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RESEARCH ARTICLE

Abbas Abedi et al, The *Experiment, 2014, Vol. 25 (4)1747-1758*

A COMPREHENSIVE PHOTOMETRY OF THE ECLIPSING BINARYGO CYG

ABSTRACT

Observations photometric of the system GO Cyg were obtained in two filters B and V in Observatory of Doctor Mojtahedi at Birjand University in August and October 2010. Using the data of photometry, light curves of system were analyzed by the phoebe software and its physical and partial geometric parameters have been extracted. Using the results of photometry analysis and half amplitude of the radial velocity curves of components, its absolute parameters have been determined. By examining the O-C curve of the eclipsing minima of eclipsing binary GO Cyg, new ephemery, mass transfer or mass loss rates of system have been determined. In addition, with attributing the periodic variations of the O-C curve to the light - time effect, the period of triplet system, its orbital parameters, minimum of mass of third body and a semi major axis of triplet system orbit have been determined.

Keywords Methods: data analysis; Methods: observational; Techniques: photometric; binaries: eclipsing

1- INTRODUCTION

The variability of GO Cyg is an eclipsing binary star ofβ Lyra with p=0.71 day, also it is a semi-detached system whose primary component (the massive and hotter one) has filledits Roche lobe, and the cooler component be slightly smaller than its Roche lobe. The system GOCyg was discovered by Schneller (1928) and classified by Kukarkin (1929) among short-period binary stars (Edalati 1997). The first spectroscopic elements of the system were published by Pearce (1933) who suggested the spectral types B9n-A0n for the components and a new spectroscopic orbit was obtained in 1988 by Holmgren by using the cross-correlation techniques. Times of minima for GO Cyg have been determined by Cester et al. (1993), Sezer et al. (1993), Jones et al. (1994) , Edalati - Atighi (1997) and Zabihinpoor et al. (2006).

According to Sezer et al.(1993) and Edalati-Atighi (1997), GO Cyg is a semi-detached system, the primary component of which fills it's Roche lobe and transfers mass to the secondary component close to its limit Roche. According to Zabihinpoor et al. (2006), the wind star is effective in mass loss and causes non-conservation mass in this system.

2. The Observation

The system GO Cyg photometry was performed in V and B filters with Photometers ssp5A during 14 nights, using the Schmidt Cassegrain 14 inch telescope at Doctor Mojtahedi Observatory at University of Birjand in August and October 2010, resulting 800 data in the light curve shown in Figure 1. In the photometry, BD +35.4180 is used as the comparison star. The data reduction was conducted with program REDWIP and for computing the phases, we have used the following ephemeris given by Sezer et al. (1985).
Min = HJD 2445865.4056 + 0.71776707ε

3. Times of minima

We were able to record the data of primary minimum of the system GO Cyg at night 8 and 11 in August 2010, and the times of minima in Heliocenteric Julian Date were calculated by fitting a Lorentzian function to the observed minima data points. These values are given in Table 1. For example, Figure 2 shows the curve of the data of magnitude variations in terms of the Heliocentric Julian Dates in B filter, which is fit with Lorentz function.

4. Light curve analysis

The photometric solution and light curve analysis is done using the phoebe software which is based on Wilson and Devinney's model. According to Edalati(1997), for the light curve analysis, the amount of orbital eccentricity and the third light were taken as zero and the temperature of the primary star was chosen 10350 k.

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The values are put into phoebe software and set in mode 4, and then it is run. In this process, we took q, T_2, i, L_1, Ω_2 as adjustable parameters and g_1, g_2, X_1, X_2, A_1, A_2 the parameters fixed.

The light curves of GO Cyg show that there exists some asymmetry in the ascending branch of the second minimum around phase interval of 0.6 to 0.7. Thus the light of the system in phases 0.25, 0.75 is not identical. To enter this asymmetry in the curves by placing the hot spot on the second star, (due to mass transfer occurring on the star) we could create this asymmetry. Figures 3 and 4 indicates the intensity curves in B and V filters and the curves corresponded by the phoebe software, respectively. Figure 5 also show the hot spot on the second star.The profile of the hot spot of the second component is given in Table 2; Photometric parameters of GOCyg specified by the phoebe software are given in Table 3. Figure 6 shows position of two stars with respect to their Roche lobes.
Table 4 compare the various solutions for GO Cyg that have been derived by different authors.

Absolute Dimensions

We have used the spectroscopic elements that have been obtained by Holmgren to determinate of the absolute parameters (Sezer 1993). By using the results of photometry analysis and half amplitude of the radial velocities of components K_1,K_2 (Figure 7) and 1 to 5 equations (Edalati1997), we could determine the absolute parameters of the system GO Cyg as presented in Table 5

$$M_{1,2}\sin^3 i=\left(1.0361\times10^{-7}\right)(1-e^2)^{3/2}K_{2,1}(K_1+K_2)^2\,P\,M_{sun}\ [1]$$

$$\frac{R_1}{R_{sun}}=4.207\left[\frac{M_1}{M_{sun}}(1+q)p^3\right]^{\frac{1}{3}}r_1(side)\ [2]$$

$$\frac{R_2}{R_{sun}}=4.207\left[\frac{M_2}{M_{sun}}\left(\frac{1+q}{q}\right)p^3\right]^{\frac{1}{3}}r_2(side)\ [3]$$

$$a_{1,2}\sin i=\left(1.9758\times10^{-2}\right)(1-e^2)^{1/2}K_{1,2}P\,R_{sun}\ [4]$$

$$\frac{L}{L_{sun}}=\left(\frac{R}{R_{sun}}\right)^2\left(\frac{T}{T_{sun}}\right)^4\ [5]$$

Determination period

We plotted the (O-C) curve versus epoch (Fig 8) by using of times of primary and secondary minima available in Gateway site of the system GO Cyg, five times of primary and secondary minima by our observation (Table 1) and linear ephemery announced by Sezer (1985).

first we consider of polynomial function

$$\Delta\,T(\epsilon)=\sum_{j=0}^{n}C_j\epsilon^j\quad[6]$$

Where $\Delta T(\varepsilon)$ is the differences between the observed and calculated times of minima for any cycle ε and C_j is of the polynomial coefficients:

$$p(\varepsilon)=T_{obs}(\varepsilon)-T_{obs}(\varepsilon-1)=P_{le}+\Delta T(\varepsilon)-\Delta T(\varepsilon-1)=P_{le}+\sum_{j=0}^{n}c_j\varepsilon^j-\sum_{j=o}^{n}c_j(\epsilon-1)^j\ [7]$$

$$\frac{dp}{d\varepsilon}=\sum_{j=0}^{n}c_j\varepsilon^{j-1}+\sum_{j=0}^{n}c_jj(\varepsilon-1)^{j-1}=\sum_{j=0}^{n-1}c_{j+1}(j+1)\varepsilon^j+\sum_{j=0}^{n-1}c_{j+1}(j+1)(\varepsilon-1)^j\quad[8]$$

$$\frac{dp}{dt}=\dot{P}=\frac{dp}{d\varepsilon}\frac{d\varepsilon}{dt}=\frac{1}{p_{le}}\frac{dp}{d\epsilon}\ [9]$$

During the first stage, by fitting quadratic function on the data (O-C), the coefficients of this quadratic function are determined. In Table 6, values of these coefficients are given. By using these coefficients, we determined the new period of the system and its gradient. Thus the new ephemery of the system can be expressed as follows:

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$$\dot{p} = 3.198 \times 10^{-8} \frac{day}{year} \; [10]$$

$$p = 0.717767098 \, day \; [11]$$

$$Min = HJD \; 2455417.44727 + 0.717767098 \, \varepsilon \; [12]$$

We determined mass transfer rate from the primary star, filling it's Roche lobe, by using the gradient of the period. The overall relationship between the partial gradient of the period and mass variations is as follows equation (Hilditch 2001):

$$\frac{\dot{p}}{p} = -2\frac{\dot{m}_1}{(m_1+m_2)} - 3\frac{\dot{m}_2(m_1-m_2)}{m_1 m_2} + 3k \; [13]$$

Where K is coefficient of magnetic braking or gravitational-waves, $\dot{m}$is mass transfer rate of the system and $\dot{m}_2$is mass transfer rate of the second star.

Assuming zero K, two overall situation may occur:

1-Conservative mass transfer:

In this case all the mass transferred reaches from $m_1$tom_2, with no mass leaving the system. In this case:

$$\dot{m} = 0 \Rightarrow \dot{m}_1 = -\dot{m}_2 \; [14]$$

Considering the absolute amount of components mass and the above relations, we obtained:

$$\frac{\dot{P}}{P} = -\frac{3\dot{m}_2(m_1-m_2)}{m_1 m_2} \xrightarrow{yields} \dot{m}_1 = -\dot{m}_2 = 3.2 \times 10^{-8} \frac{M_\odot}{year} \; [15]$$

2-Non-conservative mass transfer:

A - Mass loss:

If we consider the star wind, in the case all the mass m_1 is completely out of the system, and no mass would be transferred to the second star. Thus we obtained:

$$\dot{m} = \dot{m}_1 < 0 \;\; \& \dot{m}_2 = 0 \; [16]$$

$$\frac{\dot{p}}{p} = -2\frac{\dot{m}_1}{(m_1+m_2)} \rightarrow \dot{m} = -9.167 \times 10^{-8} \frac{M_\odot}{year} \; [17]$$

B - Mass loss and transfer:

If a part of the mass is transferred from m_1 to m_2 and the rest leaves the system: then In the case$k \neq 0$, the equation 19 has three unknowns will be determined with the available data is not possible.

$$\frac{\dot{p}}{p} = -2\frac{\dot{m}_1}{(m_1+m_2)} - 3\frac{\dot{m}_2(m_1-m_2)}{m_1 m_2} [18]$$

$$+0.486 \, \dot{m}_1 + 1.397 \, \dot{m}_2 - 4.455 \times 10^{-8} \frac{M_\odot}{year} = 0 \; [19]$$

$$\dot{m} < 0 \, , \dot{m}_1 < 0 \, , \dot{m}_2 > 0 \; [20]$$

Probability of the third body

After subtraction the corresponding parabola from the data of (o-c), the residual curve plotted in Figure 9, indicate periodic variations that may be light - time effect due to the presence of the third body. Thus by using of equations 21 and 22 (Irwin 1952) we try to determine the parameters of triplet system. Beginning with the period o4 software, the period has been measured, and by fitting the best Lorentz functions on the peak of residual data, τ_{max}, τ_{min}, has been measured. Then by giving different amounts of the eccentricity, e and longitude of periastronω, the best curve theory was fitted on the residual data versus true anomaly υ with the help of eyes, then by using the origin 8 software, e and ω are put into the function of light - time, so that the origin 8 software can perform the best correspondence. Thus values of k, e, ω, along with an error standard obtained by this software are presented in Table 7. Figure 10 shows the curve of the residual data of O-C curve, with the best curve theory light-time fitted on it.

$$K = \frac{1}{2}(\tau_{max} - \tau_{min}) = \frac{a_{12} \sin i \sqrt{1-(e\cos\omega)^2}}{2.59\times10^{10}} [21]$$

$$\tau = \frac{1}{\sqrt{1-(e\cos\omega)^2}}\left\{\frac{1-e^2}{1+e\cos\omega}\sin(\upsilon+\omega) + e\sin\omega\right\} \; [22]$$

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Where K is half amplitude of the residual curve, υ is true anomaly, a_{12} is semi major axis, e is eccentricity and ω is longitude of periastron of the orbit binary star around of the center mass of the triplet system.With the help of the values obtained, we have determined the third body mass (m_3) and the semi major axis (a_3) for different values of the orbital inclination of orbit triplet system (equations 23 and 24).The orbital elements of a third component are listed in Table 8 (Hilditch 2001).

$$\frac{(M_3 \sin i)^3}{(M_1 + M_2 + M_3)^2} = \frac{4\pi^2}{GP^2}(a_{12} \sin i)^3 \quad [23]$$

$$\frac{M_3}{(M_1+M_2)} = \frac{a_{12}}{a_3} \quad [24]$$

RESULTS AND DISCUSSION

1-According to Sezer(1993), Edalati(1997) and Zabinihinpoor(2006), asymmetry in the light curve that correspond to our results is related to gas transferred or the mass transmitted. Our results also show that GO Cyg is a semi - detached system the first component of which (massive and hotter) has filled its Roche lobe, and the second one (less massive and cooler) is slightly smaller than its Roche lobe. The system is also called near-contact. As Edalati(1997), the nature of this system should be on the verge of a new development.

2-By using of photometric solution of our light curves and other light curves, we conclude that:The temperature of the second component is increasing. The brightness of first and second components, are reducing and increasing, respectively.The star mean radius for the first component is almost constant and for the second component is increasing.

3-Due to the mass, brightness, radius of first and second components from our analysis, suggested the spectral types B9-A0 and F5-F8 for the first and second components respectively, previously reported by Pearce (1933) and Ovenden (1954).

4- Analysis of times of the minima shows a sinusoidal variation with a period of 46.41 ± 0.33 years, due to a third body whose mass is less than $0.27 M_{\odot}$.

Minimum mass of third body is so low that there is no possibility of star formation such that this body can be a brown dwarf. If we consider the maximum mass of this star that orbits 10 degree inclination, most likely this star is located on the main sequence. Due to its mass, and tables, its spectral category is M5, and its brightness is about 0.011 compare to the sun brightness. thus, according to its distance from the binary orbital, the star light does not affect on the light curve of binary system (l_3=0). Therefore, values obtained for the third object can be confirmed. To ensure of the values obtained, we drew the final residuals resulting from the subtraction of the final curve from the previous stage residuals (Fig.11). A random scattering of the data around the horizontal line passing through zero specifies that parameters are chosen correctly.

5- By considering the fact that GO Cyg is a semi-detached system, and that primary component has filled it's Roche lobe, it should be transferring the mass to the secondary, and mass m_1 should be declining but the value obtained for $\dot{m}_1$ is positive, therefore conservative mass transfer mode is not possible.

6-Since the second star hasn't filled its Roche lobe completely,the possibility of mass leaving of Lagrangian point L_2 is very low. By considering this the fact that some of stars in spectral B, have stellar winds, and A0-B9 is suggested for the primary star spectral, there is the possibility that this star has stellar winds, and the mass loss of the system has done with the following gradient :

$$\dot{m} = \dot{m}_1 = -9.167 \times 10^{-8} \frac{M_{\odot}}{year} \quad [25]$$

CONCLUSION

The results of this research show conservative mass transfer mode is not possible, and mass should be other ways out of the system. There is a third body near the binary system whose mass is less than $0.27 M_{\odot}$. The light curve analysis has shown that its contribution to the light curve is negligible.

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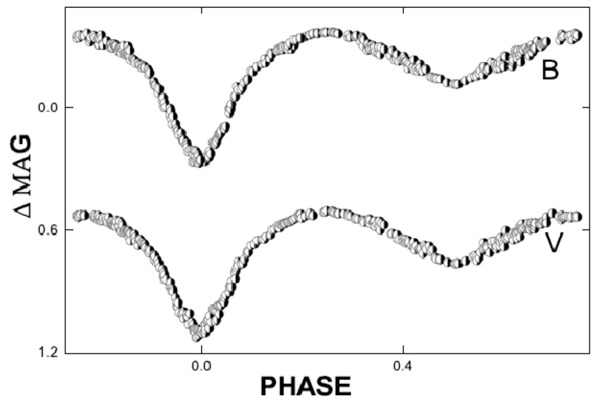

Figure 1: The observed light curves of GO Cyg binary system in delta magnitude.

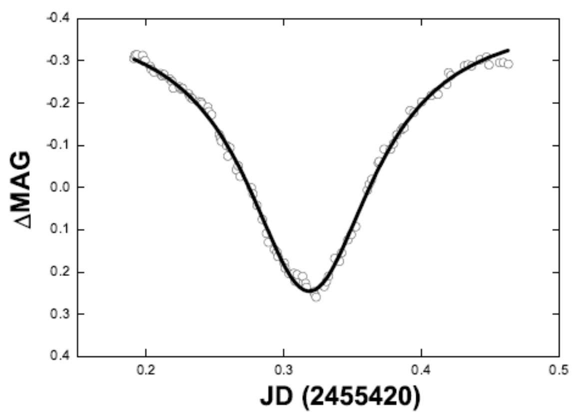

Figure 2: A sample Lorentzian fit to the observed primary minimum data.

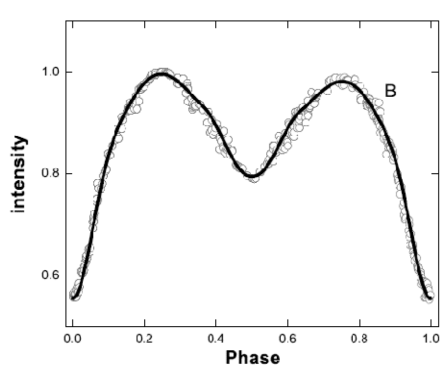

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Figure 3: The intensity curves in B filter and the curve fitted by the phoebe program.

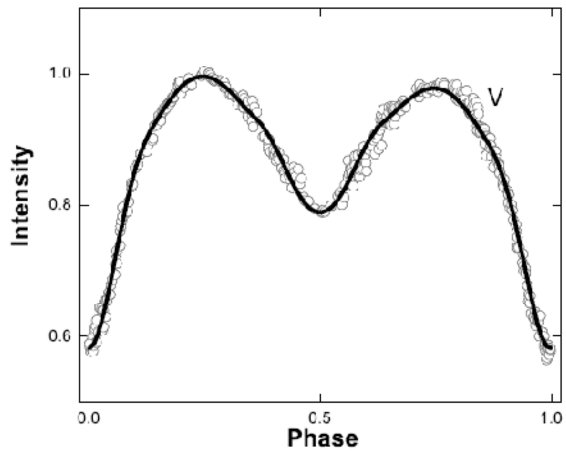

Figure 4: The intensity curves in V filter and the curve fitted by the phoebe program.

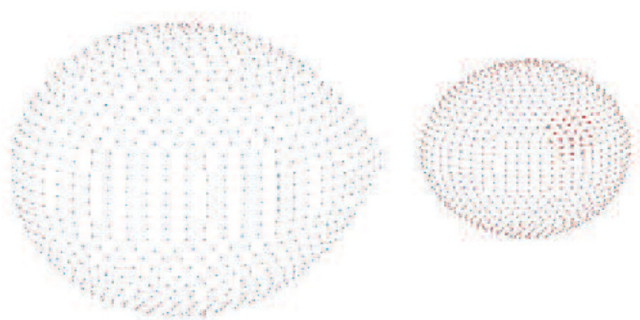

Figure 5: Position of the hot spot on the second star(in phase 0.75)

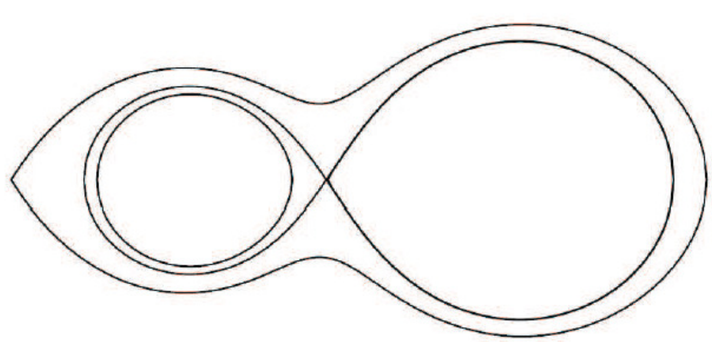

Figure 6: The configuration of GO Cyg for q = 0.428.

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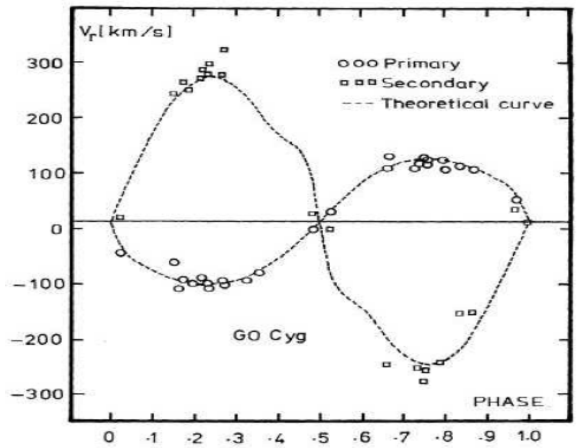

Figure 7: Radial velocity curve of GO Cyg obtained Holmgren.

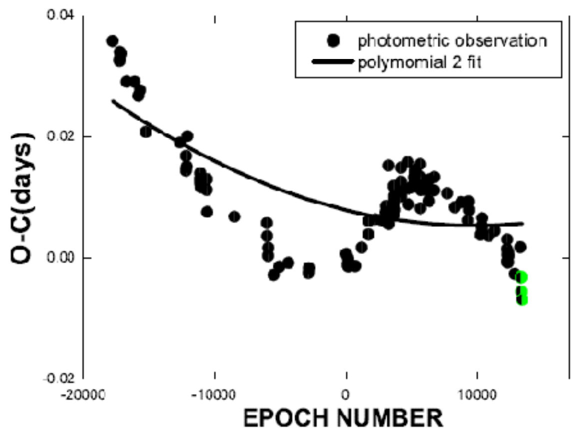

Figure 8: The O-C curve of GO Cyg with its the best fitted parabola (The minimums which are obtained by our observation, are shown by green color).

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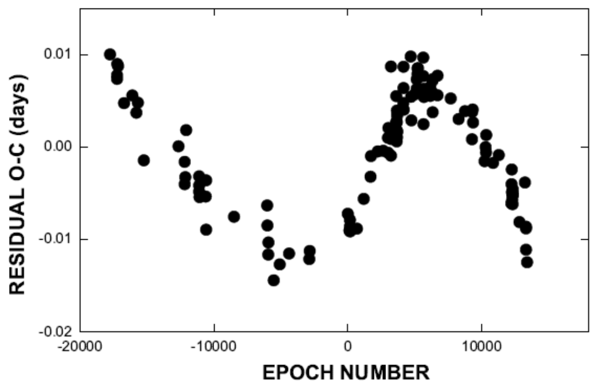

Figure 9: The residual O-C curve.

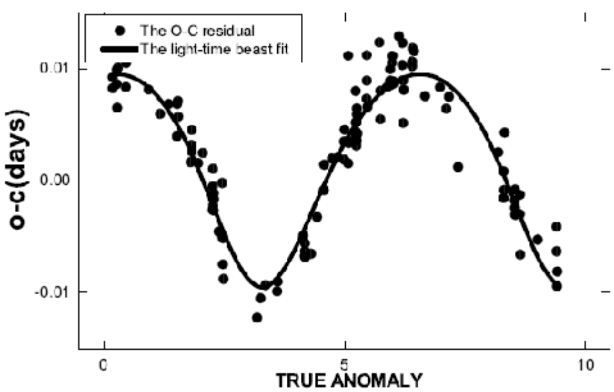

Figure 10: The residual O-C curve versus true anomaly and the best light -time curve fitted on it.

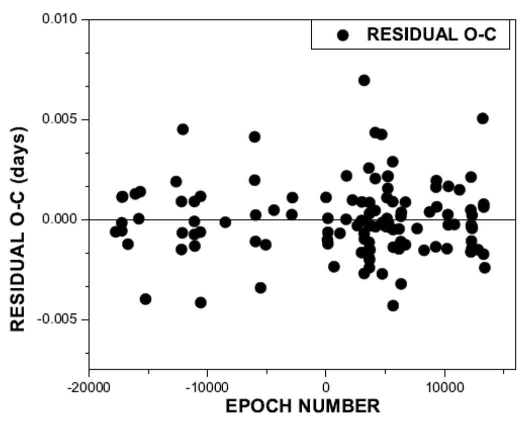

Figure 11: Final distribution of the O-C remaining data around the horizontal line that passes through the origin.

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Table 1: Photometric minima times of GO Cyg.

HJD	Filter	Eror	minimm
2455417.4472	B	0.0004	I
2455417.4455	V	0.0005	I
2455420.3184	B	0.0002	I
2455420.3182	V	0.0003	I
2455411.3638	B	0.004	II
2455411.3496	V	0.002	II
2455416.3691	B	0.001	II
2455416.3709	V	0.0009	II
2455480.2493	B	0.0007	II
2455480.2548	V	0.0009	II

Table 2: The profile of the hot spot system GO Cyg.

Star	second	second
Filter	B	V
Longitude	5.8632	6.1132
Colatitude	1.5821	1.6716
Temperature	0.412	0.415
Radius	0.49	0.53

Table 3: Physical and relative geometrical parameters of the binary system GO Cyg.

parameter	B	V	parameter	B	V
A)λ(	4400	5500	i	78.92	78.87
$q=m_2/m_1$	0.428	0.428	$L_2/(L_1+L_2)$	0.052	0.066
Ω_1	2.734	2.734	$L_1/(L_1+L_2)$	0.947	0.933
Ω_2	2.9	2.89	r_1(pole)	0.427	0.427
T(1)(˚k)	10350	10350	r_1(back)	0.482	0.482

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T(2)(˚k)	6630	6401	r_1(side)	0.455	0.455
A_1	1	1	r_2(pole)	0.260	0.262
A_2	0.5	0.5	r_2(back)	0.287	0.289
g_1	1	1	r_2(side)	0.268	0.270
g_2	0.32	0.32	$\Sigma\omega(o-c)^2$	0.002	0.003

Table 4: Photometric solutions from other light curves.

parameter	**Ovenden 1954**	**Mannino 1963**	**Sezer 1993**	**Edalati 1997**	**Zabihinpoor 2002**	**Present 2010**
i	78.78	79.88	79.72	81.96	78.05	78.95
T_1	10350	10350	10350	10350	10350	10350
T_2	5605	5904	6043	6436	6466	6520
$\frac{L_1}{(L_1+L_2)}$	0.969	0.961	0.954	0.941	0.956	0.940
$\frac{L_2}{(L_1+L_2)}$	0.031	0.039	0.034	0.058	0.044	0.059
r_1(pole)	0.482	0.482	0.482	0.482	0.482	0.482
r_1(back)	0.455	0.455	0.455	0.455	0.455	0.455
r_1(side)	0.427	0.427	0.427	0.427	0.427	0.427
r_2(pole)	0.283	0.271	0.278	0.251	0.259	0.260
r_2(back)	0.265	0.256	0.261	0.275	0.285	0.287
r_2(side)	0.257	0.249	0.254	0.258	0.267	0.268

Table 5: Absolute dimensions for GO Cyg

parameter	B	V	parameter	B	V
$M_1(M_{sun})$	2.876	2.877	$L_1(L_{sun})$	4.25	4.32
$M_2(M_{sun})$	1.230	1.231	$L_2(L_{sun})$	2.60	2.64
)$R_1(R_{sun}$	2.20	2.20	$a_1(R_{sun})$	1.62	1.62
$R_2(R_{sun})$	1.30	1.31	$a_2(R_{sun})$	3.78	3.78

Table 6: The coefficients of the quadratic function fitted on O-C curve.

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Coefficient	Value	Error
c_0	0.00816	8.84835×10^{-4}
c_1	-5.71975×10^{-7}	7.03372×10^{-8}
c_2	2.25702×10^{-11}	7.55481×10^{-12}

Table 7: Orbit parameters of triplet System

parameter	*value*	Error Estandard
P(yr)	46.41	0.33
T(HJD)	2433323	-
K(days)	0.00952	0.0002842
e	0.299	0.02
!(deg)	77.6	0.02
a_{12} sin $i(km)$	3.48×10^7	-

Table 8: Parameters of triplet System.

i(deg)	$m_3(M_\odot)$	a_{12}(AU)	a_3(AU)
10	.2787	1.34	20.24
20	0.1385	0.68	20.2
30	0.094	0.47	20.19
40	0.0729	0.36	20.17
50	0.0611	0.3	20.16
60	0.054	0.27	20.14
70	0.0497	0.25	20.07
80	0.0474	0.24	19.92

REFERENCES

1. Edalati, M.T.,&Atighi, M., Photometric Observation and Light Curves ofGO Cygni,Astrophysic and Space Science,253,107,1997.
2. Sezer,C.,Gulmen,O.,&Gudur,N.,Photometry and Analysis of The Eclipsing Variable GO Cyg, Astrophysics and Space Science, 203, 121, 1993.
3. Pearce,A.,Spectroscopic Element Of the Eclipsing Variable GO Cygni,Dominion Astrophysical Observatory, 27,62,1933.
4. Cester,B.,Giurcin,G., Mardirossian,F.,on the period of the Eclipsing Binary GO Cyg,Acta Astronomica,29,433, 1979.
5. Irwin, J. B.,The Determination of a Light Time Orbit, Astrophysical Jour-nal,116,211,1952.
6. Zabihinpoor, S.M.,&Dariush, A.,Photometric Observation and Period Study of GO Cygni, Astrophysics and Space Science 302, 27, 2006.
7. Jones, A.,Sinusoidal variation in the Period of the eclipsing Binary GO Cyg,Communication, 50, 34, 1994
8. Ovenden, M.W.,Two Color Photoelectric Photometry Of GO Cyg,Monthly Notices of the Royal Astronomical Society, 114, 569, 1954
9. Hilditch, R.W., An Introdution to Close Binary Stars ,Cambridge University Press.Scotland, 42, 209,2001

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10. Mannino, G.Fotometriafotoelettrica in due coloridellabinaria GO Cygni,OsservatorioAstronomicoUniversitario Bologna, 34,191, 1963

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