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THE RRab STAR UX Tri: DISCOVERY OF A BLAZHKO EFFECT WITH CHANGING PERIOD

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The variability of UX Trianguli was discovered in 1934 by Morgenroth (1935) and described having a "long period". In the NSV catalogue (Kukarkin et al., 1982/1988) the star is listed as NSV 616 being of semiregular type (SR). Later the star has been analyzed from Sonneberg sky patrol plates and was classified as RRab type with a period of 0.466917 days by Meinunger (1986). Regarding the light curve in this paper, Meinunger already remarked a fairly large scatter of the magnitude estimations, which he did not completely attribute to random errors, but finally he was not able to reveal any systematic reason. In 1989 the star was named UX Tri in the 69^{th} namelist (Kholopov et al., 1989). We want to confirm that UX Tri = CSV 164 = NSV 616 is identical with GSC 2294.506. The identification is in good agreement with the finding charts given by Morgenroth (1935) and Tsessevich et al. (1971).

Morgenroth and the NSV report reasonable photographic magnitudes of $13\overset{m}{.}5$ - $14\overset{m}{.}5$ for the star, whereas, the photographic magnitudes given by Meinunger ($10\overset{m}{.}5$ - $11\overset{m}{.}5$) are much too bright. This is due to the magnitudes of the reference stars used in the analysis of Meinunger. He used the stars **a** = GSC 2294.1576 (USNO A2.0: B = $12\overset{m}{.}9$; R = $12\overset{m}{.}0$) assuming $10\overset{m}{.}6$ and **b** = GSC 2294.916 (USNO A2.0: B = $13\overset{m}{.}9$; R = $13\overset{m}{.}0$) with $11\overset{m}{.}4$ which resulted in an overestimation of the brightness of UX Tri.

From 1997 to 2001 we observed UX Tri in 42 nights obtaining CCD photometric data and 36 new maximum timings.

As principal comparison star we used GSC 2294.1202 (GSC: $V = 11\overset{m}{.}7$; USNO A2.0: B = $13\overset{m}{.}0$; R = $11\overset{m}{.}6$). Our differential magnitudes refer to this star and are derived from instrumental magnitudes. We used Pogson's method and/or the determination of a polynomial maximum for the maximum timings. The scatter due to different timing methods is contained in the errors given in Table 1 which lists our maximum timings.

The maximum timings show considerable scatter in $(O - C)$ when linear elements are used (see Fig. 1) and the light curve is variable (see Fig. 2). The classification of the variable as RRab star is in agreement with the light curves. Analyzing the scatter of the maximum timings and the brightness at maximum we discovered a pronounced Blazhko effect which is described and analyzed in this paper.

Table 1: Observed times of maxima for UX Trianguli $(O-C)_1$, residuals computed according to the linear ephemeris from formula (1) and $(O-C)_c$ residuals corrected for Blazhko effect with formula (3).

Max					Max				
JD hel. – 2400000	±* [d]	$(O-C)_1$ [d]	$(O-C)_c$ [d]	rem.	JD hel. – 2400000	±* [d]	$(O-C)_1$ [d]	$(O-C)_c$ [d]	rem.
50481.2933	.0083	0.0207	0.0082	A $\mathbf{a}_x$	51927.3355	.0049	0.0061	0.0009	A **a**
51471.6276	.0069	0.0139	−0.0032	A **a**	51934.3279	.0069	−0.0053	0.0026	A **a**
51494.5030	.0017	0.0101	0.0127	A **a**	51948.3021	.0083	−0.0388	−0.0048	A **a** :
51522.5401	.0035	0.0319	0.0053	A **a**	51975.4271	.0083	0.0047	0.0078	A **a** :
51595.3160	.0100	−0.0320	−0.0044	A $\mathbf{a}_x$	51983.3466	.0042	−0.0134	0.0044	A **a**
51810.5809	.0028	−0.0181	0.0035	A **a**	52144.4542	.0024	0.0062	−0.0016	H $\mathbf{d}_V$
51817.5708	.0069	−0.0320	0.0026	A **a**	52144.4546	.0024	0.0066	−0.0012	H $\mathbf{d}_R$
51817.5718	.0045	−0.0310	0.0036	H **b**	52144.4559	.0022	0.0079	0.0001	H **c**
51840.4846	.0100	0.0026	−0.0015	A $\mathbf{a}_x$	52151.4427	.0020	−0.0092	−0.0039	H **c**
51853.5399	.0035	−0.0159	0.0044	A **a**	52191.6007	.0017	−0.0064	−0.0077	A **a**
51854.4687	.0021	−0.0209	0.0010	A **a**	52198.5891	.0035	−0.0219	−0.0102	A **a**
51874.5906	.0083	0.0234	0.0013	A $\mathbf{a}_x$	52198.5911	.0050	−0.0199	−0.0081	H **e**
51884.3709	.0020	−0.0017	−0.0055	H **b**	52199.5317	.0035	−0.0131	0.0004	H **e**
51904.4160	.0056	−0.0342	−0.0006	A **a**	52213.5110	.0069	−0.0415	−0.0019	A **a**
51912.4174	.0100	0.0295	−0.0035	A $\mathbf{a}_x$	52228.4968	.0028	0.0028	−0.0112	A **a**
51919.4125	.0069	0.0208	0.0008	A **a** :	52230.3650	.0100	0.0033	−0.0072	H **c**
51921.2761	.0028	0.0167	0.0002	A **a**	52233.6315	.0025	0.0014	−0.0030	A **a**
51926.4039	.0028	0.0083	0.0014	A **a**	52233.6325	.0100	0.0024	−0.0020	H **c**

* estimated errors of the maximum timings
remarks (rem.):
Observers: A = Achterberg; H = Husar
Observations with V or R band filters are marked with suffix „V" or „R" respectively; those marked with suffix „$_x$" are extrapolated maximum timings; „ : " denotes uncertain timing
Instrumentation:
a 0.2 m Schmidt-Cassegrain (f=1100 mm) with CCD-camera SBIG ST-6 (chip: TI TC241); unfiltered
b 0.4 m Schmidt-Cassegrain (f=1450 mm) with CCD-camera Apogee AP-7 (chip: SITe 502); unfiltered
c 0.4 m Schmidt-Cassegrain (f=2750 mm) with CCD-camera SBIG ST-8E (chip: KAF1602E); IR-cutoff filter
d 0.4 m Schmidt-Cassegrain (f=2750 mm) with CCD-camera SBIG ST-8E (chip: KAF1602E); V/R-filter (Bessel type)
e 0.2 m Schmidt-Cassegrain (f=1185 mm) with CCD-camera SBIG ST-8E (chip: KAF1602E); unfiltered

First of all a new linear ephemeris formula of the times of maximum light of UX Tri was derived using the photographic maxima from Meinunger, including two CCD observations made by Birkner (1998a, 1998b) and all our CCD observations from Table 1:

$$\begin{array}{rl} \mathrm{Max} = \mathrm{HJD}\ 2450753.488 + 0\overset{\mathrm{d}}{.}4669218 \times E. \\ \pm\ .005 \quad \pm\ .0000003 \end{array} \tag{1}$$

The given elements are based on the assumption that the maximum timings should be symmetrically distributed around zero. $(O-C)$-values calculated with formula (1) are termed $(O-C)_1$ and are shown in Fig. 1.

The rather definite spread of the $(O-C)_1$-values nearly in the whole time of observations points to the Blazhko effect, a phenomenon which is known from numerous RR Lyrae stars showing periodic light curve variations. Besides the phase position of the maximum also other characteristics of the light curve such as brightness at maximum, brightness amplitude and the rise time M-m (time difference between maximum and the preceding minimum) show periodic variations. Nevertheless, this periodicity is in most cases not completely exact. According to Smith (1995) a pronounced characteristic of the Blazhko effect is its irregularity.

The periodic variation in the light curve can be revealed best in a "Blazhko diagram", as we call the plot of the measurements of the mentioned characteristics against the

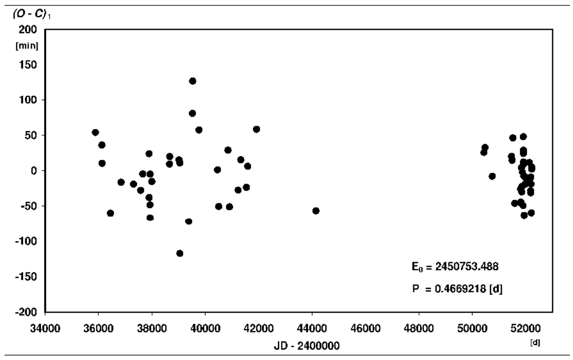

Figure 1. diagram of $(O-C)_1$-values for the available times of maximum light based on new elements (1).

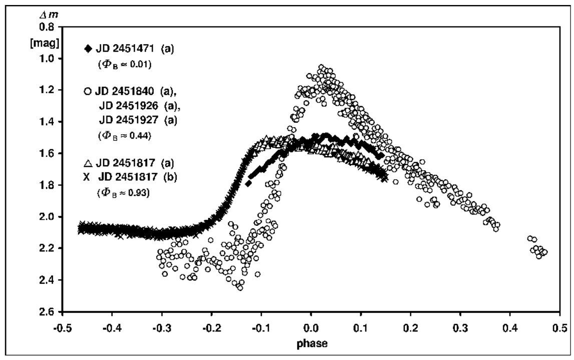

Figure 2. observed phased light curves with different amplitudes based on elements (1) at three phases of the Blazhko cycle. (**a**)/(**b**) refers to the instrumentation.

Blazhko phase Φ_B:

$$\Phi_B = \mathrm{Frac}((t - E_{B0})/P_B), \tag{2}$$

where P_B is the Blazhko period, E_{B0} an arbitrary initial epoch, t the time of a measurement and Frac(x) the digits behind the decimal point of x .

The value of the Blazhko period was determined independently with periodograms from a self written computer program and the program 'Period98' by Sperl. Including all available measurements of $(O-C)_1$-values *no single* Blazhko period could be found. The reason for this may be irregularities of the Blazhko effect (e.g. changes in the period P_B, phase jumps or decreasing amplitude of the variations) and errors of the measurements, especially of the photographic observations. However in two epochs of time a Blazhko period could be discovered. In the range from JD 2439023 to JD 2441931 the most probable value found for the Blazhko period is $P_B = 40.0$ d $\pm$ 0.1 d. From JD 2450446 till now the Blazhko period has been determined to be $P_B = 43.7$ d $\pm$ 0.15 d. The first value of P_B results from the $(O-C)_1$-values only and the second value from the $(O-C)_1$-values *and* from the brightness values at maximum. Within the small range of given errors both programs yielded the same values of P_B. These results show that the period of the Blazhko effect of UX Tri is most probably *not constant.*

For our CCD measurements Fig. 3 shows the Blazhko diagram for the $(O-C)_1$-values and Fig. 4 for the brightness of maximum at the found period value $P_B = 43.7$ d and for the value $E_{B0} = 2451471$. In the phase range $\Phi_B \approx 0.02 - 1.00$ the course of the $(O-C)_1$-values in Fig. 3 can be well approximated by a dropping straight line. In the range $\Phi_B \approx 0.00 - 0.02$ a very steep rise occurs. Because in this range there are not enough points of measurements to determine an average $(O-C)_1$-course any approximation is only tentative.

The Blazhko diagram for the brightness of maximum (Fig. 4) 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 different equipment used by the observers. It seems, however, that especially in the range $\Phi_B \approx 0.35 - 0.60$ also irregularities of the Blazhko effect contribute to this spread.

With the help of the average curves in Fig. 3 and Fig. 4 it is possible to obtain more accurate time and brightness values of the maximum making predictions for the near future. For that purpose it is necessary to calculate first an approximate value $\mathrm{Max}_{(\mathrm{linear})}$ for the time of maximum with the formula (1) and in a second step the corresponding Blazhko

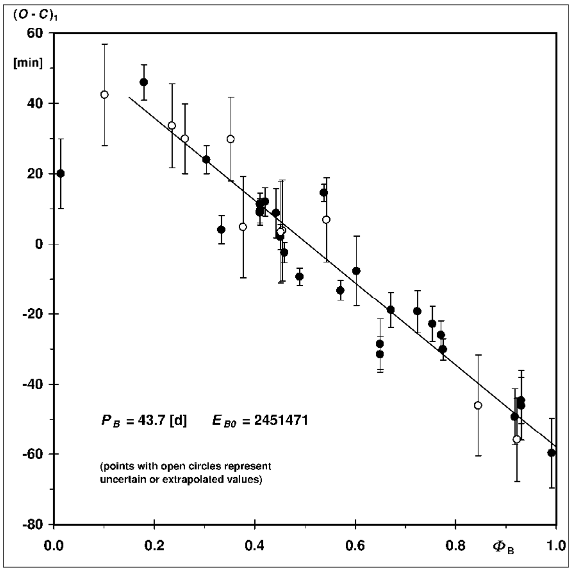

Figure 3. Blazhko diagram for the $(O-C)_1$ values of our CCD measurements. The drawn mean curve yields the correction values ΔT_B in dependence of the Blazhko phase Φ_B

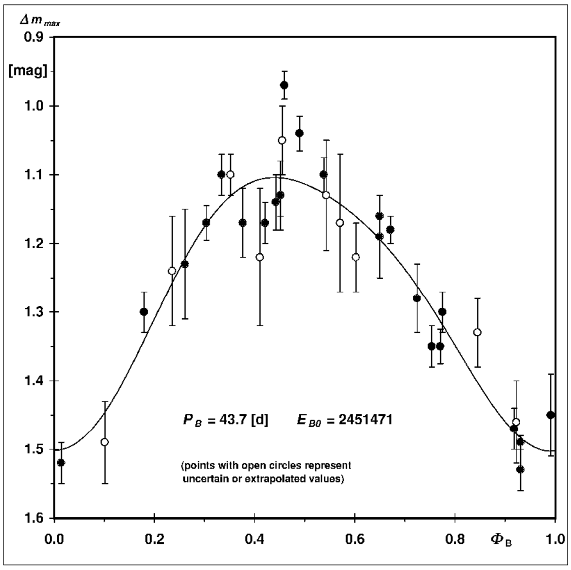

Figure 4. Blazhko diagram for the brightness values at maximum of our CCD measurements. The drawn curve yields mean values for the brightness at maximum in dependence of the Blazhko phase Φ_B

phase Φ_B with the formula (2). For this Blazhko phase Φ_B the curve in Fig. 3 yields a value ΔT_B to correct the time of maximum

$$\mathrm{Max}_{(\mathrm{corrected})} = \mathrm{Max}_{(\mathrm{linear})} + \Delta T_B, \tag{3}$$

and the curve in Fig. 4 yields direct the brightness of the maximum. In Table 1 the differences $(O-C)_c$ between the observed times and the calculated values with formula (3) are given. The scatter of these values however is larger than the error of those maximum timings which could be obtained with sufficiently small errors. This indicates that the Blazhko effect of UX Tri may need more than one period to be completely described.

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