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Variations of the superhump period of V368 Peg: monotonicity or frequency doubling ?

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The superhumps have been detected during the superoutburst in 2000, justifying the SU UMa subtype classification. The decrease of the photometric period with luminosity by a factor of 2.3 times has been detected. The models of the smooth character of this dependence vs the "smooth variation + frequency doubling" are discussed. At the brightness maximum, the presence of the "shot noise" is registered.

ИЗМЕНЕНИЕ ПЕРИОДА СВЕРХГОРБА V368 ПЕГАСА: МОНОТОННОСТЬ ИЛИ УДВОЕНИЕ ЧАСТОТЫ? Острова Н.И., Андронов И.Л., Катышева Н.А. – Обнаружены сверхгорбы во время сверхвспышки 2000 года, что подтверждает принадлежность системы к подтипу SU UMa. Обнаружено уменьшение фотометрического периода со светимостью в 2.3 раза. Обсуждаются модели постепенного характера этой зависимости и "постепенные изменения + удвоение частоты". В максимуме блеска зарегистрировано наличие "дробового шума".

ЗМІНА ПЕРІОДУ НАДГОРБА V368 ПЕГАСУ: МОНОТОННІСТЬ ЧИ ПОДВОЄННЯ ЧАСТОТИ ? Острова Н.І., Андронов І.Л., Катишева Н.А. – Виявлені надгорби під час надспалаху 2000 року, що підтверджує належність системи до підтипу SU UMa. Виявлене зменшення фотометричного періоду із світністю в 2.3 рази. Обговорюються моделі поступового характеру цієї залежності та "поступових змін + подвоєння частоти". У максимумі блиску зареєстрована наявність "дрібового шуму".

1. PHOTOMETRIC OBSERVATIONS OF V368 PEG

The dwarf nova V368 Peg was discovered in 1999 by Antipin [5]. Besides the "normal" outbursts, explained by the instability of the accretion disk, the star exhibits also brighter "superoutbursts", probably, caused by the increase of the accretion rate and precession of the elliptic accretion disk. On this basis, V368 Peg was classified as the SU UMa – subtype star. Unfortunately, any physical characteristics are not known for this newly discovered star, as it is practically not yet sufficiently studied.

To study the variability of the star, the observations were obtained by N.I.Ostrova, N.A.Katysheva and S.Yu.Shugarov from JD 2451789.41 to 2451799.56 during the superoutburst and the subsequent brightness decrease. At the maximum, the observations were carried out at the 38cm telescope equipped with the CCD camera ST-7 (JD 2451789–792) of the Crimean Astrophysical Observatory. At JD 2451794–798, the data had been obtained using the 125 cm ZTE telescope of the Crimean laboratory of the Sternberg State Astronomical institute (SAI) equipped with the CCD camera ST-6. The images were obtained using the R-filter. The exposure time varied from 10 to about 120 seconds. Altogether, 7 nights of observations (total number of points 416) have been obtained. The characteristics of observational nights are listed in the Table 1.

In the Fig.1, the overall light curve is shown, representing 4 nights during the superoutburst and 3 nights after. Here ΔR – is the average difference between the brightness of the variable star and of the comparison star.

The image processing was carried out using the program CCD-BIG by V.P.Goranskij. To take into account a difference of sensitivity of pixels, the images have been corrected using the dark current and flat field. The analysis of the brightness variations during separate nights (Fig.2) has confirmed that this star belongs to the SU

Table 1. Journal of observations of V368 Peg in the R- filter.

JD 24...	Starting time	Ending time	Number of observations	Mean value, mag	scatter, mag
51789	0.419	0.597	83	1.434	0.724
51791	0.427	0.518	64	1.583	0.593
51792	0.457	0.602	111	1.740	0.546
51794	0.412	0.493	62	2.079	0.445
51797	0.524	0.571	33	4.783	0.128
51798	0.459	0.573	62	4.870	0.120

Table 2. Periodogram of the analysis of observations V368 Peg. In the brackets, the period values are shown for the model without trend.

JD 24...	*P*, days	*r*, mag	$\Delta R=C_1$, mag	C_4, mag	S_{max}	σ, mag
51789	0.0649±0.0012	0.075	1.431±0.006	-0.170±0.111	0.497	0.052
51791	0.0784±0.0047 (0.1421±0.0748)	0.062	1.559±1.049	-4.887±6.783	0.623	0.038
51792	0.0726±0.0023	0.052	1.737±0.004	-0.240±0.097	0.457	0.040
51794	0.0561±0.0047 (0.1292±0.0883)	0.032	2.104±0.059	3.650±5.444	0.513	0.029
51797	0.0284±0.0023	0.089	4.798±0.017	5.092±1.247	0.333	0.093
51798	0.0314±0.0008	0.110	4.875±0.011	1.181±0.357	0.476	0.088

Uma-subtype because of the presence of prominent photometric waves which may be interpreted as superhumps. They may originate from the precessing accretion disk because of tidal resonance with the secondary component (cf. Osaki [6, 7]).

By varying the parameter Δt, the scalegram analysis was made [3]. As the test-function, dependent on the filter half-width, we have used the unbiased estimate of the standard deviation of observations from the fit. Such scalegrams for all nights of observations are shown in Fig.3.

This scalegram shows a presence of variability, dominated with superhumps during all nights. The sharp decrease of the scalegram's slope with a decreasing brightness is observed. This may be interpreted by an increase of noise in the signal. The brightest night JD 2451789 differs from others, as, besides the superhumps, the variability was detected, which may be explained by a presence of the shot noise, or of the chaotic variations. It is characterized by a large slope of the linear part of the "$\lg\sigma - \lg\Delta t$" curve. Such a behaviour is characteristic for this type of variability.

The appearance of the shot noise may be interpreted by two possible processes. At first, the accretion stream collides with the bright spot. The increase of the accretion rate during the superoutburst may lead an increase of the number of relatively strong blobs, the interaction of which cause a shot noise. Another reason of such variability can be discontinuities of the external parts of the disk. They arise because of unequal speeds of blobs in various regions of the accretion disk or because the stream impact causes a percussion of external parts.

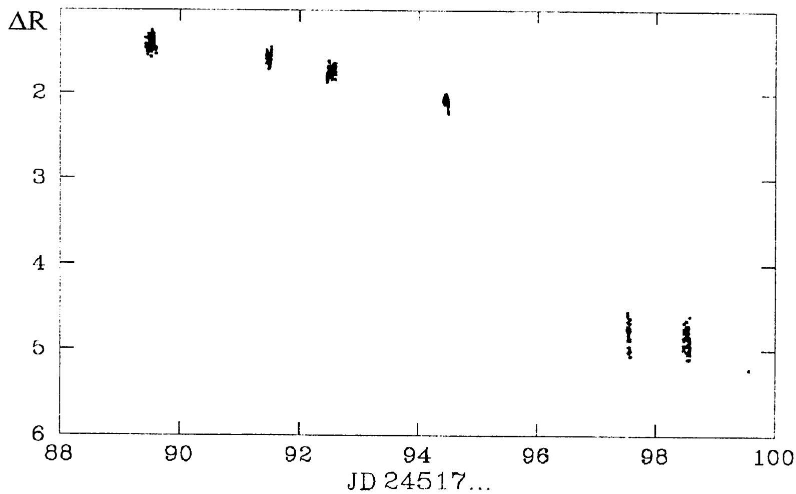

Fig.1. Light curves of V368 Peg

2. PERIODOGRAM ANALYSIS OF THE OBSERVATIONS.

The periodogram analysis of the observational data was carried out by using of the program Four-! [2], implementing harmonic approximation by the least squares method. However, because of the presence of a significant trend in some nights, the program was altered, suggesting a linearity of the trend, and using a mathematical model:

$$x_C(t) = C_1 + C_2 \cos\omega(t - t_m) + C_3 \sin\omega(t - t_m) + C_4(t - t_m) \quad (1)$$

where $x_C(t)$ is the signal at time t, t_m is the mean time of observations, $\omega = 2\pi/P$, P – is the trial period. The semi-amplitude $r = \sqrt{C_2^2 + C_3^2}$.

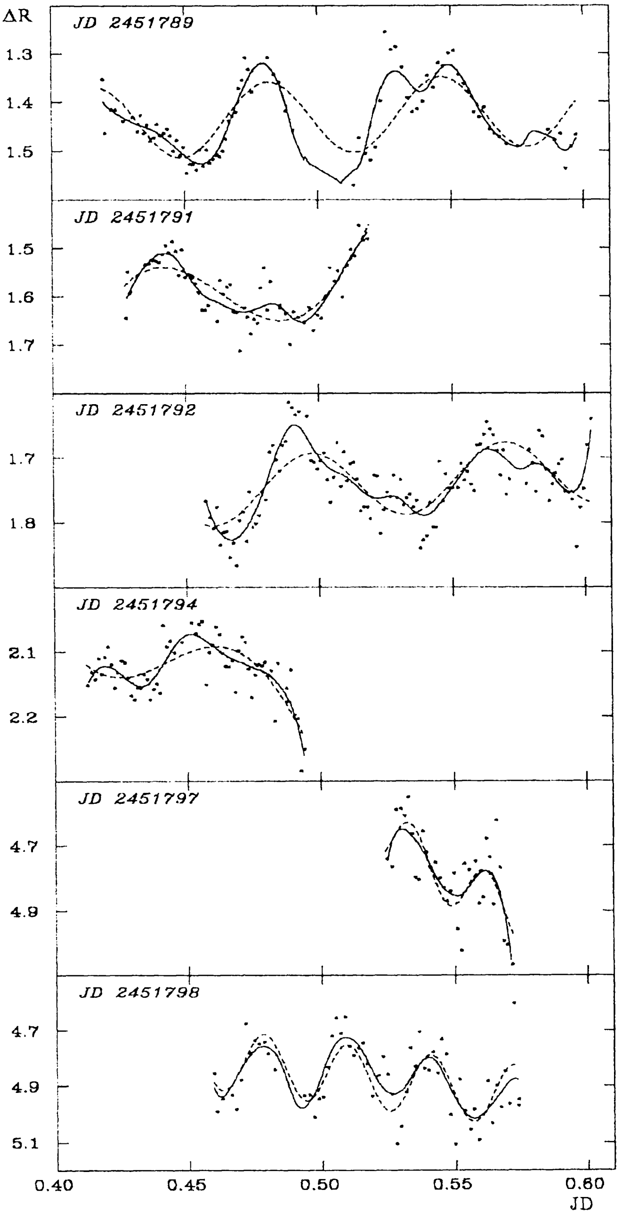

Fig.2. Light curves of V368 Peg. Points: the observations; solid line – the running parabola fit with a filter half-width of $\Delta t = 0.019$ day; dashed line – the "sine+linear trend" fit.

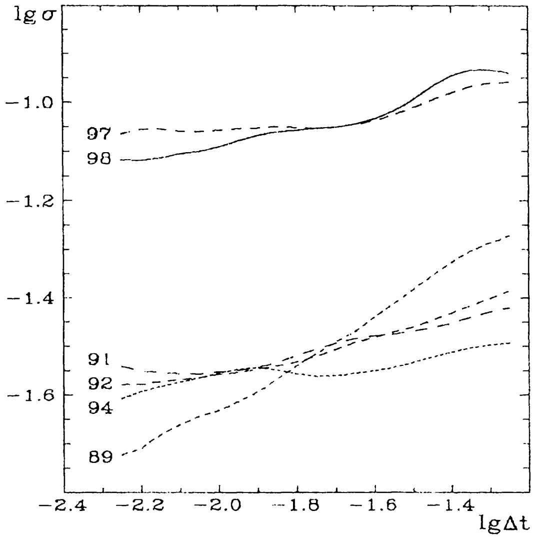

Fig.3. Test functions $\sigma = \sigma_{o-c}$ for 6 nights of observations of V368 Peg.

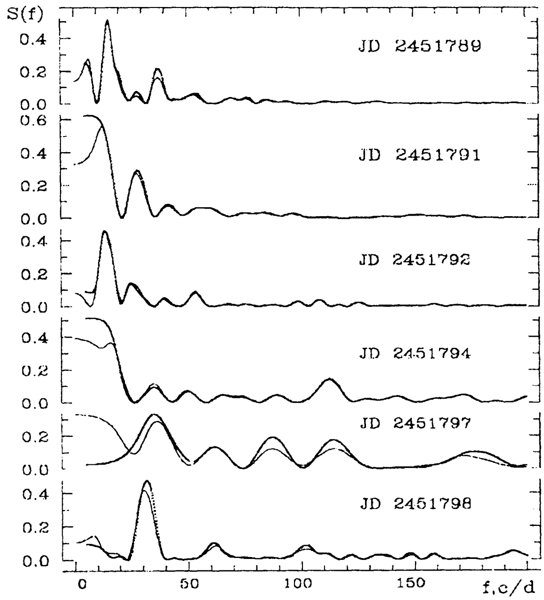

Fig.4. Periodograms for 6 nights of observations of V368 Peg: solid line for the sine fit without trend; points for the sine fit with linear trend (1).

The periodograms for 6 nights of observations are shown in Fig.4. During the night JD 2451791, the brightening of the star at the end of the most short run has caused an essential deviation of the formal period from the realistic value. Therefore, for this night, the model without a trend was used. The sharp weakening of brightness at the end of the run at JD 2451794 has caused a formal doubling of the period. However, after deleting last four (probably, bad) points, the appropriate value of the optimal period became comparable with the values obtained for other nights. The results of the periodogram analysis, taking into account these notes, are listed in the Table 2. One may note that, for short runs, the accuracy estimates of the slope exceed the corresponding values. One may note period difference, if applying models with and without trend.

One may note a significant distinction between the optimal values of the period in the first four nights (when the star was bright), and in the last two nights (when the superoutburst was already completed). Thus the photometric period varies from values of 0.056–0.078 days in the active state down to 0.028–0.031 days in the inactive state, i.e. by a factor of 2.3 times.

Such a behaviour is not understood within the generally accepted model of superhumps, where the change of period may be suggested as a precise frequency doubling owing to the effect of the ellipticity (or, generally, dominance of the $m = 2$ mode of the non-radial structure) of the accretion disk (two maxima per one period of rotation in respect to the observer).

3. VARIATIONS OF THE SUPERHUMP PERIOD – MONOTONICITY OR FREQUENCY DOUBLING?

Suggesting a linear relation between a logarithm of period and the stellar magnitude, and neglecting the weight difference, the following relation was obtained:

$$\lg P = -1.280(\pm 0.022) - 0.113(\pm 0.013)(\Delta R - 2.75) \quad (2)$$

or, taking into account the weights according to the accuracy estimates of the values of period

$$\lg P = -1.39(\pm 0.21) - 0.098(\pm 0.022)(\Delta R - 3.67) \quad (3)$$

The ratio of the coefficient of correlation r to the value of its error estimate $\sigma_r = \sqrt{(1-r^2)/(n-2)}$ is equal to 8.6 and 4.4, respectively. In this approximation, the power index in the ratio $L \sim P^\gamma$ is equal to $\gamma = 3.35 \pm 0.39$ ($\gamma = 3.97 \pm 0.90$ for a case of different weights), what is much more than the value $\gamma = 1.0 \pm 0.2$ obtained by [4] for the nova-like star BZ Cam with considerably smaller amplitude of variations of the average brightness.

In the Fig.5, the diagram "photometric period – the mean stellar magnitude" is shown. The larger error estimate of the photometric period for the 2 and 4-th nights, is owed to a relatively short length of the run. Unfortunately, there are no points in the diagram between the groups of bright and low states. Therefore, in this case, the observable effect of decrease of the superhump period may be interpreted by two possible models.

Considering the precise frequency doubling of the superhumps at the end of the superoutburst, one has to suppose a "switch-like" character of the period variations. During the superoutburst, the system brightness is at maximum. The base frequency – the frequency of a superhump therefore is visible. The contribution from harmonics is relatively small. With a decreasing brightness, the amplitude of the main wave decreases, and may become more important an effect of ellipticity of the asymmetric (not only elliptic) accretion disk. Thus the first harmonic becomes dominating over the main

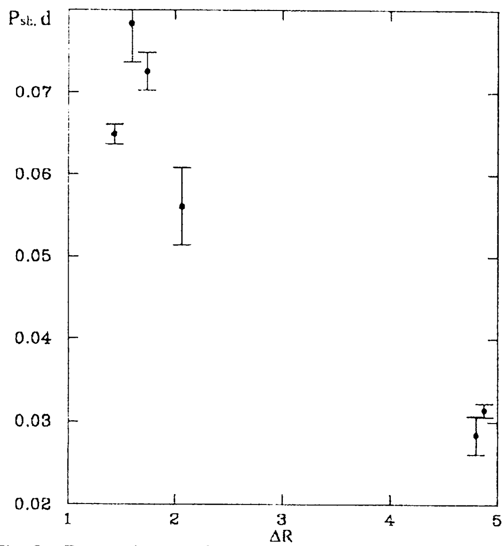

Fig.5. Dependence of the photometric period on the mean magnitude.

oscillation. This causes a precise doubling of the frequency value. According to this model, there is a sharp switch of the period values, and, therefore, the intermediate values should not be observed.

If the period varies not so sharply, a model of monotonic decrease of period is applicable. That is, with decreasing brightness of the system, the oscillation frequency grows and, equally, the period of a superhump gradually decreases. This may be a case observed in BZ Cam, the star at a nearly continuous outburst, sometimes interrupting by the excursions to a low luminosity state [4]. This effect can be interpreted by a decrease of period of rotation of the blob at the outer parts of the accretion disk owed to a step-by-step decrease of its characteristic radius. Thus, at the end of the superoutburst (when the system luminosity approaches its minimum), elliptic accretion the disk accepts gradually circle form. Therefore the photometric period P should come closer to the orbital value P_{orb}.

A "symbiotic" model may be proposed, according to which, the period decreased by a dozen per cent at the top of the outburst. Then the first harmonic becomes dominant at some level, causing the apparent frequency doubling (or, equally, the photometric period switch).

The final choice between models of step-by-step and "switch-like" variation of the photometric period can be made only when obtaining new observations during the superoutburst at a level of a luminosity, intermediate between an inactive state and the supermaximum.

CONCLUSION

The research of the dwarf nova V368 Peg has confirmed that this star belongs to the SU UMa subtype. The superhumps during the outburst have been detected. At the bright state, the presence of the red noise was revealed, that is rather rare for these systems. The photometric period variation with brightness is very clear, and the monotonic dependence may be suggested. However, it may not be justified or ruled out because of lack of observations at the descending branch between the bright and faint states. Another possibility is the gradual decrease of the period with luminosity at maximum with a subsequent frequency doubling at some level, where the Fourier harmonic becomes dominant over the main wave. The period ratio does not justify the effect of precise superhump frequency doubling while changing from the superoutburst maximum to its end. New observations are needed to cover the "period – luminosity" relation more densely, with a high importance of multilongitude campaign, taking into account a rapid decline from the superoutburst. If the frequency doubling occurs, the brightness level should be detected, where it takes place. If not, the parameters of the smooth variation should be obtained for further theoretic explanation. The theoretical explanation of the photometric period change of V368 Peg is to be proposed.

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