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Revealing the true nature of the multiple system V822 Aql

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Abstract: Given the brightness, the V822 Aql multiple star system is photometric and spectroscopically neglected. In this study high-resolution echelle spectra of the system were obtained and were used to calculate the mass ratio of the system by determining the individual lines of the components for the first time. According to this, the close binary consists of two components revolving in a circular orbit with velocity semiamplitudes of $K_1 = 45.5 \pm 0.8$ km/s and $K_2 = 204.9 \pm 0.9$ km/s ($q = 0.22 \pm 0.01$), respectively. In addition, the orbital period analysis showed a highly eccentric orbit for the close binary together with a third body moving in a 49-year orbit. The high mass function is evidence for the binary nature of the third body.

Key words: V822 Aql, stellar spectra, orbital period analysis

1. Introduction

V822 Aql (HD 183794, ADS 12538A) is a bright ($m_V \sim 7^m$) eclipsing binary system with an orbital period of ∼5.3 days. Photometric variability was discovered by [1]. The first photometry of the system was made at the Harvard University Observatory in 1963. As a result of these observations, the orbital period of the system was determined to be 2.6 days. However, with new photometric observations, [2] found that the orbital period was twice the known value and updated the new period to 5.295065 days. Photometric observations made after the last obtained light curve [3] are in the nature of survey observations (e.g., [4–6]). More recently, the ASAS V band [7] and Hipparcos [8] light curves of the V822 Aql system have been obtained. We do not have any knowledge beyond statistical information about the absolute dimensions of the components since the system does not have light curve analysis in the literature.

Lucy and Sweeney in [9] pointed to an eccentric ($e \sim 0.09$) orbit, giving the velocity semiamplitude of the secondary component as $K_2 = 135.9$ km/s and the center of mass velocity of the system as $V\gamma = -1.8$ km/s. Popper in [10] measured the radial velocity values of the secondary component as 126 km/s ($V\gamma = -4.8$ km/s) from H lines and as 196 km/s ($V\gamma = -0.2$ km/s) from the Mg II (4481 Å) line. Popper [10] also reported that the radial velocity curves obtained from the hydrogen lines are consistent with the values of [11]. Due to the weak spectral lines of the hot component rotating at high speed, it is very difficult to determine the radial velocity change of this component and thus its parameters. However, the V822 Aql system was analyzed by 30 spectra taken between 1968 and 1979 [12]. In [12] spectral types of the components were suggested as B 2.5 and B 9.5, giving a semiamplitude of the secondary component of 113 km/s and a velocity of the mass center of the system of 2.7 km/s.

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The V822 Aql is in a multiple system with two remote components (ADS 12538 C, ρ= 1 as, θ= 67°; ADS 12538 B, ρ= 26 as, θ= 298°, [4]), and compared with the values (V $\sim 9^m.96$, ρ= 1.281 as, θ= 63°) given by the Hipparcos ([8]), the position of component C does not change much over the course of about 20 years.

2. Spectroscopic data

Spectral observations of the V822 Aql system were performed with a high-resolution (R $\sim$ 41000) HERCULES echelle spectrograph attached to a 1-m diameter McLennan telescope at the Mt John Observatory. The spectrograph consists of 80 echelle orders covering the continuous wavelength range from 380 nm to 880 nm. More information about the spectrograph can be found in [13,14].

A total of 28 spectra were acquired in 17 nights of the V822 Aql system. The average S/N ratio of the spectra at 4500 Å wavelength is approximately 75. For reliable radial velocity measurement, the Thorium-Argon lamp was taken before and after the stellar spectrum. Wavelength calibration was performed by taking the correlation of these two calibration spectra according to the flux-weighted JD time of the star spectra. The white light images required for flat correction were also taken every night. The reductions of the echelle spectra were made with the Hercules Reduction Software Package (HRSP) program. The reduction steps included standard steps for echelle spectra [14]. During the normalization of the spectra, second- and third-order polynomials were fitted in the selected regions on continuity.

3. Improved ephemeris and O - C diagram

The V822 Aql system was observed at the Çanakkale Onsekiz Mart University (ÇOMU) Ulupınar Observatory and two new minimum times for the system were obtained. These observations were made using an SSP5 single-channel photometer attached to a 30-cm diameter Cassegrain-Schmidt type telescope. The minima times of the system in the literature and those obtained in this study are given in Table 1. A total of 72 minima times for the V822 Aql system covers a period of 71 years between 1945 and 2016. The O - C residuals in Table 1 were calculated with the light elements listed in Table 2. As listed in Table 1, the complete data set consists of visual (vis), photographic (pg), photoelectric (pe), and ccd times of minima. The visual and photographic observations are relatively less accurate; therefore, the weighting scheme was chosen as follows: vis = 1, pg = 5, pe and ccd = 10.

In Figure 1, it appears that O - C residuals exhibit a sinusoidal change. Such variations in the O - C curve should result from the existence of the third body or the magnetic activity of the components. However, due to the fact that the components of the V822 system are of the early-spectral type, the magnetic activity effect is not expected. In addition, the system forms a multiple system with two remote components [4,8]. For this reason, the changes in the O - C curve are modeled as light-time effect (LTE). Irwin in [15] derived the following equation to represent the O - C variations in the case of an existence of a distant companion:

$$\Delta t = \frac{a'_{1,2}\sin(i')}{c}\left\{\frac{1-e'^2}{1+e\cos(\nu'^2)\sin(\nu'+\omega')}+e\cos(\omega')\right\},$$

where a', i', e', and ω' are the semimajor axis, orbital inclination, eccentricity, and the argument of periastron of the long orbit (AB), respectively. The orbital parameters of the third component are summarized in Table 2. Also, the best-fitting LTE model is shown in Figure 1.

Table 1. Times of minima of V822 Aql.

Times of minima	O - C	Type	Method	Ref.	Times of minima	O-C	Type	Method	Ref.
29779.3000	0.0268	pri	pg	29	42998.4950	0.1644	sec	v	29
29792.4000	–0.1108	sec	pg	29	43329.4690	0.1987	pri	v	29
29869.2000	–0.0888	pri	pg	29	43726.3540	–0.0440	pri	v	29
30912.3000	–0.1109	pri	pg	29	44179.2470	0.1234	sec	v	29
30928.2000	–0.0960	pri	pg	29	44626.5260	–0.0282	pri	v	29
30933.3000	–0.2911	pri	pg	29	45537.2180	–0.0824	pri	v	29
35540.1850	–0.0874	pri	v	29	45539.9850	0.0371	sec	v	29
35542.7660	–0.1539	sec	v	29	45907.8460	–0.1069	pri	v	29
35857.9140	–0.0606	pri	v	29	46516.8520	–0.0300	pri	v	29
36101.4680	–0.0782	pri	v	29	47009.2860	–0.0344	pri	v	29
37345.8870	0.0073	pri	v	29	47234.4520	0.0926	sec	v	29
37348.5070	–0.0202	sec	v	29	47369.3090	–0.0738	pri	v	29
38230.1790	0.0283	pri	pe	2	47745.3250	–0.0054	pri	v	31
38256.5600	–0.0659	pri	v	29	47761.2320	0.0165	pri	v	31
38621.8780	–0.1053	pri	v	29	47774.5690	0.1159	sec	v	31
38624.5640	-0.0669	sec	v	29	47851.1850	-0.0461	pri	v	31
39379.1320	-0.0415	pri	v	29	47935.9210	0.1644	pri	v	29
39381.7360	-0.0850	sec	v	29	48314.5700	0.1987	sec	ccd	8
41902.4220	0.1639	sec	v	30	48409.8530	-0.0440	sec	ccd	8
42577.3330	-0.0422	pri	pe	3	48502.5060	0.1234	pri	v	29
42961.5070	0.2417	sec	v	29	48502.5400	-0.0282	pri	pe	8
48674.6880	0.0788	sec	v	29	51745.8850	0.1549	sec	v	29
48687.8350	–0.0118	pri	ccd	8	51997.3370	0.0927	pri	v	29
48814.9410	0.0134	pri	v	29	52076.7150	0.0452	pri	v	29
48862.4890	–0.0940	pri	pe	29	52134.9770	0.0618	pri	ccd	7
49045.2840	0.0223	sec	ccd	8	52383.8052	0.0233	pri	ccd	7
49053.1980	–0.0063	pri	ccd	8	52876.0670	–0.1533	pri	ccd	29
49196.1400	–0.0302	pri	v	29	53601.6020	–0.0382	pri	ccd	29
49394.7460	0.0119	sec	v	29	54639.4801	0.0129	pri	ccd	32
49550.9380	0.0004	pri	v	29	54647.4260	0.0162	sec	ccd	32
49911.0080	0.0079	pri	v	29	56863.4472	0.0648	pri	ccd	31
49913.6700	0.0224	sec	v	29					
50286.9660	0.0183	pri	v	29					
50289.6890	0.0938	sec	v	29					
50631.1590	0.0340	pri	v	29					
50633.6150	–0.1575	sec	v	29					
50991.2630	0.0756	pri	v	29					
50993.8880	0.0530	sec	v	29					
51377.7190	–0.0061	pri	v	29					
51380.4210	0.0484	sec	v	29					
51743.1040	0.0214	pri	v	29					

29: Kreiner (2004), 2: Hall (1967), 30: Isles (1975), 3: Alduseva and Kovalenko (1977), 31: O-C Gateway, 8: ESA (2001), 7: Pojmanski (2002), 32: this paper.

Table 2. Parameters of the wide orbit from the O - C analysis. Probable errors in the last digits are given in parentheses.

T_0 (day)	2452500.2727 (0.0141)
P_{orb} (day)	5.295036 (0.000021)
Q (day)	-6×10^{-9} (5×10^{-10})
T' (HJD)	2452820 (178)
P_{12} (year)	49 (4)
$a'_{12} \sin i'$ (AU)	21.0 (4.7)
e'	0.61 (0.06)
ω' (rad)	5.27 (0.07)
$f(M_3)$ ($M_\odot$)	3.8 (3.3)

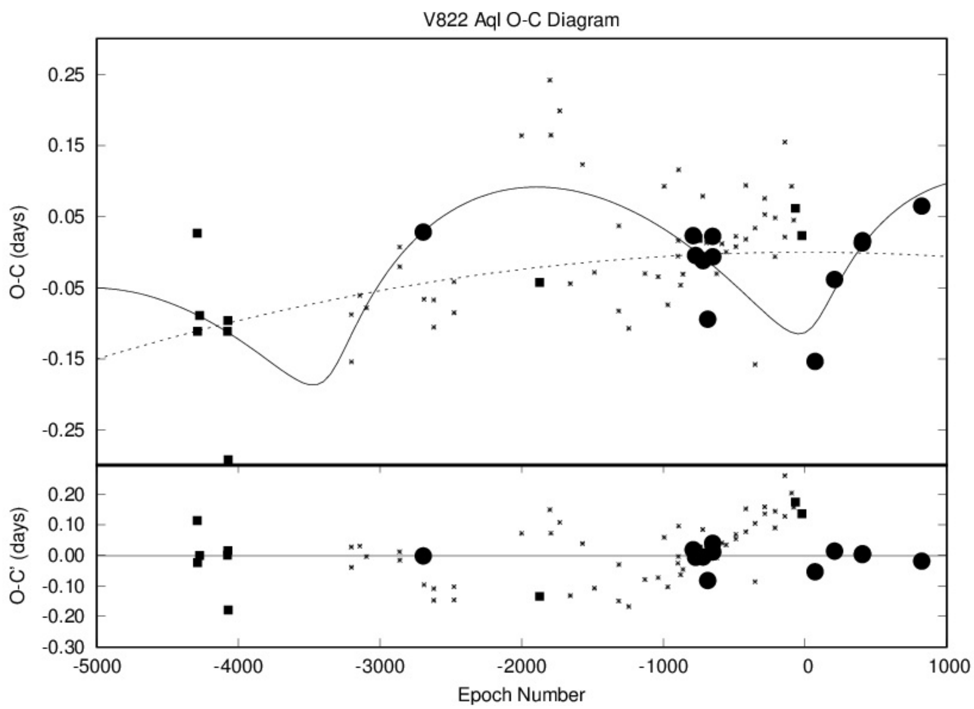

Figure 1. The O - C diagram of V822 Aql and the best-fitting LTE orbit (solid line). The O - C residuals from the best theoretical curve (bottom).

In addition, the best theoretical fit to the times of minima yields a negative quadratic term (-6×10^{-9}). From this term, it can be seen that the orbital period of the V822 Aql system decreases at a rate of about 0.07 s/year. Such a period decrease can be explained either by a mass transfer to the less massive component from the massive component or a mass loss from the system.

4. Radial velocities and spectroscopic orbit

When looking at the spectrum of the V822 Aql system, it is immediately noticeable that the spectral lines are broadened due to the fast rotation of the components. It is very difficult to measure accurate radial velocities except by some special techniques. Because of the broadened spectral lines of the components, they are blended.

In addition, the spectral lines become shallow because the contribution of the second component to the total light of the system is low. For this reason, the measurements of the radial velocities of the system were performed using two different methods: Gaussian fitting to individual spectral lines and spectral disentangling methods.

Taking the reference wavelengths from the NIST database (http://www.physics.nist.gov), the Doppler shifts of the He I (4471 Å) and Mg II (4481 Å) lines were determined from Gaussian fitting to the line centers. Obtained radial velocity values were first analyzed by the downhill simplex method [16] under the assumption of circular orbits. As a second method, the spectra of the V822 Aql system were also analyzed using the new version of the KOREL program [17,18]. This code directly gives the radial velocities and orbital parameters of the components with the Fourier disentangling method. The orbital parameters obtained with the Gaussian line-fitting technique were considered as initial inputs for the KOREL program. In the solutions, the orbital period, P, is kept constant. The semiamplitudes of the radial velocity curve of the components, ephemeris time, T_0, the eccentricity and longitude of periastron, and the mass ratio are used as free parameters. The radial velocity measurement and orbital parameters of the shallow and/or blended spectral lines can be determined by this method reliably and the disentangled spectra of the components are also obtained using the Fourier method. The disentangled spectra of the V822 Aql system obtained for the spectral region of the He I (4471 Å) and Mg II (4481 Å) lines are shown in Figure 2. The radial velocities of the V822 Aql system are given in Table 3. In additional, the obtained spectral orbital parameters are summarized in Table 4. The velocity of the mass center of the system given in this table was determined by Gaussian fitting to the disentangled spectra of the components. The radial velocities of components and the best-fitting spectroscopic orbit are shown in Figure 3.

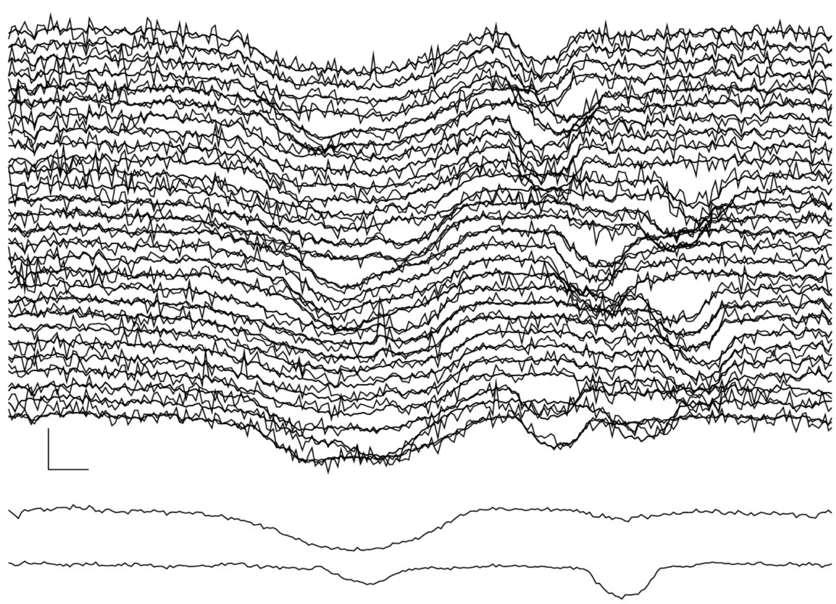

Figure 2. The spectra of the V822 Aql system in which the He I (4471 Å) and Mg II (4481 Å) lines are plotted and disentangled spectra of the primary and secondary components are given respectively at the bottom.

5. Results and discussion

In this study, new spectroscopic observations of the eclipsing multiple system V822 Aql have been analyzed. Spectral lines of the primary component were determined for the first time and the spectral parameters of this component were determined.

Table 3. Radial velocities of primary and secondary components.

No.	HJD	Phase	RV_1	$(O - C)_1$	RV_2	$(O - C)_2$
	(2 400 000+)		km/s	km/s	km/s	km/s
1	53970.8199	0.714	25.0	0.2	–217.1	0.1
2	53970.9098	0.731	25.8	0.1	–220.8	0.1
3	53971.0173	0.751	26.1	0.1	–222.3	0.1
4	53971.0544	0.758	26.1	0.1	–222.0	0.1
5	53980.8678	0.612	21.0	10.2	–149.7	0.1
6	53980.9650	0.630	20.9	6.4	–165.4	1.4
7	53981.8102	0.790	24.8	0.1	–215.9	0.1
8	53981.8506	0.798	24.2	0.1	–213.3	0.1
9	53981.9237	0.811	23.0	0.1	–207.3	0.1
10	53982.0035	0.826	21.3	0.1	–199.2	0.1
11	53983.8247	0.170	–55.2	0.1	162.7	0.1
12	53983.9035	0.185	–57.0	0.1	171.1	0.1
13	53984.9508	0.383	–59.7	-13.4	118.3	-2.0
14	53985.0077	0.394	–54.0	-9.9	113.4	3.6
15	53985.8429	0.552	3.3	6.7	–83.7	-1.3
16	53985.9207	0.566	0.3	0.1	–100.1	0.1
17	53985.9944	0.580	3.7	0.1	–116.1	0.1
18	53987.9287	0.945	–0.4	2.2	–82.4	3.8
19	53988.8278	0.115	–45.9	0.1	118.6	0.1
20	53988.9071	0.130	–54.2	-5.3	135.1	2.7
21	53988.9943	0.147	–54.6	-2.9	142.6	-3.6
22	53989.8745	0.313	–57.2	0.1	172.1	0.1
23	53989.9448	0.326	–55.7	0.1	164.8	0.1
24	53989.9715	0.331	–55.0	0.1	161.7	0.1
25	53990.0073	0.338	–54.1	0.1	157.3	0.1
26	53991.8241	0.681	22.1	0.1	–203.4	0.1
27	53995.9444	0.459	–28.2	0.1	34.6	0.1
28	53996.9712	0.653	22.1	3.7	–182.8	2.7

In additional, orbital period behavior of V822 Aql was studied based on the best quality available times of minima. The character of the O - C shows a sinusoidal variation. High mass function for the third body indicates its binary nature (see [19,20]). The spectral data must be analyzed with the light contributions of the components in order to find signatures of the third component.

The reverse parabolic contribution, which is indicative of a mass loss from the system or mass transfer from the massive component to the lesser one was also determined from the O - C analysis. However, the mass ratio of the system is a small value ($q = 0.22$), indicating that the mass ratio of the system is reversed. Thus, the V822 Aql system is a classic Algol system. In such systems, the less massive component fills the Roche lobe and transfers the mass to the massive component. In this case, the expected situation from the O - C

Table 4. Orbital parameters and their errors of V822 Aql.

Parameter	Value
P (day)	5.295036
T_0 (day)	2453967.0268 (0.0002)
K_1 (km/s)	45.5 (0.8)
K_2 (km/s)	204.9 (0.9)
e	0.00 (0.01)
V_γ (km/s)	–17.3 (0.5)
q	0.22 (0.01)
Asini ($R_\odot$)	26.19 (0.26)
$M_1\sin^3 i$ ($M_\odot$)	7.05 (0.15)
$M_2\sin^3 i$ ($M_\odot$)	1.57 (0.04)

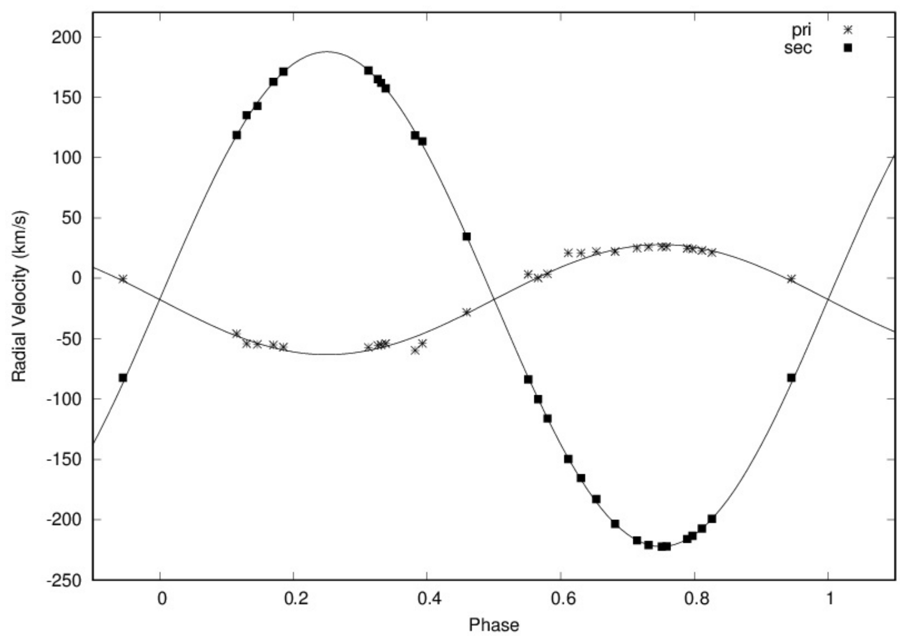

Figure 3. The radial velocities of primary and secondary component and the best spectroscopic orbital model.

analysis is not a decrease in the period but an increase. In the literature, there are such systems in which such contradictions are discussed. SX Cas is a W Ser type binary system. In this system, the mass gaining component must be a hot primary component. Hence, period increases are expected for this system, but the period was determined to be decreasing from the O - C analysis [21]. This has been explained by the fact that the loss of mass from the system with the Alfven wave-driven stellar wind is more dominant than the mass transfer to the massive component [22]. In fact, the secondary less massive component in the SX Cas system is a late type star, while components of V822 Aql are early type stars. For this reason, this mechanism cannot apply to V822 Aql. Another scenario is that V822 Aql and its third component could be a member of a hierarchical multiple system and the O - C curve of V822 Aql is part of a longer period cyclic variation. Therefore, through the orbital cycle one can see cyclic period increase and decrease.

When the gas flow from the secondary component hits the disc, not directly the primary star, a disc hotspot occurs and an increase of the energy released at the hotspot produces a stronger hotspot wind [23], which may also cause period change in the system. Such an enhanced wind effect has been identified in systems such as DQ Vel (T_2 = 9350 K), V393 Sco (T_2 = 7950 K), and Beta Lyr (T_2 = 13200 K) (see [24–27]). Therefore, our future plan is to study the indicators of such mass transfer and mass loss in V822 Aql in detail through a simultaneous analysis of photometric and spectroscopic data as done in [28].

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