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SIMULTANEOUS PHOTOMETRIC AND SPECTROSCOPIC SOLUTION FOR AW CAM

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The eclipsing binary system AW Cam (HD 48049) was discovered by Strohmeier et al. (1963). It was observed with yellow and blue filters by Harris (1968) who used the Russell Model to analyze his data. Mammano et al. (1967) obtained a spectroscopic orbit solution. Russo and Milano (1983) analyzed the Harris data with the W-D model (Wilson & Devinney, 1971) finding a semi-detached system with a mass ratio of 0.22. The next study of the system was done by Oprescu & Suran (1992) using U,B,V filters and the Wood Model finding a mass ratio of 0.5. Djurasevic et al. (2006) reanalyzed the Harris data using a variation of the W-D model, and a q-search method, they found a mass ratio of 0.36 and a detached configuration.

AW Cam was observed photoelectrically by one of us (JRF) on four nights from March 13 through April 17, 2004. The Mount Laguna Observatory 0.6-m Smith reflector was used with a thermoelectrically cooled Hammamatsu R943-02 tube and Stromgren *uvby* filters. 115 individual observations per filter were made. All photometry was carried out in pulse-counting mode. HD 48586 was used as the comparison star and HD 46046 as the check star. These stars were found to be constant in brightness. The observations were not transformed, and mean extinction coefficients were used.

Using the method of Kwee & Van Woerden (1956) we determined a time of primary minimum $HJD = 2453077.7837 \pm 0.0005$. Batten, et al. (1978) reported an eccentricity of 0.12. Again using the method of Kwee & Van Woerden (1956) the time of secondary minimum was $HJD = 2453079.7122 \pm 0.0004$, which corresponds to a phase of 0.5002 ± 0.0003. Therefore, we found no evidence of the reported eccentricity.

O-C data has been collected by Kreiner (2004) and shows no evidence of period change. We used the period given by Oprescu et. al. (1992). The epoch was chosen from our observed time of minimum and the phases were calculated using the ephemeris:

Min I(HJD) = 2453077.7837 + 0.7713468E.

We used the ELC code (Orosz and Hauschildt, 2000) to model the system. This code does not use limb darkening laws, but rather calculates it directly from the model atmospheres. We did a simultaneous solution using all four light curves and the velocity curve with a genetic optimizer algorithm. The radial velocity data and weights were taken from Mammano et al. (1967). The starting value of temperature $T_1 = 9750K$ was adopted for the primary from Cox (2000) based on the reported spectral type of A0V from Mammano et al. (1967). Hilditch and Hill (1975) reported an average $b - y = 0.022$, which corresponds to a system temperature of 9200K (Cox, 2000). Since this $b - y$ neglects reddening and includes the cooler star, this temperature is consistent with our adopted value. The starting value of $T_2 = 6500K$ was based on previous published W-D solutions.

Bolometric albedo $A_1 = 1.0$ was set to the value for a radiative atmosphere (Kallrath and Milone, 1999) and $A_2 = 0.5$ was set to the value for a convective atmosphere (Rucinski, 1969). The gravity-darkening coefficients, $g_1 = 1.0$ and $g_2 = 0.32$ were set to the usual values for a radiative primary (von Zeipel, 1924) and convective secondary (Lucy, 1967) respectively. Synchronous rotation was assumed for both stars. The free parameters were orbital inclination i, T_1, T_2, velocity semi-amplitude K_1, primary mass, and the ELC fill factors. The results are given in Table 1 in which the fill factors have been converted to potentials. Contrary to some previous work, the ELC simultaneous light and velocity solution gave a detached configuration with a mass ratio $q = 0.45$ and $K_1 = 110 \pm 5$ km/s. Representative light curves and solutions for the y and v filters are shown in Figure 1 and Figure 2, and the radial velocity curve is shown in Figure 3. Figure 4 presents the system at phase 0.25.

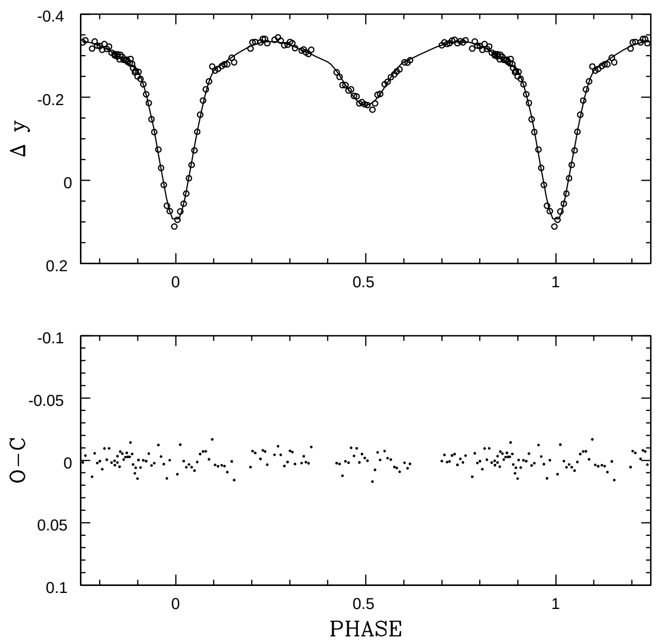

Figure 1. Light curve and ELC solution for AW Cam in the y filter. The circles represent the data points and the solid line the model fit. The lower plot presents the O-C residuals. All y-axis values are in magnitudes.

As a check, the light curves were also modeled using the W-D program (Wilson & Devinney 1971, Wilson 1992). Simultaneous solutions were performed using all four $uvby$ light curves. E. C. Olson (see Etzel & Olson 1995) provided the version of W-D program used in this study. This version added stellar atmosphere parameters based on the Kurucz (1979) models. An integration grid size of 30x30 was used. The input parameters were the same as for the ELC code. Limb darkening coefficients were taken from Van Hamme (1993). Using the results from ELC, W-D solutions were made for a detached system,

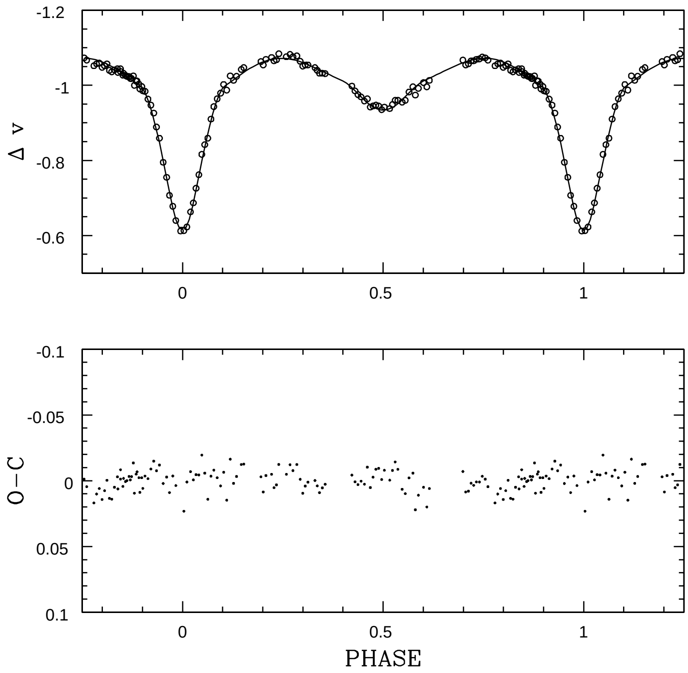

Figure 2. Light curve and ELC solution for AW Cam in the v filter. The circles represent the data points and the solid line the model fit. The lower plot presents the O-C residuals. All y-axis values are in magnitudes.

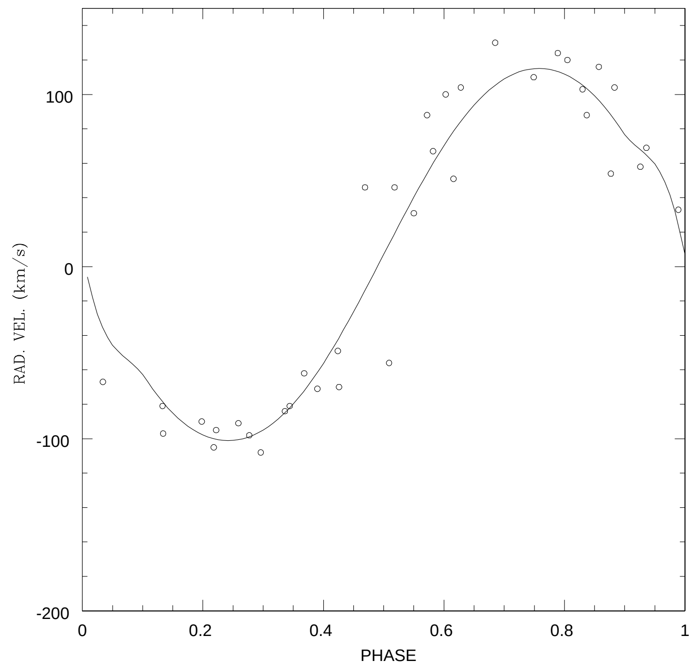

Figure 3. Radial velocity solution using the data from Mammano et al. (1967).

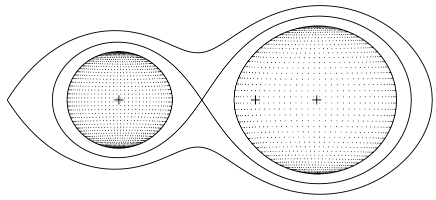

Figure 4. Roche surfaces of AW Cam using Binary Maker 3.0 (Bradstreet, 2004).

Mode 2. The free parameters were i, T_2, potentials Ω_1, Ω_2, and primary star luminosity L_1. A grid approach was used to determine the mass ratio, which yielded q = 0.45, this value was the same as found with the ELC code. The W-D results are given in Tables 1 and 2. We also attempted a Mode 5 solution because some previously published studies using the W-D code (see Introduction) found this system to be semi-detached (Mode 5) for the mass ratios they used. A grid approach in Mode 5 yielded a mass ratio q = 0.5. However, the Mode 5 solution ($\Sigma W(O-C)^2 = 0.027$) was not as good as the Mode 2 solution ($\Sigma W(O-C)^2 = 0.021$). Therefore the W-D solutions also indicate a detached system.

Previously published results have indicated both semi-detached and detached systems with mass ratios ranging from 0.22 to 0.5. Our simultaneous photometric and spectroscopic solution gave a detached system with a q = 0.45. This was also consistent with our W-D, Mode 2 (detached) grid approach. Our value for $K_1 = 110$ km/s, is essentially the same as the 112 km/s found by Mammano et al. (1967). However, inspection of Figure 3 shows that there is large uncertainty in the original data. Our analysis also determined new temperatures indicating spectral types A1 and F8 for the primary and secondary stars rather than the previously reported A0 and F2. Using our $K_1 = 110$ km/s and q = 0.45 values, the masses for the primary and secondary are 2.76 and 1.24 and the radii are 2.18 and 1.41 in solar units respectively. The value of K_1, along with the temperature, radius, and bolometric magnitude from the ELC solution, place both the primary and secondary in the main sequence band (e.g. Hilditch et al., 1988).

We thank the editor of the IBVS for supplying us with the radial velocity data. Use was made of the SIMBAD database and the NASA Astrophysics Data System Abstract Service.

Table 1 Wavelength-Independent Parameters

Parameter	W-D	Error	ELC	Error*
i	75.37	±0.1	74.68	±0.02
q	0.45	±0.01	0.45	±0.01
T_1	9550	Fixed	9550	±1
T_2	6162	±20	6109	±1
Ω_1	3.094	±0.005	3.101	±0.006
Ω_2	3.169	±0.007	3.095	±0.003
g_1	1.00	Fixed	1.00	Fixed
g_2	0.32	Fixed	0.32	Fixed
A_1	1.0	Fixed	1.0	Fixed
A_2	0.5	Fixed	0.5	Fixed
F_1	1.0	Fixed	1.0	Fixed
F_2	1.0	Fixed	1.0	Fixed
r_1(pole)	0.374	±0.001	0.373	±0.001
r_1(pnt)	0.420	±0.001	0.418	±0.001
r_1(side)	0.390	±0.001	NA	
r_1(back)	0.404	±0.001	0.403	±0.001
r_2(pole)	0.234	±0.001	0.242	±0.001
r_2(pnt)	0.256	±0.001	0.268	±0.001
r_2(side)	0.239	±0.001	NA	
r_2(back)	0.250	±0.001	0.261	±0.001
$\Sigma W(O-C)^2$	0.021		NA	

* Formal errors from solutions.

Table 2 Mode 2 Wavelength-Dependent Parameters

Parameter	y	b	v	u
x_1	0.430	0.494	0.514	0.470
x_2	0.574	0.669	0.756	0.775
L_1^a	0.930	0.947	0.957	0.954
L_2^a	0.070	0.053	0.043	0.046
l_1^b	0.923	0.941	0.952	0.949
l_2^b	0.077	0.059	0.048	0.051

a Normalized monochromatic luminosities over 4π steradians
b Normalized fractional light at phase 0.25
Probable errors for luminosities are ±0.01.

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