IRANIAN JOURNAL OF PHYSICS RESEARCH

Iranian Journal of Physics Research, Vol. 9, No. 3, 2009

Period change and δ Scuti pulsations of eclipsing binary star RZ Cassiopiae

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(Received 25 January 2009, accepted 11 August 2009)

Abstract

RZ Cas is an Algol-type partial eclipsing binary, the secondary component of which has filled its Roche lobe. Its visual magnitude is 6.18 and its period is 1.195 days. The most important characteristics of RZ Cas are period change (due to mass transfer) and anomalies in the primary minimum of its light curve (due to δ Scuti pulsations). In this paper, light curves of RZ Cas are obtained using the Johnson's U, B, V, and R filters at Isfahan University Observatory, and B and V filters at Biruni Observatory of Shiraz University. Continuous photometric measurements have also been made to detect δ Scuti type pulsations. A new ephemeris and period is obtained: *Min.I =HJD2453620.5500 +* $1^d.1952639\,E$, and a mass transfer rate of $1.5\times10^{-7}\,M_\odot yr^{-1}$ is estimated. None of the observed primary minima is flat as found by some observers before. The residuals from the observed minus computed light curves of the system give the pulsation light curves of the primary component. The frequencies of δ Scuti pulsation are searched for using the Period04 program. It is found that the dominant frequency is 65.5-68.5 cycle/day, corresponding to a period of 21-22 min.

Keywords: stars, binaries, eclipsing – stars, oscillations, δ scuti type – stars, individual, RZ Cas – eclipsing binaries, change of period

1. Introduction

RZ Cassiopeiae (RZ Cas, HD 17138, HR 815, SAO 12445, BD +69°179) is a semidetached eclipsing binary system of Algol type with an A3V primary and a K0-K4IV secondary component. Its variability was detected by Muller in 1906 [1]. Being a bright system with a very deep primary minimum in the optical wavelengths (V=6.18 mag, ΔV=1.5 mag) extensive photometric studies of this star have been done by many observers (Huffer & Kopal 1951; Chambliss 1976; Riazi, Bagheri, & Faghihi 1994; Maxted, Hill, & Hilditch 1994; Narusawa, Nakamura, & Yamasaki 1994; Varricat, Ashok & Chandrasekhar 1998) [2-7].

This system has been found to exhibit fluctuations in its light curve especially during the primary eclipse. Photometric analyses by most previous observers have shown this system to be a partially eclipsing binary though many observers have reported primary minimum to have a flat bottom for up to 22 minutes (Szafranic 1960; Margrave 1975; Burke & Rolland 1966; Nakamura, Narusawa, & Kamada 1991; Riazi, Nasiri & Ahmadi 1985; Clarke & Lister 1999; Arganbright & Hall 1988; Hegedus 1989) [8-15]. Light curve distortions are observed at the primary minimum, often as a rise in flux near the mid-eclipse. Olson described this as a probable indication of a disklike bulge around the equator of the gainer (primary) and a gas stream from the subgiant secondary to the primary. He also proposed an asymmetric distribution of brightness of the disk owing to the presence of a hot spot where the stream impinges on the disk [16].

The cause of the flat minimum and anomalous primary minimum remained an open problem until Ohshima et al. detected δ Scuti pulsations of primary component. Period and amplitude of these pulsations were 22 min. and 20 mmag., respectively [17].

δ Scuti-type variables are pulsating stars of short periods ($0^d.3$) located in the lower part of the Cepheid instability strip of H-R diagram, with luminosities ranging from the zero-age-main-sequence (ZAMS) to about 2 magnitudes above the main sequence with spectral types ranging from about A2 to F2 [18]. Pulsating stars in eclipsing binaries are important for accurate determination of fundamental stellar parameters and the study of tidal effects on the pulsations [19].

Spectroscopic (Maxted, Hill & Hilditch 1994; Duerbeck, & Hanel 1979), and radio and x-ray

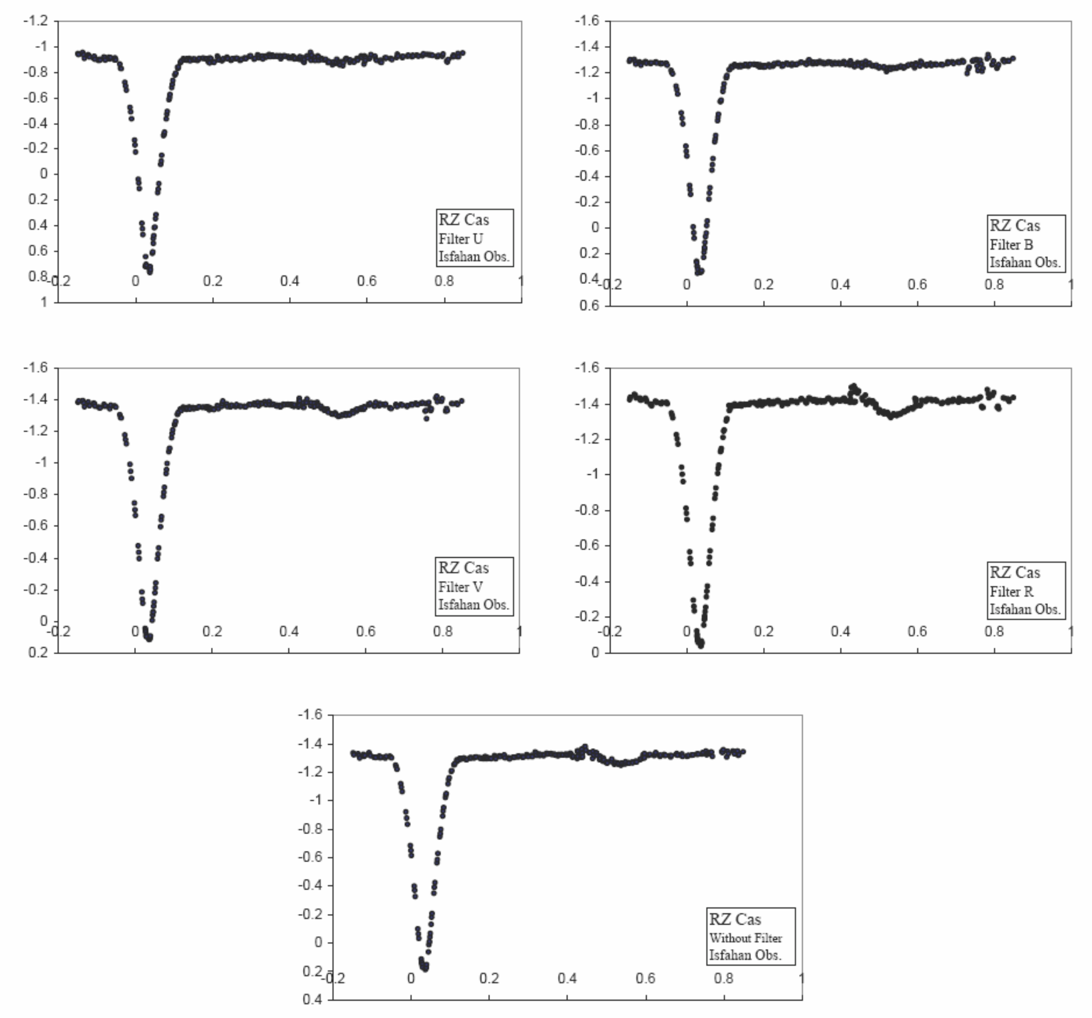

Figure 1. Light curves obtained from the reduction of observed data at Isfahan University Observatory.

observations (McCluskey & Kondo 1984; Schmitt et al. 1990; Drack, Simon & Linsky 1986; Umana, Catalano & Rodono 1991; Umana, et al. 1996; Umana et al. 1993) [21-26] are also made. These observations have also indicated strong activities and period changes for the system.

Visual and photographic observations appeared to permit a periodic representation of the O-C curve, which was interpreted as light-time effect in a triple system [27] or as apsidal motion [28 , 29]. Luyten discussed both possibilities, obtaining the periodic representation but remarking that "no definite conclusion" could be reached at the time [30]. Yet subsequent photoelectric observations, very soon demonstrated that a simple periodic representation is not possible [2]. Parenago and Szafraniec concluded that the period changes should be irregular, although they both tried to represent the residuals by a smooth curve [31 , 32]. The important fact that the period might have exhibited several sudden discontinuous changes was first put forward by Robinson [33]. Chaubey proposed that the period change of the system can be explained by a mass transfer from filled Roche lobe of the secondary to the primary component [34]. He estimated the rate of this mass transfer to be about 3.3×10^{-7} $M_{\odot}yr^{-1}$.

2. Observations

Observations are divided in two parts. The first set of observations were made with the 20” Astromechanics Telescope and RCA4509 photoelectric photometer in Biruni Observatory, Shiraz University during the period Oct to Dec 2004 using the B and V standard Johnson filters. The second set were made with the 16” Meade Telescope and OPTEC SSP-5A photoelectric photometer in Isfahan University Observatory during the period Sep to Dec 2005 through the U, B, V, R standard Johnson filters, and also through a clear window (C filter). The stars HD 16393 and TYC 4317-1437-1 were used as comparison and check stars, respectively. The data were reduced with Redwip code. The following ephemeris was used for reduction [7]:

Min. I=HJD 2450020.4070+1^{d}.1952592 E

In total, seven complete light curves were obtained in various filters which are shown in figures. 1 and 2. Some continuous photometric observations (only in V

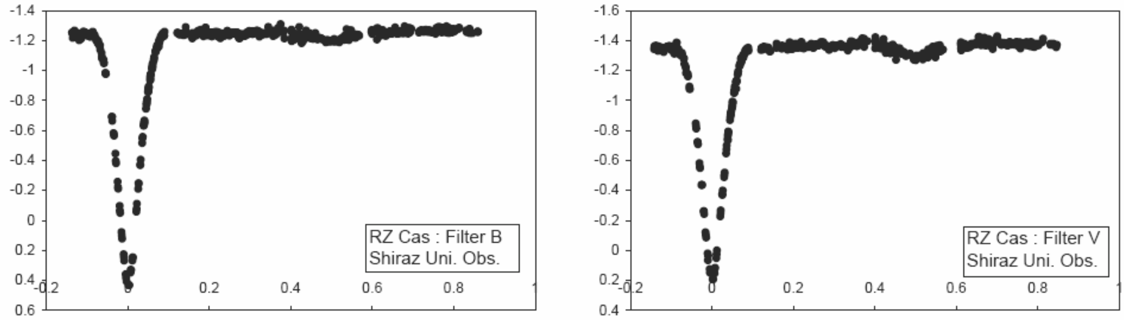

Figure 2. Light curves obtained from the reduction of observed data at Shiraz University Observatory.

Table 1: Data of continuous observations compiled for detection of δ Scuti type pulsations.

No	HJD (2453000+)	Orbital Phase	Min. type	Observatory	Data point
1	650.3711-650.5313	0.97 - 0.10	Pri	Isfahan	764
2	656.3359-656.4258	0.96 - 0.04	Pri	Isfahan	601
3	671.2773-671.3750	0.46 - 0.54	Sec	Isfahan	601
4	674.2734-674.3672	0.97 - 0.05	Pri	Isfahan	600
5	697.3008-697.4180	0.23 - 0.33	Out of Min	Isfahan	721
6	619.2266-619.4453	0.95 - 0.12	Pri	Shiraz	410

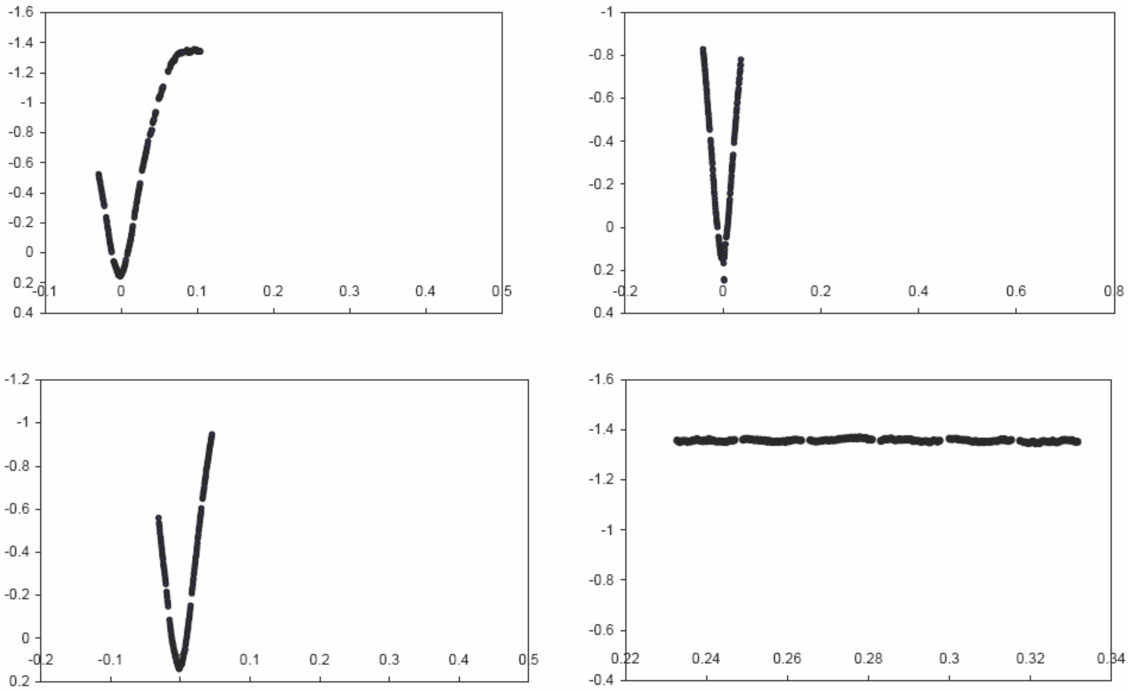

Figure 3. Light curves obtained from the reduction of continuously observed data at Isfahan University Observatory.

filter) were made to detect the δ Scuti type pulsations of primary component (Table 1). These are shown in figures 3 and 4.

3. Calculation of times of minima and period

Eleven epochs of primary minimum and seven epochs of secondary minimum were observed. Epochs of minimum were calculated by fitting parabolae to the light curves. The heliocentric julian dates of the primary minima and their O-C are listed in table 2. The numbers in the column called N show the number of total cycles of revolution since HJD2450020.4070. The following ephemeris was obtained by the analysis of phases of primary minima:

Min. I=HJD $2453620.5500+1^{d}.1952639\,E$

It can be seen that the two ephemeris are different in primary minimum by $O\text{-}C=0^{d}.0081$ or 703 s. It is also seen that the period of the system is also increased by 0.41 s. If we contribute this period change to the conservative mass transfer in the semi detached system, the rate of mass transfer from secondary to primary component would be $1.5\times10^{-7}\,M_{\odot}yr^{-1}$. This is about half

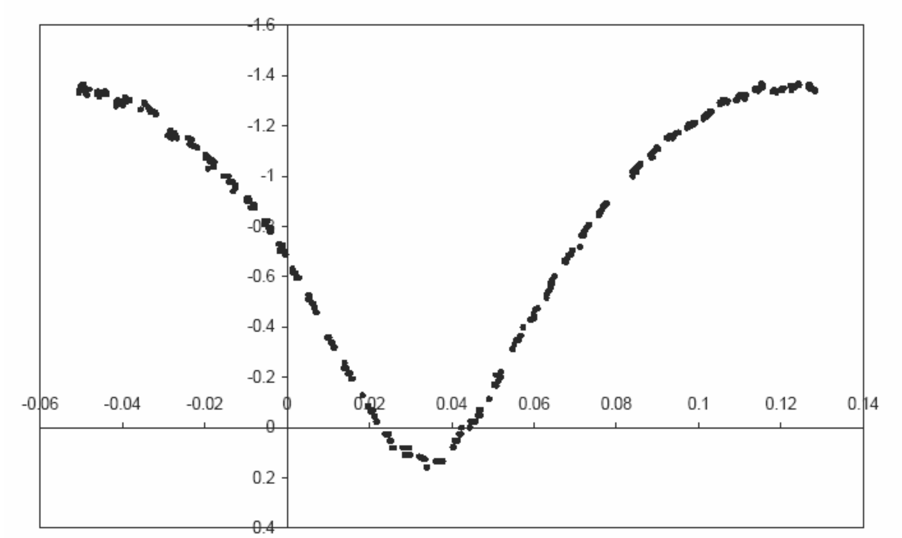

Figure 4. Light curve obtained from the reduction of continuously observed data of Shiraz University Observatory.

Table 2. Primary minima obtained from light curves.

Filter	Observatory	HJD (Min. 1) (2453000+)	Average of HJD (2453000+)	O - C	N	P
U	Isfahan	620.5674		0.033		
B	Isfahan	620.5677		0.033		
V	Isfahan	620.5679	620.5674	0.034	3012	1.1952725
R	Isfahan	620.5670		0.033		
C	Isfahan	620.5673		0.033		
B	Shiraz	307.3706	307.3705	0.0007	2750	1.1952595
V	Shiraz	307.3704		0.0005		
continuous photometry						
V	Shiraz	619.3726	619.3726	0.034	3011	1.1952725
V	Isfahan	650.4108	650.4108	0.0013	3037	1.1952597
V	Isfahan	656.3862	656.3862	0.0007	3042	1.1952595
V	Isfahan	674.3158	674.3158	0.0012	3057	1.1952597

Table 3. Secondary minima obtained from light curves.

Filter	Observatory	ΔP
U	Isfahan	- 0.016
B	Isfahan	- 0.013
V	Isfahan	+ 0.003
R	Isfahan	+ 0.005
C	Isfahan	+ 0.003
B	Shiraz	- 0.0037
V	Shiraz	- 0.0007

that obtained by Chaubey [34]. We also see that $\dot{P}$ is positive, showing that the current mass transfer is from the less massive component to the more massive one.

Table 3 shows the differences of temporal separations of minima from half, $\Delta P = P_{sec} - P_{pri} - 0.5$ which is an indicator for deviation from circular orbit. There is no meaningful evidence for ellipticity of the orbit.

4. δ Scuti type pulsations

The continuous photometric data taken during primary minima (numbers 1, 2, 4, and 6 in the table 1), were first processed by Table Curve (TC) code to find the best fitted curve. The fitted curves are found to be of the form

$$Y = \frac{a + cx + ex^2 + gx^3}{1 + bx + dx^2 + fx^3 + hx^4}. \quad (1)$$

The coefficients of the terms for each curve are listed in table 4. Then the residuals (observed data, minus the value of the fitted curve), were obtained, and were fourier analyzed by Period04 code. Three prominent modes of each data set are shown in table 5. The residuals are well described by the expression:

$$\Delta B = \sum A_i \sin\left[\left(\frac{T}{f_i}\right) + \varnothing_i\right]. \quad (2)$$

The continuous photometric data in secondary minimum

Table 4. Coefficients of terms for curves fitted to primary minima. Numbers in the first column refer to table 1.

No.	a	b	c	D	e	f	g	h
1	0.1408 ±0.0011	5.0267 ±0.4470	-3.6691 ±0.0875	925.23 ±14.053	-1321.7 ±7.7108	-2233.3 ±416.50	--- ---	--- ---
2	0.1291 ±0.0012	1.6346 ±0.3478	-3.2719 ±0.0910	755.71 ±7.6355	-1215.7 ±5.8312	885.92 ±202.48	--- ---	--- ---
4	0.1284 ±0.0008	3.6747 ±0.1997	-3.5365 ±0.0576	781.52 ±9.0363	-1198.6 ±5.2432	-1326.4 ±152.13	--- ---	--- ---
6	-0.6676 ±0.0017	-30.217 ±0.3711	47.590 ±0.2840	542.01 ±9.1332	-891.01 ±13.595	-2722.8 ±98.254	3501.5 ±172.78	3925.8 ±231.68

Table 5. Sinusoidal components of the short-period variations in the primary minimum phases. Numbers in the first column refer to table 1.

No.	Freq (cycle/day)	Ampl (mag)	Phase	Period (min)
1	65.583 52.081 92.591	0.0045 0.0031 0.0018	0.292 0.227 0.673	22.0 27.6 15.6
2	58.789 24.811 68.497	0.0062 0.0037 0.0025	0.408 0.289 0.585	24.5 58.0 21.0
4	66.070 58.426 30.032	0.0036 0.0024 0.0018	0.342 0.150 0.022	21.8 24.6 47.9
6	14.975 28.278 66.607	0.007 0.006 0.006	0.664 0.947 0.366	96.3 50.9 21.6

Table 6. Sinusoidal components of the short-period variations in the secondary minimum and out-of-eclipse phases. Numbers in the first column refer to table 1.

No.	Freq (cycle/day)	Ampl (mag)	Phase	Period (min)
3	47.265 63.528	0.0059 0.0044	0.939 0.707	30.5 22.7
5	65.660 26.668	0.0038 0.0024	0.091 0.668	21.9 54.0

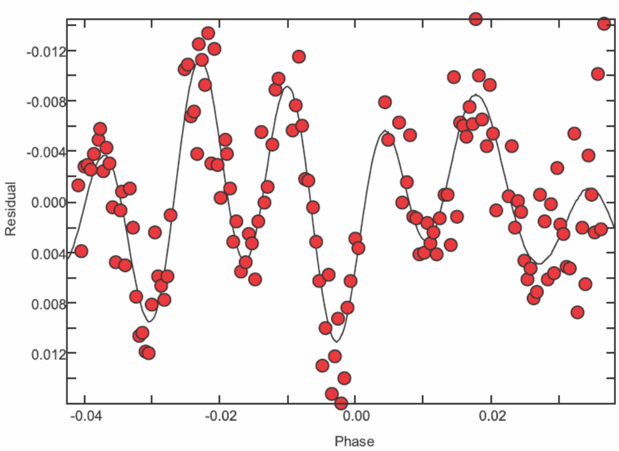

Figure 5. Residuals of the second row of table 1 versus phase, and its fitted fourier curve.

and out of minima were analyzed in a similar way. The detected periods are tabulated in table 6. It can be seen from tables 5 and 6 that all of data have common period of 21-22 min. This is in agreement with Ohshima et al., [17]. Figure 5 shows the residuals of second row of table 1 and fitted fourier curve, as an example.

5. Summary and conclusion

In this study we have obtained photoelectric photometry data in Isfahan and Shiraz University Observatories. RZ Cas, a typical semidetached eclipsing binary system consisting of a main-sequence primary and a cooler subgiant secondary. Its period is decidedly variable, but the variations are more of abrupt changes than of a secular increase or decrease. These period changes are doubtless the result of mass exchange within the system. Since the subgiant component fills its Roche lobe, it is presumably losing mass to its main-sequence companion [3].

We have found the change of period to be 0.41 second and displacement of primary minimum to be 703 seconds, comparable to the work of Varricat et al. [7] This period change corresponds to a rate of mass transfer $1.5\times10^{-7}\ M_{\odot} yr^{-1}$, about half that estimated by Chaubey [34].

The quasi-periodic light variations of RZ Cas have been reported for several years. Such variability can be caused by a hot spot on the primary produced by impingement of accreting matter. Because the falling matter makes a spot at some position on the primary, the light from such a hot spot will be fixed in orbital phase. If the variability is caused by a nonstationary property of the accreting flow, no periodic variation should be expected. Because of the regularity of this variation, it can be due to the stellar pulsation. The most plausible stellar pulsation of an A3V star is a δ-Scuti type pulsation. Considering the distribution of the δ Scuti stars, RZ Cas, an A3V star, will be at the blue edge. Because the bluer variables have shorter periods, it is reasonable that RZ Cas pulsates with a relatively short period.

In this study, we have detected a short-period pulsation for RZ Cas, with the period of about 21-22 minutes and an amplitude of about 0.006 mag. This period is consistent with other studies (Ohshima 1998, Ohshima 2001, Rodriguez & Breger 2001, Rodriguez et al., 2003, Lehmann & Mkrichian 2004) [17 , 18 , 35-37]. There are, however, some discrepancies about the amplitude. Large amplitudes as large as 0.02 mag. have been observed by Ohshima [17 , 35], but amplitudes as low as 0.009 and 0.0064 mag. have also been reported by Rodriguez et al., [36] and Lehmann & Mkrichian [37].

Acknowledgments

The authors would like to thank A. Abedi for his help in the photometric observations at Biruni Observatory.

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