

# MV LYR: ACCRETION DISC PHENOMENA

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**Abstract:** Photoelectric observations of novalike MV Lyr were carried out at Rozhen and Belogradchik observatories. The observing runs performed in  $U$  and  $B$  bands show quasi-periodic oscillations (QPOs) with period about 50 min and confidence level above the red noise power. As a possible mechanism for MV Lyr quasi-periodic oscillations the model of [1] applied to excitation of trapped oscillations in the outer edge of the accretion disk was suggested. The long-term light curve of the star was compiled for 65 years time interval and analysed for solar-like cyclical activity. The frequency analysis confirmed cyclical variability of accretion disk luminosity found by [2]. The mean lengths of the cycles were obtained more precisely: 4.7 and 21.2 years.

## 1. Introduction

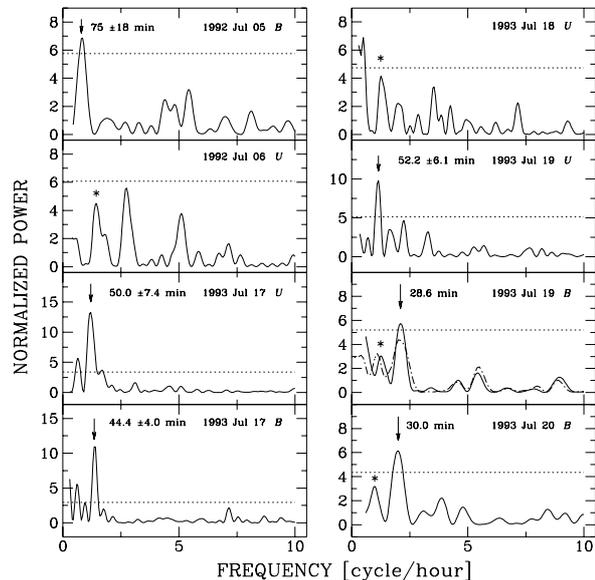
The cataclysmic variable (CV) MV Lyr has been classified during the last years as a VY Scl novalike [3]. Like all CVs, VY Scl novalikes are interacting systems consisting of a late-type star, filling its Roche lobe and transferring matter to the white dwarf primary. As the magnetic field of the VY Scl primaries is weak, the transferred matter forms an accretion disc out of which it is accreted onto the white dwarf. The luminosity of the system is principally due to the accretion disc and hence investigations of light curves give a possibility to study disc activity. The main peculiarity of the light curves of the CVs is the existence of continuous brightness variations in timescales from seconds and minutes through hours and days to several years. The long-term photometric characteristics of MV Lyr were established photographically by [4], [5], [6], [7], [8], [9] and [10]. These investigations showed that MV Lyr brightness varies irregularly between high ( $B \simeq 12.5$  mag) and low ( $B \simeq 18$  mag) states. Photoelectric studies of the star in high state carried out by [11] and [12] pointed at  $0.^d1379$  and  $3.^d8$  modulations presented simultaneously. The existence of quasi-periodic oscillations (QPOs) with period near 47 min has been assumed also.

## 2. Data and data analysis

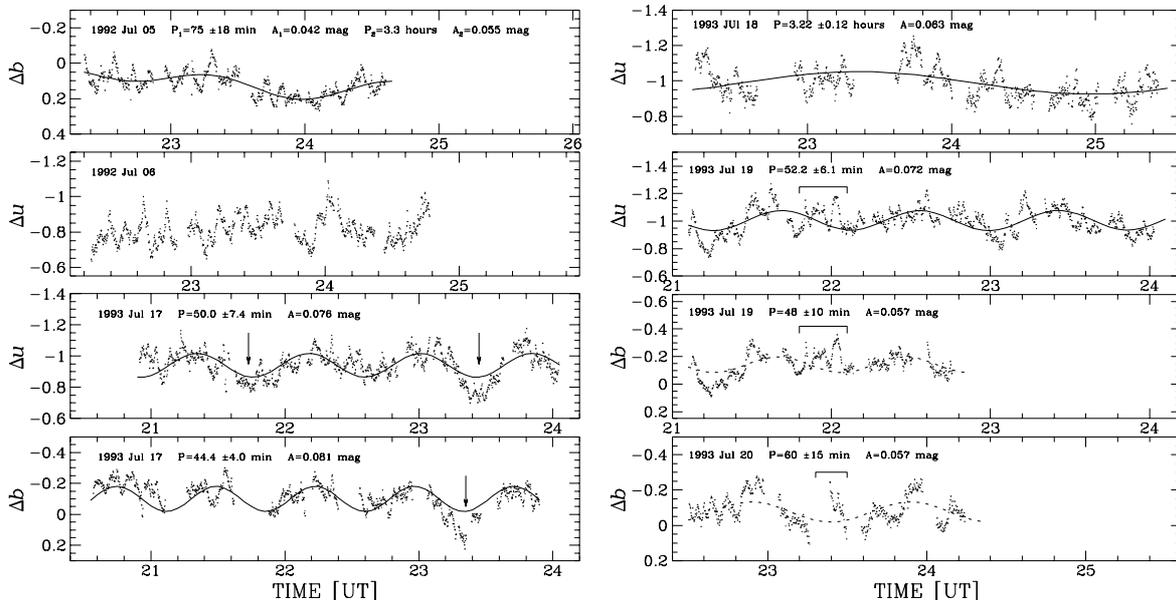
The data consist of 8 photoelectric series in the  $U$  and  $B$  photometric bands with duration from 1.6 to 3.3 hours. Apart from these runs, there are 35 additional measurements in the standard  $UBV$  system obtained from July 1992 to October 1993. The integration time for all observations was 10 sec and star "C" [13] served as a comparison star. During all nights of observations MV Lyr was in high state  $V \simeq 12.5$  mag. All observations were carried out with the one-channel photometers attached to the 60-cm Carl Zeiss telescopes of the Rozhen and Belogradchik Observatories of the BAS. The observational data were processed with the reduction software described by [14].

The method of Scargle [15] was applied to search for periodic variations in MV Lyr light curves. The power spectra of the MV Lyr photoelectric runs show a typical for a red noise shape: power law  $P(f) \sim f^{-\gamma}$  in the high frequencies. This considerably modifies the power distribution and the use of "false alarm" probability gives an unreal high statistical significance of the detected peaks. According to van der Klis [16], the variance of the red noise power spectrum is proportional to the local mean power  $\sigma_P \sim \langle P \rangle$ . A correct procedure would then be to divide the PS by some mean red noise shape in order to bring the spectrum back to constant variance and then to evaluate the significance of the peaks. In the case of MV Lyr the mean red noise shape would be found through fitting the PS to function  $\alpha/(1 + (2\pi f\tau)^\gamma)$  ( $\alpha$ ,  $\tau$  and  $\gamma$  are the parameters which we search for). Unfortunately, because of the large power scatter and the three unknown parameters, the fitting procedure fails in the low frequencies and in practice we cannot use it. To estimate the statistical significance of the peaks in the PS we used a rougher procedure. The PS of MV Lyr light curves are nearly constant in the frequencies approximately below 10 [c/h]. This allows to apply "false alarm" probability without normalization of the power spectra in the frequency interval from 0 to 10 [c/h] [17]. The power distribution in PS was approximated with exponential function  $\exp(-P/P_0)$  and 99% significance levels were calculated by

equation:  $z_0 = -P_0 \ln(1 - 0.99^{1/K})$ .  $K \simeq 10/\Delta f$  is the number of the independent frequencies in the interval 0–10 [c/h] and  $\Delta f = 1/T$ , where  $T$  is the total length of the run. To determine the power distribution better, the spectra were oversampled by factor of 3. The results are shown in Fig. 1. The uncertainties included in the figure are equal to HWHM of the peaks. In four of the runs statistical significant periodicities of about 50 min were detected. In all other runs peaks corresponding to "50 min" QPOs are seen also, but they are below 99% significance level. There are two peaks corresponding to periods about 30 min which are detected as significant also. Our opinion is that they are not due to real periodicities. The reasons for their presence can be the small length of these runs and some strong flickering peaks appearing in the minimum of "50 min" QPOs (Fig.2). The *B* runs on 19 and 20 Jul, 1993 contain only two maxima of "50 min" QPOs and the flickering peaks at the minimum cause the peak in the PS corresponding to a period shorter by factor of 2. We calculated the PS of this part of *U* run on Jul 19, 1993 (with gaps introduced as in the *B* curve) which coincided with *B* curve. From Fig.1 it can be seen that the two PS are almost the same. Although the peaks of "50 min" QPOs in the PS of the *B* runs on Jul 19 and 20, 1993 are not significant, the data allow to be fitted with the corresponding periods. The revision of the individual light curves showed that modulations with period about 3 hours could be suspected in the light curves from July 05, 1992 and July 18, 1993 only. The sinusoidal fits to the individual light curves obtained using the found periods and the amplitudes determined from these fits are shown in Fig. 2.

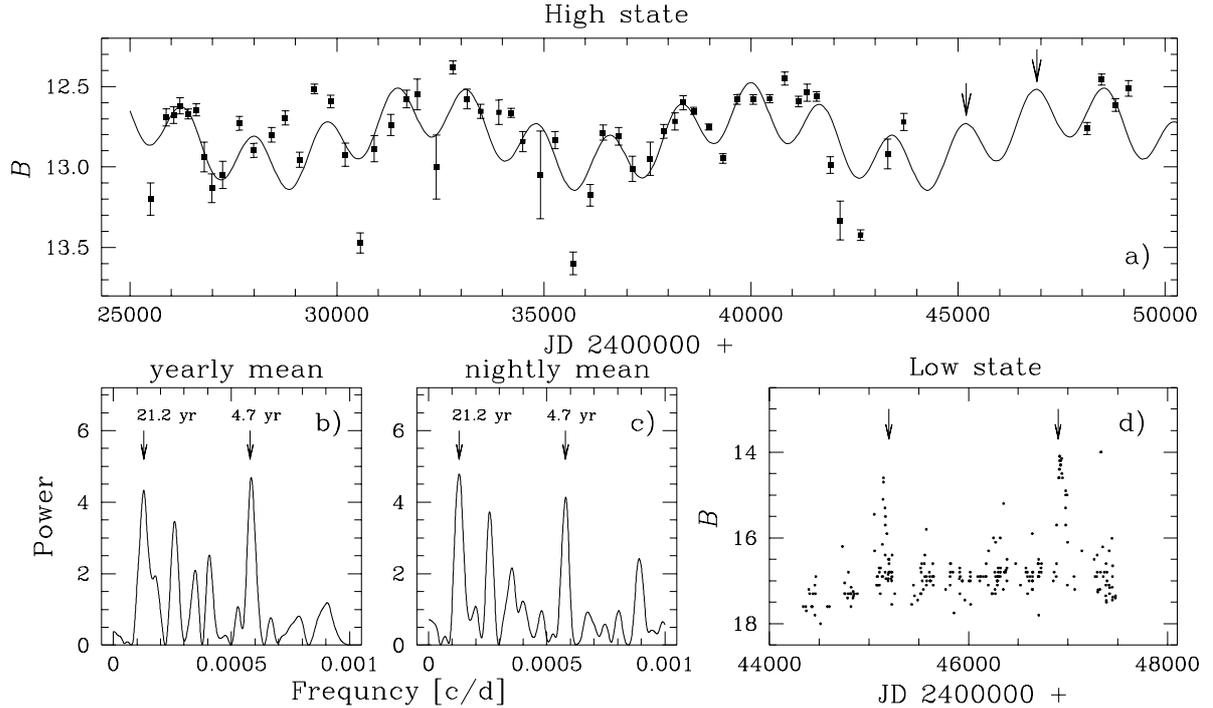


**Figure 1.** Power spectra of MV Lyr light curves (normalized to the mean power). Dashed lines mark 99% significance levels. Dash-dotted curve is the PS of a part of the *U* run on Jul 19, 1993 as discussed in the text. \* marks the peaks of "50 min" QPOs below 99% significance level.



**Figure 2.** The light curves of MV Lyr and the best fits to them. The arrows mark the deeper minima of the QPOs discussed in the text. □ marks the strong flickering peaks appearing in some minima of the QPOs. The fits with dotted lines are performed with periods corresponding to peaks marked with \*.

The long-term light curve of MV Lyr compiled by [2] was complete with exact values of Sonneberg data [7] and now covers 65 years. The observations come from Sonneberg, Asiago and Rozhen mainly.



**Figure 3.** (a) Yearly averaged long-term light curve of MV Lyr fitted with 4.7 yr and 21.2 yr periods. Error bars correspond to the standard error of the mean.; Power spectra of the yearly (b) and nightly (c) averaged long-term light curve in high state. (d) Light curve of MV Lyr in low state. The arrows mark the maxima of 4.7 yr wave found from the high state fit. They clearly coincide with the two increases of the brightness.

Only high state magnitudes were analysed for cyclical variations. The power spectra of averaged over a year and a day long-term light curve are given in Fig.3b and 3c. The strongest peaks in both periodograms correspond to cycles of  $4.7 \pm 0.2$  yr and  $21.2 \pm 4.8$  yr. The uncertainties are equal to HWHM of the peaks. Sinusoidal fit of the year averaged curve with the two periods is shown in Fig.3a. The amplitudes of both waves are 0.17 mag. The deviations from the fit most probably are due to variations of the shape and the duration of the individual cycles. It is remarkable that the two  $\sim 2.5$  mag increases of the star luminosity in the low state coincide with moments of maxima of 4.7 yr wave determined from the high state fit (Fig.3d). According to current ideas, solar like activity cycles in the secondary would cause small changes in its radius and modulate the mass transfer rate. This can be detected by several ways and one is to investigate the long-term brightness variations of CVs. Detected in MV Lyr cycle durations are in agreement with those known for single stars and other CVs.

### 3. Discussion

The periods of statistically significant QPOs observed in MV Lyr vary about 50 min. Accepting system parameters  $M_{\text{wd}} = 0.7M_{\odot}$ ,  $M_2 = 0.3M_{\odot}$  [12] and  $P_{\text{orb}} = 0.1336^{\text{d}}$  [18] we found that at distances  $r = 0.8 - 0.9R_{\text{RL}}$  ( $R_{\text{RL}}$  is Roche lobe radius of white dwarf) the Keplerian periods are  $P_{\text{K}} = 43 - 54$  min. Therefore, if MV Lyr accretion disc extends to  $0.8 - 0.9R_{\text{RL}}$ , its outer edge can be responsible for the observed QPOs. Borisov [11] suggested that "50 min" QPOs may be connected to the inhomogeneity motions at the disc outer edge induced by the gas stream from the red companion. We tried to apply the model of the trapped oscillations developed by [1] and originally directed to explain observed QPOs in dwarf novae during outburst. According to the thermal instability scenario, during the outburst the accretion disc consists of two parts with different physical conditions: a hot inner region where the hydrogen is fully ionized and outer cool region in which the hydrogen is neutral. Between these two parts there appears a narrow transition zone where the hydrogen is partially ionized. Yamasaki et al. [1] has shown by a linear analysis that there are modes of growing oscillations which are trapped just inside the transition zone and their period is approximately equal to the local Keplerian period. Since resulting brightness variations are a sum of oscillations with close periods, large amplitude QPOs can be expected.

In active state VY Scl type novalikes contain hot accretion discs and typically exhibit relatively steady high mass transfer rate  $\sim 10^{-8} M_{\odot} \text{ yr}^{-1}$ . We assumed that in some of these systems the outer edge of the disc might be cool enough to allow recombination of the hydrogen and thus might play the part of transition zone necessary for excitation of trapped oscillations. Further, the accretion rate that could cause partial recombination of the hydrogen in the outer part of MV Lyr accretion disc was estimated. According to [19] the radial distribution of the disc effective temperature is

$$T_{\text{eff}}(x) = T_0 x^{-3/4} (1 - x^{-1/2})^{1/4} \text{ K}, \quad (1)$$

where  $x = r/R_{\text{wd}}$ ,  $R_{\text{wd}}$  is the white dwarf radius calculated according to [20] and

$$T_0 = 4.1 \times 10^4 \dot{M}_{16}^{1/4} M_1^{1/4} R_{1,9}^{-3/4} \text{ K}, \quad (2)$$

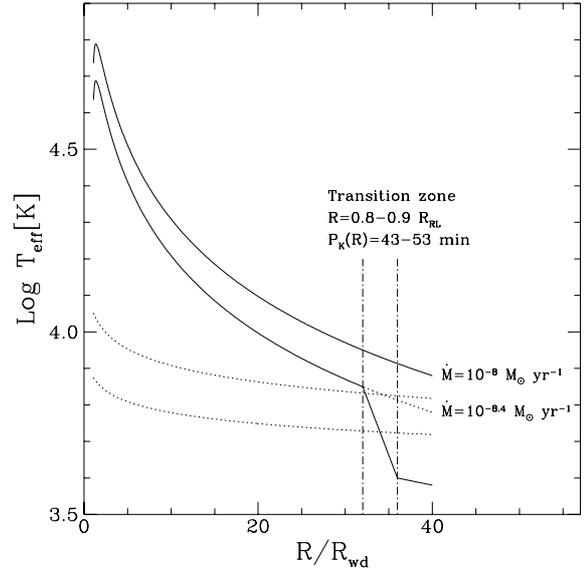
$\dot{M}_{16}$  is the mass transfer rate in units  $10^{16} \text{ g s}^{-1}$ ,  $M_1 = M_{\text{wd}}/M_{\odot}$  and  $R_{1,9}$  is the white dwarf radius in units  $10^9 \text{ cm}$ .  $T_{\text{eff,max}}$  and  $T_{\text{eff,min}}$  at which the accretion disc changes its structure were evaluated according to [21]. The results are shown in Fig.4. It is seen that if the mass transfer rate is  $\sim \dot{M} = 10^{-8.4} M_{\odot} \text{ yr}^{-1}$  the hydrogen in the outer disc parts ( $r > 0.8R_{\text{RL}}$ ) will be partially ionized and consequently generation of QPOs with periods 43 – 54 min can be expected, such as observed in MV Lyr. In two of the runs, periods longer than expected were detected. In this case period determination may be strongly affected by flickering, gaps and the small length of the runs. To understand the behaviour of the QPOs in MV Lyr light curves better, regular, long photometric observations are needed.

#### Acknowledgements.

We are very indebted to W. Wenzel who has put Sonneberg data at our disposal. The work was supported by NFSR under projects No. 346/93 and No. 715/97.

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**Figure 4.** Radial distribution of effective temperature in MV Lyr accretion disc (solid curves). The dotted curves point at  $T_{\text{eff,max}}$  and  $T_{\text{eff,min}}$  at which the disc changes its structure. The dashed-dotted lines limit the zone in which radial oscillations can be trapped.