.5	0.007588	BAVM 60
2448490.365	-2852	-0.0041	BBSAG Bull.99
2448500.366	-2825	-0.00162	BAVM 60
2448500.366	-2825	-0.00152	Samec 1997
2448500.366	-2825	-0.00142	BAVM 60
2448843.46	-1898.5	-0.00139	BBSAG Bull.102
2449546.498	0	-0.0008	IBVS 4222
2449546.498	0	-0.0004	Samec 1997
2449546.498	0	0	IBVS 4222
2449568.531	59.5	-0.00055	IBVS 4222
2449568.531	59.5	-0.00045	IBVS 4222
2449568.531	59.5	-0.00045	Samec 1997
2449571.495	67.5	0.000655	BBSAG Bull.108
2449917.92	1003	-0.00102	Samec 1997
2449918.845	1005.5	-0.00139	Samec 1997
2449919.956	1008.5	-0.00143	Samec 1997
2449920.696	1010.5	-0.00195	Samec 1997
2449920.883	1011	-0.00091	Samec 1997
2449921.439	1012.5	-0.00048	IBVS 4383
2449921.808	1013.5	-0.00119	Samec 1997
2449922.918	1016.5	-0.00192	Samec 1997
2449959.382	1115	-0.01393	BBSAG Bull.113
2449962.361	1123	0.002571	BBSAG Bull.113
2450303.416	2044	-7.8E-05	IBVS 4472
2450312.488	2068.5	-0.00022	BBSAG Bull.114
2450315.451	2076.5	0.000389	IBVS 4472
2450315.452	2076.5	0.000989	IBVS 4472
2451016.453	3969.5	0.002489	IBVS 4711
2451378.435	4947	0.004724	BAVM 132
2451378.436	4947	0.005024	IBVS 5106
2451378.436	4947	0.005224	BAVM 132
2451388.435	4974	0.005706	IBVS 5106
2451747.453	5943.5	0.006236	IBVS 5296
2452448.457	7836.5	0.010136	IBVS 5594
2452469.377	7893	0.00802	IBVS 6158

HJD Min	Epoch	O-C	Source
2452469.563	7893.5	0.008565	IBVS 6158
2452470.488	7896	0.008085	IBVS 6158
2452489.376	7947	0.009764	IBVS 5594
2452489.376	7947	0.009784	IBVS 5594
2452498.078	7970.5	0.009558	VSB 40
2452498.449	7971.5	0.009946	IBVS 5364
2452504.378	7987.5	0.014357	IBVS 5438
2452511.41	8006.5	0.010733	IBVS 5364
2452847.469	8914	0.011693	IBVS 5676
2453194.083	9850	0.013367	VSB 43
2453222.412	9926.5	0.013916	IBVS 5741
2453547.174	10803.5	0.012785	VSB 44
2453584.022	10903	0.014363	VSB 44
2453601.057	10949	0.014921	VSB 44
2453910.452	11784.5	0.014829	IBVS 5802
2453910.452	11784.5	0.014829	IBVS 5802
2453933.414	11846.5	0.016698	IBVS 5761
2453971.001	11948	0.017953	VSB 45
2453973.037	11953.5	0.016538	VSB 45
2454297.431	12829.5	0.017918	IBVS 5801
2454299.467	12835	0.017104	IBVS 5801
2454307.432	12856.5	0.0201	IBVS 6089
2454317.062	12882.5	0.021894	VSB 46
2454326.504	12908	0.021644	BAVM 193
2454327.427	12910.5	0.018664	BAVM 193
2454607.201	13666	0.021915	VSB 48
2454706.445	13934	0.021957	BAVM 203
2454707.37	13936.5	0.021378	BAVM 203
2455028.06	14802.5	0.021277	VSB 50
2455041.392	14838.5	0.022752	IBVS 5918
2455056.389	14879	0.022025	IBVS 6088
2455385.414	15767.5	0.024809	IBVS 5984
2455418.371	15856.5	0.02426	IBVS 5984
2455418.557	15857	0.024405	IBVS 5984
2455795.535	16875	0.025213	BAVM 225
2456154.37	17844	0.028558	IBVS 6090
2456489.503	18749	0.028637	IBVS 6084
2456525.421	18846	0.027294	IBVS 6084
2456560.418	18940.5	0.029031	IBVS 6086
2456834.45	19680.5	0.030214	IBVS 6149
2456841.486	19699.5	0.03089	IBVS 6152
2456842.412	19702	0.03061	IBVS 6152
2456854.446	19734.5	0.030078	IBVS 6152
2456857.41	19742.5	0.030883	IBVS 6152
2456891.478	19834.5	0.03058	IBVS 6087
2456924.435	19923.5	0.030051	IBVS 6152
2456928.324	19934	0.030277	IBVS 6152
2456929.435	19937	0.030642	IBVS 6152
2459398.121	26603.5	0.032861	This work
2459398.312	26604	0.038805	This work

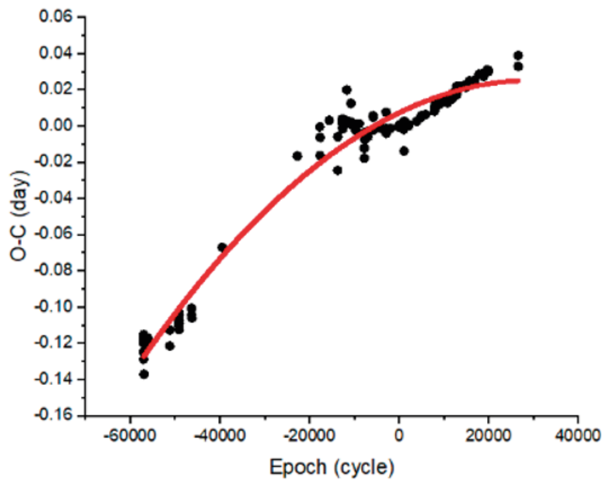

Figure 3. (O–C) diagram of V417 Aql constructed using the linear ephemeris in equation [6]

The quadratic fitting method in Figure 3 (red line), we got the corresponding equation as follows

$$O\text{-}C = [-2.02648\times10^{-11}(\pm1.39131\times10^{-12})]\ E^2 + [1.20521\times10^{-16}(\pm5.9625\times10^{-8})]\ E + 0.00723(\pm0.00087) \qquad (8)$$

When compared with the O-C and E relation (Eq.4), we got the value of dP/dE, which is equal to 2a as:

$$\frac{dP}{dE} = 2\times(-2.02648\times10^{-11}) = -\ 0.00251 \text{ days/cycle}$$

The period of V417 Aql is decreasing with the rate -4.05296×10^{-11} days/cycle or -0.00251 second/year. The reduction of the period is according to the other studies [7-8]. The decrease in the period showed that the distance between the stars was decreased according to Angular Momentum Loss (AML) theory. Angular momentum loss through magnetic braking and mass transfer leads to a period decrease.

The residuals of V417 Aql are displayed in Figure 4. As shown in the figure, the plot reveals a cyclic variation.

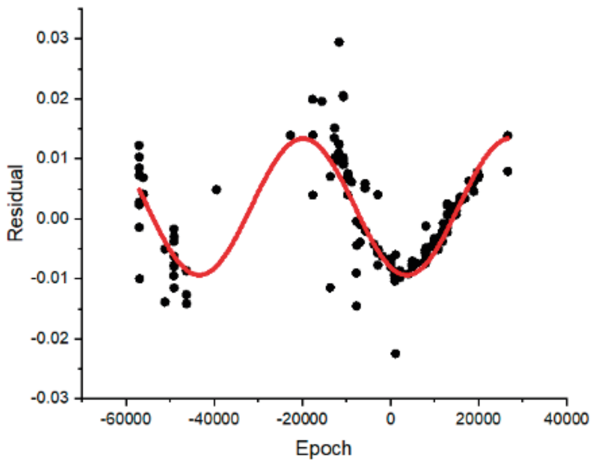

Figure 4. Residuals of V417 Aql

Residuals tend to be periodic. The probable causes of period oscillation might be from the light-time effect via the third body in the system. We can probably assume that a third body exists in the system and the period oscillation is caused by its existence. The best solution to the periodic oscillation is shown as follows:

$$\text{residual}=0.002+0.01139(\pm 0.00062)\ \sin\left(\pi \frac{\text{Epoch}-62475.65599}{2352.42087}(\pm 0.00897)\right) \quad [7]$$

According to equation [7], we can compute that the third body's distance and period are 1.966830392 AU and 47.70289105 years, respectively. A small mass function can be calculated using equation [7] along with the parameter archived from Lu et al. [6], then we got the mass function as 0.19121863MΘ. V417 Aql was observed using a 0.70-meter telescope with a CCD photometric system using the standard B and V filters at the Regional Observatory for the Public, Songkhla, Thailand, on 2 July 2021 UT. The exposure time for all filters was 60 seconds. The light cure obtained from B and V CCD photometric was analyzed. From the polynomial equation, we got the average of the first and second minimum times equal to 0.120641822 and 0.311703, respectively. The linear ephemeris derived by Qian [7-8], along with the database of eclipsing binary O-C Files by Bob Nelson, AAVSO [10] was used to calculate the O–C values of all the times of minimum light. The O-C diagram and quadratic and periodic fits are shown in Figure 5.

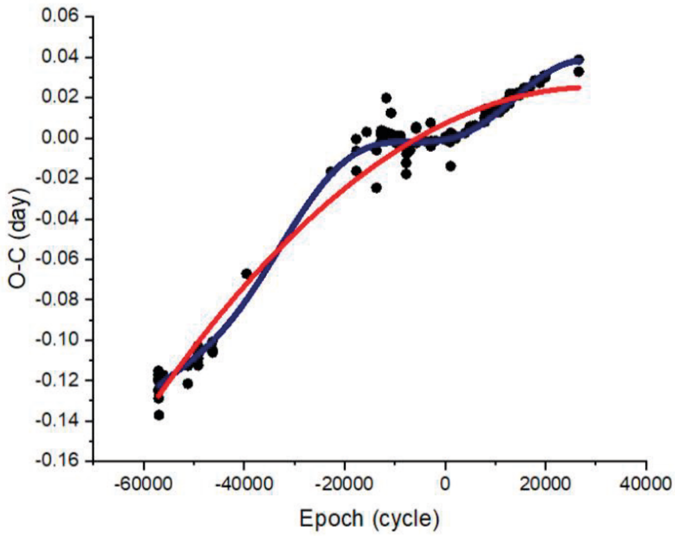

Figure 5. The O-C diagram and the solution for a binary system V417 Aql

The solution for the period change is as follows:

$$\text{O-C} = (-2.02648\times10^{-11})\ E^2 + (1.20521\times10^{-6})\ E + 0.00723 + 0.002 + 0.01139\ \sin\left(\pi \frac{\text{Epoch-}62475.65599}{2352.42087}\right) \quad [8]$$

The solution shows that the period of V417 ql is decreasing with the rate -4.05296×10^{-11} days/cycle or 0.00251 second/year. The decrease in the period showed that the distance between the stars was decreased according to Angular Momentum Loss (AML) theory. V417 Aql residuals tend to be periodic, indicating there might be a third body in the system. The sine-like term in equation [8] can fit the residuals so that we can assume the circular orbit of the third body. The calculation shows that the third body's distance, period, and mass function are about 1.97 AU, 47.7 years, and 0.19MΘ, respectively.

4. Conclusions

The comprehensive light curve analysis of V417 Aquilae (V417 Aql) has offered significant insights into the orbital variations of this short period, overcontact eclipsing binary system. Observations were meticulously conducted using a 0.70-meter telescope equipped with a CCD photometric system employing B and V filters at the Regional Observatory for the Public, Songkhla, Thailand, on 2 July 2021 UT. The detailed analysis of the constructed light curve for each filter provided an understanding of the period change of the V417 Aql system, revealing a notable long-term decrease at a rate of 0.00251 seconds/year. This consistent reduction in the period underscores the diminishing distance between the stars, a phenomenon aligning with the Angular Momentum Loss (AML) theory. Furthermore, the analysis of V417 Aql residuals indicates a potential periodic tendency, suggesting the possible presence of a third body within the system. Calculations estimate the third body's distance, period, and mass function at approximately 1.97 AU, 47.7 years, and 0.19Mʘ, respectively, reinforcing the hypothesis of its existence within the V417 Aql system. This extensive investigation augments our understanding of the V417 Aql system and contributes to the broader knowledge of orbital period variations and third-body influences in eclipsing binary systems. The findings pave the way for further research and observation, providing a foundation for exploring similar celestial systems' intricate dynamics and characteristics.

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