The Algol-type Binary VV UMa: New VRI Photometry and Search for Pulsations

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Abstract

New CCD VRI light curves and time-series analyses of the Algol-type eclipsing binary VV UMa are presented. Our new observations have been analyzed using the Wilson-Devinney code from which new geometric and photometric elements are derived. A time-series analysis of the residual light curves in the filter I indicates pulsations of the primary component with a main frequency of 17.24 c/d and a semi-amplitude of 0.004 mag. A parallel analysis of the residual light curves in the filter R indicates a main frequency of 16.50 c/d (alias of previous one), which confirms the result first obtained in the I-band.There is a slight possibility of multiperiodic behaviour, but the present data are too scarce to be affirmative. We did not find evidence for any pulsation frequency previously reported in the literature.

1. Introduction

VV UMa was first reported as a variable star by Gitz (1936). The mass function has been obtained by Struve (1950), who emphasized that the period of the system is short for a binary of class A0. UBV light curves of the system have also been investigated by Wilson (1965) and Broglia and Conconi (1977). Additionally, VV UMa appears on the MK classification of Hilditch and Hill (1975) and Hill et al. (1975) as an A2V type star. Another analysis was made by Horak (1966) and Rafert (1990) based on the data of Wilson (1965) and Broglia and Conconi (1977). BVR photometry of the system was obtained by Arévalo et al. (2001). Lázaro et al. (2001, 2002) also analyzed the uvbyβ and BVRJK light curves and found evidence of short-term small-amplitude variations in the brightness of the system. Recently, Kim et al. (2005) suggested two pulsation frequencies for the primary component of VV UMa. It is important to note that some difficulty occurs in modeling the light curve of VV UMa as Lázaro et al. (2002) mentioned. Wilson (1965) suggested an extended atmosphere around the secondary component. Broglia and Conconi (1977) analyzed their light curves using both the Russel and Merril (1952) and Wilson and Devinney (1971) methods. They proposed two possible solutions. Lázaro et al. (2002) solved the BVRJK light curves with the code BINAROCHE adopting two different values for the mass of the primary star.

2. Observations

The system was observed with the 40-cm Cassegrain telescope of the Observatory of the University of Athens, equipped with the ST8XMEI CCD camera and with Bessell VRI-filters. Observations were carried out during three nights in December 2006. Differential magnitudes are measured using GSC 3810 1515 as the comparison star, and GSC 3810 1500, the same star used by Arévalo et al. (2001), as the check star. Two primary and one secondary times of minima were obtained.

3. Light Curve Solution

Our light curves have been analysed with the PHOEBE program (Prša and Zwitter, 2005) which uses the 2003 version the Wilson-Devinney code (Wilson and Devinney, 1971; Wilson, 1979, 1990). To each filter individually we applied the code in MODE 5 which solves the light curve of semi-detached eclipsing binaries where the secondary (cooler) component fills its Roche lobe, while the primary (hotter) one is well inside its Roche lobe. Before starting the light curve solution we applied the q-search method in I filter, in order to obtain the most appropriate value for the mass ratio q, which was found to be ~0.236. Then we set it as a free parameter when solving the I light curve. For the V and R-solutions, q was fixed to the value 0.27041 obtained from the I-solution. The effective temperature of the primary component was taken from Lázaro et al. (2002), appropriate for an A2V star. The gravity darkening coefficients g_1, g_2 and the albedos A_1, A_2 of the primary and secondary components, respectively, were set to the theoretical values. The limb darkening coefficients x_1, x_2 were supplied by the code. The synthetic and observed light curves are both illustrated in Figure 1, while the parameters derived from the solutions are listed in Table 1.

Table 1. Parameters of light curve solution in MODE 5

Parameter	*V*	*R*	*I*
$i(^o)$	$81.99 \pm .13$	$80.92 \pm .10$	$79.896 \pm .16$
q	0.270*	0.270*	$0.270 \pm .004$
$T_1(K)$	9141*	9141*	9141*
$T_2(K)$	5477 ± 37	5290 ± 28	5151 ± 21
Ω_1	$3.088 \pm .016$	$3.088 \pm .013$	$3.074 \pm .013$
Ω_2	2.40	2.40	2.40
$L_1/(L_1+L_2)$	$0.959 \pm .003$	$0.943 \pm .002$	$0.927 \pm .002$
$L_2/(L_1+L_2)$	0.041	0.057	0.073
x_1	0.4486*	0.3559*	0.2673*
x_2	0.6414*	0.5539*	0.4679*
g_1	1.0*	1.0*	1.0*
g_2	0.32*	0.32*	0.32*
A_1	1.0*	1.0*	1.0*
A_2	0.5*	0.5*	0.5*
$r_1(pole)$	0.353	0.353	0.353
$r_1(point)$	0.375	0.375	0.375
$r_1(side)$	0.364	0.364	0.364
$r_1(back)$	0.370	0.370	0.370
$r_2(pole)$	0.254	0.254	0.254
$r_2(point)$	0.369	0.369	0.369
$r_2(side)$	0.264	0.264	0.264
$r_2(back)$	0.297	0.297	0.297
χ^2	0.098254	0.057660	0.031713

**adopted*

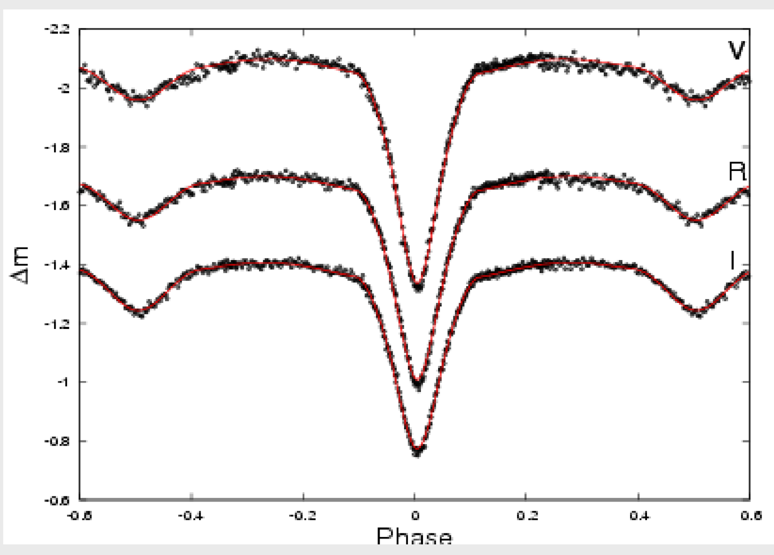

Fig. 1. Synthetic (red curve) and observed (symbols) light curves of VV UMa.

3. Pulsation of the primary component

The theoretical light curves in the VRI-filters were subsequently subtracted from the observed ones in order to search for short-period pulsations in the system. We performed each frequency-analysis in the interval from 0 to 80 c/d with the software PERIOD04 which is based on the classical Fourier analysis (Lenz and Breger 2005). All orbital phases were included because our data are limited in number. After the first computation, the residuals were subsequently prewhitened in order to search for a next frequency. The results of these frequency searches are shown in Table 2: we list the identification number of the frequency, the frequency value, the error in frequency, the signal-to-noise ratio and the reduction of the relative variance. The corresponding semi-amplitudes and residual standard deviations derived from a multi-parameter least-squares fit of sinusoidal functions are also mentioned. First, we performed the analysis in the I-band because of the higher quality of these observations. A most significant frequency of 17.24 c/d was detected with a semi-amplitude of 0.0037 mag. In addition, we found some slight evidence for a second frequency at 20.42 c/d, but this result is cautioned since it might be caused by residual effects linked to a non-optimal subtraction of the binary model at the times of primary (and secondary) eclipses.

We also performed a search with the R- and V- residuals, even though the quality of these data is (much) poorer. In both cases, a frequency of 16.5 c/d was detected at the limit of the acceptable significance level (with S/N just above 4), see Table 2). This frequency is an alias of the one detected in the I-filter: the daily aliasing combines with the 1/T (i.e. 0.215 c/d) aliasing to produce another frequency which is (1 - 1/T) c/d smaller than 17.24 c/d. In addition, we found another frequency situated at about 4.5 c/d, clearly an artifact frequency not detected in the analysis of the I-residuals. Figs. 2a, 2b and 2c illustrate the frequency analyses in the three passbands.

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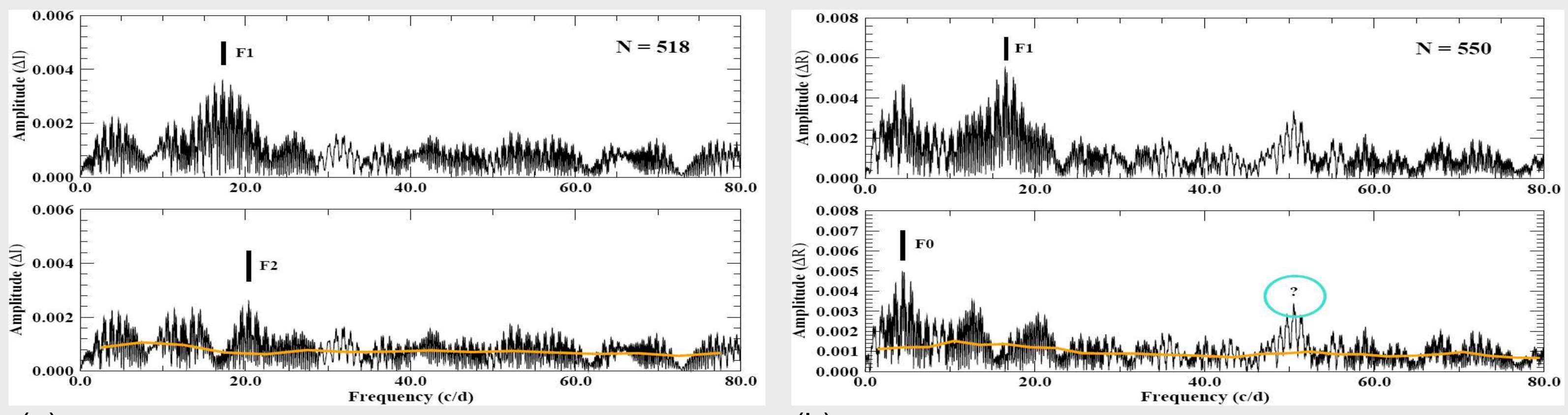
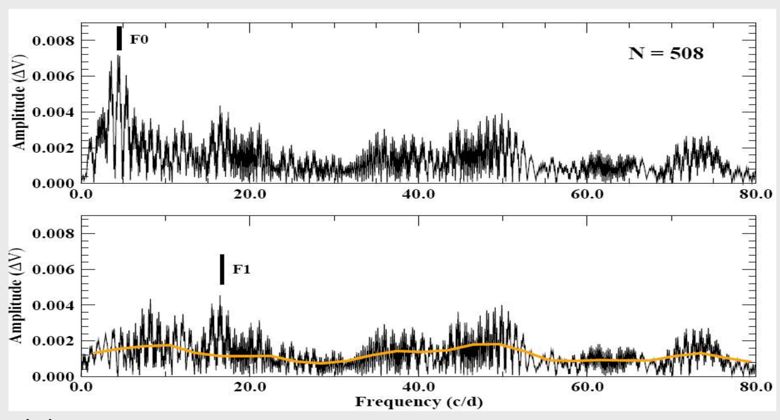
Table 2. Results of the frequency analyses of the residual data of VV UMa in three passbands

Freq. Id.	Freq. (d^{-1})	Error (d^{-1})	S/N	R (%)	Amp (mmag)	σ_{res} (mmag)
Filter I		*N = 518*				
F1	17.243	0.013	5.2	7.5	3.7	9.0
F2?	20.419	0.017	4.7	11.5	2.6	8.7
Filter R		*N = 550*				
F1	16.494	0.009	4.2	10.5	5.7	11.4
F0	4.601	0.011	4.0	18.8	4.9	10.8
Filter V		*N = 508*				
F0	4.358	0.011	4.8	13.4	7.2	12.9
F1	16.473	0.016	4.0	18.8	4.6	12.5



(a) (b)



(c)

Fig 2. Frequency analyses in I (a), R (b) and V (c) filters.

In conclusion, the frequency of 17.24 c/d (or its alias 16.49 c/d) is the only one we can trust with some confidence based on only 3 nights of data. We have found no evidence of any of the frequencies which have been previously reported (see Table 2), but the data we presently have do not allow to conclude that these have entirely disappeared, since their amplitudes appear to vary greatly from one night to the next one (see Lázaro et al. 2001; 2002; Kim et al. 2005) and so, they may stay below our current detection threshold.

4. The O-C Diagram of the system

We used 233 reliable times of minima, kindly sent to us by J. M. Kreiner (private communication), taken from his database http://www.as.ap.krakow.pl/ephem/, and 3 new minimum times from our observations. We analyzed the orbital period adopting the linear ephemeris T = 2439245.39400 + 0.68737571 × E from Kreiner et al. (2001) and assuming a parabolic variation due to mass transfer superimposed on the variation caused by a tertiary component. The results of these computations are listed in Table 3. Fig. 3 shows the O-C diagram fitted by a parabolic and sinusoidal curve.

Table 3. The LITE parameters of VV UMa

Parameter	Unit	Value
T_0	HJD	$2439245.39442 \pm 0.00102$
P_0	$days$	$0.68737571 \pm 0.00000009$
P_{third}	yrs	21.9598 ± 0.1588
A	$days$	0.0125652 ± 0.00034210
e_{third}		0.213706 ± 0.044223
ω_{third}	deg	228.7805 ± 12.5184
$f(m)_{third}$	M_{sun}	0.0220035 ± 0.0000024
dP/dt	day/yr	-5.654×10^{-10}
M_1	M_{sun}	2.0
M_2	M_{sun}	0.54
$M_{3(min)}(i = 90^o)$	M_{sun}	0.60098 ± 0.00005
χ^2		0.0055580154

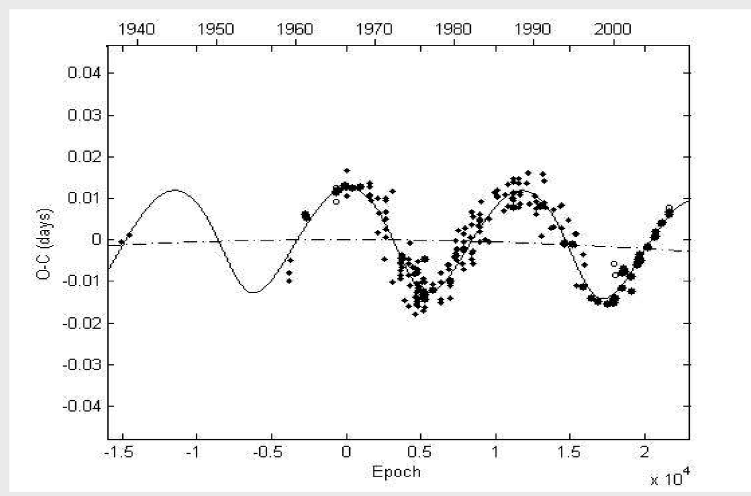


Fig 3. The O-C diagram of VV UMa fitted by a parabolic and a sinusoidal curve.

A weighted least-squares solution of the O-C data obtained by the LITE code (P. Zasche, private communication) leads to the following improved light elements:

$$T = 2439245.39442(102) + 0.68737571(9) \times E - 0.0532(2) \times 10^{-10} \times E^2$$

5. Acknowledgements

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