Photometric Analysis of V1542 Aql

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Abstract The *V* band light curve of V1542 Aql is analyzed using the Wilson-Devinney code and reveals an A-Type contact binary with a mass ratio of 0.171, an insignificant temperature difference, and a fillout of 55%.

1. Introduction

The W Ursae Majoris (W UMa) group of short-period eclipsing binaries are important test cases for theories of stellar evolution. In their review of the subject area, Maceroni and van't Veer (1996) noted that only about 15% of the 561 stars listed as W UMa-type binaries in the *General Catalogue of Variable Stars* (GCVS; Kholopov *et al.* 1985) are well-studied. As part of a continuing program (Wadhwa and Zealey 2003, 2004), we aim to analyze the numerous contact binary stars for which accurate photometric data are already available but no solutions have been published.

V1542 Aql (R.A. $19^h\,46^m\,25\overset{s}{.}1$, Dec. +08° 45' 12" (2000)) was discovered as a variable by Bernhard (1999). Bernhard and Lloyd (1999) published possible light curves but were unable to classify the nature of the variability, although they did suggest a period between about 0.172575 and 0.417570 day. Comprehensive photometry in the *V* band combined with earlier observations lead Quester and Bernhard (2001) to finally classify the system as a W UMa-type binary with the following elements:

$$\text{Min p} = \text{HJD } \underset{\pm 0.16}{2452112.1411} + \underset{\pm 0.13}{0.4175361} + \text{E}.$$

2. Light curve analysis

The *V* band photometric data and ephemeris above from Quester and Bernhard (2001) were analysed using a recent version of the Wilson-Devinney (WD) code as supplied with the WDWIN 3.6 Package (Nelson 2002). The WDWIN package consists of the WD code, a Windows interface for the WD code, which allows for easier writing of the input data files and a number of other utilities. Very little physical information exists about V1542 Aql and certain assumptions about spectral class, temperature of the primary, and maximum magnitude had to be adopted. The SIMBAD database (operated by the CDS at Strasbourg, France) lists both the *V* and *B* magnitudes for the star leading to a ($B-V$) of 0.38 corresponding to the spectral class F4 for main sequence stars. The indicative effective temperature of an F4 star is 6773K.

The maximum magnitude of the star is not well known, therefore the photometric data were normalized to the mean magnitude between phases 0.24 and 0.26 with the resulting V_{max} of about 9.2. Non-linear (square root law) limb darkening coefficients were interpolated from VanHamme (1993) using a utility provided as part of the WDwin package. As the adopted spectral class (F4) of the star would indicate a convective envelope, gravity brightening was set at 0.32 and bolometric albedos were set at 0.5. Black body approximation was used for the stars' emergent flux and simple reflection treatment was applied.

In the absence of spectroscopic mass ratios, photometric analysis is made more difficult by the presence of the so-called local minima, which can lead to convergence of minimization algorithms (as used in the WD code) to solutions far removed from the global minimum. A satisfactory solution to the local minimum problem is offered by looking at the behavior of the sum of squared residuals (Σ)—the so called "grid method" described by Maceroni *et al.* (1983) and Zhai *et al.* (1984). Normally, if the mass ratio, defined as the mass of the secondary (M_2), usually the smaller and cooler of the two stars, divided by mass of the primary (M_1), usually the larger and hotter of the two stars, is not known from spectroscopic data, it is treated as an adjustable parameter. However, if numerous different starting parameters are chosen, the programs can find several minima, more or less of equal depth, but their position depends on the initial starting parameters. It is, however, possible to perform a search for the mass ratio (q) by looking at the behavior of Σ. The WD code is used to perform several searches with spaced values of q. The WD code will always reach convergence, i.e., a point in parameter space of adjusted parameters where the suggested corrections are smaller than the probable errors, in each of them the associated value of Σ giving a measure of the quality of the solution. Selecting the value of q with the smallest Σ and then performing a further search with q now being an adjustable parameter will lead to further refinement of the parameters.

The grid method described above was used to search for a solution for several fixed values of the mass ratio (q) in the range 0.1 to 0.9. The dimensionless potential ($\Omega_1 = \Omega_2$), temperature of the secondary (T_2), luminosity (L_1) of the primary, and inclination (i) were adjusted to obtain a reasonable visual fit using the light curve (LC) part of the WD code. These preliminary parameters were then used as the starting parameters for the differential correction (DC) component of the WD code. The following parameters were adjusted during iterations: the inclination, temperature of the secondary, the non-dimensional potential, and the monochromatic luminosity L_1. Iterations were carried out until the suggested corrections were less than the estimated error for each parameter. The resulting residuals are summarized in Figure 1; it is clear from the Figure that the mass ratio of the system is near 0.2. A finer grid search with values of fixed in the range 0.11 to 0.25 was then carried out to further refine the mass ratio. The results of the fine grid search are illustrated in Figure 2, indicating the lowest residual (Σ) at q = 0.17.

The value of q (= 0.17) corresponding to the smallest residual was selected for a more detailed analysis in which the mass ratio was treated as an additional free parameter. To avoid correlation between parameters, iterations were carried out using multiple subsets (Wilson and Biermann 1976). The variable parameters were divided into two subsets as follows: $\{i, L_1, \Omega\}$ and $\{T_2, q\}$ and each subset applied in sequence. Iterations were carried out until the suggested corrections were less than the estimated error for each parameter. To determine the final error of the parameters the final iteration was carried out with all four parameters being free. The final solution is summarized in Table 1, with errors for each parameter being the standard deviation reported by the WD code. The fitted and observed light curves are illustrated in Figure 3 and a three-dimensional representation of the system constructed using Binary Maker 2.0 (Bradstreet 1983) is shown in Figure 4.

3. A-Type or W-Type

During the past 20–30 years many authors have devoted their observational and theoretical efforts to the understanding of the W Ursae Majoris type contact binaries. However, many aspects such as evolution, mass transfer processes, angular momentum loss, and possible stages of broken contact remain uncertain. Binnendijk (1970) divided late type contact binaries into two sub-classes, A and W, according to their light curve properties. Contact binary systems whose primary minima are due to the eclipse of the more massive and hotter component are A-type. The rest are W-type. The solution in Table 1 would indicate that the system is an A-Type W UMa contact binary, however, the very small difference in temperature (54K) between the stars raises the possibility that the system may be of W-Type with a mass ratio greater than 1.0, corresponding to the parameter space not searched for in the initial grid search. In this respect the system is similar to V677 Cen. Kilmartin *et al.* (1987) analyzed multi-wavelength light curves of V677 Cen to arrive at a mass ratio of 0.15, however, they found both components had the same temperature and so could not classify the system as either A- or W-type. Their data were re-analyzed by Barone *et al.* (1993) using a much wider mass ratio range. They noted that two independent solutions with mass ratios q and q', where $q' \sim 1/q$, provided a similar level of fit to the observed data, i.e. an A-Type solution with mass ratio q and a W-Type solution with a mass ratio about $1/q$. Their final analysis indicated that in fact the W-Type solution with $q = 7.06$ provided the best fit for the observed data for V677 Cen.

The light curve of V1542 Aql was further analyzed to assess if a W-Type configuration provided a better solution. Again a grid search was made with several fixed values of mass ratio in the range $4.75 < q < 7.75$. As before the same parameters were adjusted during iterations, the only additional constraint being that the temperature of the smaller star had to be greater than or equal to 6773K (fixed for the larger, "cooler," star). Iterations were again carried out until the estimated errors for all parameters were less than the suggested correction. Figure 5 illustrates the

W-Type grid search along with the residuals for the A-Type grid search, with the A-Type mass ratios expressed as reciprocals for ease of comparison. It is clear from Figure 5 that the A-Type solution provides a better fit for the observed data and as such Table 1 represents the correct solution for V1542 Aql.

4. Conclusion

An analysis of the *V*-band light curve of V1542 Aql is presented and reveals that the system is an A-Type contact binary with a small mass ratio of 0.171, small temperature difference of 54K, and a large fillout of 55%. The error bars for these values are given in Table 1.

5. Acknowledgement

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Table 1. Final solution for V1542 Aql. The fillout is the degree of contact between the two stars and is dependent on the potential. The value is calculated by the WD Code. O–C = the calculated correction to the epoch.

Parameter	*Value*	*Parameter*	*Value*
q	0.171 ± 0.003	$[g_1] = [g_2]$	0.32
$[T_1]$	6773K	$[A_1] = [A_2]$	0.50
T_2	$6719\text{K} \pm 6\text{K}$	$r_{1,\ pole}/a$	0.5139
$\Omega_1 = \Omega_2$	2.098 ± 0.01	$r_{1,\ side}/a$	0.5681
i	81.43 ± 1.0	$r_{1,\ back}/a$	0.5945
L_1	0.845 ± 0.04	$r_{2,\ pole}/a$	0.2404
L_2	0.175	$r_{2,\ side}/a$	0.2527
Fillout	55%	$r_{2,\ back}/a$	0.3078
O–C	0.0003		

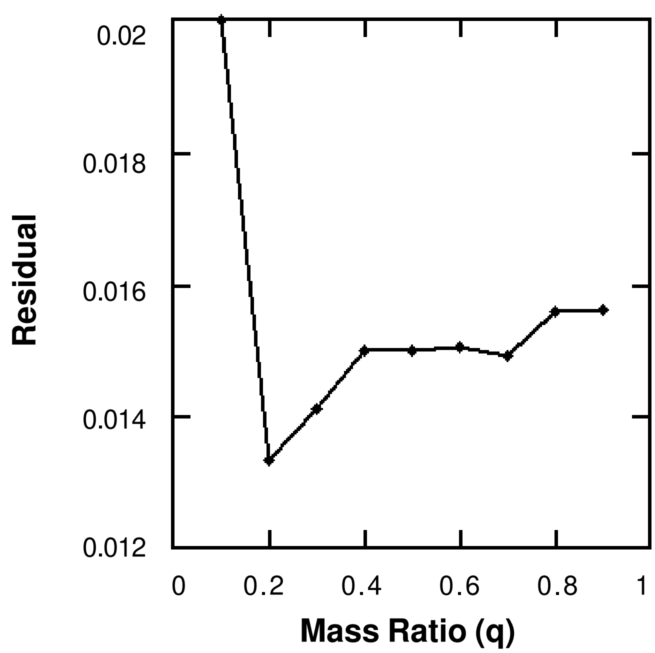

Figure 1. Coarse mass ratio search grid. The true mass ratio is likely near $q = 0.2$, where the sum of the squares of the residuals (Σ) is the smallest.

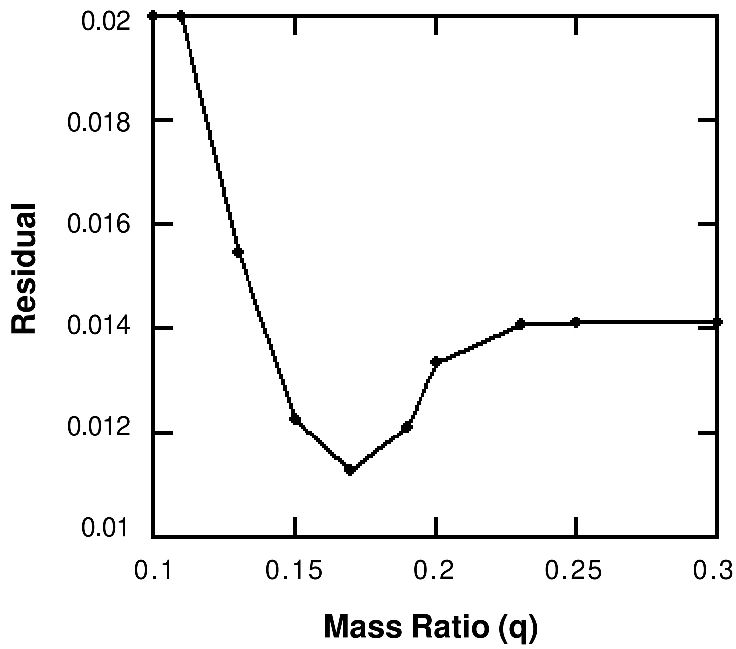

Figure 2. Fine mass ratio search grid. The true mass ratio is near $q = 0.17$, where the sum of the squares of the residuals (Σ) is the smallest.

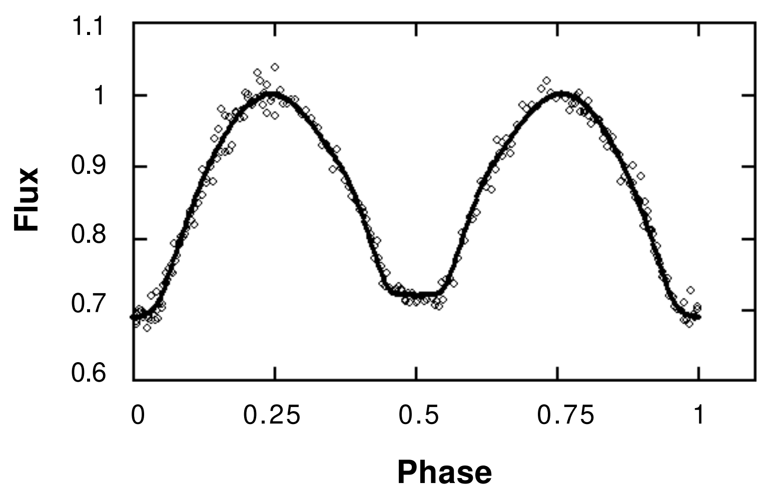

Figure 3. The observed (open circles) and calculated (solid line) light curves for V1542 Aql.

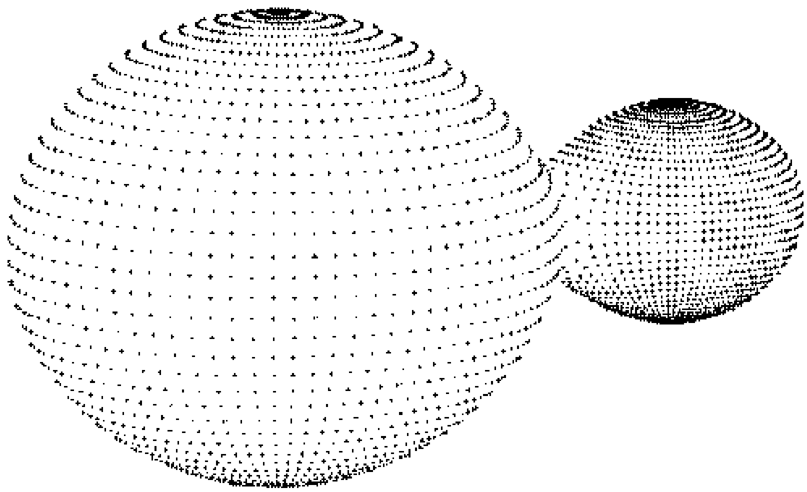

Figure 4. Three-dimensional representation of V1542 Aql at phase 0.36. The larger star is the primary with a relative luminosity of 0.845.

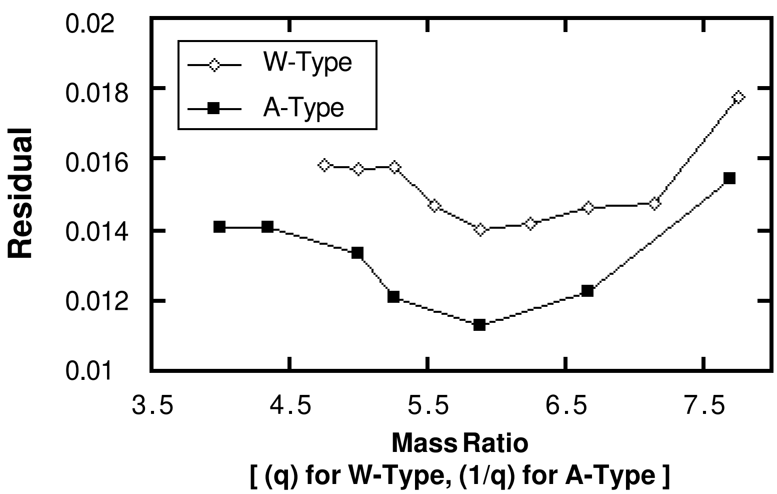

Figure 5. Comparison of A-Type and W-Type search grids. The A-Type solution provides a better fit (see text).