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Apsidal motion and light-time effect in the eclipsing binaries RU Monocerotis and DR Vulpeculae

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Abstract. We present a period analysis of the two early-type and well-known eccentric eclipsing binaries RU Mon ($P = 3\overset{d}{.}58, e = 0.45$) and DR Vul ($P = 2\overset{d}{.}25, e = 0.10$). Several new times of minimum light recorded with photoelectric means have been gathered. The $O-C$ diagrams are analyzed using all reliable timings found in the literature and new values for the elements of the apsidal motion and light-time effect are computed. We confirmed the very short period of apsidal motion of about 36.3 years for DR Vul. The third bodies have an orbital period of about 73 and 63 years for RU Mon and DR Vul, respectively.

Key words: stars: binaries: eclipsing – stars: fundamental parameters – stars: individual: RU Mon – stars: individual: DR Vul

1. Introduction

Eccentric eclipsing binaries with apsidal motion belong to the traditional sources of our knowledge about the internal structure of stars. They serve as an important test for the theoretical models of stellar evolution. The light-time effect analysis producing the existence of multiple stellar systems is a suitable contribution to stellar stastistics. The combination of apsidal motion with a light-time effect in such mutiple systems serve as an excellent laboratory of celestial mechanics for studying a wide variety of processes in stellar astrophysics. In this paper, both phenomena are studied by way of two early-type eclipsing binaries.

In particular, the two systems (RU Mon, DR Vul) analysed here are relatively well-known and frequently studied early-type binaries with a short orbital period and known apsidal motion. Moreover, both these systems triggered attention of Russian astronomers during the 80ies years (Khaliullina et al. 1985, Khaliullina 1987, thereafter K85, K87, respectively) and more then 10 years elapsed since their studies.

2. Observations of minimum light

In order to enlarge the number of times of minimum light, new observations for both systems were carried out. Our new photoelectric and CCD photometry was performed at two observatories with the aim of securing several well-covered primary and secondary minimum for each variable:

- Ondřejov Observatory, Czech Republic: 65 cm reflecting telescope with Cousins V, R filters and CCD-camera SBIG ST-6 or ST-8 at its primary focus,
- R. Szafraniec Observatory, Metzerlen, Switzerland: 35 cm Schmidt-Cassegrain telescope with unfiltered photoelectric photometer STARLIGHT-1 or CCD-camera SBIG ST-6.

The CCD measurements in Ondřejov were done using the standard Cousins B, V, R filters. In some cases, the R filter was used in our observations due to technical reasons, when another faint object was simultaneously monitored. Flat fields for the reduction of the CCD frames were routinely obtained from exposures of regions of the sky taken at dusk or dawn. Several comparison stars were chosen on the same frame as the variables. During the observations, no variations in the brightness of these stars exceeding the possible error of measurements (typical $\sigma \simeq 0.005$ mag) were detected. No correction was allowed for differential extinction, due to the proximity of the comparison stars to the variable and the resulting negligible differences in the air mass.

The new times of primary and secondary minimum and their errors were determined using the least squares fit of the data, by the bisecting cord method or by the Kwee-van Woerden algorithm. These 12 times of minimum are presented in Table 1. As an example of our CCD measurements, Fig. 1 shows the differential R-magnitude during the primary minimum of RU Mon obtained at JD 24 50884.

3. Apsidal motion and light-time effect analysis

The apsidal motion and the light-time effect in both systems were studied together by means of an $O-C$ diagram analysis. The deviation of the observed values $(O-C)_{obs}$ from the linear ephemeris is given by a superposition of the apsidal motion of

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Table 1. New photoelectric times of minimum light of RU Mon and DR Vul

System	JD Hel.- 2400000	Error [day]	Min. type	Filter Method	Ref.
RU Mon	46118.316	0.003	II	pe	1
	47960.802	0.003	II	HIP	15
	48729.8597	0.0005	I	HIP	15
	48749.394	0.001	II	HIP	15
	50122.2787	0.0007	II	CCD R	15
	50124.3121	0.0014	I	CCD	2
	50837.6714	0.0004	I	CCD	3
	50841.2557	0.0020	I	CCD	4
	50884.2736	0.0001	I	CCD R	15
DR Vul	47368.4319	0.0004	I	pe V	5
	47368.4321	0.0003	I	pe B	5
	48490.4599	0.0007	II	pe	7
	48490.4600	0.0005	II	pe	8
	48499.4666	0.0005	II	pe	7
	48534.4485	0.0008	I	pe	7
	48536.69947	0.00078	I	pe V	9
	48543.45189	0.0004	I	pe	7
	48839.355	0.003	II	pe	10
	49198.479	0.005	I	pe B	11
	49228.7300	0.0007	II	pe V,R	12
	49647.4068	0.0003	II	CCD V	15
	49889.5119	0.0003	I	CCD B	15
	49898.520	0.004	I	CCD	13
	49899.5058	0.0008	II	CCD B	15
	49917.5027	0.0011	II	CCD	13
	50014.3055	0.0005	II	CCD	15
	50562.53504	0.00003	I	CCD V	15
	50722.351	0.003	I	CCD	14
	50974.4489	0.0001	I	CCD R	15
	50984.4470	0.0011	II	CCD	16
	51046.4793	0.0005	I	CCD R	15

Ref: (1) Diethelm, BBSAG 76, (2) Diethelm, BBSAG 111, (3) IBVS 4597, (4) Diethelm, BBSAG 117, (5) IBVS 4263, (7) Wolf & Diethelm (1993), (8) Blättler, BBSAG 98, (9) IBVS 3900, (10) Blättler, BBSAG 102, (11) Diethelm, BBSAG 104, (12) IBVS 4009, (13) Diethelm, BBSAG 109, (14) Diethelm, BBSAG 116, (15) this paper, (16) Diethelm, BBSAG 118.

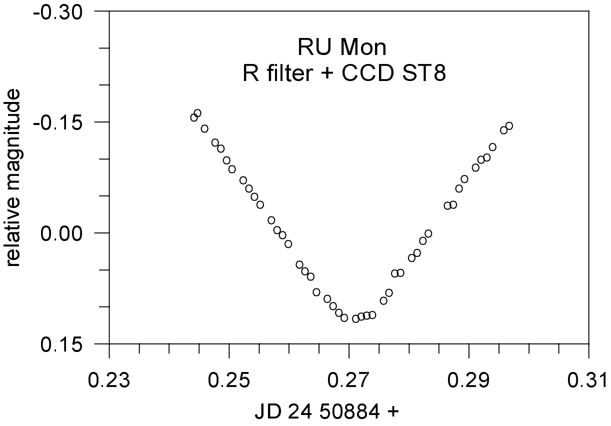

Fig. 1. A plot of the differential R-magnitudes observed during primary eclipse of RU Mon at JD 24 50884.

the eccentric binary system and by the ligh-time effect caused by a presence of a third body:

$$(O-C)_{obs} = (O-C)_{aps} + (O-C)_{lte} \ ,$$

where $(O-C)_{aps}$ represents the influence of the apsidal motion and $(O-C)_{lte}$ is the contribution of the light-time effect. Suitable numerical methods for the apsidal motion analysis were described by Giménez & García-Pelayo (1983) and Lacy (1992). Improved expressions for the prediction of eclipse times are also presented in Giménez & Bastero (1995). We used the method first mentioned, which is a weighted least squares iterative procedure, including terms in the eccentricity up to the fifth order. Due to the relatively large value of the orbital eccentricity, especially for RU Mon, we used all terms in our calculation. Our relation for the prediction of the times of minimum caused by apsidal motion is given in Wolf & Šarounová (1995).

The theory of the third body motion and the light-time effect analysis in eclipsing binaries was reviewed several times in the literature, see e.g. Irwin (1959), Mayer (1990). The light travel time is given by

$$O-C \ = \ \frac{A}{\sqrt{1-e_3^2\cos^2\omega_3}} \times \left[\frac{1-e_3^2}{1+e_3\cos v}\sin(v+\omega_3) + e_3\sin\omega_3\right] ,$$

where e_3 is eccentricity of the third-body orbit, ω_3 the longitude of periastron and v the mean anomaly. The observed semi-amplitude A of the light-time curve (in days) is

$$A = \frac{a_{12}\sin i_3}{173.15}\sqrt{1-e_3^2\cos^2\omega_3}, \qquad (1)$$

where a_{12} is semi-major axis of the relative orbit of the eclipsing pair around the common center of mass (in AU) and i_3 is the inclination of the third-body orbit. There are 10 independent variables to be determined in this procedure:

$$(T_0, P_s, e, \dot{\omega}, \omega_0) \ ,$$

for the apsidal motion and

$$(T_3, P_3, e_3, \omega_3, A)$$

for the light-time effect.

The stability of our reduction procedure was tested by solving for light time effect as well as apsidal motion parameters separately. The results of this iteration procedure were within the standard error of each variable. The relation between the sidereal and the anomalistic period, P_s and P_a, is given by

$$P_s = P_a \ (1 - \dot{\omega}/360^\circ)$$

and the period of apsidal motion by

$$U = 360^\circ P_a/\dot{\omega} \ .$$

We have collected all reliable times of minimum light gathered from the literature as well as from current databases of AAVSO, BAV, BBSAG and BRNO observers. DR Vul has been observed much more frequently lately.

We employed the following data reduction procedure. All photoelectric and CCD times of minimum were used with a weight of 10 in our computation. The current photographic as well as some of less precise measurements were weighted with a factor of 3, while the earlier visual and photographic times of minimum were given a weight of 1 due to the large scatter in these data.

4. RU Mon

The detached eclipsing binary RU Monocerotis (= GSC 5380.0802 = BD-07° 1623 = FL 689 = HIP 33163 = AN 43.1905; $\alpha_{2000} = 6^h54^m12.2^s$, $\delta_{2000} = -7° \; 35' \; 37''$, V_{max} = 10.5 mag; Sp. B7V + B7V) is one of the well-known early-type binary with an eccentric orbit ($e = 0.32$) and a period of about 3.58 days. This binary is a classical example of apsidal motion and its observational time span covers practicaly one century. It was discovered to be a variable photographicaly by L. P. Ceraskaja (Ceraski 1905). Dubiago & Martynov (1929) first discovered an apsidal motion with the period of several hundert years and estimated a high orbital eccentricity of e about 0.4. Spectroscopically RU Mon was investigated by Struve (1945). The first photoelectric UBV observations were obtained by Martynov (1965) at Mount Stromlo Observatory. See also K85 for further details and a historical review of other observations. The discovery of a third body with a mass $M_3 \simeq 2.2 M_\odot$ was announced in that analysis, where the following linear light elements were also given:

$$\text{Pri. Min.} \; = \; \text{HJD } 24\,45116.4441 + 3\overset{\mathrm{d}}{.}584653 \cdot E \; ,$$
$$\text{Sec. Min.} \; = \; \text{HJD } 24\,45118.2364 + 3\overset{\mathrm{d}}{.}584653 \cdot E \; .$$

Martynov & Khaliullina (1986) report the analysis of six spectrograms of RU Mon obtained with 6-m telescope at the Special Astrophysical Observatory during 1982–1984. All these spectrograms with a dispersion of 27 Å/mm show only the strong hydrogen lines and the interstellar K, H lines. They derived an amplitude of the radial velocity curve $K = K_1 + K_2$ = 292 km s^{-1}, masses $M_1 = 3.75 M_\odot$, $M_2 = 3.59 M_\odot$ and radii $R_1 = 2.53 R_\odot$, $R_2 = 2.45 R_\odot$ of component stars. All these values were used in the following analysis.

All times of minimum light published in K85 were incorporated into our analysis. From the Hipparcos photometry (Perryman 1997), we were able to determine three additional moments of minimum light. They are given as “HIP” minima in Table 1 together with our results of the CCD observations.

A total of 103 times of minimum light were used in our analysis, with 49 secondary eclipses among them. Adopting the orbital inclination, derived from the light curve solution, of $i = 89.8°$ (K85), the apsidal motion elements can be computed. The parameters found and their internal errors of the least squares fit are given in Table 2. In this table, P_s denotes the sidereal period, P_a the anomalistic period, e represents the eccentricity and $\dot{\omega}$ is the rate of periastron advance (in degrees per cycle or in degrees per year). The zero epoch is given by T_0 and the corresponding position of the periastron is represented by ω_0.

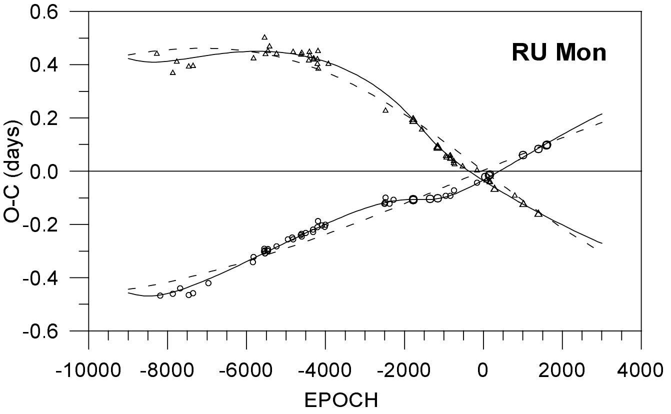

Fig. 2. $O - C$ residuals for the times of minimum of RU Mon with respect to the linear light elements. The continuous curves represent predictions for primary and secondary eclipses. The dashed curve represents the apsidal motion only. The individual primary and secondary minima are denoted by circles and triangles, respectively. Larger symbols correspond to the photoelectric and CCD measurements, which were taken into the calculations with higher weight.

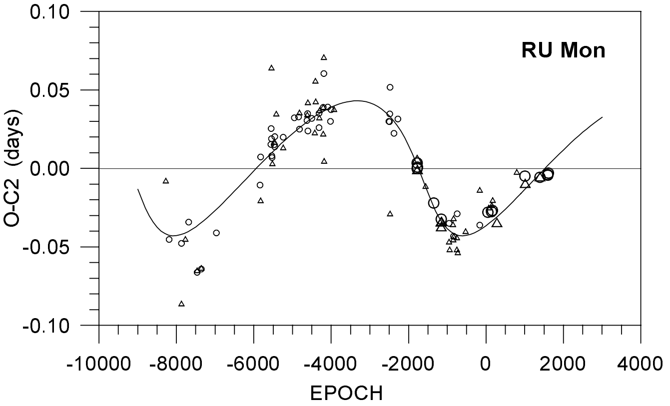

Fig. 3. Light-time effect in RU Mon after subtracting the apsidal motion variation.

The $O - C$ residuals for all times of minimum with respect to the linear light elements are shown in Fig. 2. The non-linear predictions, corresponding to the fitted parameters, are plotted as continuous and dashed curves for primary and secondary eclipses, respectively. After subtracting the apsidal motion contribution, the diagram of the light time effect on Fig. 3 can be obtained. The $O - C$ curve is well covered by minima, so that the third-body period P_3 of 73 years is relatively well established.

5. DR Vul

The nothern-hemisphere eccentric eclipsing binary DR Vulpeculae (= HDE 339 770 = BD+26° 3835 = SAO 88380 = PPM 110698 = GSC 2162.0017 = P 5335 = AN 129.1935 = FL 2993; $\alpha_{2000} = 20^h13^m46.8^s$, $\delta_{2000} = +26° \; 45' \; 01''$, V_{max} = 8.64 mag; Sp. B0V + B0.5V) is also a relatively well-known, early-type detached binary with an orbital eccentricity $e = 0.098$

Table 2. Apsidal motion and third-body orbit parameters of RU Mon and DR Vul.

Element	Unit	RU Mon	DR Vul
T_0	HJD	2445116.4706 ± 0.0007	2440300.7295 ± 0.0005
P_s	days	3.5846513 ± 0.0000008	2.2508711 ± 0.0000002
P_a	days	3.5847526 ± 0.0000008	2.2512536 ± 0.0000002
e		0.396 ± 0.005	0.095 ± 0.001
$\dot{\omega}$	$\mathrm{deg\ cycle}^{-1}$	0.0102 ± 0.0005	0.0612 ± 0.0012
$\dot{\omega}$	$\mathrm{deg\ yr}^{-1}$	1.037 ± 0.052	9.93 ± 0.20
ω_0	deg	90.1 ± 0.3	269.5 ± 0.3
U	years	347 ± 17	36.3 ± 0.7
P_3	years	73.3 ± 0.3	62.8 ± 0.7
A	days	0.043 ± 0.001	0.061 ± 0.002
e_3		0.464 ± 0.005	0.730 ± 0.005
ω_3	deg	202.0 ± 0.3	96.6 ± 0.3
T_3	JD	2439865 ± 15	2430050 ± 15

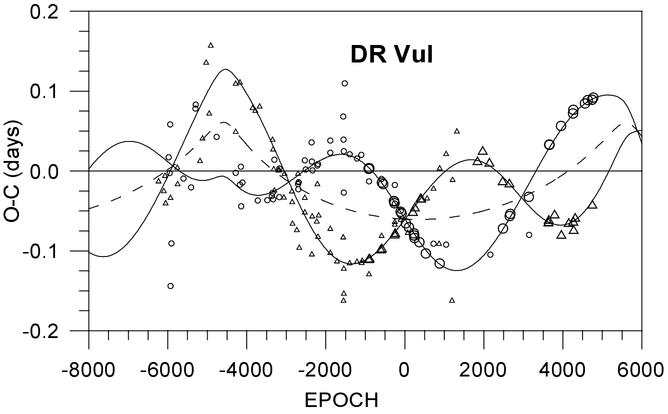

Fig. 4. $O-C$ graph for DR Vul. See legend of Fig. 2. The dashed curve represents the light-time effect.

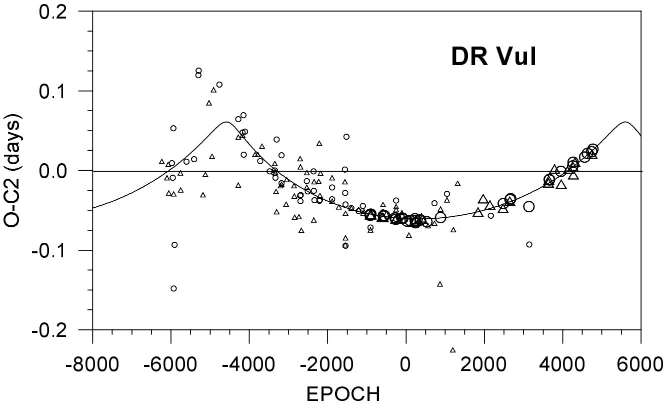

Fig. 5. Light-time effect for DR Vul. See legend of Fig. 3

and a period of about 2.25 days. It was discovered to be variable by Hoffmeister (1935). The history of further observations is summarized in detail in K87 and Wolf & Diethelm (1993). Unfortunately, this relatively bright star is not included in the Hipparcos photometry catalogue. The linear light elements derived by O'Connell (1972) are

$$\begin{aligned}\text{Pri. Min.} &= \text{HJD } 24\ 40300.6680 + 2\overset{\mathrm{d}}{.}2508645 \cdot E\ ,\\ \text{Sec. Min.} &= \text{HJD } 24\ 40301.7934 + 2\overset{\mathrm{d}}{.}2508645 \cdot E\ .\end{aligned}$$

The most recent and thoroughly covered light curve is published by Khaliullina & Khaliullin (1988) using the standard UBV system. Apsidal motion of DR Vul is discussed in several papers (O'Connell (1972), K87, Khaliullina & Khaliullin (1988)) and later by Wolf & Diethelm (1993). New photoelectric times of minimum light are nevertheless expected to improve significantly their results. The orbital inclination was adopted to be $88.3°$, following the previous results from the photometric analysis. A number of solution with different values of i showed very little dependence on this parameter and supported the use of a fixed value.

All times of minimum collected in K87 as well as the new ones given in Table 1 were used in our calculation. In this table, we compile only the new timings after that publication. A total of 175 times of minimum light were incorporated in our analysis, with 91 secondary eclipses among them. The resulting apsidal motion and light-time effect parameters are given in Table 2. The $O-C$ residuals for all times of minimum with respect to the linear light elements are shown in Fig. 4. The light-time effect, clearly visible after subtracting the influence of the apsidal motion, is presented on Fig. 5.

6. Internal structure constant

The internal structure constant is an important parameter of stellar evolution models. The period of rotation of the periastron in eccentric eclipsing binaries does not allow us to derive the individual internal stellar constant of the component stars, the observational average value of internal structure constant $k_{2,obs}$ is given by the relation

$$k_{2,obs} = \frac{1}{c_{21} + c_{22}} \frac{P_a}{U} = \frac{1}{c_{21} + c_{22}} \frac{\dot{\omega}}{360}, \tag{2}$$

where c_{21} and c_{22} are known functions of the orbital eccentricity, fractional radii, the masses of the components and the ratio

Table 3. Adopted parameters of the components and derived results.

Parameter	Unit	RU Mon	DR Vul
M_1	$M_\odot$	3.75	13.2
M_2	$M_\odot$	3.59	12.1
R_1	$R_\odot$	2.53	4.8
R_2	$R_\odot$	2.45	4.4
a	$R_\odot$	19.14	21.3
Source		Martynov & Khaliullina (1986)	Khaliullina & Khaliullin (1988)
$\dot\omega_{rel}$	deg cycle^{-1}	0.00104	0.00276
$k_{2,obs}$		0.00553	0.00909
$f(M)$	$M_\odot$	0.1105	0.2990
$a_3 \sin i_3$	AU	8.4	10.6
$M_{3,min}$	$M_\odot$	2.15	6.7
K	km s^{-1}	3.85	7.3

between rotational velocity of the stars and Keplerian velocity (Kopal 1978).

Taking into account the value of the eccentricity and the masses of the components, one has to subtract from $\dot\omega$ a relativistic correction $\dot\omega_{rel}$ (Giménez 1985)

$$\dot\omega_{rel} = 5.45 \times 10^{-4} \frac{1}{1-e^2} \left(\frac{M_1+M_2}{P}\right)^{2/3}. \quad (3)$$

The values of $\dot\omega_{rel}$ and resulting mean internal structure constants $k_{2,obs}$ are given in Table 3.

7. Mass of the third body

The derived parameters of the third body orbit allow us to determine the mass function $f(M)$ of the triple systems

$$f(M) = \frac{M_3^3 \sin^3 i_3}{(M_1+M_2+M_3)^2} = \frac{a_3^3 \sin^3 i_3}{P_3^2} = \frac{1}{P_3^2}\left[\frac{173.15\,A}{\sqrt{1-e_3^2\cos^2\omega_3}}\right]^3,$$

where P_3 is the period of the third-body (in years) and M_i are the masses of components. The systemic radial velocity of the eclipsing pair have an amplitude of

$$K = \frac{A}{P_3}\frac{5156}{\sqrt{(1-e_3^2)(1-e_3^2\cos^2\omega_3)}}.$$

Assuming a coplanar orbit ($i_3 = 90°$) we can obtain lower limits for the mass of the third component $M_{3,min}$. This value, as well as the mass function $f(M)$, $a_3 \sin i_3$ and the amplitude of the systemic radial velocity K are also given in Table 3 for both systems studied. The adopted physical parameters are taken from the literature, where the masses were determined by different methods. They are also in good agreement with the values given in Popper (1980) and Andersen (1991) for similar spectral types.

The acceleration of the rate of apsidal motion caused by the presence of the third body $\dot\omega_3$ was derived by Martynov (1973):

$$\dot\omega_3 = \frac{3}{4}\lambda m^2 + \frac{225}{32}\lambda^2 m^3 + \ldots, \quad (4)$$

where

$$\lambda = \frac{M_3}{M_1+M_2+M_3}, \quad \text{and} \quad m = \frac{P_s}{P_3}. \quad (5)$$

This correction for the apsidal motion is negligible in both systems due to the relatively long period P_3 of the third body orbit.

8. Conclusions

The photometric study of triple or multiple stellar systems with apsidal motion of the eclipsing pair is a poorly studied field of celestial mechanics. In this paper, we report new results for our observational project initiated 7 yeras ago with the primary purpose of monitoring eclipsing binaries with eccentric orbits. We derive updated apsidal motion elements and new third body orbits for two eccentric early-type eclipsing binaries by means of an $O-C$ diagram analysis.

In the case of RU Mon, the period of the third body orbit found is shorter than apsidal motion period. DR Vul presents an opposite example: the period of the third body orbit is longer then the apsidal period. In the case of RU Mon our results are in good agreement with previously obtained parameters (K85); the period of the third body orbit found in this paper is longer than value previously given.

DR Vul possesses one of the smallest known period of apsidal motion. Only the systems U Oph (21.3 yr, Kämper 1986) and GL Car (25.2 yr, Giménez & Clausen 1986) have shorter periods. The observed value of the third light $L_3 = 0.145$ in V (Khaliullina & Khaliullin 1988) is in good agreement with the lower limit for the mass of the third body at 6.7 $M_\odot$ and a spectral type of B4V. A quadruple system DR Vul, showing two highly eccentric orbits ($M_3 > 3.4\,M_\odot, P_3 = 18\,\mathrm{yr}, e_3 = 0.80; M_4 > 5.4\,M_\odot, P_4 = 47\,\mathrm{yr}, e_4 = 0.79$), as suggested in K87, was not detected in our $O-C$ analysis and seems to be rather unrealistic to us. Nevertheless, the orbital period of the third body given here is not covered satisfactorily by precise photoelectric and CCD data. Therefore, new high-accuracy timings of this eclipsing system are necessary in the future in order to improve the light-time effect parameters given above.

The internal structure constants $k_{2,obs}$ (0.0055 for RU Mon and 0.0091 for DR Vul) are in good agreement with the theoretical values for models of main-sequence stars (Claret & Giménez 1992).

A spectroscopic analysis, allowing the determination of precise masses, should be also attempted especially for the DR Vul system, where, to our knowledge, no spectrograms have been reported up to know. This massive system with relatively short orbital period could be attractive for spectroscopists. The radial velocity curve should have a semi-amplitude of more than 200 km s^{-1}.

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References

Andersen J., 1991, A&AR 3, 91
Caton D.B., Burns W.C., IBVS No. 3900
Ceraski W., 1905, Astron. Nachr. 167, 318
Claret A., Giménez A., 1992, A&AS 96, 255
Dubiago A.D., 1929, Variable Stars 1, No. 8
Dubiago A.D., Martynov D.Ya., 1929, Astron. Nachr. 235, 225
Giménez A., 1985, ApJ, 297, 405
Giménez A., 1994, Experimental Astronomy 5, 91
Giménez A., Bastero M., 1995, Ap&SS 226, 99
Giménez A., Clausen J.V., 1986, A&A 161, 275
Giménez A., García-Pelayo J.M., 1983, Ap&SS 92, 203
Hoffmeister C., 1935, Astron. Nachr. 255, 405
Irwin J.B., 1959, AJ 64, 149
Kämper B.-C., 1986, Ap&SS 120, 167
Khaliullina A.I., 1987, MNRAS 225, 425 (K87)
Khaliullina A.I., Khaliullin Kh.F., 1988, AZh 65, 108
Khaliullina A.I., Khaliullin Kh.F., Martynov D.Ya., 1985, MNRAS 216, 909 (K85)
Kopal Z., 1978, Dynamics of Close Binary Systems. Reidel, Dordrecht, Holland
Lacy Sandberg C.H., 1992, AJ 104, 2213
Martynov D.Ya., 1965, AZh 42, 1209
Martynov D.Ya., 1973, In: Tsesevich (ed.) Eclipsing Variable Stars
Martynov D.Ya., Khaliullina A.I., 1986, AZh 63, 288
Mayer P., 1990, Bull. Astron. Inst. Czech. 41, 231
O’Connell D.J.K., 1972, Ric. Astron. Specola Vaticana 8, 14
Ogloza W., 1995, IBVS No. 4263
Perryman M.A.C., 1997, The Hipparcos and Tycho Catalogues, ESA SP - 1200
Popper D., 1980, ARA&A 18, 115
Sandberg Lacy C.H., Clem J.L., et al., 1998, IBVS No. 4597
Sandberg Lacy C.H., Fox G.W., 1994, IBVS No. 4009
Struve O., 1945, ApJ 102, 100
Wolf M., Diethelm R., 1993, MNRAS 263, 527
Wolf M., Šarounová L., 1995, A&AS 114, 143