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Searching for exoplanet candidates around the evolved binary

QS Vir: a pilot study

E. S. Pereira[1] & L. A. Almeida[1,2]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo. e-mail: `elielson.pereira@usp.br`
[2] Departamento de Física Teórica e Experimental, UFRN. e-mail: `leonardodealmeida.andrade@gmail.com`

Abstract. The present work was developed with the purpose of identifying and characterizing exoplanets around evolved compact binary systems using the eclipse time variation (ETV) method and, in addition, to develop an algorithm to study the secular dynamic of such systems. As a pilot project, we chose the QS Vir system. This binary consists of a white dwarf as primary with mass of ~0.78 $M_\odot$ and a main-sequence red-dwarf star with mass of ~0.43 $M_\odot$. The binary has a short orbital period $P_{\rm orb;bin}$ = 3.168 hours. Photometric observations were performed between 2010 and 2017 by our group using the facilities of the Pico dos Dias Observatory (OPD/LNA). Light curves of the system were obtained using standard tools in Astronomy. The essential measure for our study, the mid eclipse time, was derived using a binary light curve generation code (Wilson & Devinney, 1971) and an MCMC algorithm (Monte Carlo with Markov Chain). We use a linear ephemeris to fit the mid eclipse times and obtain the (O-C) diagram, which showed a complex variation of ~ 200 seconds of amplitude. The best solution for this variation yields two circumbinary bodies: a brown dwarf (~0.05 $M_\odot$), with an orbital period of ~19 years, and a super-Jupiter (~6 $M_{\rm Jup}$) with orbital period of ~4.8 years. The solution is close to the 4/1 mean-mean resonance which can be an evidence of secular stability. Additional observations are being done to confirm this findings.

Resumo. O presente trabalho foi desenvolvido com o intuito de identificar e caracterizar exoplanetas ao redor de sistemas binários compactos e evoluídos a partir do método variação dos instantes dos eclipses (VIE), bem como desenvolver um algoritmo para estudar a dinâmica secular associada à tais sistemas. Como um projeto piloto, nós escolhemos o sistema QS Vir. Este sistema é constituído por uma anã branca, como primária, com massa de 0.78 ± 0.04 $M_\odot$ e por uma anã vermelha da sequência principal, de tipo espectral M e massa de 0.43 ± 0.04 $M_\odot$. A binária possui uma órbita cerrada de $P_{\rm orb;bin}$ = 3.168 horas (O'Donoghue et al. 2003). Observações fotométricas do alvo foram realizadas entre 2010 a 2017 pelo nosso grupo usando as facilidades do Observatório do Pico dos Dias (OPD/LNA). Curvas de luz do sistema foram obtidas usando ferramentas padrões em Astronomia. A medida essencial para o nosso estudo, o centro do instante do eclipse da primária, foi determinada usando um código de geração de curva de luz de binária (Wilson & Devinney, 1971) e um algoritmo de minimização MCMC (Monte Carlo with Markov Chain). Usando-se uma efeméride linear para ajustar aos instantes de eclipses obtivemos o diagrama (O-C), pelo qual notou-se uma complexa variação de amplitudes de 200 s. A melhor solução para esta variação, resulta em dois corpos circumbinários: uma anã marrom (~0.05 $M_\odot$) com período orbital de ~19 anos e um super Júpiter (~6 $M_{\rm Jup}$) com período orbital de ~4.8 anos. A solução está próxima da ressonância de movimentos médios de 4/1, que pode ser uma evidência de estabilidade secular. Observações adicionais estão sendo feitas para confirmar essas descobertas.

Keywords. exoplanets — planetary systems — binaries — QS Vir — resonance

1. Introduction

The formation and evolution of planets around binary systems is one of the open questions in the field of exoplanet research. Because of the Kepler mission, it is now known that some non-evolved binaries (both main sequence stars) do host exoplanets.

For example, the Kepler 47 binary has two planets that orbit the system with semi-major axes larger than 1 AU (Orosz et al. 2012) and the binary system Kepler 16 houses a Saturn-type planet with a semi-major axes of 3.9 AU (Doyle et al. 2011). However, the questions that arise are: do exoplanets survive the most energetic phases in the evolution of the host binary? If so, what would be the dynamic evolution of these bodies?

Thus, the present work was developed aiming to identify and characterize exoplanets around evolved compact binary systems from the eclipses times variations (ETV). As a pilot project, we chose the QS Vir binary system. This system consists of a white dwarf as primary with mass of 0.78 ± 0.04 $M_\odot$ and a main-sequence red dwarf with mass of 0.43 ± 0.04 $M_\odot$. The binary has a short orbital period of 3.168 hours (O'Donoghue et al. 2003).

An artistic conception of the QS Vir system is illustrated in Fig. 1.

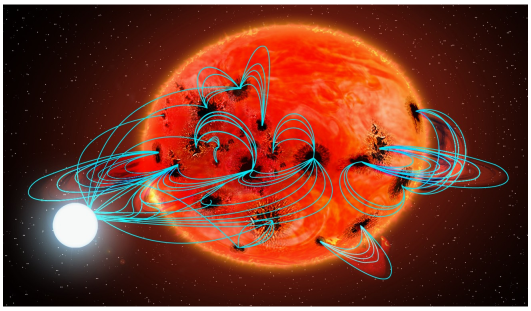

Figure 1. Artistic conception for QS Vir system. Adapted from https://www.noao.edu/outreach/press/pr07/pr0701.html.

2. Analysis, Results and Discussion

2.1. Observations and database

Photometric observations of QS Vir were performed between 2010 and 2017 using the facilities of the Pico dos Dias Observatory (OPD/LNA). Light curves (e.g., Fig. 2) of the system were obtained using standard tools for data reduction from Image Reduction and Analysis Facility (IRAF).

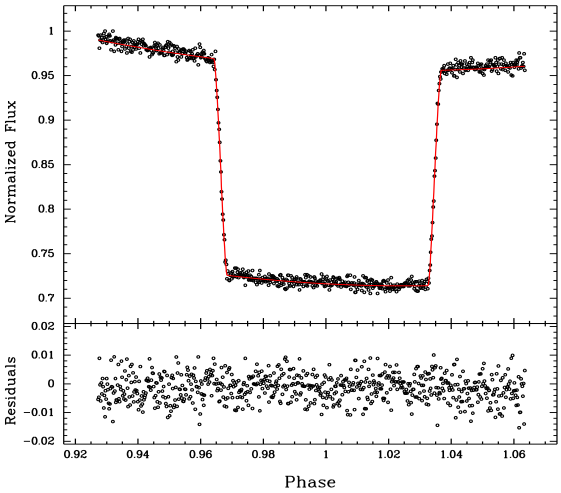

FIGURE 2. Top panel: White dwarf eclipse of QS Vir superimposed with the best solution obtained with the Wilson-Devinney code. Bottom panel: Residuals from the fitting.

The essential measurement for our study, the primary mid-eclipse time, was determined using a binary light curve generation code (Wilson & Devinney, 1971) and a Monte Carlo with Markov chain (MCMC) algorithm. One example of this procedure is shown in Fig. 2.

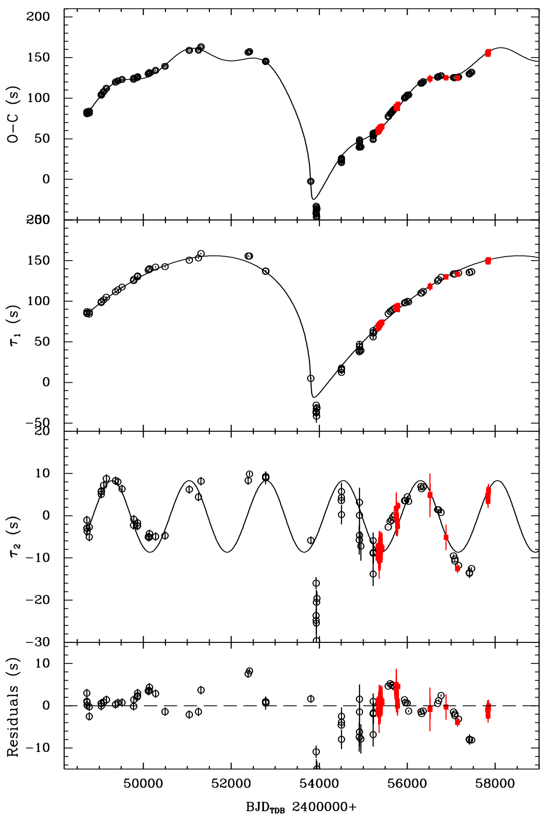

FIGURE 3. Top panel: QS Vir primary eclipse superimposed with the best solution obtained with the Wilson-Devinney code. Bottom panel: Residuals from the fitting.

2.2. Orbital period variation

Fitting a linear ephemeris to the eclipse times, we obtained the residuals, also called the (O-C) diagram. This diagram show a complex orbital period variation of ~200 seconds of amplitude. After modeling under the assumption of circumbinary bodies, we obtained as a good preliminary solution: a brown dwarf and a super Jupiter. Figure 3 and Tab. 1 show the best solution and the main parameters derived from the fit.

Table 1. Adjusted parameters from the linear ephemeris and the two time-light effect terms to the QS Vir eclipse times.

Linear ephemeris		
Parameter	Value	Unit
P	$0.150757486 \pm 1 \times 10^{-9}$	days
T_0	$2448689.63996 \pm 2 \times 10^{-5}$	MJD(BTDB)
term τ_1		
Parameter	Value	Unit
P	18.96 ± 0.38	years
T	2453831 ± 30	MJD(BTDB)
$a_{bin} \sin i$	0.36 ± 0.01	AU
e	0.95 ± 0.02	
ω	206 ± 1	°
$f(m)$	$(1.3 \pm 0.4) \times 10^{-4}$	$M_\odot$
$m \sin i$	52.7 ± 2.0	M_{Jup}
$a \sin i$	7.1 ± 0.6	AU
term τ_2		
Parameter	Value	Unit
P	4.78 ± 0.09	years
T	2453956 ± 70	MJD(BTDB)
$a_{bin} \sin i$	0.017 ± 0.002	AU
e	0.10 ± 0.03	
ω	337 ± 1	°
$f(m)$	$(2.15 \pm 0.3) \times 10^{-7}$	$M_\odot$
$m \sin i$	6.3 ± 0.6	M_{Jup}
$a \sin i$	2.8 ± 0.8	AU

The next step will be to refine the solution and test the dynamic stability in order to confirm the discovery.

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