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V375 Cas: THE BETA LYR TYPE ECLIPSING BINARY SYSTEM WITH A POSSIBLE THIRD COMPONENT

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ABSTRACT

A detailed analysis study was carried out to examine the period change of the Beta Lyr type eclipsing binary star V375 Cas, and the first results are presented in the perent study. In the analysis, the published eclipsing times of the system were used together with the minimum times derived from the *BVR* light curves obtained by photometric observations made in ÇOMUO and the *TESS* archival data. The distribution of *O-C* residuals can be represented by a sinusoidal structure superimposed on the upward parabola. Accordingly, the increase rate of the orbital period was determined as 0.052(1) s/yr and the mass transfer rate (from the less massive component to the more massive one) was +5.64x10^{-7} $M_{\odot}$/yr. The minimum mass of the third component responsible for the periodic change was found to be 2.85(40) $M_{\odot}$. In addition, the contribution of the third component to the total light was investigated by modeling the *BVR* light curves with the MC algorithm. Accordingly, the third light contribution was found to be 5% in the *B* filter, 8% in the *V* filter and 9% in the *R* filter.

Keywords: Eclipsing binary star, β Lyr type, Near-contact binary, V375 Cas, Period analysis

1. INTRODUCTION

Eclipsing binary stars are an important laboratory in the study of some complex physical processes/mechanisms in stellar astrophysics, such as mass transfer/loss, loss of angular momentum, magnetic activity, tertiary component, accretion disk, stellar evolution. In this study, it is aimed to examine the period change of the eclipsing binary star V375 Cas classified as a β lyr type system, which has been neglected in the literature.

Weber (1958) discovered the variability of the eclipsing binary V375 Cas. The system's spectral type was determined by Brodskaya (1955) as B3. Zhang et al. (1985, 1986) published the first photoelectric observations in the *BV* filters and gave the linear ephemeris as T_0=2445635.1514(16) and P=1.47338191(28) days. The authors analyzed the light curves and described V375 Cas as a semi-detached Algol-like binary star with mass ratio=0.6. Barone et al. (1992) presented the analysis of the data of V375 Cas together with three EB type eclipsing binaries and concluded that the system may be classified to be a semi-detached binary.

The target system is one of the neglected eclipsing binary stars in terms of photometric, spectroscopic and period analysis: The eclipsing binary V375 Cas takes place in several catalog studies of eclipsing binary stars that just contain limited photometric properties (Brancewicz and Dworak, 1980; Bidealman, 1982; Reed, 2003; Malkov et al., 2003; Avvakomova et al., 2013; Cruzalebes et al., 2019). Some authors also recorded the minimum light times of V375 Cas (Hubscher et al., 2005; Walter, 2005; Hubscher et al., 2006; Hubscher, 2007; Hubscher et al., 2008; Samolyk, 2008ab; Brat et al., 2009; Samolyk, 2010ab; Hubscher, 2011ab; Hubscher, 2015). The physical parameters of the system are given in Table 1 from Brancewicz and Dworak (1980).

Table 1. The physical parameters of V375 Cas from Brancewicz and Dworak (1980). ($M_\odot$: Mass in solar unit; $R_\odot$: Radius in solar unit; K: Kelvin; B: Beta Lyr)

Name	**Period (days)**	**T_1 (K)**	**T_2 (K)**	**R_1 ($R_\odot$)**	**R_2 ($R_\odot$)**	**M_1 ($M_\odot$)**	**M_2 ($M_\odot$)**	**Type**
V375 Cas	1.473380	14220	11450	3.76	4.42	9.25	5.64	B

2. MINIMUM LIGHT TIMES

The data sources of minimum light times used in the period analysis are given below:

- The β Lyr type eclipsing system V375 Cas was observed at Çanakkale Onsekiz Mart University Astrophysics Research Center and Ulupınar Observatory (ÇOMUO) in July 2017 (3 nights in total: 5, 12-13 July, 2017). In observations, the 30-cm Schmidt–Cassegrain reflector (T30) equipped with the Alta U47 CCD camera and Bessell *BVR* filters was used. The basic information on the comparison and check star observed with V375 Cas is given in Table 2, while the resulting incomplete multicolor light curve of the system is shown in Figure 1. Only one minimum light time (1 Min II) could be obtained from these observations (see Table 3). To get the minima times the Minima vers 27 software by B. Nelson* was used.

Table 2. The basic information for V375 Cas, the comparison and check stars.

Star	**Object Type**	**GSC No**	**ICRS coordinate**	**Vmag**	**Parallaxes (mas)**	**Reference**
V375 Cas	Eclipsing Binary	4285-00577	23 57 09.42 +63 00 21.97	10.10	0.5604	SIMBAD**
Comparison	Star	4285-00287	23 57 20.64 +63 06 44.70	10.07	3.5636	SIMBAD**
Check	Star	4285-00649	23 57 46.10 +63 06 54.43	11.40	0.3313	SIMBAD**

*https://www.variablestarssouth.org/software-by-bob-nelson/

**http://simbad.u-strasbg.fr/simbad/sim-fid

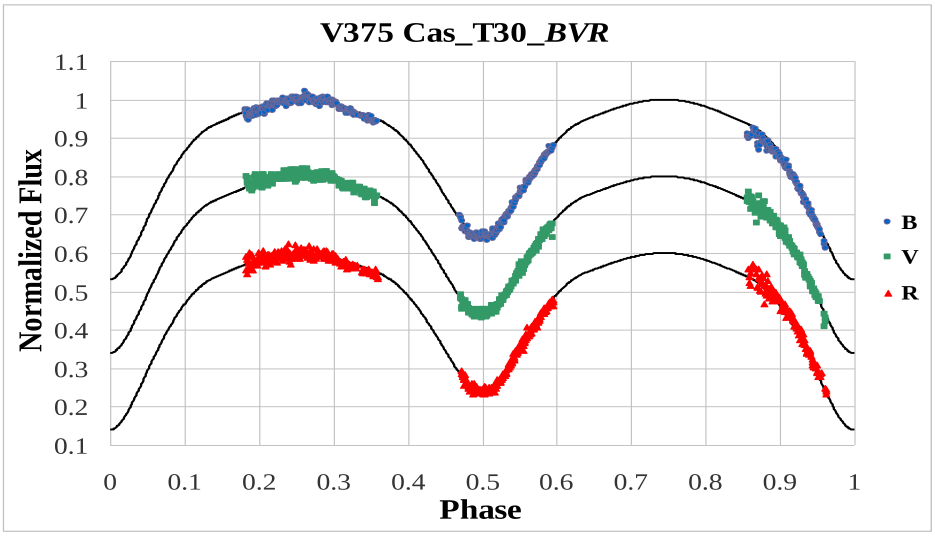

Figure 1. The incomplete *BVR* light and MC algorithm best fit curves (solid line) of V375 Cas

- The Transiting Exoplanet Survey Satellite (*TESS*) observed the target star V375 Cas at 2-minute caddence through Sector 24. These data, which are downloaded from the MAST (Mikulski Archive for Space Telescopes) archive, were used for obtaining the eclipse timings. Hence, 28 minima times in total (15 Min I + 13 Min II) were gotten using the same software in the present work. All BJD_TDB times in *TESS* were converted to HJD times via the online applet calculator given by Eastman et al. (2010). In Table 3, the minima times of *TESS* are listed together with the one of *BVR* light curves.

Table 3. The eclipse timings from *BVR* light curves and *TESS*. Values in parentheses show errors according to the last digit.

HJD (+2400000)	**Min. Type (I/II)**	**Filters**	**HJD (+2400000)**	**Min. Type (I/II)**	**Filters**
58956.3340(1)	I	*TESS*	57940.3987(1)	II	*BVR*
58957.8072(1)	I	*TESS*	58958.5440(1)	II	*TESS*
58959.2807(2)	I	*TESS*	58961.4911(2)	II	*TESS*
58960.7543(1)	I	*TESS*	58964.4378(2)	II	*TESS*
58962.2277(2)	I	*TESS*	58965.9110(1)	II	*TESS*
58963.7010(2)	I	*TESS*	58967.3848(2)	II	*TESS*
58965.1746(1)	I	*TESS*	58971.8052(2)	II	*TESS*
58966.6480(2)	I	*TESS*	58973.2784(1)	II	*TESS*
58968.1216(2)	I	*TESS*	58974.7519(2)	II	*TESS*
58969.5949(1)	I	*TESS*	58976.2254(1)	II	*TESS*
58972.5417(2)	I	*TESS*	58977.6988(2)	II	*TESS*
58975.4887(2)	I	*TESS*	58979.1722(2)	II	*TESS*
58978.4356(2)	I	*TESS*	58980.6459(1)	II	*TESS*
58979.9088(2)	I	*TESS*	58982.1190(2)	II	*TESS*
58981.3823(1)	I	*TESS*			

- Published minima times of V375 Cas were collected from the *O-C* Gateway archive. In this archive, there are 166 records* of V375 Cas for years between 1905 and 2018. It can be gotten all published times from the web page: http://var2.astro.cz/ocgate/ocgate.php?star.

  *: 73 pg (52 Min I + 21 Min II); 26 visual (23 Min I + 3 Min II); 67 CCD (48 Min I + 19 Min II).

pg: Photographic; **CCD**: Charge-Coupled Device; **Min I**: Primary minimum; **Min II**: Secondary minimum.

3. PERIOD ANALYSIS

To investigate the period variation of V375 Cas the *O-C* method was used, which is applied in many woks (e.g Erdem et al., 2007; Yıldırım et al., 2019). Using all available minimum times (see section 2), the *O-C* values were calculated according to the linear ephemeris T_0=2445635.2059 and P=1.47339361 days (Kreiner et al., 2004). Then, the *O-C* diagram was constructed (Figure 2, top panel). A sinusoidal form superimposed on an upward parabola is seen in this diagram.

The possible cause of this sinusoidal variation may be either an unseen 3rd component in the system or the magnetic activity in at least one component. In the literature, there is no evidence related to the system's magnetic activity (e.g. O'Connell effect, Halpha emission). Thus, the most likely reason for such cyclical change was assumed as a tertiary object. Using the LITE code (Zasche et al., 2009) the following equation (1) of the light-time effect (Δt) (Irwin, 1959) with a parabolic/quadratic term (Q) was applied to fit to the *O-C* variation (upper panel of Figure 2). When applying the LITE code, the weights of the visual, pg and CCD minimum times were entered as 3, 5 and 10, respectively.

$$O - C = QXE^2 + \Delta t \quad (1)$$

$$\Delta t = \frac{a_{12} sini'}{c}\left\{\frac{1-e'^2}{1+e'cos\upsilon'}\sin(\upsilon' + \omega') + e'cos\omega'\right\}$$

a_{12}, **i'**, **e'**, **ω'**, **υ'**: the semi-major axis, inclination, eccentricity, longitude of the periastron and true anomaly of the orbit of the center of mass of the eclipsing pair around that of the triple system, respectively. 678

The compliance of the observational points with the theoretical best fit (upper panel) and the residuals from this fit (lower panel) are shown in Figure 2 according to the epoch number. The cyclic *O-C* change of the system and its representation with the theoretical model are shown in Figure 3.

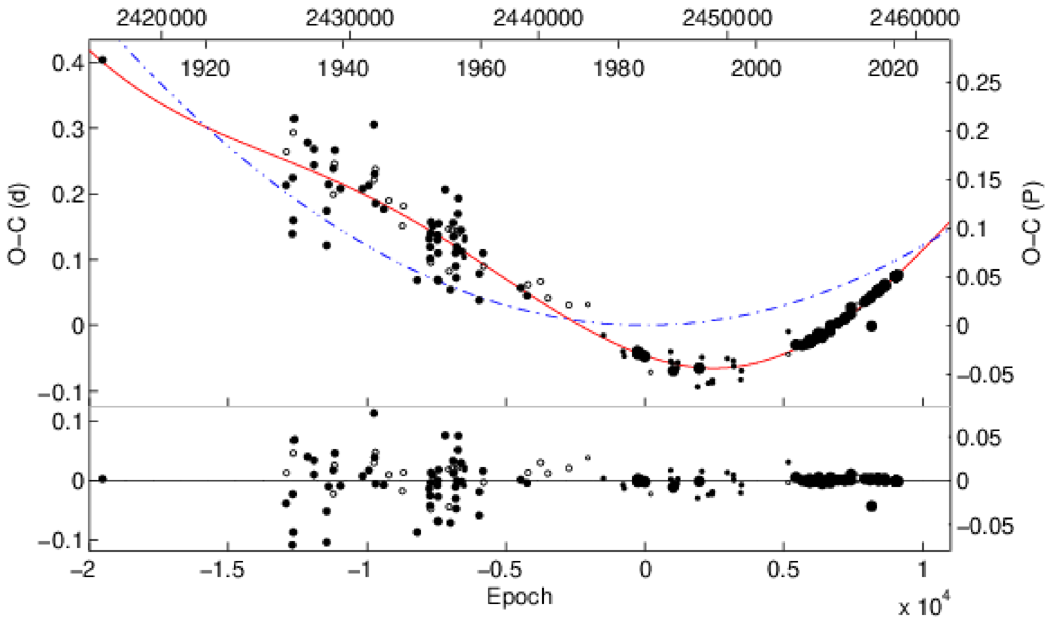

Figure 2. The O-C diagram of V375 Cas: the parabolic (dashed line) + sinusoidal (solid line) form represention of the O-C variation was shown in the top panel. In the bottom panel, the residuals from the best solution are plotted.

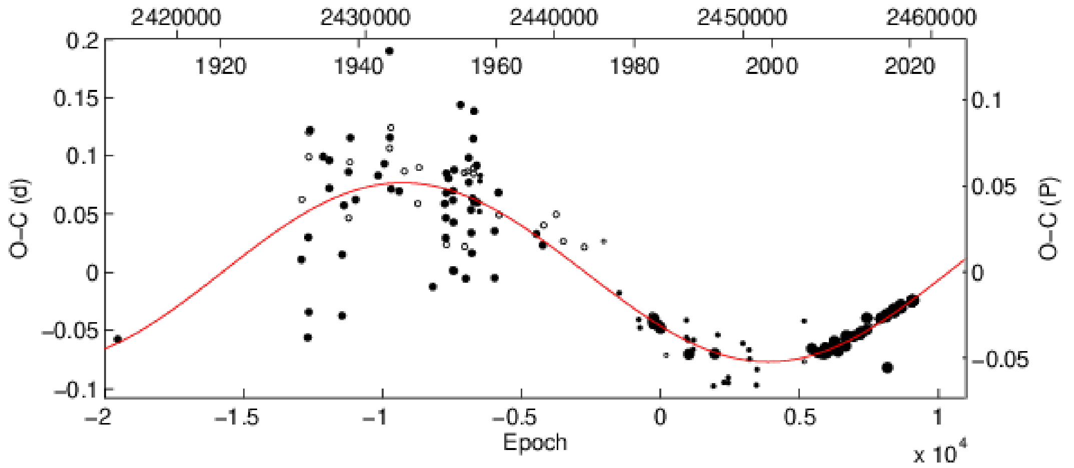

Figure 3. The periodic variation in O-C diagram for V375 Cas with the LITE theoretical fit curve (solid line)

4. RESULTS and DISCUSSION

According to the O-C analysis of V375 Cas, the orbital period is increasing and the increase rate of the period ($\dot{P}$) is calculated as 0.052(1) s/year using the quadratic term given in Equation 1. The reason for an increase of orbital period is due to the mass transfer from the less massive component to the more massive component (Huang, 1956). Under the assumption that the total mass and angular momentum of the system are conserved, the rate of mass transfer ($\dot{m}_1$) is estimated to be +5.64x10^{-7} M⊙/yr using the equation 2 (Singh and Chaubey, 1986).

$$\frac{\dot{P}}{P} = \frac{3(1-q)}{q}\frac{\dot{m}_1}{m_1} \quad (2)$$

The light-time effect (LITE) due to the unseen third component around the eclipsing binary were used to interpret the cyclic variation in the O-C diagram. The period of cyclic variation P_{12}, which is seen in Figure 3, was found to be 106 ± 5 yr, while the semi-amplitude A was obtained as 0.08 ± 0.01 days. The minimum mass of the third companion would be 2.85 M⊙ for i'= 90°. Assuming that the tertiary component is a main sequence star, it could be a star with the spectral type A1 based on its minimum mass. The results of period analysis of the eclipsing binary V375 Cas are listed in Table 4 with errors given in parenthesis.

Table 4. The results from the period analysis for V375 Cas.

Parameter	**Unit**	**Value**	**Parameter**	**Unit**	**Value**
T_0	HJD(+2400000)	45635.1979(70)	e	--	0.01(1)
$P_{orbital}$	days	1.47349574(63)	ω	°	0.70(10)
Q	days	12.09(1)x10^{-10}	T_{12}	HJD(+2400000)	35157(355)
$\dot{P}(= dP/dt)$	s/yr	0.052(1)	P_{12}	yr	106(5)
$\dot{m}_1(= dM/dt)$	M⊙/yr	+5.64x10^{-7}	f(m_3)	M⊙	0.22(6)
$a_{12}sini$	AB	13.3(5)	m_3(i'=90°)	M⊙	2.85(40)

The third light contribution was investigated by light curve analysis of the system. The BVR light curves obtained in this study (see Figure 1) were modeled according to the Wilson-Devinney method (Wilson and Devinney, 1973) using the MC algorithm (Zola et al., 2010; Özkardeş, 2021) instead of the DC code. The third light contribution in *BVR* filters was found to be 5%, 8% and 9%, respectively. The photometric results shows V375 Cas as a near contact binary with a mass ratio of 0.600±0.001 whose both components fill 98% of its Roche lobe. The MC algortihm results are given in Table 5.

Table 5. The results of light curve analysis of V375 Cas.

Parameter	**Value**	**Error**	**Parameter**	**Value**	**Error**
i(°)	85.8	0.8	Ω_2	3.1201	0.0018
Phase shift	0.0001	0.0002	r_1 (mean)	0.430	0.001
T_1 (K)	24108*	fixed	r_2 (mean)	0.337	0.001
T_2 (K)	18834	100	l_1/l_{total} $(B;V;R)$	0.66; 0.65; 0.63	0.01; 0.01; 0.01
q	0.600	0.005	l_3/l_{total} $(B;V;R)$	0.05; 0.08; 0.09	0.01; 0.01; 0.01
Ω_1	3.1200	0.0009	$\Sigma W(OC)^2$ $(B;V;R)$	0.039; 0.047; 0.059	

*: Following Tunçel Güntekin et al. (2016) the temperature of the primary component was determined as 24108 K using the MK calibration tables of Budding and Demircan (2007).

5. CONCLUSION

Near-contact binaries, such as V375 Cas, are important objects for understanding the evolutionary state of binary stars during the pass from the detached phase to the contact phase. The detailed period analysis of the near-contact eclipsing binary V375 Cas was performed in this study. The preliminary results are presented. The existence of the third component is discussed through the period analysis and light curve modeling. Obtaining the more precise multi-color photometric and high resolution spectroscopic observations of V375 Cas are necessary and important in understanding the nature of both the target star and near-contact eclipsing binary systems.

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REFERENCES

Avvakomova, E. A., Malkov, O. Yu., Kniazev, A. Yu.(2013). Eclipsing variables: Catalogue and classification. *Astronomische Nachrichten*, 334(8), p.860.

Barone, F., Di Fiore, L., Milano, L:, Pirozzi, L., Russo, G. (1992). Search for Contact Systems among Eb-Type Binaries. *Astrophysics and Space Science*, 198(2), pp.321-340.

Bidealman, W. P. (1982). Variable Stars in the Northern Luminous Stars Catalogues. *Information Bulletin on Variable Stars*, No. 2112, p.1.

Brancewic, H. K., Dworak, T. Z. (1980). A catalogue of parameters for eclipsing binaries. *Acta Astron.*, 30, pp. 501-524.

Brat, L., Trnka, J., Lehky, M…….. Kalisch, T. (2009). B.R.N.O. Contributions #36, Times of minima. *Open European Journal on Variable Stars*, 107, p.1.

Broadskaya, E. S. (1955). The spectra and magnitudes of 400 stars of spectral class 0-B5 in Milky Way area centered at α = 23h27m, δ = +61°. *Izv. Krymsk. Astrofiz.*, 14, 12.

Cruzalèbes, P., Petrov, R. G., Robbe-Dubois, S., ………., Schertl, D. (2019). A catalogue of stellar diameters and fluxes for mid-infrared interferometry. *Monthly Notices of the Royal Astronomical Society*, 490(3), p.3158-3176.

Eastman, J., Siverd, R., Gaudi, B. S. (2010). Achieving Better Than 1 Minute Accuracy in the Heliocentric and Barycentric Julian Dates. *Publications of the Astronomical Society of the Pacific*, 122(894), pp. 935.

Erdem, A., Soydugan, F., Doğru, S. S., Özkardeş, B., Doğru, D., Tüysüz, M., Demircan, O. (2007). First period analyses of five neglected Algol-type eclipsing binaries: TT And, V342 Aql, RW Cap, BZ Cas and TW Lac. *New Astronomy*, 12(8), p. 613-621.

Huang, S. S. (1956). A dynamical problem in binary systems and its bearing on stellar evolution. *Astronomical Journal*, 61, p. 49-61.

Hubscher, J., Lange, T., Paschke, A., Walter, F. (2005). Beobachtungssergebnisse Bundesdeutsche Arbeitsgemeinschaft fuer Veraenderliche Sterne e.V. *Berliner Arbeitsgemeinschaft für Veraenderliche Sterne - Mitteilungen*, 174, p. 1-11.

Hubscher, J., Paschke, A., Walter, F. (2006). Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars. *Information Bulletin on Variable Stars*, No. 5731.

Hubscher, J. (2007). Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars. Information Bulletin on Variable Stars, No. 5802.

Hubscher, J., Steinbach, H-M., Walter, F. (2008). BAV-Results of observations - Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars. *Information Bulletin on Variable Stars*, No. 5830.

Hubscher, J., Lehmann, P. B., Monninger, G., Steinbach, H-M., Walter, F. (2010). BAV-Results of Observations - Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars. *Information Bulletin on Variable Stars*, No. 5918.

Hubscher, J., Lehmann, P. B., Monninger, G., Steinbach, H-M., Walter, F. (2010). BAV-Results of Observations - Photoelectric Minima of Selected Eclipsing Binaries and Maxima of Pulsating Stars. *Information Bulletin on Variable Stars*, No. 5941.

Hubscher, J. (2011). BAV-Results of observations - Photoelectric minima of selected eclipsing binaries and maxima of pulsating stars. *Berliner Arbeitsgemeinschaft für Veraenderliche Sterne - Mitteilungen*, 215, p. 1-15.

Hubscher, J. (2011). BAV-Results of observations - Photoelectric minima of selected eclipsing binaries and maxima of pulsating stars. *Information Bulletin on Variable Stars*, No. 5984.

Hubscher, J. (2015). BAV-Results of observations - Photoelectric minima of selected eclipsing binaries and maxima of pulsating stars. *Information Bulletin on Variable Stars*, No. 6152.

Irwin, J. B. (1959). Standard light-time curves, *The Astronomical Journal*, 64, p. 149–155.

Kreiner, J. M. (2004). Up-to-date linear elements of eclipsing binaries, *Acta Astronomica*, 54, pp. 207–210.

Malkov, O. Yu., Oblak, E., Snegireva, E. A., Torra, J. (2006). A catalogue of eclipsing variables. *Astronomy and Astrophysics*, 446(2), pp.785-789.

Özkardeş ,B. (2021). V355 And: a neglected detached binary in a multiple star system. *Contributions of the Astronomical Observatory Skalnaté Pleso*, 51(2), pp. 118-131.

Reed, B. C. (2003). Catalog of Galactic OB Stars. *The Astronomical Journal*, 125(5), pp. 2531-2533.

Samolyk, G. (2008). Recent Minima of 155 Eclipsing Binary Stars. *The Journal of the American Association of Variable Star Observers*, 36(2), p. 171.

Samolyk, G. (2008). Recent Minima of 184 Eclipsing Binary Stars. *The Journal of the American Association of Variable Star Observers*, 36(2), p. 186.

Samolyk, G. (2010). Recent Minima of 161 Eclipsing Binary Stars. *The Journal of the American Association of Variable Star Observers*, 38(1), p. 85.

Samolyk, G. (2010). Recent Minima of 185 Eclipsing Binary Stars. *The Journal of the American Association of Variable Star Observers*, 38(1), p. 183.

Singh, M, Vhaubey, U. S. (1986). Mass Loss from Wolf-Rayet Stars. *Astrophysics and Space Science*, 124(2), pp.389-396.

Yıldırım, M. F., Aliçavuş, F., Soydugan, F. (2019). CN Andromedae: a shallow contact binary with a possible tertiary component. *Res. Astron. Astrophys.* 19(1), pp. 10(10).

Zasche, P., Liakos, A., Niarchos, P., Wolf, M., Manimanis, V. ve Gazeas, K. (2009). Period changes in six contact binaries: WZ And, V803 Aql, DF Hya, PY Lyr, FZ Ori, and AH Tau, *New Astronomy*, 14, 121–128.

Zhang, Rong-Xian., Zhang, Ji-Tong, Li, Chi-Sheng, Zhai, Di-Sheng. (1985). Photoelectric Observations of V375 Cas. *Information Bulletin on Variable Stars*, No. 2651.

Zhang, Rong-Xian., Zhang, Ji-Tong, Li, Chi-Sheng, Zhai, Di-Sheng. (1986). Photoelectric photometry of eclipsing binary V375 cassiopeiae. *Chinese Astronomy and Astrophysics*, 10, p. 265-271.

Walter, F. (2005). Sektion Bedeckungsveraenderliche: Lichtkurven in allen Phasen. *BAV Rundbrief*, 54, p. 164-166.

Weber, R. (1958). Catalogue d'étoiles variables nouvelles. *J. Obs.*,64, 258.

Wilson, R. E., Devinney, E. J. (1971). Realizaiton of Accurate Close-Binary Light Curves: Application to MR Cygni. *Astrophysical Journal*, 166, 605.

Zola, S., Gazeas, K., Kreiner, J. M., Ogloza, W., Siwak, M., Koziel-Wierzbowska, D., Winiarski, M. (2010). Physical parameters of components in close binary systems – VII. *Monthly Notices of the Royal Astronomical Society*, 408(1), pp. 464-474.