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V456 CYG – A DETACHED ECLIPSING BINARY

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V0456 Cyg [=TYC 3152-323-1 = AN 172.1935 = BD+38°4107, RA = $20^h28^m50\overset{s}{.}845$, Dec = $39°09'13\overset{''}{.}69$ (J2000)] was first reported to be variable by Morgenroth (1935) who classified it as an Algol-type and supplied a finder chart plus magnitude range, but no period. The first available reference to a period is due to Savedoff (1951) who listed a period of 0.89 days for this system (amongst many others). Whitney (1959) reported a much improved period of 0.8911906 days, not far off the modern value of 0.8911956 days. Wood and Forbes (1963) reported quadratic and even cubic parameters for the ephemerides for these and 332 other systems, but modern period studies with photoelectric and CCD times of minima indicate a constant period for this system (Nelson 2011). Zakirov and Eshankulova (2006) took UBVR photoelectric observations and apparently solved by Lavrov's Direct Method (no reference was given; paper is not available).

In September of the years 2006 and 2007 the author took eight medium resolution (10 Å/mm reciprocal dispersion) spectra at the Dominion Astrophysical Observatory (DAO) in Victoria, British Columbia, Canada; he then used the Rucinski broadening functions (Rucinski, 2004) to obtain radial velocity (RV) curves (see Nelson et al., 2006 and Nelson 2010 for details). The spectral range was approximately 5005-5260 Å. A log of DAO observations and RV results is presented in Table 1.

Table 1: Observation log

DAO Image #	Mid Time (HJD-2400000)	Exposure (sec)	Phase at mid-exp	V1 (km/s)	V2 (km/s)
13043	53988.8632	3600	0.758	148.8	-174.4
13045	53988.9063	3600	0.807	136.1	-164.5
13076	53989.8656	3600	0.883	95.6	-120.7
13151	53994.7636	3600	0.379	-101.2	116.6
13222	54000.8693	3600	0.230	-146.9	172.2
13224	54000.9114	3600	0.277	-146.6	172.5
11195	54366.7578	2718	0.789	147.9	-167.2
11254	54369.7784	3326	0.179	-129.3	153.9

On three nights in May of 2008, one night in August of 2008, and nine nights in July of 2010, the author took a total of 151 CCD images of the field in B, 152 in V and 148 in Rc (Cousins) at his private observatory in Prince George, British Columbia, Canada. The telescope was a 33cm f/4.5 Newtonian on a Paramount ME mount; the detector was a SBIG ST-7XME CCD cooled to -20°C. Reduction software was MIRA by Mirametrics, Inc., and either sky or box flats were used. A list of the Variable (GSC 3152-323), Comparison (GSC 3152-491) and Check (GSC 3152-365) stars appears in Table 5 (available only electronically).

The following elements were used for phasing throughout (see Nelson, 2011 for the O-C relation):

$$JD_{Hel}MinI = 54637.8691(19) + 0.89119559(17)d \times E$$

The author used the 2004 version of the Wilson-Devinney (WD) light curve and radial velocity analysis program with the Kurucz atmospheres (Wilson and Devinney, 1971, Wilson, 1990, Kallrath, et al., 1998) as implemented in the Windows software WDwint (Nelson, 2009) to analyze the data. To get started, a spectral type A2 (SIMBAD, no reference given) and a temperature T1 = 9000 ± 150 K were used; interpolated tables from Cox (2000) which gave log g = 4.195 were used; an interpolation program by Terrell (1994) gave the (van Hamme, 1993) limb darkening values; and finally, a square root (LD=3) law for the extinction coefficients was selected, appropriate for hotter stars (Bessell, 1979). (The stated error in T1 corresponds to one half spectral sub-class.) At first, radiative envelopes were chosen for both stars, appropriate for hotter stars, but shifting to convective envelopes for star 2 gave a much better fit ($\Sigma\omega^2_{res}$ = 0.00559 for rad-conv versus $\Sigma\omega^2_{res}$ = 0.00808 for rad-rad). The parameters are listed in electronic Table 6 (the last three columns are explained below).

Mode 2 (for detached stars) was chosen, based on the general appearance of the light curves. Convergence by the method of multiple subsets was reached in a small number of iterations. In particular, the mass ratio q = M2/M1 was held fixed because this value (0.8487 ± 0.0036) was well determined from the RV curves; in contrast, it is not well constrained from the photometric data.

A plot of the B,V and R light curves, and WD fit is shown later. It is important at this stage to raise the issue that there was a problem in that the derived values for absolute parameters such as mass and stellar radius. They were simply too low to fit with the primary spectral type A2, and more closely fit those of a primary spectral type A8. As indicated above, the spectral type of A2 given in SIMBAD is without reference. However, the quoted infrared magnitudes J = 10.244 and H = 10.17 (from the 2MASS survey) yield J-H = 0.074 implying the spectral type of A2 (Covey, et al., 2007). As there is no indication of a classification spectrum in the references, the spectral type must be regarded as uncertain.

Next, the lower primary temperature T1 = 7640 K (equivalent to A8 V spectral type) was adopted and new extinction coefficients produced (also listed in Table 6). The usual runs in differential corrections mode were repeated and a new solution found. In view of the uncertainty as to primary spectral type it seemed advisable to present both solutions.

A plot of the B,V and V light curves, and WD fit are shown in Figures 1 and 2; careful comparisons reveal only very slight differences in the fits. The RVs are shown in Fig. 3. (the plots from the two models are almost identical) and a three dimensional representation from Binary Maker 3 (Bradstreet, 1993) is shown in Fig. 4 (electronic only).

Third light was tested for and found to be insignificant. Next, non-zero eccentricity was tested for; a value of 0.0016 +/- 0.0006 resulted. This is a very low value and is worth ignoring.

Final WD output parameters for each model are listed in Table 2 for both models.

Table 2: Final WD output parameters

WD Quantity	Mod. 1 Value	Mod. 1 Error	Mod. 2 Value	Mod. 2 Error	WD Quantity	Mod. 1 Value	Mod. 1 Error	Mod. 2 Value	Mod. 2 Error
T1 (K)	9000	170	7640	90	V_γ (km/s)	-0.50	0.19	-0.50	0.19
T2 (K)	7696	170	6667	90	r1 (pole)	0.279	0.001	0.258	0.001
Ω_1	4.398	0.01	4.696	0.01	r1 (point)	0.298	0.001	0.271	0.001
Ω_2	4.644	0.01	4.305	0.01	r1 (side)	0.285	0.001	0.262	0.001
q = M2/M1	0.8487	0.0036	0.8487	0.0036	r1 (back)	0.293	0.001	0.268	0.001
i (deg)	84.29	0.09	82.78	0.06	r2 (pole)	0.236	0.001	0.260	0.001
L1/(L1+L2) (B)	0.739	0.001	0.666	0.001	r2 (point)	0.247	0.001	0.278	0.001
L1/(L1+L2) (V)	0.704	0.001	0.634	0.001	r2 (side)	0.240	0.001	0.265	0.001
L1/(L1+L2) (R)	0.681	0.001	0.608	0.001	r2 (back)	0.245	0.001	0.274	0.001
a (solar radii)	5.712	0.007	5.730	0.008	$\Sigma\omega^2_{res}$	0.00556		0.00653	—

Table 3: Models 1 & 2

	Model 1						Model 2					
Fund. Quantity	Star 1 Tabular	Star 1 WD	Star 1 Error	Star 2 Tabular	Star 2 WD	Star 2 Error	Star 1 Tabular	Star 1 WD	Star 1 Error	Star 2 Tabular	Star 2 WD	Star 2 Error
Sp. Type	A2 V	—	—	A8 V	—	—	A8 V	—	—	F4 V	—	—
Temp. (K)	9000	9000	167	7640	7696	87	7640	7640	87	6765	6664	58
Mass ($M_\odot$)	2.50	1.71	0.09	1.75	1.45	0.09	1.75	1.73	0.04	1.44	1.46	0.03
Rad. ($R_\odot$)	2.09	1.63	0.008	1.58	1.37	0.008	1.58	1.51	0.008	1.34	1.53	0.008
M bol	1.10	1.80	0.18	2.29	2.85	0.07	2.29	2.68	0.08	3.40	3.25	0.08
Log g (cgs)	4.195	4.24	0.014	4.284	4.32	0.012	4.284	4.32	0.002	4.342	4.23	0.002
Lum. ($L_\odot$)	25.7	15.7	1.6	7.60	5.97	0.42	7.60	6.98	0.50	3.36	4.13	0.29
Dist. (pc)	—	496	57	—	—	—	—	483	56	—	—	—

The WD output fundamental parameters and errors are listed in Table 3 along with those from the properties of zero age main sequence stars (ZAMS; Cox, 2000). Most of the errors are output or derived estimates from the WD routines. The error in q was derived from the rms deviations of points from the best-fit double sine curves. In estimating the distance, galactic extinction was allowed for using the formula
$A_V = 3E(B-V) = R \times [(B-V)_{data} - (B-V)_{tables}]$.

This last method is relatively crude in that the colour index, B-V was taken from Tycho data; the stated error in each is 0.052 and 0.056 magnitudes, translating to ± 0.076 in the difference (but this may be a worst-case scenario). The tabular values are uncertain to around 0.015 magnitudes (corresponding to one half a spectral sub-class), and lastly, the value R=3 is an approximation – it varies from place to place and many authors favour the value 3.1. This last uncertainty accounts for an error of only a few pc and is therefore well within the error estimate of 56 or 57 pc for the distance.

In conclusion, it seems clear that spectral type A8 on the ZAMS better fits the derived mass for the primary star. Other quantities including the luminosity L are well within bounds for a main-sequence star. On the other hand, star 2 seems to be somewhat evolved, as its radius and luminosity are too high for a ZAMS star. Reference to triply-interpolated evolutionary tracks from the Geneva group reveal no fit at all for solar metallicity Z = 0.02 (Schaller et al., 1992)) but a possible fit for Z = 0.04 (Schaerer et al., 1993). Taking into account the estimated errors for L and T, an age between 0.5 and 1.00 Gy is feasible. There is no easy explanation as to how the stars could be at such disparate ages, however.

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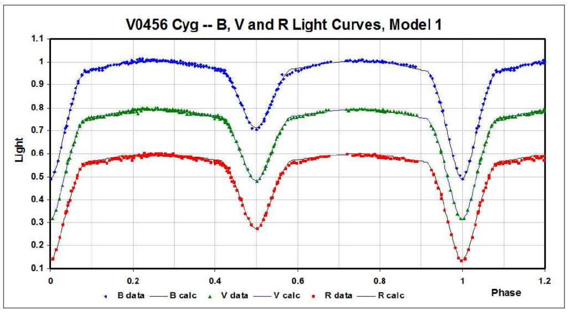

Figure 1. V456 Cyg: B,V and R Light Curves – Data and WD Fit (Model 1)

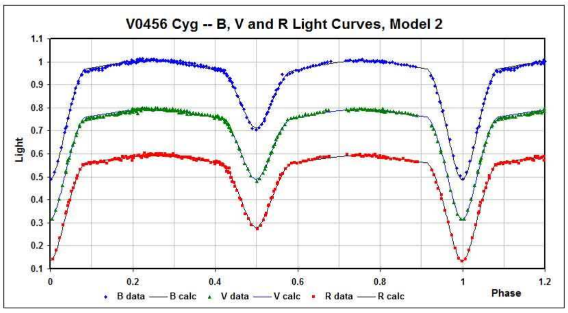

Figure 2. V456 Cyg: B,V and R Light Curves – Data and WD Fit (Model 2)

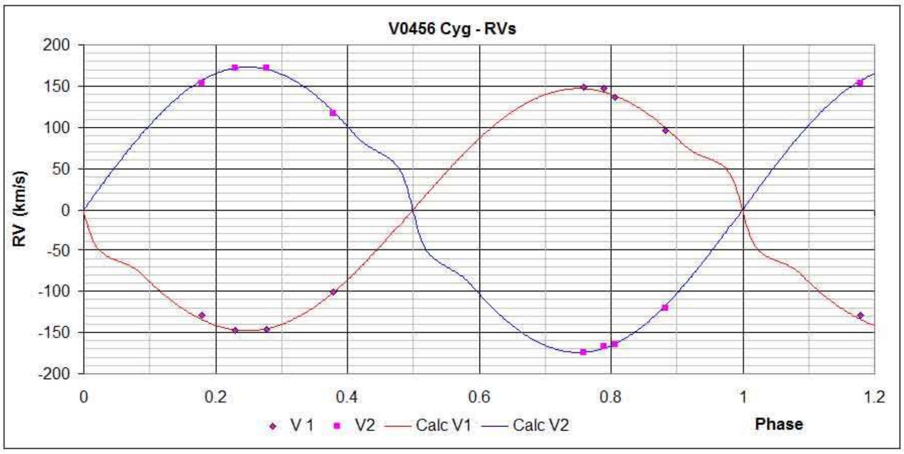

Figure 3. V465 Cyg: Radial Velocity Curves – Data and WD Fit

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