Photometric study of eclipsing binary RV Tri

F. Hroch, M. Bašný

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Abstract

We present new photometric observations of RV Tri. A complete light curve was obtained in the R and V filters. These light curves were processed by the Wilson-Devinney (WD) code and the FOTEL to get solution of this eclipsing binary system. We discuss characteristics of the system and compare our model with a previous calculation. Our observations of primary minima and the comparison with those predicted on the base of the GCVS catalogue indicates that there are significant differences. We discuss these differences in the context of period change.

1 Introduction

RV Tri (GSC 2321.0070) was recognised as a variable star by W. Strohmeier and the discovery was published in Geyer et al. (1955), where preliminary values of the light elements were given. RV Tri is classified as an Algol star type, the depth of primary and secondary minima being 1.2 and 0.1 in 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 the summer of 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 the summer/autumn of 1997 and 1998. We used the 0.60 m reflector of our observatory. The CCD front side camera placed at the Newtonian focus took 30 or 60 seconds exposures of the variable and comparison stars. V (Johnson) and R (Kron-Cousins) standard filters were used. The observations are summarised in Table 1.

The transformation between our instrumental magnitudes and Johnson photometric system gives as extra-atmospheric magnitudes and colour indexes of the comparison and check star the values listed in Table 2. We used Landolt
Table 1: The list of observations and the primary minima of RV Tri (the (O-C) differences from the GCVS ephemeris as mean of R,V).

| night      | minimum in R                  | minimum in V                  | (O-C)          |
|------------|-------------------------------|-------------------------------|----------------|
| 1997 – 09 – 20/21 | —                             | —                             | —              |
| 1997 – 09 – 21/22 | —                             | —                             | —              |
| 1997 – 09 – 28/29 | 50720.3480 ± 0.0057           | 50720.3470 ± 0.0057           | −0.0120 ± 0.0081 |
| 1997 – 10 – 19/20 | 50741.4525 ± 0.0096           | 50741.4517 ± 0.0103           | −0.0085 ± 0.0141 |
| 1997 – 10 – 31/11 - 01 | 50753.5083 ± 0.0036           | 50753.5074 ± 0.0038           | −0.0156 ± 0.0052 |
| 1997 – 11 – 10/11 | 50763.3054 ± 0.0065           | 50763.3061 ± 0.0058           | −0.0146 ± 0.0087 |
| 1998 – 09 – 24/25 | 51081.3521 ± 0.0032           | 51081.3532 ± 0.0038           | −0.0145 ± 0.0050 |
| 1998 – 11 – 11/12 | 51130.3420 ± 0.0035           | 51130.3422 ± 0.0063           | −0.0134 ± 0.0072 |

Table 2: The extra-atmospheric magnitudes and colour 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            |

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 (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 in the sky (≈ 1’). The chart of the close environment of RV Tri with comparison and check star is shown in Fig. 4. Its precise position as determined by the processing of our observations (J2000.0, the proper motion neglected) is:

$$\alpha = 2^h13^m18^s12 \quad \delta = +37^\circ01'02''1$$

The position error was smaller than 0''2 for both coordinates. We choose the USNO-A catalogue as astrometric reference catalogue.
3 Light elements

The values of the light elements published in the original paper by Geyer et al. ([1955]) and values of the elements given by the last edition of the GCVS catalogue (Kholopov et al. ([1985])) with ephemeris

\[ \text{Min I}(J.D.\text{Hel.}) = 2446033^d308 + 0^h75366648E \]

are highly inaccurate in comparison with the accuracy of the time of the minima determinations derived from our observations. We have observed an (O–C) difference of about 15 minutes at current epochs. This fact is also 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).

We have tried to verify this systematic trend in the light elements of RV Tri by observation of some primary minima during our observational periods. The times of the minima for each observational set were computed by the Kwee and van Woerden method ([1956]). Our and Nelson’s ([2000]) observations (see Fig. 2) confirm this behaviour. The procession of all times of visual minima gives us improved quadratic ephemeris (computed by the weighted robust linear least square method only for 152 accepted points)

\[ \text{Min I}(J.D.\text{Hel.}) = 2446033^d30373 + 0^h753666361 + 1^d72 \times 10^{-10} E^2 \]

\[ \pm 0^d00049 \pm 0^d000000 \pm 0^d25 \times 10^{-10} \]

(1)
which approximates the time of the minima in the range between $JD = 24 50 720$ and $JD = 24 51 130$ with a precision better than $\pm 0.004$ days. The use of this ephemeris out of this range is uncertain. We used this ephemeris for reduction of our observations to the mean light curve. We estimated the error of visually determined minima to be 10 minutes.

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 the R and 530 measurements in the V filter have been processed by the programs WD98 and FOTEL.

Figure 2: The O–C diagram for RV Tri. The GCVS light elements were used. The plus ‘+’ represents minima reported by visual observers. We estimated errors of visually determined minima on 10 minutes. The six points with error-bars on the right edge of the picture represents our minima. The last point is minimum from Nelson ([2000]).
4.1 Wilson-Devinney

WD98 — was written by R.E.Wilson and E.J. Devinney described in Wilson, Devinney ([1971]). We uses more recent WD98 modification. An operation mode for Algol type stars was run.

4.2 FOTEL

FOTEL — a computer program for the determination of photometric elements — was written by P. Hadrava for data processing at the Ondřejov observatory. FOTEL simultaneously calculates the light curve and the radial velocities with the 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 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 the 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 the colour index ($V-R$). The colour 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 hand, 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 colour 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 colour index and the spectral type.

This raw colour index analysis and a well-known characteristic of the Algol-like systems leads to the 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 the mass of the secondary is only half of that of the primary and that it is highly-evolved, in spite of being less massive, according to the Algol paradox.

These results of the preliminary analysis of the light curve provided us with the basic parameters which then served as input data for processing with the
programs WD98 or FOTEL. The values of the second order parameters (limb
darkening, albedo, gravity darkening) was used from tables by Claret ([1998]).
The use third light leads to residues not significantly different from no-third
light solution. The value of the third light parameter was comparable with its
statistical and our data measure error.

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

5 Conclusions

The accuracy of the GCVS light elements of the RV Tri is significantly lower than
that of our minima determination. Therefore, we derived improved elements
using visual observations obtained during the last 30 years (see Sect 3) and a
few of our measurements. The credibility of the visual observations is sufficient
in this case, because the amplitude of the light changes is greater than one
magnitude. The observed primary minima are good described by the quadratic
fit of the data. Its behaviour probably does not have origin in statistical errors
but it is caused by period change during the latest epoch. These observations
of all primary minima indicates a change of light elements, which is probably
caused due to slight real changes in RV Tri orbital parameters. This hypothesis
can be additionally tested by the construction of a physical model of this binary
system.

We have used two methods for the analysis of the observed light curve of
RV Tri (computer programs WD98 and FOTEL). The model approximation and
the results of both programs are consistent within statistical errors and different
processing methods. The radial velocities of the components are required for
the complete analysis of this system, but they are not available for RV Tri yet.

The derived solution can include systematic errors due to the small sensitiv-
ity of the photometric data on some parameters (especially on \( q \)). Therefore, all
of the parameters \( (i, r_1, T_1, T_2) \) are strongly correlated to \( q \). Note that \( r_1 \) and \( r_2 \)
are bounded by Eggleton’s relation. This correlation and the change of \( q \) from
0.4 to 0.5 produces different values of parameters as compared to the results
given by Brancewicz and Dworak (1980). The increase of \( q \) induce a smaller
value of \( r_1, r_2 \) and the decrease of the stars’ effective temperatures \( T_1, T_2 \). The
whole luminosity of the system is conserved in this way.

We deduce from the best fit of the light curve that the binary system RV Tri
is composed of the main-sequence primary \( (T_1 = 9500 \text{ K}) \) and the secondary
sub-giant star \( (T_2 = 4900 \text{ K}) \), i.e. of spectral classes near A0, G5. The stars has
been approximated by tri-axial ellipsoids with the effective radii 0.33 and 0.40 of
the separation of their centres. The mass ratio has been fitted to \( q = 0.36 \). We
Table 3: Photometry solutions of RV Tri.

|                 | WD98     |         | FOTEL    |         |
|-----------------|----------|---------|----------|---------|
|                 | V        | R       | V        | R       |
| $i$             | 84.5 ± 1.0 | 82.4 ± 1.0 |
| $l_1$           | 0.92 ± 0.14 | 0.94 ± 0.59 | 0.91 |
| $l_2$           | 0.08     | 0.06    | 0.09     |
| $x_1$           | 0.51     | 0.43   | 0.51     | 0.43    |
| $x_2$           | 0.83     | 0.74   | 0.83     | 0.74    |
| $g_1$           | 1.0      |        | 1.0      |        |
| $g_2$           | 0.4      |        | 0.4      |        |
| $\Omega_1$     | 3.41 ± 0.10 |      |         |         |
| $\Omega_2$     | 2.6      |        |         |         |
| $A_1$           | 1.0      |        | 1.0      |        |
| $A_2$           | 0.5      |        | 0.5      |        |
| $T_1$(K)        | 9500 ± 300 |      | 9500 ± 1400 |      |
| $T_2$(K)        | 4900     |        | 5300 ± 200 |        |
| $q$             | 0.34 ± 0.03 |      | 0.34 ± 0.41 |      |
| $r_1$(pole)     | 0.32 ± 0.01 |      | 0.33      |        |
| $r_1$(point)    | 0.33 ± 0.01 |      | 0.33      |        |
| $r_1$(side)     | 0.33 ± 0.01 |      | 0.34      |        |
| $r_1$(back)     | 0.33 ± 0.01 |      | 0.33      |        |
| $r_2$(pole)     | 0.29 ± 0.01 |      | 0.30      |        |
| $r_2$(point)    | 0.40 ± 0.05 |      | 0.39      |        |
| $r_2$(side)     | 0.29 ± 0.01 |      | 0.33      |        |
| $r_2$(back)     | 0.32 ± 0.01 |      | 0.32      |        |

* 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, $\Omega_1, \Omega_2$ - potentials, $q$ - mass ratio $m_2/m_1$, $r_1, r_2$ - relative radii
Figure 3: R filter data and model fit of light curve of RV Tri.

Figure 4: V filter data and model fit of light curve of RV Tri.
have supposed a non-eccentric orbit. The relative luminosity derived by WD98
are in good agreement with the FOTEL values: \( l_1 = 0.91, l_2 = 0.09 \).

These results partially confirm the model developed by Brancewicz and
Dworak (\[1980\]). These authors introduce the following values of the parameters
of this system: \( q = 0.47, T_1 = 8950K, T_2 = 4700K, l_1 = 0.89, l_2 = 0.11, \)
\( r_1 = 0.35, r_2 = 0.45 \) in their paper. The disagreements are probably caused
by the oversimplified method or incomplete input data. Note, that their model
does not satisfy Eggleton’s relation (Sect. \[13\]). They supposed a detached bi-
nary system in this paper.

We supposed that RV Tri is a semi-detached system in our model. The sub-
giant secondary star fills its Roche lobe. The primary star is a main-sequence
star with 65% lobe filling. RV Tri is an evolved binary system after mass
exchange. The highly evolved secondary star has a smaller mass than the less
evolved primary star. This is contrary to star evolution theories of isolated stars,
but it is in good agreement with Algol paradox theories (Wilson \[1979\]).

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 the R filter. The most striking differences are data and fit at primary minima
and shortly after it. Firstly, we made a hypothesis about a hot spot on the
surface of the primary, which is a deformation of the light curve. The careful
analysis of our whole observational equipment gave the conclusion that these
asymmetries are due to some optical inhomogeneities on the surface of the V
filter. This fact influences fitting of the synthetic light curve. The residuals at
primary minima in the V filter presents distortions of the light curve due to the
filter problem and it is possible that the temperature of the secondary contains
some systematic errors.

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