РОССИЙСКАЯ АКАДЕМИЯ НАУК

СООБЩЕНИЯ СПЕЦИАЛЬНОЙ АСТРОФИЗИЧЕСКОЙ ОБСЕРВАТОРИИ

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MV LYRAE: THE CATACLYSMIC VARIABLE, WHICH AT LEAST RETURNED TO ITS NORMAL ACTIVITY STATE

I.L.Andronov[1], I.G.Borodina[1], L.L.Chinarova[1], B.Fuhrmann[2], S.V.Kolesnikov[1], S.Korth[3], E.P.Pavlenko[4], A.I.Pikhun[1], N.M.Shakhovskoj[4], S.Yu.Shugarov[5], W.Wenzel[2]

[1] Odessa State University, Ukraine

[2] Sternwarte Sonneberg, Germany

[3] Berliner Arbeitskreis "Veranderliche Sterne", Germany

[4] Crimean Astrophysical Observatory, Ukraine

[5] Sternberg State Astronomical Institute, Russia

ABSTRACT

Tables of the photoelectric, photographic and visual observations obtained during the international campaign, are presented. The mean value of circular polarization is $\langle q \rangle=-0.03\pm0.05$ per cent, and there is no evidence for the reality of its changes on the time scale of dozens of minutes. The periodogram analysis shows transient QPOs with frequencies 15-30 and 61-92 cycles/day, and eventually the variations with the near-orbital frequency $f\approx8$ c/d.

INTRODUCTION

The variability of MV Lyr was discovered by Parenago (1946), who named the object SVS 1021. The UV excess was detected by MacRae (1952), as well as the strong emission line He II 4686 and the very weak wide hydrogen emissions (MacRae, 1952; Greenstein, 1952, 1964). The object was suggested to be an old nova.

The brightness variations with a characteristic time scale of 1-30 minutes and a wavelength-dependent amplitude were observed by Walker (1954). Besides this, the system occasionally undergoes weakenings down to 2^m below the normal brightness (Weber, 1961). The value of the spectral (orbital) period was estimated to be around 3.2^h

(Walker, 1966).

A new wave of interest on the object surged a decade later, when Vojkhanskaya et al. (1978) suspected that MV Lyr was possibly a polar (AM Her-type star). Vojkhanskaya and Mitrofanov (1980) interpreted the spectral feature near 0.42 μm as an electron cyclotron line corresponding to the magnetic field $B \approx 2.6 \cdot 10^8$Gs. Chiappetti et al. (1982) pointed out the similarity of the UV spectrum of the object in the intermediate state to the active state of AM Her and to the quiescent state of the dwarf nova SS Cyg. However, the polarimetrical measurements showed no significant polarization (Vojkhanskaya et al., 1978; Efimov and Shakhovskoj, 1980), thus the system is not a 'true' polar (cf. Robinson et al., 1981), and may be a nova-like variable or the intermediate polar (see reviews of Richter, 1987; Vogt, 1982; Warner, 1985).

A unique phenomenon was exibited by the system. Before 1979, it was one of the brightest objects among the cataclysmic variables, its magnitude was usually 12.5 - 13.5^m with rare "excursions" to the "intermediate" state 14-15^m (see Andronov et al., 1988, for the detailed description of MV Lyr and references therein). Suddenly in 1979, the brightness of MV Lyr dropped by 4-5^m (Rosino, 1980), and it was suspected that the object came into the famous "2-3 hour period gap", the secondary became smaller than the corresponding Roche lobe. The duration of such "inactive state" was estimated to be of order of 10^9 yrs (Robinson et al., 1981). However, from this "faint" state (17-18^m), the outbursts to the level of "intermediate" state (15^m) recurred every 400^d (Andronov et al., 1988). In 1989, the "vacations" ended, and the system returned to its usual activity state (Rosino, 1989; Wenzel and Fuhrmann, 1989; Hurst, 1989; Verdenet, 1989, 1990; Korth et al., 1989, 1990; Fuhrmann and Wenzel, 1990; Zoltau, 1990). Another mechanism for the modulation of the accretion rate is the solar-type activity of the secondary star (Wenzel and Fuhrmann, 1983; Bianchini, 1990).

In this paper, we present the tables of the photographic, TV, photoelectric and polarimetric observations of the object obtained during the international campaign. Preliminary results were published by Andronov et al. (1990).

UBVRI PHOTOMETRY AND POLARIMETRY

The star was observed at the 1.25 m telescope AZT-11 of the Crimean Astrophysical Observatory by N.M.Shakhovskoj and S.V.Kolesnikov on the UBVRI photometer-polarimeter of the Helsinki University (Korhonen et al., 1984). The star *c* (Walker, 1954), marked as *b* by Wenzel (1980) and Andronov and Shugarov (1982) was used as a comparison star. Its brightness was determined by linking to the standard star *BD*+28°4211 (Neckel and Chini, 1980), as well as the brightness of the star No. 8 (Andronov and Shugarov, 1982). The expressions for the reduction of the instrumental magnitude differences to the standard UBVRI system were obtained by N.I.Shakhovskaya (private communication):

$\Delta U = 0.955\ \Delta U + 0.218\ \Delta B - 0.173\ \Delta V$
$\Delta B = 1.173\ \Delta B - 0.173\ \Delta V$
$\Delta V = -0.104\ \Delta B + 1.104\ \Delta V$
$\Delta R = -0.104\ \Delta B + 0.153\ \Delta V + 0.951\ \Delta R$
$\Delta I = -0.104\ \Delta B - 0.012\ \Delta V + 1.116\ \Delta I$.

The results are presented in Table 1 and compared with the previously published *UBV* photometry. The magnitudes in *B* and *V* are in a good agreement, whereas the difference with the *U*-magnitude of Walker (1954) is relatively large.

Table 1. The brightness of the comparison stars

Star	*U*	*B*	*V*	*R*	*I*	Reference
c	12.45	12.43	12.06			Walker (1954)
c	12.24	12.40	12.06	11.73	11.57	This Paper
8	13.52	13.58	13.06			Andronov and Shugarov (1982)
8	13.48	13.62	13.10	12.62	12.31	This Paper (AZT-11)
8	13.64	13.67	13.13			This Paper (ZTE)

The instrumental magnitude differences "var-*c*" of the UBVRI observations obtained on 23.09.89 are shown in Table A1. Their mean values are 0.36^m, 1.29^m, 1.62^m, 1.88^m and 2.04^m for UBVRI, respectively. The corresponding mean-square deviations from the mean value are equal to 0.060^m, 0.052^m, 0.055^m, 0.040 and 0.053^m. They characterize the wavelength dependence of the amplitude of the brightness variations. It may be noted that Walker (1954) detected brightness variations of about 0.4^m with a characteristic time scale from 1 to 30 minutes and pointed out that the amplitude is wavelength-dependent: $\Delta B = 0.8\ \Delta U$, $\Delta V = 0.7\ \Delta U$. For our data, the amplitudes in UBVI are very similar, in *R* the amplitude is significantly smaller. The mean brightness of MV Lyr reduced to the standard system, is equal to $U=12.59^m$, $B=13.64^m$, $V=13.71^m$, $R=13.63^m$, $I=13.70^m$.

The light curve is shown in Fig. 1. Besides the original observations, we plotted the smoothing function obtained by the method of "Running Parabolae" (Andronov, 1990). The time filter half-width $\Delta t=0.035^d \approx P_{orb}/4$ is chosen to fit the variations with the characteristic time close to the orbital period P_{orb} (its value will be discussed later). The "brightness-brightness" diagrams showed an excellent correlation between the variations in the UBVR bands, as one may see from the correlation coefficients listed in Table 2.

However, the degree of correlation between the variations in *I* and in the rest four filters is significantly lower, arguing for another source of emission in the infrared.

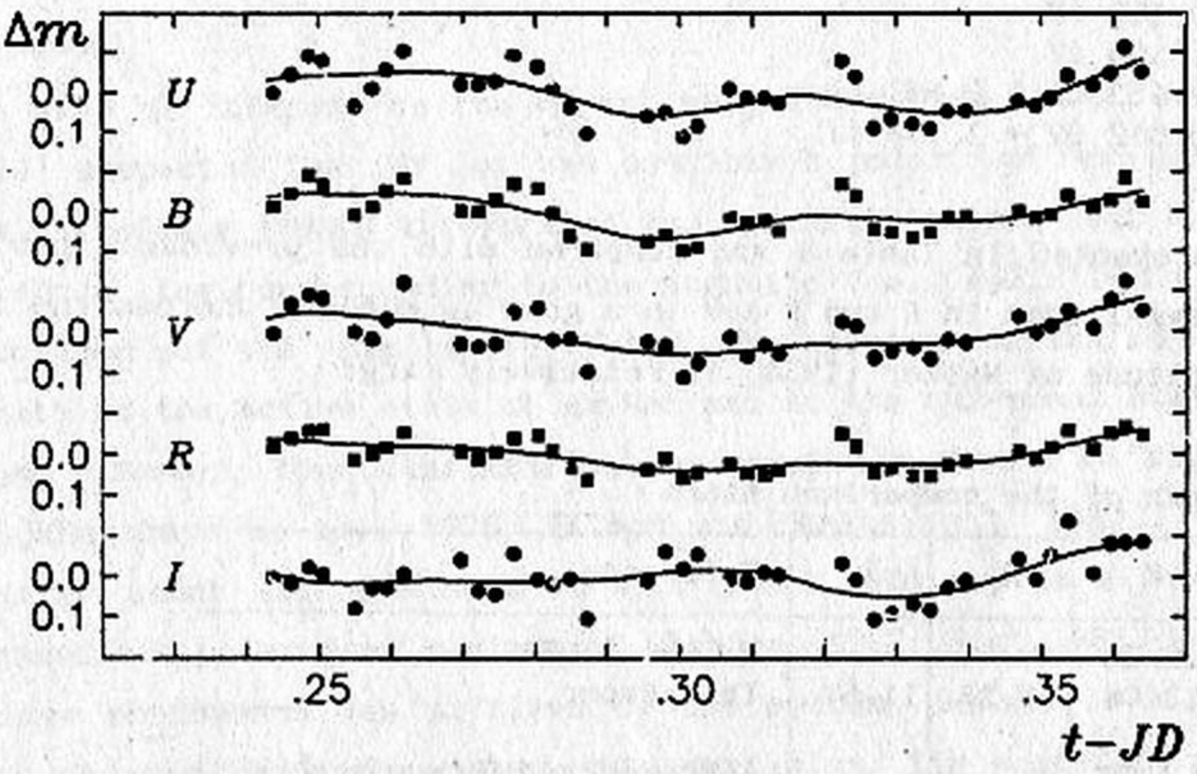

Fig. 1. The UBVRI observations obtained at AZT-11 on JD 2447793. The brightness is shown as the deviation from the nightly mean.

Table 2. The correlation coefficients for the brightness variations in the UBVRI

	U	*B*	*V*	*R*	*I*
U	1	0.955	0.873	0.909	0.489
B	0.955	1	0.883	0.917	0.374
V	0.873	0.883	1	0.918	0.500
R	0.909	0.917	0.918	1	0.585
I	0.489	0.374	0.500	0.585	1

The brightness and circular polarization measurements were obtained at the same telescope in the instrumental *V* system (see Weiss et al., 1990 for the description) on 05.10.89. The mean magnitude difference var-c=1.39^m is slightly smaller than the value 1.62^m obtained during the UBVRI run on 23.09.89. Such deviation may arise due to both the real brightness variation and the difference in the instrumental systems. The mean-squared deviation σ_0=0.067^m is little higher than that obtained on 23.09.89. The results are presented in Fig.2, as well as the "Running Parabolae" fits with Δt=0.035^d and Δt=0.010^d. No significant circular polarization q was detected during our run. The estimates of q varied from -1.1 to 1.8 per cent (64-sec integrations) with the mean value $<q>$=-0.03±0.05 per cent and the mean-square deviation σ_q=0.55 per cent. The mean values of q for the comparison star c and the standard star HD 188326 are -0.10±0.05 and 0.03±0.01 per cent, respectively, i.e. equal to zero within the estimate errors. The brightness variations appeared on the time scale of minutes, not only hours, and we made the periodogram analysis by using the least-squares fit to the observations $x(t_i)$ at times t_i:

$$x(t_i) = a + b\cos(2\pi f t_i) + c\sin(2\pi f t_i),$$

where a, b, c - are the parameters being determined for each trial frequency f. The test-function $S(f)=\sigma_c^2/\sigma_o^2$, where σ_c^2 and σ_o^2 - are variances of the "calculated" and the "observed" values of the signal (cf. Andronov et al., 1991). The "best fit" values of the frequencies, periods, amplitudes $r=(b^2+c^2)^{1/2}$, and test-functions are shown in Table 3 for different peaks on the periodogram. To test the significance of the peak, we used the ratio S/S_n, where $S_n=2/(n-1)$ is the mean level for the periodogram computed for n uncorrelated random values. The "false alarm" probability Pr_a that the peak reached his value occasionally (assuming the "white noise" model for K "independent" frequencies) was computed according to the "long" expression of Scargle (1982) (see also Burnasheva and Gollandskij, 1987)

$$Pr_a = 1-(1-Pr)^K,$$

where $Pr=(1-S)^{(n-3)/2}$ (cf. Andronov et al., 1991). The most difficult question is how to make the valuable estimate of the number K of the "independent frequencies". For n observations equidistantly distributed in time, $K=n/2$, and for the trial frequencies are separated by the value $\Delta f=1/\Delta T$, where ΔT is the full duration of the observational run. Our observations have little gaps, and one may use this estimate of Δf. We computed the test-function at 200 frequencies from 1 to 200 c/d, thus $K\approx 200\Delta f$, or $K\approx 32$ for the UBVRI run and $K\approx 27$ for the V run.

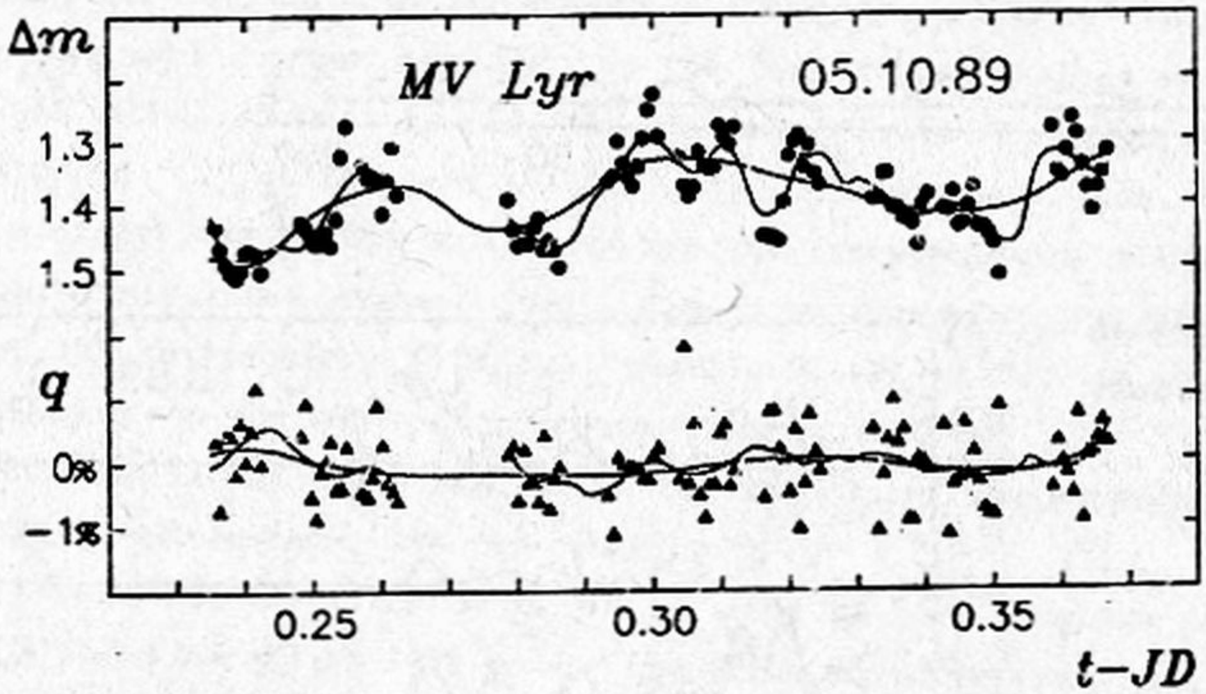

Fig. 2. The V observations obtained at AZT-11 on JD 2447805.

The significant peaks were detected in UBVR at the frequencies $f\approx 8$, 19-28 and 63-71 c/d. The "19-28" and "63-71" spikes appeared to have a complex two-maximum structure. The lowest frequency 8 c/d is close to the orbital one. The period $P_{orb}=0.1336^d$ was suspected by Walker (1966) from the spectral investigations, the brightness variations with such a cycle were detected in the low state by Andronov and Shugarov

(1983). The similar value P_{orb}=0.1324^d was obtained by Vojkhanskaya (1988). This '3-hour' wave is also seen at other light curves, and the most astonishing result is that the "best fit" frequency for the I variations is exactly twice larger without any peak near the orbital frequency. If such variations are due to the distortion of the secondary, this star must undergo the extreme luminosity changes, because the brightness in the low state is by 4-5^m fainter than that during our observations. The irradiation process (Basko and Sunyaev, 1973; King and Lasota, 1984) may not cause such luminosity changes. Moreover, the heated side will produce variations with the orbital frequency. If such variations are due to the noncircular accretion disc, it is not clear why the second harmonic is observed in I only, because the main part of the emission is radiated at shorter wavelengths. This phenomenon must be critically examined by subsequent observations, because it was obtained during only one night.

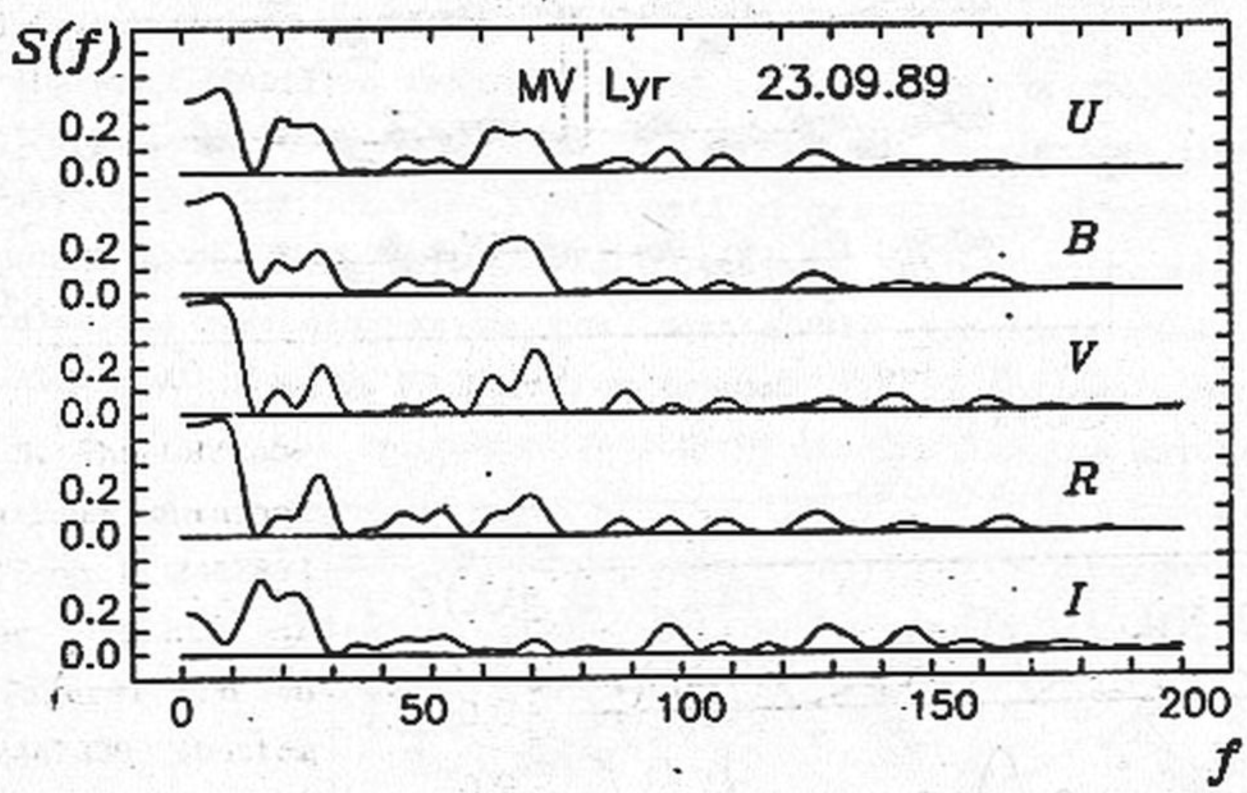

Fig. 3. The periodogram for the observations shown in Fig.1.

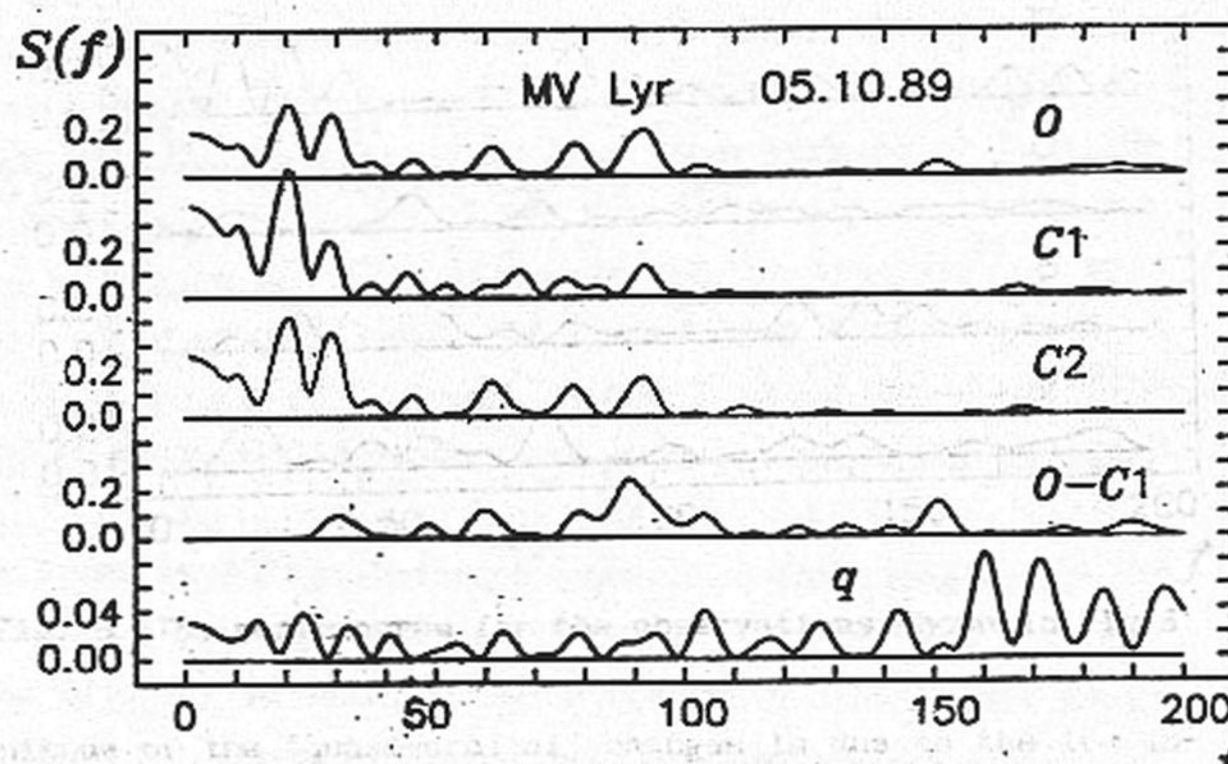

Fig. 4. The periodogram for the observations shown in Fig.2.

It may be noted that the frequency difference between the two maxima of the "splitted peaks" in UBVR variations is close to 8 c/d, i.e. the orbital frequency. One may say as well, that the first three peaks appeared very approximately at the frequencies close to $2f_{orb}$ and $3f_{orb}$. The relative magnitude of "20-min QPO" ($f \approx 60...70$) is the largest in B and V.

Some other behaviour exibits the periodogram for the V observations obtained at 05.10.89. The peak at the orbital frequency is practically not seen, the highest maxima appeared at $f \approx 20$ and 29 (at the same frequences as the "splitted peak" at the UBVRI run). The peak at $f \approx 61$ reached the "6-th place", the larger amplitude has the peak at $f \approx 92$. Thus one may say that the variations in the range 60-90 c/d are transient, whereas the frequencies 20 and 29 c/d may have a more coherent nature (eg. they may correspond to the "beat" and the rotational periods of the white dwarf), if confirmed by the subsequent observations. Some peaks of much lower height one may see on the periodogram for the circular polarization. From this run we removed one observation, which deviates significantly from others (see Fig.2), but seems to be real because it has been obtained independently through two channels. The heighest peaks are seen at the unexpectedly high frequencies 160 and 171 c/d. In the "low-frequency" region $f<100$, where the "photometric peaks" were observed, the highest peak was centered again at $f \approx 23$. However, the formal "false alarm" probability Pr_a is very high, and the peak is not statistically significant. To test the influence of smoothing the real data by the method of "Running Parabolae" (Andronov, 1990), we show also the periodograms computed for the "calculated" values with $\Delta t=0.035^d$ ($C1$) and $\Delta t=0.010^d$ ($C2$). As one may see, the smoothing "cuts" the high-frequency observation. The curve "$C1$" corresponds mainly to the orbital variations, whereas "$C2$" does not change significantly the amplitudes and the frequencies of the oscillations corresponding to all three highest peaks. The curve corresponding to the filter half-width $\Delta t=0.01^d$ satisfactory fits the "quasi-orbital" variations and "20-min" QPOs. The deviations from the curve $C1$ correspond mainly to QPOs.

Some not significant peaks are listed in Table 3, if the significant peak is present at the same frequency, but for other run.

The photoelectric observations of MV Lyr made by S.Yu.Shugarov on the 1.25 m ZTE telescope (Tables A3-A5) in 1989 and on the 60-cm Zeiss telescope during the outburst in 1987 (Tables A6, A7). The instrumental magnitudes were reduced to the standard UBV system. However, the estimate of brightness of the comparison star slightly differs as compared with the previous observations, as one can see in Table 1. The UBV light curves obtained in the high state are shown in Fig. 5.

The smoothed curve obtained by the method of "Running Parabolae" (Andronov, 1990) with $\Delta t=0.035^d$ is fitted to show the "quasi-orbital" variations. Obviously, in the observational gaps, it exibits a "strange" behaviour. The QPOs with a shorter time scale are observed. The periodogram analysis shows no peaks at the orbital frequency $f \approx 8$ c/d, but the peaks at 17, 28 and 86 are present in the first run, and in a wide range 40-60 on the second night. The periodograms are shown in Fig.6, and the highest peaks are listed in Table 3.

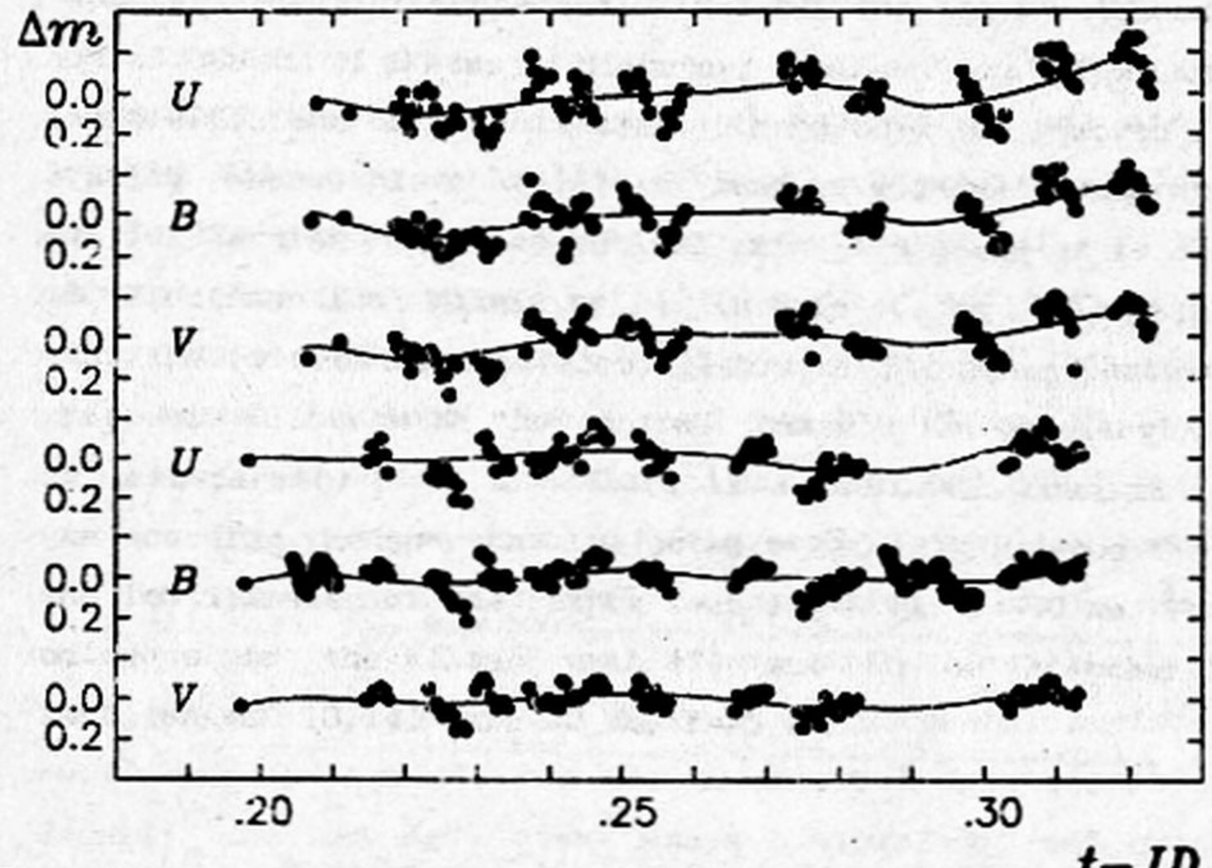

Fig. 5. The UBV observations obtained at ZTE on JD 2447837 (upper part of the Figure) and on JD 2447838 (bottom part). The brightness is shown as the deviation from the nightly mean.

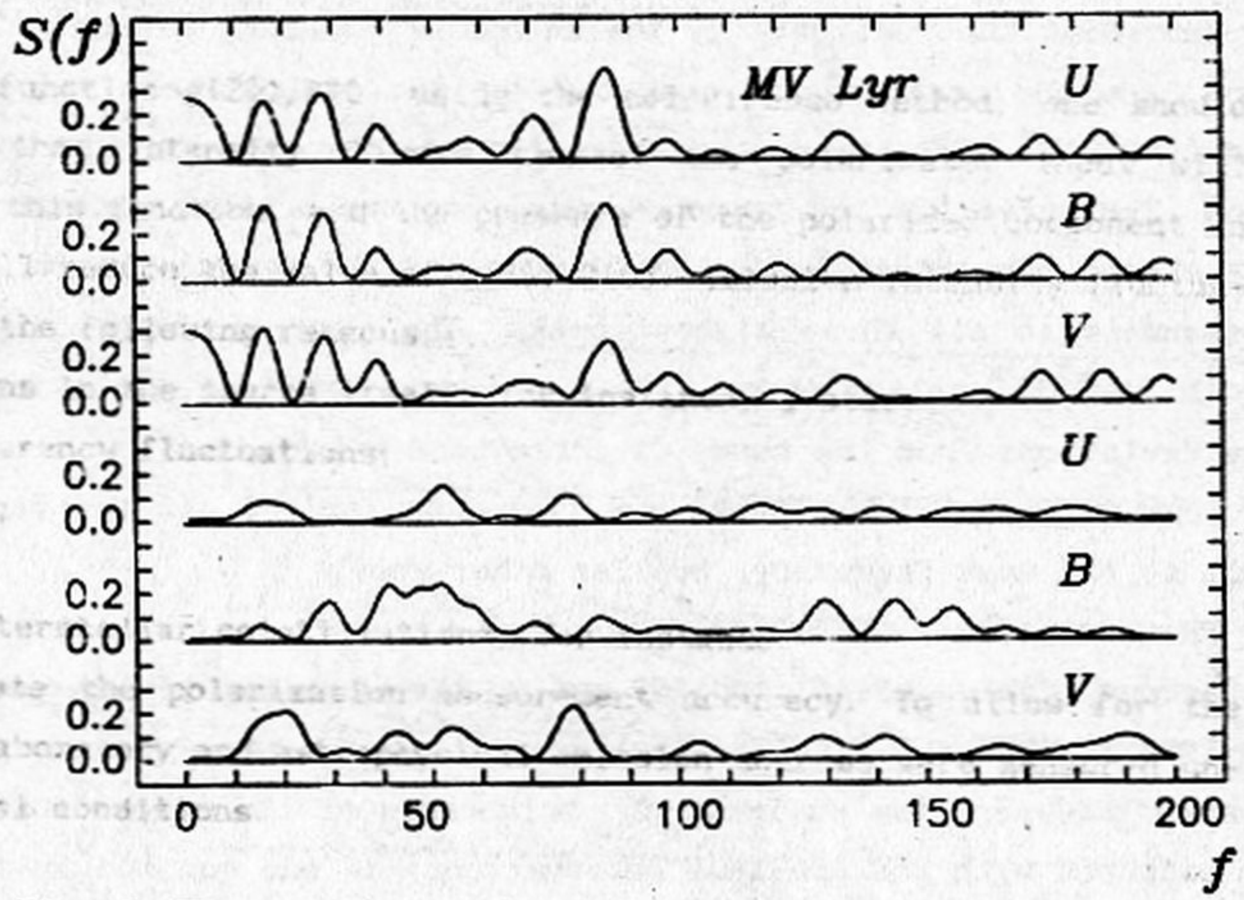

Fig. 6. The periodogram for the observations shown in Fig.5.

The relatively low magnitude of the "quasi-orbital" changes is due to the low inclination of the system (according to Vojkhanskaya, 1988, $i \approx 24°$). The QPOs may arise due to rotation of the magnetic white dwarf. The magnetic field is not so strong, as was suspected earlier, and its strength is not sufficient to prevent the formation of the accretion disc (*AD*), but its influence on the inner layers of *AD* may be quite effective. The alternatives are the following: the QPOs may arise due to the inhomogeneity of the *AD* ('blobby' disc), due to the precession ('twisted' *AD*), or due to the changing location of the 'hot spot' between the precessing AD and the accretion stream.

Another characteristic time is connected with the instability of the outflow from the inner Lagrangian point (King, 1989), which for MV Lyr may be estimated as $0.05P_{orb} \approx 9$ minutes. The corresponding frequency $f \approx 150$ c/d is twice larger as compared with the observed "20-min" QPOs.

Thus the observational properties of MV Lyr 'restored' after a long low state. The recent brightening is not an outburst, it is really a bright state, which began in 1989.

TV OBSERVATIONS

The observations were made at the 0.5 m telescope MTM-500 with a TV detector (see Abramenko et al., 1988, for the description) by E.P.Pavlenko, S.V.Kolesnikov and I.G.Borodina in two modes. First, the image was exposed by using the filter *B*, at second, the stellar images were splitted in four, corresponding to the instrumental *B*, *V*, *R* systems and the "white light" (unfiltered) *W*. The corresponding observations are shown in Tables A8 and A9 as the magnitude differences between the variable and the comparison star *8* (Table 1). The *B* curves obtained during all three nights, are shown in Fig.7. They exibit the "quasi-orbital" changes, QPOs and apparently some "dips", which appear not simultaneously in different filters.

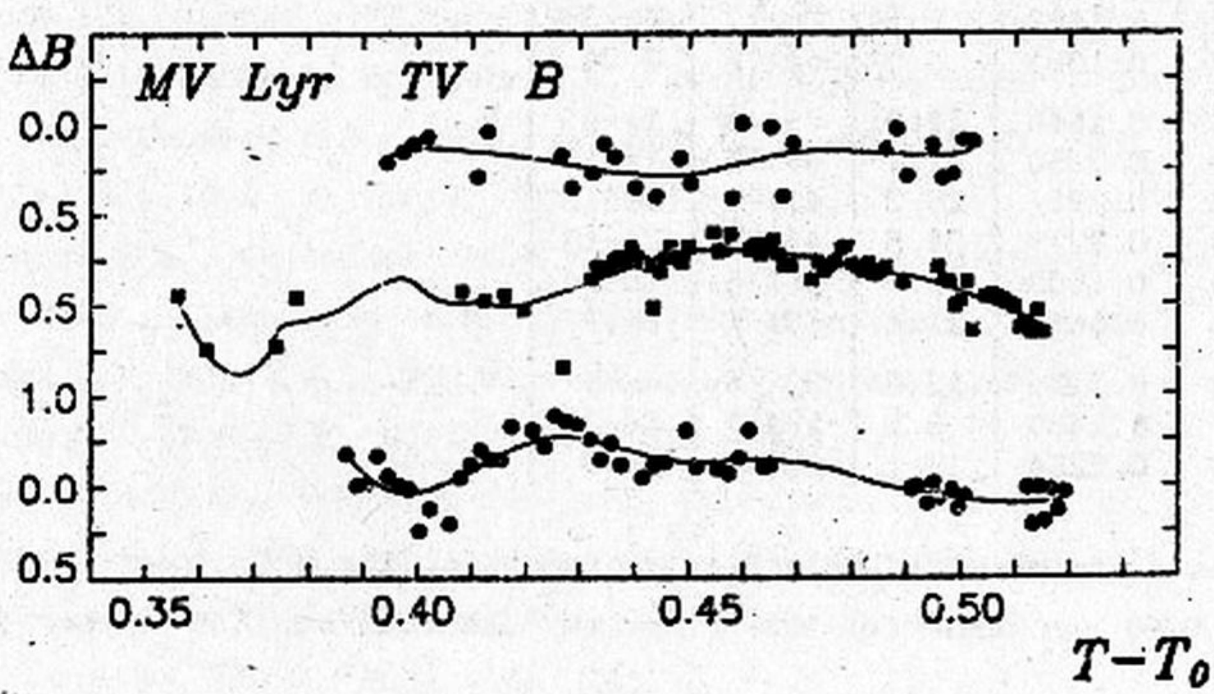

Fig. 7. The TV observations in the instrumental *B* system.

Table 3. The results of the periodogram analysis

f, c/d	*P*, min	*S*(*f*)	S/S_n	*r*	Pr_a	Rem
						AZT-11
7.9±1.4	182 ± 32	0.3528	6.9	51±11	0.010	*U*, mmag
7.5±1.9	192 ± 48	0.4141	8.1	49±10	2e-3	*B*, mmag
6.7±2.9	215 ± 93	0.4768	9.3	61±11	2e-4	*V*, mmag
7.7±1.8	187 ± 43	0.4855	9.5	40± 7	2e-4	*R*, mmag
15.6±1.0	92.3±5.7	0.3196	6.2	42±10	0.025	*I*, mmag
10.4±1.2	139 ± 16	0.1302	7.1	33± 8	0.015	*O*, mmag
20.4± .7	70.5±2.4	0.2950	16.1	50± 7	2e-7	
29.0± .6	49.7±1.1	0.2555	13.9	47± 8	4e-6	
61.2±1.0	23.5± .4	0.1210	6.6	33± 8	0.027	
77.9± .9	18.5± .2	0.1353	7.4	37± 9	0.011	
91.6± .9	15.7± .2	0.1894	10.3	41± 8	4e-4	
150.5±1.7	9.6± .1	0.0517	2.8	21± 9	0.803	
60.0±1.2	24.0± .5	0.1195	6.5	21± 6	0.029	*O–C1*, mmag
89.1± .8	16.1± .1	0.2452	13.4	32± 5	8e-6	
150.8± .9	9.5± .1	0.1481	8.1	24± 6	5e-3	
23.4±1.8	61.5±4.7	0.0384	2.1	13± 7	0.971	*q*, 0.01%
160.2±1.2	9.0± .1	0.0860	4.7	22± 7	0.198	
171.3±1.4	8.4± .1	0.0793	4.3	20± 7	0.278	
						ZTE 2444837
16.4± .6	87.9±3.2	0.2581	15.5	95±15	5e-7	U
27.9± .6	51.5±1.2	0.2904	17.4	94±14	4e-8	
85.8± .6	16.8± .1	0.3871	23.2	109±13	7e-12	
16.6± .5	86.8±2.7	0.3215	19.5	87±12	2e-9	B
28.4± .6	50.7±1.1	0.2877	17.4	82±12	4e-8	
85.7± .6	16.8± .1	0.3218	19.5	86±12	2e-9	
16.2± .6	88.8±3.1	0.3123	18.9	80±11	5e-9	V
28.4± .6	50.7±1.1	0.2766	16.7	77±11	1e-7	
86.0± .8	16.7± .2	0.2544	15.4	73±12	6e-7	
						ZTE 2444838
16.4±3.5	87.9±16	0.0841	4.7	48±15	0.17	U
52.1±1.0	27.6± .5	0.1490	8.3	76±17	4e-3	
77.5±1.3	18.6± .3	0.1083	6.0	64±18	0.04	
29.0± .6	49.6±1.0	0.1644	21.8	39± 6	1e-9	B
41.2± .5	35.0± .4	0.2350	31.1	46± 5	1e-14	
47.5± .7	30.3± .4	0.2211	29.3	41± 5	1e-13	
51.7± .6	27.8± .3	0.2379	31.5	44± 5	7e-15	
129.3± .7	11.1±.06	0.1608	21.3	36± 5	2e-9	
143.6± .6	10.0±.04	0.1614	21.4	36± 5	2e-9	
19.9±1.4	72.3±5.0	0.2086	12.0	33± 6	4e-5	V
53.5±1.4	26.9± .7	0.1403	8.1	29± 7	5e-3	
78.3± .8	18.4± .2	0.2284	13.1	38± 7	1e-5	

Remarks: The amplitudes *r* are measured in millimagnitudes for the brightness variations, and in units of 0.01 per cent for the circular polarization. The number 2e-3 means $2 \cdot 10^{-3}$.

PHOTOGRAPHIC AND VISUAL PHOTOMETRY

The star was studied from the photographic plates of Moscow, Odessa and Sonneberg plate collections. The preliminary results were published by Wenzel (1980ab), Andronov and Shugarov (1982, 1983), Wenzel and Fuhrmann (1983, 1989), Fuhrmann (1985), Gotz et al. (1987), Andronov et al. (1988, 1990), Fuhrmann and Wenzel (1990). Here we present all our observations obtained before 1990. Brightness of the comparison stars was determined by Andronov and Shugarov (1982) and Wenzel and Fuhrmann (1983). The observational results are shown in Tables A10-A12.

After the unusual outburst in 1987, the star was visually monitored by some observers in France, Germany and the United Kingdom. The *AFOEV* observations were published by Verdenet (1989, 1990a). The observations of the members of *BAV* group are shown in Tables A13. The light curve was published by Korth et al. (1988).

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