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STUDY OF SUPERHUMPS IN THE RECENTLY DISCOVERED SU UMA DWARF NOVAE

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ABSTRACT

In this work we present the results of light curve analysis for two cataclysmic variables detected recently in the SDSS project: SDSS J090350.73+330036.1 and J150240.98+333423.9. Photometric observations of the first were obtained during a superoutburst in May 2010. Our observations clearly indicate the presence of superhumps in the light curves, suggesting SDSS J090350.73+330036.1 is an SU UMa dwarf nova. We determined the period of the superhumps. We also carried out fitting using a spiral-arm model in order to determine parameters of the accretion disk, hot line, and other components of this system. Photometric observations of the second, J150240.98+333423.9, were obtained during the post-maximum decline, during April-June 2012. Photometric variability of this system has been studied in an inactive state. We obtained its parameters via a combined model fitted to the observed light curves by χ^2 minimization.

Key words: Cataclysmic variables: SU UMa dwarf novae: photometry: light curves: individual – J090350.73 + 330036.1; J150240.98 +333423.9.

1. INTRODUCTION

The main factor characterizing a binary system is the shape of its light curve. The processes in accretion disks of different stages of activity can be studied in detail using the light curves of catalysmic variables, as the nature of the stellar components of CVs is known fairly well (non-magnetic white dwarfs and normal stars), and their orbital variability can often be used to reliably determine the geometry of the binary system. By fitting the light curve of a close binary system using a specific model, we can determine the parameters of the stars, accretion disk, matter flows, and other components of the system, as well as estimate to what degree the model considered can plausibly explain observed features in the light curve. In this work, we analyze detailed light curves of two poorly studied cataclysmic variables, SDSS J090350.73+330036.1 and SDSS J150240.98+333423.9, which were obtained using photometric observations. We describe the models which were used for determination of the parameters of these systems and considered variations of these parameters in the course of our observations.

2. SDSS J090350.73+330036.1

2.1. Observations

This object was identified as a new CV in the fourth year of the SDSS (2004–2005), and suspected to be an eclipsing binary Szkody et al. (2005) with an amplitude of variability $\sim 1^m$ on a time scale of about 80-90 min. The eclipsing nature of J0903 was confirmd by Littlefair et al. (2008). He also estimated the parameters of this system from an analysis of the white dwarf eclipse. The J0903 system was in an inactive state between September 2004 and May 2010. Information on the sharp increase of the brightness of J0903 by $\sim 4^m$ appeared after May 20, 2010 (vsnet-alert No. 11999, 2010). Subsequent observations of this object (including ours) displayed obvious superhumps in the light curve. Our observations started 24 May and lasted until 30 May, 2010 on the 60 cm telescope of the Sternberg Astronomical Institute in Crimea, with Apogee 47 detector (528×512 pixels, 1 pixel = 12 mkm) in R band. The brightness of J0903 declined at the rate of $0^m.11$ per day (1^m for 8.8^d, in good agreement with the typical value 9^d for SU UMa stars). This first detected superoutburst for J0903 was observed by five teams; the observational data, including ours, were collected in a survey by Kato et al. (2010). We improved the orbital ephemerides of J0903 system from this paper. The ephemerides

Min.phot. = JD2455342.33444 + 0.059073525^dN

were used to calculate the orbital phases in our analysis at the observational epochs between May 24 and 30, 2010, and the corresponding mean light curves were constructed.

2.2. Light Curves

Constructed light curves of J0903 are presented in Figure 1 on the same scale: the differences ΔR between the

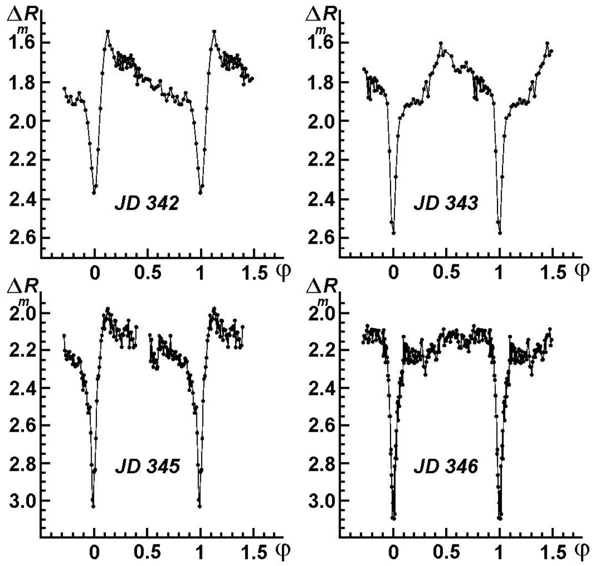

Figure 1. Selected orbital light curves of J0903 in the R band during the decline in brightness, near and after the superoutburst maximum. The orbital phases are plotted along the horizontal axis.

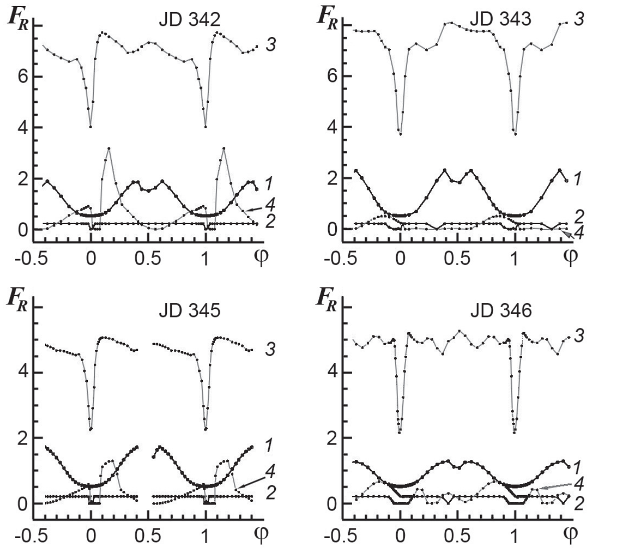

Figure 2. Contributions of the various components to the integrated flux of J0903 during superoutburst in 2010 (arbit.units): 1 red dwarf, 2 white dwarf, 3 accretion disk, 4 hot line.

magnitudes of J0903 and the comparison star are plotted on the vertical axis, and orbital phases are plotted along the horizontal axis. Our light curves show that the maximum flux from the system dropped by $\sim 0^m.8$ over the seven days of our observations and the minimum flux decreased by $\sim 0^m.6$. The eclipse depth varied in the range of $0^m.6 \sim 1^m.1$ during the outburst as the total brightness of the system decreased.

The individual (unaveraged) data reveal flux fluctuations at a level of $\sim 0^m.04 - 0^m.12$; the light curves obtained on May 28 (JD2455342) and 30 (JD2455347) have gaps of $\sim 0.13P$ and $\sim 0.14P$, respectively. The light curves of J342 and J345 are anomalous; light curve J346, with humps before the eclipse, is close to a classical curve; the light curve of J343 has a hump near an orbital phase of 0.5.

Superhumps are observed in the light curves of J0903. As the superoutburst proceeds, the shapes of the light curves change, and the superhumps evolve. Dips with different amplitudes at different orbital phases are visible in the out-of-eclipse parts of all the light curves.

Dips are result of an accretion disk centre eclipse by asymmetric formations at the outer regions of the disk with the appearance of spiral arms O'Donoghue (1990). The appearance of spiral arms is believed to be due to tidal shocks initiated by a fairly massive secondary and changing conditions of angular momentum transfer in the disk when the disk temperature increases during an outburst.

2.3. Spiral-Arm Mmodel

Fitting the light curves of cataclysmic variables in various states of activity states within different models shows that the standard close-binary model with a hot spot in the region where a gaseous flow collides with the disk agrees well with a classical cataclysmic variable light curve, with a hump before the primary minimum, but completely fails to fit anomalous light curves and dips in the light curves out of eclipse. The parameters of all system components were determined with a spiral-arm model. Together with a hot line, this model takes into account geometrical irregularities on the accretion disk surface – two thickenings at its outer edge which decrease exponentially in the vertical direction toward the white dwarf, and have the appearance of spiral arms. The phase-dependent radiation from an accretion disk with spiral arms is the major factor determining the dip phases and depths in this model; the contribution of the hot line is secondary to the process of dip formation and is significantly smaller. The hot line manifests mostly through the amplitudes of the pre-eclipse and anomalous humps, while variations in the radiation from the secondary results in a small drop in the brightness near phase $\varphi \sim 0.5$, due to the integrated reflection and ellipsoidal effects in the red-dwarf brightness. This model can explained the dips and anomalous curves.

We analysed each light curve separately.

2.4. Analysis

The contribution of the different components to the integrated flux of J0903 can be seen in Figure 2. The main contribution to the brightness of the J0903 system during the outburst is the accretion disk. The highest disk flux (∼8.1 relat.units) is observed on the third day of our observations; after the outburst maximum the disk flux decreased by 1-2 relat.units per day and became ∼4.4 by the last night of our observations. Contributions from the red dwarf depend on the degree of star heating by the hot radiation of the boundary level and decreases with the drop of the last one. A comparison of the red dwarf light curves at the outburst maximum (curves 2, 3) and at the last date of our observations shows the de-

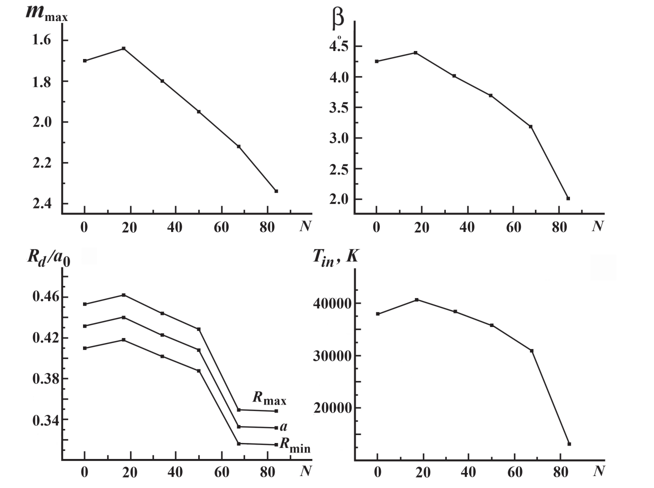

Figure 3. Maximum out-of-eclipse flux m_{max} and disk parameters (radius R_d, thickness of outer edge β, temperature of the inner parts of the disk T_{in}) as functions of the orbital cycle number N at superoutburst

crease of the reflection effect. The brightness of the red dwarf on the last night demonstrates mostly ellipsoidal variations. Radiation from the white dwarf during the superoutburst (∼0.2 relat.units) does not change in the frame of the model used and could not noticeably influence the shape of the light curve because of its small value. During the maximum of the superoutburst the intensity of radiation from the disk inner regions - the boundary layer in the equatorial region of the star - significantly increases. From this area accretion onto the white dwarf occurs.

2.5. Results

Figure 3 illustrates clearly that an increase of the temperature T_{in} at the maximum of superoutburst is accompanied by an increase of the disk radius R_d and the thickness of the outer edge β. At the outburst maximum the temperature in this area become about $T_{in} \sim 41000$ K, and by the end of our observations it decreases to ~ 13000 K (the temperature of white dwarf). The mean value of the radius near the outburst maximum reaches $a \sim 0.44a_0$, the brightness decrease of $\sim 0^m.7$ is accompanied by a decrease in radius to $\sim 0.33a_0$, which is 20% more than its value in a quiet state: according to Littlefair et al. (2008), $R_d \sim 0.27a_0$ so we can conclude that the system was in the stage of slow decline at the last night of our observations but did not reach the quiescent value.

2.6. Superhumps in Spiral-Arms Model

The superhumps phases were derived with the following ephemerides, corrected by our data:

Max.sh. = BJD2455340.4150(2) + 0.060320 dE.

During the outburst P_{sh} decreased from $0^d.060364$ to $0^d.060073$, at a rate of $(dP/dT)P \sim 12.3 \times 10^{-5}$ (an average value for SU Uma stars is $(1 - 15) \times 10^{-5}$. Deviations from the mean brightness of the system were determined to correct for the brightness decline. The amplitudes of superhumps as a function of the phase φ ($P_{sh} = 0^d.06032$) are shown in Fig.4. The different symbols refer to different nights. Only out-of-eclipse observations of J0903 were used. Deviations from the mean brightness of the system were determined to correct for brightness decline.

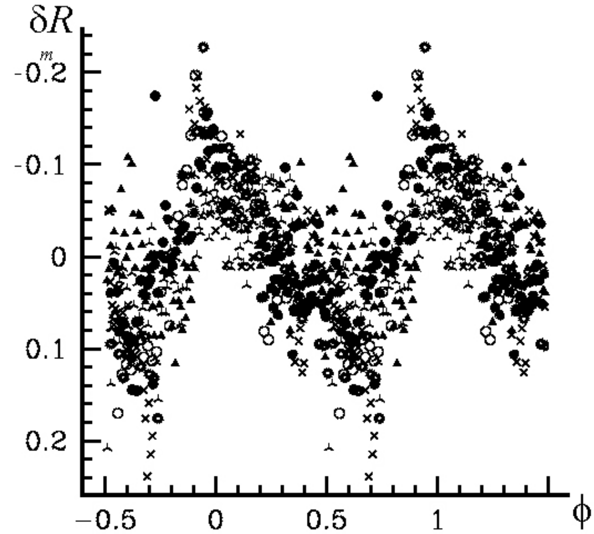

Figure 4. The amplitudes of superhumps as a function of superhump period phases

3. SDSS J150240.98+333423.9

3.1. Observations

Monitoring of SDSS J150240.98+333423.9 was started in April 2012 after receiving information from VSNet about sudden the increase of system brightness and an outburst beginning in this system. Observations were done with the 60 cm telescope with the Apogee 47 detector in V band, the duration of observational sets were 3.5 − 7 h depending on the sky conditions. The accuracy of our data was 1-2% (the good nights) and 3-4% (the bad nights). During the period of observations from April – June 2012 more than 750 images were obtained covering 6 nights. Aperture photometry was performed with the MAXIM DL package. Detailed light curves for J1502 were constructed using these data. They are shown in Fig. 5.

3.2. Search of the orbital period

All our observations from JD 2456041–JD 2456081 were used for the independent orbital period search. The light curves of J1502 were analyzed with the Lafler & Kinman (1965) method, which is well-suited to eclipsing binaries. The special PC code devised by V. Goranskij was applied. The range for the period search was $P_{orb} \sim 0^d.055$–$0^d.065$ with a step of $0^d.002$. The result is shown in Fig.6. The most significant peak on the Lafler & Kinman periodogram is $\nu = 16.974874$ days^{-1}, with corresponding period value $P_{orb} = 0^d.0589106$. For T_o we take the moment JD2456041.4359625 which corresponds to the middle of the 3rd minimum on the first

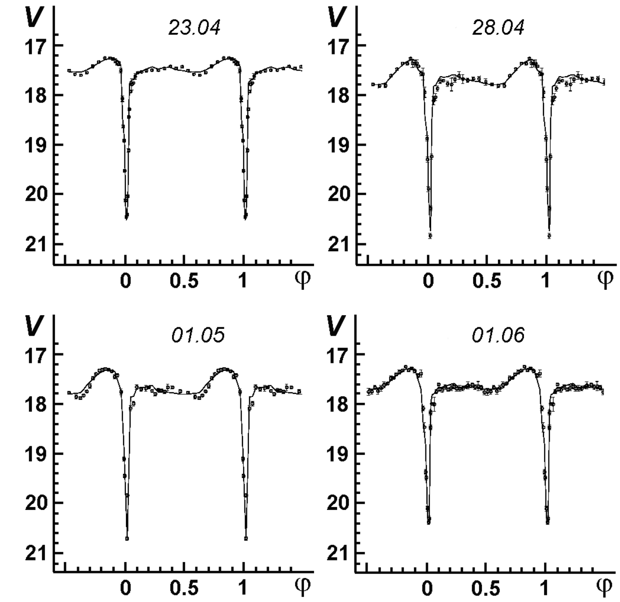

Figure 5. Some of the observational light curves of J1502 obtained in 2012 (points)

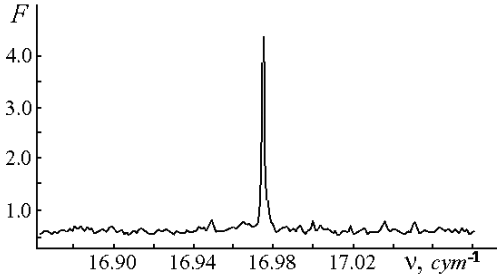

Figure 6. Power spectrum of the 2012 data for J1502 showing a thin peak near $\nu = 16.97$

observational night, JD2456041.

3.3. Model for J1502

Various models have been fitted to obtain light curves of J1502. The best fit to the mean light curves gives a combined model for CVs. Such a model was used to determine the main parameters of the J1502 components which contribute to the total brightness of the system.

This model considers not only the radiation of hot lines but also the radiation of the hot spot on the back side of the gaseous stream (lee side). In the frame of the combined model the inverse problem of J1502 parameter determination is solved. The results of a fit to the J1502 data are shown in Fig.1, where points indicate the J1502 observational light curves and solid lines the synthetic light curves.

3.4. Results

Photometric data were obtained at the end of J1502 outburst in April 2012 and in a quiet state $\sim$ 350 cy-

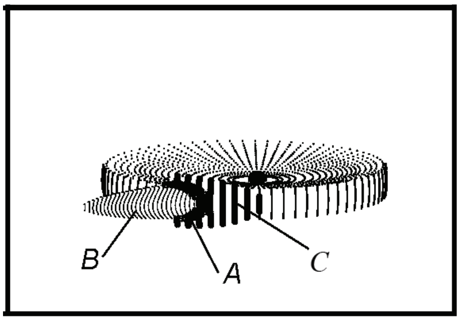

Figure 7. Schematic layout of J1502 components in the combined model: A and B - the regions of the highest energy release on the hot line surface near the disk edge (A) and the colder stream, lying outside area of shock wave heating (B). C is the hot spot; one can see the disk outer edge thickening in the area of the hot spot, which leads to the deformation of corresponding inner parts of the disk

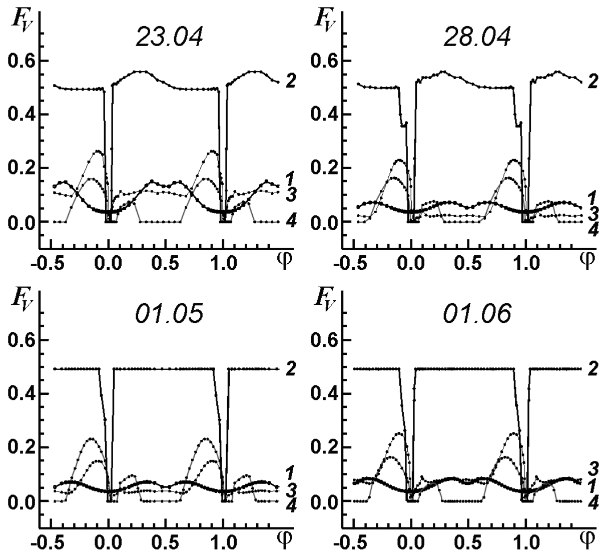

Figure 8. Contributions of various components to the integrated flux of J1502:1 red dwarf, 2 white dwarf, 3 accretion disk, 4 hot line

cles after the beginning of the outburst (V band, 6 nights, more than 750 images). They are divided into two groups:

- the first covers a period of $\sim$ 140 orbital cycles,
- the second covers $\sim$ 20 orbital cycles The separation between observations of these groups is $\sim$ 500 orbital cycles.

J1502 light curves obtained from our photomtric observations demonstrate:

- eclipses with depth up to $\sim 1^m$,
- a change of brightness outside of the eclipse up to $\sim 0^m.3$,
- a change of the flux in the orbital hump region up to $\sim 0^m.3$
- the level of system brightness corresponding to the inactive stage.

The orbital period determined from all our data is

$P = 0^d.0589106$. The value of the orbital period essentially does not change for more than 37200 orbital cycles, staring from the previous observations of Shears et al. (2011)

The prameters of J1502 were derived in the frame of the combined model. Analysis of the variation of the derived parameters R_d and the temperature in the boundary level T_{in} show evidence for smooth variations of these parameters between outbursts: for the first group of observations the accretion disk radius and temperature in the inner regions of the disk decrease and the temperature distribution along the radius approaches the steady-state value; for the second group ($\sim 500 P_{orb}$)- the picture is opposite.

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