Photometric Observation and Period Study of GO Cygni

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Abstract
Photometric observations of GO Cygni were performed during the July-October 2002, in B and V bands of Johnson system. Based on Wilson's model, the light curve analysis were carried out to find the photometric elements of the system. The O-C diagram which is based on new observed times of minima suggests a negative rate of period variation ($\frac{dP}{dt} < 0$) for the system.

1 Introduction
GO Cygni (HD196628; $\alpha : 20^h37^m, \delta : +35^\circ26'$) has been classified as a $\beta$-Lyr type eclipsing binary of short period of about $P = 0^d.71$ whose visual magnitude varies from a maximum light value of $V_{\text{max}} = +8.6$ to a minimum light value of $V_{\text{min}} = +9.25$ and has a period variation. The results of the light curve analysis and the period study can be found in many papers such as Ovenden (1954), Popper (1957), Rovithis et al. (1990), Hall & Louth (1990), Sezer et al. (1993), Edalati & Atighi (1997), Rovithis et al. (1997), and Oh & Ra (1998).

The structure of the paper is as follows. In Sec.2 we introduce the process of observations and find the times of minima. In Sec.3 the period study of the system is presented. The Wilson-Devinney model has been used to get the orbital and physical parameters of the system which are given in Sec.4. In Sec.5, the absolute dimensions of the system is calculated by the use of spectroscopic data together with the parameters estimated from the present study. A brief discussion and our main conclusions are presented in Sec.6.

2 Observations and times of minima
We present the observed light-curve of GO Cygni, together with the new times of minima from the photometric observations carried out at Biruni Observatory. The 20 inches cassegrainian reflector which is equipped with an uncooled RCA4509 multiplier phototube, was used for differential photometry in B($\lambda = 4200\,\text{Å}$) and V($\lambda = 5500\,\text{Å}$) filters of Johnson’s system. The observations were performed during Aug./Sep. 2002 versus HD 197292 and HD 197346 as
the comparison and the check stars. In each observing run in B or V filter, the integration time was fixed for 10 seconds. The observed data were transferred to computer using an A/D converter. The reduction of data and atmospheric corrections were done using REDWIP code developed by G. P. McCook to obtain the complete light-curves in the two filters (Fig. 1). The times of minima in *Heliocentric Julian Date* (two primary and two secondary) were calculated by fitting a Lorentzian function to the observed minima data points (Dariush et al. 2003). Fig. 2, shows a sample Lorentzian fit to the observed primary minimum of GO Cyg on Aug. 31 in filter B.

3 Period study

Though a constant period for GO Cyg was first measured by Szczyrbak (1932) other studies such as Purgathofer & Prochazka (1967), Cester et al. (1979), Sezer et al. (1985), Jones et al. (1994), Rovithis et al.(1997), and Edalati & Atighi (1997) suggested a period variation in GO Cyg. For all the observed photoelectric times of primary and secondary minima from 1951 to 2002 the computed (O-C)’s versus epoch is plotted in Fig. 3. For each minima, the residuals are calculated according to the ephemeris given by Hall & Louth (1990)

\[
Min.I = HJD2433930.40561 + 0^d.71776382 \times E.
\]
In equation 1, $E$ is the number of cycles. Since the period is changing with time an extra \emph{quadratic term} can be added to equation 1 and rewrite it as

$$\text{Min.I} = HJD2433930.40561 + 0^d.71776382 \times E + \xi \times E^2.$$  

(2)

From the method of least square the coefficient of quadratic term in equation 2 is easily found to be $\xi = 9.35 \times 10^{-11}$. As it is seen from Fig. 3a, the O-C residuals suggest a polynomial function in the form of

$$\Delta T(E) = \sum_{j=1}^{n} c_j E^j;$$  

(3)

where $\Delta T(E)$ is the differences between the observed and calculated times of minima for any cycle $E$. In the case of GO Cyg, the $3^{rd}$ order polynomials ($j = 3$ in equation 3) seems to be fitted better than the parabola ($j = 2$ in equation 3) to the observed times of minima. The value of the polynomial coefficients $c_j$ and the \emph{rms error} of the approximation are listed in Table 1. The residuals of the observed O-C from $\Delta T(E)$ which do not deviate more than $\pm 0.01d$ are shown in Fig. 3b and 3c. Using equation 3, the real period of the GO Cyg and its relative rate of change can be calculate according to the following formula (see Kalimeris et al. 1994)

$$P(E) = P_e + \Delta T(E) - \Delta T(E - 1),$$  

(4)

$$\dot{P}(E) = \frac{dP}{dE} = \left\{ \sum_{j=0}^{n-1} (j+1)c_{j+1}E^j - \sum_{j=0}^{n-1} (j+1)c_{j+1}(E-1)^j \right\},$$  

(5)
where $P_e$ is an ephemeris period given in equation 1. Fig. 4 shows the period of GO Cyg as a function of time and its relative rate of change according to the 3rd order polynomial fitting function on the O-C diagram. From Fig. 4, it is obvious that at present time, the period is decreasing. We refer the reader to Sec. 6 where we presented a completed discussion about the period variations.

## 4 Light curve analysis

The photometric solution and light curve analysis is done using the Wilson and Devinney’s (1971) model which is based on Roche model. Before doing analysis we binned the observed data in B and V filters presented in Fig. 1 in equal phase intervals and applied Wilson’s LC code in mode 4. This mode is for semidetached binaries with star 1 accurately filling its limiting lobe, which is the classical Roche lobe for synchronous rotation and a circular orbit, but is different from the Roche lobe for nonsynchronous and eccentric cases. The applied constraints are that $\Omega_1$ has the lobe filling value and that $L_2$ is coupled to the temperatures. The LC code consists of a main FORTRAN program for generating light curves. Solutions were obtained for each of the B and V filters, separately. The preliminary values for the orbital and physical elements of the system were adopted from the previous studies. The third light and eccentricity were supposed to be equal to zero ($e = 0, l_3 = 0$). In order to optimize the parameters, an auxiliary computer programme was written to compute the sum of squares of the residuals (SSR) in both B and V filters, using LC outputs. The set of parameters ($i, q, T_2, \Omega_1, \Omega_2, L_1,$ and $L_2$) given in Table 2, are derived after optimization in the way as we described. Fig. 5 and 6 show the optimized theoretical light curves together with the observed light curves in B and V filters. These theoretical curves, correspond to the optimized parameters given in Table 2. In Table 4 we tabulated our results (as an average in B and V filters) together with previous photometric solutions from other sources.

## 5 Absolute dimensions

By combining the photometric and spectroscopic data, it is possible to estimate the absolute physical and orbital parameters of the system. The first spectroscopic elements of the system

| Coefficient | Second | Third |
|-------------|--------|-------|
| $c_0$       | $-2.92771 \times 10^{-4}$ | $1.45 \times 10^{-3}$ |
| $c_1$       | $-6.38377 \times 10^{-7}$ | $-2.371 \times 10^{-6}$ |
| $c_2$       | $1.26577 \times 10^{-10}$ | $3.01298 \times 10^{-10}$ |
| $c_3$       | $1.26577 \times 10^{-10}$ | $3.01298 \times 10^{-10}$ |
| rms error   | 0.00625 | 0.00597 |

Table 1: Coefficients of second and third order approximation of the (O-C) diagram of GO Cyg.
Figure 3: (a) Plot of (O-C)'s versus epoch for all the observed photometric times of primary and secondary minima from 1951 to 2002. The residuals are calculated according to equation 1. The dotted line and solid line represent a $3^{rd}$ order polynomial ($j=3$ in equation 3) and a parabola ($j=2$ in equation 3) fitting functions to all of the residuals respectively (see Table 1). (b) Residuals between the observed O-C differences and the best fitted parabola. (c) Residuals between the observed O-C differences and the best fitted $3^{rd}$ polynomial.
Figure 4: The period of GO Cyg as a function of time (continues line) and its relative rate of change (dotted line) according to the equations 4 and 5 with $j=3$. The difference $P - P_e$ is referred to the ephemeris period $P_e=0.71776382\text{d}$ which is given in equation 1.
| Parameter          | Filter B | Filter V |
|-------------------|----------|----------|
| $\lambda$(Å)      | 4200     | 5500     |
| $i$(degree)       | 77.72±0.02 | 78.38±0.02 |
| $q(\frac{M_2}{M_1})$ | 0.428±0.001 | 0.428±0.001 |
| $\Omega_1$        | 2.734    | 2.741    |
| $\Omega_2$        | 2.905±0.005 | 2.902±0.002 |
| $T_1$(fixed)      | 10350    | 10350    |
| $T_2$             | 6528±30  | 6404±40  |
| $A_1$             | 1        | 1        |
| $A_2$             | 0.5      | 0.5      |
| $g_1$             | 1        | 1        |
| $g_2$             | 0.32     | 0.32     |
| $x_1$             | 0.82     | 0.58     |
| $x_2$             | 0.79     | 0.51     |
| $\frac{L_1}{L_1+L_2}$ | 0.965   | 0.947   |
| $\frac{L_2}{L_1+L_2}$ | 0.035   | 0.053   |
| $r_1$(pole)       | 0.427    | 0.427    |
| $r_1$(point)      | 0.586    | 0.586    |
| $r_1$(side)       | 0.455    | 0.455    |
| $r_1$(back)       | 0.482    | 0.482    |
| $r_2$(pole)       | 0.259    | 0.259    |
| $r_2$(point)      | 0.300    | 0.300    |
| $r_2$(side)       | 0.267    | 0.267    |
| $r_2$(back)       | 0.285    | 0.285    |
| $\Sigma(O-C)^2$  | 0.00172  | 0.00214  |

Table 2: Optimized parameters of GO Cygni.
Figure 5: Theoretical light curve (LC output; solid line) in filter B according to the parameters given in Table 2. Points are the observational data.

were prepared by Pearce (1933) and a more recent spectroscopic orbit was obtained in 1988 by Holmgren using the cross-correlation techniques (Sezer et al., 1992). We use the spectroscopic elements of Holmgren together with the orbital parameters and physical parameters which have been calculated already from our observation to calculate the absolute dimensions of GO Cyg. The results of these calculations based on equations 6 (see Kallrath & Milone, 1999) is given in Table 3. In equations 6, \( f(M_1, M_2, i) \) is mass function, \( M_{\text{tot}} = M_1 + M_2 \) is the total mass, \( K_1 \) is the radial velocity amplitude of component 1, \( a \) is the relative semi-major axis, and \( g \) is the acceleration due to gravity at the surface.

\[
\begin{align*}
M_1 &= \frac{f(M_1, M_2, i)(1+q)^2}{q^2 \sin^4 i} \\
f(M_1, M_2, i) &= \frac{P}{2\pi G} (1 - e^2)^{3/2} K_1^3 \\
\frac{M_2}{M_\odot} &= q \left( \frac{M_1}{M_\odot} \right) \\
g &= G \frac{M}{R^2} = G \frac{M/M_\odot}{(R/R_\odot)^2}; g_\odot = 2.74 \times 10^2 \text{m/s}^2 \\
\frac{L}{L_\odot} &= \left( \frac{R}{R_\odot} \right)^2 \left( \frac{T}{T_\odot} \right)^4 \\
P^2 &= \frac{4\pi^2}{G} \frac{M_1 + M_2}{a^3} \\
a &= a_1 \frac{1-q}{q} = (1 + q)a_2
\end{align*}
\]

(6)
6 Results and discussion

A closer look at Fig. 5 and 6, shows that the primary minimum is symmetric around phase 1 and the secondary minimum occurs at phase 0.5. Also, the out of eclipse portion of the light curve in two figures is the same which is consistent with the results of Sezer et al. (1985) and Jassur & Puladi (1995). But there is a lack of symmetry in the secondary minimum of both figures around phase interval of 0.6 to 0.7 which was also reported earlier (Sezer et al., 1993 and Edalati & Atighi, 1997). Since the O-C diagram of GO Cyg clearly shows a variation in period, the asymmetry in secondary minimum is most probably due to gas streaming or mass transfer. The result of our study support this idea that the primary component \(M_1\) has filled its Roche lobe, and the second component \(M_2\); less massive and cooler one) is somewhat

| Parameter | Filter B | Filter V |
|-----------|----------|----------|
| \(\lambda\) (Å) | 4200 | 5500 |
| \(M_1(M_\odot)\) | 2.74 | 2.82 |
| \(M_2(M_\odot)\) | 1.73 | 1.75 |
| \(R_1(R_\odot)\) | 2.16 | 2.17 |
| \(R_2(R_\odot)\) | 1.09 | 1.08 |
| \(L_1(L_\odot)\) | 58.72 | 57.54 |
| \(L_2(L_\odot)\) | 2.17 | 2.13 |

Table 3: Absolute elements of GO Cygni.
smaller than its Roche lobe. Let the total mass of the binary system be $M_{\text{tot}} = M_1 + M_2$ and take the total angular momentum of the orbiting pair as $J_{\text{orb}}$. In reality, the total angular momentum $J_{\text{tot}}$ is composed of two terms $J_{\text{orb}}$ and $J_{\text{spin}}$ (spin or rotational angular momentum) such that $J_{\text{tot}} = J_{\text{orb}} + J_{\text{spin}}$, but in practice the contribution of the total spin angular momentum is no more than 1-2% of $J_{\text{orb}}$, so it can be ignored (Hilditch, 2001). Now consider a conservative mass transfer between the two components as well as the conservation of total orbital angular momentum $J_{\text{orb}}$. Therefore $\dot{M} = \frac{dM_{\text{tot}}}{dt} = 0$ or $dM_1 = -dM_2$ (since all the mass lost by one component is gained by its companion), also $\frac{dJ_{\text{orb}}}{dt} = 0$. Using the relation between $M_{\text{tot}}$ and $J_{\text{orb}}$ together with Kepler’s third law, lead us to the following relation (Hilditch, 2001)

$$\dot{M}_1 = \frac{\dot{P} M_1 M_2}{3P(M_1 - M_2)},$$

(7)

in which $P$ and $\dot{P}$ are -in order- the orbital period and the rate at which the orbital period is changing and $M_1$ is mass of the massive (and hotter) component.

Now suppose that the system follows path 1 on the O-C diagram which is defined by the parabolic fit. In this case according to the equations 4 and 5, $\dot{P} > 0$ (also $M_1 > M_2$), so it is clear from equation 7 that $\dot{M}_1 > 0$ and the mass of the more massive component ($M_1$) must increases with time. But from the Roche model we expect $\dot{M}_1 < 0$ since the primary component has filled its Roche lobe and is loosing its mass to its cooler companion $M_2$. As a result if we consider a simple conservative model for mass transfer with the spin angular momentum ignored then there is an inconsistency between the rate of period change and conservative model of mass transfer of the system. This deviation may be due to the role of stellar winds or spin-orbital angular momentum interchange.

On the other hand if the system follows path 2 on the O-C diagram where is defined by a 3rd order polynomial, then it is clear from Fig. 4 that at the present time and after 1996, $\dot{P} < 0$, which means that equation 7 is valid and the mass of the primary component is transferring to the secondary one ($\dot{M}_1 < 0$ and $\dot{M}_2 > 0$) which is in agreement with the Roche model we considered for the GO Cyg. The point is that the ascending branches of both parabolic and 3rd order polynomial fit to the O-C data points in Fig. 3a intersect around period cycle $E=24000$ (see also Rovithis et al. 1997), so the observations after this time is very important to give a clear understanding of the period change of GO Cyg and its behaviour. The results of our observations strongly support this idea that the rate of period change is negative but we must extend our observational baseline in order to collect more minima to study the behaviour of the GO Cyg O-C diagram and to see which model is most probable. If the new times of minima still follow path 2 in O-C diagram then there is no doubt that the increase in rate of change of the period of the system has been stopped and the system is now undergoing a decrease of period.
| Parameters | Ovenden (1954) | Mannino (1963) | Popper (1980) | Sezer et al. (1993) | Rovithis et al. (1997) | Edalati et al. (1997) | Present study |
|------------|----------------|----------------|--------------|---------------------|-----------------------|-----------------------|---------------|
| $i$(degree) | 78.777         | 79.880         | 77.606       | 79.722              | 78.414                | 82.311                | 78.05         |
| $T_1$      | 10350          | 10350          | 10350        | 10350               | 10350                 | 10350                 | 10350         |
| $T_2$      | 5605           | 5904           | 5966         | 6043                | 6912                  | 6428                  | 6452          |
| $\frac{L_1}{L_1+L_2}$ | 0.969         | 0.961          | 0.972        | 0.954               | 0.931                 | 0.931                 | 0.956         |
| $\frac{L_2}{L_1+L_2}$ | 0.031         | 0.039          | 0.028        | 0.034               | 0.069                 | 0.068                 | 0.044         |
| $r_1$(back) | 0.482          | 0.482          | 0.482        | 0.482               | 0.555                 | 0.481                 | 0.482         |
| $r_1$(side) | 0.455          | 0.455          | 0.455        | 0.455               | 0.504                 | 0.455                 | 0.455         |
| $r_1$(pole) | 0.427          | 0.427          | 0.427        | 0.427               | 0.445                 | 0.426                 | 0.427         |
| $r_2$(back) | 0.282          | 0.271          | 0.221        | 0.278               | 0.303                 | 0.275                 | 0.285         |
| $r_2$(side) | 0.265          | 0.256          | 0.214        | 0.261               | 0.280                 | 0.258                 | 0.267         |
| $r_2$(pole) | 0.257          | 0.249          | 0.210        | 0.254               | 0.265                 | 0.251                 | 0.259         |

Table 4: Photometric solutions from other light curves.

1. Based on the observations in Bucharest.
2. Average on B and V filters.

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References

[1] Cester, B., Giuricin, G., Mardirossian, F., & Mezzetti, M., 1979, Acta Astr., 29, 433.
[2] Dariush, A., Zabihinpoor, S. M., Bagheri, M. R., Jafarzadeh, Sh., Mosleh, M., & Riazi, N., 2003, IBVS 5456.
[3] Edalati, M.T., & Atighi., 1997, Astrophys. Space Sci., 253, 107.
[4] Hall, D.S., & Louth, H., 1990, J. Astrophys. Astron., 11, 271.
[5] Hilditch, S., Close Binary Stars, 2001, Cambridge University Press, USA.
[6] Jassur, D.M.Z., & Puladi, R., 1995, Earth and Space Physics., 22, 1 & 2, 4.
[7] Jones, R.A., Snyder, L.R., Freg, G., Dalmau, F.J., Alog, J. & Bonvehi, L., 1994, I.A.P.P.P. Commun., 54, 34.
[8] Kalimeris, A., Livaniou-Rovithis, H., & Rovithis, P., 1994, *Astron. & Astrophys.*, **282**, 775.

[9] Karllath, J., & Milone, E.F., 1999, *Eclipsing Binary Stars*, Springer, USA.

[10] Mannino, G., 1963, *Publ. Univ. Bologna.*, **8**, 15.

[11] Oh, K. D. & Ra, K. S., 1998, *J. Astron. Space Sci.*, **15(1)**, 69.

[12] Ovenden, M.W., 1954, *Mon. Not. R. Astron. Soc.*, **114**, 569.

[13] Pearce, J.A., 1933, *J.R. Astron. Soc. Can.*, **27**, 62.

[14] Popper, D.M., 1957, *Astrophys. J. Suppl.*, **3**, 107.

[15] Popper, D.M., 1980, *Ann. Rev. Astron. Astrophys.*, **18**, 115.

[16] Purgathofer, A. & Prochazka, F.: 1967, *Mitt. Univ. Stern Wien*, 13, 151.

[17] Rovithis-Livaniou, H., Rovithis, P., Oprescu, G., Dumitrescu, A., & Suran, M. D., 1997, *Astron. & Astrophys.*, **327**, 1017.

[18] Rovithis, P., Rovithis-Livaniou, H., & Niarchos, P.G., 1990, *Astron. Astrophys. Ser.*, **83**, 41.

[19] Sezer, C., Gulmen, O., & Gudur, N., 1985, *IBVS 2743*.

[20] Sezer, C., Gulmen, O., & Gudur, N., 1993, *Astrophys. Space Sci.*, **203**, 121.

[21] Szczyrbak, S., 1932, *SAC*, **10**, 44.

[22] Wilson, R.E. & Devinney, E.J., 1971, *Astrophys. J.*, **166**, 605.