PHOTOMETRIC OBSERVATIONS
AND
APSIDAL MOTION STUDY OF V1143 CYGNI

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Abstract

Photometric observations of the eccentric eclipsing binary V1143 Cygni were performed
during the August-September 2000 and July 2002, in B and V bands of the Johnson system.
The analysis on both light curves was done separately using the 1998 version of Wilson’s
LC code. In order to find a new observed rate of apsidal motion, we followed the procedure
described by Guinan and Maloney (1985). A new observed rate of apsidal motion of 3.72
degrees/100yr was computed which is close to the one reported earlier by Khaliullin (1983),
Gimenez and Margrave (1985), and Burns et al.(1996).

1 Introduction

V1143 Cygni (HD 185912; HR 7484; BD+54°2193; \( V_{\text{max}} = +5.86; B-V=+0.46; \alpha =
19^h38^m41.8^s; \delta = +54^\circ58'25.7''\)) is a double-lined eclipsing binary, consists of a pair
of F5V stars with high orbital eccentricity (e=0.540) and a relatively long period of
7.640 days (see Fig.1). According to Andersen et al. (1987) who have determined the
stellar and orbital properties of this system accurately, the corresponding radii and
masses are \( r_1 = 1.346 \pm 0.023R_\odot, r_2 = 1.323 \pm 0.023R_\odot \) and \( m_1 = 1.391 \pm 0.016M_\odot, \)
\( m_2 = 1.347 \pm 0.013M_\odot \), respectively.

It is known that V1143 Cyg is one of the best examples of eclipsing binaries with
apsidal motion, in which the observed rate of apsidal motion is greater than the value
predicted by general relativity and stellar evolutionary models.
The observed rate of apsidal motion is due to the contribution of two terms; a classical term as well as the general-relativistic term. In this sense, the observational apsidal motion rate is

\[ \dot{\omega}_{\text{obs}} = \dot{\omega}_{\text{cl}} + \dot{\omega}_{\text{GR}}, \]

where \( \dot{\omega}_{\text{cl}} \) denotes the classical or Newtonian term and \( \dot{\omega}_{\text{GR}} \) is the relativistic contribution which can be determined using the formulas given by Gimenez (1985). In the case of V1143 Cyg, the observed rate of apsidal motion is \( \dot{\omega}_{\text{obs}} = 3^{\circ}.52/100^\prime \pm 0^{\circ}.72/100^\prime \) (Burns et al. 1996) while Andersen et al. (1987) calculated a faster theoretical apsidal motion of \( \dot{\omega}_{\text{theo}} = 4^{\circ}.25/100^\prime \pm 0^{\circ}.72/100^\prime \) in which the expected relativistic and classical (Newtonian) contributions to apsidal motion are \( \dot{\omega}_{\text{cl}} = 2^{\circ}.39/100^\prime \) and \( \dot{\omega}_{GR} = 1^{\circ}.86/100^\prime \), respectively. It is seen that the classical and relativistic contributions are of the same order in this system.

2 Observations

V1143 Cygni was observed during 24 nights from July to September 2000 at Biruni Observatory of Shiraz University (Longitude: 52°31' E, Latitude: 29°36' N). Observations were made with a 51cm cassegrainian telescope equipped with an uncooled RCA4509 multiplier phototube. Two stars HD 184240 (\( V_{\text{max}} = +6.30 \)) and HD 186239 (\( V_{\text{max}} = +7.10 \)) were selected as comparison and check stars respectively. The integra-
tion time for all of the observations were fixed to 10 seconds. The output signals of the photomultiplier were fed to a computer after amplification, using an A/D converter. The measurements were made using B and V filters of intermediate-bandpass blue $\lambda_{\text{max}} = 4400 \text{Å}$ and yellow $\lambda_{\text{max}} = 5530 \text{Å}$ which are matched closely to the Johnson’s UBV system. Times were converted to Heliocentric Julian Day Number (HJD). Data reduction and atmospheric corrections were done to obtain the complete light-curves in two filters, using a computer code developed by G. P. McCook. Figures 2 and 3, represent the observed light curves in B and V filters respectively. In order to enhance the accuracy of the present work, two other minima were observed on July 16 and 18, 2002. This time, the star HD 185978 (F8; $m_V = +7.8$) was selected as the comparison star.

![Figure 2: Observed light curve of V1143 Cygni in the B filter.](image)

**3 Times of minima and light curve analysis**

From the observed light curves, heliocentric times of minima (one primary and one secondary) were computed by fitting a Lorentzian function to the observed minima data points (see Figures 4 and 5). This function can be expressed as

$$y = y_o + \frac{2A}{\pi} \frac{w}{4(x - x_c)^2 + w^2},$$

(2)

where $y_o$ is the baseline offset, $A$ is total area under the curve from baseline, $x_c$ is the center of the minimum and $w$ is full width of the minimum at half height. The minima were calculated according to the ephemeris given by Andersen et al. (1987)

$$\text{Min.I} = \text{HJD2449234.6144} + 7^{d}.64075217 \times E,$$

(3)
Figure 3: Observed light curve of V1143 Cygni in the V filter.

and are given in Tables 2 and 3. The corresponding errors in primary and secondary minima are: ±0.00066 and ±0.00220, respectively. Meanwhile, in each filter, the depths of minima are as follows:

Filter B: Min.I: $0^m.53 \pm 0.02$, Min.II: $0^m.25 \pm 0.02$

Filter V: Min.I: $0^m.48 \pm 0.02$, Min.II: $0^m.23 \pm 0.02$

Figure 4: A sample Lorentzian fit to the primary minimum.

The B and V light curves of V1143 Cyg have been analyzed separately by using the Wilson code in order to derive photometric elements of this system. The program
consists of two main FORTRAN programs **LC** (for generating light and radial velocity curves) and **DC** (to perform differential corrections and parameter adjustment of the LC output). The model which upon the program is based on, has been described and quantified in papers by Wilson (1979, 1990, 1993). Since the system V1143 Cygni is detached with both components residing well inside their respective Roche lobes (Burns et al. 1996), the solution was performed in mode 2. In our analysis, we assumed a value of zero for the third light \( l_3 = 0 \). Also we fixed the ratio of the axial rotation rate to the mean orbital rate for stars 1 and 2 \( F_1, F_2 \). Before running the **LC** code, the position of the preaeron was estimated from the apsidal motion study as discussed in section 4. In order to optimize the observed parameters given in Table 1, we wrote an auxiliary computer programm to compute the sum of squares of the residuals in both filters by using the **LC** output. Figures 6 and 7 show the sum of the squared residuals versus selected parameters for the two filters. For example, Figure 6(a) represents the weighted sum of the squared residuals \( \sum \omega r^2 \) (SSR) versus *eccentricity* \( (e) \) and *inclination angle* \( (i) \) for filter B.

Figures 8 and 9, show the optimized theoretical light curves together with the observed light curves in B and V filters. The theoretical curves correspond to the optimized parameters given in Table 1.
Figure 6: The weighted sum of squared residuals $\sum \omega r^2$ (SSR) versus parameters using Wilson’s LC code in B filter.

Table 1.
Optimized parameters of V1143 Cygni.

| Parameter     | Filter B       | Filter V       |
|---------------|----------------|----------------|
| $i$           | 87.3 ± 0.1     | 87.1 ± 0.1     |
| $e$           | 0.536 ± 0.005  | 0.539 ± 0.005  |
| $\omega$      | 0.855 ± 0.004  | 0.855 ± 0.004  |
| $q(M_2/M_1)$  | 0.99 ± 0.01    | 0.98 ± 0.01    |
| $\Omega_1$    | 17.4 ± 0.5     | 18.0 ± 0.5     |
| $\Omega_2$    | 19.6 ± 0.5     | 20.0 ± 0.5     |
| $L_2/L_1$     | 0.89 ± 0.05    | 0.82 ± 0.05    |

Finally, the observed times of minima on July 16 and 18, 2002 are calculated according to the ephemeris
Figure 7: The weighted sum of squared residuals $\sum \omega r^2$ (SSR) versus parameters using Wilson’s LC code in V filter.

$$Min.I = HJD2447087.5669 + 7^d.64075095 \times E,$$

(4)
given by Burns et al. (1996) and are tabulated in Tables 2 and 3:

4 Apsidal motion

Due to the deep, narrow eclipses of V1143 Cyg and its high eccentricity, the rate of apsidal motion can be determined exactly by analysis of primary and secondary eclipse timings. In their paper, Guinan and Maloney (1985) described the procedure that must be followed to determine the apsidal motion rate from the change in the displacement of the secondary minimum from the half point (0.5 phase) according to

$$D = [(t_2 - t_1) - 0.5 \times \text{Period}].$$

(5)
D in turn, is related to $\omega$ the longitude of preastron by the formula given by Sterne (1939):

$$D = \frac{P}{\pi} \left[ \tan^{-1} \left( \frac{e \cos(\omega)}{1 - e^2} \right) + \frac{e \cos(\omega)}{1 - e^2 \sin^2(\omega)} \left( 1 - e^2 \right)^{1/2} \right],$$

(6)

where $P$ is the period and $e$ is eccentricity. The observed photoelectric times of primary and secondary minima from 1969 to 2002 are collected in Tables 2 and 3. As you can see from Table 4, the slow decrease in $D$ is due to the advance of the line of apsides of the orbit. By computing the slope of a line fitted to all of the secondary minima given in Table 3, we determined an observed rate of apsidal motion of $\dot{\omega}_{\text{obs}} = 3^\circ.72/100^{\text{yr}} \pm 0.37/100^{\text{yr}}$ (see Figure 10).
Figure 9: Theoretical light curve (LC output) in filter V. Points are the observational data.

Table 2.
The photoelectric times of primary minima for V1143 Cyg. The O-Cs are computed according to equation 7.

| H.JD. (2400000.+)| O-C(day) | Epoch | Reference                        |
|------------------|---------|-------|----------------------------------|
| 39339.616        | -0.22773| -376  | Snowden and Koch (1969)          |
| 39385.6881       | -0.00011| -370  | Snowden and Koch (1969)          |
| 40837.4313       | 0.00017 | -180  | Battistini et al. (1973)         |
| 41135.4208       | 0.00033 | -141  | Battistini et al. (1973)         |
| 42212.7651       | -0.00142| 0     | Koch (1977)                      |
| 42617.727        | 0.00061 | 53    | Koch (1977)                      |
| 43305.3943       | 0.00021 | 143   | Guinan et al. (1987)             |
| 45253.7858       | -0.00008| 398   | Gimenez and Margrave (1985)      |
| 47087.5669       | 0.00049 | 638   | Burns at al. (1996)              |
| 48019.73800      | -0.00016| 760   | Caton and Burns (1993)           |
| 49234.6144       | -0.00336| 919   | Lacy and Fox (1994)              |
| 51771.34410      | -0.00338| 1251  | Dariush et al. (2001)            |
| 52474.29443      | -0.00225| 1343  | Dariush et al. (2003)            |

1. This minimum is observed spectroscopically and because of its unusually high O-C, it is not shown in the O-C diagram.
2. This minimum was published as 2439385.6831 by Hamme and Wilson (1984) which seems to be misprint.
Table 3.

The photoelectric times of secondary minima for V1143 Cyg, together with the computed values of $D$ and $\omega$, using equation 6. The O-Cs are computed according to equation 8.

| H.JD. (2400000.+ | O-C(day) | Epoch | $D$   | $\omega$ | Reference             |
|----------------|---------|-------|-------|---------|-----------------------|
| 38932.932      | -0.00431| -430  | 1.8685| 47.97   | Snowden and Koch (1969) |
| 38978.7807     | 0.00000 | -424  | 1.8727| 47.83   | Snowden and Koch (1969) |
| 42615.75       | -0.01896| 52    | 1.8439| 48.82   | Koch (1977)$^1$         |
| 43066.575      | 0.00286 | 111   | 1.8646| 48.11   | Koch (1977)             |
| 44487.7482     | -0.00002| 297   | 1.8579| 48.34   | Gimenez and Margrave (1985) |
| 47085.5910     | -0.00598| 637   | 1.8449| 48.78   | Burns at al. (1996)     |
| 51792.28645    | -0.00122| 1253  | 1.8370| 49.05   | Dariush et al. (2001)   |
| 52472.30445    | -0.00834| 1342  | 1.8281| 49.35   | Dariush et al. (2003)   |

1. Due to its unusually high O-C, it is not included in determination of the observed rate of apsidal motion.

Figure 10: The displacement of the secondary minima given in Table 3, from the 0.5 phase versus epoch. The observed rate of apsidal motion ($\dot{\omega}_{\text{obs}}$) can be calculated for the slope of this curve.

The residuals given in Tables 2 and 3 are calculated for each of the minima according to the ephemeris given by Gimenez and Margrave (1985)

\[
\text{Min.}I = HJD2442212.76652 + 7^{d}64075217 \times E, \quad (7)
\]
\[ Min.II = HJD2442218.45092 + 7^d64073165 \times E. \]  

(8)

The computed (O-C)s versus Julian day is plotted in Figure 11 for both primary and secondary minima. This diagram shows no changes in period within the 0.01 days.

![Figure 11: The O-C diagram in days for all the primary and the secondary minima tabulated in Tables 2 and 3.](image)

5 Results and discussion

Table 4 contains independent determinations of the observed apsidal motion of V1143 Cyg together with the corresponding period of apsidal revolution \( U \). The relation between the apsidal motion period \( U \) and the observed rate of apsidal motion (\( \dot{\omega}_{obs} \)) has a simple form

\[ U = \frac{360P}{\dot{\omega}_{obs}}, \]  

(9)

where \( \dot{\omega}_{obs} \) is expressed in degrees per cycle and \( P \) is the anomalistic period expressed in days. To determine a more accurate value for \( \dot{\omega}_{obs} \) we need more accurate timings of secondary minima. From Table 4, it seems that expanding our observational baseline, may decrease the discrepancy between \( \dot{\omega}_{obs} \) and \( \dot{\omega}_{theo} \). Figure 12 shows \( D \) as a function of \( \omega \) using equation 6 for V1143 Cygni and DI Herculis. In the case of DI Herculis (\( P=10.550 \) days, \( e=0.49 \)) the discrepancy is much larger than that of V1143 Cygni. For this system the observed rate of apsidal motion is about one-third of the theoretical one which is due to the classical and relativistic contribution (Claret, 1998; Dariush and Riazi, 2003). The dots in Figure 12, represent our observational period for the V1143 Cyg and DI Herculis apsidal revolution. It is clear that up to now, our observational
baseline covers only a very small fraction of the period of apsidal revolution \( U \). In the case of DI Herculis, the presence of a third body is a plausible explanation for the discrepancy between \( \dot{\omega}_{\text{obs}} \) and \( \dot{\omega}_{\text{theo}} \), but until no further observational evidence has been reported this possibility. Our results for V1143 Cyg supporting \( 3.72 \pm 0.37/100\text{yr} \) is slightly closer to the theoretical apsidal motion rate \( (4.25 \pm 0.72/100\text{yr}) \), computed with previous studies of this system.

![Graph showing \( D \) as a function of \( \omega \) using equation 6 for V1143 Cygni and DI Herculis.](image)

**Figure 12:** \( D \) as a function of \( \omega \) using equation 6 for V1143 Cygni and DI Herculis.

### Table 4.

| \( \dot{\omega}_{\text{obs}}^{\circ}/100\text{yr} \) | \( \pm \text{Error} \) | \( U^{\text{yr}} \) | Source                  |
|-----------------------------------------------|----------------|-----------------|------------------------|
| 3.49                                         | \( \pm 0.38 \) | 10320           | Khaliullin (1983)       |
| 3.36                                         | \( \pm 0.19 \) | 10710           | Gimenez and Margrave (1985) |
| 3.52                                         | \( \pm 0.72 \) | 10230           | Burns et al. (1996)     |
| 3.72                                         | \( \pm 0.37 \) | 9680            | Present study\(^1\)     |

\(^1\)This value is computed from all the secondary minima presented in Table 4 except 2442615.75 of Koch (1977). Including this minimum, it is changed to 3.45 degree/100yr +/- 0.65 degree/100yr.

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