ISSN 1845–8319

MULTICOLOUR PHOTOMETRY OF UNUSUAL DWARF NOVA HS 0218+3229

P. GOLYSHEVA[1], N. KATYSHEVA[1], S. SHUGAROV[1,2], N. BORISOV[3] and M. GABDEEV[3]

[1]*Sternberg Astronomical Institute, Lomonosov Moscow State University 119991, Universitetskij pr., 13, Moscow, Russia*
[2]*Astronomical Institute of the Slovak Academy of Science, 05960 Tatranská Lomnica, Slovakia*
[3]*Special Astrophysical Observatory of the RAS, 369167, Nizhny Arkhyz, Karachaevo-Cherkesia, Russia*

Abstract. Our analysis of the 200 photographic and the 2000 CCD frames of the cataclysmic variable HS 0218+3229, taken from 1963 till 2011, showed the existence of two outbursts in 1980 and 2007 with the amplitude of about 4 magnitude in V and pg bands. We classified the object as an UGSS type dwarf nova with rare outbursts of the symmetrical shape, which characterizes the "inside-out" outbursts. Using the O–C diagram, we refined the orbital period of the system $P_{orb} = 0.^{d}2973559$. Orbital light curves showed a double-wave modulation caused by an ellipticity effect of the secondary K5 V star. The spectrum of HS 0218+3229 is dominated by emission lines of hydrogen and neutral helium.

Key words: photometry - close binary systems - dwarf novae - spectra

1. Introduction

Cataclysmic variables are highly evolved close binary systems. They consist of a donor star (a red dwarf) and a white dwarf (WD). Because of flow of matter from the donor onto the WD an accretion disk is formed, that has a significant effect on the radiation from the system. Under certain conditions, the disk can greatly increase the luminosity and we observe an outburst of the dwarf nova.

HS 0218+3229 (RA = $2^h21^m33^s.49$, Del = $+32^o43'24''.0$, J2000, 2MASS) was suspected as a CV by Gänsicke *et al.* (2002). Later the system was studied by Rodríguez-Gil *et al.* (2009). They did not observe any outbursts, but their spectral observations showed the emission lines of hydrogen and neutral helium of a weak accretion disc and the absorption lines of a cold component. They described the second component as a K5V star which contributes of 80-85% to the R-brightness of the system. Rodríguez-Gil et al. (2009) determined: the orbital period $0^d.297229661 \pm 0^d.000000001$, inclination of the orbit $i = 59^\circ \pm 3^\circ$, mass ratio $0.52 < q < 0.65$, mass of the white dwarf $0.44 < M_1(M_\odot) < 0.65$, mass of the secondary $0.23 < M_2(M_\odot) < 0.44$ and distance to the system of 0.87–1.0 kpc. HS 0218+3229 was also identified as X-ray source RXS J022133.6+324343 and as IR-source 2MASS J02213348+3243239.

Independently HS 0218+3229 was discovered and studied by Antipin (see Golysheva *et al.*, 2012). Two outbursts of HS 0218+3229 that occured in 1980 and 2007 yrs were detected. One more outburst (in 2002) was found by P. Wills in the database NEAT[1].

2. Observations

The photometric CCD-observations were carried out with the 50-cm telescope in Stará Lesná (Slovakia) and 50- and 125-cm telescopes of the Crimean laboratory of SAI. More than 2000 CCD frames in $UBVR_{C,J}I_{C,J}$ bands at the period from 2006 to 2010 years were received. More detailes about these observations were described in the paper by Golysheva *et al.* (2012).

Two spectra of HS 0218+3229 were taken on September, 17/18, 2010 in the prime focus of the Russian 6-m telescope BTA with the SCORPIO multi-mode focal reducer (Afanasiev and Moiseev, 2005) at the spectroscopic mode with the long slit and CCD-camera EEV CCD 42-40. Spectra were obtained with the exposition 300 sec under satisfactory atmospheric conditions, with S/N = 15. The grating VPHG (1200 lines/mm) provided the spectral resolution 5 Å in the spectral range 4000–7300 Å. For flux calibration and the calibration of the wavelength the star BD+33^{o}2642 and Ar-Ne-He lamp were observed. Spectra were reduced, sky and bias have been removed and then divided by a flat-field frame. Astronomical data packages in IDL system were used for reduction of the spectral observations. HS 0218+3229 was in its quiescence state.

[1]NEAT – Near-Earth Asteroid Tracking: http://neat.jpl.nasa.gov/

3. Analysis of Photometric Data

HS 0218+3229 was observed during the 70 nights from November 2006 till November 2011. One outburst was found by S. Antipin on the four photo plates from the SAI archive in September 1980. Another outburst was caught in October 2007. Overall $UBVRI$-light curves obtained in 2006-11 are presented in Figure 1. The detailed V-light curves of the 2007 outburst are shown in Figure 2: the outburst light curve is on the upper figure and the nightly LCs during outburst are in the bottom. The magnitudes of comparison stars from the paper Golysheva *et al.* (2012) were used for the frame calibration.

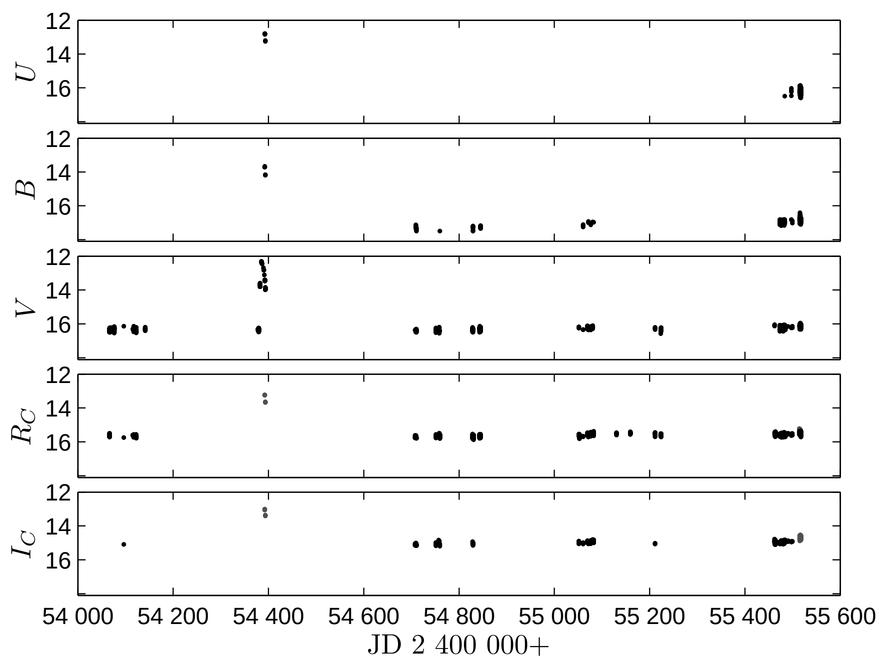

Figure 1: The overall light curves in $UBVRI$-bands. The observations in R_J, I_J bands are plotted by grey points.

The last outburst was fully recorded only in the V-band. We estimated the following stellar magnitudes at the maximum by extrapolation: $U{\approx}11^m.3 \pm 0^m.2$, $B{\approx}V{\approx}12^m.3 \pm 0^m.2$, and $R_J{\approx}I_J{\approx}12^m.2 \pm 0^m.2$.

These values were used for the estimation of the outburst amplitudes. It was found that the amplitude of the outburst was the highest in the U-band: $\sim 5^m$, in B-band $\sim 4.^m5$ and was lower in R and I-bands ($\sim 3^m$ and 2.5^m, accordingly).

The light curve of the 2007 outburst has a more symmetric shape than for most dNe (see Figure 2). The coefficient of asymmetry (the ratio of duration of the rising branch to the duration of all outburst) is 0.22 for our object. The maximum of outburst occurred within the interval JD 2454384–385.

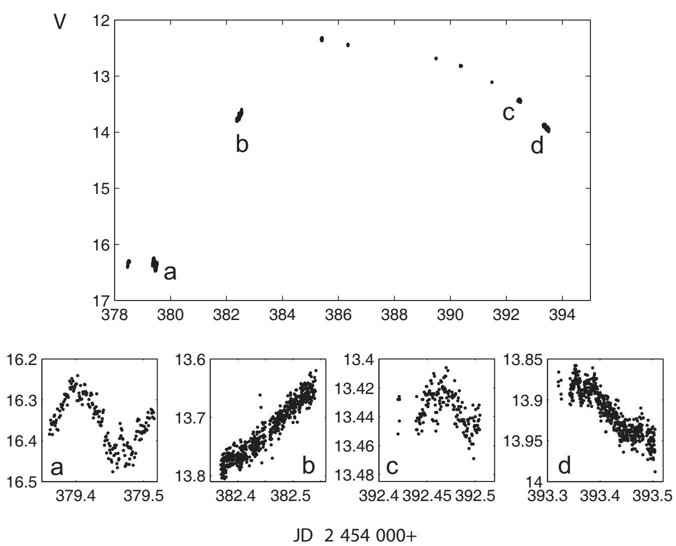

Figure 2: The LC of the 2007 outburst in the V band (top), the nightly LCs during the outburst (bottom).

As seen in Figure 2, during the outburst there are no significant short-period variations of the brightness, while in the quiescent state periodic oscillations are shown up distinctly. This variability can be explained by the orbital motion of the system.

Figure 3 shows the nightly $UBVR_cI_j$ outside the outburst period in 2010.

A large UV-excess should be noted. During the outburst the position of the star in the two-color diagram is close to that of an absolute black body with a temperature of about 15000 K. At the brightness minimum the position of the variable corresponds to a star of spectral class K5V–K6V. More detailed information about two-color diagrams was given in the paper by Golysheva *et al.* (2012).

An orbital wave with the amplitude of $0^m.13 - 0^m.19$, depending on the spectral band, can be seen in Figure 3. A similar variation of the brightness has been observed by Rodríguez-Gil *et al.* (2009) also. It should be noted that they made their observations with a clear filter. They showed that the brightness of the star varied with a period $0.^d297229661$.

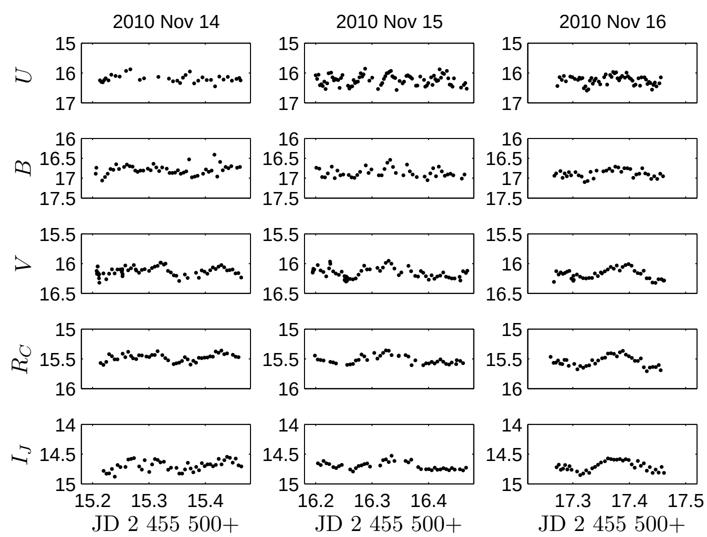

Figure 3: The nightly $UBVR_cI_j$ (from top to bottom)light curves of 14^{th}, 15^{th} and 16^{th} November 2010.

We investigated our light curves and concluded that during the orbital period there was a double wave. The double wave over the period is related to a distorted shape (an ellipsoidal surface of the Roche lobe) of the cold component. A rapid variation in the brightness unrelated to the orbital wave can be seen in the U and B-bands in Figure 3. This variability has a characteristic time of ∼40–50 min and in the U-band the observed maximum amplitude of the rapid variability is up to $0^m.7$. In the B-band the amplitude is somewhat less at $0^m.4$. We assume that this flickering is related to the hottest component of the system, i.e. the fluctuations of the hot region where the stream interacts with the accretion disk.

In the paper by Golysheva *et al.* (2012) it was shown that orbital double wave changed during the October 2007 outburst. While the amplitudes of the humps before the outburst were different, after the outburst they became similar.

Using the observations of minima from Rodriguez-Gil *et al.* (2009) and our data, we determined more precise value of the orbital period from O–C diagram (Table I) and got the orbital ephemeris:

$$JD_{min\ hel} = 2453653.0286 + 0.^{d}2973559 \cdot E,$$

where $T_0 = 2453653.0286$ was taken from Rodriguez-Gil *et al.* (2009).

In Table I the times of minima for JD$<$ 2453656 were taken from Rodríguez-Gil *et al.* (2009), later dates – our observations, uncertain data are marked by ":".

The O–C diagram is plotted in Figure 4. It consists of two parts, corresponding to the main (left) and the secondary (right) minima.

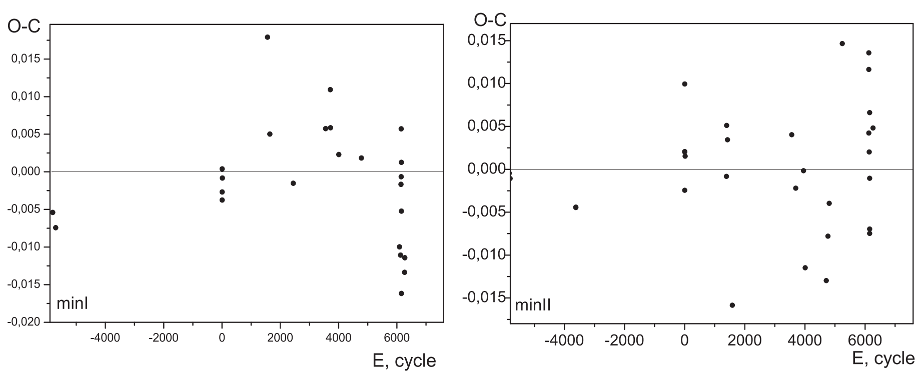

Figure 4: The O–C diagrams for the main minima (left) and the secondary minima (right).

The summed light curves, folded with the determined period, are plotted in Figure 5. The double wave per a period is clearly seen, especially in V and R_c-bands. In the U and B-bands the double wave is not so obvious but there is some fading at phase 0. It can be seen from the orbital curves, a brightness minimum (and reddening) sets at times when the secondary component is visible from the side of the "nose" ($\varphi = 0.5$) or from the trailing side ($\varphi = 0.0$) (see Figure 5).

Table I: Minima times of HS 0218+3229 at phases 0 and 0.5.

HJD	E, cycle	O–C	HJD	E, cycle	O–C
51926.274	-5807	-0.005	51918.399	-5833.5	-0.001
51956.305	-5706	-0.007	51926.427	-5806.5	-0.001
53653.029	0	0.000	52576.445	-3620.5	-0.004
53653.918	3	-0.003	52577.337	-3617.5	-0.004
53654.809	6	-0.004	53652.882	-0.5	0.002
53655.704	9	-0.001	53653.774	2.5	0.002
54117.220	1561	0.018	53654.674	5.5	0.001
54141.293	1642	0.005	53654.959	6.5	-0.002
54379.469	2443	-0.001	53655.855	9.5	0.001
54709.542	3553	0.006	54066.502	1390.5	-0.001
54758.611	3718	0.011	54067.400	1393.5	0.005
54759.498	3721	0.006	54076.319	1423.5	0.003
54843.349	4003	0.002	54122.390:	1578.5	-0.016
55076.476	4787	0.002	54710.581:	3556.5	0.004
55463.325	6088	-0.010	54751.610	3694.5	-0.002
55473.434	6122	-0.011	54828.330	3952.5	0.000
55476.417	6132	-0.002	54845.268:	4009.5	-0.011
55480.290	6145	0.006	55052.524:	4706.5	-0.013
55480.581	6146	-0.001	55071.560	4770.5	-0.008
55481.475	6149	0.001	55082.566:	4807.5	-0.004
55482.647:	6153	-0.016	55211.340:	5240.5	0.015
55483.550	6156	-0.005	55473.310:	6121.5	0.014
55515.359	6263	-0.013	55473.598	6122.5	0.004
55516.253	6266	-0.011	55476.579:	6132.5	0.012
			55480.435	6145.5	0.002
			55481.324	6148.5	-0.001
			55481.629:	6149.5	0.007
			55482.507:	6152.5	-0.007
			55484.589	6159.5	-0.007
			55517.310	6269.5	0.005

The phased color-indices curves of the main and secondary minima differ slightly. An interpretation of these variations was made in Golysheva *et al.* (2012).

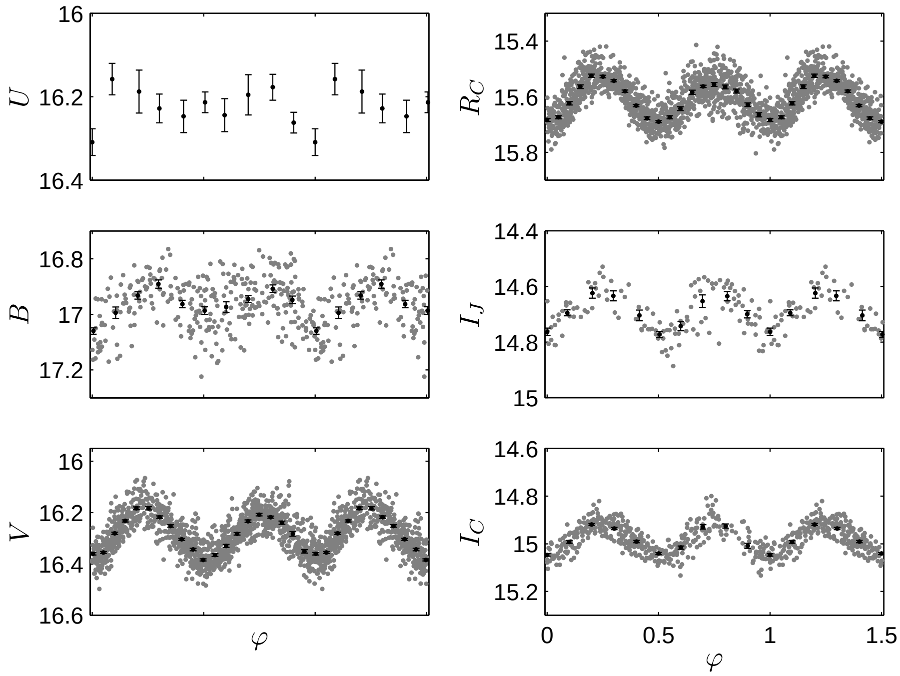

Figure 5: The phased light curves.

4. Spectroscopic Observations

The spectrum of HS 0218+3229 was obtained at the 6-m telescope BTA with the SCORPIO multi-mode focal reducer. Emission Balmer lines (H_α, H_β, H_γ, H_δ and higher lines) and emissions of neutral helium $\lambda\lambda$ 4471, 4921, 5015, 5875, 6678, 7065 Å are present in the spectrum. The flux ($erg/s/cm^2$) versus wavelength is plotted in Figure 6. Balmer emissions are not bifurcated, helium lines are more complex.

The form of the spectrum of September 2010 is very different from the spectrum obtained by Rodriguez-Gil *et al.* (2009). Emission lines of neutral helium λ 5875 Å became stronger. The humps of the red companion became less pronounced and emission Balmer decrement more flat.

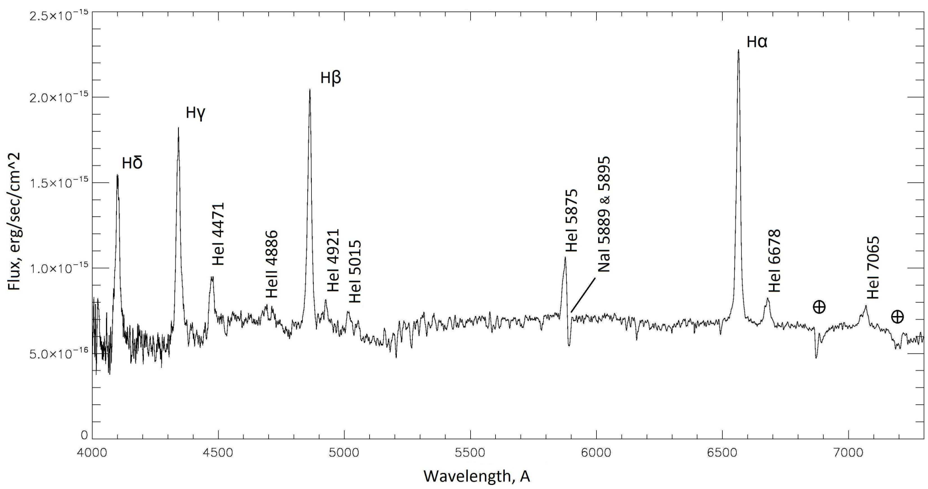

Figure 6: Spectrum of HS 0218+3229.

We can propose that the rate of mass transfer on the 17-18th of September 2010 was larger than on the 28-29th of October 2002. The spectrum became bluer and filled the spectrum of the secondary component.

5. Summary

1. We classified HS 0218+3229 as a rare subtype of dwarf novae (UGSS) with a more symmetric form of outburst (with a asymmetry coefficient 0.22 instead of 0.10 for most of such stars). It could be explained by a critical density of mater that is initially attained in the inner parts of the disk, after which the outburst propagates toward its outer parts (a so-called "inside-out outburst" , see Smak (1984), Cannizzo *et al.* (1986)). The instability develops in the inner, rather than outer, parts of the disk at low accretion rates, $\dot{M} < 10^{-10} M_{\odot}/\text{year}$, since it is in just this case that matter is able to reach the inner parts of the disk and accumulate there. Thus, given the symmetry of the light curve of an outburst, we may conclude that $\dot{M}$ is small. The same result follows from an estimate of the luminosity of the accretion disk and the red component (see Golysheva *et al.*, 2012).
2. The outburst amplitude changes from 5^m in the U-band to $2^m.5$ in the I-band.
3. Using the O–C diagrams we refined the orbital period and got the ephemeris $JD_{minhel} = 2453653.0286 + 0.^{d}2973559 \cdot E$.

4. The form of the spectrum of September 2010 is very different from the spectrum obtained by Rodriguez-Gil *et al.* (2009). The emission lines of neutral helium $\lambda\,5875$ Å became stronger. The humps of the red companion became less pronounced and the emission Balmer decrement more flat.
5. At quiescence there is a small variability with an amplitude of $0^m.2$ and with a characteristic time of hundreds of days (See Golysheva *et al.*, 2012).

Note, that in Golysheva *et al.* (2012) some parameters of the system were estimated and compared with the parameters derived by Rodriguez-Gil *et al.* (2009). But, there are still some unsolved problems:

- recurrent time between outbursts is unknown;
- the variability in U and B-bands connecting with the instability of accretion disk;
- a long-term periodicity, associated with solar-like activity of the secondary is poorly studied.

Acknowledgements

This work is partially based on observational data obtained with the 6-m telescope BTA of the SAO RAS. PG is grateful to the LOC and the SOC and RFBR grant 12-02-00186 for financial support. This work was partially supported by grants: VEGA-grant 2/0038/10, NSh-2374.2012.2, RFBR 11-02-00495, RFBR 11-02-01213. NK is thankful for support from SAIA (Slovakia)

References

Afanasiev, V. and Moiseev, A.: 2005, *Astron. Lett.* **31** 194.

Cannizzo, J. K., Wheeler, J. C., and Polidan, R. S.: 1986, *Astrophys. J.* **333**, 227.

Gänsicke, B. T., Beuermann, K., and Reinsch, K.: 2002, *ASP Conf. Ser.* **261**, 190.

Golysheva, P. Yu., Antipin, S. V., Zharova, A. V., Katysheva, N. A., Chochol, D., and Shugarov, S. Yu.: 2012, *Astrophysics* **55**, 2.

Rodríguez-Gil, P., Torres, M. A. P., Gänsicke, B. T., Muñoz-Darias, T., Steeghs, D., Schwarz, R., Rau, A., and Hagen, H.-J.: 2009, *Astron. Astrophys.* **496**, 805.

Smak, J.: 1984, *Acta. Astron.* **35**, 357.