OUTBURST CYCLE LENGTH VARIATIONS IN THE DWARF NOVA EM CYGNI

I.L. Andronov, L.L. Chinarova
Astronomical Observatory, Odessa State University
T.G.Shevchenko Park, Odessa 270014 Ukraine

ABSTRACT. The cycle length of the dwarf nova EM Cyg undergoes season–to–season changes which may be interpreted by changes of the accretion rate caused by a solar–type activity of the secondary star. The mean brightness of EM Cyg varies with a cycle of $\approx 3000^d$ and is highly correlated with an amplitude of the sine–like variations. Unexpectedly no correlation was found between the seasonal values of the cycle length and the mean value or amplitude.

Key words: Stars: Cataclysmic: Dwarf Novae: EM Cyg

Introduction.

Disks accreting matter from the secondary filling its Roche lobe are dynamically unstable (Meyer and Meyer–Hofmeister 1984, Lin et al. 1985). The outburst occur regularly after the quiescent stage. Although the time intervals "P" between subsequent outbursts vary by few dozens percent, the mean value of the cycle length was believed to be a relatively constant characteristic of the dwarf novae. Search for possible correlations between the outburst characteristics was done by Szkody and Mattei (1984), Gicger (1987) and some other authors. The most famous of such correlations is the "amplitude–cycle" relation (Kukarkin and Parenago 1934), which was recently revised by Richter and Brauer (1989).

Decades of photographic and visual monitoring of dwarf novae allows to study long–term changes. Kurochkin (1981), Mattei et al. (1986), Cook (1987), Shakun (1987ab, 1988, 1989), Shakun and Timko (1994) reported on cycle length variability of V 1504 Cyg, SS Aur, U Gem, AR And, UU Aql, RU Peg and VZ Aqr. Vogt (1982) described quasi–periodic behaviour of the supermaxima in SU UMa – type stars. Bianchini (1987, 1990) explained the few year scale variations of CV's by a solar–type activity of the secondary. Similar slow variations of the X–ray sources were reviewed by Priedhorsky and Holt (1987). Andronov and Shakun (1990) have shown that the mean cycle length changes abruptly at least in 4 stars, thus one may say about the "switchings" between two separate values, rather than about quasi–sinusoidal variations. Chinarova (1995) reported on relatively smooth cycle length variations in X Leo, AB Dra, IR Gem, AY Lyr and LL Lyr with characteristic times ranging from 1500^d to 8000^d. This phenomenon may be important for understanding the existing theoretical models of the outbursts as the limit cycles of the accretion disk structure variations.

Periodogram Analysis of EM Cygni.

The most intensely studied object of our sample is EM Cyg. For the analysis we have used 4506 observations from the AFOEV database (Schweitzer, 1996). To make the data obtained by different observers compatible, we have studied the "mag–mag" diagrams and derived coefficients for reduction of the magnitudes to the "standard" AFOEV visual system (a). The numbers of "sure" observations are n=3109(a), 697(h), 205(e), 16(p).

The following method was used. At first, the light curve was approximated by the method of "running parabolae" (Andronov 1990) with a filter half–width $\Delta t = 7^d$ by using the "main set" of observations, and a "smoothed" values m_C were computed at times t of the minor set of observations m obtained by a fixed author.

There values were used to constrain a "$m - m_C$" diagram, as well as those obtained by smoothing the minor set at times of the major. After rejection of few uncertain observations we have found that the rest n_1 points are highly correlated. We used a linear combination

$$\tilde{m} = \bar{m}_C + \frac{\sigma_C}{\sigma}(m - \bar{m}), \qquad (1)$$

where $\bar{m}$ and σ^2 are the sample mean and variance of the initial data m and the index "C" corresponds to the smoothed values of the signat at same times. Such reduction (1) saves the sample mean and variance of $\tilde{m}$ equal to that of smoothed values m_C at the same times. After such a reduction, we added the minor observations to the majority, and applied consequently the same procedure to the observations marked as "h", "e, "p". For "e" and "p the coefficients "σ_C/σ" deviate from unity more than for "h".

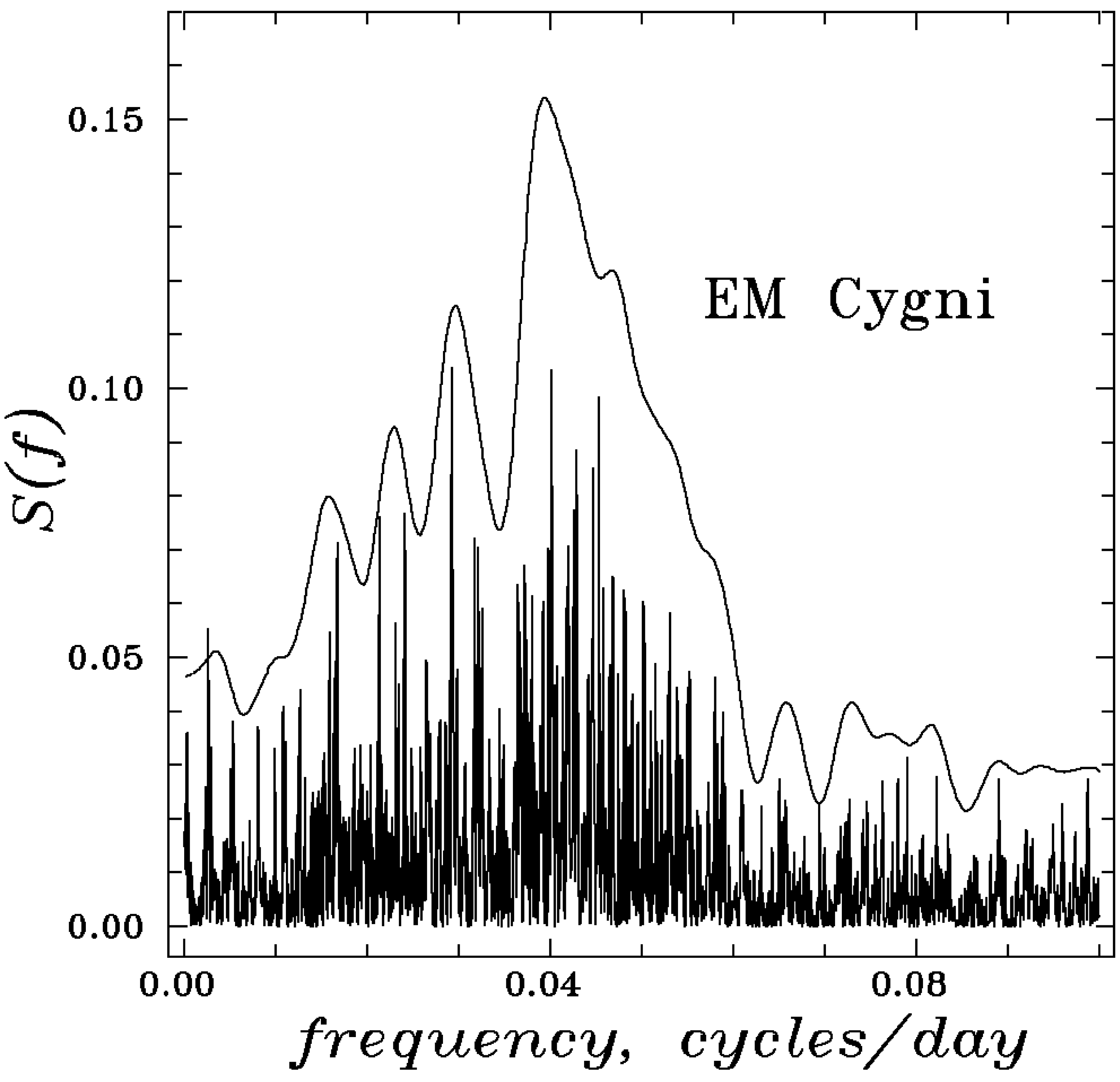

Figure 1: Periodograms $S(f)$ for the whole set of observations of EM Cyg (bottom) and a weighted mean periodogram for seasonal periodograms (up). Vertical axis is marked every 0.05. Vertical lines indicate frequences corresponding to maxima. one may note the periodogram values for the whole set.

The whole set of observations reduced to one scale ($n = 4027$, $\langle m\rangle = 13.^{m}15$, $\sigma_O = 0.^{m}532$) was studied by using the periodogram analysis with a least squares fit

$$m(t) = a + b\sin 2\pi ft + c\cos 2\pi ft \qquad (2)$$

and a test function $S(f) = \sigma_C^2/\sigma_O^2$, where "O" and "C" correspond to r.m.s. deviations of the original and smoothed with a fit (1) values from their sample means. The expectation for the white noise is $\bar{S} = 2/(n-1) = 0.0005$. The computer code FOUR–0 (Andronov, 1994) was used.

Although the presence of any coherent periodicities in the luminosity changes of a dwarf nova is doubtful, we made an analysis of the whole data set ($n = 4027$, JD 2440739–9166) in a frequency range $0 < f \le 0.1$ cycles/day ($P \ge 10^{d}$). The periodogram is shown at Fig.2. The characteristics of few highest peaks are listed in Table 1.

We have also subdivided the observations into 24 "seasons" and computed the similiar periodograms for them. The "weighted mean" periodogram with the weights $\rho_j = n_j\sigma_{Oj}^2$ for j^{th} season

$$S(f) = \frac{\sum_{j=1}^{n_s} \rho_j\ S_j(f)}{\sum_{j=1}^{n_s} \rho_j} \qquad (3)$$

is shown at Fig.2, and the most prominent peaks are listed in Table 2. One may note that, despite obvious

Table 1. Characteristics of the high peaks at the periodogram for all observations of EM Cyg (in the descending order of height).

f	P	$S(f)$	r	$S/\bar{S}$	L_p
0.0293	34.174±0.009	0.0259	0.12	52	20
0.0401	24.913±0.004	0.0259	0.12	52	20
0.0454	22.041±0.003	0.0251	0.12	51	20
0.0429	23.308±0.004	0.0222	0.11	45	17
0.0447	22.363±0.003	0.0214	0.11	43	16
0.0409	24.821±0.005	0.0207	0.11	42	15
0.0426	23.478±0.006	0.0194	0.10	39	14
0.0241	41.437±0.012	0.0194	0.10	39	14
0.0218	46.780±0.015	0.0191	0.10	38	14
0.0317	31.501±0.008	0.0181	0.10	36	13
0.0398	25.095±0.005	0.0179	0.10	36	13
0.0168	59.672±0.027	0.0178	0.10	36	13
0.0420	23.806±0.006	0.0178	0.10	36	13
0.0322	31.092±0.008	0.0176	0.10	35	13

Table 2. Characteristics of the mean weighted periodograms of EM Cyg.
R.m.s. value of r for pure white noise is $r_{WN} = 0.^{m}169$.

f	P	$S(f)$	r	σ_{O-C}
0.0230	43.6±0.4	0.093	0.226	0.500
0.0297	33.7±0.2	0.115	0.252	0.494
0.0394	25.4±0.2	0.154	0.291	0.483
0.0467	21.4±0.1	0.122	0.259	0.492

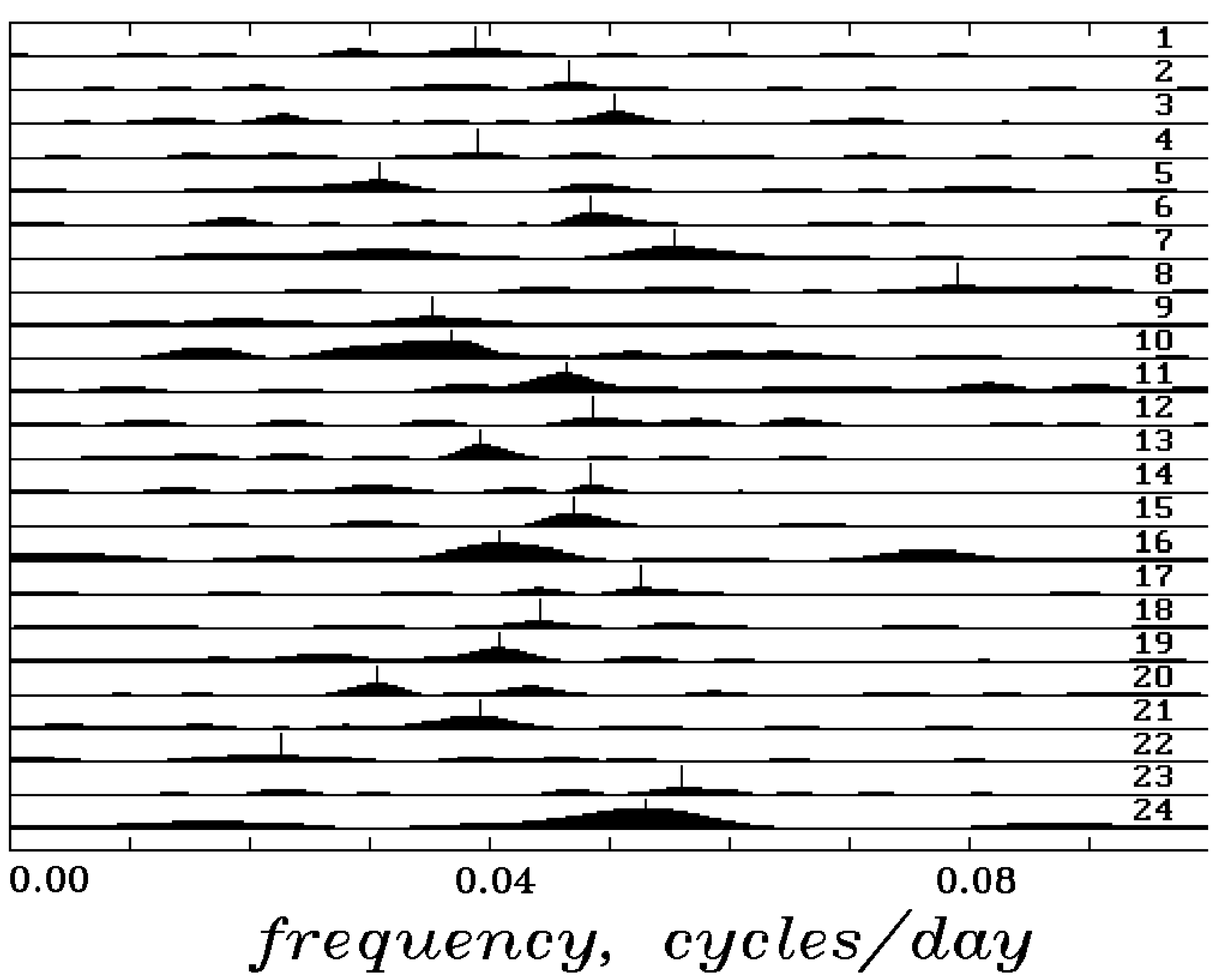

Figure 2: Periodograms $S(f)$ for the individual seasons. Shift step is equal to 1 (dimensionless units). Vertical lines indicate frequences corresponding to maxima at a given seasonal periodogram.

difference of the shape of the periodogram, two peaks of similiar height appear at $P = 25^{\rm d}$ and $34^{\rm d}$. Details of application of the weighted mean periodogram to another cataclysmic variable TT Ari are published by Tremko et al. (1996).

One may note significant variations of the "mean" cycle length from season to season. As in other dwarf novae, they may be explained by variations of the accretion rate (Andronov and Shakun 1990) due to solar–type activity of the secondary (Bianchini 1988) filling its Roche lobe. Detailed study of the correlations between outburst characteristics will be published elsewhere.

Dependence on time of the best fit period P, semi–amplitude r and mean brightness a is shown at Fig 3. One may see variations of all these parameters. Variations of a seem to be more regular, than of other parameters, and have a time scale $\Pi \approx 3000^{\rm d}$. This value is close to that observed in other cataclysmic variables (e.g. Bianchini 1988, 1990, Andronov and Shakun 1990). However, this object shows more sharp variations of r and P.

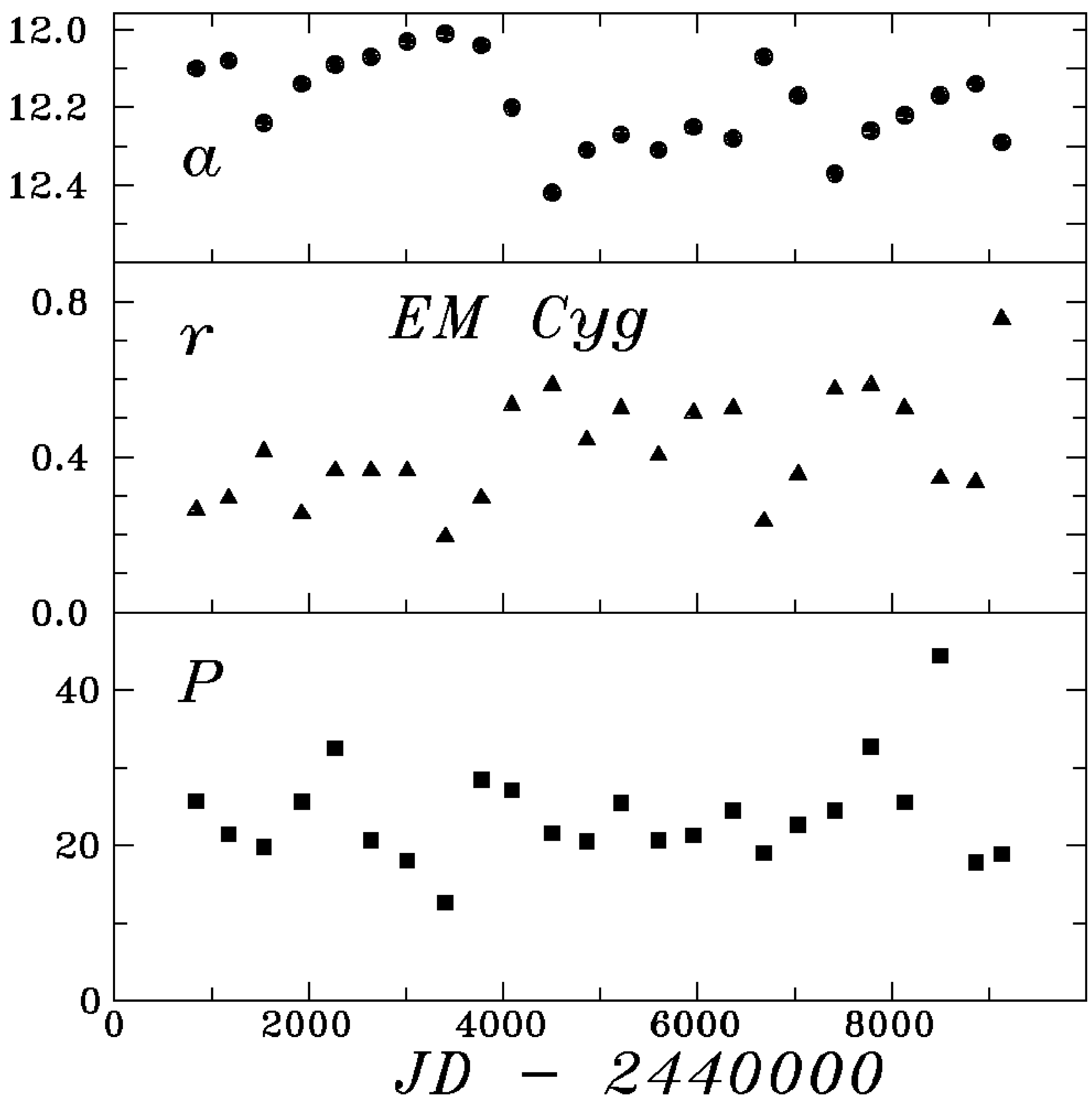

Figure 3. Variations of the cycle length (P), semi–amplitude (r) and mean level (a) for seasonal sine–like fits.

Correlations between the outburst characteristics.

To study possible correlations between the characteristics, we have analysed the seasonal best fit parameters. Contrary to previous studies (e.g. Szkody and Mattei 1984, Gicger 1987), we use the "effective" seasonal characteristics instead of the shapes of the individual outbursts. For the analysis, we have chosen the following parameters: $\langle t\rangle$ – mean time of the observations within one season (thus possible correlations may reflect apparent trends); P – "best fit" period; $f = 1/P$ – corresponding frequency; $S(f)$ – height of the maximal peak (i.e. ratio "signal"/"signal+noise"); r and a – semi–amplitude and mean level in the fit (1); σ_O, σ_{O-C} – r.m.s. deviations of the observations from the mean and sine curve, respectively. Also we used the brightness at "mean maximum" $(a - r)$ and "mean minimum" $(a + r)$.

The table of the seasonal characteristics was published by Chinarova and Andronov (1995). In the present work we have recomputed the periodograms avoiding one misprint found in the AFOEV database. Depite the qualitative the results have not been changed, the quantitative characteristics are slightly different. The corrected values of the parameters for the season JD 2447302–7540 are: the sample mean time $\langle t\rangle = 2447411$, the number of data $n = 248$, the test–function $S(f) = 0.405$, the "false alarm probability" $Pr = 10^{-26.2}$, the semi–amplitude $r = 0\overset{\rm m}{.}58 \pm 0\overset{\rm m}{.}05$, the cycle length $P = 24\overset{\rm d}{.}52 \pm 0\overset{\rm d}{.}14$, the mean $a = 13\overset{\rm m}{.}37 \pm 0\overset{\rm m}{.}03$, the r.m.s. deviations $\sigma_O = 0\overset{\rm m}{.}61$, $\sigma_{O-C} = 0\overset{\rm m}{.}47$.

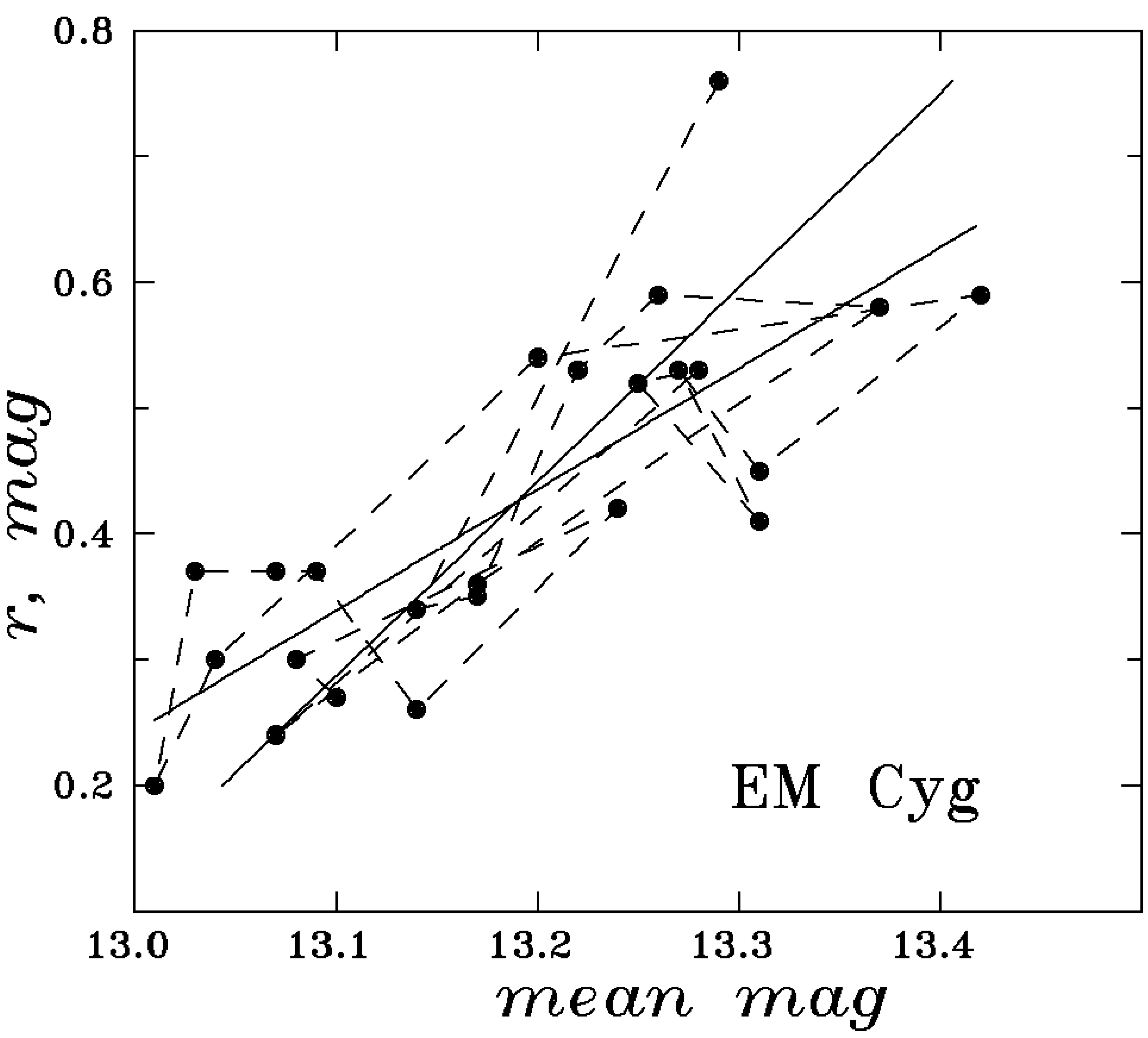

Figure 4. "Semi–amplitude – mean level" diagram for seasonal sine-like fits for EM Cygni.

Table 3. Correlation coefficients ρ for different characteristics of the seasonal sine–like fits of EM Cyg (above the diagonal) and $v=\rho/\sigma_\rho$ (below the diagonal). The $3\sigma_\rho$ level corresponds to a value $\rho=0.538$. The values exceeding this value are marked by a bold font.

	$\langle t\rangle$	P	f	$S(f)$	r	a	σ_O	σ_{O-C}	$a+r$	$a-r$
$\langle t\rangle$	1	0.165	–0.108	0.204	0.501	0.428	**0.620**	0.468	0.495	–0.245
P	0.8	1	**–0.913**	–0.019	0.084	0.069	0.218	0.273	0.081	–0.045
f	–0.5	**–10.5**	1	–0.113	–0.223	–0.213	–0.338	–0.325	–0.231	0.078
$S(f)$	1.0	–0.1	–0.5	1	**0.869**	**0.564**	0.458	–0.128	**0.773**	**–0.662**
r	2.7	0.4	–1.1	**8.2**	1	**0.790**	**0.820**	0.309	**0.956**	**–0.574**
a	2.2	0.3	–1.0	**3.2**	**6.0**	1	**0.845**	0.493	**0.934**	0.049
σ_O	**3.7**	1.0	–1.7	2.4	**6.7**	**7.4**	1	**0.762**	**0.878**	–0.207
σ_{O-C}	2.5	1.3	–1.6	–0.6	1.5	2.7	**5.5**	1	0.415	0.155
$a+r$	2.7	0.4	–1.1	**5.7**	**15.4**	**12.3**	**8.6**	2.1	1	–0.310
$a-r$	–1.2	–0.2	0.4	**–4.1**	**–3.3**	0.2	–1.0	0.7	–1.5	1

As is well known (e.g. Korn and Korn, 1961), the ratio $v=\rho/\sigma_\rho$, where ρ is the sample correlation coefficient and $\sigma_\rho=((1-\rho^2)/(n-2))^{1/2}$, obeys the "Student" $t-$ distribution, if the general correlation coefficient is equal to zero. As the $t-$ distribution is close to the normal one for $n\geq 20$, one may use the "3σ" criterion, corresponding to the probability of random deviations of the value larger than 3σ of 0.3 per cent. Thus the statistically significant correlations correspond to $|v|>3$.

Results are presented in Table 3. Obviously, some of the parameters are achived to be correlating, e.g. $P-f$, $r-\sigma_O$. However, we made an analysis to search for possible new correlations. Some are "funny" – such as an increase of the "noise" characterized by σ_{O-C} with time. However, this may be attributed not to worth typical accuracy of the observations, but to increased instability of the light curve. Unfortunately, no correlation was found between the mean brightness and the outburst frequency, which could be achieved for the constant accreted mass between subsequent outbursts seen in some dwarf novae (e.g. Gicger 1987).

An interesting correlation was found between the semi–amplitude r and the mean level a. Corresponding diagram is shown in Fig. 4. Mean of the seasonal values are $\bar{a}=13\overset{m}{.}18\pm0\overset{m}{.}02$ and $r=0\overset{m}{.}41\pm0\overset{m}{.}02$, with a "gradient" $\sigma_r/\sigma_a=1.06\pm0.16$. Thus no correlation between $a-r$ and a and an exellent correlation between $a+r$ and a. It is strange that $a-r$ and r are noticeable correlated. Another unexpected result is that the mean cycle length P is *not* correlated neither with r, nor with a. This is in a contradiction with a theoretical expectation and must be checked for other stars.

Characteristics of the individual outbursts.

For the determination of the characteristics of the individual cycles we have used the "running parabola" fit with the filter half–width $\Delta t=10^d$ which is optimal for variations with a cycle length $\geq 20^d$. Alltogether 174 minima and 180 maxima have been determined. The corresponding error estimates of the brightness are $0\overset{m}{.}082$ and $0\overset{m}{.}079$, respectively. The range of the maxima is $11\overset{m}{.}82-13\overset{m}{.}12$, of the minima is $13\overset{m}{.}07-14\overset{m}{.}46$. The corresponding mean values $12\overset{m}{.}60\pm0\overset{m}{.}02$ and $13\overset{m}{.}73\pm0\overset{m}{.}02$, thus the mean amplitude is $1\overset{m}{.}13\pm0\overset{m}{.}03$. One may note an apparent trend of the brightness at minimum at a mean value $dm/dt=(27\pm7)\cdot10^{-6}$ mag/day with no significant trend of the brightness at maximum.

The variations of the brightness at the extrema are shown in Fig.5. They were fitted with polynomials of different order. The minima show more pronounced variations with time, and the statistically significant degree of the fit is 8. Thus we have used the same order for the fits of the minima and of the extrema (both minima and maxima, what corresponds to a mean brightness level). The fits show the waves with a cycle length $\approx 3000^d$ what justifies the result seen in the parameters of the seasonal sine fits.

Brief Notes on Other Stars.

The stars V792 Cyg, FS Aur, PU, PV, PY, QY, V336, V368, V372 Per were studied on archive plates of the Moscow and Odessa Sky Patrol Collections. For some stars the Sonneberg observations of H.Busch were added. The tables of individual observations were published by Andronov et al. (1993ab). Moments of maxima were determined and the corresponding cycle lengths were estimated. Characteristics of the outbursts are compared with that predicted by statistical relationships published in the literature. HN Cyg was erreneously classified as an UG variable in some papers, it is a long–period variable with two main oscillations. For other stars the following preliminary results were obtained (Chinarova 1995) by determination of

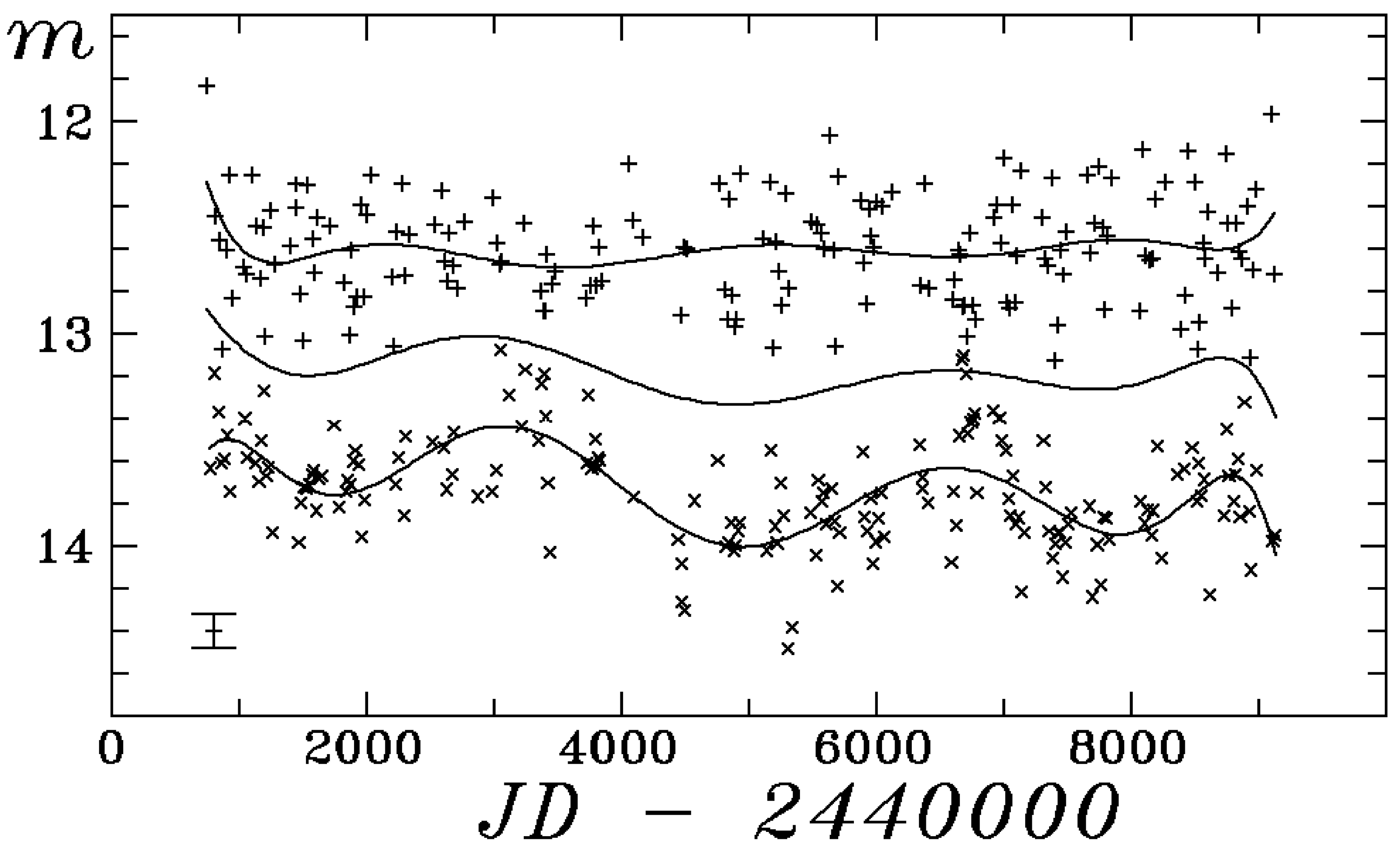

Figure 5. Dependence on time of the brightness in maxima (crosses), minima (inclined crosses) and their fits by a 8-th order polynomial separately and joinly (lines). The vertical bar shows an error estimate corresponding to a mean weight of the individual data point.

the best fit period corresponding to the moments of maxima in separate seasons (algorithm published by Andronov (1991)). However, we plan to revise these results by using more complete data from the AFOEV, VSOLJ and AAVSO data files:

X Leo: Variations of P from $11\overset{\rm d}{.}06 \pm 0\overset{\rm d}{.}03$ to $17\overset{\rm d}{.}72 \pm 0\overset{\rm d}{.}07$ with possible cycle $\Pi \approx 8000^{\rm d}$.

AB Dra: From $9\overset{\rm d}{.}74 \pm 0\overset{\rm d}{.}03$ to $14\overset{\rm d}{.}47 \pm 0\overset{\rm d}{.}04$ with $\Pi \approx 2500^{\rm d}$.

IR Gem: From $10\overset{\rm d}{.}19 \pm 0\overset{\rm d}{.}06$ to $26\overset{\rm d}{.}49 \pm 0\overset{\rm d}{.}66$ with $\Pi \approx 1500^{\rm d}$.

AY Lyr: From $19\overset{\rm d}{.}67 \pm 0\overset{\rm d}{.}19$ to $29\overset{\rm d}{.}99 \pm 0\overset{\rm d}{.}27$ with $\Pi \approx 5000^{\rm d}$.

LL Lyr: From $49^{\rm d} \pm 1^{\rm d}$ to $120^{\rm d} \pm 5^{\rm d}$.

Discussion.

The detailed study of the temporal behaviour of the individual time intervals showed apparent cyclicity with a characteristic time of some years, which may be relatively smooth and similar to the solar–like activity (Bianchini, 1990) or may be "alternating" between two distinctly different values (Andronov and Shakun 1990). This may indicate the presence of two subclasses of stars, possibly corresponding to different mechanisms (cf. Smak 1984).

Changes in the cycle occurence rate may be explained by a modulation of the accretion rate due to a long–term activity of the secondary. Another type of variability in the secondary was found by Shakhovskoy et al. (1993) who detected an UV Cet–like flare in the polar AM Her. These results argue for necessity of further study of consequences of the red star activity onto accretion flow in binary systems.

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