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THE ANALYSIS OF SUPERWASP PHOTOMETRIC DATA FOR THE OVERCONTACT BINARY QW GEM

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SUMMARY: The paper presents an analysis of photometric observations of the eclipsing binary QW Gem. The orbital and physical parameters of the system are derived using the modeling code by G. Djurašević. Photometric observations are obtained from the SuperWASP public archive and the spectroscopic elements are adopted from a recently published radial velocity study. The results suggest that QW Gem is a binary in overcontact configuration, consisting of two stars of similar surface brightness but in different evolutionary stages.

Key words. binaries: eclipsing – stars: fundamental parameters – stars: individual: QW Gem

1. INTRODUCTION

QW Gem (HD 264672, HIP 32845; $\alpha_{2000} = 6^h50^m46^s.06572$, $\delta_{2000} = +29°27'11''.3492$) is an eclipsing binary of the W UMa type. W UMa type stars are close, interactive systems in which components share a common envelope. Typically, they have orbital periods between 5 and 20 hours and mass ratios $q = M_2/M_1 \approx 0.2 - 0.5$. The components are usually of late spectral types (between F and K) with nearly equal surface temperatures due to the large-scale energy transfer through the shared atmosphere, which makes them especially astrophysically interesting. In addition, many W UMa stars are members of multiple systems.

Unlike most overcontact systems, QW Gem has a relatively scarce history of study. It was discovered by the Hipparcos mission and, from the analysis of these observations, Selam (2004) determined a mass ratio 0.3, a degree of contact 0.5, and an orbital inclination of 85°. It was also one of the targets of the radial velocity study of close binary stars by Rucinski et al. (2003). They measured a mass ratio of 0.334 ± 0.009 and estimated its spectral type to be F8V. They classified it as a W-type W UMa system. Using this result, Kreiner et al. (2003) derived the combined spectroscopic and photometric solution based on the light curve measurements from Mt. Suhora Observatory. They obtained the following absolute parameters of the system: $M_1 = 1.314 \pm 0.035 M_\odot$, $M_2 = 0.438 \pm 0.014 M_\odot$, $R_1 = 0.747 \pm 0.017 R_\odot$ and $R_2 = 1.258 \pm 0.029 R_\odot$. They also noted that it wasn't possible to obtain a good fit to the observations without the inclusion of a third light in the model. This conclusion was confirmed by Pribulla and Rucinski (2006) who found that QW Gem is a part of a triple system by analyzing the data from the Washington Double Star Catalog and the Hipparcos mission.

The present study is also based on the spectroscopic elements from Rucinski et al. (2003) but uses the photometry from the SuperWASP public archive (Butters et al. 2010).

SuperWASP is a project dedicated to the detection of extra-solar planets (Pollacco et al.

2006). It consists of two robotic observatories: SuperWASP-North, located in the island La Palma, and SuperWASP-South, located at the site of the South African Astronomical Observatory. Both instruments consist of eight wide-angle Canon 200mm telephoto lenses, each equipped with a custom filter resembling g+r (Fukugita et al. 1996), and an e2v 2k×2k CCD camera. The data is reduced by a dedicated data analysis pipeline (Pollacco et al. 2006) which performs aperture photometry in three software apertures and then applies the SYSREM detrending algorithm (Tamuz et al. 2005) to the photometry from the second aperture.

2. NEW TIMES OF MINIMA

The SuperWASP light curve consists of 3783 individual measurements taken between years 2004 and 2008. The data was cleaned of extreme outliers by iterative sigma-clipping at the 2σ level, reducing the dataset to 3232 data-points.

The 60 times of minimum light found in this dataset are given in Table 1. I also collected all the available times of minima from the literature - 11 additional points (Diethelm 2003, Drozdz and Ogloza 2005, Krajci 2005, Nelson 2005, Nelson 2006, Dvorak 2008, Hubscher et al. 2009 and Samolyk 2010) and used the Hipparcos ephemeris to determine the preliminary cycle number and to compute the O-C diagram. Both, the primary and the secondary minima were used in the O-C calculation. The diagram is well fitted with a straight line, which results in the following ephemeris:

$$MinI = HJD\ 2451927.5724(3) + 0.35812272(4) \times E$$

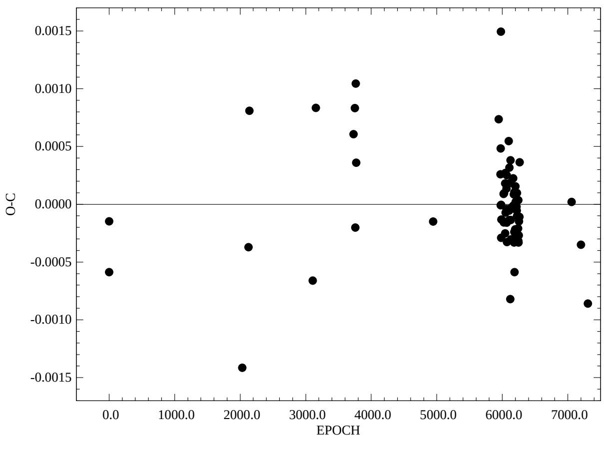

Fig. 1. *The O-C residuals between the times of minimum light and the best fitting ephemeris.*

The O-C diagram with the new ephemeris is plotted in Fig. 1 and there is no indication of period change.

Table 1. Times of minima from SuperWASP data.

JD+2450000	Type	JD+2450000	Type
3263.7289(2)	I	4118.5674(3)	I
3270.7125(3)	II	4120.5361(6)	II
3272.681(2)	I	4121.6117(3)	II
3275.7265(3)	II	4122.5065(2)	I
3277.6955(3)	I	4123.4019(2)	II
4056.6127(3)	I	4123.5807(2)	I
4066.6397(3)	I	4135.3990(2)	I
4067.5352(3)	II	4135.5783(2)	II
4067.7138(2)	I	4139.5175(2)	II
4068.611(1)	II	4140.4124(2)	I
4069.6835(2)	II	4141.4869(2)	I
4070.5785(2)	I	4142.3825(2)	II
4070.7577(2)	II	4142.5609(6)	I
4083.6504(2)	II	4146.5006(2)	I
4084.5454(3)	I	4147.3963(2)	II
4084.7245(2)	II	4149.5449(8)	II
4085.6201(3)	I	4150.4399(2)	I
4091.5292(3)	II	4153.4842(2)	II
4091.7078(2)	I	4154.3796(2)	I
4092.60362(8)	II	4155.4538(2)	I
4094.5729(2)	I	4156.3493(4)	II
4098.6916(3)	II	4156.5282(2)	I
4099.5867(3)	I	4162.4371(2)	II
4100.4823(2)	II	4163.5113(2)	II
4100.6609(2)	I	4164.4070(3)	I
4101.5561(3)	II	4165.4810(3)	I
4111.5844(2)	II	4166.3764(2)	II
4114.4488(2)	II	4167.4509(2)	II
4114.6278(3)	I	4170.4949(4)	I
4115.5235(3)	II	4171.3907(3)	II

3. LIGHT CURVE ANALYSIS

The analysis of the light curve was performed by using the modeling program of G. Djurašević (Djurašević 1992, see also Djurašević et al. 1998). The model of the binary is based on the Roche geometry and the light curve fitting procedure is based on the simplex algorithm. The fitting is done through an iterative cycle of corrections to model parameters, minimizing the sum of squared residuals between the observed and the synthetic light curve, $\Sigma(O-C)^2$.

Limb darkening was applied using the nonlinear approximation of Claret (2000) and tables of limb darkening coefficients calculated by A. Prša[1] for the SuperWASP passband. The coefficients are interpolated at each iteration for the current values of the effective temperature and the surface gravity. The details of this procedure are explained in Djurašević et al. (2004).

[1]http://phoebe.fmf.uni-lj.si/?q=node/110

In this paper I refer to a more massive component as the primary and the less massive as the secondary. I adopted the values given in the study by Rucinski et al. (2003) for the mass ratio ($q = M_2/M_1 = 0.334 \pm 0.009$), separation ($a\sin(i) = 2.5223R_\odot$), and the temperature of the primary (more massive) component ($T_1 = 6200$ K), according to the estimated spectral type (Lang 1992). The values for the bolometric albedo and the gravity darkening exponent were kept fixed at the typical values for W-type W UMa stars: $A_{1,2} = 0.5$ and $\beta_{1,2} = 0.0925$ (Rafert and Twigg 1980). A phase shift of 0.5 was applied to the light curve, so that the secondary (less massive) star is eclipsed at phase zero.

Starting from the solution obtained by Kreiner et al. (2003), I performed a Monte Carlo search of the parameter space by running the fitting procedure 500 times with randomly generated parameters. The search showed that a shallow overcontact configuration with a fill-out factor (defined as $f = \frac{\Omega_{\rm inner}-\Omega}{\Omega_{\rm inner}-\Omega_{\rm outer}}$) of about 13% gives the best fit to the data. The solution with the best χ^2 value was chosen as the starting point for a further analysis, in which the orbital inclination, magnitude shift and the contribution of the third light were fixed.

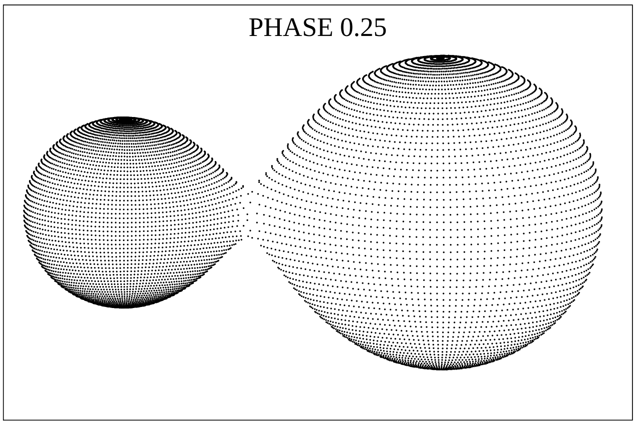

Fig. 2. *The geometrical appearance of QW Gem at phase 0.25.*

The results of the analysis are given in Table 2. The errors for the adjusted parameters were estimated by running the fitting procedure with the minimal and maximal values for all the fixed parameters (within one sigma according to the reported standard errors), and by adopting the deviation of parameter values between these solutions as a measure of uncertainty. The errors for the absolute system parameters are then derived analytically from the errors of model parameters. The SuperWASP light curve of QW Gem and the fit obtained from the modeling are shown in Fig. 3. Geometry of the system at phase 0.25 is shown in Fig. 2.

Table 2. Physical and orbital parameters of QW Gem.

Data and fit	
Number of observations	3232
$\sum(O-C)^2$	0.1781
σ	0.0074
Fixed parameters	
$q(M_2/M_1)$	0.334±0.009
$a\sin(i)[R_\odot]$	2.5223
T_1 [K]	6200
A_1	0.5
A_2	0.5
β_1	0.0925
β_2	0.0925
Adjusted parameters	
$i[^o]$	80.2 ± 0.3
T_2 [K]	6370 ± 20
F_1	1.0120 ± 0.0007
l_3	0.275 ± 0.003
Derived quantities	
$\Omega_1 = \Omega_2$	2.51 ± 0.03
$f[\%]$	13.1 ± 0.2
Absolute system parameters	
$R_1[R_\odot]$	1.24 ± 0.05
$R_2[R_\odot]$	0.76 ± 0.04
$M_1[M_\odot]$	1.3 ± 0.2
$M_2[M_\odot]$	0.44 ± 0.06
$\log(g_1)$	4.4 ± 0.2
$\log(g_2)$	4.3 ± 0.3
$M_1^{\rm bol}$	4.0 ± 0.3
$M_2^{\rm bol}$	5.0 ± 0.3
$a[R_\odot]$	2.56 ± 0.04

4. CONCLUSIONS

I have carried out a photometric analysys of the eclipsing binary QW Gem using the data from the SuperWASP public archive and spectroscopic results from a recent radial velocity study. I measured 60 new times of minima and updated the ephemeris. Based on the shape of the O-C curve, there is no indication that the orbital period is changing.

The light curve was further analysed with the modeling code by Djurašević (1992). According to the model proposed in this study, QW Gem is an overcontact system with a main sequence primary and an evolved secondary. Since the less massive star is eclipsed in the primary minimum, QW Gem is a W-type W UMa system (Binnendijk 1970). The surface temperatures are nearly equal ($\Delta T \approx 170$ K), indicating a good thermal contact between the

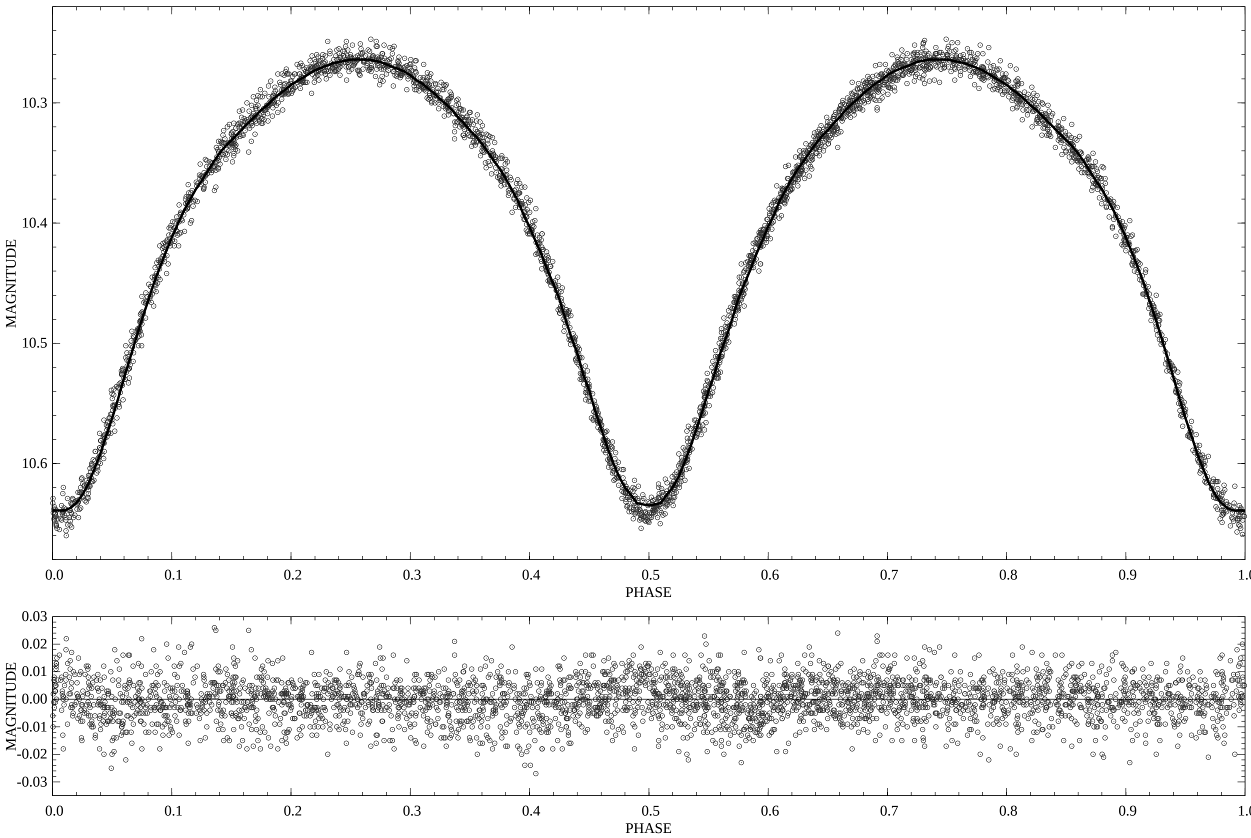

Fig. 3. *Top: The SuperWASP light curve of QW Gem (open circles) and the optimal synthetic light curve (black line); Bottom: O-C residuals.*

components. Compared to the photometric solution of Kreiner et al. (2003), the solution obtained in the current study gives a smaller fill-out factor ($f = 13.1\%$, as opposed to $f = 23\%$). However, the absolute values for the masses and the radii are in fairly good agreement.

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ФОТОМЕТРИЈСКА АНАЛИЗА ПОСМАТРАЊА ИЗ АРХИВЕ SUPERWASP КОНТАКТНОГ ТЕСНОГ ДВОЈНОГ СИСТЕМА QW GEM

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Оригинални научни рад

Овај рад представља анализу фотометријских посматрања еклипсно двојне звезде QW Gem. Орбитални и физички параметри су добијени из модела Г. Ђурашевића. Фотометријска посматрања су преузета из архиве кривих сјаја пројекта SuperWASP, док су спектроскопски елементи преузете из скорашње студије радијалних брзина. Резултати показују да је QW Gem контактни тесни двојни систем, са компонентама приближно истог површинског сјаја, али у различитим еволутивним фазама.