TU Comae Berenices: Blazhko RR Lyrae Star in a Potential Binary System

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Received February 2, 2016; revised April 25, 2016; accepted April 28, 2016

Abstract We present the results of a photometry campaign of TU Com performed over a five-year time span. The analysis showed that the possible Blazhko period of 75 days published by the *General Catalogue of Variable Stars* is not correct. We identified two Blazhko periods of 43.6 and 45.5 days. This finding is based on measurement of 124 light maxima. A spectral analysis of the complete light curve confirmed these two periods. Besides the Blazhko amplitude and phase modulations, another long term periodic phase variation has been identified. This long term periodic variation affects the times of maximum light only and can be attributed to a light-travel time effect due to orbital motion of a binary system. The orbital parameters have been estimated by a nonlinear least-square fit applied to the set of (O-C) values. The Levenberg-Marquart algorithm has been used to perform the nonlinear least-square fit. The tentative orbital parameters include an orbital period of 1676 days, a minimal semi-major axis of 1.55 AU, and a small eccentricity of 0.22. The orbital parameter estimation also used 33 (O-C) values obtained from the SWASP survey database. Spectroscopic radial velocity measurements are needed to confirm this binarity. If confirmed, TU Com would be the first Blazhko RR Lyrae star detected in a binary system.

1. Introduction

The star TU Comae Berenices (TU Com) is classified in the *General Catalogue of Variable Stars* (Samus *et al.* 2011) as an RR Lyrae (RRab) variable star with a period of 0.4618091 day and a possible Blazhko period of 75 days. This period of 75 days was derived by Ureche (1965) from photographic observations. Using Fourier analysis of previous observations including ROTSE data (Wozniak *et al.* 2004), Sódor and Jurcisk (2005) questioned this Blazhko modulation. McGrath (1975), who observed this star at the Maria Mitchell Observatory (Nantucket, Massachusetts), did not detect a secondary modulation with a period of 75 days but one with a period of approximately 40 days.

Our results are based on 23,577 observations gathered during 150 nights between January 13, 2009, and May 23, 2015. The specifications of telescopes and CCD cameras used in this project and the number of observations for each telescope are provided in Table 1.

The CCD images were dark- and flat-field corrected with MAXIMDL software (Diffraction Limited 2004), and aperture photometry was performed using LESVEPHOTOMETRY (de Ponthière 2010), a custom software which also evaluates the SNR and estimates magnitude errors. The comparison

Table 1. Telescope and camera specifications, numbers of observations, and photometric mean uncertainties.

Location	*Observer*	*Telescope Type*	*Camera Type*	*Number of Observations*	*Mean Uncertainty (mag.)*
Cloudcroft, New Mexico	Hambsch	F/6.3 Meade 0.30m	SBIG ST9XM	17252	0.014
Mol, Belgium	Hambsch	Celestron 0.30m	SBIG ST8XME	700	0.032
Framingham, Massachusetts	Menzies	F/8 Hyperion 0.32m	SBIG STL-6303	2696	0.022
Bozeman, Montana	Sabo	F/6.8 PlaneWave 0.43m	SBIG STL-1001	906	0.019
Cloudcroft, New Mexico	de Ponthière	F/6.3 Meade 0.30m	SBIG ST-7	1301	0.022
Lesve, Belgium	de Ponthière	F/6.2 Meade 0.20m	SBIG ST-7	722	0.024

Table 2. TU Com comparison stars.

GSC Identification	*UCAC4 Identification*	*R.A. (2000)* h m s	*Dec. (2000)* ° ' "	*B*	*V*	*B–V*	*Reference/Check*
2527-162	606-048343	12 13 40.55	+31 00 46.22	14.868	14.167	0.701	C1
2527-073	605-049038	12 14 18.96	+30 59 22.82	15.126	14.473	0.653	C2

stars are given in Table 2. The comparison star coordinates and magnitudes in B and V bands were obtained from the UCAC4 catalog (Zacharias *et al.* 2012). All the observations have been reduced with C1 as the magnitude reference and C2 as the check star. The observations were performed with a V filter and are not transformed to the standard system. The photometric observations were uploaded by the authors to the AAVSO International Database (Kafka 2015) where they can be retrieved.

All the data with an uncertainty larger than 0.050 magnitude have been eliminated from the dataset. The observations were not limited to the time of maxima, as can be seen in the folded light curve presented in Figure 1. This light curve is folded on the pulsation period determined in the next section. The photometric uncertainties for each telescope and location are provided in Table 1.

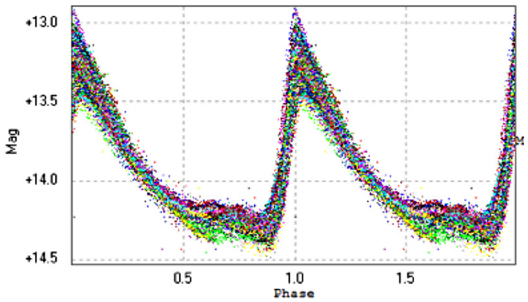

Figure 1. Folded light curve on the pulsation period.

2. Light curve maxima analysis

A custom software (de Ponthiere 2010) fitting the light curve with a smoothing spline function (Reinsch 1967) was used to measure the times and magnitudes of light curve maxima. The observed times of light maxima are compared to a linear ephemeris to get the observed minus calculated (O–C) values. The (O–C) values and M_{max} (Magnitude at Maximum brightness) of the 124 observed maxima are listed in Table 8 given in the Appendix.

A linear regression of (O–C) values has provided a pulsation period of 0.4618665 day, which has been used to establish the pulsation ephemeris.

$$\begin{aligned} HJD_{Pulsation} = {} & (2456416.6221 \pm 0.0008) \\ & + (0.4618665 \pm 0.0000006)\ E_{Pulsation} \end{aligned} \quad (1)$$

The origin of the ephemeris has been arbitrarily set to the highest recorded brightness maximum. The derived pulsation period is slightly different from the value of 0.4618091 published in the *General Catalogue of Variable Stars* (Samus *et al.* 2011). Figure 2 shows the (O–C) and M_{max} values in the top and bottom panels, respectively.

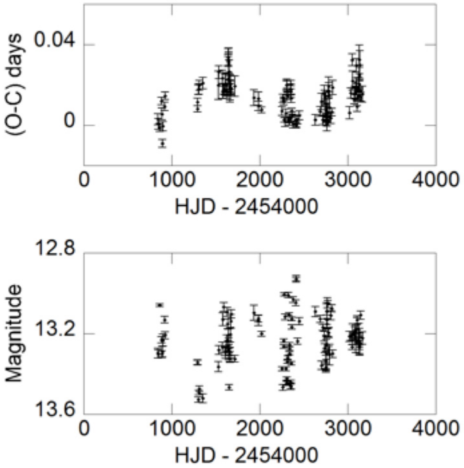

Figure 2. Top panel: O–C values, besides the Blazhko modulation of the times of maxima, a long term periodic variation is evident. Bottom panel: Magnitude at Maximum Brightness, the long term periodic variation seen in (O–C) is not apparent in the Magnitude at Maximum Brightness.

Besides the variations due to the Blazhko effect, a long term periodic variation of the times of maxima (O–C) is apparent from an inspection of Figure 2 (Top). This long term variation is not present in the magnitudes at maximum M_{max} shown in Figure 2 (Bottom). The presence of this long term variation in the (O–C) and not in the M_{max} can be explained by a light-travel time effect caused by an orbital motion around the common center of mass in a binary system.

RR Lyrae stars detected in binary systems are relatively rare; this is probably due to the technical challenges raised by the detection of the light-travel time effect in the observation datasets. At the end of the last century, TU UMa was the only one identified in a binary system (Saha and White 1990; Wade *et al.* 1999; Liska *et al.* 2015). Meanwhile, 12 RR Lyrae stars were recently discovered in the galactic bulge (Hajdu *et al.* 2015), and with data provided by the high precision photometry of the Kepler mission, other RR Lyrae stars in the galactic field have been identified as potential binary systems (Li and Qian 2014; Guggenberger and Steixner 2015). All those RR Lyrae stars are not affected by the Blazhko effect and do not show eclipses. The only RR Lyrae star detected in an eclipsing binary system is the non-classical RR Lyrae OGLE-BLG-RRLYR-02792, which has a mass of 0.26 $M_{\odot}$ (Pietrzynski *et al.* 2012).

To derive the (O–C) values, Hajdu *et al.* (2015) utilized the Hertzsprung (1919) method which compares the light curve to

Table 3. TU Com frequency spectrum components obtained from light curve maxima.

From	*Frequency (d^{-1})*	*σ(d^{-1})*	*Period (d)*	*σ(d)*	*Amplitude*	*Φ (cycle)*	*SNR*
(O–C) values	0.00061	1.3×10^{-4}	1634.8	356	0.00585 d	0.198	19.1
(O–C) values	0.02209	0.78×10^{-4}	45.28	0.095	0.0229 d	0.044	7.92
M_{max} values	0.02306	2.2×10^{-4}	43.37	0.42	0.108 mag.	0.056	14.8
M_{max} values	0.02204	1.1×10^{-4}	45.36	0.22	0.082 mag.	0.504	11.1

a template. This method is not appropriate for stars influenced by the Blazhko effect since their light curves do not repeat from one pulsation cycle to another. It is for this reason that Hajdu *et al.* (2015) eliminated stars impacted by the Blazhko effect from their investigations.

The periods and amplitudes of the (O–C) and M_{max} values have been determined with PERIOD04 (Lenz and Breger 2005), a Fourier analysis and sine-wave fitting program. The results are presented in Table 3. Two Blazhko periods (43.37 and 45.36 d) are detected in the M_{max} analysis but only one of those (45.28 d) is found in the (O–C) analysis. A long period (1634.8 d) is detected in the (O–C) analysis. As this long period is not detected in the M_{max} analysis, it can be attributed to an orbital motion around a center of mass.

The two close Blazhko periods found in the magnitude at maximum spectrum are also detected in the spectral analysis of the light curve as shown in the next section. The presence of a main Blazhko period and another periodic modulation close to it has been reported for XZ Cyg by LaCluyzé, A., *et al.* (2004). They also detected long term variations of the main Blazhko period over a time span of several decades. Their analyses of XZ Cyg are based on observations covering a time span of several decades, which is not the case for our observations.

In order to detect a potential Blazhko period variation, we have created seasonal subsets of the magnitude at maximum values and applied a Fourier analysis followed by a sine-wave fitting. The results are presented in Table 4. The number of observations for the 2010 and 2012 seasons is too limited to perform a Fourier analysis and the corresponding subsets do not appear in Table 4.

It is unclear if the period variations are due to real Blazhko period deviation or to a non-repetitive Blazhko effect from one cycle to another.

TU Com was also observed by the robotic SuperWasp-North telescope (Butters *et al.* 2010) located on the island of La Palma (Spain) between 2004 and 2008. The star is identified as J121346.95+305907.6 in the SuperWASP database. From the light curves available on the SuperWASP website, 37 brightness maxima have been identified. Their measured (O–C) values are reported in the Appendix (Table 9). The magnitudes at maximum brightness are not reported in this table since it was not possible to reliably determine the offset between the SWASP magnitudes and the reference magnitudes used in our image reduction. The four maxima recorded in 2004 (JD 2453130 to 2453174) have large (O–C) values greater than 2 hours. These (O-C) values should be questioned and are not used in this paper; it is possible that an error occurred in the WASP automatic image reduction or in the data distribution process.

Table 4. TU Com period variation obtained from magnitude at maximum values.

Subset (year)	*Period (d)*	*σ(d)*	*N_{obs}*
2009	45.61	1.39	9
2011	43.90	0.82	25
2013	44.09	0.13	29
2014	44.49	0.27	26
2015	41.33	0.83	24

3. Frequency spectrum analysis of the light curve

The light curve of a Blazhko star may be considered as a signal modulated in amplitude and phase. The signal spectrum is characterized by a pattern of multiplets ($kf_o \pm nf_B$) based on a pulsation frequency f_o and Blazhko modulation frequency f_B. Generally, from ground-based observations, only the central triplets are detected, as the other components are hidden in the noise. The amplitudes, phases, and uncertainties of the spectral components have been obtained with PERIOD04 by performing successive Fourier analyses, pre-whitenings, and sine-wave fittings. Only the components having a signal to noise ratio (SNR) greater than 3 have been retained as significant signals.

Table 5 provides the complete list of spectral components. Besides the pulsation frequency f_o and its harmonics nf_o, two groups of triplets corresponding to Blazhko periods and a component based on the suspected orbital period have been found. The frequencies and periods corresponding to Blazhko frequencies f_{B1} and f_{B2} and to an orbital period are given in Table 6. The two Blazhko periods corresponding to f_{B1} and f_{B2} are close to the periods found in the analysis of magnitude at maximum brightness. The orbital period of 1,601 days is in relatively good agreement with the value of 1,634.8 days found in the (O–C) analysis.

During the sine-wave fitting, the pulsation frequency f_o, ($f_0 - f_{B1}$), ($2f_o + f_{B2}$), and ($2f_o - f_{Orb}$) have been left unconstrained and the other frequencies have been forced as combinations of the four unconstrained frequencies. The uncertainties of frequencies, amplitudes, and phases estimated from Monte Carlo simulations have been multiplied by a factor of two as it is known that the Monte Carlo simulations underestimate these uncertainties.

Figure 3 presents the (O–C) values pre-whitened with the assumed orbital period of 1,601 days versus time. By comparison with the top panel of the Figure 2, it can be seen that the long term variation is effectively removed and only variations due to the short term Blazhko effect remain.

The same (O–C) pre-whitened data folded with the 43.66-

Table 5. TU Com multi-frequency fit results.

Component	$f(d^{-1})$	$\sigma(f)$	A_i	$\sigma(A_i)$ (mag.)	Φ_i	$\sigma(\Phi_i)$ (cycle)	SNR
f_o	2.165128	8.69×10^{-7}	0.3998	0.0017	0.3296	0.0006	117.1
$2f_o$	4.330256		0.2050	0.0017	0.9899	0.0015	60.7
$3f_o$	6.495383		0.1178	0.0017	0.7559	0.0021	32.3
$4f_o$	8.660511		0.0636	0.0018	0.4953	0.0042	16.8
$5f_o$	10.82564		0.0400	0.0016	0.2296	0.0075	11.3
$6f_o$	12.99077		0.0302	0.0018	0.9825	0.0080	9.7
$2f_o - f_{Orb}$	4.329631	8.75×10^{-6}	0.0530	0.0016	0.7854	0.0059	15.7
$f_o - f_{B1}$	2.142221	11.1×10^{-6}	0.0300	0.0016	0.7745	0.0086	9.1
$f_o + f_{B1}$	2.188034		0.0395	0.0019	0.0218	0.0084	10.3
$3f_o - f_{B1}$	6.472477		0.0171	0.0015	0.1028	0.0086	4.6
$3f_o + f_{B1}$	6.51829		0.0294	0.0015	0.4460	0.0143	8.1
$2f_o + f_{B2}$	4.352244	12.9×10^{-6}	0.0367	0.0018	0.8150	0.0075	10.0
$f_o - f_{B2}$	2.143139		0.0344	0.0019	0.4456	0.0326	10.1
$f_o + f_{B2}$	2.187117		0.0100	0.0017	0.1479	0.0083	3.0

Table 6. TU Com triplet component frequencies and periods.

Component	Derived from (d^{-1})	Frequency (d^{-1}) (d)	σ (d)	Period	σ
f_o		2.165128	$8.69 \times 10{-}7$	0.461867	1.85×10^{-7}
f_{B1}	$f_o - f_{B1}$	0.022906	$1.11 \times 10{-}5$	43.66	0.02
f_{B2}	$2f_o - f_{B2}$	0.021989	$1.30 \times 10{-}5$	45.48	0.02
f_{Orb}	$2f_o - f_{Orb}$	0.000625	$8.9 \times 10{-}6$	1601.0	22.9

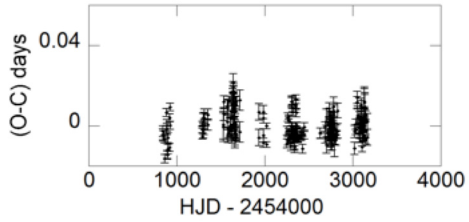

Figure 3. (O–C) values pre-whitened with the 1601-day assumed orbit period.

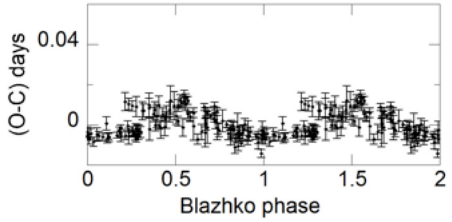

Figure 4. (O–C) values pre-whitened with the 1,601-day assumed orbit period and folded with the 43.66-day Blazhko period.

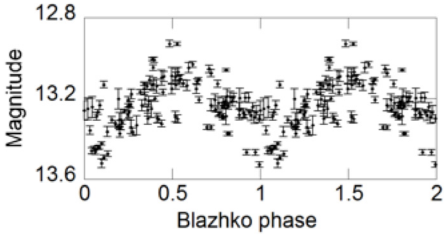

Figure 5. Magnitude at maximum brightness folded with the 43.66-day Blazhko period.

day Blazhko period are shown in the phase diagram of Figure 4, and the phase diagram of the magnitude at maximum using the same Blazhko period is given in Figure 5. In the phase diagrams of (O–C) values and magnitudes at maximum, the remaining scatter of the data is likely due to the presence of the second Blazhko period or to the non-repetitive Blazhko effect from one cycle to another.

4. Orbital parameter estimation

A pulsating star residing in a binary system can be seen as a regular "clock" in orbit around a center of mass. This orbital motion will affect the times of light maxima. For a pulsating star not affected by the Blazhko effect, besides a possible secular pulsation rate acceleration/deceleration, the orbital motion will be the only source of variations of the (O–C) values. Those (O–C) variations allow the evaluation of the orbital parameters by a non-linear least square fit with respect to the light-travel time equation. When applied to Blazhko pulsating stars, the Blazhko effect will be considered as noise affecting the (O–C) measurements. The Blazhko effect will increase the uncertainties of the orbital parameter estimation.

The light-travel time equation due to orbital motion is given by Hilditch (2001):

$$\tau = \frac{(a_{RRL} \sin i)}{c} \frac{(1 - e^2)}{(1{+}e \cos \nu)} \sin(\nu{+}\omega) + \tau_0 \qquad (2)$$

where a_{RRL} is the semi-major axis, e is the eccentricity, ν is the true anomaly, i is the orbit inclination, ω the periastron longitude, and c the speed of light. Without the additional term τ_0, the zero-point of τ is reached when the star is at the same distance as the mass center of the binary system, that is, when $\nu + \omega = \pm k \pi$. The zero-point of the (O–C) values obtained in section 2 has been arbitrarily set to the time of the highest recorded light maximum. The additional offset τ_0 is introduced to compensate for the difference between these two zero-points.

The true anomaly can be calculated from:

$$\tan\frac{\nu}{2} = \sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2} \tag{3}$$

where E is the eccentric anomaly which is evaluated by solving the Kepler equation:

$$E - e\sin E = 2\pi\,(t - T_{peri})\,/\,P_{orb} \tag{4}$$

and where T_{peri} is the epoch of periastron passage and P_{orb} is the orbital period. The semi-major axis a and the orbital inclination i are linked without additional information on the secondary star.

To obtain the estimation of orbital parameters (a_{RRL} sin i / c, e, ω, P_{orb}, T_{peri}, τ_0) the Levenberg-Marquart algorithm was used to minimize the sum of squares of the residuals $r_i = (O\text{–}C)_i - \tau\,(t_i\,,\,\boldsymbol{\beta})$ where t_i are the observed times of maxima and $\boldsymbol{\beta}$ the vector of parameters (a_{RRL} sin i / c, e, ω, P_{orb}, T_{peri}, τ_0). For each observed time of maxima, the light-travel time $\tau\,(t_i\,,\,\boldsymbol{\beta})$ is obtained by solving the Kepler equation (4) and calculating Equations (3) and (2).

The orbital parameter estimation was performed with the 124 (O–C) values derived from our observations (Table 8) and with 33 (O–C) values obtained from the SuperWASP survey (Table 9). The four (O–C) values corresponding to maxima recorded in 2004 were eliminated as they are abnormally large and are in question.

The results of the least-square fit are:

a_{RRL} sin i / c = 0.00893 d (1.55 AU)
P_{orb} = 1,676 d = 4.59 years
e = 0.22
ω = –0.978 rad
T_{peri} = 2455006 HJD
τ_0 = 0.0117 d

Using these orbital parameters, the theoretical light-travel times have been calculated and are compared to the (O–C) values in Figure 6.

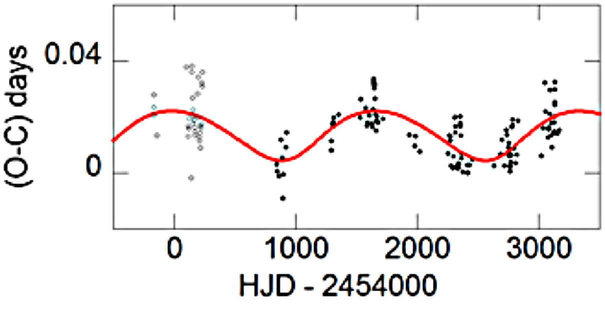

Figure 6. The (O–C) values (black diamonds) already presented in Figure 2 are compared to the light-travel time (red line) calculated from the orbital parameter solution. The (O–C) values derived from the SWASP database for the years 2005 and 2006 are represented with open diamonds.

The estimated orbital parameters are relatively uncertain as the scatter of the (O–C) values used for the orbital parameter estimation is as large as the orbit light-travel time variations.

An estimation of the semi-amplitude of the star's radial velocity may be derived from Equation (5):

$$K = (2\pi a_{RRL}\sin i)\,/\,(1 - e^2)^{1/2} = 10.3\ \text{km/s}. \tag{5}$$

From Kepler's third law, the mass function for a barycentric orbit $M = (4\pi^2\, a_{RRL}{}^3)\,/\,P_{orb}{}^2$ is related to star masses through $M = (G\ m_s{}^3)\,/\,(m_{RRL} + m_s)^2$, where m_{RRL} and m_s are the masses of TU Com and the secondary star, respectively, and G is the gravitational constant. If m_{RRL} and m_s are expressed in solar masses $M_\odot$ and P_{orb} in years, G is equal to $4\pi^2$ and Kepler's third law can be rewritten as

$$\frac{m_s{}^3\sin^3 i}{(m_{RRL}+m_s)^2} = \frac{a_{RRL}{}^3\sin^3 i)}{P_{orb}{}^2} \tag{6}$$

Assuming a classical RR Lyrae mass of 0.7 $M_\odot$ for TU Com, the minimum mass of the secondary star (m_s sin i) may be evaluated by solving Equation (6) rewritten as a third order polynomial. With the numerical values of 1.55 AU for (a sin i) and 4.59 year for P_{orb} the real solution of the polynomial provides a minimal mass (m_s sin i) for the secondary star fortuitously equal to 0.70 $M_\odot$. The third order polynomial has been solved for other orbital inclinations and the results are provided in Table 7.

Table 7. Secondary mass and semi-major axes of the two stars for different orbital inclinations.

Orbital Inclination (degrees)	*Secondary Mass ($M_\odot$)*	*a_{RRL} (AU)*	*a_s (AU)*
90	0.70	1.55	1.54
80	0.72	1.57	1.53
70	0.77	1.65	1.50
60	0.87	1.78	1.44
50	1.07	2.02	1.32
40	1.45	2.40	1.16
30	2.36	3.09	0.92
20	5.56	4.52	0.57
10	34.84	8.90	0.18

RR Lyrae stars are old stars and the secondary star probably formed at the same epoch and would have the same metallicity. With these assumptions, it may be assumed that the secondary star is in a more evolved state than the RR Lyrae star and eventually it ended as a white dwarf, because massive stars evolve more rapidly than lower mass ones. It is possible that the secondary star brightness is not large enough to allow spectroscopic measurement of its radial velocity.

If the radial velocities of the two stars may be measured, the mass ratio may be derived from the relationship:

$$\frac{m_s}{m_{RRL}} = \frac{V_{RRL}}{V_s} = \frac{a_{RRL}}{a_s} \tag{7}$$

This relationship also shows that the chances to measure the secondary radial velocity are reduced when the mass is larger.

5. Conclusions

This observational campaign and data analysis has shown that the Blazhko period of 75 days mentioned in the *General Catalog of Variable Stars* is not correct. Alternatively, two Blazhko periods of 43.6 and 45.5 days have been identified from a light curve maxima analysis and confirmed from the spectral analysis of the light curve. The origin of the two Blazhko periods remains unclear; it could be due to a real second period or to a variation of a main Blazhko period or to the non-repetitive Blazhko effect from one cycle to another. A long term periodic variation of the (O–C) values suggests that TU Com is in a binary system with an orbital period of about 1,676 days. A tentative set of orbital parameters have been derived from a non-linear least square fit of the (O–C) values with respect to the light-travel time equation. The authors intend to continue their photometric observations in future years to extend the amount of data and to refine these results. They also invite other amateur astronomers to join their campaign. In order to confirm the binarity of TU Com, it is suggested that this star be integrated into a spectroscopic radial velocity measurement campaign like the study started by Guggenberger *et al.* (2015). Applying the radial velocity method to determine the orbital parameters will be a challenge as the radial velocities are also impacted by the pulsation/motion of the atmospheric layers which will be additionally affected by the Blazhko effect.

6. Acknowledgements

The AAVSO is acknowledged for the use of AAVSOnet telescopes at Cloudcroft (New Mexico). The authors thank Dr. K. Kolenberg and Prof. Dr. G. Rauw for their help with the secondary star evolution analysis and the referee for the comments which helped to clarify and improve the paper. This work has made use of data from DR1 of the WASP data (Butters *et al.* 2010) as provided by the WASP consortium, and the computing and storage facilities at the CERIT Scientific Cloud, reg. no. CZ.1.05/3.2.00/08.0144, which is operated by Masaryk University, Czech Republic.

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Appendix

Table 8. TU Com measured brightness maxima.

Maximum HJD	*Error*	*O–C (day)*	*E*	*Magnitude*	*Error*
2454844.8935	0.0028	0.0030	–3403	13.297	0.025
2454849.9716	0.0026	0.0006	–3392	13.301	0.020
2454861.9785	0.0020	–0.0011	–3366	13.059	0.007
2454881.8518	0.0020	0.0120	–3323	13.231	0.016
2454888.7734	0.0029	0.0056	–3308	13.302	0.016
2454892.9157	0.0020	–0.0089	–3299	13.291	0.026
2454901.6995	0.0024	–0.0005	–3280	13.232	0.030
2454918.7984	0.0020	0.0093	–3243	13.131	0.016
2454924.8080	0.0019	0.0146	–3230	13.209	0.018
2455292.4472	0.0015	0.0081	–2434	13.343	0.012
2455293.3744	0.0018	0.0116	–2432	13.344	0.012
2455305.3889	0.0024	0.0175	–2406	13.527	0.013
2455310.4699	0.0025	0.0180	–2395	13.491	0.012
2455311.3954	0.0024	0.0198	–2393	13.474	0.014
2455353.4264	0.0028	0.0209	–2302	13.522	0.022
2455528.9345	0.0070	0.0198	–1922	13.364	0.026
2455534.0216	0.0032	0.0263	–1911	13.281	0.022
2455577.8959	0.0040	0.0233	–1816	13.268	0.027
2455583.8938	0.0038	0.0170	–1803	13.129	0.032
2455589.8991	0.0025	0.0180	–1790	13.068	0.022
2455607.9143	0.0054	0.0204	–1751	13.286	0.025
2455608.8384	0.0045	0.0208	–1749	13.293	0.030
2455624.5386	0.0030	0.0175	–1715	13.234	0.027
2455632.8512	0.0031	0.0165	–1697	13.093	0.022
2455637.9380	0.0034	0.0228	–1686	13.152	0.024
2455642.5675	0.0045	0.0336	–1676	13.207	0.028
2455643.4901	0.0028	0.0325	–1674	13.279	0.011
2455644.4129	0.0026	0.0316	–1672	13.284	0.010
2455645.3363	0.0050	0.0312	–1670	13.288	0.043
2455648.5686	0.0050	0.0305	–1663	13.281	0.025
2455648.5703	0.0060	0.0322	–1663	13.257	0.037
2455650.4122	0.0058	0.0266	–1659	13.467	0.013
2455656.8727	0.0043	0.0210	–1645	13.288	0.020
2455660.5618	0.0026	0.0151	–1637	13.306	0.015
2455661.4891	0.0038	0.0187	–1635	13.324	0.014
2455662.4125	0.0070	0.0184	–1633	13.306	0.036
2455668.8806	0.0043	0.0203	–1619	13.205	0.036
2455671.6500	0.0034	0.0185	–1613	13.139	0.034
2455677.6537	0.0026	0.0180	–1600	13.103	0.021
2455716.4519	0.0050	0.0194	–1516	13.325	0.016
2455933.9852	0.0040	0.0136	–1045	13.097	0.037
2455982.9391	0.0023	0.0096	–939	13.126	0.018
2455983.8664	0.0033	0.0132	–937	13.136	0.025
2456019.4246	0.0014	0.0077	–860	13.201	0.012
2456254.9758	0.0022	0.0070	–350	13.375	0.009
2456261.9102	0.0021	0.0134	–335	13.467	0.015
2456272.9948	0.0010	0.0132	–311	13.264	0.008
2456273.9171	0.0015	0.0117	–309	13.236	0.009
2456279.9123	0.0011	0.0027	–296	13.006	0.008
2456290.9961	0.0023	0.0017	–272	13.117	0.014
2456298.8521	0.0022	0.0060	–255	13.375	0.010
2456309.0270	0.0031	0.0198	–233	13.447	0.010
2456309.9508	0.0024	0.0199	–231	13.443	0.010
2456310.8747	0.0020	0.0200	–229	13.423	0.008
2456315.0281	0.0017	0.0166	–220	13.34	0.007
2456315.9498	0.0018	0.0146	–218	13.319	0.009
2456323.7893	0.0013	0.0024	–201	13.009	0.012
2456334.8733	0.0015	0.0016	–177	13.105	0.007
2456339.0304	0.0019	0.0019	–168	13.256	0.011
2456339.9558	0.0019	0.0035	–166	13.274	0.009
2456340.8788	0.0017	0.0028	–164	13.298	0.008
2456351.9774	0.0029	0.0166	–140	13.46	0.015
2456352.9023	0.0027	0.0178	–138	13.463	0.014
2456353.8284	0.0021	0.0201	–136	13.441	0.010
2456358.9022	0.0021	0.0134	–125	13.347	0.009
2456363.9763	0.0015	0.0070	–114	13.168	0.011
2456364.8983	0.0013	0.0052	–112	13.128	0.008
2456376.9021	0.0018	0.0005	–86	13.032	0.015
2456410.6207	0.0017	0.0029	–13	13.047	0.014
2456414.7748	0.0015	0.0002	–4	12.929	0.017
2456416.6221	0.0009	0.0000	0	12.93	0.008
2456427.7097	0.0022	0.0028	24	13.238	0.015
2456452.6526	0.0022	0.0049	78	13.139	0.017
2456630.9308	0.0026	0.0027	464	13.091	0.026
2456687.7446	0.0024	0.0069	587	13.127	0.018
2456699.7581	0.0041	0.0118	613	13.358	0.021
2456717.7616	0.0023	0.0026	652	13.17	0.015
2456734.8635	0.0045	0.0154	689	13.213	0.024
2456737.6330	0.0036	0.0137	695	13.273	0.022
2456750.5609	0.0031	0.0093	723	13.373	0.018
2456753.3302	0.0060	0.0074	729	13.342	0.033
2456753.7909	0.0033	0.0063	730	13.365	0.019
2456754.7192	0.0055	0.0108	732	13.333	0.048
2456757.4857	0.0041	0.0061	738	13.258	0.030
2456757.4866	0.0033	0.0070	738	13.3	0.028
2456758.4116	0.0065	0.0083	740	13.251	0.043
2456763.4845	0.0036	0.0007	751	13.088	0.041
2456763.4866	0.0031	0.0028	751	13.152	0.027
2456764.4098	0.0024	0.0022	753	13.131	0.023
2456764.4142	0.0043	0.0066	753	13.091	0.038
2456767.6445	0.0022	0.0039	760	13.048	0.025
2456772.7275	0.0021	0.0063	771	13.054	0.019
2456778.7420	0.0033	0.0166	784	13.195	0.021
2456781.5139	0.0039	0.0173	790	13.281	0.018
2456782.4395	0.0048	0.0191	792	13.195	0.026
2456794.4377	0.0079	0.0088	818	13.305	0.052
2456808.7503	0.0026	0.0036	849	13.109	0.024
2456816.6050	0.0019	0.0065	866	13.075	0.018
2456828.6257	0.0036	0.0187	892	13.3	0.018
2457018.9021	0.0031	0.0061	1304	13.214	0.025
2457037.8485	0.0025	0.0160	1345	13.211	0.022
2457049.8734	0.0030	0.0324	1371	13.267	0.012
2457054.9436	0.0047	0.0220	1382	13.202	0.050
2457074.7947	0.0023	0.0129	1425	13.207	0.015
2457080.8020	0.0024	0.0159	1438	13.217	0.018
2457081.7261	0.0031	0.0163	1440	13.19	0.038
2457082.6492	0.0027	0.0156	1442	13.193	0.028
2457091.8921	0.0024	0.0212	1462	13.243	0.051
2457093.7481	0.0033	0.0297	1466	13.234	0.022
2457101.5879	0.0028	0.0178	1483	13.178	0.025
2457104.8167	0.0039	0.0135	1490	13.152	0.030
2457106.6599	0.0025	0.0093	1494	13.133	0.021
2457124.6781	0.0021	0.0147	1533	13.233	0.015
2457125.6022	0.0020	0.0151	1535	13.238	0.015
2457128.3765	0.0056	0.0182	1541	13.199	0.049
2457129.7641	0.0028	0.0202	1544	13.195	0.022
2457130.6878	0.0020	0.0201	1546	13.267	0.012
2457131.6168	0.0034	0.0254	1548	13.243	0.023
2457132.5395	0.0056	0.0244	1550	13.268	0.032
2457133.4715	0.0071	0.0326	1552	13.259	0.048
2457134.3925	0.0070	0.0299	1554	13.251	0.054
2457149.6183	0.0023	0.0141	1587	13.108	0.021
2457166.7087	0.0039	0.0154	1624	13.222	0.030

Table 9. TU Com brightness maxima derived from SuperWASP database.

Maximum HJD	*Error*	*O–C (day)*	*E*
2453130.5345	0.0079	0.09241	–7115
2453137.4585	0.0022	0.088413	–7100
2453144.4709	0.0167	0.172816	–7085
2453174.4205	0.0052	0.101095	–7020
2453831.5834	0.0069	0.027993	–5597
2453832.4998	0.0032	0.02066	–5595
2453833.4265	0.0035	0.023627	–5593
2453856.5096	0.0069	0.013403	–5543
2454101.7852	0.0084	0.037901	–5012
2454114.6964	0.0029	0.01684	–4984
2454115.6165	0.0027	0.013207	–4982
2454120.7032	0.0063	0.019376	–4971
2454121.6234	0.0049	0.015843	–4969
2454143.7753	0.0038	–0.00185	–4921
2454145.6606	0.0077	0.035986	–4917
2454146.5865	0.0049	0.038153	–4915
2454150.7320	0.0033	0.026854	–4906
2454156.7298	0.0046	0.02039	–4893
2454157.6558	0.005	0.022657	–4891
2454158.5747	0.0035	0.017824	–4889
2454165.5038	0.0079	0.018927	–4874
2454169.6550	0.0055	0.013329	–4865
2454170.5818	0.0067	0.016396	–4863
2454171.5038	0.005	0.014663	–4861
2454194.6109	0.0103	0.028439	–4811
2454195.5406	0.0092	0.034406	–4809
2454202.4539	0.0032	0.019709	–4794
2454206.6025	0.0026	0.01151	–4785
2454208.4512	0.0035	0.012744	–4781
2454213.5362	0.0047	0.017213	–4770
2454214.4571	0.0049	0.01438	–4768
2454215.3754	0.0057	0.008947	–4766