Research in Astron. Astrophys. **2009** Vol. **9** No. **11**, 1270–1276
http://www.raa-journal.org *http://www.iop.org/journals/raa*

Research in Astronomy and Astrophysics

DZ Lyn: a contact binary with components in poor thermal contact

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Received 2009 May 16; accepted 2009 June 16

Abstract CCD photometric observations of the short-period eclipsing binary DZ Lyn were obtained during seven nights in March-April 2008 in the B, V, R_c and I_c bands; these observations confirm the short-period ($P = 0.378\,\mathrm{d}$) of the system. The presented light curves are analyzed by means of the 2003 version of the Wilson-Devinney (WD) program. A grid of solutions for several fixed values of mass ratio was calculated. The best fitting possible is for a mass ratio of $q = 0.885$, a degree of contact $f = 0.18$ and a low orbital inclination of $i = 57.6°$. The results show that DZ Lyn is an A-subtype W Ursae Majoris contact binary in poor thermal contact; in fact the difference between the mean temperatures of the components is about 1800 K. The star DZ Lyn seems to be another member of the class of poorly understood close binaries in or near geometrical contact but far from thermal contact. The absolute dimensions are estimated and its dynamical evolution is inferred.

Key words: binaries: eclipsing — stars: fundamental parameters — stars: individual: DZ Lyn

1 INTRODUCTION

Eclipsing binaries which show an EB-type light-curve, but have an orbital period which falls in the range of classical W Urase Majoris systems, are very important for testing the theory of the evolution of contact binaries since they are candidates for binaries that are to become overcontact systems or are in the broken-contact phase predicted by Thermal Relaxation Oscillation (TRO) theory (Flannery 1976; Lucy 1976; Robertson & Eggleton 1977). Lucy & Wilson (1979) introduced for these stars the class of B-type systems which are systems in geometrical contact, but not in thermal contact, and therefore there are large surface temperature differences between the components that produce differences in the levels of the minima.

B-type systems are sometimes referred to as PTC (Poor Thermal Contact) systems (Rucinski & Duerbeck 1997). When such EB-type binaries exhibit orbital periods in the range of 0.3 to 0.7 d, and the spectral type is around F-G, they can be considered as candidates for W UMa systems in the phase of broken contact (Milano et al. 1989).

The light variability of the eclipsing binary DZ Lyn (HD 67894) was discovered by Maciejewski et al. (2003), using a Schmidt-Cassegrain telescope equipped with a CCD camera and a Richardson spectrograph. The authors pointed out that it was an EB-Type binary system with the following ephemeris

$$\mathrm{Min.I} = \mathrm{HJD}\ 2452722.47342 + 0.378018 \times E. \quad (1)$$

Based on the obtained spectrum, DZ Lyn was classified as an F3V spectral type star.

2 OBSERVATIONS

A total of 587 filtered B, V, R_c and I_c CCD observations were carried out on seven nights between JD 2454529 and JD 2454560 by one of us (MM) utilizing a 0.2 m Meade LX200 Schmidt-Cassegrain telescope equipped with an SBIG ST7 CCD Camera based on a Kodak KAF 401E chip (768×512 pixels of 9×9 microns), and a 16 bit A/D converter, without an antiblooming gate. The resulting field of view is 11.7×7.8 arcmin with a pixel resolution of 1.9×1.9 arcsec (binning 2×2). The frames were reduced using prism software by Cavadore & Gaillard; a self-developed sub-routine performed the initial data reduction (dark subtraction, flat field division) and automatic differential photometry of the target object, with comparison and check stars excluding images with poor SNR, generally less than 50, or with tracking errors. Measurements were made in the B, V, R_c and I_c bands using Johnson-Cousins filters and transformed into standard differential magnitudes as described by Cohen (2002) by means of a Microsoft Excel © spreadsheet.

The comparison star used was TYCHO2 2979.2354.1 ($m_v = 11.55$, $B - V = 0.41$), while USNO B1 1328.0240214 ($m_v = 13.80$; $B-V = 0.57$) served as the check star. The times of minima, presented in Table 1, all heliocentric, permit us to refine the orbital period as follows:

$$\mathrm{Min.I} = \mathrm{HJD}\ 2452722.47326(37) + 0.3780162(8) \times E. \tag{2}$$

Table 1 CCD Time of Minima of DZ Lyn

Band	JD(Hel.)+2400000	Epoch$_{(2)}$	$(O-C)_1$	$(O-C)_2$
B	54529.3893	4780.0	–0.0102	–0.0014
V	54529.3916	4780.0	–0.0079	0.0009
R_c	54529.3888	4780.0	–0.0107	–0.0019
I_c	54529.3903	4780.0	–0.0092	–0.0004
B	54531.4640	4785.5	–0.0146	–0.0058
V	54531.4633	4785.5	–0.0153	–0.0065
R_c	54531.4644	4785.5	–0.0142	–0.0054
I_c	54531.4719	4785.5	–0.0067	0.0021
B	54538.4680	4804.0	–0.0039	0.0049
V	54538.4642	4804.0	–0.0077	0.0011
R_c	54538.4621	4804.0	–0.0098	–0.0010
I_c	54538.4637	4804.0	–0.0082	0.0006
B	54560.3884	4862.0	–0.0085	0.0004
V	54560.3933	4862.0	–0.0036	0.0053
R_c	54560.3872	4862.0	–0.0097	–0.0008
I_c	54560.3952	4862.0	–0.0017	0.0072

3 PHOTOMETRIC SOLUTION

In order to determine the parameters of the system, we used the 2003 version of the DC program (Wilson & Devinney 1971; Wilson 1994; Wilson & van Hamme 2003). The analyses were done for the available B, V, R_c and I_c light curves simultaneously.

In the preliminary solution, we did not impose any constraint on the configuration of the system, and we used Mode 2 - a detached configuration with no constraint on the potentials (Leung & Wilson 1977). Convergence of the minimization procedure was obtained by means of the method of multiple subsets (Wilson & Biermann 1976). We made a solution grid for the mass ratio q, from the range 0.1 to 1.2. The first results reveal the primary star to be slightly overcontacting, while the secondary ones do not show clear indications; in some iterations, the value of the potential indicated that the star overflowed its Roche lobe but this was not the same for other iterations. So, we decided to analyze DZ Lyn in Mode 3 (overcontact configuration), Mode 4 (semi-detached configuration with star 1 accurately filling its limiting lobe) and Mode 5 (semi-detached configuration with star 2 accurately filling its limiting lobe).

In Mode 4, DC was not able to reach any convergence; this is obvious because the constriction applied in this mode is in contrast with the behavior observed in Mode 2. During all the calculations in Mode 5, as a constraint of the mode, the secondary fills its Roche lobe, while the primary star was found again to be slightly overcontacting. The semi-detached configuration dose not, therefore, lead to an acceptable model for DZ Lyn. Our final grid, with q varying in the same range, assumes physical contact between the components of the system, Mode 3.

The following system parameters were adopted: based on the spectral type F3V, we let the temperature of the primary component be 6860 K using the tables of Habets & Heintze (1981). The bolometric and wavelength-dependent limb darkening coefficients ($x_{1\mathrm{bolo}} = x_{2\mathrm{bolo}}$, $y_{1\mathrm{bolo}} = y_{2\mathrm{bolo}}$, $x_{1BVRI} = x_{2BVRI}$), using the square root law (LD = 3), were taken from van Hamme (1993) for log g = 4.0 and solar abundances. The gravity-darkening exponents were adopted to be $g_1 = g_2$ = 0.32 for the convective envelopes (Lucy 1967), and the bolometric albedos were $A_1 = A_2$ = 0.50 (Rucinski 1969). A fine surface grid, N1 = N2 = 30, N1L = N2L = 25, and symmetrical partial derivatives for each of the adjustable parameters (ISYM = 1) were adopted during all calculations. The simple reflection model (Wilson 1990) was used with a single reflection (MREF = 1, NREF = 1). The third light was not allowed, $l_3 = 0.0$, circular orbit and synchronous rotation were assumed ($F_1 = F_2 = 1$).

The parameters we left adjustable using Mode 3 were: the inclination i, the mean surface temperature of the secondary component T_2, the non-dimensional surface potential, $\Omega_1(= \Omega_2)$, and the monochromatic luminosity of the primary component L_1 (the black-body option was used in the computing code).

Since a spectroscopically determined mass ratio $q = m_2/m_1$ is not available, a search for a solution was made for several fixed values of q in the range between 0.1 and 1.2. A sufficient number of runs of the DC program was made until the sum of the residuals $\sum(\mathrm{res})^2$ showed a minimum and the corrections to the parameters became smaller than their probable errors. The solution for each value of q indicated that the best fitting was for $q = 0.9$, $\sum(\mathrm{res})^2 = 0.7713$, as shown in Figure 1.

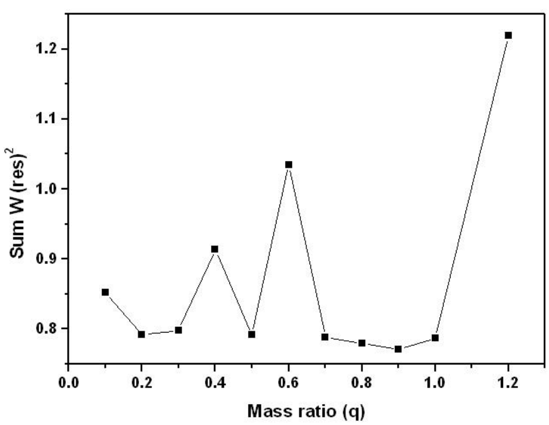

Fig. 1 Relation $\sum(\mathrm{res})^2$ - mass ratio q in Mode 3 for DZ Lyn.

Starting with the preliminary solution for $q = 0.9$, we made a more detailed analysis with q being treated as an additional free parameter, our best solution converged to a value of mass ratio $q = 0.885$. Figure 2 shows the observations (points) and the obtained final fits (lines).

To show the quality of the solutions, the residuals $(O - C)$ are plotted against the orbital phase in Figure 3. For about 90 percent of all the points, the residuals range from –0.02 to +0.02 mag, which indicates that the solution fits the observations fairly well, except for the V filter (Fig. 2). The parameters obtained are given in Table 2, and the errors reported in this table are underestimated due to the applied modeling code.

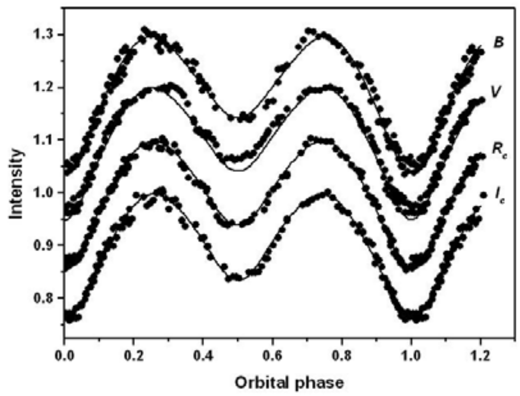

Fig. 2 Original CCD (B, V, R_c, I_c) light curves (points) and the theoretical ones (lines) for DZ Lyn. For convenience, the light curves are shifted by arbitrary amounts in intensity.

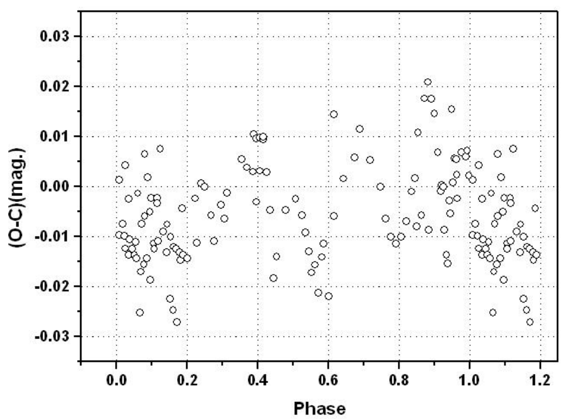

Fig. 3 Residuals $(O - C)$ of the solution for DZ Lyn.

Our results showed that DZ Lyn is a contact binary with components in poor thermal contact; no asymmetries are observed in the maxima. According to Flannery (1976), the value of the stability parameter = 0 demonstrates that no mass transfer occurs, due to the equal potential on the two components. This statement is supported by the fact that no magnetic activity (spots) has been found. The poor thermal contact ($\Delta T = 1792\,\mathrm{K}$) explains the EB-type light curve and the degree of thermal decoupling DT = $(\frac{T_1 - T_2}{T_1}) = 0.26$ (Lipari & Sistero 1988) indicates that DZ Lyn is an A-type W Ursae Majoris system. The degree of geometrical contact, defined as $f = (\Omega_{\rm in} - \Omega_{1,2})/(\Omega_{\rm in} - \Omega_{\rm out})$ is only about 18 percent. The configuration of DZ Lyn in the orbital plane is shown in Figure 4.

4 ESTIMATED ABSOLUTE ELEMENTS OF DZ LYN AND ITS DYNAMICAL EVOLUTION

Mass is not an easily determinable stellar parameter, especially for overcontact binaries. It can only be obtained by knowing both photometric and spectroscopic elements. However, from the statistical period-mass relation (Gazeas & Stępień 2008) we made an estimation of the mass of the primary star $M_1 = 1.25\,M_\odot$. From the derived mass ratio, $m_c/m_h = q = 0.88555$ and the assumed mass of $1.25\,M_\odot$ for m_h, the mass of the secondary component has been derived as $1.11\,M_\odot$.

Table 2 Light Curve Solution for DZ Lyn

Parameter	Value
i	57.600° ±0.232°
$T_1(K)$	6860*
$T_2(K)$	5068 ± 3
f	0.180 ± 0.004
$\Omega_1 = \Omega_2$	3.4731 ± 0.0082
$q = m_2/m_1$	0.88555 ± 0.00378
$A_1(= A_2)$	0.50*
$g_1(= g_2)$	0.32*
$L_{1B}/(L_1 + L_2)$	0.778 ± 0.006
$L_{2B}/(L_1 + L_2)$	0.131 ± 0.002
$L_{1V}/(L_1 + L_2)$	0.752 ± 0.006
$L_{2V}/(L_1 + L_2)$	0.174 ± 0.002
$L_{1R}/(L_1 + L_2)$	0.707 ± 0.005
$L_{2R}/(L_1 + L_2)$	0.207 ± 0.007
$L_{1I}/(L_1 + L_2)$	0.673 ± 0.004
$L_{2I}/(L_1 + L_2)$	0.242 ± 0.008
$X_{1B} = X_{2B}$	0.221*
$X_{1V} = X_{2V}$	0.077*
$X_{1R} = X_{2R}$	–0.032*
$X_{1I} = X_{2I}$	–0.094*
L_3	0
Primary component	
r(pole)	0.3775 ± 0.0012
r(side)	0.3993 ± 0.0015
r(back)	0.4358 ± 0.0024
Secondary component	
r(pole)	0.3579 ± 0.0013
r(side)	0.3774 ± 0.0016
r(back)	0.4153 ± 0.0025
$\sum(\text{res})^2$	0.777851

* assumed parameters

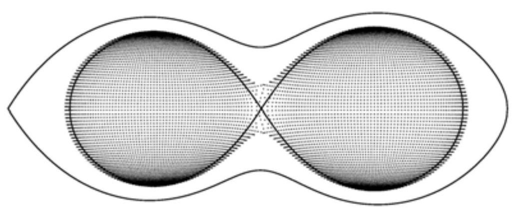

Fig. 4 Configuration of the components of DZ Lyn in the orbital plane, according to our solution.

Combined with the photometric solution and its period, using the well known formulae (Milano & Russo 1983), we estimated the absolute parameters for this system, as reported in Table 3.

The computed absolute elements of DZ Lyn are used to estimate the evolutionary status of the system by means of the mass-radius diagram (Fig. 5). It can be seen that the radii of both components correspond to the values for ZAMS stars with the same masses; in fact, if the primary component could be at the ZAMS location, its radius should be $1.15\,R_{\odot}$ (Awadalla & Hanna 2005), according to the present estimated radius of $1.18\,R_{\odot}$. So, DZ Lyn may be classified as an unevolved contact binary

Table 3 Estimated Absolute Elements for DZ Lyn

Primary	Secondary
Mass $(M_\odot) = 1.25$	Mass $(M_\odot) = 1.11$
Radius $(R_\odot) = 1.18$	Radius $(R_\odot) = 1.12$
$\log(L/L_\odot) = 0.45$	$\log(L/L_\odot) = -0.12$

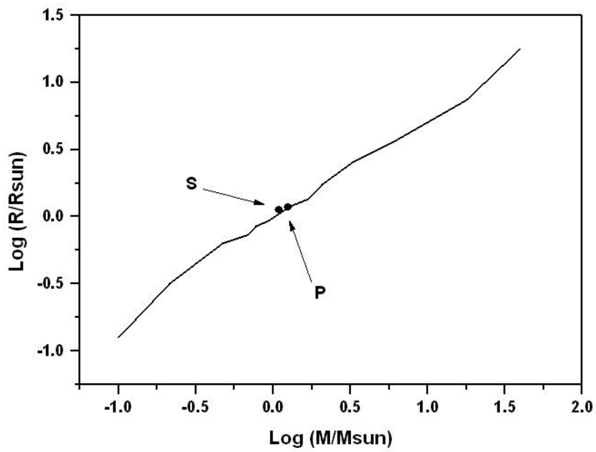

Fig. 5 Location of the primary and secondary components of DZ Lyn on a $\log M$ - $\log R$ diagram. The solid line shows the ZAMS.

undergoing thermal relaxation oscillation. With the present absolute elements (Table 3) we can infer the dynamical evolution of the binary orbit of the system using the Orbital angular momentum J_0 (Eker et al. 2006).

In their paper, Eker et al. investigated 119 chromospherically active binaries (CAB) and 102 W UMa stars by means of the Orbital angular momentum (OAM, J_0) and systemic mass (M); they found, in the log J_0 - $\log M$ diagram, a curved borderline named a contact border separating the detached and the contact systems. The physical significance of this line is that it marks the maximum OAM for a contact system to survive. If the OAM of a contact system is more than $J_{\rm lim}$, the contact configuration breaks.

The position found for DZ Lyn in the $\log J_0$ - $\log M$ diagram is slightly under the $J_{\rm lim}$ borderline, with log J_0 = 51.969 (cgs), which justifies the geometrical contact situation.

5 CONCLUSIONS

The light curve analysis presented here indicates that DZ Lyn is another example of the increasing number of W UMa binaries in poor thermal contact displaying EB-type light curves. Systems of this kind are interesting from the point of view of the "Thermal Relaxation Oscillation" theory. According to this theory, an unevolved W UMa system undergoes oscillation about a state of marginal contact. In the phase when the thermal contact between the components does not exist or is weak, the system exhibits an EB-type light curve, which is called a B-type contact binary, and the system is at the beginning or end of the contact phase.

DZ Lyn possess EB-type light curves. The components are geometrically in contact with each other and the binary system is still in the domain of the period-color diagram dominated by conventional W UMa binaries. Moreover, for W UMa systems undergoing such oscillations, the systems are in shallow contact and the degree of overcontact f is restricted to be less than 30 percent.

In the context of TRO theory, DZ Lyn seems to have recently left the EB stage of broken contact. Thus, the components still have a large temperature difference. Also, the large mass ratio found for the system is predicted by TRO theory. During the semidetached phase, q increases because the primary component is losing mass through its inner Lagrangian point L_1 as it attempts to achieve thermal equilibrium. Thus according to TRO theory, the system appears to be in the early contact phase of thermal relaxation oscillations.

From the photometric solution of the B, V, R_c and I_c light curves of DZ Lyn, using the WD code, we conclude that the system is in a shallow contact with a filling factor of about 0.18. It is an A-type W Ursae Majoris variable star, with a high mass ratio $q = 0.885$. The primary (deeper) minimum occurs when the larger, more massive star, is eclipsed by its smaller, less massive companion.

The absolute dimensions of DZ Lyn cannot be determined directly because radial velocity observations are unavailable. Astrophysical parameters for the two components of DZ Lyn are presented in Table 3, based on the period-mass relation by Gazeas & Stępień (2008). Both of the components in the system appear to be main sequence stars. In the $\log J_0$ - $\log M$ diagram, DZ Lyn is shown as a contact system slightly under the contact borderline between the detached and contact regions. This situation also explains the difficulties encountered in the choice of the DC operating mode. Of course, our solution is only based on photometric observations. The lack of photoelectric times of minima for DZ Lyn makes it very difficult to determine the nature of any orbital period changes occurring now. For a better understanding of the properties and the evolutionary state of this interesting system, spectroscopic observations and more photometric data are needed.

Acknowledgements We would like to thank Dr. Oleg Malkov for allowing a debate on the typology of the system.

References

Awadalla, N. S., & Hanna, M. A. 2005, Journal of Korean Astronomical Society, 38, 43
Cohen, L. 2002, Computing and Using CCD Transformation Coefficients, AAVSO Information Sheet, see *www.aavso.org*
Eker, Z., Demircan, O., Bilir, S., & Karataş, Y. 2006, MNRAS, 373, 1483
Flannery, B. P. 1976, ApJ, 205, 217
Gazeas, K., & Stępień, K. 2008, MNRAS, 390, 1577
Habets, G. M. H. J., & Heintze, J. R. W. 1981, A&AS, 46, 193
Leung, K.-C., & Wilson, R. E. 1977, ApJ, 210, 853
Lipari, S. I., & Sistero, R. F. 1988, PASP, 100, 377
Lucy, L. B. 1967, Zeitschrift fur Astrophysik, 65, 89
Lucy, L. B. 1976, ApJ, 205, 208
Lucy, L. B., & Wilson, R. E. 1979, ApJ, 231, 502
Maciejewski, G., Czart, K., Miedzielski, A., & Karska, A. 2003, IBVS, 5431, 1
Milano, L., & Russo, G. 1983, MNRAS, 203, 235
Milano, L., Barone, F., Mancuso, S., Russo, G., & Vittone, A. A. 1989, A&A, 210, 181
Robertson, J. A., & Eggleton, P. P. 1977, MNRAS, 179, 359
Rucinski, S. M. 1969, Acta Astronomica, 19, 245
Rucinski, S. M., & Duerbeck, H. W. 1997, PASP, 109, 1340
van Hamme, W. 1993, AJ, 106, 2096
Wilson, R. E., & Devinney, E. J. 1971, ApJ, 166, 605
Wilson, R. E., & Biermann, P. 1976, A&A, 48, 349
Wilson, R. E. 1990, ApJ, 356, 613
Wilson, R. E. 1994, PASP, 106, 921
Wilson, R. E., & van Hamme, W. 2003, Computing Binary Stars Observables, the 4th editon of the W-D program (*ftp.astro.ufl.edu, dicrectory pub/wilson/lcdc2003*)