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The white dwarf in dwarf nova SDSS J080434.20+510349.2: Entering the instability strip?

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Abstract. SDSS J080434.20+510349.2 is a WZ Sge type binary that displayed a rare outburst in 2006 (Pavlenko et al. 2007). During the long-lasting tail of the late stage of the outburst, the binary showed a two-humped or four-humped profile of the orbital light modulation. The amplitude of the orbital light curve decreased while the mean brightness decreased; moreover, that occurred \( \sim 10 \) times faster during the fast outburst decline with respect to the late quiet state of slow outburst fading. There were no white dwarf pulsations detected in this system, neither 1 - 1.5 months prior to the outburst, nor in 1.5 - 2 months after the 2006 outburst. However, strong non-radial pulsations with period 12.6 minutes and a mean amplitude of 0.05\textasciimacron{} were first detected in the V band with the 2.6-m Shajn mirror telescope of the Crimean astrophysical observatory, \( \sim 8 \) months after the outburst. The evolution of pulsations over two years, in 2006 - 2008, is considered. It is supposed that pulsations first appeared when the cooling white dwarf (after the outburst) entered the instability strip, although the possibility of temporary lack of pulsations at some occasions could not be excluded.

1. Introduction

Twelve cataclysmic variables (CVs) with orbital period close to the evolutionary orbital period minimum, containing a pulsating white dwarf (WD), were known up to now (Mukadam et al. this volume). SDSS J080434.20+510349.2 (hereafter SDSS J0804) is the 13th system showing such pulsations (Pavlenko and Malanushenko 2009) which are generally believed to be due to non radial g-mode pulsations of the white dwarf (Warner and Robinson 1972). P. Szkody et al. reported that there are 4 dwarf novae (PQ And, GW Lib, V455 And, REJ 1255+26) containing an accreting WD pulsator that have undergone outbursts (paper available at www.narit.or.th/conference-prcsa2008/). SDSS J0804 (Pavlenko et al. 2007) is the 5th binary of such type. SDSS J0804 is a WZ Sge type star that displayed an outburst in 2006 with 11 rebrightenings. Superhumps, that have been observed both during the main outburst and the rebrightenings, were replaced later on by the orbital two-humped light variations (Zharikov et al. 2008; Pavlenko 2007) typical of the WZ Sge stars in quiescence. The phenomenon of a second series of rebrightenings or “mini-outbursts”, with longer recurrence time and less amplitude, was found by Zharikov et al. (2008). In quiescence before outburst, the optical spectrum of SDSS J0804 displayed a blue continuum with broad absorption lines from a white dwarf, surrounding the double-peaked Balmer emission lines formed in the accretion disk (Szkody et al. 2006). These authors also noted the particular behavior of the binary during one night in 2005: quiet state - sudden increase of brightness (0.5\textasciimacron{}) in a few minutes) accompanied by increase of amplitude.
from 0.05\text{m} to 0.2\text{m}, that was never detected after the outburst (Zharikov et al. 2008). Despite J0804 was a promising CV to search for the WD non-radial g-mode pulsations, it did not show them before the 2006 outburst (Szkody et al. 2006). We had pointed attention to the short-term light variations, with the most significant 12.6 min. oscillation in 2008, January 1, when its amplitude at some pulses was commensurable with orbital light modulation $\sim 0.05\text{m}$ (Pavlenko and Malanushenko 2009). The results of searching for possible pulsations in the available data base of our observations, both before and after the 2006 outburst, in order to detect their first appearance, is presented here.

2. Observations
Taking into account the small amplitude of short-term variations of SDSS J0804, the analysis was restricted by using the most precise CCD data collected from 14 nights in 2006 - 2008, ensuring the accuracy of a single brightness measure to better than $0.01\text{m} - 0.015\text{m}$, time resolution of a few minutes for the multicolor observations and 20 - 30 seconds for observations in white light. They were obtained with the 2.6-m Shajn telescope of the Crimean astrophysical observatory (CrAO) using the CCD FLI 1001E in Johnson B, V, R bands or in white light reduced to R. All measurements were made with respect to the comparison stars pointed by Zharikov et al. (2008). The photometric standards in cluster M67 (Mendoza 1967) were observed as well and used to measure the V and R values of comparison stars. Other details of observations are given in Pavlenko and Malanushenko (2009). The time resolution of observations was different and varied from a few minutes for multicolor observations to 15 - 20 seconds for observations in white light.

3. Outburst and orbital light curves
The light curve of SDSS J0804 for 2006 - 2008 is given in Fig.1, including one night prior to the outburst. The dense part of points corresponds to rebrightenings. After the end of rebrightenings, the rapid brightness decline continued and has been observed during $\sim 3 - 4$ weeks. Then the star began to fade very slowly. We first found SDSS J0804 in the 2006 outburst (Pavlenko et al. 2007) at the end of the outburst plateau (two days before the plateau end). Assuming the possible plateau duration to be 2 - 3 weeks one could expect the start of the plateau outburst at JD $\sim 2453780 - 2453787$. The color-index V-R was estimated for several dates during the different stages of the outburst. For JD 2453856-2453858 (fast brightness fading after rebrightenings), mean V = 16.4\text{m}, V-R= 0.17\text{m}; for JD 2454479 (late fading stage), mean V = 17.26\text{m} and V-R = 0.11\text{m}.

The dramatic change of the nightly light curve profile has been detected during the fast stage of the outburst fading in the three weeks after rebrightenings were finished (see Fig. 2). To make sure that this modulation is really the orbital one, the data were folded on the orbital period using the ephemeris $\text{MinI} = \text{HJD} 2453744.37 + 0.0590048(3)E$ (Pavlenko and Malanushenko 2009). One could see that the light curve is already a two-humped one, but the heights of the neighbor humps are 0.0.3\text{m} and 0.0.05\text{m} for (a), 0.3\text{m} and 0.1\text{m} for (b) and 0.2\text{m} and 0.2\text{m} for (c). Both minima are observed close to phases 0.0 and 0.5. While the slightly deeper minimum in (a) and (b) cases falls into phase 0.0, the deepest minimum in case (c) falls into phase 0.5. Note the sharp eclipse-like minimum at phase near 0.0 for (a) and (b) cases. The two-humped light curve and the perfect fitting to the ephemeris are convincing arguments for considering this modulation as the orbital one.

The orbital light curves for later stages of the outburst display small amplitude and show diversity of their two-humped profiles. In Fig. 3 typical examples of the orbital light curves obtained 195 - 775 days after the end of rebrightenings are shown. Some of them (a) display two near-equal sine-like waves per period, another - W UMa-like - nceighbor humps with round
maxima and sharp minima (c). The curves (b) and (d) demonstrate rather four-humped than two-humped light curves (or splitting of the humps with unequal heights).

The dependence of the amplitude of the orbital light curves on the mean brightness is shown in Fig. 4. The amplitudes decrease when brightness decreases, but with a different rate. It is possible to pick out three different dependencies: the first one corresponds to the data shown in Fig. 2 (they are shown by the dashed line) - at that time the dependence is the sharpest; the second one refers to the data of the quiet long-lasting fading (dash-dotted line). Note that the amplitude decrease (expressed in intensities per unit of intensity) was \( \sim 10 \) times faster during the fast outburst decline than during the slow fading. The third dependence corresponds to the data falling into the vicinity of the maxima of the two mini-outbursts (dotted line). These amplitudes themselves are slightly bigger than the amplitude apart the mini-outbursts.

**Figure 1.** Light curve of the outburst of SDSS J0804. The V and R data are marked by filled and open circles respectively. Part of the data are averaged and expressed as one or two points per night. Arrows point to the data used for the subsequent periodogram analysis.
4. Analysis of the short-term variations

The white dwarf pulsations in CVs are difficult to search for, because these variations could be contaminated by other multiperiodical and quasi-periodical signals connected with orbital and rotational motion, instability in the accretion stream and disk. The orbital light modulation profile itself also could vary from night to night as it was described above. The investigation of the short-term light variations is performed for three data sets: 1) before outburst, 2) during the fast outburst decline $\sim$ 3 weeks after the end of rebrightenings and 3) during the long tail of the outburst.

The light curve for 2006, January 8 (1 - 1.5 monthsc before outburst) is shown in Fig. 5 (a). One could see the jump-like brightness decrease from $V = 17.4^m$ to $V = 17.7^m$, which occurred during $\sim$ 9 minutes. A similar behavior had been observed by Szkody et al. (2006) also before outburst at JD 2453380, but in the “opposite direction”: they detected a sharp brightness increase of $0.5^m$. The Fourier transform (FT) for the initial data, corresponding to the lower linear part of the light curve, has been calculated (see Fig. 5 (b)). The most significant peaks point to one quarter and one half of the orbital period. After the orbital wave subtraction, the FT was calculated again for residuals. The ISDA package was used for calculations (Pelt 1992). The amplitude periodogram is shown in Fig. 5 (c), where the amplitudes are normalized according to Pelt (1992). No significant peaks were seen on that periodogram (Fig. 5 (c)).

The most dense data from the second data set (JD 2453856) were selected for the analysis. The FT for original data is presented in Fig. 6 (a), where the significant peaks point to the orbital period and its twice value. FT for the data after orbital period is removed is shown in

Figure 2. Example of data for April 30, May 01 and May 02, 2006 folded on the orbital period. For clarity data are plotted twice.

Figure 3. Example of data for October 21, 2006; February 26, 2007; January 13, 2008 and May 23, 2008 folded on the orbital period. For clarity data are plotted twice.
**Figure 4.** Dependence of the orbital amplitude on mean brightness expressed as intensity (arbitrary values). Dashed line is drawn through the data of April 30, May 01 and May 02, corresponding to the rapid outburst decline after the end of the rebrightenings. Dash-dotted line is drawn through the data belonging to the “long tail” of the outburst and before one (last point), and dotted line is drawn through the data from two mini outbursts.

**Figure 5.** a) The light curve for 2006, Jan 08; b) Fourier transform for the initial data; c) Same as b) but with orbital period removed.
Figure 6. The Fourier transform for the initial data of 2006, April 30 (a), those for the data after orbital period is removed (b) and data folded on the best period for residual spectrum 0.01156 day (16.7 min). For clarity data are plotted twice.

Fig. 6 (b). There are a few peaks of low significance, the most prominent one pointing to the frequency $86 \text{ day}^{-1}$ (16.7 min.). This corresponds to the light variations with a mean amplitude of 0.025$m$ (see Fig. 6 (c)). In Fig. 7 (a - k) the original light curves for the data from the third set of observations are shown. For each data the FT after orbital period subtraction was calculated, and the corresponding periodograms are shown in Fig. 7 (l - u). One could see that every periodogram (with exception of (m)) shows a sequence of significant peaks. These series concentrate within $40 - 150 \text{ day}^{-1}$. The most stable pulsation corresponds to $114 \text{ day}^{-1}$ (12.6 min.) and its twice value $57 \text{ day}^{-1}$. The peak at $68 \text{ day}^{-1}$ could be caused by the four-humped structure of the orbital light curve profile, because it coincides just with $1/4 P_{\text{orb}}$. The less stable peak could be seen at frequency near $74 \text{ day}^{-1}$ and its twice value $148 \text{ day}^{-1}$. Many of peaks are probably not connected with WD pulsations.

5. Discussion

The orbital light curves of SDSS J0804 had typically a two-humped profile, often displaying the splitting of one or both humps. The color-index V-R continued to decrease with time during the long brightness decay, indicating the decrease of the accretion disk contribution to the total light and, so, the increase of the white dwarf contribution. The source J0804 is localized in the Galaxy in a region of low interstellar extinction; its $E(V-R)$ could be calculated following Schlegel et al. (1998), and it is roughly $E(V-R) = \sim 0.037m$, so the corrected color index is $(V-R)_0 = 0.073m$. That corresponds to a black-body temperature $\sim 15000^\circ$ K with accuracy of a few of thousands K. Taking into account that $\sim 2$ years after the outburst the disk could also still contribute to the total light, one could expect that the temperature of the white dwarf was hotter than $15000^\circ$ K.

The dependence of the orbital amplitude on the mean brightness could be caused by the decreasing brightness of the bright tail of the accretion disk, due to the decrease of the mass transfer rate over the source, that occured $\sim 10$ times faster during the fast outburst decline, with respect to the late quiet state of slow outburst fading. Such dependence is obviously caused by the decreasing of the initially more enhanced mass transfer rate; decreasing itself was $\sim 10$ times faster during the fast outburst decline (after the end of rebrightenings) than during the late stage of the outburst.

The variable and sometimes four-humped orbital modulation points to a complex and variable
Figure 7. The light curves (a - k) and corresponding Fourier transforms (l - u) for the observations of SDSS J0804 in 2006 - 2008. The solid lines are drawn at the frequencies 57 and 114 day$^{-1}$, while the dotted one at 68 day$^{-1}$. 
morphology of the accretion disk.

We did not find any significant pulsation during the period 1 - 1.5 months before the outburst. The first detection of the most stable 12.6-min. pulsations was \( \sim 8 \) months after the expected start of the outburst. It is not clear whether the lack of pulsations of JD 2454063 was due to their temporary disappearance, or was caused by insufficient data statistics. It is already known that the pulsators in dwarf novae could stop their pulsations by some reason, contrary to what occurs in the ZZ Ceti stars (Southworth et al. 2008). So, the lack of pulsations in SDSS J0804 in two occasions before outburst at JD 2453384 (Szkody et al. 2006) and at JD 2453856 could not be used to claim that before the outburst the white dwarf never pulsated. However it is possible to suggest that compressional heating during the outburst and further fast cooling entered the white dwarf of SDSS J0804 into the instability strip.

It is also impossible to be confident on the 16.7 min. periodicity of JD 2453856 as that of the white dwarf pulsations, because the periodogram is different from those shown in Fig. 7.

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