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PHOTOMETRY OF THE ALGOL-TYPE BINARY Z DRACONIS

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Ceraski (1903) first reported the eclipsing nature of Z Draconis, concluding that it was an Algol-type binary. Russell & Shapley (1914) analyzed the photoelectric observations of Dugan (1912) and gave a rough estimate of a distance of 1000 light years for the system. No other published light curves since that of Dugan appear to exist, although the system's times of minimum have been reasonably well observed, as can be seen in the $O-C$ diagram given by Kreiner et al. (2001) based on available times of minimum. Struve (1947) measured radial velocities of the primary.

Z Dra was observed with a 0.25-m Schmidt–Cassegrain telescope and a Santa Barbara Instrument Group ST-7XE CCD camera with BVR_CI_C filters. Calibration (bias, dark, flat) and aperture photometry were done with IRAF (Tody, 1993).

Differential photometric observations were made on seven nights in the period 2005 February to 2005 March. GSC 4396-1170 was used as the comparison star and GSC 4396-0455 was the check star. The Johnson $B-V$ values, based on Tycho B_T-V_T values transformed according to Bessell (2000), are 0.52 ± 0.05 for the comparison star and 0.80 ± 0.12 for the check star. The Johnson $B-V$ for the variable, again based on Tycho data, is 0.45 ± 0.06. The standard deviation for comparison minus check observations was 0.02 magnitudes in B and 0.01 magnitudes in V, R_C and I_C. The instrumental differential magnitudes for Z Dra are available from the IBVS web site as 5742-t2.txt (B), 5742-t3.txt (V), 5742-t4.txt (R_C) and 5742-t5.txt (I_C).

The new photometric data and the radial velocities of Struve (1947) were analyzed simultaneously with the PHOEBE program (Prša & Zwitter, 2005) which uses the most recent release of the 2003 version the Wilson–Devinney program (WD; Wilson & Devinney, 1971; Wilson, 1979). WD's mode 5 was employed, as appropriate for Algol-type binaries. The gravity darkening exponents were fixed at 0.32 and the bolometric albedos were set to 0.5 for both stars. The logarithmic limb darkening law was used with coefficients from Van Hamme (1993).The mean effective temperature of of the primary was initially set equal to 8083 K based on the A5 spectral type given by Struve (1947) and the calibrations of Flower (1996). The reader should note that the temperatures are not accurate to 1 K as this figure might imply but are uncertain by approximately 200 K. The resulting mass and radius of the primary were 1.49 $M_\odot$ and 1.49 $R_\odot$, values that are significantly lower than expected for an A5 V star and more in line with an F4 V star, which is the classification given in the GCVS. The Tycho and 2MASS colors of the system are also in better agreement with the later spectral type, so another solution assuming $T_1 = 6725\ K$

was performed and the results are presented in Table 1. The derived value for the time derivative of the orbital period ($\dot{P}$) was adjusted to allow for a period difference over the nearly six decades of time between the photometric and spectroscopic observations. The $O-C$ diagram of times of minimum (Kreiner et al., 2001) shows complex behavior so the derived value of $\dot{P}$ is useful only as an indicator of the long-term trend of the period changes.

Knowing the magnitude differences in B and V between the two components from the light curve solution, we can compute the intrinsic $B-V$ of the system assuming the intrinsic $B-V$ of the primary (viz. Terrell et al., 2005). An F4 star should have a $B-V$ value of about 0.40. The resulting $B-V$ of the binary is 0.45, in excellent agreement with the observed value, so the interstellar reddening toward Z Dra is small. The estimated distance to the system is 312 ± 28 pc, consistent with the value of 236 ± 80 pc determined by Hipparcos.

Table 1. Parameters for the light/velocity curve Sslution with $T_1 = 6725\ K$

Parameter	Value	Std. error†
a	$6.38\ R_\odot$	$0.06\ R_\odot$
V_γ	-31.3 km sec^{-1}	0.3 km sec^{-1}
i	$87\overset{\circ}{.}00$	$0\overset{\circ}{.}09$
T_2	4149 K	12 K
q	0.294	0.002
Ω_1	4.64	0.02
HJD$_0$	2453430.71662	0.00009
P	$1\overset{d}{.}3574179$	$0\overset{d}{.}000007$
$\dot{P}$	-1.7×10^{-9}	6.5×10^{-11}
$L_1/(L_1+L_2)_B$	0.958	0.002
$L_1/(L_1+L_2)_V$	0.912	0.002
$L_1/(L_1+L_2)_{R_C}$	0.866	0.003
$L_1/(L_1+L_2)_{I_C}$	0.820	0.003
M_1	$1.47\ M_\odot$	$0.04\ M_\odot$
M_2	$0.43\ M_\odot$	$0.01\ M_\odot$
R_1	$1.48\ R_\odot$	$0.01\ R_\odot$
R_2	$1.78\ R_\odot$	$0.02\ R_\odot$

† Formal errors from the differential corrections solution

All of the light curves show a slightly elevated light level compared to the theoretical curves before the ingress of the secondary eclipse. The mean light curve of Dugan (1912), gathered over approximately 3.5 years, appears to show the same asymmetry, perhaps indicating that this is a persistent feature. The fit to the secondary eclipse in the B light curve is poor and the fit to both eclipses in the I_C curve is also poor. The I_C light curve shows a strong asymmetry between the two maxima. The portion of the light curve between phases 0.6 and 0.9 is noticeably flatter than that between phases 0.1 and 0.4. Some attempts at fitting a variety of single hot and cool spots were made but none appeared to satisfactorily fit the asymmetries of all the light curves, indicating that a single spot model is insufficient.

A high-resolution spectroscopic study of the system is sorely needed. Since the eclipses are partial, the photometric mass ratio is questionable (viz. Terrell & Wilson, 2005) thus making this a preliminary solution. Measurement of the radial velocities of the

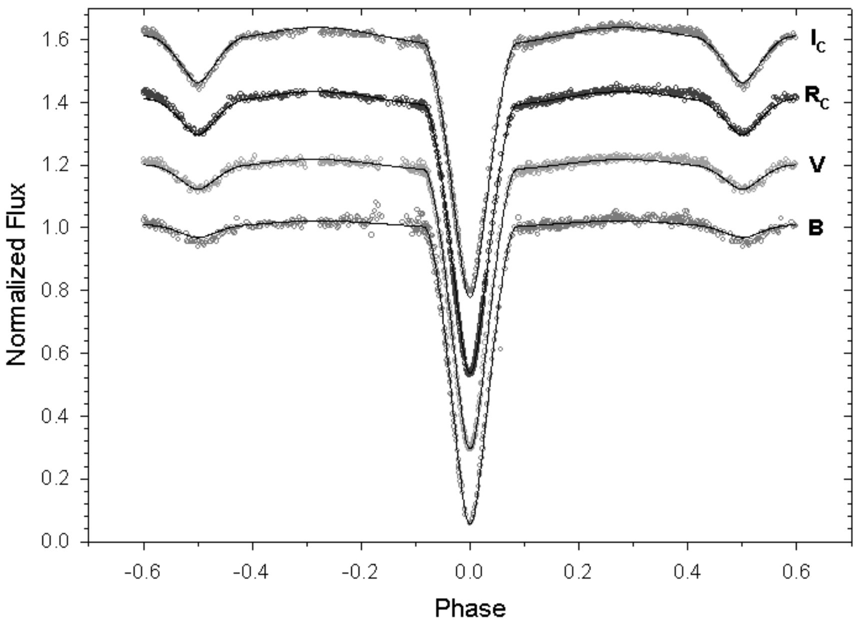

Figure 1. BVR_CI_C light curves of Z Dra and the fits from the Wilson–Devinney solution. The curves have been shifted vertically for clarity.

secondary is crucial to alleviating the concern about the mass ratio. Further photometric observations would reveal any temporal variability of the light curve asymmetries.

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