

ABSOLUTE DIMENSIONS AND MASSES OF ECLIPSING BINARIES. III. CW CANIS MAJORIS

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ABSTRACT

The eclipsing binary CW CMa has been found to be strongly double-lined on high signal-to-noise ratio digital spectral scans obtained with the Reticon and Digicon spectrometers of the 2.7 m reflecting telescope at McDonald Observatory. Absorption lines of both components are of nearly equal strength in the 4500 Å region, and radial velocities of high precision have been obtained for both stars. Spectroscopic orbits derived from these data have been combined with the photometric orbit of Williamon to give very accurate masses and radii: $(2.09 \pm 0.02 M_{\odot}, 1.89 \pm 0.04 R_{\odot})$ for the primary and $(1.98 \pm 0.02 M_{\odot}, 1.79 \pm 0.07 R_{\odot})$ for the secondary. The uncertainties are conservatively estimated standard errors. An analysis of the line profiles of both components indicates that they are synchronously rotating with the orbital period. A limited range of theoretical evolutionary tracks can be fitted simultaneously to both stars of CW CMa. The approximate age of this system is 2×10^8 years.

Subject headings: stars: eclipsing binaries — stars: evolution — stars: individual

I. INTRODUCTION

The two previous papers in this series (Lacy 1977, hereafter Paper I; Lacy 1981, hereafter Paper II) dealt with double-lined eclipsing binaries which were either too faint (CM Dra) or had too large a light ratio (YZ Cas) to be observed successfully with traditional photographic spectroscopic techniques. CW CMa, however, probably *could* be observed successfully with photographic methods, albeit with much greater observational difficulty than that encountered with a solid state array detector. The southerly declination of CW CMa ($-23^{\circ}6'$) and, until recently, its lack of an accurate light curve may have helped discourage observation in the past by observers in the northern hemisphere.

The light variations of CW CMa (HD 57802, SAO 173554, $-23^{\circ}53'35''$) were studied photographically by Deurink (Van Hoof 1949) and photoelectrically by Williamon (1976). The orbital period is about 2.1 days, the HD spectral type is B9, and the eclipses are of nearly equal depth, about 0.4 mag. The only photoelectric photometry of the system appears to be that of Williamon (1976), who found $V = 8.58$, $B - V = 0.14$, and $U - B = 0.07$ outside eclipse. Williamon's light curves have been analyzed by Williamon using the methods of Russell and Merrill (1952) and by Mezzetti *et al.* (1980) using Wood's (1972) WINK computer program. No previous radial velocity work has been done on this system.

II. OBSERVATIONS AND ANALYSIS

Digital spectral scans of CW CMa were obtained mainly using the Reticon detector on the coude spectrometer of McDonald Observatory's 2.7 m reflector. This device has been described by Vogt, Tull, and Kelton (1978). A smaller number of scans were obtained using the dual-array Digicon mounted on the same sliding table as the Reticon. The Reticon scans consist of 1024 data words corresponding to photodiodes on the array spaced at 25 μm between centers. The Digicon scans consist of pairs of 936 data words corresponding to the two adjacent arrays of photodiodes, each array having a diode spacing of 30 μm between centers. The scans were obtained in the blue region of the spectrum at a central wavelength of approximately 4505 Å and a dispersion of 4.4 Å mm⁻¹, or 0.11 Å per diode for the Reticon and 0.14 Å per diode for the Digicon. A projected slit of 0.55 Å or 0.66 Å was used in all cases.

It was possible to use a slit this broad because the rotational broadening was approximately 1 Å for both components, so the additional instrumental broadening had only a small effect on the ability to resolve stellar absorption lines. Each scan covered about 100 Å for the Reticon and 125 Å for the Digicon. The signal-to-noise ratio of the scans was typically 100. Two Reticon scans taken at opposite quadratures are shown in Figure 1. The lines of both components are well resolved near quadratures, but crowding is a problem (as always) in this blue spectral region.

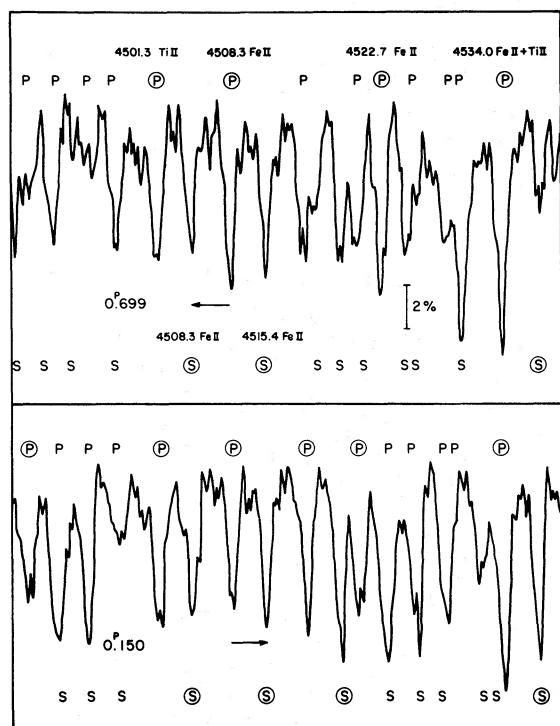


FIG. 1.—Reticon scans of CW CMa at opposite quadrature phases. Features due to the primary (P) component are labeled and identified above each scan and those of the secondary (S) are shown below each scan. The circled features are those actually used in the cross-correlation analyses for radial velocities. The secondary's features are shifted relative to those of the primary as indicated by the arrows. The bar shows the flux corresponding to 2% of the continuum.

Reduction of the Reticon scans was done in the same way as described in Paper II. After correcting for instrumental effects and normalizing the scans to the continuum, they were plotted and compared with scans of 68 Tau, a sharp-lined radial velocity standard of similar spectral type to the components of CW CMa. Unblended lines of the primary and secondary were identified and used to derive radial velocities by cross-correlating with corresponding features in scans of 68 Tau which had been synthetically broadened to match the observed line widths. The radial velocity adopted for 68 Tau is that discussed in Paper II, i.e., $+38.0 \pm 0.8 \text{ km s}^{-1}$ (IAU system). It is known that 68 Tau is a visual binary (ADS 3206) with a separation of $1''.5$ and a magnitude difference of 4.1 mag. The orbital period should be 300–400 years. In Paper II it was found that the velocity of 68 Tau was probably variable. The radial velocity variations may be due to the orbital motion and/or other causes. The binary 68 Tau also has a common proper motion companion of 11 mag at $77''$ separation. The velocity of 68 Tau at the time of my observations of CW CMa was determined by me and independently by F. Fekel, as discussed in Paper II.

Reduction of the Digicon scans was complicated by the fact that the dispersion curve for the Digicon is nonlinear and slightly variable. It was found that the dispersion relation could be approximated adequately by a pair of straight lines in the regions of interest. This was done separately for each scan. Each scan was then reduced in two pieces and the results averaged. Heliocentric corrections were applied to all results.

The results of the radial velocity reductions are shown in Figure 2 and listed in Table 1. Phases were computed using the ephemeris of Williamon (1976). Sinusoidal radial velocity curves were fitted to the observations of the primary and secondary components individually using a least squares algorithm. Deviations from the fitted sinusoidal curves do not show a pattern as they would if the orbit were noncircular, so the orbit is considered to be circular. The photometric data also indicate a circular orbit. The resulting orbital elements and uncertainties are listed in Table 2. All uncertainties listed in this paper are standard errors.

The spectroscopic orbits have been combined with the photometric orbit of Williamon (1976) to yield the absolute dimensions and masses of Table 2. Williamon's (1976) solution was preferred over the reanalysis of Mezzetti *et al.* (1980) because the latter's light ratios lead to very unrealistic values of the colors of the component stars. The geometric elements of both solutions are essentially in agreement. The uncertainties of the photometric orbital elements were estimated by me based on the analyses of Williamon (1981) and Mezzetti *et al.* (1980).

Rotational velocities of both components of CW CMa have been estimated using unblended line profiles. Gaussian profiles were fitted to observations within 1.4 full width at half-maximum intensity. The resulting

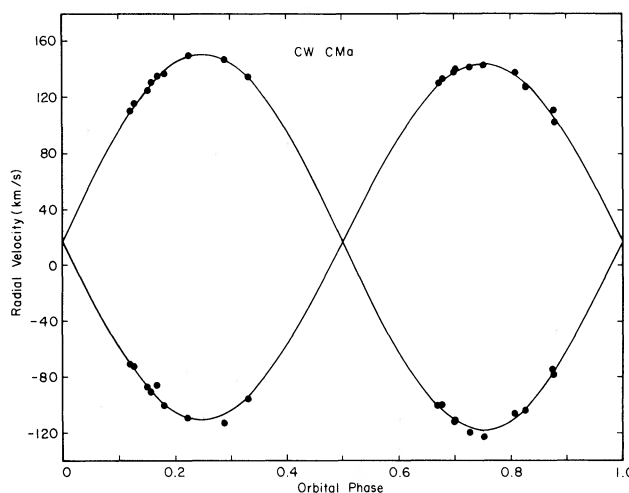


FIG. 2.—Radial velocity observations of CW CMa and fitted spectroscopic orbits.

TABLE 1
OBSERVED RADIAL VELOCITIES OF CW CANIS MAJORIS
AND RESIDUALS FROM THE COMPUTED ORBIT

DATE (JD ₀ -24,440,000)	INSTRUMENT ^a	ORBITAL PHASE	RADIAL VELOCITY AND RESIDUAL (km s ⁻¹)			
			Primary	O - C	Secondary	O - C
4173.988.....	R	0.874	111.0	3.4	-74.8	4.7
4174.955.....	R	0.330	-96.3	-1.2	135.0	0.0
4175.964.....	R	0.807	137.0	0.7	-106.5	3.3
4178.966.....	R	0.224	-109.4	-0.1	150.3	0.2
4179.972.....	R	0.699	140.2	2.4	-111.1	0.3
4180.928.....	R	0.150	-86.9	-0.1	124.5	-1.7
4364.613.....	D	0.877	102.7	-3.1	-78.7	-1.2
4366.622.....	D	0.826	128.0	-2.1	-104.6	-1.2
4570.927.....	R	0.288	-113.1	-5.7	146.8	-1.3
4571.850.....	R	0.724	140.7	-1.8	-120.6	-4.1
4571.906.....	R	0.750	141.7	-2.6	-123.5	-5.1
4625.767.....	R	0.181	-100.9	-1.9	137.2	-2.0
4626.803.....	D	0.670	128.6	0.3	-100.6	0.9
4626.865.....	D	0.699	138.2	0.5	-111.9	-0.4
4627.756.....	R	0.120	-70.7	-0.2	110.3	1.3
4627.838.....	R	0.158	-91.5	-1.1	131.1	1.0
4677.649.....	R	0.677	133.1	2.2	-99.9	4.3
4677.692.....	R	0.697	137.0	-0.2	-111.8	-0.9
4678.603.....	R	0.127	-72.3	2.4	114.7	1.2
4678.689.....	D	0.168	-86.0	8.2	134.8	0.7
Standard deviations				3.0		2.5

^aR = Reticon; D-Digicon.

TABLE 2
PHYSICAL PROPERTIES AND STANDARD ERRORS OF CW CANIS MAJORIS

Property	Primary	Secondary
Relative radii	0.1702 ± 2%	0.1615 ± 4%
Orbital period (days)		2.11797737
Epoch of primary minimum (HJD)		2442090.1657
Orbital inclination (degrees)		82.98 ± 0.2
Radial velocity semiamplitudes (km s ⁻¹) ...	127.6 ± 0.8	135.1 ± 0.6
Center-of-mass velocities (km s ⁻¹)	16.7 ± 0.7	16.8 ± 0.6
Mass ratio		1.058 ± 0.008
Masses (solar units)	2.092 ± 0.015	1.977 ± 0.016
Radii (solar units)	1.885 ± 0.038	1.789 ± 0.072
Log g (cgs units)	4.21 ± 0.02	4.23 ± 0.03
Apparent magnitude and colors		
outside eclipse:		
<i>V</i>		8.58
<i>B</i> - <i>V</i>		0.14
<i>U</i> - <i>B</i>		0.07
Interstellar reddening <i>E</i> (<i>B</i> - <i>V</i>)		0.15
Interstellar extinction <i>A_V</i>		0.50
Relative luminosities:		
<i>y</i>	0.545	0.455
<i>b</i>	0.557	0.443
<i>u</i>	0.549	0.451
Component colors:		
(<i>B</i> - <i>V</i>) ₀	-0.04	+0.01
(<i>U</i> - <i>B</i>) ₀	-0.03	-0.06
Bolometric absolute magnitudes		
(from colors)	0.9 ± 0.2	1.2 ± 0.2
Visual absolute magnitudes	1.1 ± 0.2	1.4 ± 0.2
Distance (pc)		330 ± 10%
Composition (from models):		
<i>X</i>		0.65 ± 0.05
<i>Y</i>		0.32 ± 0.05
<i>Z</i>		0.03 ± 0.01
Age (years)		(1.5 ± 0.8) × 10 ⁸

widths—1.04 Å for the primary and 1.03 Å for the secondary—were then corrected for the instrumental profile (0.52 Å) using standard nonrotating star profiles, for smoothing (hanning, 0.22 Å), and for phase smearing, i.e., change of velocity during the exposures. The broadening due to phase smearing was estimated as

$$\Delta\lambda_s = \frac{2\pi\lambda K}{cP} \Delta t \cos\theta,$$

where λ is the central wavelength, K is the radial velocity semiamplitude, c is the speed of light, P is the orbital period, Δt is the integration time, and θ is the orbital phase in angular measure. This effect was negligible in the case of YZ Cas because the exposure times were much shorter and the orbital period was much longer than in the present case. For CW CMa, the average exposure time was 73 minutes, and the average phase smearing was 0.12 Å for the primary and 0.13 Å for the secondary.

The remaining line widths were attributed to rotation as discussed in Paper II. The resulting estimates of rotational velocities are 46 ± 3 km s⁻¹ for the primary and 45 ± 3 km s⁻¹ for the secondary. Since the synchronous velocities are 45 ± 1 km s⁻¹ and 43 ± 2 km s⁻¹, it appears that the stars are rotating synchronously with the orbital period.

III. DISCUSSION

The masses and radii of both components of CW CMa are known to high accuracy, so a detailed comparison with theoretical stellar evolution calculations can be made. In order to make this comparison, the absolute magnitudes of both stars in CW CMa have been evaluated from their $B-V$ colors and radii using the method of Popper (1980). The colors of the components (in Table 2) were calculated from Williamon's (1976) light ratios and outside eclipse photometry.

Johnson and Morgan's (1953) Q -method has been used to estimate interstellar reddening, $E(B-V) = 0.154$ mag, and intrinsic spectral type, A0 V. This is consistent with the HD spectral type of B9, but the reddening vector from A0 V crosses the unreddened main sequence near the observed colors of CW CMa, so there is some ambiguity about whether or not the star is really significantly reddened. My own judgment is that, since the position of CW CMa in the two-color diagram is significantly above the unreddened main sequence of

Deutschman, Davis, and Schild (1976) and Johnson (1966) by about 0.03 mag, one should use the non-zero value of $E(B-V)$. This assumption results in the radiative parameters of Table 2.

Several other problems in the photometric solution showed up during the course of this analysis. The color indices of the components computed from the photometric solution are not those of normal stars. This points to small errors in one or more of the light ratios. Also, the components' $(B-V)_0$ values computed from the photometric elements correspond to a difference in visual surface brightness parameters of 0.021, but the visual light curve solution gives 0.008. Another way of putting this is to say that the visual light curve solution combined with the visual surface brightness-color relation of Popper (1980) predicts a $(B-V)_0$ color difference of about 0.02 mag, whereas the V and B light curve solutions together give a $(B-V)_0$ color difference of 0.05 mag. This could be just a problem in the V or B light curve solutions, or both, or it could be due to the same kind of differential metallicity effects noted by Popper (1971). These problems with the light ratios should not, however, have a significant effect on the accuracy of the geometrical elements.

Agreement between the observed masses, radii, and derived bolometric magnitudes and the models of Hejlesen (1980) can be achieved at a range of ages and compositions. The solutions are not as tightly constrained as those of YZ Cas because both stars in CW CMa have nearly the same mass. One reasonable solution is $\tau = 1.5 \times 10^8$ yr and $(X, Z) = (0.65, 0.03)$, where τ is the age and (X, Z) the composition of hydrogen and heavy elements by mass. Equally good solutions are $\tau = 2.5 \times 10^8$ yr and $(X, Z) = (0.70, 0.02)$, and $\tau = 8 \times 10^7$ yr and $(X, Z) = (0.60, 0.04)$. Both stars are still in the core hydrogen-burning main-sequence band.

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