TIME SERIES ANALYSIS OF THE AFOEV OBSERVATIONS OF SYMBIOTIC STARS UV AUR, TX CVN AND V 1329 CYG

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ABSTRACT. One – frequency sine approximations allowed to obtain the following best fit parameters: periods $P = 389.23 \pm 0.47^d$, 3779 ± 73^d, 958.7 ± 1.2^d mean brightness $a = 9.23 \pm 0.02^m$, 9.73 ± 0.01^m, 13.26 ± 0.07^m. semi–amplitudes $r = 0.92 \pm 0.026^m$, 0.02 ± 0.007^m, 0.49 ± 0.10^m and epochs for mean maxima $T_M = 2446551.4 \pm 1.8$, 7014 ± 21, 5345 ± 3^d for UV Aur, TX CVn and V 1329 Cyg, respectively. Extreme values and cycle lengths vary with time, their characteristics are tabulated.

Key words: Stars: Binaries, Symbiotic, UV Aur, TX CVn, V 1329 Cyg.

Introduction

Detailed analysis of observations of these stars on photographic plates of the Sternberg State Astronomical Institute (SAI) in Moscow are presented by Chinarova (1995). Tables of the individual photographic data were published by Hric et al. (1994) as a part of large international campaign initiated by Hric and Skopal (1989). Reviews on the structure and evolution of these objects one may find e.g. in Boyarchuk (1983) and Kenyon (1986).

Here we discuss results based on the visual observations from the AFOEV database described by Schweitzer (1993). Statistical characteristics (number of observations n, times of start and begin of the run t_1 and t_n, sample mean $\overline{m}$ and a r.m.s deviation σ_O) are:

*	n	t_1	t_n	$\overline{m}$	σ_O
UV Aur	650	3934	9098	9.08^m	0.79^m
TX CVn	1340	3302	9168	9.68^m	0.24^m
V 1329 Cyg	1617	0890	9166	13.22^m	0.44^m

Methods for data reduction

For a more precise determination of the period we used a computer code FOUR–1 described by Andronov (1994). The light curve was approximated by a trigonometric polynomial

$$m(t) = a_0 + \sum_{k=1}^{j} (a_k \cos(2\pi f_k t) + b_k \sin(2\pi f_k t)),$$
$$= a_0 - \sum_{k=1}^{j} r_k \cos(2\pi f_k (t - t_{Mk})), \qquad (1)$$

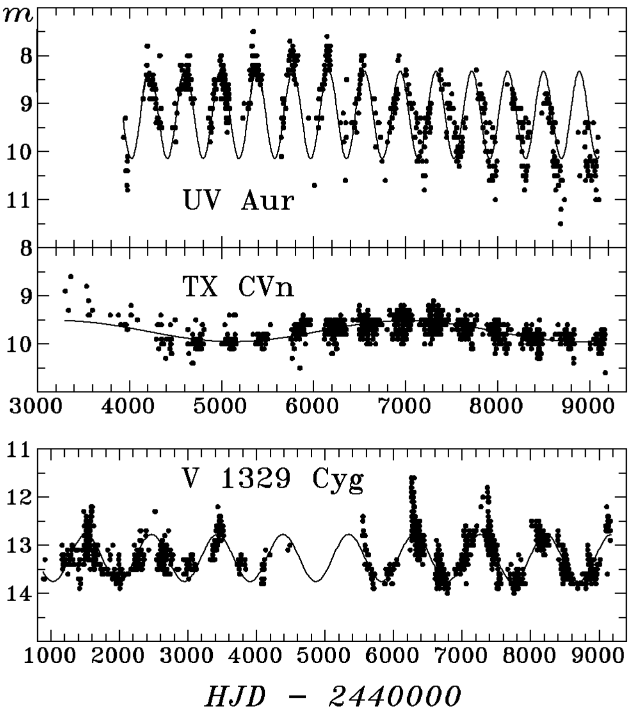
where $m(t)$ is a smoothed value of the brightness m at time t. Coefficients a_k $(k = 0...j)$ and b_k $(k = 1...j)$ are determined by using the method of least squares for fixed values of frequencies f_k. Semiamplitude of variations at each frequency is equal to $r_k = (a_k^2 + b_k^2)^{1/2}$. As a test function for trial frequencies $f_k = 1/P_k$, we have used

$$S(f) = \frac{\sigma_C^2(f)}{\sigma_O^2} = 1 - \frac{\sigma_{O-C}^2(f)}{\sigma_O^2}, \qquad (2)$$

where σ_O^2, $\sigma_{O-C}^2(f)$and $\sigma_{O-C}^2(f)$ are variances of the "observed" signal (O), "calculated" value (C) and of the deviations "observed–calculated" $(O - C)$ for a set of f $(f_1...f_j)$. For each j the "best fit" value(s) of period(s) were computed precisely by using the method of "differential corrections".

Light curves are shown in Fig. 1,2. Periodograms corresponding to one–frequency models are shown in Fig. 3. Best fit parameters are listed in the Abstract.

To study variability in the individual cycles we use the method of "running parabolae"



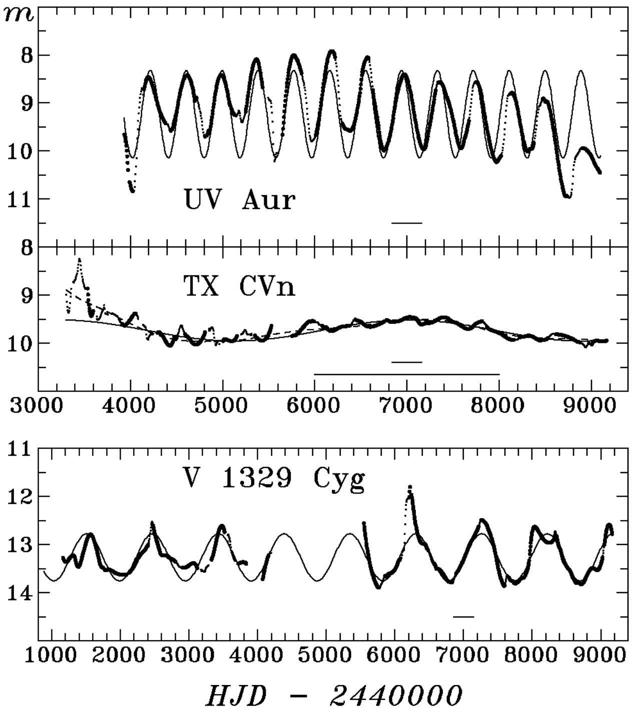


Figure 1 (left). Light curves of UV Aur, TX CVn an V 1329 Cyg. Filled circles are original observations, line is a best sinusoidal fit.

Figure 2 (right). Smoothed light curves. Large points correspond to a "good approximation" by using the method of "running parabola" (RP), when there are ≥ 3 data points locate closer than $0.3\Delta t$ from the trial time. Small points correspond to worth accuracy when the data are far from the trial time. Full time interval $2\Delta t$ is marked by corresponding horizontal bars. For all stars $\Delta t = 160^d$. Additional dashed line for TX CVn shows a RP fit with $\Delta t = 1000^d$ corresponding to long–term changes.

Table 1. Characteristics of the maxima of UV Aur obtained by "running sines" and "running parabolae" fits

T		E	ϕ		mag		$n_{0.5}, n_{0.1}$		σ_{O-C}	r		T_{RP}		m_{RP}	
4184	± 43	-6	-.08	±.11	8.43	± .11	41	12	.31	.49	± .11	4193	± 9	8.46	± .07
4614	8	-5	.02	.02	8.41	.04	47	28	.22	.68	.09	4613	6	8.42	.04
4990	4	-4	-.01	.01	8.42	.05	83	28	.26	.78	.08	4985	4	8.42	.05
5364	5	-3	-.05	.01	8.11	.05	47	31	.25	.92	.12	5367	5	8.09	.05
5781	6	-2	.02	.01	8.00	.04	47	27	.25	.95	.08	5772	5	8.01	.04
6177	7	-1	.04	.02	7.92	.07	54	29	.33	.94	.07	6186	5	7.92	.05
6564	4	0	.03	.01	8.06	.07	42	6	.24	.95	.06	6572	5	8.05	.07
6969	6	1	.07	.02	8.33	.09	43	3	.29	.75	.07	6969	7	8.40	.08
7374	9	2	.11	.02	8.46	.12	55	6	.36	.70	.08	7354	12	8.56	.11
7751	6	3	.08	.01	8.46	.12	52	2	.29	.83	.08	7750	17	8.55	.11
8146	15	4	.10	.04	8.81	.15	53	7	.42	.71	.10	8141	2	8.79	.09
8477	9	5	-.05	.02	8.64	.17	54	3	.38	.82	.09	8479	2	8.90	.10
8935	129	6	.13	.33	9.94	.15	32	6	.45	.31	.15	8902	134	9.94	.22

Table 2. Moments of minima of UV Aur obtained by "running sines" and "running parabolae" fits

T		E	ϕ		mag		$n_{0.5}$	$n_{0.1}$	σ_{O-C}	r		T_{RP}		m_{RP}	
4021 ±	12	-7	.50 ±	.03	10.68 ±	.31	16	0	.34	1.20 ±	.21	4032 ±	5	10.86 ±	.42
4407	12	-6	.49	.03	9.70	.14	50	0	.30	.57	.09	4439	10	9.60	.20
4807	8	-5	.52	.02	9.79	.14	50	0	.23	.70	.09	4811	7	9.72	.16
5164	7	-4	.44	.02	9.73	.14	86	0	.30	.76	.08	5210	4	9.40	.16
5563	3	-3	.46	.01	10.67	.21	42	0	.22	1.29	.11	5563	4	10.22	.46
5977	5	-2	.52	.01	9.93	.14	57	2	.26	.98	.08	5967	17	9.79	.38
6379	8	-1	.56	.02	9.76	.11	41	5	.33	.89	.09	6383	18	9.58	.14
6765	7	0	.55	.02	10.00	.11	30	4	.29	.81	.10	6749	8	9.99	.15
7172	7	1	.59	.02	9.95	.07	48	12	.33	.79	.08	7182	9	9.96	.09
7582	12	2	.65	.03	9.90	.06	45	19	.30	.65	.08	7586	5	9.95	.06
7956	11	3	.61	.03	10.23	.08	43	17	.36	.84	.10	7970	10	10.23	.11
8329	23	4	.57	.06	10.06	.12	46	13	.41	.62	.09	8310	9	10.01	.11
8743	13	5	.63	.03	11.17	.23	41	1	.40	.90	.13	8718	10	10.94	.23

Table 3. Middles of ascending and descending branches of UV Aur obtained by "running sines" and extrema of V 1329 Cyg from the RP fit.

T		E	ϕ		mag		$n_{0.5}$	$n_{0.1}$	σ_{O-C}	r		T_{RP}		m_{RP}	
UV Aur: middle of the ascending branch												V 1329 Cyg: maxima			
4116 ±	4	-7	.74±	.01	9.49±	.18	41	1	.27	1.07 ±	.08	1317 :	±13	13.22 ±	.05
4519	12	-6	.78	.03	9.05	.08	53	8	.27	0.64	.08	1564	9	12.79	.04
4893	8	-5	.74	.02	9.19	.07	83	15	.27	0.76	.08	2463	6	12.53	.16
5271	7	-4	.71	.02	8.93	.09	57	4	.24	0.80	.08	3478	9	12.61	.03
5676	5	-3	.75	.01	9.11	.06	46	11	.23	1.13	.10	6190	8	12.04	.13
6081	5	-2	.79	.01	8.88	.07	48	9	.26	0.99	.08	7265	11	12.48	.10
6472	7	-1	.80	.02	8.91	.07	43	16	.33	0.86	.08	8037	12	12.63	.05
6865	7	0	.81	.02	9.17	.07	36	14	.27	0.85	.08	8335:	3	12.72	.07
7265	10	1	.83	.02	9.21	.09	48	14	.36	0.74	.08	9121	15	12.59	.08
7672	12	2	.88	.03	9.30	.12	49	2	.29	0.62	.07				
8056	10	3	.87	.03	9.53	.18	42	0	.36	0.68	.09				
8407	19	4	.77	.05	9.48	.20	58	0	.41	0.51	.08				
8839	32	5	.88	.08	10.40	.31	33	1	.40	0.50	.14				
UV Aur: middle of the descending branch												V 1329 Cyg: minima			
4310±	16	-6	.24±	.04	9.14±	.08	45	17	.33	0.61 ±	.09	1390 :	±6	13.46 ±	.07
4711	10	-5	.27	.03	9.10	.10	50	3	.22	0.69	.08	1793	7	13.54	.03
5082	12	-4	.22	.03	9.08	.06	79	32	.27	0.64	.08	2086	18	13.63	.05
5463	4	-3	.20	.01	9.48	.14	48	2	.24	1.44	.12	2923	97	13.48	.05
5873	6	-2	.26	.01	8.96	.14	44	0	.27	0.97	.09	5769	8	13.91	.07
6280	4	-1	.30	.01	8.84	.12	58	1	.30	0.95	.06	6827	5	13.78	.03
6665	4	0	.29	.01	9.06	.09	40	5	.24	1.08	.07	7755	6	13.81	.02
7072	6	1	.34	.02	9.12	.09	57	6	.32	0.85	.07	8261 :	5	12.96	.04
7482	9	2	.39	.02	9.23	.07	48	14	.29	0.68	.07	8717	7	13.83	.04
7863	9	3	.37	.02	9.43	.09	42	16	.37	0.81	.11				
8218	13	4	.28	.03	9.32	.10	43	9	.41	0.69	.11				
8615	5	5	.30	.01	9.91	.07	47	24	.34	0.96	.08				

(RP) described by Andronov (1990) with a filter half–width Δt depending on the mean cycle length. Moreover, we tried a new method of "running sines" (RS). For each trial time t_0 the one–frequency least squares fit is computed by taking into account only the data in the interval $[t_0 - \Delta t, t_0 + \Delta t]$:

$$m(t, t_0) = a_0(t_0) - \sum_{k=1}^{j} r_k(t_0) \cos(2\pi f_k(t - t_0)) \tag{3}$$

The smoothing function is $m(t_0, t_0)$. In this paper we used the filter half–width $\Delta t = P/2$ and $j = 1$.

UV Aurigae

Observations range between 7.5^m to 11.5^m with one estimate 6.4^m at JD 2448127.6 removed which is possibly a misprint. In this system one of the stars is pulsating. Comparison of the data with the one–frequency fit (Fig. 1,2) shows significant cycle–to–cycle changes of the shape. Individual intervals between successive maxima (Tab. 1) are highly variable from 331^d to 430^d. However, the phase changes computed according to the best fit ephemeris are relatively small from –0.08 to +0.08. Here we have not taken into account the last not sure maximum for which the error estimates are large. For comparison of different methods we list in Tab. 1,2 also the characteristics of maxima and minima obtained by the RP method. The RS fit is more smooth, making the shape more sinusoidal. The RP one better fits sharp parts of the light curve.

Periodogram for $O - C$ shows 3 peaks which are formally significant. This is an effect of long–term changes of the phase curve. Significant changes of the mean brightness $a_0(t_0)$ may be noted. The values corresponding to the moments $m(t_0, t_0) = a_0(t_0)$ are listed in Table 3 separately for ascending and descending branches. The range of the brightness variations at "half branch" is from 9.05^m to 10.40^m.

The best fit period 389^d is in agreement with the values obtained for photographic data obtained prior to the AFOEV observations ($P = 377.9 \pm 5.6^d$, $j = 1$, $P = 399.0 \pm 1.7^d$, $j = 4$ (Chinarova 1995) and for recent photoelectric B measurements ($P = 396^d$, Luthardt (1992)). However, the amplitude of the visual observations is much larger than that of pg ($\approx 0.8^m$) or B ($\approx 0.5^m$).

TX Canum Venaticorum

Photometric behaviour of this relatively bright object BD+37°2318 in 1890–1952 yrs was studied by Mumford (1966) who published 9 comparison stars. The periodogram shows highest peak at $P = 3779 \pm 73^d$.

The best fit period for $O - C$ is $P = 474.5 \pm 3.9^d$. The two–frequency model parameters are $a_0 = 9.68 \pm 0.05^m$, semiamplitudes $r_1 = 0.215 \pm 0.007^m$ ($P_1 = 3768 \pm 74^d$, $T_{M1} = 2446988 \pm 21$) and $r_2 = 0.056 \pm 0.007^m$ ($P_2 = 475.3 \pm 3.9^d$, $T_{M2} = 2446887 \pm 10$).

First period corresponds to the "9–yr cycle" mentioned by Skopal et al. (1992), whereas the second one differs significantly from our three "candidates", possibly arguing for a period change. Photographic data by Chinarova (1995) cover the time interval studied by Skopal et al. (1992), but show smaller amplitude $\approx 0.2^m$ (pg) of the "long wave" as compared with $\approx 0.4^m$ (vis).

One may note that there was a luminosity excess of the star prior to JD 24444200 as one may see from the sine and running parabola fits at Fig.2. Thus we have also computed a periodogram for $(O - C)_{RP}$ corresponding to the RP fit with $\Delta t = 1000^d$. The peaks are much lower than at two other periodograms, the highest of which corresponds to $P = 465 \pm 5^d$ and $r = 0.036 \pm .007^m$.

The periodogram computed for our observations on 42 compact distributed in time SAI plates obtained from JD 2445850 to 2447680 shows a complex structure. Three peaks with a nearly equal significance level correspond to periods 282.9 ± 2.9^d ($j = 2$), 352.2 ± 3.0^d ($j = 3$) and 426.5 ± 4.2^d ($j = 4$). These 3 peaks with lower height are present also for $j = 1$. From the whole data set we have chosen 959 AFOEV points in the same time interval and computed a periodogram for $(O - C)_{RP}$. There are few peaks of similar height, one of them corresponding to $P = 485 \pm 10^d$ and $r = 0.043 \pm .008^m$.

Individual cycle lengths obtained from the

RP fit vary from 351^d to 493^d with a mean 360^d. The amplitudes vary from 0.04^m to 0.36^m with a mean 0.15^m. This also argues for cyclic or semi–regular waves rather than for periodic variations.

V 1329 Cygni

Results of the previous studies of the object were published by e.g. Arkhipova (1987). Skopal et al. (1992) presented a part of the AFOEV light curve and 28 pg observations.

Our analysis of the AFOEV data show significant deviations from the sine fit. The characteristics of the extrema derived from the RP fit are listed in Table 3. Individual cycles are characterized by lengths ranging from 772^d to 1084^d with a mean 958.3^d in excellent agreement with the value from the sine fit. The amplitudes range from 0.84 to 1.33^m with a mean 1.13^m. An outburst–like event at JD 2446190 leads to amplitude increase up to an unusually large value 1.87^m. One may note mild extrema marked by semicolon in Table 3 which are owed to relatively small value of $\Delta t = 160^d$ adopted. However, larger values of Δt lead to worth approximation of the brightening.

The brightness estimates on 165 SAI plates (Chinarova 1995) showed two brightness minima near JD 2443871 (14.34^m) and 2444900 (14.47^m) corresponding to a period $P \approx 1030^d$. A maximum between them occurred near JD 2444427 (13.29^d). Significant difference of the brightness at minima caused apparent deviation of the best fit value $P = 966 \pm 15$ corresponding $j = 2$. These data fill the gap in the AFOEV observations.

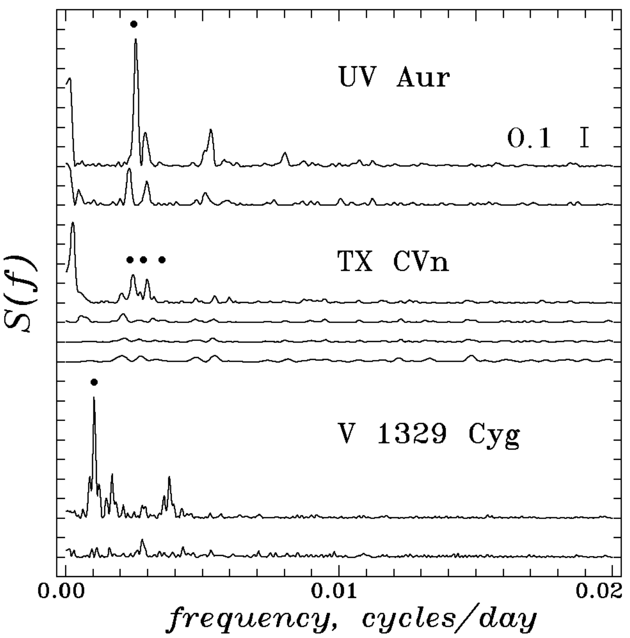


Figure 3. One–frequency periodograms for the original (C) observations (up), residuals from the best sinusoidal fit ($O-C$) (lower). For TX CVn are additionally shown the periodograms for deviations from the RP fit $(O-C)_{RP}$ for all data (5^{th} curve) and for the shorter time interval coinciding with that covered by our photographic study (6^{th} curve). Filled circles mark best fit periods (3 candidates for TX CVn) corresponding to photographic observations of Chinarova (1995).

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