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Photometric and Spectroscopic Observations of the Algol Type Binary V Triangle

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Abstract

Time-series, multi-color photometry and high-resolution spectra of the short-period eclipsing binary V Tri were obtained through observation. The completely covered light and radial velocity (RV) curves of the binary system are presented. All times of light minima derived from both photoelectric and CCD photometry were used to calculate the orbital period and new ephemerides of the eclipsing system. The analysis of the $O - C$ diagram reveals that the orbital period is 0.58520481 days, decreasing at a rate of $dP/dt = -7.80 \times 10^{-8}$ day yr^{-1}. The mass transfer between the two components and the light-time-travel effect due to a third body could be used to explain the period decrease. However, a semi-detached configuration with the lower-mass component filling and the primary nearly filling each of their Roche lobes was derived from the synthesis of the light and RV curves by using the 2015 version of the Wilson–Devinney code. We consider the period decrease to be the nonconservative mass transfer from the secondary component to the primary and the mass loss of the system, which was thought to be an EB type, while it should be an EA type (semi-detached Algol-type) from our study. The masses, radii, and luminosities of the primary and secondary are $1.60 \pm 0.07\, M_{\odot}$, $1.64 \pm 0.02\, R_{\odot}$, and $14.14 \pm 0.73\, L_{\odot}$ and $0.74 \pm 0.02\, M_{\odot}$, $1.23 \pm 0.02\, R_{\odot}$, and $1.65 \pm 0.05\, L_{\odot}$, respectively.

Key words: binaries: eclipsing – stars: fundamental parameters – stars: individual (V Tri)

1. Introduction

V Tri (GSC 02293-01403, SV* HV 3347), a short-period eclipsing binary system, was discovered by Miss Leavitt (Leavitt & Pickering 1913) from Harvard plates according to the discordance of the resulting magnitude. This system is classified as an Algol type, with a magnitude range from $10^{\rm m}.5$ and $11^{\rm m}.8$. Hoffmeister (1919) identified its β Lyrae type nature through photographical photometry (magnitude: $10^{\rm m}.6 \sim 11^{\rm m}.5$). Photographic light curves of the system were first derived by Jordan (1929), who found a range of magnitudes that were greater than the results of Hoffmeister (1919); however, the secondary minimum was found to be less deep. Cannon (1934) determined the spectral type of V Tri as A3. The geometric and physical parameters for this binary system were determined using the iterative method by Brancewicz & Dworak (1980). They revised the spectral types as A3+F6 for both components and also classified it as a β Lyrae type. Giuricin et al. (1983) marked V Tri as an "a" system, meaning it is in a non-contact configuration, but some authors were more inclined to classify it as having a near-contact configuration (Budding 1984; Gray et al. 1994; Shaw 1994). In a recent study, Gürol et al. (2006) derived the physical parameters of the system from *BVR* light curves using the Mode 2 (detached configuration) and Mode 5 (semi-detached configuration with the secondary component accurately filling its limiting lobe) of the Wilson–Devinney (WD) 2003 code.

A large amount of light minimum times for V Tri have been published by many amateurs and professional astronomers with visual, photographic, photoelectric, and CCD observations in the database of times of minima and maxima.[6] The ephemeris of the system has been gradually updated using the light minima (Hoffmeister 1919; Jordan 1929; Wood & Forbes 1963). The peculiar period behavior of this system was discussed by Gray et al. (1994) based on light minimum timings from 1902 to 1992. Furthermore, Gürol et al. (2006) analyzed the period of V Tri and attributed the $O - C$ (observed minus calculated period) variations of all minima to the light-time effect caused by a third body.

In order to study the period variation and determine a set of precise absolute parameters for V Tri, we carried out both photometric and spectroscopic observations for this binary system. Precision *BV*-band light curves in phase, 6 new light minima, and 10 radial velocities (RVs) of the primary component have been obtained at different observing stations in recent years. In this paper, we first introduce the observations and image-processing progress in Section 2. New ephemerides and period variation analysis based on the photoelectric and CCD minimum times are given in Section 3. In Section 4, we derive the photometric solution of the system based on the high accurate light curves and RVs of the primary star using the 2015 version WD code. We conclude with a summary and discussion of this binary system.

2. Observations and Data Processing

The photometric observations for V Tri were carried out across two seasons in order to obtain more times of light minima and complete light curves in phase. This was done using the 85 cm reflector telescope at the Xinglong Station of the NAOC[7] in 2003 December and 2007 October, respectively. In the first season, the data were collected with an AP7P 512×512 CCD camera, which provides a field of view of about $6' \times 6'$ with an image scale of about $0''.7$ per pixel. A

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Table 1
Journal of the Time-series CCD Photometric and Spectroscopic Observations for V Tri

Date (UT)	Observatory	Telescope	Filter	N_{obs}	Observer
Photometric Observations					
2003 Dec 25	BAO	85 cm	V	297	XBZ
2003 Dec 26	BAO	85 cm	V	297	XBZ
2007 Oct 12	BAO	85 cm	BV	914	XBZ
2007 Oct 13	BAO	85 cm	BV	1218	XBZ
2007 Oct 14	BAO	85 cm	BV	2115	XBZ
Spectroscopic Observations					
2015 Nov 03	SPM	2.12 m		3	LFM, TQC
2015 Nov 05	SPM	2.12 m		7	LFM, TQC

Note. XBZ: Xiao-Bin Zhang; LFM: Lester Fox-Machado; TQC: Tian-Qi Cang.

single Johnson *V* filter was used, and the exposure time was 60 s for each exposure. A total number of ~400 useful frames was obtained over two nights. In the second season, all CCD frames were collected using a PI MicroMAX 1024 BFT CCD camera with a field of view of about 16′.5 × 16′.5. The pixel scale is 0″.96 per pixel. Two standard Johnson–Cousin–Bessell filters in the *B*- and *V*-bands were used to record the variations in the light curves over three days. The typical exposure times were set at 30 s or 15 s for *B*-band and 15 s or 8 s for *V*-band measurements, depending on the weather condition. There were a total of 2125 useful frames in the *B*-band and 2122 in the *V*-band. Because these data record an entire light curve of the eclipsing system for each filter, the early photometric data were only used to determine the times of minima. Finally, we obtained six light minima and complete *B*- and *V*-band light curves of V Tri. A detailed journal of observation is given in Table 1.

All CCD images were reduced preliminarily with the standard process of the IRAF[8]/CCDRED package (including subtracting the bias and dark current, and dividing flat-fields from the object frames), and then the instrument magnitudes of the stars were extracted from these images using the aperture photometry of the IRAF/DAOPHOT package (Stetson 1987). All relatively bright stars with good visibility in the viewing field were selected as reference candidate stars for differential photometry. Finally, GPM 22.913124+30.390996 and 2MASS J01321631+3022599 were employed as the comparison and check stars, respectively. The main information for the variable, comparison, and check stars, taken from the web of Aladin sky atlas, is given in Table 2. The observing time has been transformed into Heliocentric Julian Days (HJD) to obtain the phased light curve of the object, as given in the top panel of Figure 1. The magnitude difference between the comparison and check stars was performed to be stable within 0.03 magnitude during the observations in the *B*- and *V*-bands, as is shown in the bottom panel.

The spectroscopic observations for V Tri were carried out with the 2.12 m telescope at the Observatorio Astronémico Nacional on the Sierra San Pedro Mártir (OAN-SPM) in México on 2015 November 03 and 05. We used a 2048 × 2048 E2V CCD-4240 to collect the high-resolution (the maximum resolution is $R = 18{,}000$ at 5000 Å) echelle spectra at the slit size 1″. The spectral range coverage was from 3800 to 7100 Å. We finished the preliminary spectrum process, including bias and flat calibration, in the IRAF/CCDRED package. The cosmic rays were effectively removed from the object frames using the STSDAS/lacos_spec package in IRAF. Then, the data reduction was primarily performed using the IRAF/ECHELLE package to obtain the normalized continuous spectrum, as shown in Figure 2. The spectral line of the binary system agrees well with the spectral energy distribution for A3V from the stellar spectral library by Pickles (1998). Due to the large difference in brightness between the two components of the binary system, we only calculated the RVs of the primary star from the processed spectra according to the formula

$$\mathrm{RV} = C \cdot \frac{\Delta\lambda}{\lambda} \quad (1)$$

where C is the speed of light, $\Delta\lambda$ is the wavelength difference between the object and RV standard star at the center position of the same absorption line, and λ is the standard center wavelength of the absorption line. Finally, we convert the RV to the heliocentric RV by using the task *bcvcorr* in the IRAF/RVSAO package. Each mean RV value with the statistical error is calculated from the observed spectral data, as listed in Table 3.

3. New Ephemerides and Period Variation

V Tri is an interesting study target, and many amateur and professional astronomers have observed the light minimum times using visual, photographic, photoelectric, and CCD methods. In our observations, six light minima of this binary system were recorded over five nights. The times of the light minima were determined by fitting the light curves with a quadratic function, and their errors were estimated using the Monte Carlo method. Moreover, 75 minimum times measured by photoelectric (pe) and CCD photometry were picked out from all available light minima in order to study the orbital period variation of the system. All 81 minima and their errors (if available) are listed in the first two columns of Table 4. Based on the latest linear ephemeris,

$$\begin{aligned}\mathrm{Min.I(HJD)} = {} & 2,452,490.44221 \pm 0.00052 \\ & + (0.585205686 \pm 0.000000024)E \end{aligned} \quad (2)$$

was published by Gürol et al. (2006) from photoelectric and CCD measurements. Using the classical $O - C$ method, we calculated the revised linear and quadratic ephemerides for V Tri as follows:

$$\begin{aligned}\mathrm{Min.I(HJD)} = {} & 2,454,387.0918 \pm 0.0001 \\ & + (0.58520500 \pm 0.00000004)E \end{aligned} \quad (3)$$

$$\begin{aligned}\mathrm{Min.I(HJD)} = {} & 2,454,387.0924 \pm 0.0001 \\ & + (0.58520481 \pm 0.00000004)E \\ & - (6.24 \pm 0.69) \times 10^{-11}E^2. \end{aligned} \quad (4)$$

The $O - C$ linear and quadratic residuals for the times of light minimum are listed in the sixth and seventh columns of Table 4, respectively. The $O - C$ diagram of period analysis is displayed in Figure 3; the solid line represents the quadratic approximation referring to the quadratic ephemeris. Although no additional reliable light minimum times were published from HJD 2448573.6579 to HJD 2451835.5974 (from approximately

[8] Image Reduction and Analysis Facility.

Table 2
Main Feature Parameters of the Variable, Comparison, and Check Stars

Star	R.A. (ep = J2000)	Decl. (ep = J2000)	*B* (mag)	*V* (mag)	*B* − *V* (mag)	Sp_type
V Tri	$01^{h}31^{m}47\overset{s}{.}103$	$+30°22'01\overset{''}{.}57$	11.32	10.96	0.36	A3
Comparison	$01^{h}31^{m}39\overset{s}{.}158$	$+30°23'27\overset{''}{.}76$	11.3	…	…	…
Check	$01^{h}32^{m}16\overset{s}{.}32$	$+30°22'59\overset{''}{.}9$	13.7	13.4	0.3	…

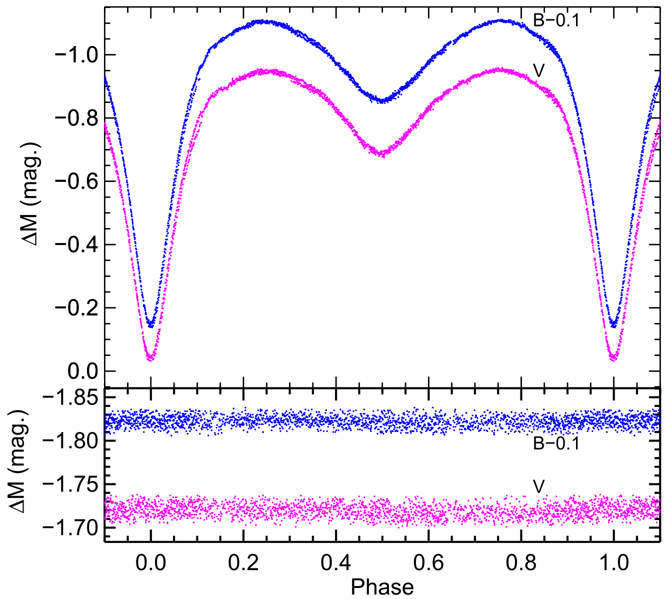

Figure 1. Top panel: the differential light curves of V Tri in the *B*- and *V*-bands. Bottom panel: the differential magnitude between the comparison star and check star.

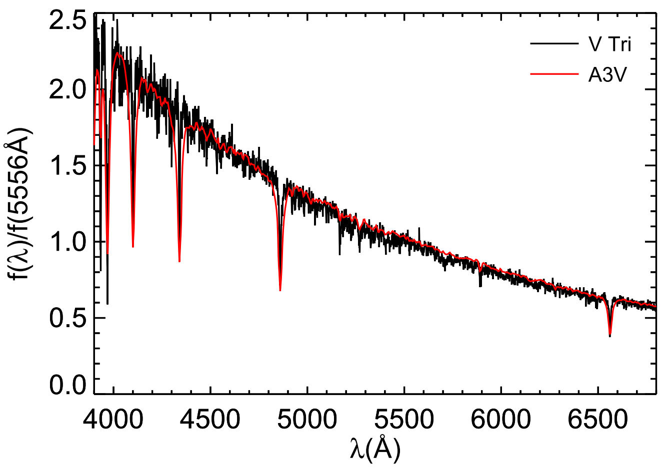

Figure 2. The spectrum of V Tri is represented by the black curve, and the spectrum of A3V from the stellar spectral flux library is indicated by the red curve.

1992 to 1999), the period analysis produces a good fit for these photoelectric and CCD minimum times and yields a new period $P = 0.58520481$ days. The period is slightly shorter than those obtained by Wood & Forbes (0.58520771 days; 1963), Gray et al. (0.5852060 days; 1994), Kreiner et al. (0.58520570 days; 2001), and Gürol et al. (0.58520569 days; 2006), but is obviously longer than that of Hoffmeister (0.5851993 days; 1919). The downward parabola, as shown in Figure 3, suggested that the orbital period of the system has been

Table 3
Heliocentric Radial Velocities of the Primary Component for V Tri

HJD (2,400,000+)	Phase	RV km s^{-1}
57329.8787	0.6448	18 ± 5
57329.9087	0.6962	36 ± 5
57329.9535	0.7727	45 ± 7
57331.7023	0.7610	45 ± 7
57331.7255	0.8008	44 ± 8
57331.8449	0.0048	−74 ± 10
57331.8754	0.0568	−120 ± 10
57331.9108	0.1173	−134 ± 9
57331.9333	0.1559	−144 ± 9
57331.9667	0.2128	−158 ± 7

undergoing a continuous period decrease over the past few decades. The rate of continuous period decrease was calculated as approximately $dP/dE = -1.25 \times 10^{-10}$ day cycle^{-1} or $dP/dt = -7.80 \times 10^{-8}$ day yr^{-1} from the quadratic ephemeris. The period decrease possibly indicates that the mass transferred from the more-massive component to the less-massive one.

It is also possible that a third body may be the cause of period change in Algol-type systems (Hoffman et al. 2006). The period variation of the V Tri system has been attributed to the light-time effect by Gürol et al. (2006). They assumed a third body causes the sinusoidal variation in the orbital period of the eclipsing binary star system. Including our six CCD light minima, we collected all available light minima from the literature to find out how the orbital period has changed over the last few decades. The $O - C$ variation of all light minimum times is shown in Figure 4. We can find a sinusoidal-like $O - C$ pattern after Epoch $> -20 \times 10^{3}$, which may indicate that this system consists of the binary V Tri orbited by a distant third body. One visual value (2429217.4780) is excluded from the figure due to its substantial deviation from the other data.

4. Light Curves and Photometric Solution

All of the observations have been transferred into phases by using the newly derived quadratic ephemeris, as shown in Figure 1. Unlike that obtained by Jordan (1929), the obvious symmetry of the light curves is shown at the maximum, and there is no so-called O'Connell effect on the light curves, as pointed out by Gürol et al. (2006). Agreeing with the primal classified type (Leavitt & Pickering 1913), the general feature of the light curves belongs to that of an Algol-type binary system with equal light maximum and minimum. The magnitude variations are found to be about 0.96 and 0.89 mag for the primary eclipse and about 0.24 and 0.27 mag for the secondary eclipse in the *B*- and *V*-bands, respectively.

The photometric solution of the binary system was carried out in order to derive the system parameters with the complete light curves in the *B*- and *V*-bands and RVs of the primary

Table 4
Photoelectric and CCD Times of Light Minima of V Tri along with the Residuals Computed from the Quadratic Ephemerides

HJD (2,400,000+)	Error	Method	Min	E	L($O-C$) days	LQ($O-C$) days	References
48567.8091	⋯	pe	I	−9944.0	−0.0042	−0.0004	1
48568.6880	⋯	pe	II	−9942.5	−0.0031	0.0006	1
48573.6579	⋯	pe	I	−9934.0	−0.0074	−0.0037	1
50094.6140	⋯	CCD	I	−7335.0	0.0009	0.0023	2
51835.5974	0.0004	CCD	I	−4360.0	−0.0006	−0.0008	3
51869.5414	0.0001	CCD	I	−4302.0	0.0015	0.0013	3
51870.7109	0.0009	CCD	I	−4300.0	0.0006	0.0004	3
51897.6312	0.0002	CCD	I	−4254.0	0.0015	0.0012	3
51899.3855	0.0020	CCD	I	−4251.0	0.0001	−0.0001	4
51948.5432	0.0002	CCD	I	−4167.0	0.0006	0.0004	3
52190.5292	0.0026	pe	II	−3753.5	0.0044	0.0040	5
52201.3504	0.0005	pe	I	−3735.0	−0.0007	−0.0011	5
52230.6117	0.0001	CCD	I	−3685.0	0.0003	−0.0001	3
52305.5171	0.0002	CCD	I	−3557.0	−0.0005	−0.0010	3
52485.4720	0.0024	pe	II	−3249.5	0.0038	0.0033	5
52490.4437	0.0003	pe	I	−3241.0	0.0013	0.0008	5
52497.4679	0.0003	CCD	I	−3229.0	0.0030	0.0025	6
52528.7718	0.0002	CCD	II	−3175.5	−0.0015	−0.0021	7
52547.7920	0.0010	CCD	I	−3143.0	−0.0005	−0.0010	7
52554.8155	0.0001	CCD	I	−3131.0	0.0005	−0.0000	7
52618.6029	0.0002	CCD	I	−3022.0	0.0006	0.0000	3
52628.5515	0.0001	CCD	I	−3005.0	0.0007	0.0001	3
52902.4272	0.0001	pe	I	−2537.0	0.0005	−0.0002	8
52940.4659	0.0010	CCD	I	−2472.0	0.0008	0.0002	4
52944.2703	0.0011	CCD	II	−2465.5	0.0014	0.0008	9
52944.5625	0.0005	CCD	I	−2465.0	0.0010	0.0004	9
52986.6965	⋯	CCD	I	−2393.0	0.0003	−0.0004	10
52998.9864	0.0001	CCD	I	−2372.0	0.0008	0.0002	11
53001.0359	0.0003	CCD	II	−2368.5	0.0021	0.0015	11
53266.4247	0.0001	pe	I	−1915.0	0.0005	−0.0002	12
53300.3674	0.0001	pe	I	−1857.0	0.0013	0.0006	12
53303.5809	0.0003	pe	II	−1851.5	−0.0039	−0.0046	12
53315.5830	⋯	CCD	I	−1831.0	0.0015	0.0008	10
53339.5759	⋯	CCD	I	−1790.0	0.0010	0.0003	10
53349.2321	0.0007	pe	II	−1773.5	0.0014	0.0006	12
53361.2302	0.0015	CCD	I	−1753.0	0.0027	0.0020	4
53384.6350	⋯	CCD	I	−1713.0	−0.0007	−0.0014	10
53662.6093	0.0012	pe	I	−1238.0	0.0013	0.0006	13
53684.2617	0.0002	CCD	I	−1201.0	0.0011	0.0004	14
53714.6914	⋯	CCD	I	−1149.0	0.0001	−0.0006	10
53763.2656	0.0008	CCD	I	−1066.0	0.0023	0.0016	4
54000.5666	0.0002	CCD	II	−660.5	0.0027	0.0020	4
54026.3146	0.0027	CCD	II	−616.5	0.0017	0.0010	15
54026.6067	0.0002	CCD	I	−616.0	0.0012	0.0005	15
54055.2800	0.0002	CCD	I	−567.0	−0.0006	−0.0012	16
54117.3124	0.0001	CCD	I	−461.0	0.0001	−0.0006	17
54381.5324	0.0009	CCD	II	−9.5	0.0000	−0.0005	18
54386.2141	0.0003	CCD	II	−1.5	0.0001	−0.0005	11
54387.0915	0.0001	CCD	I	0.0	−0.0003	−0.0009	11
54387.9682	0.0005	CCD	II	1.5	−0.0014	−0.0020	11
54388.2614	0.0001	CCD	I	2.0	−0.0008	−0.0014	11
54435.6628	0.0001	CCD	I	83.0	−0.0010	−0.0016	19
54435.6641	0.0001	CCD	I	83.0	0.0003	−0.0003	19
54707.7832	0.0001	CCD	I	548.0	−0.0010	−0.0014	20
54857.3034	0.0011	CCD	II	803.5	−0.0006	−0.0010	21
55069.4402	0.0002	CCD	I	1166.0	−0.0007	−0.0009	22
55102.5045	0.0016	CCD	II	1222.5	−0.0004	−0.0007	22
55115.6713	0.0001	CCD	I	1245.0	−0.0007	−0.0010	23
55120.9374	0.0002	CCD	I	1254.0	−0.0015	−0.0017	23
55139.6633	0.0003	CCD	I	1286.0	−0.0022	−0.0024	23
55207.2586	0.0006	CCD	II	1401.5	0.0020	0.0018	24
55231.5420	0.0001	CCD	I	1443.0	−0.0006	−0.0008	23
55461.5283	0.0028	pe	I	1836.0	0.0001	0.0001	25

Table 4
(Continued)

HJD (2,400,000+)	Error	Method	Min	E	L($O-C$) days	LQ($O-C$) days	References
55514.4850	0.0016	CCD	II	1926.5	−0.0043	−0.0042	22
55837.8148	0.0001	CCD	I	2479.0	−0.0002	0.0001	26
55896.3357	0.0010	pe	I	2579.0	0.0002	0.0005	27
55905.7014	0.0004	CCD	I	2595.0	0.0026	0.0029	28
56205.9088	0.0004	CCD	I	3108.0	−0.0002	0.0004	29
56258.5768	0.0001	CCD	I	3198.0	−0.0006	0.0000	30
56523.9654	0.0003	CCD	II	3651.5	−0.0025	−0.0015	31
56558.7864	0.0003	CCD	I	3711.0	−0.0012	−0.0002	31
56578.6839	0.0001	CCD	I	3745.0	−0.0006	0.0004	29
56592.4372	0.0025	pe	II	3768.5	0.0003	0.0013	32
56596.5329	0.0048	pe	II	3775.5	−0.0004	0.0006	32
56902.8873	0.0001	CCD	I	4299.0	−0.0008	0.0006	29
56943.5574	0.0052	CCD	II	4368.5	−0.0025	−0.0010	33
56949.4112	0.0069	CCD	II	4378.5	−0.0007	0.0007	33
56949.7038	0.0001	CCD	I	4379.0	−0.0007	0.0007	29
56952.6297	0.0001	CCD	I	4384.0	−0.0008	0.0006	29
56966.6747	0.0001	CCD	I	4408.0	−0.0008	0.0007	29
57307.8501	⋯	CCD	I	4991.0	0.0001	0.0020	34

References. (1) Gray et al. (1994), (2) Baldwin & Samolyk (1997), (3) Baldwin & Samolyk (2003), (4) Brát et al. (2007), (5) Muyesseroglu et al. (2003), (6) Demircan et al. (2003), (7) Nelson (2003), (8) Hubscher (2005), (9) Maciejewski & Karska (2004), (10) Baldwin & Samolyk (2006), (11) Present Study, (12) Hubscher et al. (2005), (13) Hubscher et al. (2006), (14) Zejda et al. (2006), (15) Hubscher & Walter (2007), (16) Dogru et al. (2007), (17) Dogru et al. (2009), (18) Hubscher et al. (2008), (19) Samolyk (2008a), (20) Samolyk (2008b), (21) Hubscher et al. (2010), (22) Brat et al. (2011), (23) Samolyk (2010), (24) Gokay et al. (2012), (25) Hubscher (2011), (26) Samolyk (2012), (27) Hubscher & Lehmann (2012), (28) Diethelm (2012), (29) Samolyk (2015b), (30) Samolyk (2013b), (31) Samolyk (2013a), (32) Hubscher (2014), (33) Hubscher (2015), (34) Samolyk (2015a).

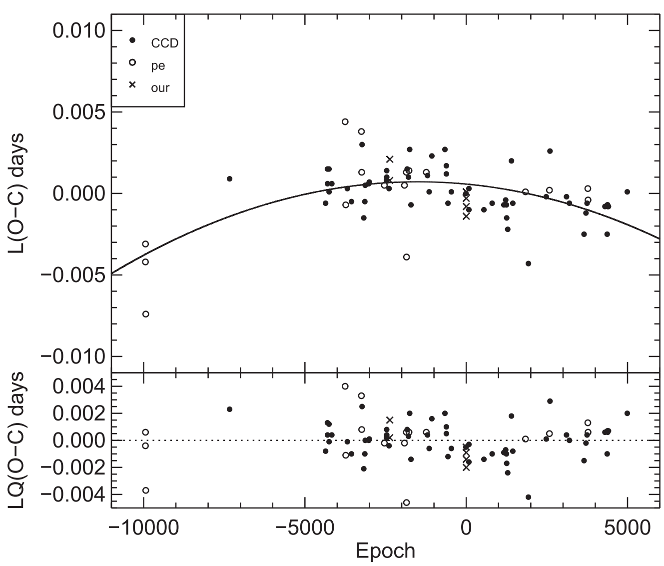

Figure 3. Orbital period analysis for V Tri.

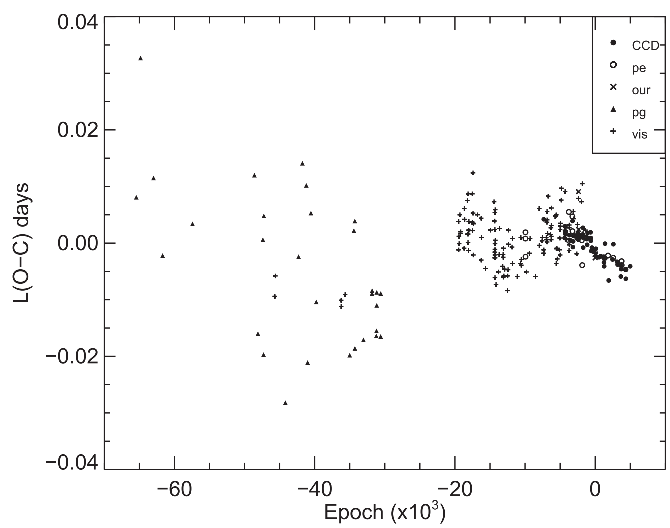

Figure 4. $O-C$ variation of V Tri in reference to Equation (2).

component. The 2015 version of the Wilson–Devinney (WD) code (Wilson & Devinney 1971; Wilson 1979, 1990; Wilson & van Hamme 2016) with the Kurucz atmospheres (Kurucz 1993) was applied to the numerical light curve analysis. The nonlinear limb-darkening law with the logarithmic form was added in the analysis progress. We defined the massive component as Star 1 and the less-massive one as Star 2 in the following photometric analysis. In order to derive the photometric solution, we initially assumed some input parameters and kept them constant while running the WD code. According to the spectral type determined from the spectrum (Figure 2), and through the calibration of Cox (2000), the temperature of Star 1 was modified as $T_1 = 8750$ K. The gravity-darkening exponents were given as $g_1 = 1.0$ for Star 1 and $g_2 = 0.32$ for Star 2, and the bolometric albedos were taken as $A_1 = 1.0$ and $A_2 = 0.5$, respectively (Wilson & van Hamme 2016). The initial bolometric (X_1, X_2, Y_1, Y_2) and monochromatic (x_1, x_2, y_1, y_1) limb-darkening coefficients of the components were adopted from van Hamme (1993). The adjustable parameters are listed as follows: the phase shift, ϕ_0, the orbital inclination of the binary system, i, the mean temperature of Star 2, T_2, the surface potentials, Ω_1 and Ω_2, for both components, the monochromatic luminosities of Star 1, L_{1B} and L_{1V}, and the mass ratio, $q = m_2/m_1$.

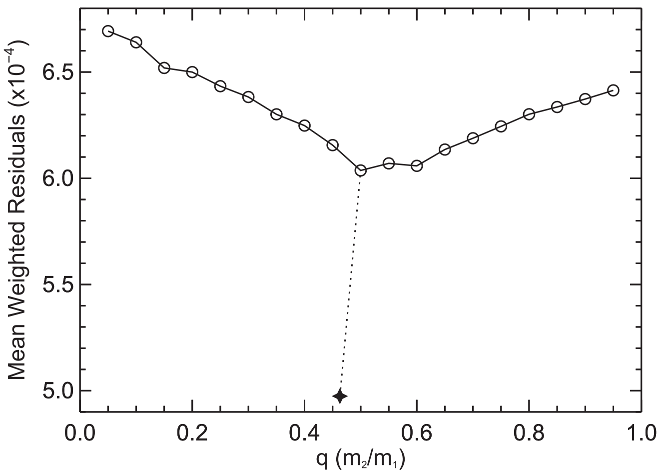

Figure 5. The relation of the mean weighted residuals vs. the assumed q. The best-fit photometric solution converged at $q = 0.463$, depicted by star symbol.

Brancewicz & Dworak (1980) and Bondarenko & Perevozkina (1996) published different mass ratios, 0.60 and 0.34, respectively, in their works. In the latest photometrical study for V Tri, Gürol et al. (2006) searched two mass ratios for detached configuration (0.508) and semi-detached configuration (0.458) with the q-searched method. We assumed a probable mass ratio range from 0.05 to 0.95, then a series of test values was used to search for a reliable mass ratio of Star 2 and Star 1. We run the differential corrections main program (DC) from mode 2, and then switched the program into mode 5. A set of convergent numerical solutions corresponding to each assumed mass ratio q was computed after many iterations of the adjustable parameters. The relation between the mean weighted residuals and the assumed q is described with open circles in Figure 5. A photometric mass ratio was considered at $q = 0.5$ from the result of the q-search. Next, we set q as an adjustable parameter and ran the DC program again to compute a more reliable value. After enough iterations, the best-fit photometric solution converged at $q = 0.463 \pm 0.001$ (the star symbol in Figure 5) for the semi-detached configuration. Then, the orbital semimajor axis, a, was adjusted. Finally, we derived a set of parameters of photometric analysis for the eclipsing binary system, as listed in Table 5.

The B- and V-band observed and synthetic light curves are displayed in the top panel of Figure 6. The characteristics of the light curves indicate that this system is a typical Algol-type eclipsing binary system having a semi-detached configuration with the secondary component accurately filling its limiting lobe. Using the equation $f = R/r_{\rm cr}$, where R is the stellar radius and $r_{\rm cr}$ is the critical Roche lobe, we determined that the filling factor of the primary is 93.9%. This indicates that V Tri is a near-contact semi-detached binary system. The sinusoidal synthetic curve and the observed RVs of the primary component are shown in the bottom panel of Figure 6, and the corresponding sum of squares of the residuals is 0.0622. The systemic RV and the amplitude of RVs are $-64\ {\rm km\ s^{-1}}$ and $107\ {\rm km\ s^{-1}}$, respectively. Combining the photometric solution with the spectroscopic results, the absolute parameters including the mass, radius, and luminosity for each component of the system were computed from the WD code, as listed in Table 6. Based on Kepler's third law $m_1 + m_2 = (4\pi^2/G)(a^3/P^2)$, the relative radius formula $r = R/a$, and the luminosity $L = 4\pi\sigma R^2 T^4$, the errors of these parameters are calculated by the error propagation method.

Table 5
Photometric Solution for V Tri

Parameter	Best-fit Value	Formal Error
$a(R_\odot)$	3.91	0.10
$q = m_2/m_1$	0.463	0.001
$T_1(K)$	8750	b
$T_2(K)$	5902	±6
g_1, g_2	1.0, 0.32	b
i	84.19	±0.05
A_1, A_2	1.0, 0.5	b
Ω_1	2.9375	±0.0015
$\Omega_2 = \Omega_{\rm in}$	2.8045	b
X_1, X_2(bolo)	0.654, 0.646	c
Y_1, Y_2(bolo)	0.119, 0.211	c
x_1, $x_2(B)$	0.768, 0.837	c
y_1, $y_2(B)$	0.331, 0.140	c
x_1, $x_2(V)$	0.660, 0.760	c
y_1, $y_2(V)$	0.281, 0.234	c
$L_1/(L_1 + L_2)(B)$	0.9354	±0.0005
$L_1/(L_1 + L_2)(V)$	0.8971	±0.0006
r_1(pole)	0.3989	±0.0002
r_1(point)	0.4732	±0.0005
r_1(side)	0.4200	±0.0002
r_1(back)	0.4406	±0.0003
r_2(pole)	0.2938	±0.0002
r_1(point)	0.4216	±0.0002
r_2(side)	0.3065	±0.0002
r_2(back)	0.3391	±0.0002
$\sum(O - C)^2$	0.1797	

Note. b: Assumed; c: van Hamme (1993).

5. Summary and Discussions

We performed time-series photometric observations for the eclipsing binary system V Tri in the B- and V-bands. Six times for primary and secondary minima were obtained on 2003 December 25 and 26, and also from 2007 October 12 to 14. Meanwhile, the light curves were recorded with the CCD camera in a complete phase. We carried out the high-resolution spectroscopic observations with the echelle spectrometer on 2015 November 3 and 5. The spectral type of the system is determined to be A3V by comparison with the spectral model in the stellar spectral library by Pickles (1998). Moreover, 10 RVs of the primary were determined from the spectra.

We calculated new linear and quadratic ephemerides for V Tri, based on the 81 minimum times that were measured by photoelectric and CCD photometry from publications and this study. The period of this system (0.58520481 days) is very similar to the results of previous research. The orbital period of the system has decreased with the rate of -7.80×10^{-8} day yr^{-1} over the past few decades. If the decrease in orbital period is attributed to the mass transfer between the two components of the system, the more-massive star will transfer mass to the companion. However, a semi-detached configuration with the less-massive star filling its Roche lobe was yielded by the light curve simulation for the system. This suggests that V Tri used to be an EB-type binary system. The component reached its Roche lobe and rapidly transferred the mass to the primary, which was the less-massive star, and, accordingly, the orbital period decreased. The system did not exhibit periodical change in X-ray intensity (Shaw & Smith 2000), indicating that the mass transfer has become inactive. As the mass transfer slows, the accretion disk settles onto the primary, which leads to the primary

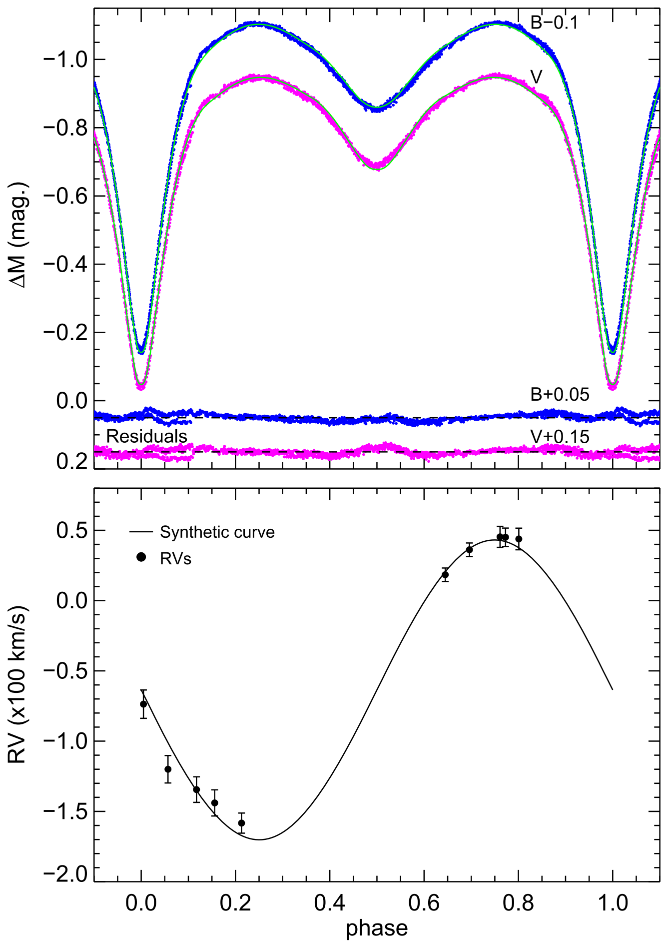

Figure 6. Top panel: observed B- and V-band light curves of V Tri and the synthetic curves (green lines). Bottom panel: observed RVs (filled circles) of the primary component of V Tri and the synthetic curve (solid line).

Table 6
Absolute Parameters of V Tri

Parameter	Primary	Secondary
Mass($M_{\odot}$)	1.60 ± 0.07	0.74 ± 0.02
Radius($R_{\odot}$)	1.64 ± 0.02	1.23 ± 0.02
Luminosity($L_{\odot}$)	14.14 ± 0.73	1.65 ± 0.05

becoming a relatively normal more-massive star. The tidal forces synchronize the rotation of the primary with the orbit, and the system acts as an Algol-type binary, as seen in our study. Now, V Tri evolves in a slow mass-transfer evolutionary stage on the nuclear timescale. The rate of conservative mass transfer from the component to the primary was estimated to be about $6.12 \times 10^{-8} M_{\odot}\,\mathrm{yr}^{-1}$.

Gürol et al. (2006, see their Figure 3) analyze the $O - C$ residuals that were derived from the linear equation based on the collected light minimum times. The light-time effect due to a third body in the binary system was used to explain the result of the sinusoidal fit to the residuals. Additional new photoelectric and CCD minimum times were added in order to verify the light-time effect. Sinusoidal-like residuals of all light minima (Epoch $> -20 \times 10^3$, Figure 4) indicate that this system is likely to have a third companion. However, this result is not completely concrete, because more visual values form the sine-like structure.

The photometric solution indicates that the temperature of the more-massive star is 2848 K higher than the less-massive one. It also indicates that V Tri could be an A-type near-contact system. The mass ratio and orbital inclination of V Tri were found to be $q = 0.463 \pm 0.001$ and 84.20 ± 0.05, respectively, which are slightly larger than the ratio of 0.458 ± 0.005 and the inclination of 84.07 ± 0.19 given by Gürol et al. (2006). The absolute parameters for each component of the binary system were computed from the photometrical results, as displayed in Table 6. These parameters are also differ significantly from previous values. Due to the high-precision time-series photometrical data and high-resolution spectroscopic data, our credible parameters will expand the understanding of the character of V Tri at its present evolutionary stage.

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References

Baldwin, M. E., & Samolyk, G. 1997, in Observed Minima Timings of Eclipsing Binaries, No. 4, ed. M. E. Baldwin & G. Samolyk (Cambridge, MA: American Association of Variable Star Observers)
Baldwin, M. E., & Samolyk, G. 2003, in Observed Minima Timings of Eclipsing Binaries, No. 8, ed. M. E. Baldwin & G. Samolyk (Cambridge, MA: American Association of Variable Star Observers)
Baldwin, M. E., & Samolyk, G. 2006, in Observed Minima Timings of Eclipsing Binaries, No. 11, ed. M. E. Baldwin & G. Samolyk (Cambridge, MA: American Association of Variable Star Observers)
Bondarenko, I. I., & Perevozkina, E. L. 1996, OAP, 9, 20
Brancewicz, H. K., & Dworak, T. Z. 1980, AcA, 30, 501
Brat, L., Trnka, J., Smelcer, L., et al. 2011, OEJV, 137, 1
Brát, L., Zejda, M., & Svoboda, P. 2007, OEJV, 74, 1
Budding, E. 1984, BICDS, 27, 91
Cannon, A. J. 1934, BHarO, 897, 12
Cox, A. N. 2000, Allen's Astrophysical Quantities (New York: Springer)
Demircan, O., Erdem, A., Ozdemir, S., et al. 2003, IBVS, 5364, 1
Diethelm, R. 2012, IBVS, 6011, 1
Dogru, S. S., Donmez, A., Tuysuz, M., et al. 2007, IBVS, 5746, 1
Dogru, S. S., Erdem, A., Donmez, A., et al. 2009, IBVS, 5893, 1
Giuricin, G., Mardirossian, F., & Mezzetti, M. 1983, A&AS, 54, 211
Gokay, G., Demircan, Y., Gursoytrak, H., et al. 2012, IBVS, 6039, 1
Gray, J. D., Samec, R. G., Williams, D. B., & Zetzl, J. T. 1994, IAPPP, 58, 4
Gürol, B., Müyesseroğlu, Z., & Özdemir, T. 2006, AN, 327, 698
Hoffman, D. I., Harrison, T. E., McNamara, B. J., et al. 2006, AJ, 132, 2260
Hoffmeister, C. 1919, AN, 208, 249
Hubscher, J. 2005, IBVS, 5643, 1
Hubscher, J. 2011, IBVS, 5984, 1
Hubscher, J. 2014, IBVS, 6118, 1

Hubscher, J. 2015, IBVS, 6152, 1
Hubscher, J., & Lehmann, P. B. 2012, IBVS, 6026, 1
Hubscher, J., Lehmann, P. B., Monninger, G., Steinbach, H.-M., & Walter, F. 2010, IBVS, 5918, 1
Hubscher, J., Paschke, A., & Walter, F. 2005, IBVS, 5657, 1
Hubscher, J., Paschke, A., & Walter, F. 2006, IBVS, 5731, 1
Hubscher, J., Steinbach, H.-M., & Walter, F. 2008, IBVS, 5830, 1
Hubscher, J., & Walter, F. 2007, IBVS, 5761, 1
Jordan, F. C. 1929, PAllO, 7, 125
Kreiner, J. M., Kim, C.-H., & Nha, I.-S. (ed.) 2001, An Atlas of O–C Diagrams of Eclipsing Binary Stars (Cracow: Wydawnictwo Naukowe Akademii Pedagogicznej)
Kurucz, R. L. 1993, in IAU Symp. 151, Light Curve Modeling of Eclipsing Binary Stars, ed. E. F. Milone (New York: Springer), 93
Leavitt, H. S., & Pickering, E. C. 1913, HarCi, 179, 1
Maciejewski, G., & Karska, A. 2004, IBVS, 5494, 1
Muyesseroglu, Z., Torun, E., Ozdemir, T., et al. 2003, IBVS, 5463, 1
Nelson, R. H. 2003, IBVS, 5371, 1
Pickles, A. J. 1998, PASP, 110, 863
Samolyk, G. 2008a, JAVSO, 36, 171
Samolyk, G. 2008b, JAVSO, 36, 186
Samolyk, G. 2010, JAVSO, 38, 183
Samolyk, G. 2012, JAVSO, 40, 975
Samolyk, G. 2013a, JAVSO, 41, 328
Samolyk, G. 2013b, JAVSO, 41, 122
Samolyk, G. 2015a, JAVSO, 43, 238
Samolyk, G. 2015b, JAVSO, 43, 77
Shaw, J. S. 1994, MmSAI, 65, 95
Shaw, J. S., & Smith, E. 2000, ASSL, 254, 191
Stetson, P. B. 1987, PASP, 99, 191
van Hamme, W. 1993, AJ, 106, 2096
Wilson, R. E. 1979, ApJ, 234, 1054
Wilson, R. E. 1990, ApJ, 356, 613
Wilson, R. E., & Devinney, E. J. 1971, ApJ, 166, 605
Wilson, R. E., & van Hamme, W. 2016, Computing Binary Stars Observables, ftp://ftp.astro.ufl.edu/pub/wilson/lcdc2015
Wood, B. D., & Forbes, J. E. 1963, AJ, 68, 257
Zejda, M., Mikulasek, Z., & Wolf, M. 2006, IBVS, 5741, 1