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V364 CAS – AN EVOLVED DETACHED ECLIPSING BINARY

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V364 Cas (= TYC 3270-1606-1 = BD 49 226, RA = $00^h52^m43\overset{s}{.}009$, Dec = $+50°28'10\overset{''}{.}16$ (2000)) seems to have been discovered by Kippenhahn (1953 - earliest SIMBAD reference) but no further details are available. Perova (1957) discusses three variable stars – presumably with elements and light curves for V364 Cas, but again, no further details are available. Hilditch & Hill (1975) did Stromgren observations of V364 Cas, along with those of many other eclipsing systems. Chaubey (1984), using photoelectric observations in U, B and V did a set of two analyses – one based on the Russell and Merrill (Russell & Merrill, 1952) method, the other based on Kopal's method (Kopal, 1981). Clearly, an up-to-date analysis using a modern physical model is overdue.

During September of 2006 (and 2007), the author took nine high 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., 2006a for details). The spectral range was 5004–5267 Å and the reciprocal dispersion, 10 Å/mm.

Table 1. A log of DAO observations and RV results

DAO Image #	Mid Time (HJD-2400000)	Exposure (sec)	Phase at Mid-exp	V1 (km/s)	V2 (km/s)
13087	53989.9690	3600	0.708	147.38	−120.22
13099	53990.7688	3600	0.227	−132.29	137.20
13101	53990.8146	3600	0.256	−134.71	137.94
13103	53990.8632	3600	0.288	−131.77	132.04
13114	53990.9920	3600	0.371	−101.29	105.34
13127	53991.7376	3600	0.854	114.33	−98.50
13142	53992.9787	2730	0.659	124.22	−97.79
13154	53994.8602	3600	0.878	105.39	−84.35
11257 (Taken in 2007)	54369.8310	3600	0.882	98.25	−84.63

On 10 nights October of 2006, the author took a total of 350 CCD images of the field in V, 349 in R_C and 344 in I_C (both Cousins) at his private observatory in Prince George, British Columbia, Canada. The telescope was a 33 cm 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 sky flats were used.

Table 2. A list of the Variable, Comparison and Check stars

Type	TYC 3270-	R.A. J2000	Dec. J2000	V Mags	$B-V$ Mags
Variable	1606	$0^h52^m43\overset{s}{.}021$	$50°28'10\overset{''}{.}099$	11.2–11.9	A7
Comparison	612	$0^h52^m39\overset{s}{.}557$	$50°29'39\overset{''}{.}557$	11.36	1.33
Check	96	$0^h52^m50\overset{s}{.}855$	$50°28'32\overset{''}{.}936$	12.38	0.14

The following elements were used for phasing throughout (see Nelson, 2008 for the $O-C$ relation):

$$\text{JD Hel Min I} = 53732.727(4) + 1.5430670(2)\text{E}$$

There was some initial confusion as to which was the primary eclipse (since the eclipse depths are very close). However, modeling revealed that the star initially considered to be the secondary was in fact the hotter of the two. Therefore, even though it is smaller and has the lesser mass, it must be considered the primary star as, when eclipsed, it gives the deeper eclipse that is considered to be phase 0 (by photometric tradition). The above elements reflect that designation. The primary eclipse, then, is an occultation and is flat-bottomed as a result (see electronic Fig. 4); the other eclipse is a transit (see the V light curve in Fig. 1 and VRI light curves as electronic Fig. 5).

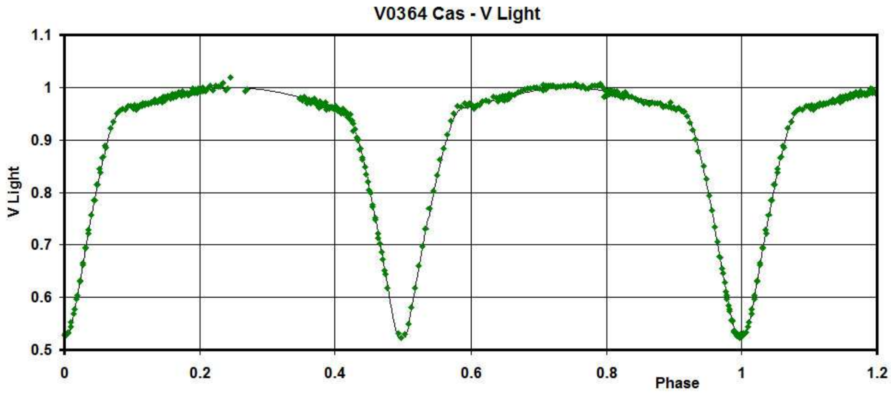

Figure 1. V364 Cas: V Light Curve – Data and WD Fit

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, 2009a) to analyze the data. To get started, a spectral type A7 V (Brancewicz & Dworak, 1980) and a temperature $T_1 = 7816 \pm 240$ K were used; interpolated tables from Cox (2000) which gave $\log g = 4.282$ 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). Radiative envelopes were chosen for both stars, again appropriate for hotter stars. The parameters are listed in Table 3.

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 $q = M_2/M_1$ was held fixed because this value (1.080 ± 0.002) was well determined from the RV curves; in contrast, it is not well constrained from the photometric data.

The solution was very robust in that when one started with significantly different initial values for the important parameters (inclination, T_2, and potentials 1 and 2), the iterations zeroed in on the same solution. Correlations between parameters were, except for one parameter, all less than 0.5. Therefore, varying almost all the parameters at once yielded rapid convergence.

Third light was tested for and found to be insignificant. Next, non-zero eccentricity was tested for; a value of 0.0006 ± 0.0003 resulted. This is a very low value and is worth ignoring.

A plot of the V light curve and WD fit are shown in Fig. 1; the RVs are shown in Fig. 2. A three dimensional representation from Binary Maker 3 (Bradstreet, 1993) is shown in Fig. 3. The reader will note that the shapes are tidally distorted. This accounts for the fact that the light curves between eclipses are not flat and, as a result, are easy to model with no ambiguities in the potentials, as occurred with MW UMa (Nelson, 2009b).

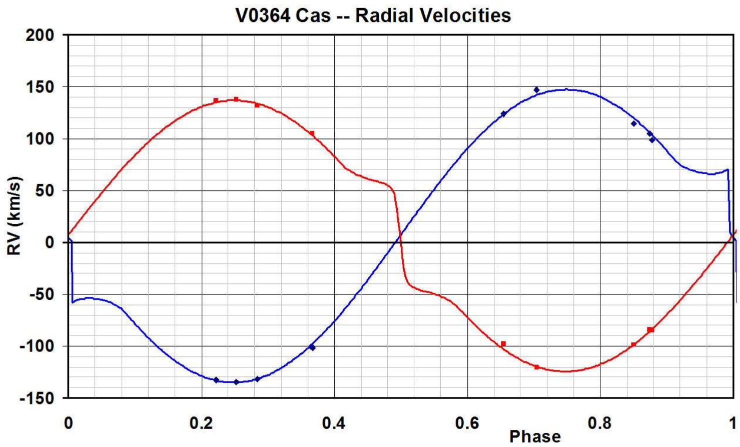

Figure 2. V364 Cas: Radial Velocity Curves – Data and WD Fit.

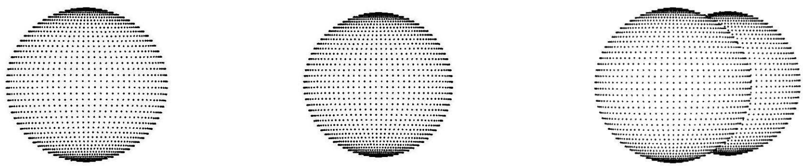

Figure 3. Binary Maker 3 representation of the system – at phases 0.75 and 0.97.

Table 3. Final WD output parameters

Quantity	Value		Error	Quantity	Value	Error	Quantity	Value	Error
	Star 1	Star 2							
g	0.320	0.320	[fixed]	T_1 (K)	7816	86	a (solar radii)	8.32	0.01
A	0.500	0.500	[fixed]	T_2 (K)	7780	86	V_γ (km/s)	6.2	0.1
x (bol)	0.194	0.330	[fixed]	Ω_1	5.349	0.006	r_1 (pole)	0.233	0.001
y (bol)	0.545	0.388	[fixed]	Ω_2	4.882	0.006	r_1 (point)	0.242	0.001
x (V)	0.076	0.202	[fixed]	$q = M_2/M_1$	1.080	[fixed]	r_1 (side)	0.236	0.001
y (V)	0.730	0.590	[fixed]	i (deg)	89.6	0.1	r_1 (back)	0.240	0.001
x (R_c)	0.039	0.105	[fixed]	$L_1/(L_1+L_2)$ (V)	0.424	0.0005	r_2 (pole)	0.273	0.001
y (R_c)	0.662	0.587	[fixed]	$L_1/(L_1+L_2)$ (R)	0.422	0.0005	r_2 (point)	0.291	0.001
y (R_c)	0.662	0.587	[fixed]	$L_1/(L_1+L_2)$ (I)	0.421	0.0005	r_2 (side)	0.279	0.001
y (I_c)	0.572	0.536	[fixed]	$\Sigma\omega^2_{res}$	0.00971	—	r_2 (back)	0.286	0.001

The WD output fundamental parameters are listed in Table 4 along with those from the properties of zero age main sequence stars (ZAMS; Cox, 2000). In estimating the distance, galactic extinction was allowed for using the formula $A_V = 3E(B-V) = 3((B-V)_{\rm data} - (B-V)_{\rm tables})$. This method is relatively crude in that neither star is on the main sequence (throwing in question the tabular value for $(B-V)$). Also, the value 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 4 pc and is therefore well within the error estimate of 45 pc.

As one will note from the table, both stars are over-luminous for the (solar abundant) ZAMS (Cox, 2000) by factors of about 1.5 and 2 (respectively).

Performing 2-dimensional interpolations (using the adopted temperatures and WD masses) in the under-abundant (Z = 0.004, Y = 0.252) evolutionary tracks of Charbonnel et al. (1993) yields close agreement for the luminosities of both stars (see Table 5).

Table 4.

Fundamental Quantity	Star 1			Star 2		
	Tabular	WD	error	Tabular	WD	Error
Sp. Type	A7 V			A7 V		
Mass ($M_\odot$)	1.80	1.57	0.10	1.80	1.69	0.11
Radius ($R_\odot$)	1.60	1.97	0.01	1.60	2.33	0.01
M bol	2.12	2.00	0.17	2.12	1.66	0.17
Log g (cgs)	4.28	4.04	0.004	4.28	3.93	0.004
Luminosity (Lo)	8.80	13	2	8.80	18	3
Distance (pc)	—	670	44	—	—	—

The lesser-abundant (Z = 0.001) tracks of Schaller (1992), the greater-abundant (Z=0.008) tracks of Shaerer (1993), plus the solar-abundant (Z = 0.02) tracks of Schaller (1992) are added for comparison. Note that all the papers are by the same Swiss group and represent a homogeneous set of calculations.

Table 5. Luminosities (solar units)

Abundance	Z = 0.001 Schaller 1992	Z = 0.004 Charbonnel 1993	WD Result	Z = 0.008 Schaerer 1993	Z = 0.02 Schaller 1992
Star 1 Luminosity	30	14	13	9.1	4.7
Star 2 Luminosity	38	20	18	15	8.4

In conclusion, V364 Cas is detached binary with both stars evolved off the ZAMS; they also appear to be have sub-solar abundances. Reference to the data tables of Charbonnel (1993) reveals an apparent age of around 1.3×10^9 years (from the ZAMS). An abundance study for this system would be useful in order to test the evolutionary tracks for Z = 0.004.

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