Two bodies with high-eccentricity around the cataclysmic variable QS Vir

L. A. Almeida & F. Jablonski
Instituto Nacional de Pesquisas Espaciais, Brasil
`email: leonardo@das.inpe.br`

Abstract

QS Vir is an eclipsing cataclysmic variable with 3.618 hrs orbital period. This system has the interesting characteristics that it does not show mass transfer between the components through the L1 Lagrangian point and shows a complex orbital period variation history. Qian et al. (2010) associated the orbital period variations to the presence of a giant planet in the system plus angular momentum loss via magnetic braking. Parsons et al. (2010) obtained new eclipse timings and observed that the orbital period variations associated to a hypothetical giant planet disagree with their measurements and concluded that the decrease in orbital period is part of a cyclic variation with period ~ 16 yrs. In this work, we present 28 new eclipse timings of QS Vir and suggest that the orbital period variations can be explained by a model with two circumbinary bodies. The best fitting gives the lower limit to the masses $\mathbf{M_1}\sin(i) \sim 0.009$ $\mathbf{M_\odot}$ and $\mathbf{M_2}\sin(i) \sim 0.049$ $\mathbf{M_\odot}$; orbital periods $\mathbf{P_1} \sim 7.6$ yrs and $\mathbf{P_2} \sim 17.2$ yrs, and eccentricities $\mathbf{e_1} \sim 0.62$ and $\mathbf{e_2} \sim 0.9$ for the two external bodies. Under the assumption of coplanarity among the two external bodies and the inner binary, we obtain $\mathbf{M_1} \sim 0.0093$ $\mathbf{M_\odot}$ and $\mathbf{M_2} \sim 0.05$ $\mathbf{M_\odot}$.

1. Introduction

QS Vir is an eclipsing binary consisting of a white dwarf plus a red dwarf that has spectral type M3.5-M4 (O'Donoghue et al. 2003). It was discovered in the Edinburgh-Cape faint blue object survey (Kilkenny et al. 1997). O'Donoghue et al. (2003) using the information about the white dwarf spin suggested that QS Vir is a hibernating cataclysmic variable. With orbital period close to the period-gap of the catalysmic variables (CVs), 3.618 hrs, and a secondary close to the transition between stars with a radiative core and completely convective stars, this CV is an interesting target for more detailed studies.

Here, we present 28 new eclipse timings of QS Vir from May to August, 2010. We gathered these to all measurements in the literature and re-analysed the orbital period variation of this system. We suggest that a plausible explanation for the orbital period variations is the presence of two bodies with high-eccentricity around the binary.

2. Observations and data reduction

The data were collected along an observational program on orbital period variations of compact binaries that is being carried out with the facilities of Laboratório Nacional de Astrofísica (LNA/MCT). Table 1 summarizes the characteristics of the data collected for QS Vir.

Table 1: Log of the photometric observations and new eclipse timings for QS Vir

Date	N	t_{exp}(s)	Telescope	Filter	Cycle	Eclipse Timing (MJD(BTJD))
May 15, 2010	8500	2	1.6-m	V	44063	55331.96800 ± 0.000015
					44064	55332.11872 ± 0.000015
May 20, 2010	3000	2	1.6-m	V	44096	55336.94300 ± 0.000015
May 21, 2010	8300	2	1.6-m	Unfiltered	44103	55337.99835 ± 0.000015
					44104	55338.14909 ± 0.000015
Jun 01, 2010	2800	5	0.6-m	Unfiltered	44177	55349.15437 ± 0.000029
Jun 03, 2010	4000	4	0.6-m	Unfiltered	44189	55350.96347 ± 0.000023
Jun 12, 2010	800	6	0.6-m	Unfiltered		
Jun 16, 2010	4500	4	0.6-m	Unfiltered	44275	55363.92863 ± 0.000023
					44276	55364.07937 ± 0.000023
Jun 17, 2010	4900	4	0.6-m	Unfiltered	44282	55364.98394 ± 0.000023
					44283	55365.13470 ± 0.000023
Jun 18, 2010	4000	5	0.6-m	Unfiltered	44289	55366.03922 ± 0.000029
Jun 19, 2010	2800	4	0.6-m	Unfiltered	44295	55366.94377 ± 0.000023
					44296	55367.09452 ± 0.000023
Jun 20, 2010	2500	6	0.6-m	Unfiltered	44302	55367.99909 ± 0.000035
Jun 21, 2010	2000	5	0.6-m	Unfiltered	44309	55369.05439 ± 0.000039
Jul 06, 2010	3000	4	0.6-m	Unfiltered	44408	55383.97940 ± 0.000023
Jul 07, 2010	3350	4	0.6-m	Unfiltered	44415	55385.03469 ± 0.000023
Jul 08, 2010	4000	4	0.6-m	Unfiltered	44421	55385.93924 ± 0.000023
					44422	55386.08998 ± 0.000023
Jul 10, 2010	3000	4	0.6-m	Unfiltered	44434	55387.89908 ± 0.000023
					44435	55388.04983 ± 0.000023
Jul 11, 2010	3500	4	0.6-m	Unfiltered	44441	55388.95439 ± 0.000023
Jul 21, 2010	1000	8	0.3-m	Unfiltered	44508	55399.05516 ± 0.000046
Jul 30, 2010	2000	4	0.6-m	Unfiltered	44567	55407.94984 ± 0.000023
Jul 31, 2010	2250	4	0.6-m	Unfiltered	44574	55409.00516 ± 0.000023
Aug 02, 2010	2000	4	0.6-m	Unfiltered		
Aug 18, 2010	1500	4	0.6-m	Unfiltered	44693	55426.94531 ± 0.000023
Aug 20, 2010	1500	4	0.6-m	Unfiltered	44706	55428.90514 ± 0.000023

The reduction of the photometric data was done with the usual `IRAF cl` tasks and consists of subtracting a master median bias image from each program image, and dividing the result by a normalized flat-field. Figure 1 shows some light curves obtained in our program.

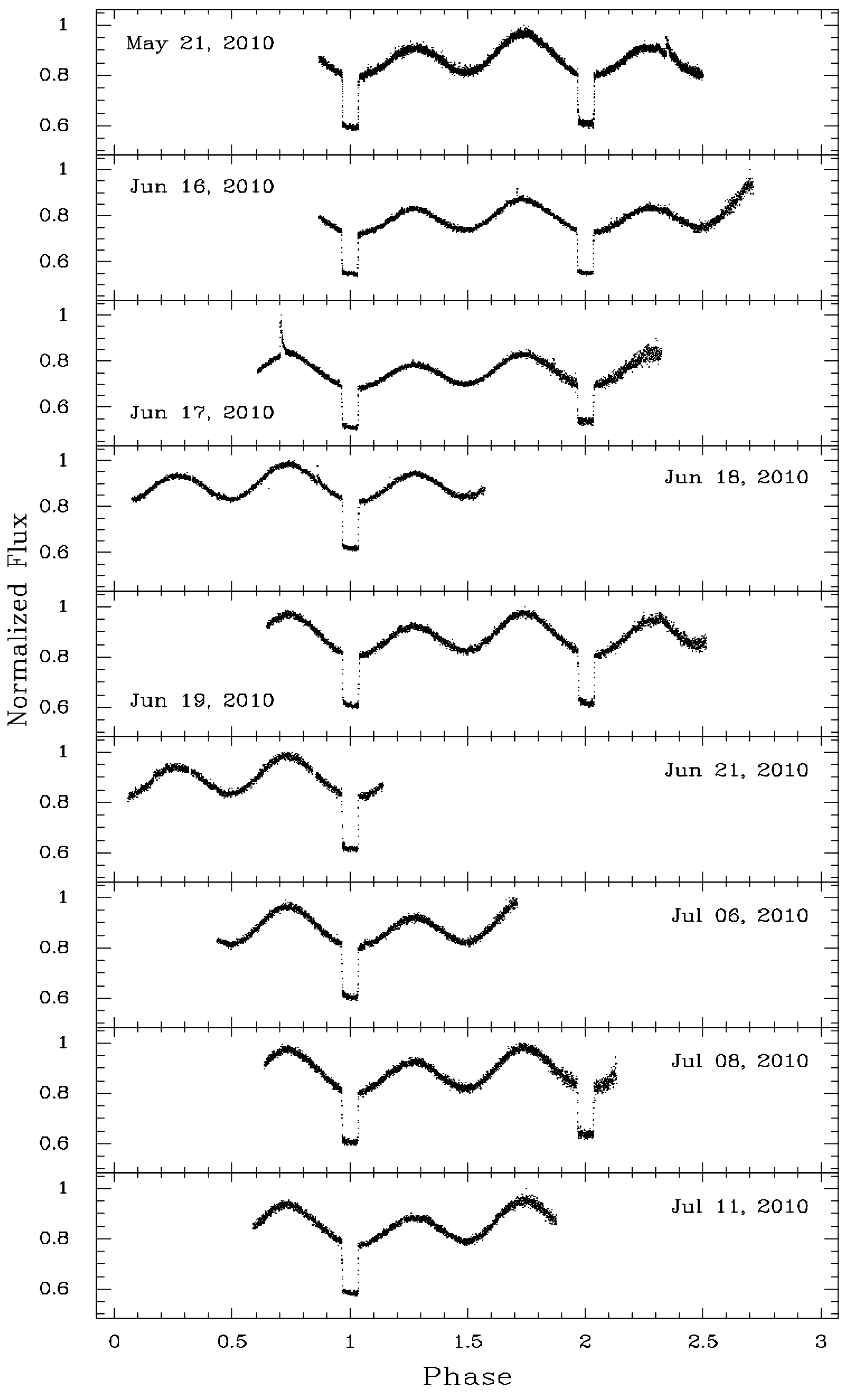

Figure 1: Unfiltered light curves of QS Vir obtained with the 1.6-m and 0.6-m telescopes at Picos dos Dias Observatory, Brazil.

3. Analysis and Results

3.1 Eclipse timings

We use the Wilson-Devinney code (Wilson & Devinney 1971) to fit the light curves of QS Vir to obtain the mid-eclipse timings. The geometrical and physical parameters, e.g., inclination, radii, temperatures and masses obtained by O'Donoghue et al. (2003) for QS Vir were adopted as initial values for the fitting procedure. In Figure 2, we show a result of this procedure for the light curve obtained on May 21, 2010. We estimated that the error of the mid-eclipse timings is of the order of seconds. Table 1 shows the mid-eclipse timings obtained by us.

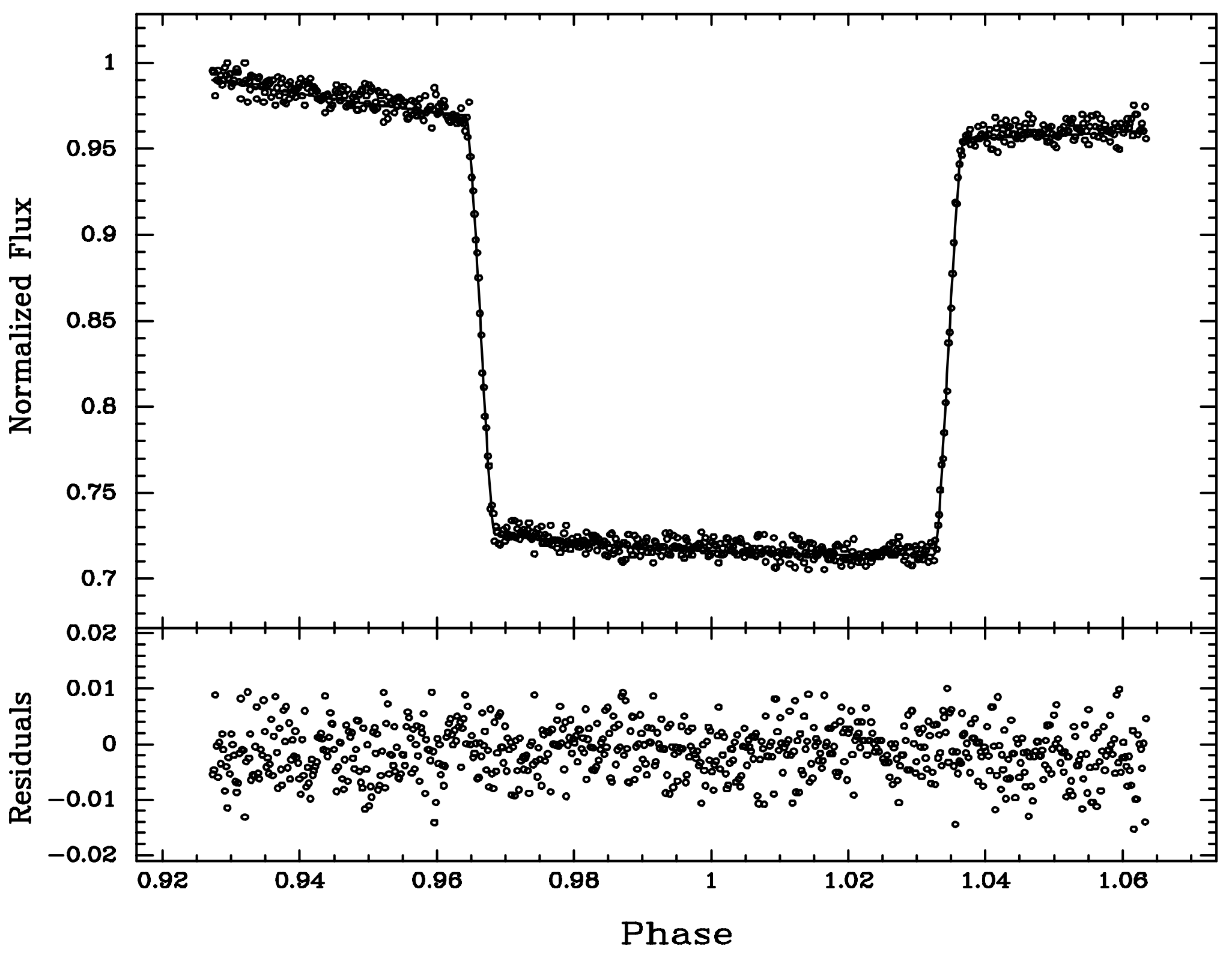

Figure 2: Upper panel: light curve and model fit to the primary eclipse of QS Vir observed on 21 May, 2010. A linear slope was added to account for the varying brightness of the secondary star. Lower panel: The residuals obtained from the fitting procedure.

3.2 Orbital period variation

Initially we examined if the period of QS Vir could be represented by a linear ephemeris. The resulting O−C diagram shows a complex orbital period variation with semi-amplitude ~ 100 s. The second step was fitting the eclipse timings using a linear ephemeris plus a single light-travel time (LTT) effect. The residuals of this last fitting have a cyclic variation with semi-amplitude ~ 20 s. Finally, we fit the eclipse timings with the following equation,

$$T_{min} = T_0 + E \times P + \tau_3 + \tau_4, \tag{1}$$

where T_0, E and P are the epoch, the cycle count and the period of the binary, respectively, and τ_3 and τ_4 are the LTT effects (Irwin 1952). Each LTT includes five parameters: semi-major axis, a, inclination, i, argument of periastron, ω, Keplerian mean motion, n, and epoch of periastron passage, T. We exclude from this analysis the mutual interaction between the external bodies. For the fitting we use the PIKAIA algorithm (Charbonneau 1995) to look for a global solution, followed by a Monte Carlo Markov Chain (MCMC) procedure to sample the parameters of Equation 1 around this solution. Figure 2 shows the result of this procedure and Table 2 shows the numerical values with the associated $\pm 68\%$ uncertainties.

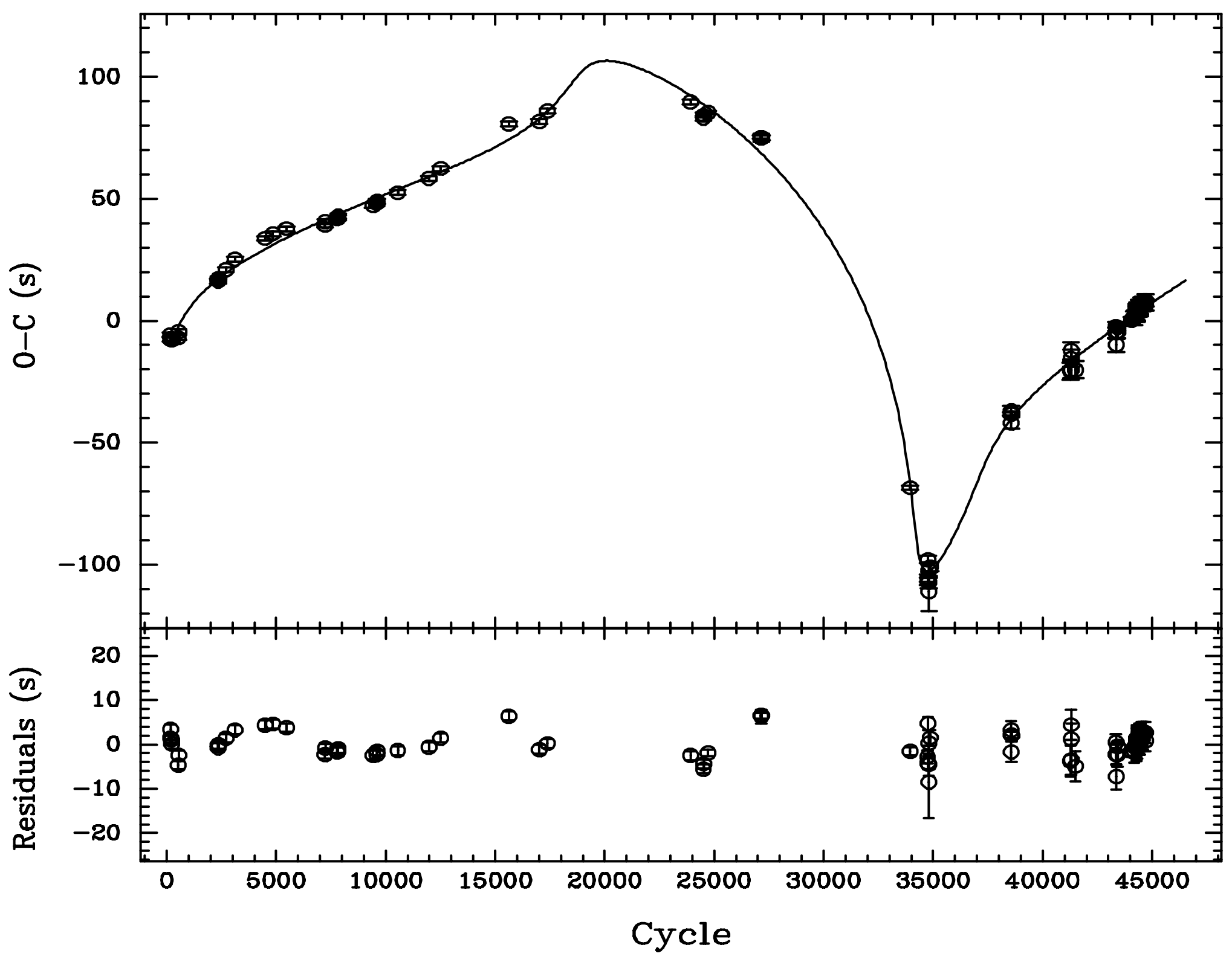

Figure 3: Upper panel: (O−C) diagram of the eclipse timings in QS Vir built with respect to the linear part of the ephemeris in Equation 1. The observed data are presented with open circles and the solid line represents the best fitting including the two LTT effects. Lower panel: The residuals around the fit.

Table 2: Parameters for the linear plus two-LTT ephemeris of QS Vir.

Linear ephemeris		
Parameter	Value	Unit
P	0.150757478 $\pm 2 \times 10^{-9}$	days
T_0	2448689.14124$\pm 3 \times 10^{-5}$	MJD(BTDB)
	τ_3 term	
Parameter	Value	Unit
P	7.6 ±0.23	years
T	54307±30	MJD(BTDB)
$a \sin i$	0.03 ±0.0015	AU
e	0.62 ±0.2	
ω	32.4 ±1.6	degrees
$f(M)$	(5.3 ±0.3)$\times 10^{-7}$	$M_\odot$
	τ_4 term	
P	17.2±0.22	years
T	53845±10	MJD(BTDB)
$a \sin i$	0.28±0.015	AU
e	0.9±0.2	
ω	213±3	degrees
$f(M)$	(7.8±0.2)$\times 10^{-5}$	$M_\odot$

4. Discussion

Cyclic variations of the orbital period of compact binary systems in time-scales from years to decades can be explained by either the LTT effect or the Applegate mechanism. The LTT effect is a periodic variation and occurs because the distance from a binary to the observer varies due to gravitational interaction among the inner binary and the external body (Irwin 1952). The Applegate mechanism was proposed by Applegate (1992) and consists of the coupling between the binary period and changes in the shape of the secondary generated by the quadrupole momentum variation and consequently causing cyclic changes in the binary orbital period. Following the same method used by Brinkworth et al. (2006), we obtained that the required energy for the Applegate mechanism is larger than the total radiant energy of the secondary in 1 yr, considering the variation with semi-amplitude $\sim 20s$. Thus, both τ_3 and τ_4 terms obtained by us could not be explained by the Applegate mechanism. Therefore, the only explanation for the observed periodic variations of the orbital period in QS Vir is the light-travel time effect by two outer bodies.

References

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