UX Trianguli

PULSATION PERIOD CHANGE SINCE 2005 AND RE-ANALYSIS OF THE BLAZHKO EFFECT

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Abstract:
CCD observations after JD = 2453662 show again a small change of the main pulsation period. The period is now ***P = 0.4669286 ± 0.0000006 [d]****. The change is* ***ΔP = + 2.44 × 10⁻⁵ [d]*** *if compared with the period in the previous time range. The strong Blazhko effect is confirmed by this paper with unchanged Blazhko period* ***P_B = 43.70 ± 0.06 [d]****. A light curve particularity ("double maximum") around Blazhko phase* ***Φ_B = 0.97*** *is presented.*

1. Published knowledge about UX Tri

All available information about UX Tri has been reviewed by us in our prior publications of 2001 [1] where we reported our discovery of the Blazhko effect of UX Tri and 2006 [2] with some follow-up observations and analyses.

2. New CCD observations since 2006 (JD > 2454464)

In the 6 years since the publication of our OEJV paper on UX Tri in 2006 we obtained 27 new CCD observations of maxima from this star; 9 being made by H. Achterberg, 18 by D. Husar. These observations allow again an investigation of changes in the pulsation behaviour of UX Tri. In this publication we analyse pulsation period changes and the strong Blazhko effect of this star as well. We especially check for eventual changes of the Blazhko period.

The new maximum timings are represented in Table 1 of this paper. The maximum timings were obtained by the determination of the time of maximum of a polynomial fit and/or in some cases with Pogson's method. The systematic errors due to different timing methods are also contained in the estimated errors for the maximum timings which are given in Table 1.

As reference and/or comparison stars for photometry we used: GSC 2294-1999 (Tycho: Johnson V = 11.162 mag; GSC: V = 11.0 mag; USNO A2.0: R = 11.1 mag), GSC 2294-0900 (Tycho: Johnson V = 11.800 mag; GSC: V = 11.6 mag; USNO A2.0: R = 11.6 mag) and GSC 2294-1202 (GSC: V = 11.7 mag; USNO A2.0: R = 11.6 mag).

HJD -2400000	error *) [d]	$(O-C)_4$ [d]	Blazhko Phase Φ_B	observer	instrument.
54464.5463	0.0035	0.0052	0.502	ATB#63	a
54479.4616	0.0035	-0.0212	0.844	ATB#64	a
54735.3505	0.0015	-0.0091	0.699	HSR#42	t
54749.3376	0.0029	-0.0299	0.019	HSR#44	cu
54767.5859	0.0022	0.0082	0.437	HSR#46	cu
54787.6372	0.0056	-0.0184	0.896	ATB#66	a
54831.5167	0.0045	-0.0302	0.900	ATB#67	a
54834.3152	0.0017	-0.0333	0.964	HSR#49	cu
54839.4905	0.0071	0.0058	0.082	ATB#68	a
54842.3047	0.0017	0.0184	0.147	HSR#50	cu
54843.2450	0.0030	0.0249	0.168	HSR#51	cu
54875.4107	0.0049	-0.0275	0.904	ATB#69	a
55078.5534	0.0016	0.0013	0.553	HSR#52	s_1
55079.4870	0.0018	0.0010	0.574	HSR#53	s_1
55099.5325	0.0030	-0.0314	0.033	HSR#54	s_1
55100.4800	0.0060	-0.0178	0.054	HSR#55	s_1
55114.5200	0.0020	0.0144	0.376	HSR#56	s_1
55128.5123	0.0012	-0.0012	0.696	HSR#57	s_1
55148.6060	0.0033	0.0146	0.156	HSR#60	s_1
55166.3414	0.0020	0.0067	0.562	HSR#61	s_1
55194.3788	0.0049	0.0284	0.203	ATB#70	a
55222.3479	0.0045	-0.0182	0.843	ATB#71	a
55244.3250	0.0028	0.0132	0.346	ATB#72	a
55409.6170	0.0040	0.0125	0.129	HSR#63	s_1
55417.5597	0.0022	0.0174	0.310	HSR#64	s_1
55466.5808	0.0012	0.0110	0.432	HSR#65	s_2
55546.4304	0.0018	0.0158	0.259	HSR#66	s_2

Table 1: 27 so far unpublished observed times of maxima for UX Tri from CCD observations of the authors;
$\boldsymbol{(O-C)_4}$ in this table is calculated with $\boldsymbol{E_0}$ = 2453662.3578, $\boldsymbol{P}$ = 0.4669286 [d].

* estimated errors of maximum timings

Observer: ATB = Achterberg, HSR = Husar
(the observations are numbered consecutively #nn for each observer)

instrumentation (instrument.):
a 0.2 m S.C. Refl. (f = 1100 mm); CCD camera SBIG ST-6 (chip: TI TC241); unfiltered
cu 0.4 m S.C. Refl. (f = 2750 mm); CCD camera SBIG ST-8E (chip: KAF1602E); unfiltered
s_1 0.2 m S.C. Refl. (f = 950 mm); CCD camera SBIG ST-7 (chip: KAF0400); unfiltered
s_2 0.3 m S.C. Refl. (f = 1750 mm); CCD camera SBIG ST-8 (chip: KAF1600); luminance filter
t 0.115 m Apo-Refr. (f = 805 mm); CCD camera: SBIG-ST8E (chip: KAF1602E); unfiltered

3. Period change and new instantaneous elements for JD > 2453662 (October 2005)

When introducing the newly derived maxima in an ***(O-C)*** graph with the old elements for the time region after the first observed pulsation change it is obvious that at least since 2007 the measured values become more and more positive. This was a sign that the pulsation period had again changed. In this chapter we derive a new pulsation period and the size of the period change.

A change in the pulsation period of a RR Lyrae star can easily be detected by calculation the **(*O-C*)** values from the observed maximum timings with a linear ephemerid equation by use of constant elements (***E*₀**, ***P***) and plotting these values in a diagram in dependence of the time. When the pulsation period is constant the **(*O-C*)** values lie nearby a straight line. However, by occurrence of a period jump the slope of the line changes at the time of the period change.

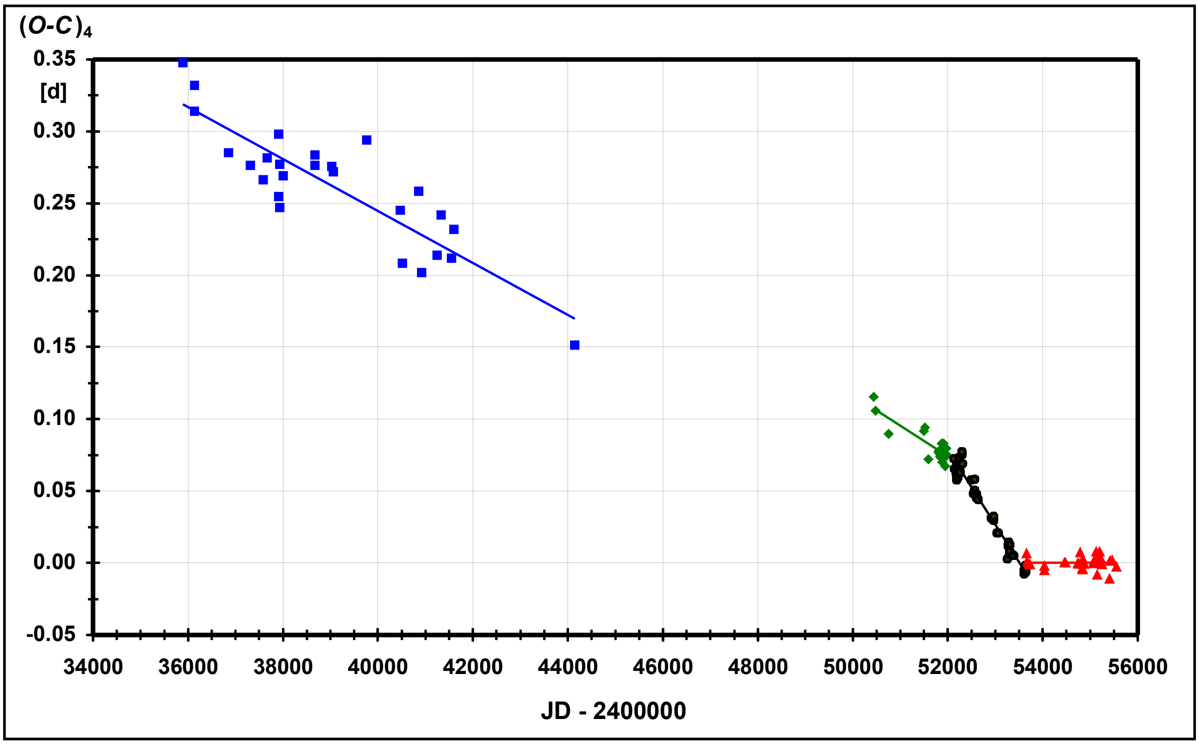

Fig.1: ***(O-C)*** diagram of UX Tri

Fig.1 shows the **(*O-C*)** diagram of all available useful maximum observations of UX Tri over a time period from JD 2435893 to JD 2455546. Four regions of time can clearly be distinguished:

1. Region of photographic observations (JD 2435893 to 2444146, blue in Fig.1);
2. Region of CCD observations before first observed period change (JD 2450446 to JD 2451983, green in Fig.1);
3. Region of CCD observations between the two observed period changes (JD 2452144 to JD 2453655, black in Fig.1);
4. Region of CCD observations after second observed period change (JD 2453662 to JD 2455547, red in Fig.1).

Between region 1 and region 2 a large gap appears of more than 17 years without observations. In this time period no statement can be made for the time dependency of the pulsation period. The diagram in Fig.1 clearly shows that the pulsation period of UX Tri has changed (at least) twice at about JD 2452090 and once more at approximately JD 2453662. The first of these changes was already described in detail previously [2].

The **(*O-C*)** values in Fig.1 are calculated with $\boldsymbol{E_0}$ = 2453662.3578, ***P*** = 0.4669286 [d] (elements of the fourth time range). The four straight lines drawn in the **(*O-C*)** diagram are the linear regression lines of the respective region. In order to reduce the scatter of the **(*O-C*)** values in the three CCD ranges these values were corrected relating to the Blazhko effect (see [1] and [2]). In the region of the photographic observations such a Blazhko correction was not possible to be applied, as no reliable Blazhko period is known there. For the determination of the pulsation period and in the **(*O-C*)** diagrams for the CCD observations only points of the descending branch are used (Blazhko phase $\boldsymbol{\Phi_B} > 0.08$) because the scatter of the **(*O-C*)** values of the steep ascending branch of the Blazhko curve (see chapter 4, Fig. 5) is rather high.

All **(*O-C*)** values are related to a distinct pair of elements $\boldsymbol{E_0}$ and ***P***. In this paper for the **(*O-C*)** values the following designation is used: $\boldsymbol{(O\text{-}C)_n}$, where n is the number of the related time interval. For instance $\boldsymbol{(O\text{-}C)_4}$ means that the **(*O-C*)** values are calculated with the above given elements $\boldsymbol{E_0}$ = 2453662.3578, ***P*** = 0.4669286 **[d]** of the fourth time interval. The linear regression line of this region therefore has an exact horizontal direction (see **(*O-C*)** diagrams Fig.1 and Fig.2).

The two period changes that occurred seem to take place in a rather short time of a few days especially the second one. Unfortunately our data do not allow deciding whether the period changes occurred only in one pulsation period. This is due to the inaccuracy of the maximum timings and the small number of measurements in the temporal vicinity of the period change. Moreover, a change of the pulsation period can occur in combination with a phase jump. Therefore it is only possible to estimate a time interval in which the period change has happened.

It is possible to estimate the size of the time interval in which an abrupt period change occurred by analysing the scatter of the (***O-C***) values. If in an (***O-C***) diagram calculated with the period $\boldsymbol{P}_0$ the (***O-C***) straight line has a slope

$$\tan\alpha = \Delta(\boldsymbol{O\text{-}C})/\Delta t = (\boldsymbol{P_0} - \boldsymbol{P})/\boldsymbol{P_0} = \Delta\boldsymbol{P}/\boldsymbol{P} \qquad (\Delta\boldsymbol{P}/\boldsymbol{P} \ll 1)$$

where ***P*** is the valid period after the period change. An error $\Delta(\boldsymbol{O\text{-}C})$ is then related with a time error

$$\Delta t = \Delta(\boldsymbol{O\text{-}C}) \cdot \boldsymbol{P}/\Delta\boldsymbol{P}.$$

It should be mentioned that this formula can also be used to calculate the time shift Δt caused by a phase jump which corresponds to the respective $\Delta(\boldsymbol{O\text{-}C})$ value.

To estimate the size of the time interval in which an abrupt period change occurred it is only necessary to use in the above formula for $\Delta(\boldsymbol{O\text{-}C})$ the root mean square deviation of the average of *n* (***O-C***) values from observed maximum timings

$$\Delta(\boldsymbol{O\text{-}C}) = \left[\Sigma((\boldsymbol{O\text{-}C})_i)^2/(n\,(n\text{-}1))\right]^{1/2} \qquad i = 1 \ldots n\,.$$

From the observed maximum timings and with the values $P \approx 0.4669$ [d], $\Delta P = 2.44 \times 10^{-5}$ [d] and $\Delta(O\text{-}C) = 7.915 \times 10^{-4}$ [d] results that the second period change occurred in the time range of about JD 2453662 ± 15 [d].

From 30 maximum timings which lie after the second period change in the range from JD 2453662 to 2455547 we derived new instantaneous elements for UX Tri. From these 30 maximum timings 25 are those from Table 1 and five other observations were found in the GEOS RR Lyrae database [3]. For this time interval the ***(O-C)*** diagram is shown in Fig.2 with increased time resolution compared to Fig.1.

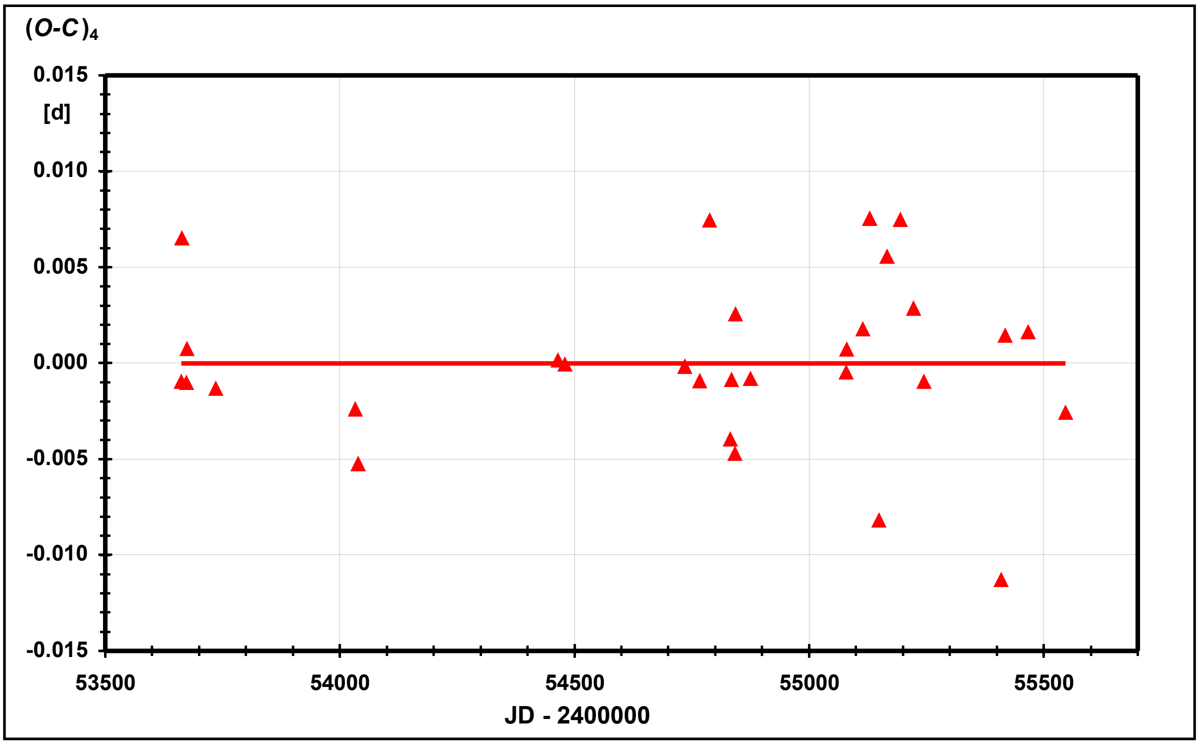

Fig. 2. ***(O-C)*** diagram with ***(O-C)***$_4$ values corrected for Blazhko effect.
Only CCD observations since the 2nd period change and with Blazhko phase > 0.08 are shown.
The ***(O-C)*** values are corrected for the Blazhko effect (E_{B0} = 2451471; P_B = 43.70 [d]) and calculated with the new elements E_0 = 2453662.3578, P = 0.4669286 [d] for observations in the time range from JD 2453662 to JD 2455547;
red line: linear regression line for observations in the fourth time range plotted in the diagram.

As the used time base from JD 2453662 to JD 2455547 for the determination of the pulsation period is relatively short and the number of observations (n = 30) is limited, the result of the calculation is influenced comparatively strong by the ***(O-C)*** scatter caused by the Blazhko effect and a non-homogeneous distribution of the observed maxima over the Blazhko phase.

Also the determination of the Blazhko period may be influenced if the pulsation period is not exactly determined. In order to eliminate this we use an iterative process which was described in the appendix (chapter 9) of our former OEJV publication [2]. From the analysis of the corrected ***(O-C)*** data from JD 2453662 to JD2455547 the following instantaneous ephemeris equation can be derived:

$$\mathbf{HJD(Max)} = \mathbf{2453662.3578} + \mathbf{0.4669286\ [d]} \times \boldsymbol{E}.$$
$$\pm\, \mathbf{0.0011} \pm \mathbf{0.0000006\ [d]}$$

The change in the period is $\Delta P = +\mathbf{2.44 \times 10^{-5}}$ **[d]** if compared with the period in the previous time range (cf. Table 2).

4. Determination of the Blazhko period for time range after second period change

For determination of the Blazhko period P_B we both analysed the scatter of the uncorrected ***(O-C)*** values of maximum times and the regular variations of the brightness in maximum light caused by the Blazhko effect.

The value of the Blazhko period was determined independently with periodograms from a self written computer program and with the program 'Peranso' [4]. The search in time and frequency does give the same results within the given errors. Fig.3 and Fig.4 show two such periodograms with different time resolution. From periodogram Fig.3 follows that the Blazhko ground period of UX Tri lies by 43.7 [d] because that is the strongest spectral peak and that by the halve value of 21.85 [d] did not appear any spectral peak. The distinct spectral peak at the first harmonic period of 87.4 [d] arises because with this period in a Blazhko diagram the periodical deviations of the **(*O-C*)** values are presented just twice.

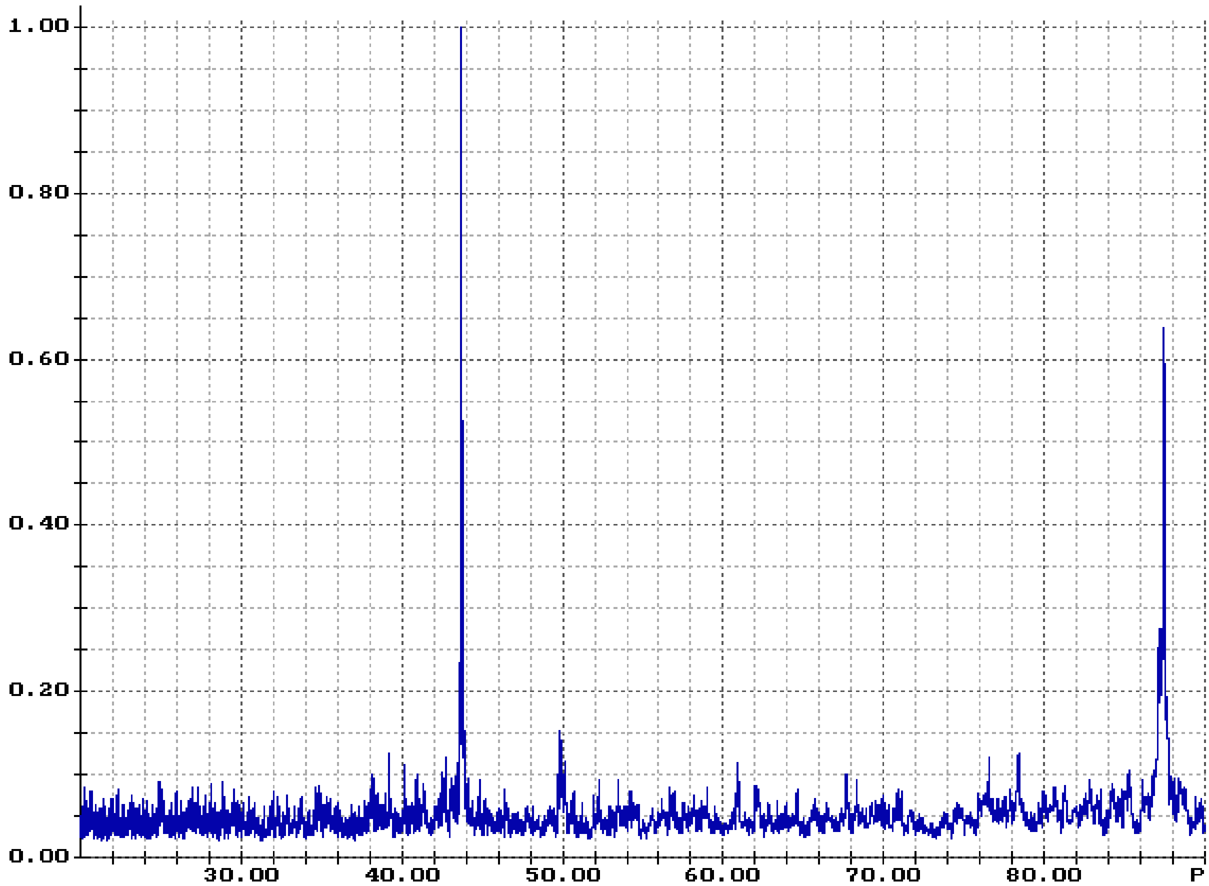

Fig.3: Example for a periodogram of the ***(O-C)*** values for the time range after the second period change with low time resolution but a large period range (20 to 90 [d]).
The periodogram was calculated with a self written program which is working with the phase-dispersion-minimization (PDM) method. The ***(O-C)*** values used for the periodogram were calculated with the new derived elements. The values of the x-coordinate are in days and the y-coordinate shows relative values. In the presented diagram the main spectral peak in the periodogram is situated at 43.71 [d].

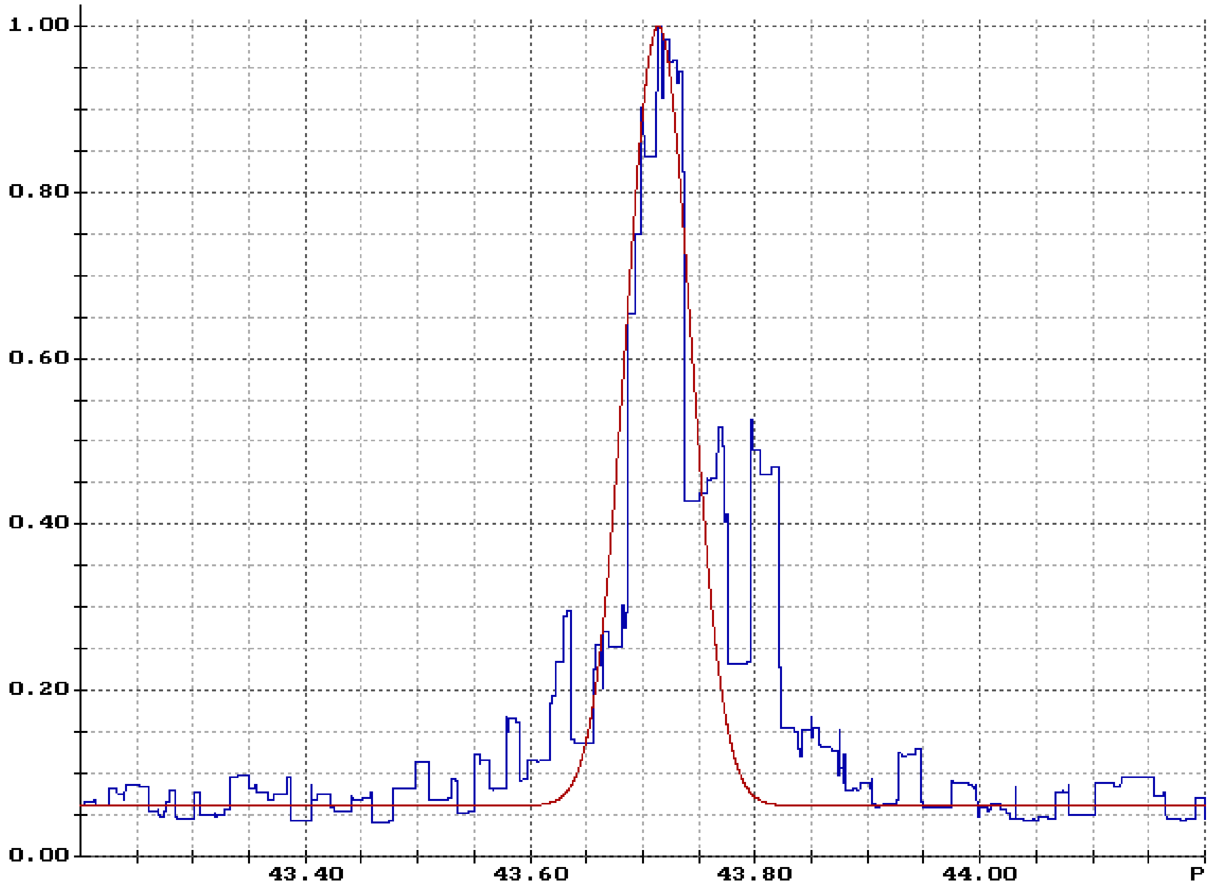

Fig.4. The same periodogram as Fig.3 but with high time resolution and a small period range from 43.2 [d] to 44.2 [d].
The structure of the spectral peak which is seen here is produced by the used PDM method. The Gaussian bell-shaped red curve can be adapted to the shape of the spectral peak for better estimation of the position of the peak centre and its full width at half maximum (FWHM). Because of the asymmetrical peak shapes the maximum of the periodogram not necessarily coincides with the position of the peak centre. In the here presented example the maximum of the periodogram lies at the same period ***P*** as the position of the peak centre (43.71[d]), the FWHM amounts to about 0.07 [d] and the noise in the neighbourhood of the peak is rather small with about 6% of the maximal amplitude.

By studying the periodograms in Fig.3 and Fig.4 one gets a good impression of the quality and accuracy by which the Blazhko period can be determined with the PDM method.

The derived Blazhko period for the time range after the second period change agreed within a tolerance range of ± 0.06 [d] with the values which were previously given for the earlier time ranges and this is also valid if all available CCD ***(O-C)*** values from JD 2450466 to JD 2455547 are analysed in a single data file. Therefore we determine the mean value of the Blazhko period $P_{B,T}$ derived with the different methods from the ***(O-C)*** values of maximum times consistently to be:

$$P_{B,T} = 43.70 \pm 0.06\ [d].$$

The behaviour of UX Tri within the Blazhko period can be shown clearly, presenting the measured data in a so called Blazhko diagram in which the ***(O-C)*** values or the brightness of maxima are plotted against the Blazhko phase Φ_B. Blazhko phase $\Phi_B = 0$ is determined by a reference epoch E_{B0}, for which we used in this paper the same definition and value E_{B0} = JD 2451471 as in our earlier publication [1] and [2].

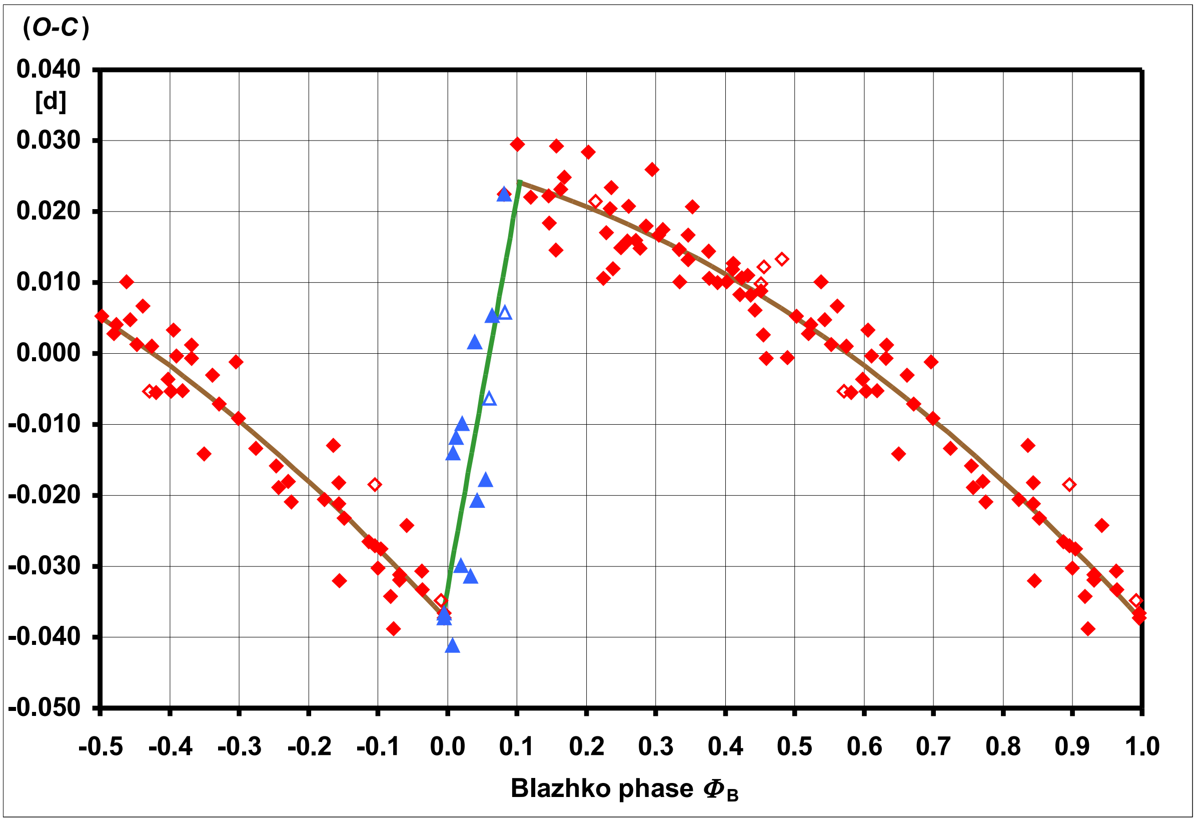

Fig.5: Blazhko diagram for the ***(O-C)*** values of all CCD observations between JD = 2450446 and JD = 2455547.

Blazhko elements for the diagram are $\boldsymbol{E_{B0}}$ = 2451471, $\boldsymbol{P_B}$ = 43.70 [d];
(O-C) values are calculated with the respectively valid elements in the different time ranges (cf. Table 2); nine observations of the total of 118 observations were eliminated in case that the following conditions were true: |(O-C) – Blazhko time correction| > 15 min in the descending part of the curve and |(O-C) – Blazhko time correction| > 30 min in the ascending part of the curve.

Symbols:

Diamonds (red):	uncorrected ***(O-C)***-values of the descending slope of the Blazhko curve,
Line (brown):	parabolic declining regression slope of the Blazhko curve,
Triangles (blue):	uncorrected ***(O-C)***-values of the ascending slope of the Blazhko curve,
Line (green):	straight regression line of the ascending Blazhko curve,
Open symbols:	signify uncertain times of maxima.

time range #n	**JD of time range**	***P*[d]**	$\boldsymbol{E_0}$
2: before 1st period change	2450446 – 2451984	0.4669218	2450753.4880
3: between period changes	2452144 – 2453655	0.4669042	2452233.6227
4: after 2nd period change	2453662 – 2455547	0.4669286	2453662.3578

Table 2. Time ranges and elements ***P*** and $\boldsymbol{E_0}$ used by the calculation of the Blazhko diagram in Fig.5

It should be mentioned that in this table the period for time range #3 differs slightly from the value $\boldsymbol{P_{OEJV}}$ = 0.4669046 ± 0.0000006 [d] published in [2]. With the new observations it became clear that the last four observations which have been used for the period calculation in [2] belong already to the forth time range. In this paper we use the newly derived period from table 2.

The Blazhko diagram in Fig.5 for ***(O-C)*** values shows a fast change of the ***(O-C)*** values in the range of the Blazhko phase between $\Phi_B \approx -0.01$ and $\Phi_B \approx 0.10$ which can approximately represented by a straight line (green in Fig.5). The light curves in this Blazhko phase range have rather flat maxima, so that the errors of the measured maximum timings in these cases are often quite large. That is one reason that the ***(O-C)*** values in the area of the steeply ascending slope of the Blazhko curve in Fig.5 are frequently uncertain. For the rest of the Blazhko period ($\Phi_B \approx 0.08$ to $\Phi_B \approx 1.0$) the ***(O-C)*** values gradually decline on an average. Its mean slope is represented in Fig.5 by a quadratic regression curve (brown line) which deviates quite clearly from linearity. The green and the brown curves in Fig.5, frequently called "Blazhko curve", may be used to deliver a better prediction of times of maxima than only with a linear ephemerid equation.

The equation for the quadratic descending regression curve (brown line) is

$$(O\text{-}C)_{(corr)1}\ [d] = -0.04217\ (\Phi_B)^2 - 0.2240\ \Phi_B + 0.02688 \quad \text{(valid region } \Phi_B \approx 0.08 \text{ to} \approx 1)$$

and for the linear ascending regression straight line (green) the equation is

$$(O\text{-}C)_{(corr)2}\ [d] = 0.5503\ \Phi_B - 0.03325 \quad \text{(valid region } \Phi_B \approx -0.01 \text{ to} \approx +0.1).$$

In the small transition regions from $\Phi_B \approx 0.08$ to 0.10 and from $\Phi_B \approx 0.99$ to 1.00 respectively $\Phi_B \approx -0.01$ to 0.00 both equations are valid. With the given equations it is possible to correct the times of maximum brightness obtained with a valid linear ephemerid formula to take the Blazhko effect into consideration:

$$\text{Max}_{(corrected)} = \text{Max}_{(linear)} + (O\text{-}C)_{(corr)i}$$

in which $(O\text{-}C)_{(corr)i}$ had to be chosen according to the Φ_B region in above given formulas. The calculation of the Φ_B value is shown in [1] and [2].

It should be remarked that the scatter around the curve seems to be quite large compared with the error in the maximum timings. One reason could be of course small changes of the pulsation period (period change noise). A search for a systematic periodicity in this behaviour (e.g. a second Blazhko period) was again not successful. Therefore it is desirable to accumulate much more data in order to perform such an analysis with better precision. The question if the observed small deviations are regular or irregular again remains open.

Using the same methods as for the ***(O-C)*** values of maximum times we determined the Blazhko period $P_{B,M}$ also from the variations of the brightness values in maximum light. The result is exactly the same:

$$P_{B,M} = 43.70 \pm 0.06\ [d].$$

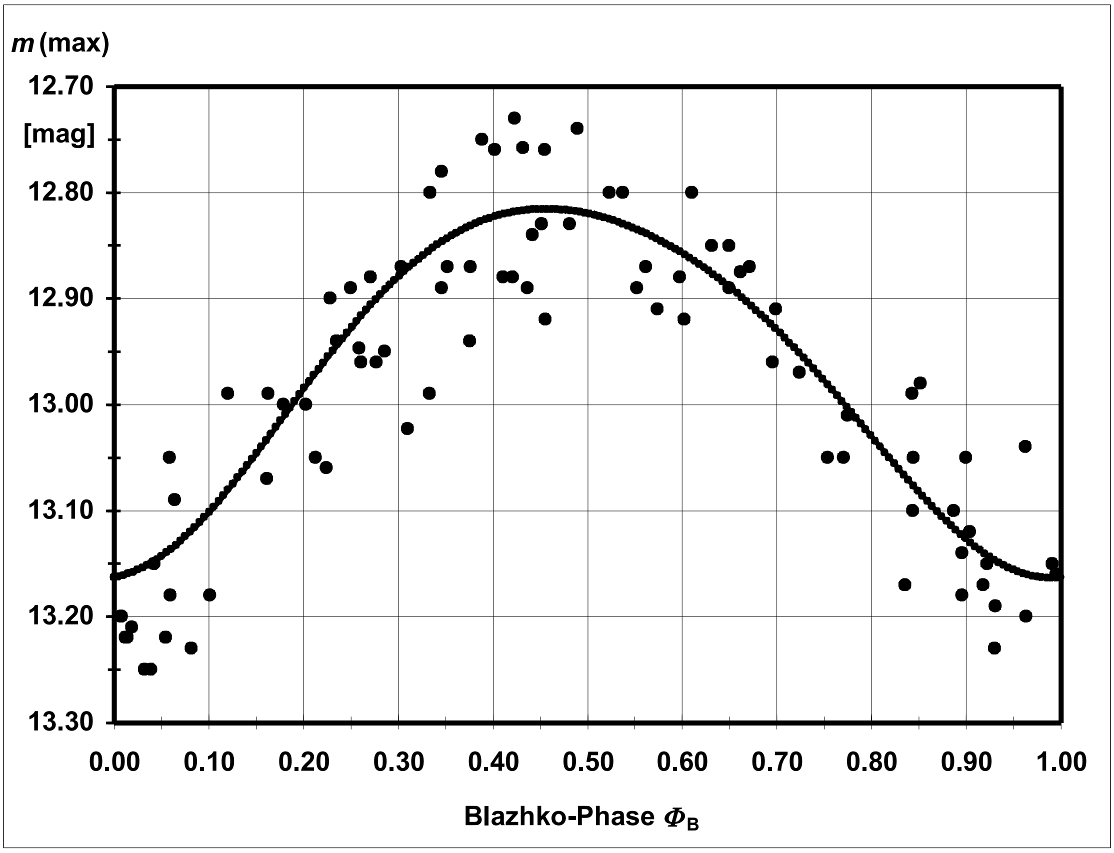

Fig.6: Blazhko diagram for the brightness in maximum light of all useful CCD observations since JD = 2450446 with known brightness values.
Used Blazhko elements are: $\boldsymbol{E}_{B0}$ = 2451471 and $\boldsymbol{P}_B$ = 43.70 [d].

This type of analysis has the clear advantage, that the brightness values are completely independent from the pulsation period. On the other hand the Blazhko diagram for the brightness of maximum (Fig.6) reveals a relatively large spread of the points around the drawn average curve. One reason for this could be systematic errors in the measured brightness values caused by the different equipment used by the observers at the different sites, which we tried however to compensate by an appropriate adjustment derived from some parallel observations.

The first result is that both methods yield the same Blazhko period within quite small errors. This can only be expected, if both the variation of the times of maximum light (scatter in the **(O-C)** values) and the variation of the brightness values at maximum are due to the same physical process.

The second major result is that the Blazhko period remained *unchanged* within small errors (of ± 0.06 [d]) compared with the results from observations in the years 1999 – 2006 shown in [1] and [2].

5. Variations of the light curve of UX Tri during the Blazhko cycle

Already in our first publication of UX Tri we presented the pronounced changes of the light curves over the Blazhko cycle. The fastest light curve changes occur between $\boldsymbol{\Phi}_B \approx 0.9$ and

$\Phi_B \approx 0.2$. As this was already evident in 2001 we tried thereafter to give the highest priority to observe within these Φ_B limits.

As already shown in our former publication the light curve becomes very flat around Blazhko phase $\Phi_B \approx 0.0$ (Fig.6 and Fig.7 in [2]) with some evidence for a "double maximum". In this publication we can show the first time a very precise light curve showing very clearly such a double maximum ($\Phi_B \approx 0.972$) in Fig.7, which was obtained just recently. Again this shows the importance of further photometric studies especially in this phase of the Blazhko cycle with improved photometry (e.g. photometric errors < 1%).

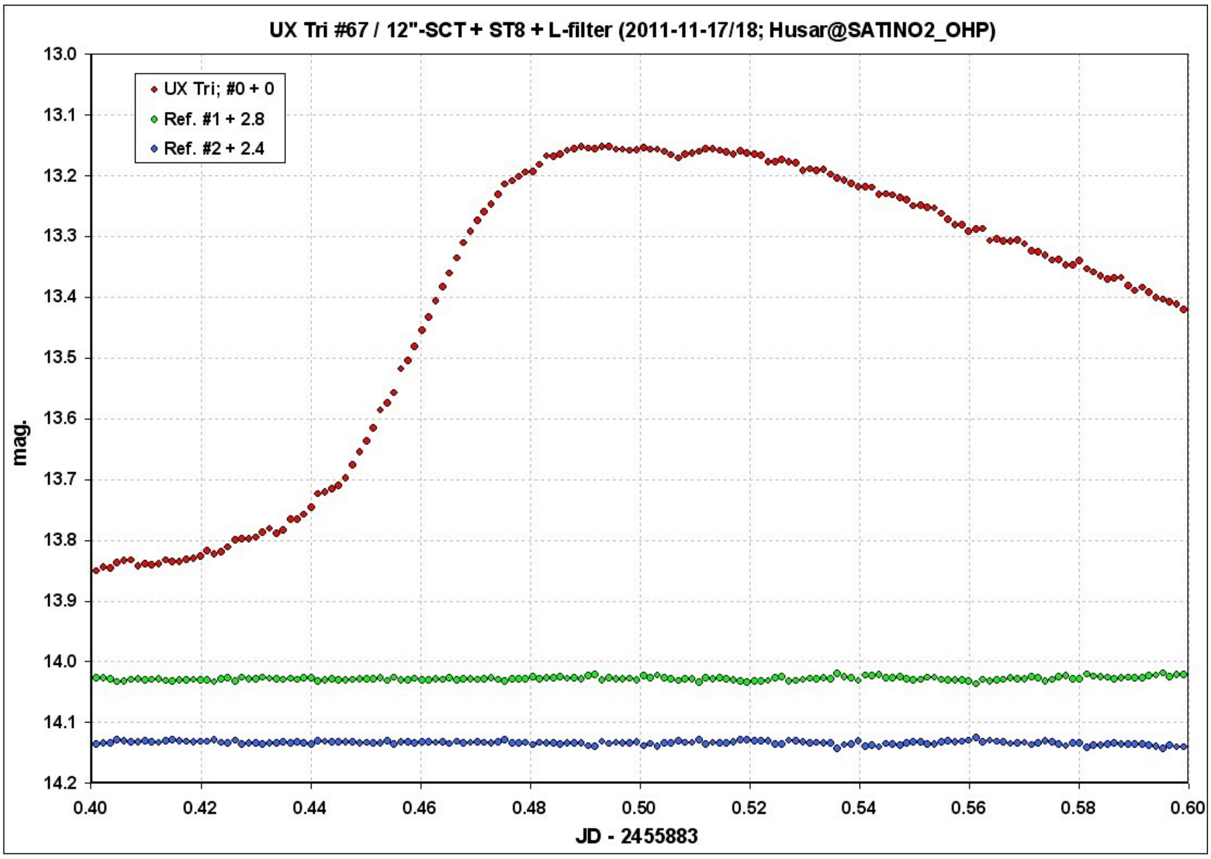

Fig.7: Light curve showing a clear indication for two separated maxima ("double maximum") at HJD 2455883.4975 and HJD 2455883.5189. The photometric error is 0.006 mag (1 sigma).

6. Final remarks and request for observations to be continued

From the ***(O-C)***-Blazhko diagram (Fig.5) and the light curve (Fig.7) it is evident that the light curve shows very interesting changes in its Blazhko phase around $\Phi_B = 0.0$. We suggest again observing in this phase with the highest priority. As a lot of observed light curve effects have a low brightness amplitude ("flash", magnitude oscillations, double maxima) a photometric precision of 0.02 mag or better is very desirable. For maximum S/N ratio the use of unfiltered measurements is suggested. In case of using larger telescopes the additional use of B-filters is interesting as the effects of shock waves (the "flash") are supposed to be more prominent [5].

7. Acknowledgements

One of us (D.H.) would like to thank the "Foundation for Interactive Astronomy and Astrophysics" ("Stiftung Interaktive Astronomie und Astrophysik") of Tübingen/Germany [6] for the possibility to use the 0.2 m and 0.3 m SATINO telescopes located on the site of the Observatoire de Haute Provence (France) and the staff of this observatory for technical assistance.

Further we want to acknowledge the use of the GEOS RR Lyr database [3] as a valuable source for times of maximum data. This research made also use of the SIMBAD data base, operated by the CDS at Strasbourg (France) and related bibliographical services from ADS.

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