Section C:
Interactions

The Astrophysics of Planetary Systems: Formation, Structure, and Dynamical Evolution
Proceedings IAU Symposium No. 276, 2010
A. Sozzetti, M. G. Lattanzi & A. P. Boss, eds.

doi:10.1017/S1743921311020941

Two bodies with high eccentricity around the cataclysmic variable QS Vir

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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 $\sim$ 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 $M_1 \sin(i) \sim 0.0086\ M_\odot$ and $M_2 \sin(i) \sim 0.054\ M_\odot$; orbital periods $P_1 \sim 14.4$ yrs and $P_2 \sim 16.99$ yrs, and eccentricities $e_1 \sim 0.62$ and $e_2 \sim 0.92$ for the two external bodies. Under the assumption of coplanarity among the two external bodies and the inner binary, we obtain a giant planet with $\sim 0.009\ M_\odot$ and a brown dwarf with $\sim 0.056\ M_\odot$ around the eclipsing binary QS Vir.

Keywords. planetary systems, binaries: eclipsing, stars: individual (QS Vir)

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). 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. Analysis of the orbital period variation and discussion

We fit the eclipse timings with the following equation,

$$T_{min} = T_0 + E \times P + \tau_3 + \tau_4, \tag{2.1}$$

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 light-time travel effects (LTTEs) (Irwin 1952). Each LTTE 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

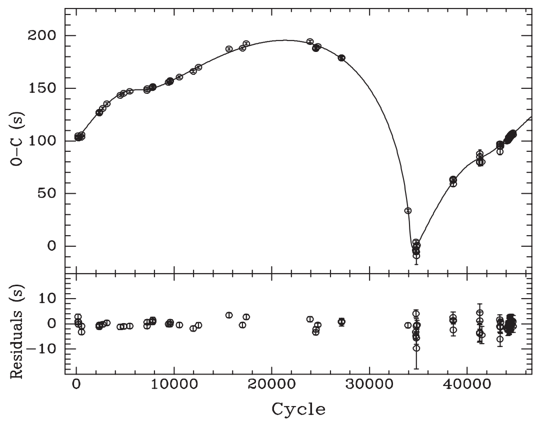

Figure 1: Upper panel: (O−C) diagram of the eclipse timings in QS Vir built with respect to the linear part of the ephemeris in Equation 1. The observed data are presented with open circles and the solid line represents the best fitting including the two LTTEs. Lower panel: The residuals around the fit.

Table 1: Parameters for the linear plus two-LTTEs ephemeris of QS Vir.

Parameter	Value	Unit
Linear ephemeris		
P	$0.150757481 \pm 1 \times 10^{-9}$	days
T_0	$2448689.13995 \pm 2 \times 10^{-5}$	MJD(BTDB)
τ_3 term		
P	14.40 ± 0.08	years
T	2454880 ± 20	MJD(BTDB)
$a \sin i$	0.0446 ± 0.001	AU
e	0.62 ± 0.02	
ω	180.0 ± 2.6	degrees
$f(M)$	$(4.3 \pm 0.3) \times 10^{-7}$	$M_\odot$
τ_4 term		
P	16.99 ± 0.07	years
T	2448689 ± 30	MJD(BTDB)
$a \sin i$	0.320 ± 0.01	AU
e	0.92 ± 0.02	
ω	219 ± 3	degrees
$f(M)$	$(1.1 \pm 0.1) \times 10^{-4}$	$M_\odot$

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 Markov chain Monte Carlo (MCMC) procedure to sample the parameters of Equation 1 around this solution. Figure 1 shows the result of this procedure and Table 1 shows the numerical values with the associated ±68% uncertainties.

Cyclic variations of the orbital period of compact binary systems in time-scales from years to decades can be explained by either the LTTE or the Applegate mechanism. The LTTE 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. 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 ∼ 20 s. 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.

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https://doi.org/10.1017/S1743921311020941 Published online by Cambridge University Press