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THE CLASSICAL ALGOL XZ UMa — OBSERVATIONS AND ANALYSIS

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XZ UMa (= SV*BV 32 = BD+50 1651 = TYC 3429 1530, $9^h31^m24\overset{s}{.}5$, $+49^\circ28'03''$, J2000.0) is listed in the General Catalogue of Variable Stars, 4th Edition (Kholopov, 1985) as type EA/SD, period = 1.22232 days, spectral type A5 + F9, and referenced to Remus (1956), who provided the chart (and is presumably the discoverer), and to the authors of the GCVS (who presumably determined the period).

No published light curves or analysis could be found (although there are catalogue parameters given—see Brancewicz & Dworak (1980) and Svechnikov & Kuznetsova (1990)), nor is there any evidence of any existing radial velocities, so this system was selected for study.

Times of minima have been continuously observed since about 1970; an $O-C$ plot (Nelson, 2005a) reveals continuous changes in the period, alternately increasing and decreasing, which suggests a sinusoidal relationship of period 7770 days. (However, this relationship—if it exists—has been observed over only one putative sine period and is therefore highly speculative.)

The following elements (calculated from the last few hundred cycles) were used for phasing:

$$\text{JD Hel Min I} = 53048.7928(32) + 1.2223115(10) \times E.$$

Eleven high-resolution (10 Å/mm) spectra were taken by one of the authors (RHN) in April 2005 at the Dominion Astrophysical Observatory (DAO) in Victoria, British Columbia, Canada. The spectral range was 4997–5260 Å. A log of observations and the derived heliocentric radial velocities is presented in Table 1 and a list of IAU Standard Radial Velocity Stars (Roberts & Boksenberg, 1986) from which the XZ UMa radial velocities were derived is given in Table 2.

Intermediate reductions (overscan removal, cosmic ray cleaning, setting apertures, fitting background, summation of counts, reduction to 1 dimension, calibration from Fe-Ar arc spectra, and finally dispersion correction) were performed by Ravere, software developed by one of the authors (Nelson, 2005b). Final determination of radial velocities was performed by "Broad", software developed by the same author that uses the Rucinski broadening functions (Rucinski, 2004). As expected, there was some scatter in the values

Table 1

DAO Image #	Start time (HJD – 240000)	Exposure (sec)	Phase at mid-exp	V_1 (km/s)	V_2 (km/s)
3139	53487.6569	3000	0.081	−78	67
3141	53487.7072	3600	0.122	−104	93
3143	53487.7570	3600	0.163	−120	125
3146	53487.8125	3600	0.209	−127	149
3007	53481.7576	3600	0.255	−137	144
3118	53486.6574	3600	0.264	−133	151
3124	53486.7500	3600	0.339	−120	139
3128	53486.8048	3600	0.384	−99	110
3179	53489.6527	7200	0.748	90	−185
3064	53483.6757	3600	0.824	76	−170
3155	53488.6549	3600	0.898	44	−121

Table 2

DAO Image #	Star HD-	V (mag)	Sp. Type	RV (km/s)
3004, 3033	089449	4.78	F6 IV	6.3
3036, 3069	102870	3.59	F8 V	4.3
3019	149803	8.58	F7 V	−7.5
3022, 3057, 3193	154417	6.00	F9 V	−16.8
3026, 3061	187691	5.12	F8 V	0

for a given XZ UMa spectrum from the various radial velocity standard spectra. The mean and standard deviation were taken and those values lying outside twice the sample standard deviation were rejected. In this way, the standard deviations for each radial velocity determination of V_1 and V_2 averaged 6.5 and 8.5 km/s (resp.); the rms deviations from the best-fit WD radial velocities were 7.5 and 11.0 km/s (resp.). Conversions from geocentric radial velocities (relative to that of IAU standard stars) to heliocentric radial velocities was accomplished by one of the authors (RHN) using his own software.

Photometric observations were carried out by DT and JG in the B, V and I_c bands; 754, 770 and 815 values were obtained, respectively. The 14" telescope at the Sonoita Research Observatory (SRO), equipped with a Santa Barbara Instrument Group STL-1001E camera was used to obtain the photometric data. The usual data processing procedures (bias and dark subtraction and flatfielding) were done using IRAF†. Comparison stars are listed in Table 3; the magnitudes and colours are from the Tycho catalogue (ESA, 1997). The data are in the SRO instrumental system

We used the latest version of the Wilson–Devinney (WD) light curve and radial velocity analysis program with the Kurucz atmospheres (Wilson & Devinney, 1971; Wilson, 1990; Kallrath et al., 1998) to analyze the data. To get started, we used the above $B-V = 0.20 \pm 0.04$; the tables of Flower (1996) gave temperature $T_1 = 7766 \pm 240$ K; interpolated tables from Cox (2000) gave $\log g = 4.282$; an interpolation program by Terrell (1994) gave the (van Hamme, 1993) limb darkening values; and finally, a logarithmic ($LD = 2$) law was selected, appropriate for hotter stars (Bessell, 1979). Fitting a double sine wave

†IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 3

Star	GSC ID	V	$B-V$
Var	3429-1530	10.49	0.20
Comp	3429-449	10.33	0.36
Check	3429-1027	9.96	0.53

Table 4

Quantity	Value Star 1	Value Star 2	Error	Quantity	Value	Error
F	1.000	1.000	[fixed]	i (deg)	83.96	0.06
g	1.000	0.320	[fixed]	$L_1/(L_1+L_2)$ (B)	0.820	0.001
A	1.000	0.500	[fixed]	$L_1/(L_1+L_2)$ (V)	0.728	0.002
x (bol)	0.673	0.642	[fixed]	$L_1/(L_1+L_2)$ (I)	0.609	0.002
y (bol)	0.203	0.166	[fixed]	ϕ_0	0.0006	0.00004
x (B)	0.822	0.847	[fixed]	e	0	[fixed]
y (B)	0.332	0.059	[fixed]	a (solar radii)	7.02	0.1
x (V)	0.716	0.784	[fixed]	V_γ (km/s)	−20.4	0.2
y (V)	0.284	0.181	[fixed]	r_1 (pole)	0.2389	0.0008
x (I)	0.507	0.631	[fixed]	r_1 (point)	0.2457	0.0009
y (I)	0.213	0.225	[fixed]	r_1 (side)	0.2416	0.0008
T_1 (K)	7766	—	240	r_1 (back)	0.2445	0.0008
T_2 (K)	—	5346	5	r_2 (pole)	0.3176	0.0004
Ω	4.794	—	0.013	r_2 (point)	0.4542	0.0016
f (fill factor)	−4.470	0.000	0.040	r_2 (side)	0.3320	0.0004
$q=M2/M1$	0.626		0.003	r_2 (back)	0.3642	0.0004

to the radial velocity data gave a mass ratio of $q = M_2/M_1 = 0.658 \pm 0.029$ km/s and a centre of mass radial velocity $V\gamma = -19.5 \pm 0.9$ km/s.

The general appearance of the light curve suggested a detached or semidetached system. Mode 5 (semidetached—Algol) gave the best fit. We selected radiative values for the bolometric albedo and gravity darkening exponents (albedo $A_1 = 1$ and gravity exponent $g_1 = 1$) for star 1 and convective values ($A_2 = 0.5$ and $g_2 = 0.32$) for star 2 based on temperature T_1 and the anticipated temperature T_2, respectively.

Because of the changes in the $O-C$ diagram that suggest a third body, we attempted to adjust third light in the simultaneous light/radial velocity curve solution. However, we could find no statistically significant value of third light in any of the three passbands. Because of the difficulty in recovering small amounts of third light, especially in partially eclipsing systems like XZ UMa, our null result on third light should not be taken as necessarily negating the third body hypothesis. We also adjusted the angular rotation rate of the primary but we found no evidence of asynchronism. Further, attempts with a detached configuration gave a poorer fit, hence the detached configuration can be ruled out.

The results of the fit are listed in Table 4 and fundamental derived quantities, in Table 5. [Note: 's.u.' = solar units.] Note also that the errors quoted are the standard errors computed from the covariance matrix in the differential corrections solution.

A 3-D representation generated by Binary Maker 3.03 (Bradstreet, 1993) is presented in Figure 3.

Table 5

Fund. Quantity	Star 1	error	Star 2	error
Spectral Type	A7		G7	
Mass ($M_\odot$)	1.92	0.09	1.20	0.05
Radius ($R_\odot$)	1.70	0.03	2.38	0.04
$\log g$ (CGS)	4.26	0.2	3.76	0.2
Luminosity ($L_\odot$)	9.5	0.1	4.2	0.1
Distance (pc)	504	26		

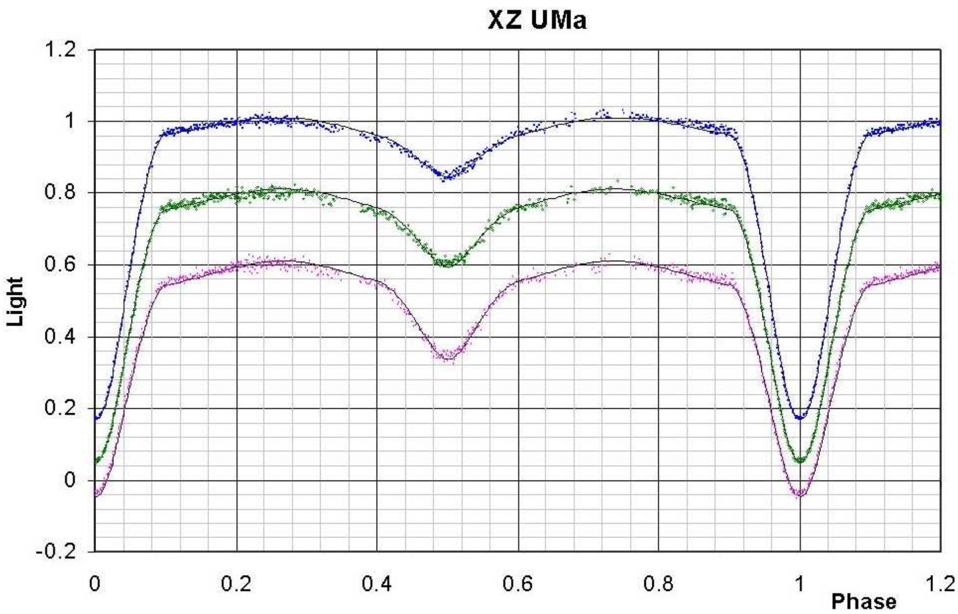

Figure 1.

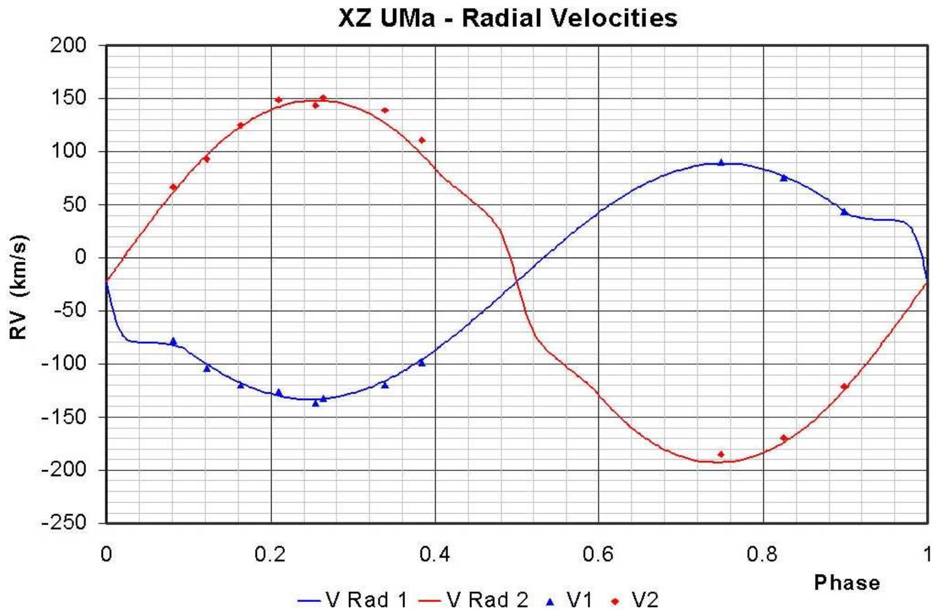

Figure 2.

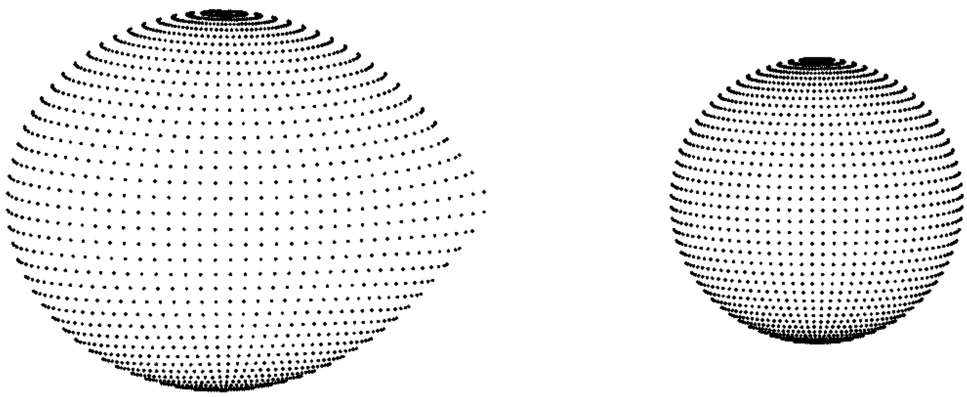

Figure 3.

XZ UMa is a classical Algol, as discussed in Giuricin et al. (1983), in that the A7 primary lies in the middle of the main sequence band (Iben, 1967), and the evolved G7 secondary lies above this band (i.e., is overluminous) by about a magnitude. Further, the masses and stellar radii for this system lie near the lower end of the Algol group and the period is relatively short, as is fitting for late-type Algol systems (ibid). However, the mass ratio, q, lies at the upper end of the group, suggesting that the system is still early in its mass transfer phase. The sinusoidal shape of the $O-C$ plot, as previously mentioned, suggests the presence of a third body (light time effect); however, examination of the spectra does not immediately support this hypothesis. Further monitoring of times of minima over the next decade or two should resolve the matter (but note Zavala, 2004 for an alternate explanation of cyclic period changes).

If there is a third body, this system would somewhat resemble the near Algol DL Vir (EA, A3 + K0-2, $q = 0.485$), where there is evidence of a G8 III third star (Schoffel & Popper, 1974; Schoffel, 1977)—directly from spectra and indirectly from $O-C$ analysis. (The eclipsing pair is only single lined; the mass ratio of this pair comes from analysis of the radial velocities of the A3 and G8 stars.) Although this system was at one time semi-detached (and therefore underwent mass transfer), it now seems to be slightly under-contact; it is also more evolved than XZ UMa. However, the light curve analysis was done using the Russell–Merrill model—an analysis with a modern light curve synthesis code is long overdue.

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References:

Bessell, M.S., 1979, *PASP*, 91, 589

Bradstreet, D.H., 1993, Binary Maker 3.03, in: Milone, E.F. (ed.), Light Curve Modelling of Eclipsing Binary Stars, pp. 151–166 (Springer, New York); "Binary Maker" software available from http://www.binarymaker.com/

Brancewicz, H.K., & Dworak, T.Z., 1980, *Acta Astron.*, 30, 501

Cox, A.N., ed., 2000, Allen's Astrophysical Quantities, 4th ed., (Athlone Press, London)

ESA, 1997, The Hipparcos and Tycho Catalogues (ESA SP-1200)

Flower, P., 1996, *ApJ*, 469, 355

Giuricin, G., Mardirossian, F., & Mezzetti, M., 1983, *Astrophys. J. Suppl. Ser.*, 52, 35

Iben, I., 1967, *Ann. Rev. Astr. Ap.*, 5, 571

Kallrath, J., Milone, E.F., Terrell, D., & Young, A.T., 1998, *ApJ*, 508, 308

Nelson, R.H., 2005a, Eclipsing Binary $O-C$ Files, http://www.aavso.org/observing/programs/eb/omc/nelson_omc.shtml

Nelson, R.H., 2005b, Software, by Bob Nelson, http://members.shaw.ca/bob.nelson/software1.htm

Kholopov, P.N., et al., 1985, General Catalogue of Variable Stars, 4th ed., Moscow

Remus, G., 1956, *KVB*, No. 16

Roberts, C.K., & Boksenberg, A., The Astronomical Almanac for the Year 1986, pp. H42–43

Rucinski, S.M., 2004, *IAU Symp.*, **215**, 17, in: Stellar Rotation, ed. Andre Maeder and Philippe Eenens, ASP (San Francisco)

Schoffel, E., & Popper, D.M., 1974, *Publ. Astron. Soc. Pacific*, 86, 267

Schoffel, E, 1977, *A&A*, 61, 107

Svechnikov, M.A., & Kuznetsova, Eh.F., 1990, Catalogue of Approximate Photometric and Absolute Elements of Eclipsing Variable Stars, Vols. 1–2, Sverdlovsk, Ural University

Terrell, D., 1994, Van Hamme Limb Darkening Tables, v1.1., http://www.boulder.swri.edu/~terrell/ld/

van Hamme, W., 1993, *AJ*, 106, 2096

Wilson, R.E., & Devinney, E.J., 1971, *ApJ*, 166, 605

Wilson, R.E., 1990, *ApJ*, 356, 613

Zavala, R.T., 2005, *ASP Conference Series*, **335**, 137, in: The Light-Time Effect in Astrophysics, ed. C. Sterken, ASP (San Francisco)

ERRATUM FOR IBVS 5715

The orbital inclination of XZ UMa had been omitted from IBVS 5715. It should be $83.9^\circ \pm 0.1^\circ$.

Bob Nelson