We present photometric observations of the dwarf nova 1RXS J053234.9+624755. We performed a detailed analysis of the superoutburst that occurred in August 2009. We found the superhump period to be $P_{sh} = 0.057122(14)$ days. Based on the $O-C$ diagram we conclude that $P_{sh}$ increased during the plateau at the rate of $dP_{sh}/dt = (9.24 \pm 1.4) \cdot 10^{-5}$. Both the $O-C$ analysis and evolution of the superhumps light curve favour the model in which superhumps originate in a variable source located in the vicinity of the hot spot. In addition, the evolution of the light curve suggests that the superhump light source approaches the disc plane as the superoutburst declines. Detailed analysis of the superoutburst plateau phase enabled us to detect a signal which we interpret as apsidal motion of the accretion disc. We detected additional modulations during the final stage of the superoutburst characterized by periods of $104$ and $188$ s which we tentatively interpret as quasi periodic oscillations. Estimations of $A_0$ and $A_n$ are in agreement with the dependence discovered by Smak (2010) between the amplitude of superhumps and the orbital inclination.

**Key words:**
accretion, accretion discs - binaries: cataclysmic variables, stars: dwarf novae, oscillations, stars: individual: 1RXS J053234.9+624755, 2MASS J05323386+6247 520, USNO-B1.0 1527-00176070, USNO-B1.0 1527-00176070

**Received Month Day, Year**
1. Introduction

Over 30 years have passed since the discovery of superhumps in cataclysmic variables (Vogt 1974, Warner 1995). Different physical processes have been proposed to explain the origin of the superhump phenomenon. Models considered have included the ejection of matter from the white dwarf due to pulsation instabilities (Vogt 1974), periodic modulation of dissipation in the elliptical and precessing accretion disc (Osaki 1989), or models which explain superhumps in terms of the oscillations of a hot spot caused by uneven stream flows from the secondary (Smak 2009c). Nowadays we possess enough knowledge about the components of dwarf novae to describe these systems completely. It seems likely that under the strength of argument provided by Smak (2010), most doubts regarding superhumps will be dispelled soon. However, each new model should be tested by observations and therefore it is important to observe dwarf novae especially during superoutbursts, i.e. when superhumps occur predominantly.

1RXS J053234.9+624755 (1RXS J0532) is an example of a dwarf nova with documented superoutbursts. It was discovered quite unexpectedly as a counterpart of an X-ray source in the ROSAT all-sky bright catalog by Bernhard et al. (2005). Detailed investigation of the Sonneberg Plate Archive for this object found eight outbursts between 1990 and 2005 with a mean interval of 133.6d. Soon, further observations resulted in the detection of superhumps in the light curve of 1RXS J0532 and revealed that this star is a SU UMa type dwarf nova (Poyner & Shears 2006). Monitoring of superoutbursts showed the evolution from a clear tooth-shape light curve variation to more random flickering (Parimucha & Dubovsky 2006). Based on spectroscopic observations an orbital period of 0.05620(4) d was reported by Kapusta & Thorstensen (2006). An observational campaign during the 2005 superoutburst reported by Imada et al. (2009) showed the superoutburst accompanied by a precursor. The light curve of the precursor revealed a gradual increase in the amplitude of the light variation which was interpreted as developing superhumps. As this is in contradiction to the standard Thermal - Tidal Instability (TTI) model, further interpretation was based on the "refined" TTI model. The authors concluded that the existence of the precursor and the presence of growing superhumps during the precursor are related to the mass ratio of the system. This in turn determines the 3:1 resonance radius and the tidal truncation radius ratio which are supposed to be responsible for the behavior of the superhumps (Osaki 2005). Moreover, the photometric data provided an estimate of the length of the supercycle, \( \sim 450 \) days, and the superhump period, \( P_{sh} = 0.57169(6) \) d (Imada et al. 2009).

2. Observations

Our observational campaign of 1RXS J0532 lasted from 24 August 2009 to 10 September 2009, and was performed as part of the long-term observational project
- CURious Variable Experiment (CURVE, Olech et al. 2009, Rutkowski et al. 2009). In this paper we report observations that cover 17 nights and include 7271 measurements. Thanks to the CURVE collaboration we were able to use several telescopes in different locations. This greatly minimized the effect of bad weather on our campaign, so observational gaps were generally shorter than one day.

The data were collected mainly by two telescopes: the 1.3-m Ritchey-Chretien telescope of the Skinakas Observatory, Crete, Greece, and the 0.6-m Cassegrain telescope of Warsaw University Observatory. In Skinakas Observatory we used "white light" and Johnson $B,V,R,I$ filters. We observed with the ANDOR 2048x2048 back-illuminated CCD array with 13.5 $\mu$m pixels. The Warsaw University Observatory was equipped with the Tektronix 512x512 TK512CB back-illuminated CCD camera with 27 $\mu$m pixels.

In addition, two one-night observing runs were carried out by two smaller telescopes. The first run on 24 August was carried by a 25-cm Newtonian telescope equipped with a Starlight Xpress HX-516 CCD and located in West Challow, England. The second run on 25 August was performed by a 35-cm Schmidt-Cassegrain telescope equipped with a ST-7 CCD located in Kielce, Poland (Jan Kochanowski University of Humanities and Sciences).

Exposure times varied from 10 sec (for the 1.3-m telescopes) to 120 sec (for

### Table 1

Observational journal of the 2009 1RXS J0532 campaign.

| Date in 2009 | Start [HJD] | End [HJD] | Dur. [hr] | Obs. index | No. of points | $<V>$ | $A_{max}$ |
|--------------|-------------|-----------|-----------|-------------|--------------|-------|-----------|
| Aug 24       | 24554740    | 24554760  | 1.90      | West Ch.    | 197          | 11.97 | 0.039 ± 0.007 |
| Aug 25       | 69.342298   | 69.522114 | 4.31      | Kielce      | 120          | 12.24 | 0.151 ± 0.010 |
| Aug 28       | 72.457581   | 72.634828 | 4.25      | Skinakas    | 625          | 11.93 | 0.110 ± 0.005 |
| Aug 29       | 73.463275   | 73.626979 | 3.93      | Skinakas    | 450          | 12.10 | 0.114 ± 0.005 |
| Aug 30       | 74.449727   | 74.548565 | 2.37      | Skinakas    | 247          | 12.32 | 0.085 ± 0.007 |
| Aug 31       | 75.484640   | 75.631456 | 3.52      | Skinakas    | 822          | 12.39 | 0.078 ± 0.015 |
| Aug 31       | 75.508670   | 75.613440 | 2.51      | Ostrowik    | 171          | 12.40 | —           |
| Sep 01       | 76.327500   | 76.615850 | 6.92      | Ostrowik    | 425          | 12.35 | 0.106 ± 0.005 |
| Sep 02       | 77.468199   | 77.632007 | 3.93      | Skinakas    | 319          | 12.40 | 0.131 ± 0.005 |
| Sep 02       | 77.322880   | 77.423630 | 2.42      | Ostrowik    | 96           | 12.44 | —           |
| Sep 03       | 78.459024   | 78.633852 | 4.20      | Skinakas    | 947          | 12.42 | 0.152 ± 0.010 |
| Sep 04       | 79.463728   | 79.621767 | 3.79      | Skinakas    | 974          | 12.57 | 0.146 ± 0.010 |
| Sep 05       | 80.479105   | 80.627843 | 3.57      | Skinakas    | 1047         | 13.12 | 0.173 ± 0.012 |
| Sep 05       | 80.441150   | 80.619560 | 4.28      | Ostrowik    | 278          | 13.09 | —           |
| Sep 07       | 82.363320   | 82.477090 | 2.73      | Ostrowik    | 154          | 14.50 | 0.55 ± 0.05  |
| Sep 08       | 83.364140   | 83.620240 | 6.14      | Ostrowik    | 167          | 14.52 | 0.50 ± 0.05  |
| Sep 09       | 84.367280   | 84.623550 | 6.15      | Ostrowik    | 174          | 14.78 | 0.85 ± 0.01  |
| Sep 10       | 85.353360   | 85.536260 | 4.39      | Ostrowik    | 46           | 14.40 | 0.81 ± 0.05  |
the 35-cm telescopes). Exposures with the 1.3-m Skinakas telescope were auto-guided. For the other telescopes, even without autoguiding, PSF profiles seemed undistorted and mostly circular.

The IRAF package was used for data reduction and PSF photometry was performed with DAOphotII. The majority of measurements were made without filters (in white light). Occasionally, when using the 1.3-m telescopes, $B, V, R, I$ exposures were taken to calibrate the global light curve. Performing the observations in white light allowed us to take shorter exposures and minimize guiding errors. However this approach could potentially introduce uncertainty when comparing measurements from different photometric systems.

Relative unfiltered magnitudes of 1RXS J0532 were determined as the difference between the magnitude of the variable and the magnitude of a nearby comparison star, 2MASS J05323636+6245536. The SIMBAD database provided the $B, V$ magnitudes for this star. To find $R$ and $I$ magnitudes we selected another comparison star, 2MASS J05325096+6246161. We also investigated other possible comparison stars in the field but these all introduced larger errors and more scatter in the light curve.

We adopted the following magnitudes for 2MASS J05323636+6245536: $B = 11.49 \pm 0.01$, $V = 11.21 \pm 0.01$, $R = 10.08 \pm 0.01$, $I = 10.69 \pm 0.02$. We assumed that our white light measurements introduced constant shifts with respect to standard $V$ magnitudes. Twelve $V$ measurements were obtained during the superoutburst and used to estimate the $V$ magnitude for the rest of the collected data. The light curves in white light have been shifted by a constant value to agree with the points obtained in the $V$ filter. We estimate the errors introduced by his procedure to be smaller than $\sim 0.2$ mag.

Table 1 presents a journal of our CCD observations of 1RXS J0532. Successive columns contain the date, start and end of the observational run in HJD; duration of the observation during a particular night; location of the observatory; number of points gathered during the night; the approximate average brightness in $V$; and the maximum superhump amplitude. In total, 1RXS J0532 was observed for over 73 hours.

3. Global light curve and its color variation

The lower panel of Figure 1 presents the photometric measurements of 1RXS J0532 during our campaign. In the complete light curve one can clearly see the precursor - a characteristic increase of brightness before the real superhump maximum. Such a precursor is occasionally observed for SU UMa stars, however, as far as we know there is no proven relationship between the presence of a precursor and the orbital period, mass ratio or other parameter of the system.

There was only one night in our campaign (24 August) that allowed us to analyse the characteristics of the precursor. In the light curve from this night, a quasi
Fig. 1. Top: The $O-C$ values corresponding to the particular phases of the superoutburst. The black curve is the best fitting second order polynomial for cycles $E < 80$. The straight line is the best fit for cycles between $E = 80$ and $E = 150$. Triangles and filled circles indicates $O-C$ values for maxima and minima respectively. Middle: The maximum amplitude of the superhumps for each night. Bottom: Our complete light curve of the 2009 superoutburst of 1RXS J0532. Diamonds denote the dates with $B, V, R, I$ measurements.

A sinusoidal modulation can be observed with average brightness of $V = 11.97$. A rough peak-to-peak distance measurement gives $P_p = 0.059$ d with an uncertainty of the order of $0.005$ d. This uncertainty is too large to draw conclusions about early superhumps or compare $P_p$ with the orbital period. Nevertheless, the presence of the precursor is certain.

During the observation on 25 August, a sharp rise in brightness was detected. However the initial level was $V = 12.45$, about 0.5 magnitude less than during the previous night. By this time the precursor stage had ended and the brightness of the star was increasing towards the real superoutburst maximum.

Similar behaviour of the overall superoutburst light curve of 1RXS J0532, es-
Table 2

BVRI photometry of 1RXS J0532 performed during the 2009 superoutburst.

| Date       | B                  | V                  | R                  | I                  |
|------------|--------------------|--------------------|--------------------|--------------------|
| 28.08.2009 | 11.902 ± 0.012     | 11.934 ± 0.012     | 11.039 ± 0.011     | 11.899 ± 0.012     |
| HJD-2455000→ | (72.569417)       | (72.569811)       | (72.570205)       | (72.570598)       |
|            | 11.887 ± 0.014     | 11.924 ± 0.014     | 11.014 ± 0.016     | 11.881 ± 0.012     |
|            | (72.570992)        | (72.571386)        | (72.571779)        | (72.572173)        |
| 02.09.2009 | 12.411 ± 0.011     | 12.418 ± 0.012     | —                  | 12.33 ± 0.012      |
| HJD-2455000→ | (77.454877)       | (77.457828)       | —                  | (77.459414)       |
|            | 12.396 ± 0.011     | 12.42 ± 0.011      | —                  | 12.323 ± 0.012     |
|            | (77.455687)        | (77.458534)        | —                  | (77.46012)         |
| 03.09.2009 | 12.537 ± 0.013     | 12.54 ± 0.012      | —                  | 12.466 ± 0.012     |
| HJD-2455000→ | (78.443584)       | (78.448480)       | —                  | (78.451084)       |
|            | 12.538 ± 0.012     | 12.551 ± 0.012     | —                  | 12.441 ± 0.012     |
|            | (78.445910)        | (78.449846)        | —                  | (78.452010)        |
| 04.09.2009 | 12.607 ± 0.014     | 12.602 ± 0.013     | —                  | 12.495 ± 0.014     |
| HJD-2455000→ | (79.449179)       | (79.451066)       | —                  | (79.453589)       |
|            | 12.605 ± 0.012     | 12.615 ± 0.014     | —                  | —                  |
|            | (79.450070)        | (79.452478)        | —                  | —                  |
|            | 12.644 ± 0.015     | 12.660 ± 0.014     | —                  | 12.534 ± 0.015     |
|            | (79.626680)        | (79.627711)        | —                  | (79.628463)        |
|            | 12.656 ± 0.014     | 12.660 ± 0.014     | —                  | 12.557 ± 0.016     |
|            | (79.631009)        | (79.628463)        | —                  | (79.629215)        |
| 05.09.2009 | 13.099 ± 0.013     | 13.104 ± 0.014     | —                  | (12.895 ± 0.014)   |
| HJD-2455000→ | (80.470725)       | (80.472692)       | —                  | (80.474579)        |
|            | 13.117 ± 0.013     | 13.083 ± 0.013     | —                  | 12.904 ± 0.014     |
|            | (80.471639)        | (80.473676)        | —                  | (80.475447)        |

Especially the presence of the precursor has been reported by Imada et al. (2009). They studied the 2005 superoutburst in terms of the TTI model. Here, we propose a different interpretation of this phenomenon. We consider the model in which a superoutburst is caused by enhanced mass transfer from the secondary (Smak 2008ab; 2009b). A rapid decline in the brightness at the end of the precursor is most likely an indication that the normal outburst is ending.

However, the disc at this moment is already heated, so irradiation of the secondary by the disc is intense. Due to the irradiation, the secondary star is heated and the mass transfer increases again. This consequently leads to an increase in the brightness of the hot spot and the whole system.
In addition, oscillations of the hot spot (due to variable dissipation of kinetic energy of the stream) could be responsible for superhumps observed during the precursor and the rest of the superoutburst.

We do not observe a classic plateau after the maximum, in contrast to the observations of Imada et al. (2009). Instead we see a clear deviation from a straight line with a prominent change in slope around HJD 2455075, a clear indication that the rate of mass transfer can vary.

After 5 September, a fast decrease in brightness was detected. At minimum, the observed star was observed at around $V = 14.8$.

Unfortunately, due to observing schedule constraints, we were not able to collect data on 26 and 27 August. Therefore we have to estimate that at maximum the superoutburst reached a brightness close to $V = 11.5$ and that the superoutburst amplitude was around $V = 3.3$.

3.1. Color variation

Most of the data were gathered without filters but several exposures were taken in $B, V, R$ and $I$ filters. Table 2. presents the results from these measurements. Two comparison stars, 2MASS J05323636+6245536 and 2MASS J05325096+6246161, were used to derive these results. The measured $B-V$ colour indices (in the -0.34 to 0.19 range) correspond to the known colour index for dwarf novae in outburst (e.g. Bailey 1980, Echevarria & Jones 1983). While it would have been desirable to measure the colour index of the early superoutburst, this was not possible due to observing constraints.

4. Superhumps

Superhump evolution during our observing campaign can be followed in Figure 2. At the beginning of our observing run on 24 August only a hint of modulations was visible. However the second night revealed the development of superhumps on the rising branch of the superoutburst with an amplitude of 0.15 mag. Fully formed and regular superhumps were visible on 28 August but with a lower amplitude of approximately 0.11 mag. This is a consequence of the fact that the superoutburst maximum occurred most probably two days before 28 August. However, the superhump amplitude was relatively small, especially if we assume the standard $dA/dt \sim 0.015$ (mag/day) and compare it with an amplitude of $\sim 0.28$ (mag) at the superoutburst maximum read from figures in Imada et al. (2009) and Poyner & Shears (2006).

The evolution of superhumps after 28 August is also very interesting. Firstly, signs of secondary humps can be noticed on 29 and 30 August. Secondly, after 31 August the minima became much more prominent and clearer than the rather fuzzy maxima, in contrast to the situation before 31 August when the maxima were mostly much sharper than the minima. Moreover, the minima of the light curve on
Fig. 2. Evolution of superhumps in the light curve of 1RXS J0532 during the 2009 superoutburst. Filled circles correspond to the observations performed at Skinakas Observatory, except on Aug 24 and Aug 25. Crosses denote data from the Ostrowik Station. Open circles show measurements taken in the Skinakas Observatory with the $V$ filter, used during the calibration procedure.
1 September suggest that the bright spot became fuzzy and reduced in size. The superhump source was in the most part hidden behind the accretion disc, but only for a very short time as manifested by the sharp, narrow dips in the light curve during that night. Such hot spot radius variations are in agreement with the hot spot oscillation model and hot spot eclipses observed in OY Car or Z Cha (Smak 2007, 2008b). Why did such transitions occur around 1 September and not before? To answer this question we refer to Smak (2010), Figure 2. The main conclusion drawn from that figure is that the superhump source is located close to but above the disc rim. According to the work of Smak (2007, 2008ab), we assume that the mass transfer rate can vary during a superoutburst. This allows us to conclude that the distance of the superhump source from the disc plane may be changing as well. In particular, the source is going to be more fuzzy and closer to the disc plane as the superoutburst declines.

After 5 September the system started fading quickly. Strong flickering became very prominent. Starting on 7 September, the flickering very effectively masked other periodicities and only hints of superhump modulation can be seen.

4.1. $O-C$ analysis

During the whole superoutburst the light variation of 1RXS J0532 shows clear but complex modulations (Figure 2). Previous studies have found a similar behaviour in other dwarf novae systems. In some cases even alternating superhump periods have been reported (e.g. Olech et al. 2004, Rutkowski et al. 2007). In order to study this behaviour in detail we investigated the maxima and minima present in our light curve of 1RXS J0532 adopting the following procedure.

Firstly, we de-trended the global light curve. For each night’s observations we subtracted a first or second order polynomial and derived a periodogram. The ZUZA code (Schwarzenberg-Czerny 1996) and its perort procedure was used to obtain the power spectrum. The strongest signal is at the period $P = 0.05714 \pm 0.00010$ d ($f = 17.4994$ c/d, Figure 3). In order to check if the derived period is stable we investigated the maxima and minima present in our light curve of 1RXS J0532 adopting the following procedure.

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$$HJD_{\text{max}} = 72.4677(19) + 0^d.057143(19)E,$$

for the maxima, and

$$HJD_{\text{min}} = 72.508(2) + 0^d.057098(21)E,$$

for the minima, where $E$ is the cycle count (Epoch). Equations 1 and 2, for maxima and minima respectively, have been used to construct the $O-C$ diagram presented in the upper panel of Figure 1. The times of extrema can be fitted with a quadratic ephemeris (for $E < 80$) which are given by the following equations for maxima and minima respectively:

$$HJD_{\text{max}} = 72.4673 + 0^d.0571117E + 3.05 \cdot 10^{-6}E^2$$

$$\pm 0.002 \pm 0.000022 \pm 0.55$$

(3)
Table 3

Times of the extrema in the lightcurve of 1RXS J0532 during the 2009 superoutburst.

| E | HJD* max | Error  | O − C | E | HJD* min | Error  | O − C |
|---|----------|--------|-------|---|----------|--------|-------|
| -70 | 68.4850 | 0.0071 | 0.017303 | -71 | 68.4819 | 0.0041 | 0.027830 |
| -69 | 68.5299 | 0.0030 | 0.005040 | -70 | 68.5098 | 0.0021 | -0.001368 |
| -54 | 69.3807 | 0.0010 | -0.001273 | -55 | 69.3619 | 0.0007 | -0.005732 |
| -53 | 69.4413 | 0.0021 | 0.002194 | -54 | 69.4170 | 0.0007 | -0.007730 |
| -52 | 69.4968 | 0.0011 | 0.000541 | -53 | 69.4741 | 0.0011 | -0.007727 |
| 0  | 72.4586 | 0.0020 | -0.009080 | 0  | 72.5000 | 0.0008 | -0.008000 |
| 1  | 72.5193 | 0.0006 | -0.005593 | 1  | 72.5516 | 0.0005 | -0.013498 |
| 2  | 72.5787 | 0.0004 | -0.003306 | 2  | 72.6166 | 0.0002 | -0.005595 |
| 3  | 72.6336 | 0.0007 | -0.005579 | 17 | 73.4738 | 0.0008 | -0.004859 |
| 18 | 73.4930 | 0.0006 | -0.003272 | 18 | 73.5319 | 0.0005 | -0.003857 |
| 19 | 73.5480 | 0.0007 | -0.005395 | 19 | 73.5914 | 0.0002 | -0.001454 |
| 20 | 73.6080 | 0.0007 | -0.002548 | 53 | 75.5271 | 0.0004 | -0.007073 |
| 35 | 74.4606 | 0.0021 | -0.007131 | 36 | 75.5139 | 0.0005 | -0.00130 |
| 53 | 75.4890 | 0.0009 | -0.007274 | 54 | 75.4573 | 0.0005 | -0.009566 |
| 55 | 75.6125 | 0.0012 | 0.001891 | 55 | 75.5126 | 0.0004 | -0.007768 |
| 68 | 76.3652 | 0.0008 | 0.011753 | 69 | 76.5690 | 0.0005 | -0.007070 |
| 69 | 76.4116 | 0.0007 | 0.001080 | 70 | 76.3759 | 0.0004 | -0.014604 |
| 70 | 76.4694 | 0.0006 | 0.001737 | 71 | 76.4237 | 0.0008 | -0.00306 |
| 71 | 76.5326 | 0.0008 | 0.007744 | 72 | 76.4818 | 0.0008 | -0.006309 |
| 72 | 76.5957 | 0.0007 | 0.013751 | 85 | 77.5974 | 0.0005 | -0.007714 |
| 85 | 77.3352 | 0.0008 | 0.010313 | 86 | 78.5074 | 0.0009 | -0.004152 |
| 86 | 77.3951 | 0.0006 | 0.013111 | 86 | 78.5645 | 0.0010 | -0.004154 |
| 88 | 77.5002 | 0.0005 | 0.003875 | 107 | 78.6184 | 0.0007 | -0.00957 | |
| 90 | 77.6200 | 0.0006 | 0.009469 | 90 | 78.4682 | 0.0007 | -0.005707 |
| 105 | 78.4650 | 0.0012 | -0.002664 | 105 | 79.5269 | 0.0008 | -0.004105 |
| 106 | 78.5205 | 0.0011 | -0.004307 | 123 | 79.5840 | 0.0008 | -0.004102 |
| 107 | 78.5786 | 0.0015 | -0.003390 | 139 | 80.4406 | 0.0004 | -0.003966 |
| 108 | 78.6339 | 0.0017 | -0.005213 | 140 | 80.4896 | 0.0011 | -0.012064 |
| 123 | 79.4768 | 0.0018 | -0.001951 | 141 | 80.5498 | 0.0008 | -0.008962 |
| 124 | 79.5421 | 0.0013 | -0.001137 | 142 | 80.6096 | 0.0005 | -0.006259 |
| 140 | 80.4513 | 0.0010 | -0.016456 | 173 | 82.3863 | 0.0006 | 0.000415 |
| 141 | 80.5256 | 0.0009 | 0.000771 | 174 | 82.4489 | 0.0014 | 0.005918 |
| 143 | 80.6350 | 0.0017 | -0.004105 | 209 | 84.4129 | 0.0012 | 0.002344 |
| 226 | 85.3907 | 0.0013 | 0.008655 | 226 | 85.3907 | 0.0013 | 0.008655 |

$^*$ HJD - 2455000

and

$$HJD_{\text{min}} = 72.4673 + 0^d.0571069E + 3.19 \cdot 10^{-6}E^2 \pm 0.0029 \pm 0.000344 \pm 0.89$$

(4)

The period derivatives calculated from Eqs. (3) and (4) separately for maxima
and minima differ slightly ($\dot{P}_{\text{max}} = (10.68 \pm 1.9) \cdot 10^{-5}$ and $\dot{P}_{\text{min}} = (11.18 \pm 3.1) \cdot 10^{-5}$). Thus we decided to derive the rate of period change based on an $O-C$ analysis for the maxima and minima together.

For $E < 80$ we fitted a second order polynomial. The best-fitting quadratic equation was:

$$O-C(\text{days}) = -7.88(1.29) \cdot 10^{-3} + 1.17(1.68) \cdot 10^{-5} E + 2.64(41) \cdot 10^{-6} E^2.$$  \hspace{1cm} (5)

Equations (1,2,5) can be used to determine the $P_{\text{sh}}$ derivative. From the definition we have:

$$O-C = a + bE + \frac{1}{2} \frac{dP}{dt} P E^2$$

so

$$\dot{P} = \frac{dP}{dt} = \frac{2a}{P}$$

where $\bar{P}$ is the average period used to generate the $O-C$ diagram. We take the weighted mean of the periods from Eq. 1 and 2 to obtain $\bar{P} = P_{\text{sh}} = 0.057122(14)$d. Thus for parameters from Eq. 5 we get:

$$\dot{P} = (9.24 \pm 1.4) \cdot 10^{-5} \text{ or } (5.28 \pm 0.04) \cdot 10^{-6}(\text{days/cycle}).$$  \hspace{1cm} (6)

This is the rate at which the superhump period ($P_{\text{sh}}$) increased during the so-called stage B (see paragraph 3.2 in Kato et al. 2009). We fitted a constant function to the cycles between 80 and 150 and obtained

$$O-C_{80-150}(\text{days}) = -0.000316(51)E + 0.0344(58),$$  \hspace{1cm} (7)

where the coefficient before $E$ suggests a constant period equal to $P_q = 0.056806(51)$d (that is shorter than $P_{\text{sh}}$ by approximately 0.000316d). It is worth noting that Kato et al. (2010) report that period analysis for 1RXS J0532 of their data collected during quiescence reveals a period of 0.5690(2) d. Most likely the variation found by us has the same physical nature as the modulation found by Kato et al.

Extrema detected for $E > 150$ do not follow the same constant trend and probably come from orbital modulations of the hot spot.

### 5. Power spectrum analysis

Figure 3 shows the power spectrum of 1RXS J0532 obtained for all the data collected during the 2009 superoutburst. The Analysis of Variance (AOV) method with 3 harmonics was used to analyse it. The strongest peak is at frequency $f = 17.4994 \pm 0.0323$ c/$d$, which corresponds to a period of $P = 0.057145(105)$d, consistent with the superhump period of the system. However the error is about one order of magnitude larger than that obtained through the $O-C$ analysis. Therefore
Fig. 3. Top: Power spectrum of 1RXS J0532 for the complete observing run during the 2009 superoutburst. The most significant peak occurs at frequency $f_{sh} = 17.4994 \pm 0.0323 \, \text{c/d}$ corresponding to period $P_{sh} = 0.05715(10) \, \text{d}$. Bottom: Pre-whitened spectrum after removing the dominant frequency corresponding to the above period. The most prominent remaining peaks are located at frequencies $f = 4.329 \, \text{c/d}$ and $f = 5.334 \, \text{c/d}$.

we finally adopt the value derived from the $O-C$ analysis, $P_{sh} = 0.057122(14) \, \text{d}$, as our most accurate measure of the superhump period.

Superoutburst light curves of some dwarf novae contain additional periodicity which can be revealed by the pre-whitening procedure. Such light modulations are often connected to the orbital period or other kind of superhumps (eg. Olech et al. 2009, Rutkowski et al. 2009). We checked if such a periodicity can also be detected in the case of 1RXS J0532. In order to do that, from the de-trended light curve of a particular night, we individually subtracted the frequency 17.4994c/d (corresponding to the superhump period). We fitted a Fourier series by the least squares method and subtracted it from the data. Next, all light curves obtained in this way were combined and a power spectrum computed. This method of pre-whitening allowed us to remove the influence of variable amplitude and light curve shape on the spectrum. The periodogram obtained with this method is presented in the bottom panel of Figure 3. Lets assume that some other periodicity (like orbital period or negative superhumps period) close to $P_{sh}$ was present before in the light curve. Those variations should be clearly visible in the pre-whitened spectrum (like for instance in Olech et al. 2007). However, there is no significant signal
around \( f \sim 17.5 \text{c/d} \) distinguishable from the noise and only a low-power multiplet is visible. Two highest peaks in this multiplet at frequencies \( f_1 = 4.329 \pm 0.036 \) and \( f_2 = 5.334 \pm 0.036 \) are visible. The nature of those peaks is unknown. This could be the effect of imperfect subtraction of the signal \( P_{sh} \) or its alias. However, it could also be a result of physical processes going on in this system, especially because other systems also show peaks in the same frequency range. In particular observations of WX Hyi and SDSS J162520.29+120308.7 (Olech et al. 2011 in preparation, private communication) reveal peaks at frequencies around 5-6 c/d in the quiescence spectrum.

5.1. High-frequency variations

Relatively large scatter in the light curves observed on 30 and 31 August and 3 and 4 September suggest the presence of additional variability. We expect that the oscillations responsible for this scattering must be much shorter than \( P_{sh} \). Dwarf nova oscillations or quasi-periodic oscillations (QPO) can be a reasonable explanation for such modulations (eg. Woudt & Warner (2002), Woudt et al. (2010) and references therein). We checked if such oscillations were present in our light curve.

The observing run on 30 August is too short to look for quasi-periodic variability. However, observations performed on 31 August, 3 and 4 September consist of long runs, with exposure times around 10s. The data have good quality and the variable star has a signal level \( \sim 8000 \text{ADU} \) over the noise which results in errors of the order of 0.01 mag. Hence, we looked for QPO variability in the data from these three nights.

We applied the following procedure to the data from 31 August, 3 and 4 September. First we removed the global superoutburst trend and then, for each night separately, we removed the modulations responsible for the superhumps by fitting a Fourier series with 10 harmonics. We then calculated the power spectra.

The complex character of the superhump light curve prevents a complete removal of all frequencies connected with the superhumps. We only present results for 3 September for which the above procedure gave the best result ie. the most prominent peaks are higher than \( 4 \sigma \) (over 99.99% confidence level). Figure 4 shows the AOV periodogram obtained with 2 harmonics. We show the spectrum from 160 c/d as low frequency peaks don’t contain any relevant information but only information about less than perfect removal of the non-strictly-periodic superhump modulation and noise.

Two particularly clear peaks are present in the periodogram at frequencies \( f_1 = 460.34 \pm 1.63 \text{c/d} \) (188s) and \( f_2 = 823.96 \pm 3.35 \text{c/d} \) (104s). The corresponding periods, and their low coherence, are characteristic of the quasi periodic oscillations observed in some dwarf novae. Although the spectrum we obtained looks credible, the high humidity that occurred during these nights could have caused condensation on the glass covered CCDs and affected our measurements and greatly increased the noise.
The two highest peaks are located at frequencies $f_1 = 460.34 \pm 1.62 \text{ c/d}$ and $f_2 = 823.96 \pm 3.35 \text{ c/d}$. The dotted horizontal line represents the 4σ confidence level.

5.2. Apsidal motion of accretion disc

Smak (2009a) presented several arguments that the evidence presented earlier by several authors for disc eccentricity in dwarf novae is a result of measurement errors or arbitrary incorrect assumptions. However, he did not rule out the existence of an eccentric accretion disc. In the TTI model, such eccentricity is a crucial ingredient and thus its absence would result in the rejection of the entire TTI model. But even for the Smak interpretation of superhumps, the presence of such an eccentric disc which "precesses" (in the sense of apsidal motion) would give the necessary clock for superhumps timing.

From Figure 1, one might expect a decreasing trend of brightness from night to night consistent with the globally decreasing trend of the plateau region. Instead, on some nights we clearly see a trend of increasing brightness. One might suspect that atmospheric extinction could be responsible for this behavior. However, since we performed differential photometry, only the second order extinction coefficient $k''$ could cause this. We determined the colour difference between the variable and comparison stars to be about 0.3 mag. Assuming quite a high, but still reasonable, value of $k''$, we find that for air mass between 1 and 2 the change in brightness due to differential colour extinction cannot be larger than 0.02 mag. This is about one order of magnitude too small to produce the observed behavior. Moreover, we studied over a dozen stars in the field and only 1RXS J0532 exhibited this trend. Even if we assume that this is an instrumental effect, it cannot explain the observed brightness oscillation around the mean trend of the plateau.

This raised our suspicion that an additional periodicity may be present in the light curve.

To investigate this behavior further, we fitted two linear functions to model the plateau stage of the superoutburst. Two functions were needed because of the shape of the observed plateau (see section 3). The dashed lines in Figure 5 represent these linear fits to the corresponding parts of the superoutburst. For each night shown in Figure 5 the mean values of time and magnitude were derived. An indicative cubic spline curve through these mean values is shown to highlight the variations.
in brightness around the straight lines.

In order to measure the period of this modulation, for each night shown on Figure 5 we calculated average values\(^1\) for successive pairs of maxima and minima. In doing this we have assumed that each extremum is defined by two parameters: brightness - \(m\) and time - \(t\). Finally, we subtracted trends modeled previously with the linear functions. The resulting residuals are presented in Table 4.

For the residuals we calculated the AOV periodogram with five harmonics using the ZUZA code. The results are presented in Figure 6. The most prominent peak is located at \(f = 0.5885 \pm 0.014\) c/d which corresponds to \(P = 1.6992\) days.

Figure 7 presents a residual light curve phased with this period. In addition a sine function with this period is superimposed on the residuals. Although the scatter is substantial, the periodic modulation can be clearly seen.

There is a well know relation between the beat period \(P_{\text{prec}}\), the orbital period \(P_{\text{orb}}\) and the superhump period \(P_{\text{sh}}\) observed during a superoutburst:

\[
\frac{1}{P_{\text{prec}}} = \frac{1}{P_{\text{orb}}} - \frac{1}{P_{\text{sh}}} \tag{8}
\]

For \(P_{\text{sh}} = 0.05712\) d and \(P_{\text{orb}} = 0.05620\) d we obtain \(P_{\text{prec}} = 3.39\) d.

\(^1\)according to \((sh(m,t)_{\text{max1}} + sh(m,t)_{\text{min1}})/2, (sh(m,t)_{\text{min1}} + sh(m,t)_{\text{max2}})/2, (sh(m,t)_{\text{max2}} + sh(m,t)_{\text{min2}})/2\ldots\)
Table 4
Residual values of mean magnitude with respect to linear fits to the lightcurve of 1RXS J0532 during the 2009 superoutburst.

| HJD* (d)   | res (mag) | HJD* (d)   | res (mag) | HJD   | res (mag) |
|-----------|-----------|-----------|-----------|-------|-----------|
| 72.4793   | 0.01726   | 75.5600   | 0.03376   | 77.4098 | 0.01363   |
| 72.5099   | 0.00436   | 75.5720   | 0.02074   | 77.4913 | -0.00465  |
| 72.5367   | -0.00443  | 75.5903   | 0.01157   | 77.5211 | -0.02241  |
| 72.5662   | -0.00954  | 75.6067   | 0.00948   | 77.6096 | -0.05293  |
| 72.5978   | -0.01596  | 76.3331   | 0.03623   | 78.4862 | -0.03166  |
| 72.6252   | -0.02317  | 76.3501   | 0.01641   | 78.5148 | -0.04767  |
| 73.4826   | 0.004494  | 76.3782   | 0.00607   | 78.543  | -0.06373  |
| 73.5123   | -0.01504  | 76.4106   | -0.00069  | 78.3712 | -0.06583  |
| 73.5399   | -0.02862  | 76.4411   | -0.00699  | 78.5991 | -0.07422  |
| 73.5704   | -0.03136  | 76.4684   | -0.02820  | 78.6264 | -0.07129  |
| 73.5999   | -0.03157  | 76.4961   | -0.04059  | 79.4857 | 0.05210   |
| 74.4569   | 0.02922   | 76.5227   | -0.06353  | 79.5161 | 0.05341   |
| 74.4843   | 0.01618   | 76.5510   | -0.07693  | 79.5345 | 0.05609   |
| 74.5093   | 0.01461   | 76.5827   | -0.08707  | 79.5632 | 0.06177   |
| 75.5086   | 0.04597   | 77.3510   | 0.03033   | 79.6042 | 0.06172   |
| 75.5426   | 0.039046  | 77.3845   | 0.03047   |       |           |

* HJD - 2455000

If the narrower side of the eccentric accretion disc is turned towards the observer we observe minimum brightness. When the more extended side of the disc is turn toward the observer we detect maximum brightness. Hence two maxima and two minima caused by the orientation of the accretion disc should be visible per orbital period.

Since we measured a modulation with period $P = 1.6992 \, \text{d}$, we interpret this to be the effect of apsidal motion of the accretion disc with period $P = P_{\text{prec}}/2$.

Such apsidal oscillations should mostly be visible in objects with high orbital inclination, which is in agreement with the high $i$ value measured for 1RXS J0532.

6. Conclusions

a. It has been confirmed that 1RXS J053234+624755 is a SU UMa star. The measured superhump period is $P_{\text{sh}} = 0.057122(14) \, \text{d}$. The superoutburst is characterized by a slight rebrightening in the later phase of the plateau. The amplitude of the superoutburst was determined to be 3.3 mag.

b. We determined the rate of superhump period change to be $\dot{P} = 9.5 \cdot 10^{-5}$. This value is noticeably different than the rates obtained for for superoutbursts in 2005 and 2008 ($\dot{P} = 5.7 \cdot 10^{-5}$ and $10.2 \cdot 10^{-5}$, Imada et al. 2009 and Kato et al. 2009, respectively).
c. We proposed that the observed superhump light curve behavior can be explained if we assume that the distance of the superhump source from the disc plane decreases as the superoutburst declines.

d. Additional data analysis allowed us to detect a quasi-periodic signal at the frequency $f_1 = 460.34 \pm 1.63 \text{c/d (188s)}$. This frequency, however, may be spurious and simply the result of high humidity during the observation.

e. Detailed analysis of the superoutburst plateau phase enabled us to detect oscillations with a period $P_{\text{prec}}/2 = 1.699 \pm 0.005 \text{d}$, which we interpret as the effect of an apsidal motion of the accretion disc.

f. Based on the double peaks in the emission lines, Kapusta & Thorstensen (2006) concluded that the orbital inclination, $i$, of 1RXS J0532 is not far from edge on. Given the prominence in the spectroscopic data of the double peaks in the emission lines, it is almost certain that $i$ is larger than 70 deg. Taking into account the fact that there are no observed disc eclipses, we have assumed $i = 75 \text{ deg}$. Even though we were not able to observe this system during the maximum of the superoutburst, visual inspection of the amplitude of superhumps in Figure 4 in Poyner & Shears (2006) and Figure 3 in Imada et al. (2009) gave $A_0 = 0.28 \pm 0.01 \text{ mag}$. Using eq. (4) and (5) from Smak (2010) we obtained
Fig. 7. Phased light curve of residuals with period $P = 1.6992\text{d}$ obtained after subtracting the linear trend. The solid line shows a sine function with the above period.

$A_n = 0.151$ mag. These results are consistent with the dependence between superhump amplitude and orbital inclination discovered by Smak (2010).

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