"20–MIN" OSCILLATIONS OF THE CATACLYSMIC VARIABLE TT ARI

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ABSTRACT. Results based on 16 nights in B, 3 in UBV and 1 in UBVRI are presented. Periodograms for detrended nightly runs showed significant peaks at different frequences from 28 to 103 c/d. Most prominent of them correspond to the best fit periods 23.7, 15.2, 27.5 and 51.6 min. Characteristics of the peaks are listed in tables. It seems that in TT Ari we observe contributions of several mechanisms of instability with similar time scales rather than a single QPO with secular decrease of the cycle.

Key words: Stars: Cataclysmic Variables; QPOs; TT Ari.

TT Ari shows a wide variety of time scales characterizing its variability at 8 seconds (Kozhevnikov 1985), ≈ 20 min, 3 hours (Smak and Stępień 1969), ≈ 5 hours (Wenzel et al. 1986, Tremko et al. 1992), 3.76^d (Semeniuk et al. 1976), few years (Hudec 1984). Some international campaigns were organized (cf. Wenzel et al. 1986, Tremko et al. 1993, 1995). Here we present some results based on the observations obtained in 1988.

The presence of "Quasi–periodic fluctuations with a cycle length of 14–20 min and an amplitude up to 0.2^m in B" was detected by Smak and Stępień (1969). Williams (1966) argued for three (!) predominant periodicities with P = 13.9, P = 17.6 and P = 42.2 minutes with equal amplitudes of 0.028^m of the first two waves and 0.016^m of the third wave. Semeniuk et al. (1987) reported on a trend in this "period" the value of which had decreased from 27 minutes in 1961 to 17 minutes in 1985. Even at low state ($V = 16.5^m$), when accretion is ceased, the variations are present with separation between the prominent maxima from 4 to 30 minutes (Shafter et al. 1985). Udalski (1988) obtained values from 18 to 22 minutes on different nights during the observational season 1987/88. The oscillation most stable in phase for 4 runs obtained by Andronov et al. (1992) corresponds to 60.7±0.6 c/d (23.7 min). This differs from the value 15.3 min obtained by Hollander and van Paradijs (1992) from observations taken three months earlier.

The designation of the observational runs are the following. First two letters correspond to the observatory (AB – Abastumani, KR - Kraków, PI – Piszkesteto, SB – Sonneberg, SP – Skalnate Pleso). Three digits correspond to (HJD–2447000). After that a letter indicating the filter may be present. If not, than the default instrumental system is B. Detailed description of the instruments and discussion on other time scales is presented by Tremko et al. (1995). Tables of observations for the runs MO 335 (obtained by D.E.Kolosov from Moscow) and OD 448 (obtained by A.I.Movchan and A.N.Rudenko from Odessa) were published by Andronov et al. (1992) and used for the present analysis.

To remove a "3–hour" trend we have used the method of "running parabolae" (Andronov 1990) with a filter half–width $\Delta t = 0.05^d$. After that the residuals $O - C$ were analyzed by using a one–harmonic fit with unknown zero level (the program FOUR–1 by Andronov (1994)). All periodograms were computed for the same frequency range from 0.5 to 200 cycles/day. As a characteristic of the separation between the "independent frequencies" we have chosen $\Delta f = (n-1)/(n(t_n-t_1))$, where n is the number of observations and t_k, $k = 1...n$ are the moments of observations in a run (Andronov 1994). The value of Δf for the mean weighted periodogram was determined as a weighted mean from Δf obtained for the individual runs.

Periodograms obtained in different colors during one night show nearly similar behaviour both for UBV observations obtained in Abastumani and for UBVRI (Piszkesteto). However, the relative heights of the peaks at fixed frequencies are wavelength–dependent. Thus the most prominent peak may occur at different frequencies. Highest peaks for these runs are listed in Table 1. Sometimes a second peak is listed corresponding to the frequency seen at other wavelengths. One may note an apparent frequency trend observed during three subsequent nights in Abastumani.

The designations in Tables 1–3 are: $n-$ the number of observations, σ_O- the r.m.s. deviation from the mean, f is the best fit frequency measured in cycles/day, $S(f) = \sigma_C^2/\sigma_O^2 = 1-\sigma_{O-C}^2/\sigma_O^2$ and $Lp = -\lg Pr$, where Pr is the "false alarm probability", i.e. the probability that the peak of the height equal or more than the observed one may appear for the "white noise" signal. The best fit semi–amplitude r may be estimated as $r = \sigma_O\sqrt{2\,S(f)}$.

Table 1. Characteristics of highest peaks at a periodogram for multicolor observations

run	σ_{O-C}	f	$S(f)$	L_p
AB 421	$\Delta f = 13.6$ c/d,	n=60		
U	0.047	76.7± 2.2	0.29	3.0
B	0.035	74.5± 3.3	0.26	2.4
V	0.039	73.8± 2.2	0.33	3.7
V	0.039	111.7± 1.4	0.25	2.3
AB 422	$\Delta f = 13.9$ c/d,	n=58		
U	0.053	100.6± 1.9	0.24	2.0
B	0.040	87.3± 1.6	0.32	3.3
V	0.037	100.6± 2.0	0.31	3.3
AB 423	$\Delta f = 11.9$ c/d			
U	0.053	186.6± 1.9	0.22	2.5
U	0.053	110.1± 2.0	0.19	1.9
B	0.038	109.0± 1.7	0.21	2.3
V	0.036	111.4± 1.6	0.26	3.3
PI 454,	$\Delta f = 5.7$ c/d,	n=83		
U	0.049	91.2± 0.6	0.20	2.2
B	0.041	133.1± 0.7	0.16	1.4
V	0.039	40.0± 0.9	0.17	1.5
R	0.041	39.7± 0.8	0.19	2.1
I	0.038	73.4± 0.9	0.19	1.9

This confirms good correlation between variations in different spectral bands, which differ in amplitudes but not in phases. Some differences in the periodograms may be attributed to uncorrelated variations.

Tremko et al. (1995) proposed a method to determine the effective colours of variations which have the same shape (generally not sinusoidal) but wavelength–dependent amplitudes by using the autocovariation matrix (AKM) of the brightness variations in different colours. The colours of "20–min" observations are more blue, than of the "3–hour wave" which is more blue than the mean emission. E.g. the values U–B= -1.04^m, -1.24^m, -1.35^m and B–V=0.19^m, 0.05^m, 0.12^m for "mean brightness", "fast" and "slow" variations, respectively.

For the sinusoidal fits the effective colours may in principal be determined from the amplitude ratios and show results similar to that obtained from the autocovariation analysis. E.g. for the run AB 423 Δ(U–B) $= -2.5\lg(r_U/r_B) = -0.24^m \pm 0.33$ (in respect to the mean color). The value is close to that

(-0.31^m) obtained from the ACM analysis, but the error estimate is very large because the relative accuracy of the amplitude of the aperiodic signal is $\approx 25\%$. Corresponding error estimates obtained by using the ACM method are by $4-6$ times smaller and the may be recommended for determination of the colours.

A variety of periodogram shapes is observed for "long" one–color runs. No peak appears during all the runs, despite some of them occur many times. Characteristics of four highest peaks corresponding to all runs are listed in Table 2. They do not show presence of one coherent period, but may be useful for future comparison with other data. One may note a significant difference of the periodograms obtained during a same night (runs SB 415 and SP 415; PI 454 and SP 454) but in not equal time intervals. Even the periodograms for the overlapping time intervals from different observatories show different shapes of $S(f)$, because the segments cover different branches of the light curve. This shows remarkable variability of the cycle length at a very short (hour) time scale. One may note the extremely low probabilities of the random appearance of such high peaks. Apparently very low "false alarm probability" computed as described by Andronov (1994) does not argue for *coherent* oscillations. It only indicates that the signal is not "white noise". Not all of them are independent, but the aliases often correspond to the peaks of the height compared with that of the "true" peak.

Most prominent peaks at the weighted mean periodogram are listed in Table 3. The highest peak at $P = 23.7$ min does not obey the "Period–Time" relationship by Semeniuk et al. (1987). However, the second peak at 15.2 min does obey and coincides with the value 15.3 min obtained by Hollander and van Paradijs (1992). They discussed some models of such a decrease and argued that the "period" may be a beat one between the Kepler frequency at a magnetospheric radius and a rotational frequency of the white dwarf.

The model of Hollander and van Paradijs (1992) may explain drastic changes in the "period" without significant variations of the mean luminosity. However, it seems that TT Ari shows contributions of several instability mechanisms with similar time scales rather than a single QPO.

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Table 2. Characteristics of four highest peaks at periodograms for "long" runs

run	n	σ_{O-C}	f_1	$S(f)$	L_p	f_2	$S(f)$	L_p
SB 412	293	0.039	58.3± 0.4	0.22	13.8	68.3± 0.6	0.12	6.4
SB 413	401	0.042	32.1± 0.6	0.05	2.4	39.2± 0.5	0.05	2.9
SB 414	290	0.050	76.5± 0.9	0.12	6.7	85.3± 0.9	0.09	4.3
SB 415	370	0.037	94.8± 0.5	0.12	8.8	103.3± 0.4	0.14	10.1
SP 415	578	0.036	47.0± 0.2	0.14	16.5	62.9± 0.2	0.15	19.1
MO 435	868	0.044	29.9± 0.4	0.10	18.8	59.9± 0.3	0.13	23.7
KR 437	501	0.048	23.7± 0.6	0.07	6.8	43.9± 0.6	0.06	5.3
KR 438	562	0.045	27.9± 0.4	0.18	22.2	55.2± 0.5	0.09	10.0
SP 444	592	0.039	51.6± 0.3	0.09	10.0	61.2± 0.3	0.14	18.1
OD 448	855	0.054	44.0± 0.4	0.07	11.2	60.0± 0.2	0.14	26.3
SP 450	745	0.040	56.9± 0.2	0.08	11.3	77.9± 0.2	0.11	17.3
SP 452	468	0.041	52.9± 0.3	0.22	23.8	81.9± 0.3	0.11	10.6
SP 454	640	0.043	27.4± 0.4	0.09	11.2	44.1± 0.3	0.14	18.4
KR 456	709	0.039	26.7± 0.5	0.07	8.7	59.4± 0.4	0.07	9.7
KR 471	357	0.043	59.2± 0.6	0.13	9.5	73.3± 0.7	0.16	11.9
KR 477	715	0.044	25.4± 0.4	0.09	12.7	34.0± 0.6	0.05	5.5

Table 2 (continued)

run	Δf	f_3	$S(f)$	L_p	f_4	$S(f)$	L_p
SB 412	6.3	92.9± 0.4	0.27	17.8	112.7± 0.5	0.13	7.2
SB 413	5.7	58.7± 0.6	0.08	5.5	91.9± 0.5	0.13	10.9
SB 414	8.1	98.6± 0.9	0.10	5.3	130.5± 0.9	0.06	2.6
SB 415	5.3	109.6± 0.5	0.09	5.8	132.9± 0.6	0.06	3.3
SP 415	4.3	90.9± 0.3	0.09	10.3	104.5± 0.2	0.10	11.6
MO 435	7.3	94.8± 0.3	0.14	27.8	112.4± 0.3	0.14	26.7
KR 437	7.2	53.9± 0.3	0.26	30.6	73.5± 0.5	0.10	10.3
KR 438	6.1	78.6± 0.4	0.16	18.8	108.4± 0.5	0.07	6.9
SP 444	4.0	92.1± 0.4	0.10	11.4	141.3± 0.2	0.09	10.1
OD 448	4.2	86.6± 0.2	0.08	14.3	95.9± 0.3	0.06	10.3
SP 450	3.6	108.5± 0.2	0.10	14.9	113.7± 0.2	0.08	12.1
SP 452	5.6	102.4± 0.4	0.09	8.4	134.4± 0.5	0.10	8.6
SP 454	4.3	61.4± 0.2	0.15	20.6	67.3± 0.2	0.10	12.1
KR 456	5.7	83.7± 0.3	0.09	13.5	103.7± 0.4	0.06	8.4
KR 471	9.7	100.2± 0.7	0.12	8.5	114.6± 0.8	0.10	7.0
KR 477	5.4	62.6± 0.5	0.06	7.1	141.1± 0.5	0.07	9.9

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Table 3. Characteristics of peaks of a mean periodogram with a "false alarm" probability less than 10^{-50}.

f, c/d	P,min	$S(f)$	L_p	r
27.9± 0.2	51.6	0.0497	57.3	0.014
52.4± 0.2	27.5	0.0515	60.9	0.014
60.9± 0.1	23.7	0.0784	116.2	0.017
71.7± 0.2	20.1	0.0463	50.4	0.013
91.4± 0.3	15.7	0.0493	56.5	0.014
94.5± 0.2	15.2	0.0536	65.2	0.014
113.4± 0.2	12.7	0.0482	54.2	0.013