CYCLE–TO–CYCLE CHANGES IN THE MIRA-TYPE STAR RT CYG

V.I. Marsakova, I.L. Andronov

Department of Astronomy, Odessa State University,
T.G.Shevchenko Park, Odessa 270014 Ukraine,
E–mail: astro@paco.odessa.ua

ABSTRACT. RT Cyg was observed on photographic negatives of the Odessa plate collection. These data were reduced to the visual AFOEV system. The complete data set (n =7154) was studied by using several methods described by Andronov (1997b). 3-rd order trigonometric polynomial fit to the mean light curve corresponds to the period $P = 190\overset{d}{.}162 \pm 0\overset{d}{.}003$ (coinciding with the value listed in GCVS (Kholopov et al., 1987) and asymmetry 0.458 (0.44 in GCVS). The characteristics of the cycles are determined and studied by using the correlation analysis.

Key words: Stars: Mira–type, RT Cyg

Introduction

RT Cyg is one among well studied stars which monitoring during decades was carried out by the amateur astronomers. Acording to GCVS IV (Kholopov et al. 1985) the brightness varies from $6\overset{m}{.}0$ to $13\overset{m}{.}1$ (V), the ephemeris for maximum is the following:

$$MaxHJD = 2444588 + 190.166 \cdot E \qquad (1)$$

The asymmetry is equal to $A = 0.44P$. We used both photographic and visual observations to study temporal behavior of the brightness as the initial characteristic, and of the parameters of the individual cycles as characteristics of the pulsations.

Photographic Observations

The brightness of the star was measured on 292 photographic negatives of the Sky Patrol of the Astronomical Observatory of the Odessa State University. The photographic brightness of comparison stars was published by Strelkova (1953). After removing the estimates "fainter than" 269 data points remained. The range of brightness variations $7\overset{m}{.}00 - 13\overset{m}{.}61$ (pg).

The periodogram analysis was carried out by using the computer code FOUR-M by Andronov (1994) for multi–harmonic approximation. The test function $S(f) = \sigma^2_{O-C}/\sigma^2_O$ vs. trial period is shown at Fig. 1. The minimum value of $S(f)$ corresponds to 190^d, i.e. to the value known before. Other minima apparently occur at the trial periods $2P$ and $2P/3$.

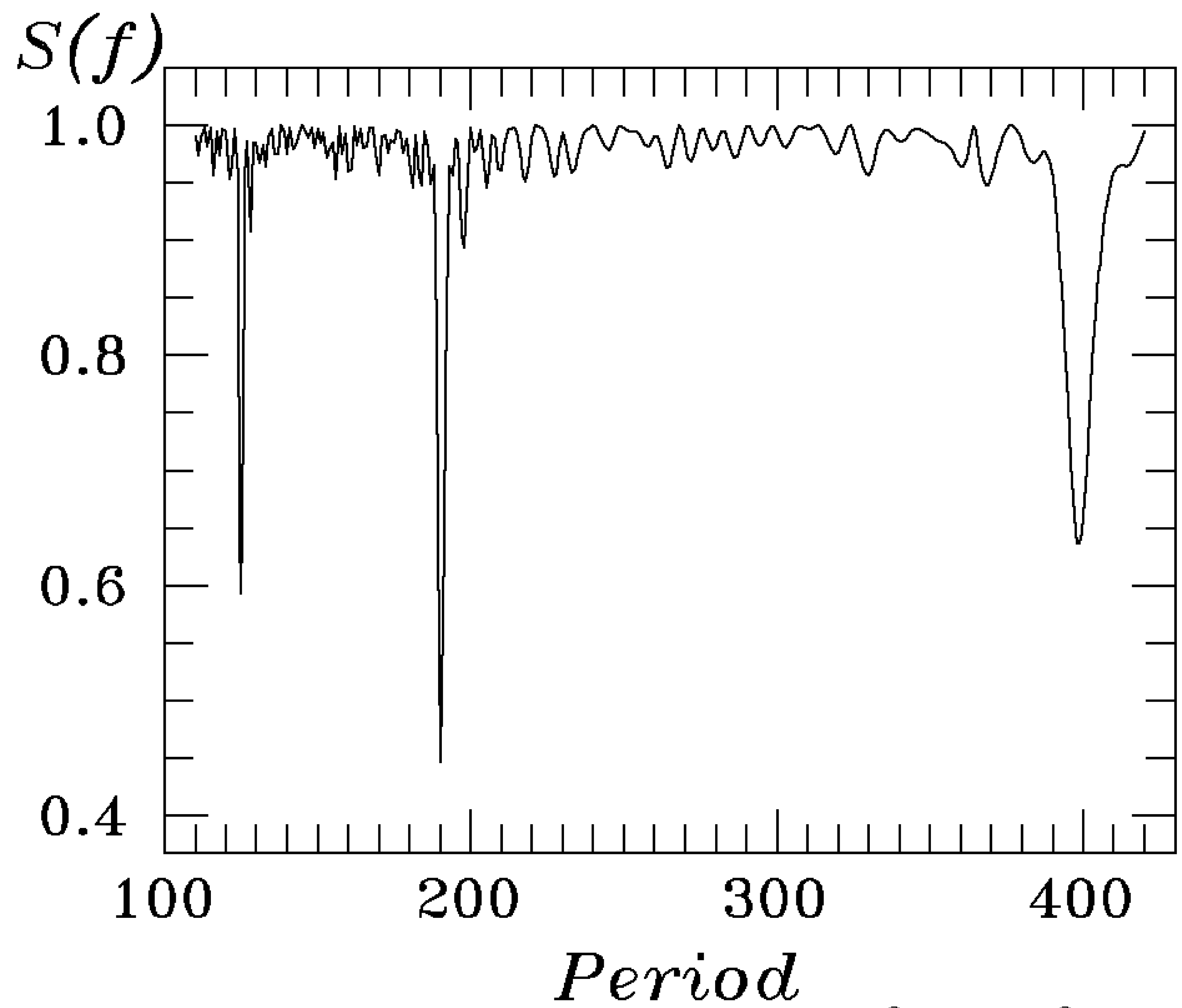

Figure 1. Test function $S(f) = \sigma^2_{O-C}/\sigma^2_O$ for RT Cyg.

The statistically significant order of trigonometrical polynomial for these observations is $m = 2$. By using differential corrections, we have obtained the period value $P = 190.28 \pm 0.08$ for $m = 2$ coinciding with that listed in GCVS IV. However, the estimates of the asym-

Table 1. Results of trigonometrical polynomial fit of the phase light curves using photographic, visual (AFOEV) and whole series of observations. s is order of the trigonometrical polynomial, P is a mean period, also mean asymmetry, amplitude and magnitudes in maximum and minimum are listed.

Data	s	P	Asym.	Ampl.
Pg	2	190.28	0.405	4.19
		± 0.04	± 0.009	± 0.06
AFOEV	3	190.166	0.462	4.52
		pm 0.003	± 0.003	± 0.02
All	3	190.162	0.458	4.54
		± 0.003	± 0.003	± 0.02

Data	m_{max}	m_{min}
Pg	7.37	11.56
	± 0.06	± 0.09
AFOEV	7.42	11.94
	± 0.02	± 0.02
All	7.40	11.94
	± 0.02	± 0.02

metry $A = 0.405$ for $m = 2$ differ from the value 0.44 listed in the GCVS. The possible explanations are the difference of the light curves in visual and photographic systems and variations of the asymmetry in the interval covered by photographic observations.

AFOEV Data

The observations were made by the members of the AFOEV (JD 2422897-50169). The AFOEV database was described by Schweitzer (1993). From all data we deleted not sure values and estimates "fainter than". We thank the amateur astronomers for their intensive studies.

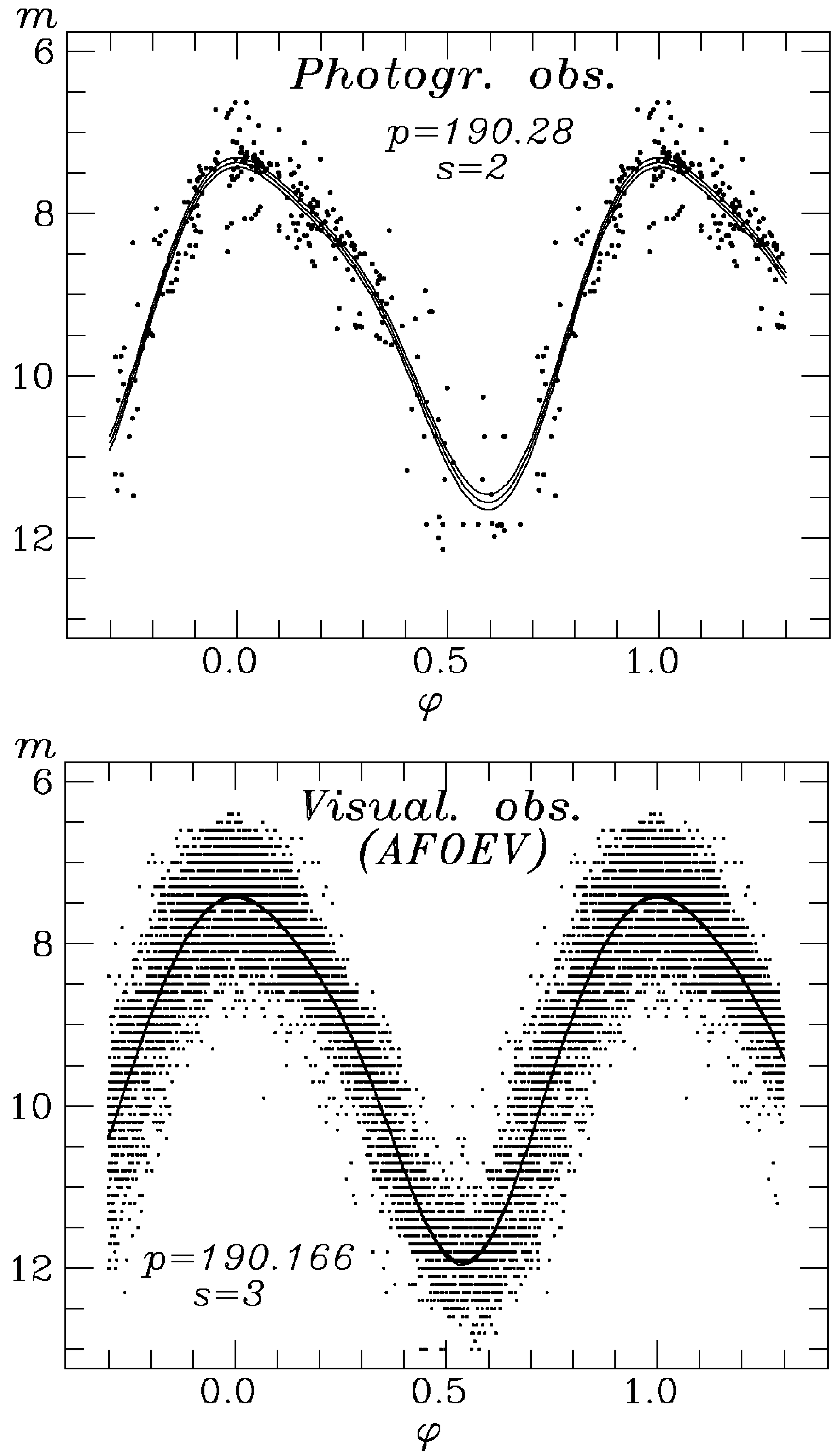

Figure 2. Photographic (up) and visual (bottom) phase light curve of RT Cyg. The lines correspond to the smoothing function and 3σ deviations from it.

Table 2. Amplitudes r_i and phase ϕ_i of waves of trigonometrical polynomial fit for photographic and AFOEV observations.

Photographic

number of waves	r_i	ϕ_i
1	2.000 ± 0.049	0.067 ± 0.004
2	0.409 ± 0.045	-0.240 ± 0.017

AFOEV

number of waves	r_i	ϕ_i
1	2.194 ± 0.010	0.028 ± 0.001
2	0.286 ± 0.010	-0.368 ± 0.006
3	0.050 ± 0.010	0.037 ± 0.031

Table 3. Characteristics of extrema: moments and their error estimates; magnitudes and their error estimates.

T	m	T	m	T	m
Maxima		44400.5 ± 2.0	7.41 ± 0.08	27962.9 ± 1.0	12.38 ± 0.05
22907.1 ± 1.5	7.06 ± 0.07	44589.7 ± 2.1	7.44 ± 0.03	28145.2 ± 0.7	11.88 ± 0.07
23095.3 ± 2.2	7.06 ± 0.08	44774.2 ± 3.3	6.97 ± 0.07	28350.1 ± 5.0	12.25 ± 0.09
23270.7 ± 1.3	6.86 ± 0.05	29490.7 ± 1.7	12.02 ± 0.08	28534.0 ± 1.1	12.60 ± 0.03
23472.7 ± 1.3	7.81 ± 0.05	44970.5 ± 1.4	8.12 ± 0.06	28724.3 ± 1.3	12.02 ± 0.09
23669.7 ± 1.0	7.68 ± 0.05	45147.2 ± 0.9	7.31 ± 0.06	28919.3 ± 2.0	11.94 ± 0.07
23864.9 ± 0.6	7.22 ± 0.06	45347.3 ± 1.3	7.48 ± 0.08	29097.3 ± 1.2	11.32 ± 0.09
24047.0 ± 0.6	7.32 ± 0.03	45543.7 ± 0.9	7.08 ± 0.03	29293.2 ± 1.0	11.92 ± 0.06
26152.7 ± 2.5	7.21 ± 0.04	45732.0 ± 1.6	7.18 ± 0.12	29859.4 ± 1.1	11.93 ± 0.11
26335.6 ± 1.2	6.89 ± 0.04	45917.8 ± 0.5	6.99 ± 0.04	30245.7 ± 5.0	11.88 ± 0.17
26514.0 ± 2.1	7.31 ± 0.05	46109.9 ± 3.0	7.50 ± 0.10	31003.5 ± 2.0	11.18 ± 0.11
26712.3 ± 1.5	6.86 ± 0.07	46309.4 ± 2.0	7.59 ± 0.04	39733.8 ± 2.3	11.81 ± 0.13
26901.1 ± 0.9	6.88 ± 0.04	46498.1 ± 1.5	7.35 ± 0.05	39937.6 ± 1.2	11.78 ± 0.17
27103.3 ± 0.8	7.26 ± 0.04	46681.4 ± 0.6	6.77 ± 0.03	40117.8 ± 0.9	11.69 ± 0.11
27289.0 ± 1.5	7.36 ± 0.06	46889.8 ± 3.4	8.51 ± 0.06	40320.4 ± 3.5	12.28 ± 0.11
27477.6 ± 1.7	7.33 ± 0.08	47060.7 ± 1.2	7.60 ± 0.04	40489.5 ± 2.4	12.31 ± 0.08
27662.2 ± 1.0	6.71 ± 0.05	47268.3 ± 1.0	7.72 ± 0.05	41078.7 ± 3.7	12.06 ± 0.13
27861.0 ± 3.8	8.15 ± 0.04	47440.5 ± 0.8	7.29 ± 0.03	41263.0 ± 3.4	11.67 ± 0.11
28057.2 ± 1.1	7.79 ± 0.04	47626.4 ± 2.0	6.83 ± 0.05	42219.0 ± 1.1	11.28 ± 0.10
28241.4 ± 2.6	6.71 ± 0.11	47828.6 ± 0.4	7.91 ± 0.02	42602.0 ± 2.7	11.68 ± 0.17
28435.2 ± 1.2	8.08 ± 0.04	48013.0 ± 0.8	7.20 ± 0.04	42978.1 ± 1.8	12.25 ± 0.11
28617.9 ± 1.9	7.95 ± 0.07	48204.1 ± 0.9	8.02 ± 0.02	43367.0 ± 1.5	11.47 ± 0.12
28808.5 ± 2.0	7.36 ± 0.06	48387.6 ± 1.7	7.16 ± 0.04	43741.0 ± 0.8	11.80 ± 0.14
28997.7 ± 2.0	7.42 ± 0.06	48575.1 ± 0.8	7.80 ± 0.03	44120.0 ± 0.8	11.99 ± 0.07
29191.4 ± 1.2	7.02 ± 0.04	48770.7 ± 0.8	6.97 ± 0.03	44508.9 ± 1.2	11.80 ± 0.08
29382.5 ± 2.2	7.70 ± 0.05	48954.3 ± 1.8	7.77 ± 0.03	44883.0 ± 1.2	12.53 ± 0.08
29566.5 ± 1.4	7.81 ± 0.05	49145.4 ± 0.6	6.70 ± 0.03	45065.9 ± 1.8	11.70 ± 0.10
29951.1 ± 2.7	8.13 ± 0.06	49336.5 ± 1.2	7.20 ± 0.04	45263.8 ± 1.7	12.18 ± 0.08
30329.8 ± 9.2	8.37 ± 0.08	49526.3 ± 0.8	7.48 ± 0.03	45453.5 ± 0.9	12.30 ± 0.09
30702.7 ± 2.5	7.12 ± 0.08	49723.2 ± 1.7	6.96 ± 0.03	45645.3 ± 0.7	12.27 ± 0.07
30919.9 ± 1.3	8.08 ± 0.03	49912.2 ± 0.8	8.15 ± 0.02	45829.3 ± 1.3	11.83 ± 0.13
31093.1 ± 1.5	6.37 ± 0.12	50090.3 ± 0.5	7.33 ± 0.03	46019.9 ± 1.6	12.08 ± 0.08
34714.3 ± 2.5	7.12 ± 0.09	Minima		46407.8 ± 1.1	11.82 ± 0.12
36406.1 ± 0.7	7.40 ± 0.04	23003.4 ± 0.7	12.02 ± 0.05	46591.3 ± 0.6	11.07 ± 0.05
39644.3 ± 2.6	8.07 ± 0.06	23179.5 ± 0.9	11.45 ± 0.06	46788.8 ± 2.4	12.61 ± 0.10
40003.1 ± 2.6	7.66 ± 0.12	23387.5 ± 0.8	12.02 ± 0.04	46972.6 ± 0.7	12.51 ± 0.09
40403.3 ± 2.5	8.56 ± 0.06	23571.6 ± 1.1	11.59 ± 0.07	47168.4 ± 1.8	12.22 ± 0.10
40775.9 ± 3.0	8.21 ± 0.06	23766.8 ± 0.9	11.64 ± 0.06	47358.9 ± 0.7	11.89 ± 0.04
41166.7 ± 2.3	8.15 ± 0.04	23953.1 ± 1.0	11.90 ± 0.06	47545.5 ± 1.3	11.34 ± 0.08
41541.1 ± 1.5	6.93 ± 0.10	24146.4 ± 1.6	11.56 ± 0.05	47734.3 ± 0.9	12.46 ± 0.05
41912.1 ± 5.7	7.72 ± 0.18	24341.4 ± 1.2	12.07 ± 0.08	48113.4 ± 0.5	12.27 ± 0.05
42304.1 ± 2.6	7.22 ± 0.11	26059.6 ± 1.5	11.75 ± 0.08	48299.0 ± 1.1	11.87 ± 0.15
42684.9 ± 0.8	6.67 ± 0.05	26241.0 ± 1.2	11.81 ± 0.06	48493.5 ± 0.6	12.30 ± 0.04
42870.8 ±11.3	7.89 ± 0.10	26438.5 ± 0.9	11.97 ± 0.07	48872.8 ± 0.7	11.49 ± 0.04
43080.9 ± 2.7	7.32 ± 0.09	26624.5 ± 0.9	11.52 ± 0.07	49058.7 ± 1.9	11.52 ± 0.17
43261.5 ± 3.2	7.63 ± 0.08	26810.6 ± 1.0	11.72 ± 0.10	49249.1 ± 0.6	11.44 ± 0.06
43444.0 ± 1.6	7.04 ± 0.05	27014.0 ± 1.2	12.27 ± 0.07	49439.6 ± 1.1	12.00 ± 0.13
43628.7 ± 1.6	6.92 ± 0.17	27202.4 ± 0.9	12.16 ± 0.06	49629.0 ± 0.6	11.89 ± 0.06
43830.3 ± 1.6	7.09 ± 0.06	27390.1 ± 0.9	12.26 ± 0.05	49816.0 ± 1.5	12.96 ± 0.12
44029.0 ± 2.1	7.91 ± 0.04	27575.6 ± 1.2	11.50 ± 0.09	50010.3 ± 0.9	12.19 ± 0.06
44206.4 ± 0.8	6.93 ± 0.04	27771.5 ± 0.7	12.01 ± 0.05		

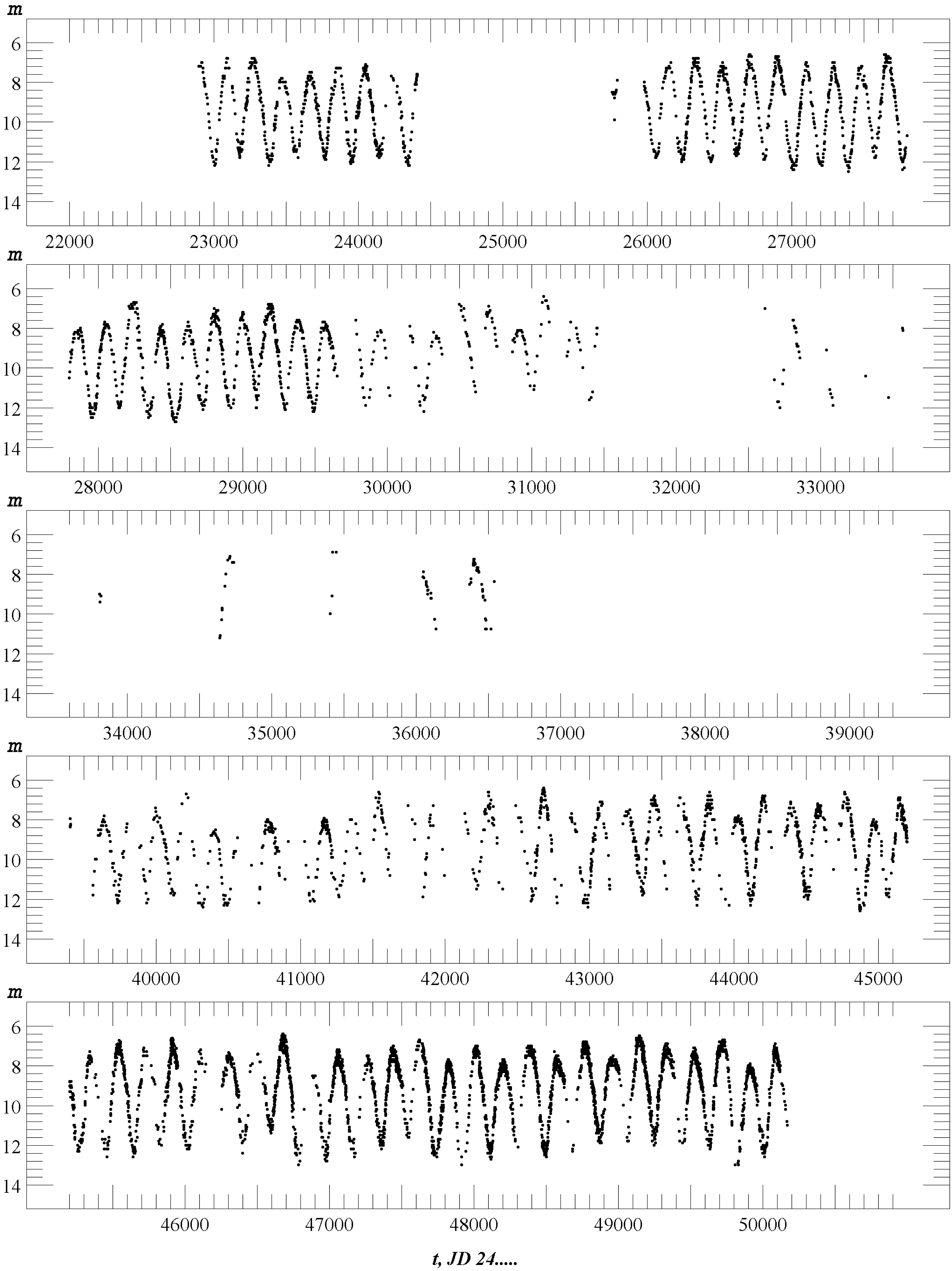

Figure 3. Visual and reduced photographic observations of RT Cyg

The light curve was fitted by the method of "running parabolae" (Andronov, 1990, 1997a). The best fit value of the filter half–width maximazing the "signal/noise" ratio was found to be 50^d. This parameter was used to compute the smoothed values at the times of our photographic observations. Then a characteristic curve $m_{vis}(m_{pg})$ was approximated by a parabola, and our photographic values were transformed to the AFOEV visual system. For further analysis alltogether 7521 data points were used.

Phase light curves for visual, photographic and whole series of the observations are shown in the Fig. 2. Tables 1-2 include characteristics of these light curves in three case and amplitudes and phases of waves for photographic and visual observations for comparison.

The whole light curve is presented in Fig. 3. The graph was created by using the program by Shapovalova (1997).

Characteristics of the individual cycles

The "running parabolae" fit was recomputed for all these observations, and the time and brightness of the extrema was determined with corresponding error estimates as described by Andronov (1997a). Characteristics of extrema are listed in the Table 3.

Next step is to determine the following parameters of the individual cycle: the central maximum (marked as "0"), previous and next maxima ("1" and "2"), previous and next minima ("3" and "4"). The times t and magnitudes m were used also to compute characteristics $t_{ij} = t_i - t_j$. The set of parameters was determined for each from 81 individual maxima. Obviously, some parameters for a trial maximum could be absent, thus the correlation coefficient r was computed for smaller number of pairs. Results are shown in Table 5. For easier reading, we have also computed the ratio r/σ_r, where $\sigma_r^2 = (1-r^2)/(n-2)$ is the error estimate of r (cf. Whittacker and Robinson 1926). As a rough criterion of the presence of statistically significant correlation one may use $|r/\sigma_r| > 3$.

Most significant ($\frac{r}{\sigma_r} \geq 4$ and not trivial correlations are listed in Table 4. It is notable that amplitude is in average constant (correlations between $\rho(m_0, m_3)$); and mean brightness vary smothly ($\rho(m_{02}, m_{34})$), these variations and depends on period between minima (t_{34}). Also we can note correlation between amplitude (of descending branch) and period between minima.

Table 4. Most significant correlations

Parameters		r	$\frac{r}{\sigma_r}$	Number of pairs
m_{02}	m_{34}	79.4119	84.6792	44
m_2	m_4	70.7519	72.8860	55
m_0	m_3	63.9637	64.9913	63
m_2	m_{34}	-70.8096	64.9892	44
m_2	m_{40}	63.9982	60.6351	55
m_3	m_{02}	59.5199	52.8956	53
m_{02}	t_{34}	-58.1279	46.2959	44
m_{40}	t_{34}	55.7654	45.5646	48
t_{01}	m_{01}	46.9793	41.9036	64
m_2	t_{34}	53.6266	41.1753	44
m_3	m_{01}	48.5442	40.0400	54

The correlation $\rho(m_{02}, m_{34})$ is similar to one apeared in W Lyr (Marsakova and Andronov, 1997). Also it seen similarity in the correlations $\rho(m_2, m_{40})$ (RT Cyg) and $\rho(m_2, m_{30})$ (W Lyr): between brightness in next maximum and amplitude of descending or ascending branch, respectively.

The whole table may be used for comparison with theoretical models of "weak chaos" in the pulsations of the Mira-type stars.

The dependence of all these parameters on time was also studied. There are long-term changes onto which more rapid variations are superimposed. One may see e.g. the (O-C) diagram for maxima and minima and the fits suggesting the shift between maxima and minima is constant. Formally the polynomial of 4^{th} order is statistically significant, but it only shows decade-scale cyclicity.

References:

Andronov I.L.: 1990, *Kinematika Fizika. Neb. Tel*, **6**, N 6, 87.

Andronov I.L.: 1994, *Odessa Astron. Publ.*, **7**, 49.

Andronov I.L.: 1997a, *As. Ap. Suppl. Ser.*,

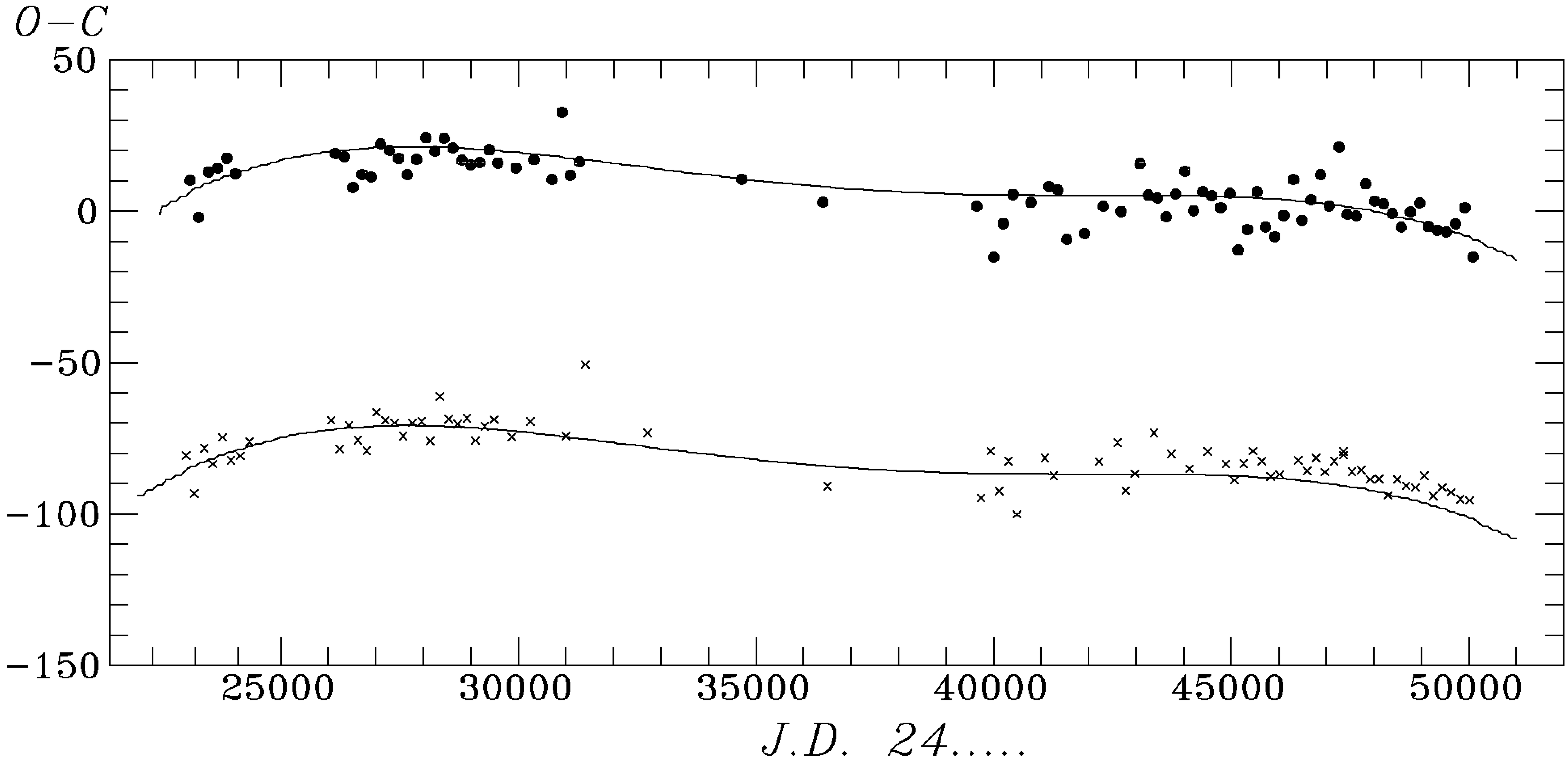

Figure 4. O–C diagram for maxima (above) and minima (below). The linear and $4^{th}-$ order polynomial fits are shown.

Table 5. Correlation coefficients r between different characteristics of the light curve of RT Cyg. Below the diagonal: $100 \cdot r$; above the diagonal: r/σ_r.

	m_0	m_{30}	m_{40}	m_1	m_2	m_3	m_4	t_{01}	t_{20}	t_{03}	m_{30}	t_{40}	m_{40}	m_{01}	m_{02}	m_{34}	t_{43}	$\frac{t_{03}}{t_{43}}$	$\frac{t_{03}}{t_{01}}$
m_0	*	1	1	-2	-2	6	-0	4	-3	-0	-7	-4	-10	11	11	4	-4	2	-2
m_{30}	8	*	1	-0	-4	-1	-5	-1	-0	-3	-1	1	-4	1	3	3	-0	-1	-3
m_{40}	16	10	*	1	-2	4	-1	-1	-1	-3	2	-0	-2	1	2	3	-3	-1	-3
m_1	-29	-3	11	*	0	-0	-0	-3	0	-0	2	1	1	-11	-2	0	1	-0	2
m_2	-29	-44	-25	6	*	-2	7	-1	4	2	0	3	6	-2	-11	-6	4	-1	2
m_3	64	-6	44	-6	-22	*	1	2	-3	1	1	-3	-4	4	5	6	-2	2	-0
m_4	-4	-55	-15	-4	71	9	*	-0	2	1	0	1	6	-0	-4	-6	2	0	1
t_{01}	41	-7	-9	-35	-10	29	-3	*	-4	4	-1	-6	-2	4	2	0	-2	5	-2
t_{20}	-35	-5	-14	4	41	-42	29	-48	*	-3	-0	8	4	-2	-4	-4	4	-6	-1
t_{03}	-1	-40	-37	-4	22	16	22	50	-40	*	1	-4	1	0	-0	-0	2	10	8
m_{30}	-66	-14	24	29	2	16	7	-18	-2	17	*	1	4	-5	-3	1	2	-0	2
t_{40}	-45	14	-0	9	39	-37	16	-66	74	-52	14	*	4	-3	-4	-3	6	-13	-1
m_{40}	-79	-49	-20	14	64	-47	65	-31	47	15	54	44	*	-5	-14	-9	5	-1	2
m_{01}	81	10	8	-80	-22	49	-1	47	-27	6	-53	-36	-59	*	6	2	-3	2	-2
m_{02}	80	37	27	-21	-81	60	-49	30	-47	-5	-37	-50	-89	64	*	8	-5	2	-2
m_{34}	48	40	45	5	-71	67	-67	6	-50	-7	7	-35	-80	30	79	*	-3	1	-1
t_{43}	-47	-5	-38	19	54	-31	30	-35	48	30	29	66	56	-39	-58	-45	*	-2	4
$\frac{t_{03}}{t_{43}}$	30	-14	-10	-5	-10	30	1	57	-69	85	-6	-89	-22	24	26	21	-32	*	3
$\frac{t_{03}}{t_{01}}$	-24	-37	-41	24	30	-5	15	-22	-9	73	28	-8	23	-31	-30	-13	52	45	*

125, 207.

Andronov I.L.: 1997b, *IAU Symp. 180 Planetary Nebulae,* Kluwer Acad. Publ., 341.

Khopolov P.N. et al.: 1987, *General Catalogue of Variable Stars,* 4-th ed., **3**, 368pp.

Marsakova V.I., Andronov I.L.: 1997, *Kinematika Fizika. Neb. Tel,* **13,** N 6, 49.

Schweitzer E.: 1993, *Bull. AFOEV*, **64**, 14.

Strelkova E.P.: 1953, *Izvestija Astron. Obs. Odessa State Univ.*, **3**, 275.

Whittaker E., Robinson G.: 1926, *The Calculus of Observations,* Blackies & Sons, London.

Shapovalova L.L.: 1997, *Odessa Astron. Publ.,* **10**, 131.