J. Astrophys. Astr. (2006) **27,** 47–56

Photometric Modelling of Close Binary Star CN And

D. M. Z. Jassur[1,2,*] & A. Khodadadi[2]
[1]*Faculty of Physics, Tabriz University, Tabriz, Iran.*
[*]*e-mail: Jassur@tabrizu.ac.ir*
[2]*Center for Applied Physics and Astronomical Research, Khadjeh Nassir Addin Observatory, Tabriz, Iran.*

Received 2004 April 15; accepted 2006 March 16

Abstract. The results of two color photometry of active close binary CN And are presented and analyzed. The light curves of the system are obviously asymmetric, with the primary maximum brighter than the secondary maximum, which is known as the O'Conell effect. The most plausible explanation of the asymmetry is expected to be due to spot activity of the primary component. For the determination of physical and geometrical parameters, the most new version of W–D code was used, but the presence of asymmetry prevented the convergence of the method when the whole light curves were used. The solutions were obtained by applying mode 3 of W–D code to the first half of the light curves, assuming synchronous rotation and zero eccentricity. Absolute parameters of the system were obtained from combining the photometric solution with spectroscopic data obtained from radial velocity curve analysis. The results indicate the poor thermal contact of the components and transit primary minimum. Finally the O–C diagram was analyzed. It was found that the orbital period of the system is changing with a rate of $dP/dt = -2.2(6) \times 10^{-10}$ which corresponds to mass transfer from more massive component to less massive with the rate of $dM/dt \sim 4.82 \times 10^{-8}\, M_{\mathrm{sun}}/\mathrm{year}$.

Key words. Close binaries—stars spot—active starts—light curve analysis.

1. Introduction

The variability of CN And (= BD + 39 59) was discovered by Hoffmeister (1949). On the basis of photographic data, Tsesevich (1956) classified the system as an Algol-type binary and derived an orbital period of 2.599 days. Later Lochel (1960) classified it as a WUMa-type system and was the first to correctly determine the period of 0.462798 days. The system has been observed by many authors (e.g., Seeds and Abernathy 1982; Michaels *et al.* 1984; Evren *et al.* 1987). The light curves are characterized by interesting asymmetries (Rafert *et al.* 1985) similar to V1010 Ophiuchi binaries (Shaw 1994). Its light level of activity was attested by two flares seen by Yu-Lan and Quing-Yao (1985), as well as its X-ray luminosity of $\log Lx = 30.55$ (Shaw *et al.* 1996). Two groups of investigators have attempted analyzing the light curves for geometrical and

Table 1. Observed times of minima of CN And.

J.D.Hel 2451000+	Type of Min	$(O–C)_1$	$(O–C)_2$
458.3786	I	−0.0250	−0.0058
469.2556	II	−0.0236	−0.0043
471.3341	I	−0.0277	−0.0083
807.3239	I	−0.0262	−0.0045
811.2607	II	−0.0231	−0.0014
814.2692	I	−0.0227	−0.0010

physical parameters, disregarding the lack of any information on spectroscopic mass ratio. Kaluzny (1983) expected the mass ratio to be within $0.55 < q_{ph} < 0.85$. Rafert *et al.* (1985) found the most likely interval to be $0.5 < q_{ph} < 0.8$; they saw indications of strong contact. In the present work, the light curves of the system CN And have been analyzed on the basis of new photoelectric observations carried out by authors and spectroscopic mass ratio given by Rucinski *et al.* (2000).

2. Observations and data

The present observations of CN And were carried out with 40 cm Cassegrain telescope of Khadjeh Nassir Addin Observatory of Tabriz University during the summer of 1999 and 2000. The observations were made in B and V filters with peak wavelength (widths) of 4350 A° (970 A°) and 5500 A° (850 A°) respectively. A single channel photometer equipped with an unrefrigerated photomultiplier tube (RCA 1P21) was used. The output current was amplified and fed into a PC via an A/D conventor for rapid data access. Two stars GSC 02787-01780 and BD + 39 65 were used as comparison and check stars respectively. During the observations four primary and two secondary times of minima were obtained in each filter, by parabolic fitting to the observational points, making use of the least square method. Those minima are given in Table 1 where $(O–C)_1$ and $(O–C)_2$ residuals have been computed using equations

$$\text{J.D.Hel (Min I)} = 2450698.9591(18) + 0.46279372(13) \times E$$

and

$$\text{J.D.Hel (Min I)} = 2450698.9447(14) + 0.46279092(19) \times E - 9.8(6) \times 10^{-11} \times E^2$$

given by Samec *et al.* (1998) respectively.

We obtained ∼300 individual points for each filter with standard error of single observation ∼0.02 mag. The data were reduced to outside atmosphere and to standard system based upon comparison star reading and standard stars observations. Standard magnitudes and colors of variable stars in different phases are given in Table 2.

Figures 1 and 2 show the corrected light curves. The light curves are obviously asymmetric, with the primary maximum (phase 0.25) being brighter than the secondary maximum (phase 0.75) which is known as the O'Conell effect. Δ(Max I − Max II) is ∼0.09 in B and ∼0.10 in V filters.

Table 2. Standard magnitudes and colors of CN And in different phases.

Phase	V (mag)	$(B-V)$
0.00	10.43 ± 0.02	0.47 ± 0.02
0.25	9.78 ± 0.01	0.43 ± 0.01
0.50	10.13 ± 0.02	0.42 ± 0.01
0.75	9.88 ± 0.01	0.47 ± 0.02

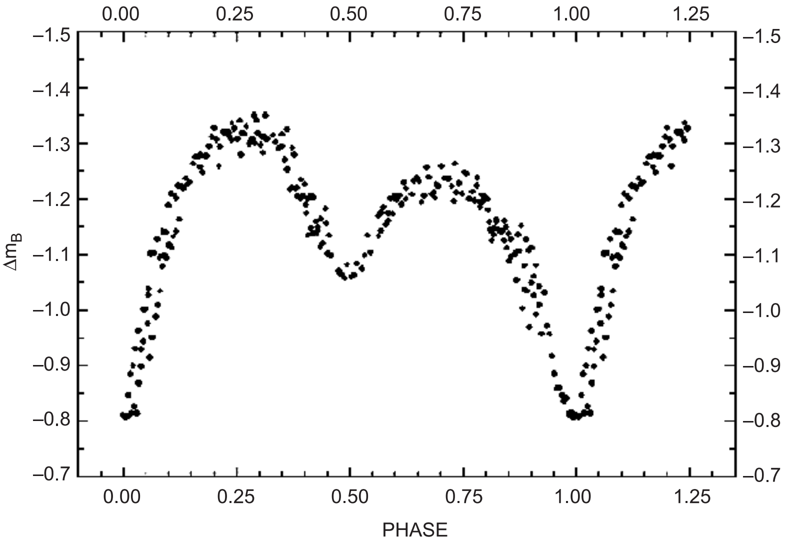

Figure 1. Standard ΔB (Var – Comp) light curve of CN And for observations in 2000.

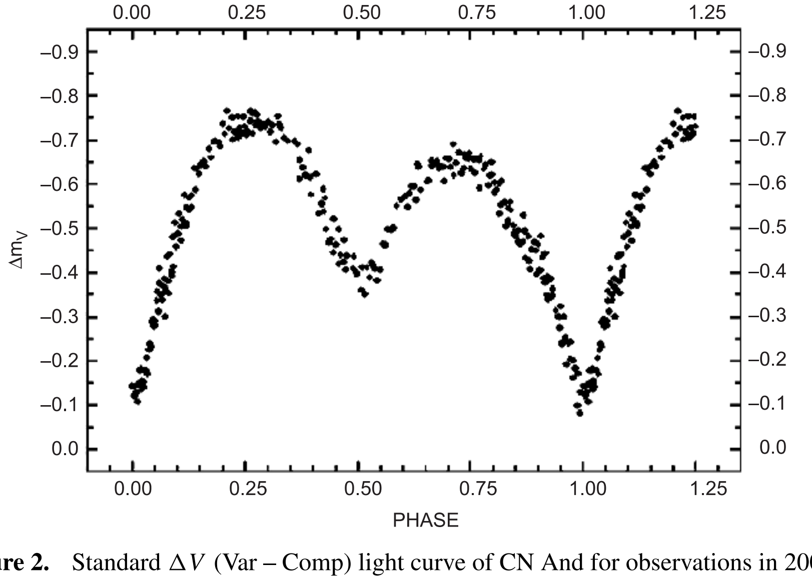

Figure 2. Standard ΔV (Var – Comp) light curve of CN And for observations in 2000.

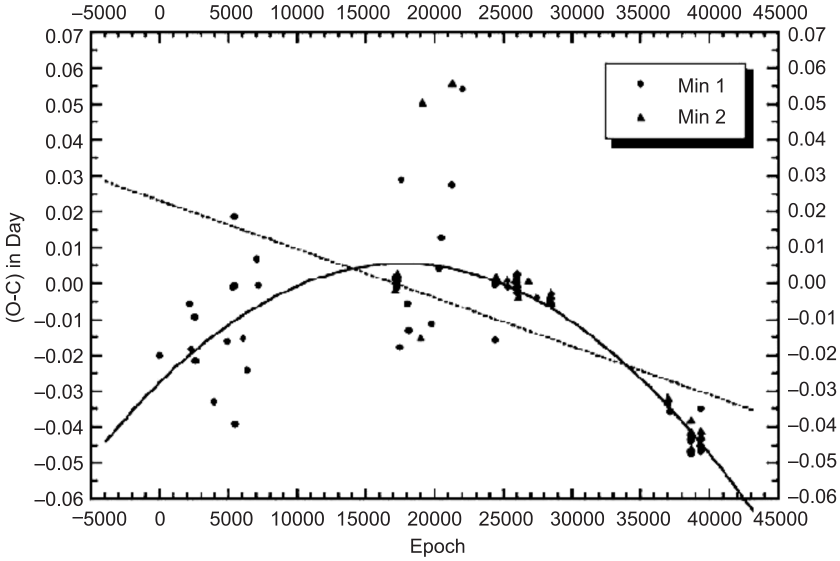

Figure 3. Linear and quadratic fit of all minima.

3. Period variation

From a comprehensive discussion of all times of minima of CN And, Samec *et al.* (1998) concluded that a representation of the observed times of minima could be made by a parabola, implying a steady rate of period variation of $dP/dt = -4.24 \pm 0.26 \times 10^{-11}$. We have re-investigated these data including also our own values given in Table 1.

We assigned weights of 1, 2, and 6 to visual, photographic and photoelectric minima respectively. Linear and quadratic weighted least-square fits to all minima (Fig. 3) yielded ephemerides:

$$\text{J.D.Hel (Min I)} = 2433570.5067(\pm 0.0026) + 0.462793293(\pm 0.000000076)\text{E}$$

and

$$\text{J.D.Hel (Min I)} = 2433570.4567(\pm 0.0018) + 0.462798329(\pm 0.000000148) \times \text{E} - 1.048(\pm 0.0298)10^{-10}\,\text{E}^2.$$

Residuals for each of these fits are shown in Figs. 4 and 5. The corresponding dP/dt is $-2.2(6)10^{-10}$. The significance of this period changes will be discussed in section 5.

4. Analysis

We used Wilson and Devinney (1971) differential correction method to analyze the observed light curves. It was assumed that CN And has a circular orbit and the rotational and orbital spins are synchronous. Also black-body models were employed. In deriving the photometric solution, the following parameters were adopted: Standard values of

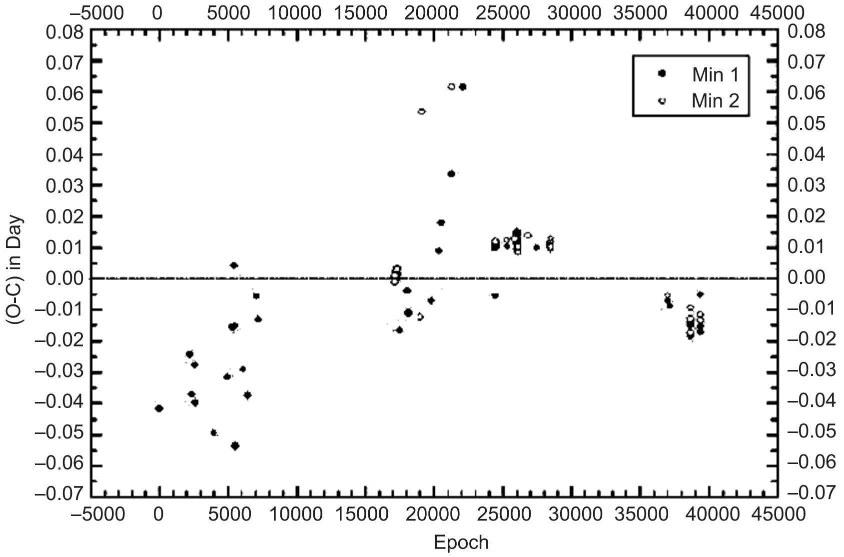

Figure 4. Residuals for linear least-square fit.

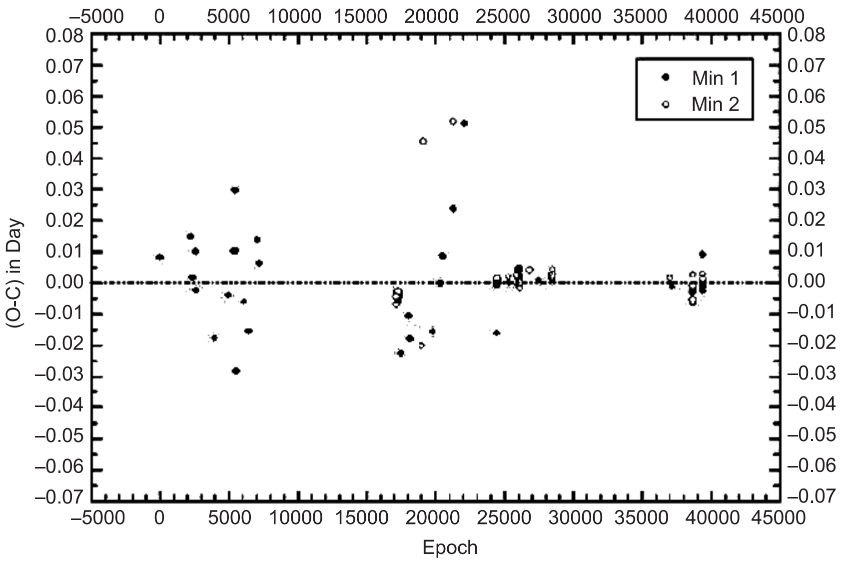

Figure 5. Residuals for quadratic least-square fit.

gravity darkening coefficients $g_1 = g_2 = 0.32$ for B and V filters and the bolometric albedoes $A_1 = A_2 = 0.5$ consistent with that of convective atmospheres (Lucy 1967). The limb darkening coefficients appropriate to spectral types of both components (F5 + G5) were found by interpolation from tables given by Al-Naimiy (1978).

Unfortunately, the information from light curves are not usually sufficient to derive an accurate value for mass ratio, q. Spectroscopic observations, on the contrary, lead to a more reliable and relatively accurate value for q. For the case of CN And, a mass ratio

Table 3. Spots - parameters.

Parameter	Spot no. 1	Spot no. 2
Co-latitude	70°	90°
Longitude	294°	174°
Angular-size	25°	18.5°
Temperature	5236° k	5544° k

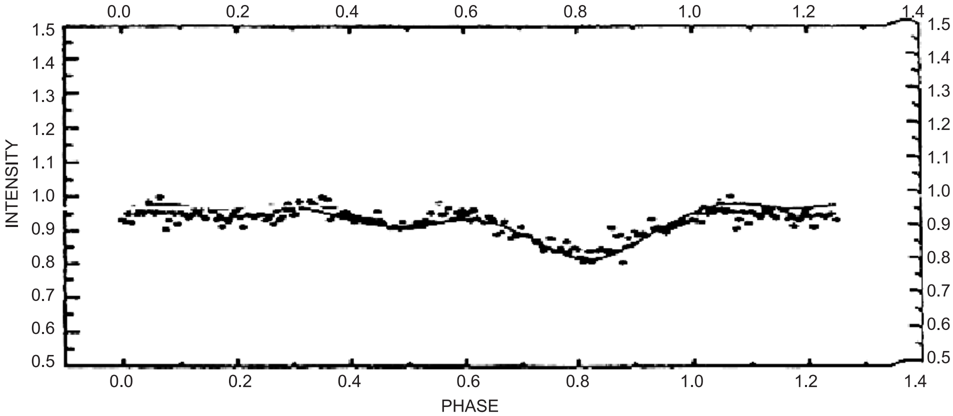

Figure 6. Intensity variation due to spots and the theoretical curve fit based on parameters given in Table 3.

of 0.39 has been reported from radial velocity observations by Rucinski *et al.* (2000). We adopted this value for q. W–D code in mode 3 (contact and near contact configurations) was employed in which the luminosity of secondary component is coupled and cannot vary independently. The presence of asymmetry prevented the convergence of the method when the whole light curves were used.

The solutions were obtained in three steps as described below:

- Mode 3 of W–D code was applied to the first half of the light curves to obtain uncleaned parameters specifying the system.
- We deconvolved the theoretical light-curve corresponding to our adopted model in the first step from the observed light curve. The object of this was to obtain the intrinsic light variation of the system. The quasi-sinusoidal light variations were interpreted in terms of cool star-spots covering a significant fraction of stellar photosphere. Two circular spots were assumed on the equator of the primary, each with different values of ΔT (temperature difference between spots and surrounding photosphere). The corresponding sizes of area covered by spots were obtained using a method based on Budding's theory (1977). This procedure was repeated for B and V bands. The sizes of spotted area were plotted versus ΔT for each filter. The intersection point of these curves corresponded to spots $\sim$1000 degrees cooler than the surrounding photosphere. Spots parameters are given in Table 3. Figure 6 shows the theoretical fit to the observed light variations due to spots.
- We cleaned the original observations by correcting for the presence of the distor-

Table 4. Photometric parameters of CN And.

Parameter	B $\lambda = 4350\,A$	V $\lambda = 5550\,A$	Mean values
i	70.52 ± 0.17	69.22 ± 0.19	69.87
q	0.39	0.39	0.39
T_1	6138 ± 22	6182 ± 18	6160
T_2	4690 ± 11	4628 ± 13	4659
$\Omega_1 = \Omega_2$	2.625 ± 0.005	2.609 ± 0.007	2.617
$L_1/(L_1 + L_2)$	0.9263 ± 0.0013	0.9031 ± 0.0018	–
$L_2/(L_1 + L_2)$	0.0737	0.0969	–
r_1 (pole)	0.4322	0.4522	0.4422
r_1 (side)	0.4615	0.4869	0.4742
r_1 (back)	0.5017	0.5057	0.5037
r_2 (pole)	0.2816	0.2954	0.2885
r_2 (side)	0.3112	0.2918	0.3015
r_2 (back)	0.3415	0.3391	0.3403
Ω_{in}	2.657	2.657	2.657
Ω_{out}	2.419	2.419	2.419

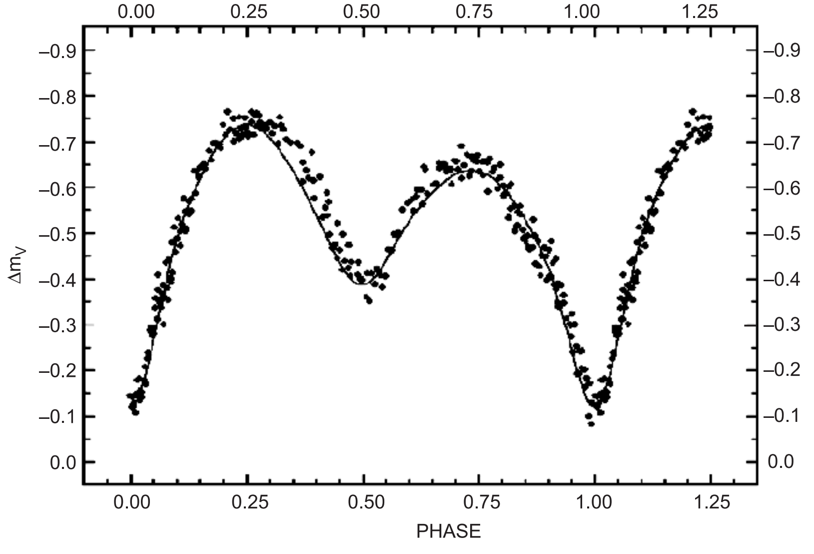

Figure 7. Observed and theoretical light curve of CN And based on parameters given in Table 4 (V-filter).

tion wave, adding the theoretical distortion wave effects to the data with opposite signs. Mode 3 of W–D code was then used to find cleaned parameters to provide us with information about the physical properties of the system. The set of parameters for which a fairly good fit to the observed points was obtained, are summarized in Table 4. The theoretical light curves fit of CN And based on the parameters in Table 4 are shown in Figs. 7 and 8.

The geometric and physical parameters determined from photometric solution were

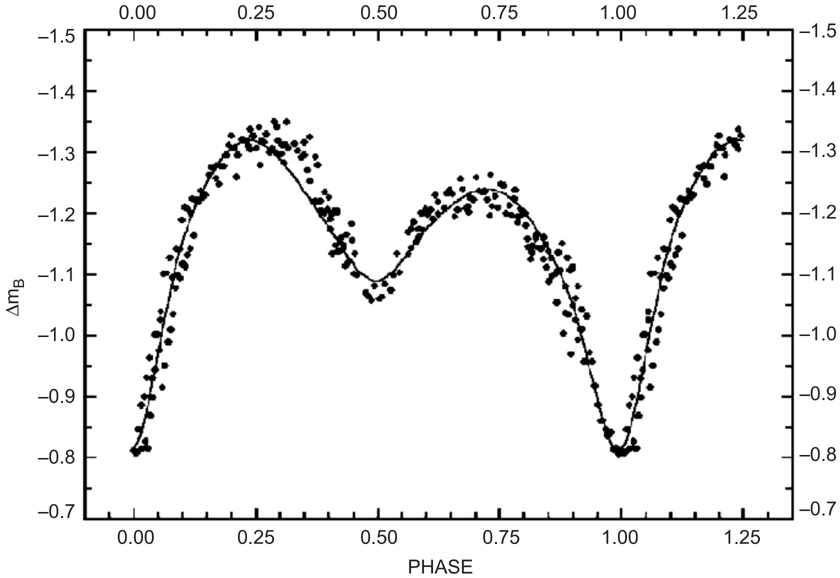

Figure 8. Observed and theoretical light curve of CN And based on parameters given in Table 4 (B-filter).

Table 5. Absolute dimensions of CN And calculated for mean values of Table 4.

Parameter	M/M_{sun}	R/R_{sun}	T/T_{sun}	L/L_{sun}
Primary	1.267	1.439	1.066	2.679
Secondary	0.494	0.943	0.806	0.376

combined with the spectroscopic data obtained from radial velocity analysis for both components by Rucinski *et al.* (2000) to yield the absolute dimension of the system (Table 5).

5. Concluding remarks

From the present study of the active binary CN And based on new photometric and spectroscopic data, we may conclude that:

1. The system CN And is an A-sub type WUMa binary with an over-contact configuration with fill-out factor defined as $f = (\Omega_{in} - \Omega_{1,2})/(\Omega_{in} - \Omega_{out})$ equal to 17%. This result is in agreement with that of Kaluzny (1983) and Rafert *et al* (1985) who found the system to be over-contact, but in contradiction to Van Hamme *et al.* (2001) who found semi-detached configuration.
2. The difference between the temperatures of the components is large ($\sim$1500 k), so the system is an over-contact binary with components in poor thermal contact.

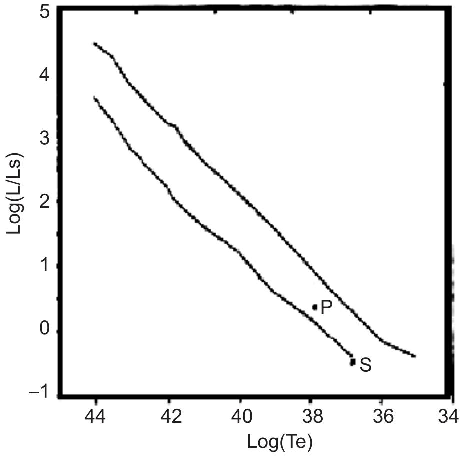

Figure 9. Positions of both components of CN And on H–R diagram.

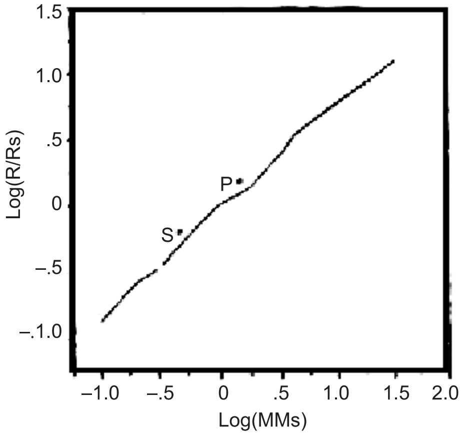

Figure 10. Positions of both components of CN And on R–M diagram.

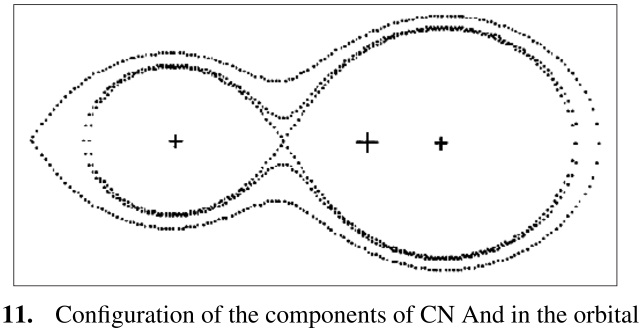

Figure 11. Configuration of the components of CN And in the orbital plane.

3. The positions of both components are shown in H–R and mass–radius diagrams in Figs. 9 and 10 respectively. It can be seen that the radii of both components are larger than the corresponding values for ZAMS stars with the same masses. So CN

And may be classified as an evolved over-contact undergoing thermal relaxation oscillation. Configuration of the system is shown in Fig. 11.

4. The period changes of the system (see section 3) which is decreasing continuously, could be interpreted in terms of mass transfer between two components. Assuming mass conservation, the rate of mass transfer is:

$$\Delta m/m = 3.472 \times 10^{-11}$$

or

$$dM/dt = 4.82(6) \times 10^{-8}\, M_{\rm sun}/\text{year}.$$

Acknowledgements

This work has been supported by the Vice Chancellor for research affairs of Tabriz University.

References

Al-Naimiy, H. 1978, *Astrophys. Space Sci.*, **53**, 181.
Budding, E. 1977, *Astrophys. Space Sci.*, **48**, 267.
Evren, S., Ibanoglu, C., Tunca, Z., Akan, M. C., Keskin, V. 1987, *IBVS*, No. 3109.
Hoffmeister, C. 1949, *AN*, **12**, 1.
Kaluzny, J. 1983, *Acta Astr.*, **33**, 345.
Lucy, L. B. 1967, *Zeitschrift fur Astrophysik*, **65**, 89.
Lochel, K. 1960, *M.V.S.* 457–458.
Michaels, E. J., Markworth, N. L., Rafert, J. B. 1984, *IBVS*, No. 2474.
Rafert, J. B., Markworth, N. L., Michaels, E. J. 1985, *PASP*, **97**, 310.
Rucinski, S. M., Lu, W., Mochnacki, S. M. 2000, *AJ*, **120**, 1133–1139.
Samec, R. G., Laird, H., Mutzke, M., Faulkner, D. R. 1998, *IBVS*, No. 4616.
Seeds, M. A., Abernathy, D. K. 1982, *PSAP*, **94**, 1001.
Shaw, J. S. 1994, *Soc. Astron. Ital.* **65(1)**, 95.
Shaw, J. S., Caillaut, J. P., Schmitt, J. H. M. M. 1996, *APJ*, **461**, 951.
Tsesevich, W. 1956, *A.C.Kasan*, **170**, 14.
Van Hamme, W., Samec, R. G., Gothard, N. W., Wilson, R. E., Faulkner, D. R., Branly, R. M. 2001, *AJ*, **122**, 3436.
Wilson, R. E., Devinney, E. J. 1971, *Astrophys. J.* **166**, 605.
Yu-Lan, Y., Qing-Yao, L. 1985, *IBVS*, No. 2705.