A&A manuscript no.
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Photometric study of eclipsing binary RV Tri

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Abstract. We present new precise photometric observations of RV Tri. Complete light curve was obtained in the R and V filters. These light curves were processed by computer programs FOTEL and EBOP and a solution of the double system was calculated. We discus characteristics of the system and compare our model with a previous calculation. Our observations of primary minima and their comparison with those predicted on base of the GCVS catalogue have indicated significant differences. We discuses these differences in context of a period change.

Key words: photometry – eclipsing binary

1. Introduction

RV Tri (GSC 2321.0070) was recognized as a variable star by W. Strohmeier and the discovery was published by Geyer et al. (1955), where preliminary values of the light elements were given. RV Tri is classified as Algol star type, the depth of primary and secondary minima being 1.2 and 0.1 magnitude, respectively. The times of primary minima have been frequently visually determined during last three decades, but a detailed analysis of this star is still missing. Therefore, we have observed RV Tri with a new CCD camera equipment at our observatory in summer 1997. The mean light curve which we obtained from the observations enables us to study this system.

2. Observations

The data presented in this paper were obtained during observation periods in summer/autumn 1997 and 1998. We used 0.6 m reflector of our observatory. The CCD front side camera placed at Newtonian focus took 30 or 60 seconds exposures of the variable and comparison stars. V (Johnson) and R (Kron-Cousins) standard filters were used during all observation period. The observations are summarized in Table 1.

Table 1. The list of observations and the primary minima of RV Tri ((O-C) differences as mean of R,V).

night	minimum in R	minimum in V	No. R+V	epoch	(O-C)
1997 – 09 – 20/21	—	—	141		
1997 – 09 – 21/22	—	—	95		
1997 – 09 – 28/29	50720.3480 $\pm$ 0.0057	50720.3470 $\pm$ 0.0057	179	6219	-0.0120 ± 0.0081
1997 – 10 – 19/20	50741.4525 $\pm$ 0.0096	50741.4517 $\pm$ 0.0103	85	6247	-0.0085 ± 0.0141
1997 – 10 – 31/11 – 01	50753.5083 $\pm$ 0.0036	50753.5074 $\pm$ 0.0038	104	6263	-0.0156 ± 0.0052
1997 – 11 – 10/11	50763.3054 $\pm$ 0.0065	50763.3061 $\pm$ 0.0058	54	6276	-0.0146 ± 0.0087
1998 – 09 – 24/25	51081.3521 $\pm$ 0.0032	51081.3532 $\pm$ 0.0038	255	6698	-0.0145 ± 0.0050
1998 – 11 – 11/12	51130.3420 $\pm$ 0.0035	51130.3422 $\pm$ 0.0063	148	6763	-0.0134 ± 0.0072

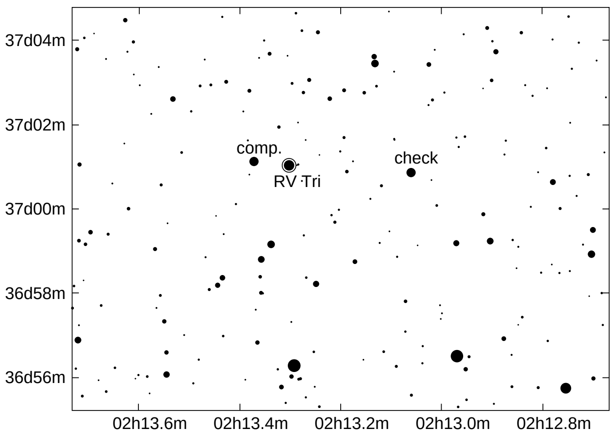

Fig. 1. Identification chart constructed on base of the USNO catalogue for RV Tri (eq. J2000.0).

The transformation between our instrumental magnitudes and Johnson photometric system gives for extra-atmospheric magnitudes and color indexes of the comparison and check star the values listed in Table 2. We used Landolt photometric standards (Landolt (1992)) for derivation of these transformations.

The standard image processing was applied to every image. The synthetic differential aperture photometry was done by MUNIPHOT, a computer program for time series photometry processing (Hroch (1998)). Differential photometry of both variable and comparison stars were not reduced for the extinction because the stars in question are very close each to other on the sky ($\sim 1'$). The chart of the close environment of RV Tri with comparison and check star is shown on Fig. 1. Its precise position as determined by processing of our observations (J2000.0, the proper motion neglected)

$$\alpha = 2^{\rm h}13^{\rm m}18\overset{s}{.}12 \;\; \delta = +37^\circ01'02\overset{''}{.}1$$

Table 2. The extra-atmospheric magnitudes and color index of observed stars in Johnson photometric system.

star	V	(V - R)
comp. (GSC 2321.1715)	13.096 ± 0.089	0.387 ± 0.094
check (GSC 2321.0692)	13.349 ± 0.082	0.713 ± 0.093
RV Tri, max.	11.0	0.2
RV Tri, min.	12.2	0.3

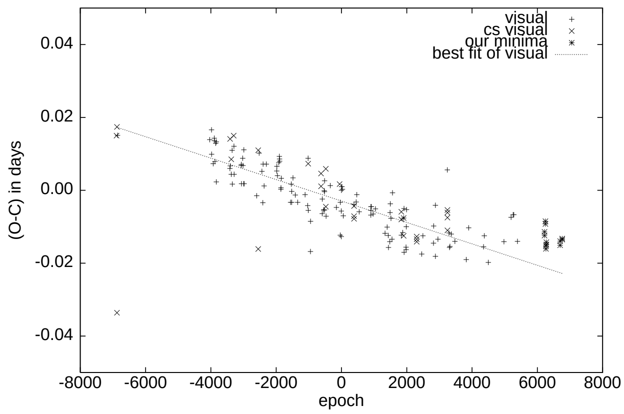

Fig. 2. The O–C diagram for RV Tri. The GCVS light elements were used. The line corresponds to the elements (1). The plus '+' represents minima reported by visual observers over the world without Czech and Slovak observers, their data are labeled by the crosses '×'. The asterisk '∗' on right edge represents our minima.

The position error was smaller than $0\farcs2$ for both coordinates. We choose the USNO-A catalogue as astrometric reference catalogue.

3. Light elements

The values of light elements published in the discovery paper by Geyer et. al. (1955) and values of the elements given by last edition of GCVS catalogue(Kholopov et al. (1985)) are highly inaccurate in comparison with the accuracy of time of minima determinations derived from our observations. We have observed an (O–C) difference about 15 minutes at current epochs. This fact is illustrated by the (O–C) diagram compiled from visual observations of the primary minima times of RV Tri (see Fig. 2) currently entered in the B.R.N.O. database (Variable Star Section of Czech Astronomical Society). The procession of all times of visual minima gives us improved light elements (computed by the robust linear least square method only for 152 accepted points)

$$\begin{array}{lll} \mathrm{Min\,I(J.D.Hel.)} = & 2446033\overset{\mathrm{d}}{.}3051 + & 0\overset{\mathrm{d}}{.}75366354\,E \\ & \pm 0\overset{\mathrm{d}}{.}0004 & \pm 0\overset{\mathrm{d}}{.}00000015 \end{array} \qquad (1)$$

We have tried to verify these elements by observation of some primary minima during our observational periods. The times of minima for each observational set were computed by the Kwee and van Woerden method (1956). Our minima (see Fig. 2) do not satisfy the elements (1) with required precision (differences about 10 minutes), and so we used improved elements (the same period, but the basic minimum a mid our minima) for the reduction of our observations to the mean light curve

$$\mathrm{Min\,I(J.D.Hel.)} = \begin{array}{cc} 2450924^{\mathrm{d}}\!.5898 + & 0^{\mathrm{d}}\!.75366354\,E \\ \pm 0^{\mathrm{d}}\!.0003 & \pm 0^{\mathrm{d}}\!.00000015 \end{array} \qquad (2)$$

These elements approximate times of minima in range between JD = 2450720 and JD = 2451130 with precision better than ±0.0004 day. The use of the above elements out of this range is uncertain.

4. Light curve analysis

We employed the observational data of RV Tri for the acquisition of orbital and physical parameters of the system. The results of 530 measurements in R and 530 measurements in V filter have been processed by the programs EBOP and FOTEL.

4.1. EBOP

EBOP — *E*clipsing *B*inary *O*rbit *P*rogram — was written by P. B. Etzel according to the model developed by Nelson and Davis (1972) in 1975 (the NDE model). We use the 1985 update for calculations. The model uses numerical integration by dividing the stellar disk into finite concentric rings to approximate various physical effects in an eclipsing binary system.

4.2. FOTEL

FOTEL — a computer program for the determination of *phot*ometric *el*ements — was written by P. Hadrava for data processing at the Ondřejov observatory (Hadrava (1990)). FOTEL simultaneously calculates light curve and radial velocities with aim to determine the parameters of the studied system. The latest version (1994) approximates the Roche potential by an effective potential. The construction of a binary system model follows the classical paper by Wilson (1979), but many improvements made by the author are included.

4.3. Data analysis

The shape of the light curve of RV Tri is similar to light curves of Algol-like systems. Therefore, we supposed that the system is semi-detached. Some parameters of a semi-detached system are mutually dependent. A radius of the secondary (filling component) r_2 and mass ratio $q = M_2/M_1$ satisfies an approximative condition developed by Eggleton (1983) and reduces the number of free parameters. Note, the r_2 (and r_1, of course) depends strongly on the shape of the light curve, but the mass ratio is poorly determined from the photometric observations.

When the system is at maximum light, the star surfaces are not obscured and the effective temperature of whole system can be estimated from a color index (V–R). The color index of the system at light maximum (0.2 mag) indicates that the system contains a star of A (or hotter) spectral type.

On the other side, when the larger part of the luminous component is obscured, the system is at minimum light and it is more red with a (V–R) index of 0.3 magnitude. This color change implicates, that the secondary component is of F (or colder) spectral type. We have used tables by Allen (1976) to estimate the relation between the color index and the spectral type.

This raw color index analysis and a wide-known characteristic of the Algol-like systems leads to conclusion that the observed light changes consists of a semi-detached binary system, which contains a hot main-sequence primary and a cold sub-giant secondary star. The secondary star probably fills its Roche lobe. We suppose in our initial computations, that a mass of the secondary is only half of the primary and that it is highly-evolved, in spite of being less massive, according to the Algol paradox.

These results of preliminary analysis of the light curve provided us with basic parameters which then served as input data for processing with the programs EBOP or even these FOTEL. The calculations were realized in R and V filters separately (EBOP) or, alternatively in both filters simultaneously (FOTEL).

The resulting physical parameters are given in Table 3. The calculated light curve of the system RV Tri together with the observational data in R filter are presented in Fig. 3. The residues (O–C) were also drawn (on the top of Fig. 3) for better appreciation of the calculation. The light curve, the observational data and residues for V filter are presented in Fig. 4.

5. Conclusions

The accuracy of the GCVS light elements of the RV Tri is lower than that of our minima determination. Therefore, we derived another elements using visual observations obtained during the last 30 years (see Sect 3). Credibility of the visual observations is sufficient, because the amplitude of the light changes is greater than 1 magnitude. The elements derived in this way do not correspond to our minima observations entirely.

Table 3. Photometry solutions of RV Tri.

	EBOP		FOTEL
parameter	V	R	RV
i	$88^\circ\!.0 \pm 1^\circ\!.1$	$87^\circ\!.6 \pm 0^\circ\!.9$	$88^\circ\!.00 \pm 0^\circ\!.02$
l_1	0.91 ± 0.01	0.90 ± 0.01	–
l_2	0.09 ± 0.02	0.10 ± 0.01	–
$x_1^*, x_2^*, g_1^*, g_2^*$	0.0	0.0	0.0
F_1^*	–	–	0.0
F_2^*	–	–	1.0
A_1^*	–	–	$0.9(V), 0.5(R)$
A_2^*	–	–	$1.2(V), 1.4(R)$
T_1(K)	–	–	9700 ± 150
T_2(K)	–	–	5380 ± 20
q	0.4^*	0.4^*	0.40 ± 0.15
r_1	0.356 ± 0.003	0.365 ± 0.003	0.358 ± 0.049
r_2	0.297 ± 0.005	0.301 ± 0.003	0.305 ± 0.063
$(r_1)_{\rm back}$	–	–	0.371
$(r_2)_{\rm back}$	–	–	0.337
$(r_1)_{\rm side}$	–	–	0.361
$(r_2)_{\rm side}$	–	–	0.298
$(r_1)_{\rm pole}$	–	–	0.349
$(r_2)_{\rm pole}$	–	–	0.284

* not fitted, i - orbital inclination, l_1, l_2 - relative luminosity, x_1, x_2, g_1, g_2 - limb and gravity darkening, A_1, A_2 - albedo, T_1, T_2 - effective surface temperature, F_1, F_2 - synchronization index, q - mass ratio m_2/m_1, r_1, r_2 - relative radii

The extrapolation of elements (1) to the epoch $E = 6500$ predicts (O-C) difference of -0.022 ± 0.005 days, but the mean of our observations indicates difference of only -0.014 ± 0.003 days. This significant difference probably does not have the origin in statistical errors, but it is caused by period change during the latest epoch. We interpret this incompatibility of light elements as probably slight real changes in RV Tri orbital parameters.

We have used two methods for the analysis of the observed light curve of RV Tri (computer programs EBOP and FOTEL). The model approximation and the results of both programs are consistent, in spite of the fact that FOTEL uses a more realistic model. The radial velocities of the components are required for the complete analysis of this system, but they are not available for RV Tri yet.

We deduce from the best fit of the light curve that the binary system RV Tri is composed of the main-sequence primary ($T_1 = 9700$ K) and the secondary sub-giant star

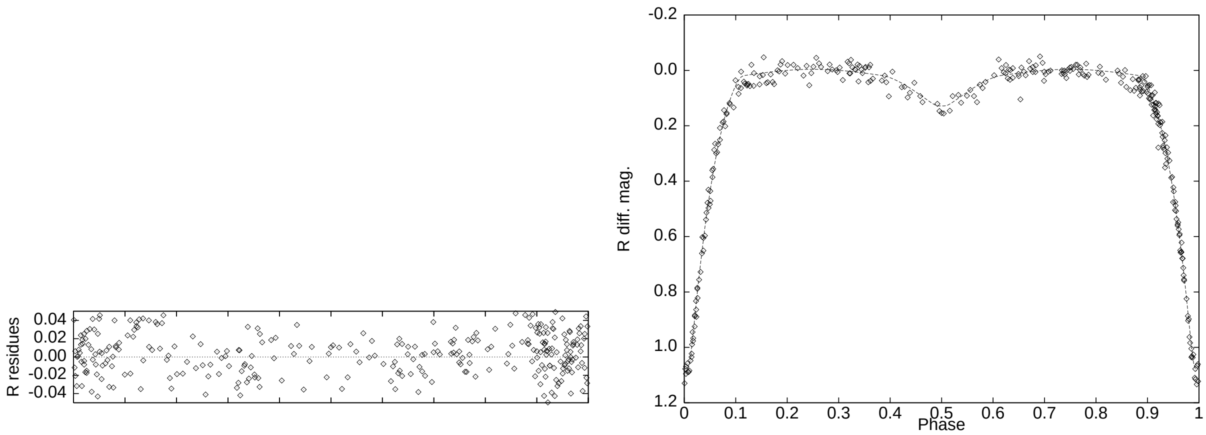

Fig. 3. R filter data and model fit of light curve of RV Tri.

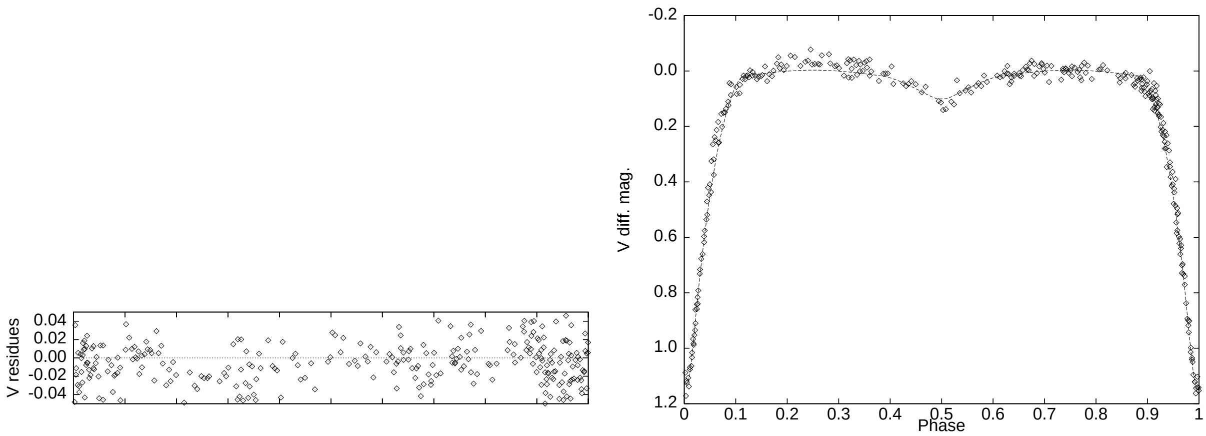

Fig. 4. V filter data and model fit of light curve of RV Tri.

($T_2 = 5400$ K), i.e. of spectral classes near A0, G5. The stars have been approximated by tri-axial ellipsoids with the effective radii 0.36 and 0.31 of the separation of their centers. The mass ratio has been fitted to $q = 0.4$. We have supposed non-eccentric orbit. The relative luminosities derived by EBOP are in good agreement with FOTEL values: $l_1 = 0.94, l_2 = 0.07$. We have neglected the influence of limb and gravity darkening, because the reflection of light from the star surfaces dominates.

These results partially confirm the model developed by Brancewicz and Dworak (1980). The authors introduce the following values of the parameters of this system: $q = 0.47$, $T_1 = 8950$K, $T_2 = 4700$K, $l_1 = 0.89$, $l_2 = 0.11$, $r_1 = 0.35$, $r_2 = 0.45$ in their paper. The small disagreements are probably caused by the oversimplified method or incomplete input data. Their model does not satisfy Eggleton relation (Sect. 4.3).

The Figure 4 shows some distortions of the observed light curve. The difference between the measured points and the model light curve does not have only statistical character, systematic trends can also be clearly seen. The V light curve shows an asymmetry, but the equivalent features are strongly suppressed in R filter. The careful analysis of our whole observational equipment gave conclusion that these asymmetries are due to some optical inhomogeneities on the surface of the V filter.

Acknowledgements. We are very much indebted to Z. Mikulášek, J. Hollan and R. Hudec for their valuable help and advice. Thanks are also due to A. Paschke, M. Zejda and all the visual observers for permission to use their data from the B.R.N.O. database and P. Hadrava and P. B. Etzel for the use of their software. We have done much of computation at the Supercomputing Center of the Masaryk University in Brno. We have used the USNO catalogue for astrometry and map plotting. We also wish to thank Miss J. Brandstettrová for her valuable comments and reading the manuscript.

References

Allen, C. W., 1973, Astrophysical Quantities, 3rd edition, The Athlone Press, London

Brancewicz H.K., Dworak T.Z., 1980, Acta Astron. 30, 501

Eggleton, P. P., 1983, ApJ 268, 368

Geyer E., Kippenhahn R., Strohmeier W., 1955, Kleine Veröff. Bamberg, No. 11

Hadrava P., 1990, Contrib. Astron. Obs. Skal. Pl. 20, 23

Hroch F., In Dušek,J., Zejda,M. (eds), Proc. of the 20th stel. conf. of the Czech and Slovak Astr. Inst., Brno 1998, p. 30

Kholopov et al., General Catalogue of Variable Stars 4th edition, Nauka, Moscow 1985

Kwee K.K., van Woerden H., 1956, Bull. Astron. Inst. Netherlands 12, 327

Landolt A.U., 1992, AJ 104, 340

Nelson B., Davis W. D., 1972, ApJ 174, 617

Wilson R.E., 1979, ApJ 234, 1054