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MULTICOLOR PHOTOMETRY OF THE DWARF NOVA HS 0218+3229

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This is a study of the cataclysmic variable HS 0218+3229. An analysis of 2000 CCD and 200 photographic observations of this close binary system from 1963-2010 reveals two outbursts (in 1980 and 2007) with amplitudes of about 4^m in the pg and V bands. This variable has been classified as a UGSS-type dwarf nova with rare, symmetric outbursts, which are typical of "inside-out" outbursts. The orbital period is found with greater accuracy to be $0^d.2973559$, during which a double wave is observed owing to the ellipsoidal shape of the secondary component— a class K5V star. The phase light curves and color index curves are introduced and explained, and an interpretation of the position of the object in two-color diagrams is provided. A difference in the orbital light curves before and after the outbursts is detected, and some physical characteristics of this close binary system are determined.

Keywords: *photometry: stars: close binary systems: dwarf novae*

1. Introduction

Cataclysmic stars are close binary systems in a later stage of evolution. They consist of a donor star (a Main Sequence red dwarf) and a white dwarf (WD). Because of accretion of matter from the donor onto the WD, an accretion disk that has a significant effect on the radiation from the system develops around it. 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°43'24".0, J2000, 2MASS) was first suspected of being a cataclysmic variable (CV) by Gänsicke, et al. [1]. From 2000 through 2005, Rodriguez-Gil, et al. [2], made photometric and spectral observations of the variable with various telescopes. A study of the photometric series for this system did

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not reveal any outbursts, and they classified HS 0218+3229 as a cataclysmic variable without establishing a precise type. The presence of strong emission lines in the hydrogen series in the spectrum of this object indicates that the accretion disk in the system is weak. Absorption lines in the red part of the spectrum characterize the predominance of a cold component of class K5V. In that article the following were determined: orbital period $0^d.297229661 \pm 0^d.000000001$, angle of inclination of the orbit of the close binary system $i = 59^{\circ} \pm 3^{\circ}$, and mass ratio $0.52 < q < 0.65$. The mass of the white dwarf, *a*, was estimated to be $0.44 < M_1/M_{\odot} < 0.65$ and that of the secondary component, $0.23 < M_2/M_{\odot} < 0.44$, with a distance to the system of 0.87-1.0 kpc.

The star was discovered independently in 2006 by S. V. Antipin based on negatives from the GAISh (Shternberg Institute) photographic archive and identified as a flaring variable, probably a dwarf nova. Just one burst, in September 1980, with an amplitude of about $4^m.5$ in the *pg* band, was detected among the photographs.

HS 0218+3229 has been identified with the x-ray source 1RXS J022133.6+324343 and the 2MASS source J02213348+3243239.

2. Observations

After a report by Antipin [3], it was decided to begin systematic observation of this object in order to study its flaring variability in more detail and provide a more accurate classification of this new variable star. Our first photometric studies were conducted with a Pictor-416 CCD camera at the Crimean laboratory of GAISh on the 50-cm AXT-5 Maksutov telescope. Later, observations were continued with an Apogee-47p array positioned at the Cassegrain focus of the Zeiss-600 telescope, and in November, 2010, we used the 125-cm ZTE reflector with a VersArray 512 array. The observations were made in the $UBV(RI)_C$ Johnson-Cousins system, but a small set of observations were made in the $(RI)_J$ bands. Subsequently, a substantial portion of these data were obtained using an SBIG-10XME array mounted at the Newton focus of the 50-cm telescope at the Astronomical Institute of the Slovak Academy of Sciences (Stara Lesna).

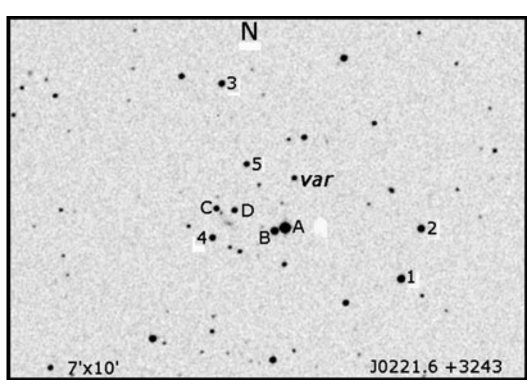

Fig. 1. A finding chart of the variable and the comparison stars (see Table 1). “Var” denotes the variable.

TABLE 1. Comparison Stars

N	U	B	V	R_J	R_C	I_J	I_C
A	12.30	12.22	11.72	11.24	11.42	11.00	11.15
B	14.86	14.64	13.98	13.37	13.58	13.08	13.27
C	16.45	16.29	15.59	15.00	15.21	14.71	14.90
D	16.21	16.14	15.61	15.09	15.28	14.94	15.09
1	14.64	14.48	13.84	13.24	13.48	12.98	13.16
2	15.49	15.15	14.37	13.77	13.98	13.43	13.63
3	16.04	15.81	15.16	14.61	14.81	14.31	14.49
4	15.85	15.70	15.05	14.48	14.68	14.16	14.35
5	16.77	16.40	15.61	14.90	15.14	14.50	14.73

N is the comparison star designation.

Figure 1 is a finding chart of the variable showing the comparison stars we used. We used comparison stars surrounding the star CT Tri from Ref. 4 for determining the stellar magnitudes listed in Table 1. The magnitudes in the $(RI)_J$ bands were converted from the Cousins system to the Johnson system using the conversion formula given in Ref. 5.

Table 2 is an observation log with the julian and calendar dates of the observations, the stellar magnitudes in the B, V, R_C, and I_C bands averaged over the nights, the number of frames on each night, and comments indicating the instrument used for the observations. Analogous listings for the U, R_J, and I_J bands are given separately at the end of this table. The measurement error is, on the average, $0^m.02$-$0^m.05$ in the V, R_C, and I_C bands, and $0^m.03$-$0^m.08$ in the U and B bands.

3. General character of the light curve of HS 0218+3229

3.1. Outbursts of the variable. S. V. Antipin studied about 200 photographic plates from the GAISh archive during 1963-1997. At its minimum, the brightness of the object was about $16^m.5$, and during an outburst recorded on four negatives from that archive (September 1980), the brightness reached magnitude 12 in the *pg* band.

Yet another outburst (in December 2002) was found by P. Wills in the data base of observations from the NEAT (Near-earth Asteroid tracking: http://neat.jpl.nasa.gov) project.

A third outburst (Fig. 2) took place in 2007 and we have studied it in detail. It lasted about two weeks and the brightness reached 12^m in the V band during the outburst. No other outbursts have been recorded.

We note that these kinds of rare outbursts with a probable interval between them of several years (or more rarely) are not entirely typical of most dwarf novae, which have more frequent outbursts (tens of days apart).

Light curves in the U, B, V, $R_{C,J}$, and $I_{C,J}$ bands derived from our observations are shown in Fig. 3. In the U

TABLE 2. Observation Log

JD	Date	B	n	V	n	R_C	n	I_C	n	Notes
1	2	3	4	5	6	7	8	9	10	11
54066	26.11.2006	-	-	16.40	57	15.62	57	-	-	ZTE, VA
54067	27.11.2006	-	-	16.35	66	-	-	-	-	M, Pi;
54069	29.11.2006	-	-	16.36	44	-	-	-	-	M, Pi
54074	04.12.2006	-	-	16.32	11	-	-	-	-	M, Pi
54076	06.12.2006	-	-	16.33	67	-	-	-	-	M, Pi
54096	26.12.2006	-	-	16.14	1	15.75	1	15.09	1	SL, X-10
54115	14.01.2007	-	-	16.31	1	15.59	1	-	-	SL, X-10
54117	16.01.2007	-	-	16.30	12	15.66	16	-	-	SL, X-10
54122	21.01.2007	-	-	16.33	19	15.65	17	-	-	SL, X-10
54141	09.02.2007	-	-	16.31	17	-	-	-	-	SL, X-10
54378	04.10.2007	-	-	16.33	24	-	-	-	-	Z, Ap47
54379	05.10.2007	-	-	16.35	178	-	-	-	-	Z, Ap47
54382	08.10.2007	-	-	13.72	575	-	-	-	-	Z, Ap47
54385	11.10.2007	-	-	12.34	87	-	-	-	-	Z, Ap47
54386	12.10.2007	-	-	12.44	5	-	-	-	-	Z, Ap47
54389	15.10.2007	-	-	12.68	3	-	-	-	-	Z, Ap47
54390	16.10.2007	-	-	12.82	4	-	-	-	-	Z, Ap47
54391	17.10.2007	-	-	13.11	3	-	-	-	-	Z, Ap47
54392	18.10.2007	13.70	5	13.43	175	-	-	-	-	Z, Ap47
54393	19.10.2007	14.18	6	13.92	505	-	-	-	-	Z, Ap47
54707	28.08.2008	-	-	16.37	1	15.71	4	15.10	3	SL, X-10
54708	29.08.2008	-	-	16.37	1	-	-	-	-	SL, X-10
54709	30.08.2008	17.21	7	16.40	22	15.66	7	15.08	25	SL, X-10
54710	31.08.2008	17.36	5	16.41	14	15.78	5	15.11	10	SL, X-10
54751	11.10.2008	-	-	16.38	20	15.71	16	15.07	24	SL, X-10
54757	17.10.2008	-	-	16.24	1	15.66	6	14.94	4	SL, X-10
54758	18.10.2008	-	-	16.37	12	15.62	36	14.92	4	SL, X-10
54759	19.10.2008	-	-	16.41	3	15.69	79	15.12	5	SL, X-10
54828	27.12.2008	17.12	1	16.37	43	15.69	52	14.99	2	SL, X-10
54829	28.12.2008	17.3	15	16.35	10	15.68	27	15.06	15	SL, X-10
54830	29.12.2008	-	-	-	-	15.72	145	-	-	SL, X-10
54843	11.01.2009	-	-	16.29	22	15.65	44	-	-	SL, X-10

TABLE 2. (Continued)

1	2	3	4	5	6	7	8	9	10	11
54845	13.01.2009	17.26	14	16.35	19	15.68	22	-	-	SL, X-10
55051	07.08.2009	-	-	16.20	3	15.60	15	14.97	17	SL, X-10
55052	08.08.2009	-	-	-	-	15.70	40	-	-	SL, X-10
55060	16.08.2009	17.17	3	16.37	3	15.69	3	15.02	3	SL, X-10
55069	25.08.2009	-	-	16.21	17	15.55	14	14.94	17	SL, X-10
55071	27.08.2009	16.97	2	16.26	21	15.61	27	15.00	25	SL, X-10
55075	31.08.2009	-	-	-	-	15.57	1	-	-	SL, X-10
55076	01.09.2009	-	1	16.27	27	15.57	29	14.96	34	SL, X-10
55080	05.09.2009	16.96	1	16.19	12	15.48	13	14.89	11	SL, X-10
55082	07.09.2009	16.99	1	-	-	15.53	16	14.93	13	SL, X-10
55130	25.10.2009	-	-	-	-	15.53	25	-	-	SL, X-10
55152	16.11.2009	-	-	-	-	16.01	1	-	-	SL, X-10
55159	23.11.2009	-	-	-	-	15.48	25	-	-	SL, X-10
55211	14.01.2010	-	-	16.26	5	15.52	29	15.05	3	SL, X-10
55223	26.01.2010	-	-	16.38	4	15.61	8	-	-	SL, X-10
55224	27.01.2010	-	-	16.31	12	15.61	18	-	-	SL, X-10
55246	18.02.2010	-	-	-	-	15.22	1	-	-	SL, X-10
55462	22.09.2010	-	-	16.09	4	15.49	2	14.90	11	SL, X-10
55463	23.09.2010	-	-	-	-	15.54	40	14.94	56	SL, X-10
55464	24.09.2010	-	-	-	-	15.55	15	14.99	17	SL, X-10
55473	03.10.2010	16.97	36	16.25	61	15.59	6	14.99	6	SL, X-10
55476	06.10.2010	16.98	48	16.21	21	15.59	75	14.95	15	SL, X-10
55480	10.10.2010	16.92	5	16.25	80	15.60	77	14.97	31	SL, X-10
55481	11.10.2010	16.93	16	16.20	49	15.57	55	14.94	40	SL, X-10
55482	12.10.2010	16.92	16	16.19	30	15.55	41	15.00	5	SL, X-10
55483	13.10.2010	16.96	12	16.18	37	15.54	21	14.91	21	SL, X-10
55484	14.10.2010	-	-	16.23	29	15.61	34	14.89	8	SL, X-10
55490	20.10.2010	-	-	16.15	1	15.52	4	14.89	3	SL, X-10
55497	27.10.2010	16.82	2	16.22	3	15.57	2	14.93	2	SL, X-10
55499	29.10.2010	16.96	2	16.19	3	15.56	2	14.91	2	SL, X-10
55514	13.11.2010	-	-	-	-	15.47	27	-	-	ZTE, VA
55515	14.11.2010	16.97	45	16.13	64	15.48	46	-	-	ZTE, VA
55516	15.11.2010	16.99	40	16.17	69	15.52	43	-	-	ZTE, VA
55517	16.11.2010	16.95	37	16.18	44	15.55	39	-	-	ZTE, VA

TABLE 2. (Conclusion)

JD	Date	U	n	R_J	n	I_J	n	Notes
55392	18.10.2007	12.81	5	13.16	5	13.04	5	Z, Ap47
55393	19.10.2007	13.23	3	13.58	6	13.38	6	Z, Ap47
55483	13.10.2010	16.40	1	-	-	-		SL,X-10
55484	14.10.2010	-	-	-	-	-		SL,X-10
55497	27.10.2010	16.25	1	-	-	-		SL,X-10
55514	13.11.2010	-	-	15.19	5	-		ZTE,VA
55515	14.11.2010	16.22	35	15.20	2	14.69	46	ZTE,VA
55516	15.11.2010	16.25	83	15.19	2	14.70	42	ZTE,VA
55517	16.11.2010	16.22	55	-	-	14.70	38	ZTE,VA

Notes to the tables.

JD_{hel}= JD+2400000 is the Julian date; *U, B, V,* $R_{C,J}$, and $I_{C,J}$ are stellar magnitudes averaged over a night; *n* is the number averaged; SL denotes the 50/2500 cm telescope at the Astronomical Institute of the Slovak Academy of Sciences; X-10, the SBIG-10XME array; Z, the 60/7500 cm Zeiss-600 telescope at the Crimean laboratory of GAISh; Ap47, the Apogee-47p array; VA, the VersArray 512 array; M, the 50/70/200 cm AZT-5 Maksutov-system telescope at the Crimean laboratory of GAISh; Pi, the Pictor-416 array; and, ZTE, the 125/2000 cm ZTE telescope at the Crimean laboratory of GAISh.

band the star was observed a total of 8 nights. Unfortunately, the outburst of October 2007 was fully recorded only in the *V* band, while the object was observed for only two nights in the other bands during the drop in brightness following the maximum. We can assume that the amplitude of the outburst was highest in the *U* band (around 5^m) and lower in the *R* band (~3^m).

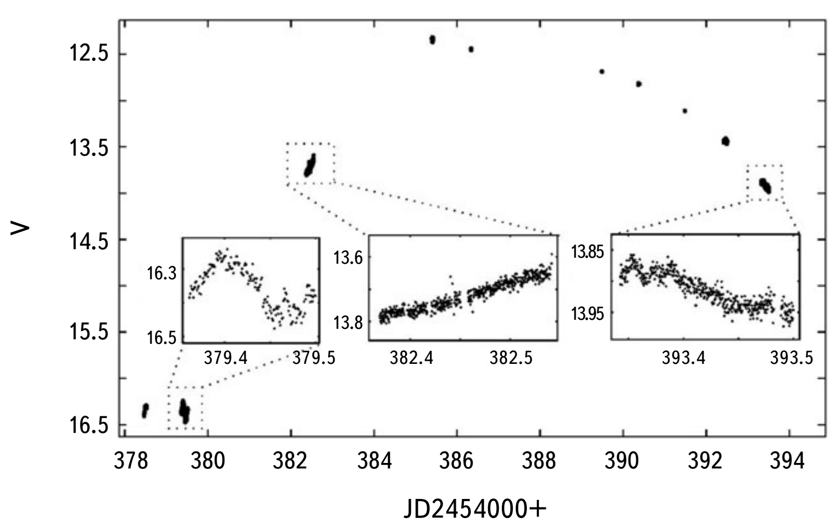

Fig. 2. The outburst of the star from October 8 to 19, 2007.

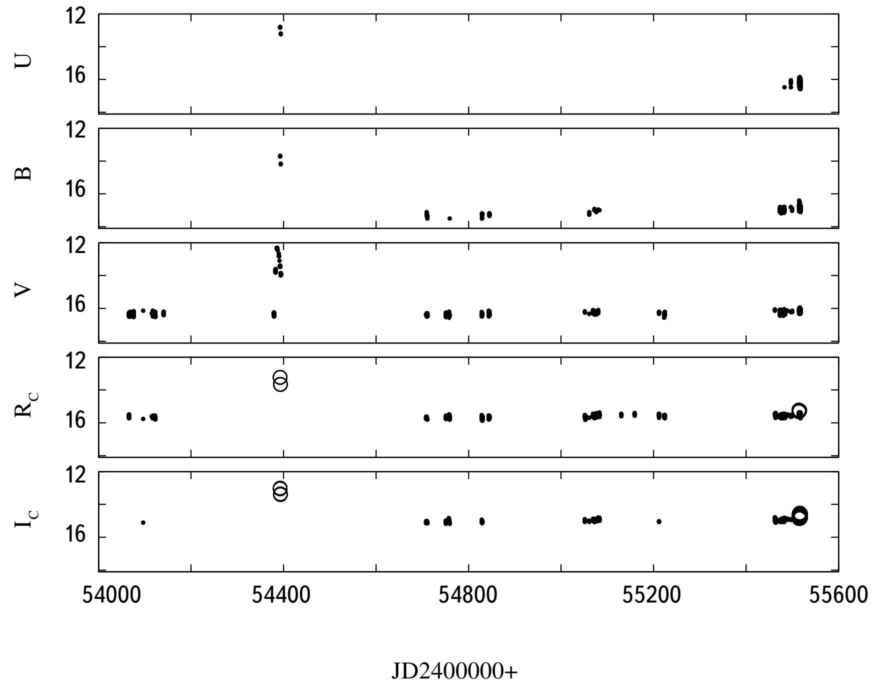

Fig. 3. $UBV(RI)_{C,J}$ observations of the variable from 2006 through 2010. The grey points indicate observations in the Johnson system.

3.2. Light curve during the time of the outburst and in the quiescent state. The light curve for the outburst of October 2007 has a more symmetric shape than for most SS Cyg stars (see Fig. 2). The asymmetry coefficient (ratio of the rising branch to the duration of the outburst) is ~0.22 for our object. The maximum occurred within the interval JD 2454384-385. We estimated the asymmetry relative to two brightness levels, 14^m and $16^m.2$. Since we did not

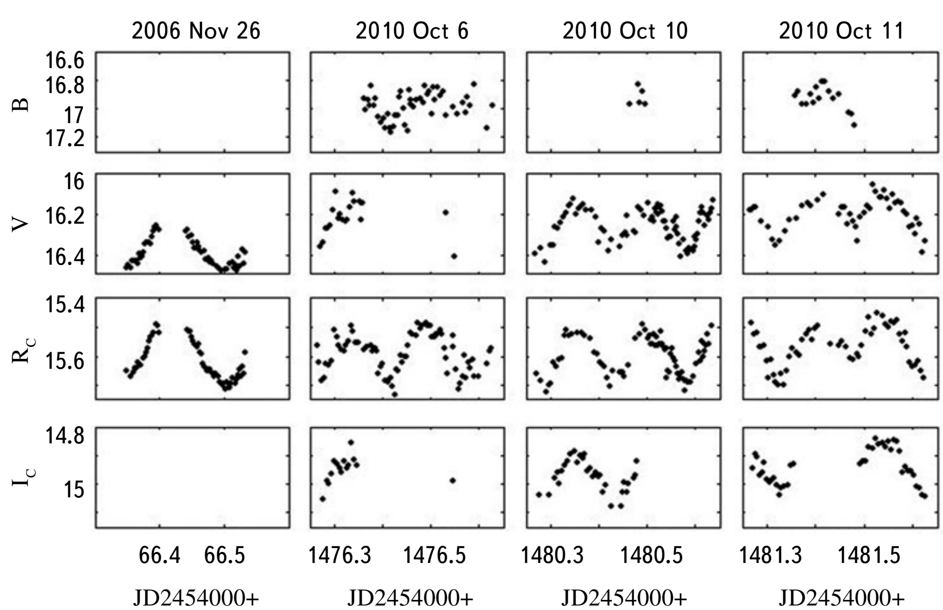

Fig. 4. $BV(RI)_C$ observations of the variable outside an outburst.

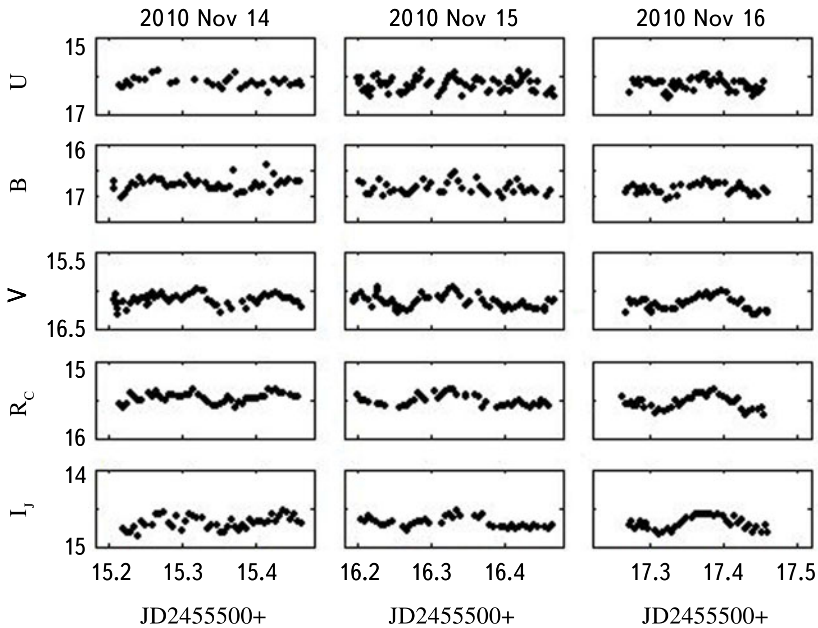

Fig. 5. $UBVR_CI_J$ observations of the variable outside an outburst.

observe the end of the outburst, the second estimate was less reliable, but these values were close in both cases. The outburst began within the interval JD 2454380-381 and it probably ended within the interval JD 2454396-398 (see Fig. 2). We estimate the duration of the outburst to be 15-16 days.

We note that, for the star SS Cyg, itself, the asymmetry coefficient lies within 0.10-0.13 (determined from light curves in the AAVSO archive, at http://heasarc.gsfc.nasa.gov/docs/xte/Greatest_Hits/sscyg.ps.gif). The overall duration of the outburst was ~15^d, while the rise took less than 2^d.

The similar shape of the light curve for the outburst of HS 0218+3229 can be explained by the fact that a critical density of matter 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" [6,17]).

Instability develops in the inner, rather than outer, parts of the disk at low accretion rates, $\dot{M} < 10^{-10}\, M_{\odot}/\mathrm{year}$, 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 (see Section 6).

The three inset graphs of Fig. 2 show the light curves on individual nights in the bright and pre-outburst states. Figures 4 and 5 show light curves outside the outburst period. It can be seen that during the outburst, no short-period variations can be seen in the brightness, while in the quiescent state periodic oscillations show up distinctly. This variability can be explained by the orbital motion of the system. The double wave over the period is related to the distorted shape (an ellipsoidal surface of the Roche cavity) 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 Fig. 5. 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 variability

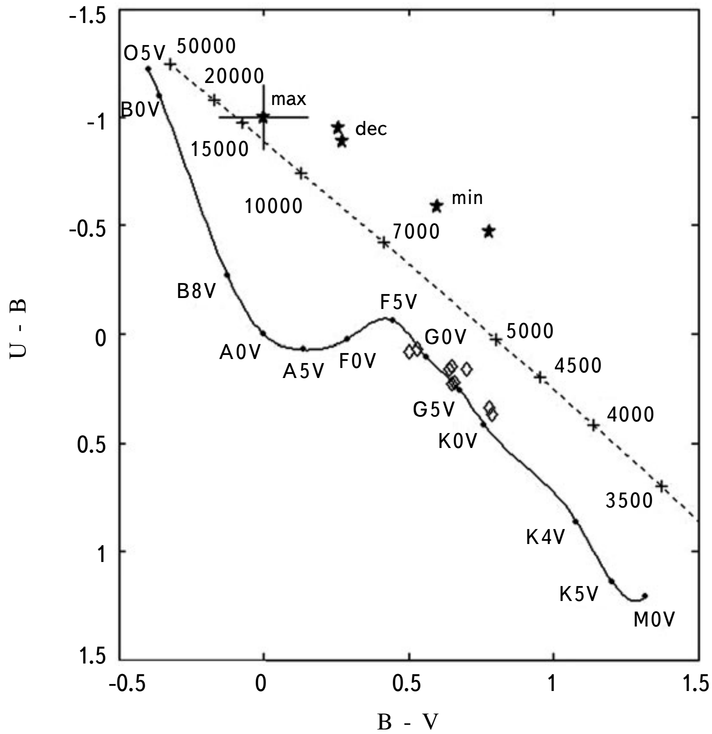

Fig. 6. A two-color *U-B, B-V* diagram. The stars indicate the positions of the variable during an outburst ("max"), during the decrease after an outburst ("dec"), and at the brightness minimum ("min"). The diamonds indicate the comparison stars. The crosses give the uncertainty in the estimated color indices during a maximum (see the text).

is related to the hottest components of the system, i.e., to flickering of the hot region where the stream interacts with the accretion disk. Figures 6 and 7 confirm that a strong *UV* excess is observed only in the *U* and *B* bands, while radiation from just the red dwarf predominates in the *VRI* bands.

An orbital wave with an amplitude of $0^m.13$-$0^m.19$, depending on the band, can be seen in the *V, R*, and I bands (Fig. 8). A similar variation in the amplitude of the system brightness has also been observed by Rodriguez-Gil, et al. [2]. It should be noted that they made their observations without a filter.

Besides the previously mentioned oscillations in the brightness, outside the outbursts a slow variability in the average brightness of HS 0218+3229 with an amplitude of ~$0^m.2$ and a characteristic time on the order of ten-twelve days (Fig. 3) has been observed.

3.3. Two-color diagrams. Two-color *U-B, B-V* and $U\text{-}R_J$, $(R\text{-}I)_J$ diagrams are shown in Figs. 6 and 7. The curves plotted there for the Main Sequence stars and an absolute black body are from Ref. 8 and the calculations of Dolin [9].

The positions of the color indices of the comparison stars on the diagrams are not significantly distorted by

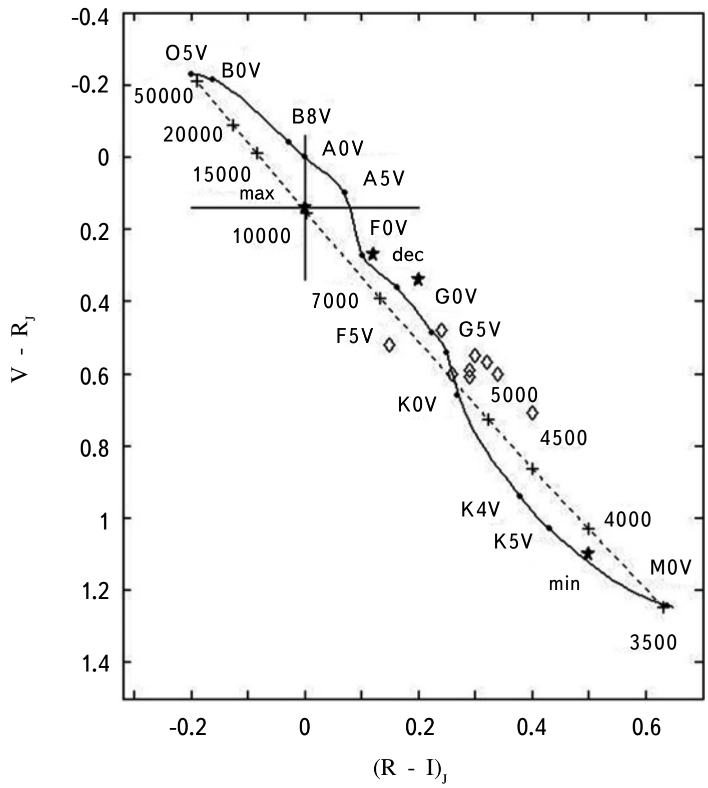

Fig. 7. A two-color V-R_J, $(R$-$I)_J$ diagram. The notation is as in the preceding figure.

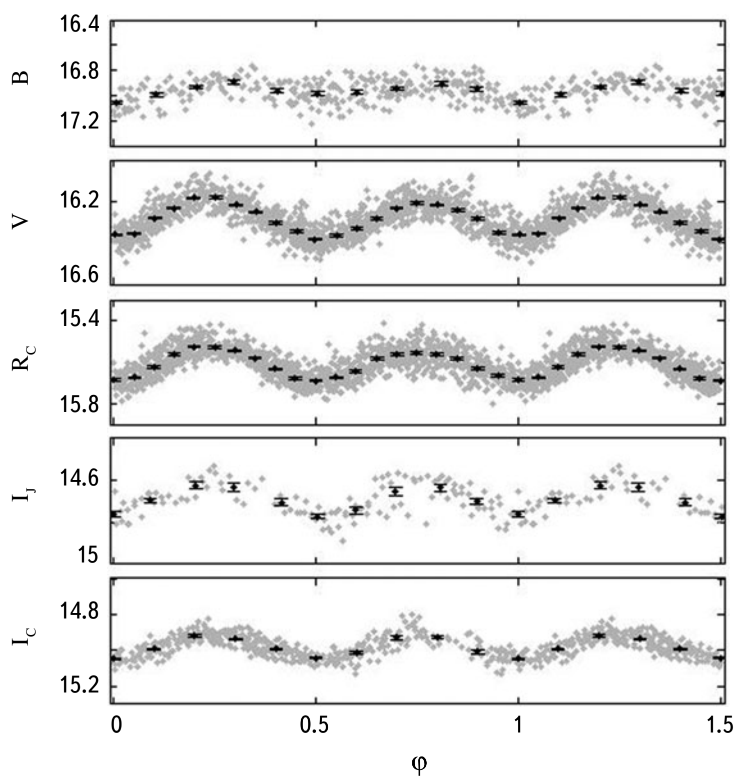

Fig. 8. Phase light curves in the V, V, R_C, I_J, and I_C bands. The error corresponding to 1σ is indicated.

interstellar reddening. The interstellar reddening is estimated to be $E(B-V)=0^m.07$ [2]. Thus, in most cases (except Section 6) we have neglected the interstellar reddening in interpreting the data.

As noted above, during the time of the outburst the star was observed only in the *V* band, and during the brightness decay phase for a week after the maximum it was observed in the $(UBVRI)_J$ bands. 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 $R_J \approx I_J \approx 12^m.2 \pm 0^m.2$.

During the outburst of October 2007, the UV excess reached -1^m and outside the outburst it was $-0^m.8$. The color index *B-V* changed, therefore, from 0^m to $+0^m.7$ (see Fig. 6). These changes can be explained by the fact that the flaring accretion disk is radiating mainly in the blue region of the spectrum. At this time 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 (see Fig. 7). At the brightness minimum the position of the variable corresponds to that of a star of spectral class K5V-K6V (see Fig. 7).

4. The search for periodic oscillations in the brightness of HS 0218+3229

The photometric series were used to find the period of the variation in the brightness. The time series analysis was carried out using the Deeming and Lafler-Kinman methods with the program "ÉFFEKT" by V. P. Goranskii (http://vgoray.front.ru/goray-r.htm). An orbital period was found for each spectral band. Almost identical values of the period were found in the *V*, R_C, and I_C bands, as expected. A different photometric behavior of the variable was observed in the U and B bands (see Section 4.1) and those data were not used to find an orbital period. An analysis of the data in the *V*, R_C, and I_C bands showed that the period does not vary during any of our observations before and after the outburst of 2007. The exact elements of the brightness variation that we determined are $JD^{min}_{hel} = 2453653.0286 + 0.2973559 \cdot E$.

We sought a period for the object using both our observations (2006-2010) and data from Ref. 2 obtained during 2001-2005. This resulted in a 10-year series of observations, and the error in determining the period does not exceed $\pm 0^d.0000010$. The epoch of the brightness minimum JD^{min}_{hel} corresponding to passage of the secondary component in front of the white dwarf is taken from Ref. 2.

This ephemeris was used to construct phase light curves (Fig. 8) and in all the other calculations. Rodriguez-Gil, et al. [2], found a somewhat different value for the orbital period, $0^d.29722966$. Note that this value of the period does not match all the observations.

4.1. Study of the variation in the color indices during the orbital period. To study the variability in the color of the system we plotted orbital phase light curves for all the bands; these are shown in Figs. 8 and 9. A double wave with slightly different amplitudes of the minima and maxima can be seen clearly in the *V*, R_C, I_C, and I_J bands. The double wave is caused by the elliptical shape of the red component, since it contributes 80-85% of the overall

R band brightness of the system in the quiescent state [2] and dominates the combined emission from the system. The color index curve also manifests a double wave over a period.

In the *U* and *B* bands the double wave is either not so clearly visible or is not visible at all, since the accretion disk, rather than the ellipsoidal red component, is the major contributor to the light in these bands. However, in the *U* band a slight attenuation of the brightness may be observable near zero phase, when the white dwarf and the accretion disk lie behind the red component and they are partially eclipsed (Fig. 9).

Figure 10 shows the changes in various color indices and in the V brightness of the system; these correlations were plotted from observations outside the outburst and reflect the changes in the brightness in the course of an orbital period.

Note that the weaker the star's brightness is, the bluer the *B-V* color of the system becomes. This dependence follows from the fact that, at the time of the minimum brightness at phases 0 and 0.5, the visible area of the cold component is minimal and at this time there is an increase in the relative contribution to the total radiation in the B band from the hot white dwarf and the accretion disk.

In the longer-wavelength bands (*R* and *I*), the dependence is different. In this region the contribution from the disk is negligible, and it is mostly just the red component that radiates; this also follows from the position of

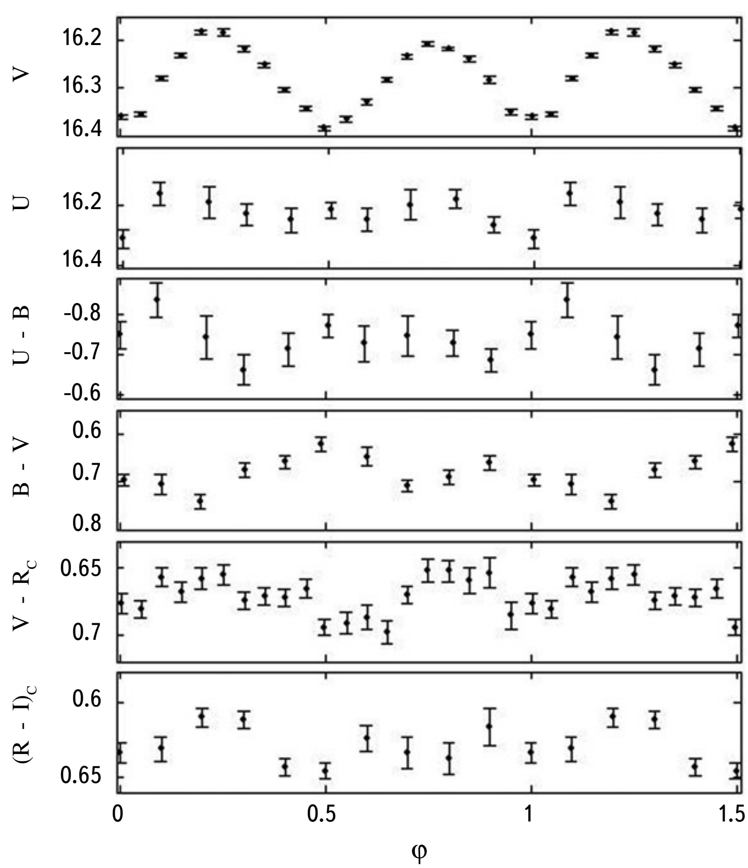

Fig. 9. Orbital light curves for the *U* and *V* bands, and for the color indices *U-B*, *B-V*, $V\text{-}R_C$, and $(R\text{-}I)_C$. The error corresponding to 1σ is indicated.

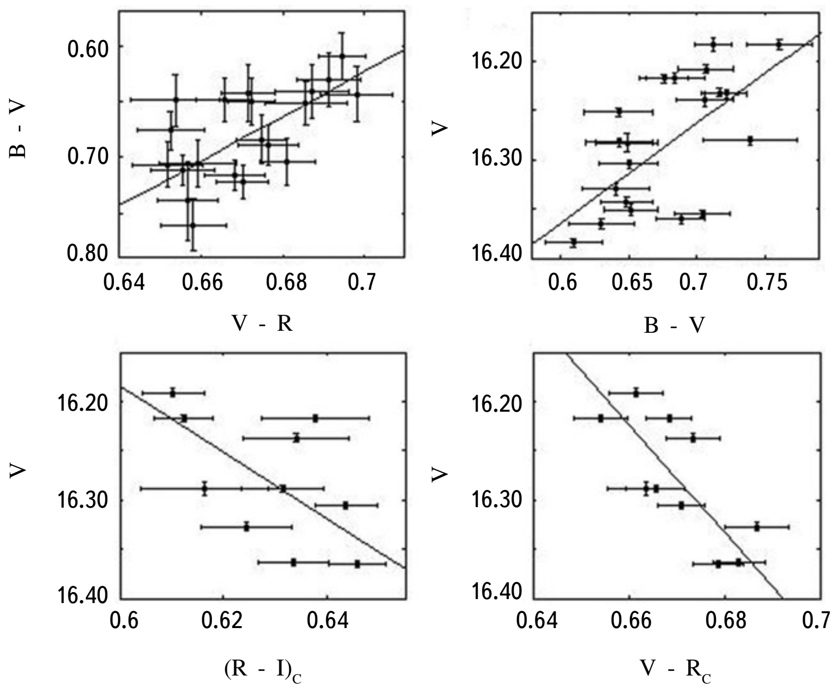

Fig. 10. Plots showing the behavior of the color indices at the brightness minimum during an orbital period.

the system in Fig. 7. The graphs of the color indices *V-R* and *R-I* as functions of the *V* magnitude (Fig. 10) imply that when the brightness of the system is fainter, it will be more reddened.

It can be seen that in the orbital curves, a brightness minimum (and reddening) sets in at times when the secondary component is visible from the side of the "nose" (φ = 0.5) or from the trailing side (φ = 0.0) (see Figs. 8 and 9).

The observed reddening can be explained by gravitational darkening. Since the red component fills its Roche cavity and has the shape of a pear, the acceleration of gravity in the "nose" and at the trailing end of the secondary component is less than at longitudes separated by 90° from these points, so that these areas of the surface of the red dwarf that are more distant from the center have a slightly lower temperature. This problem has been examined in part in Ref. 10. The best agreement between the theoretical light curves (Fig. 3 of Ref. 10) and our observations was obtained with an angle of inclination of about 45°, complete filling of the Roche cavity (both correspond roughly to our data), a gravitational darkening coefficient of about 0.25, and darkening at the edge of about 0.2. Thus, we can assume that our star has a small gravitational darkening coefficient of about 0.25; this is consistent with a K5V spectral class for the star.

In a large-scale two-color *B-V, V-R* diagram plotted just for the orbital wave in the state outside an outburst (see Fig. 10), it can be seen that the redder the star is according to the *B-V* color index, the bluer it will be in terms of the *V-R* color index. This sort of reverse variation in the color indices also confirms that the "bluing" at phases 0 and 0.5 in the *B* band corresponds to "reddening" at the same phases in the *R* band. Thus, in bands at shorter wavelengths than *V*, emission from the accretion disk and white dwarf predominate in the total emission from the

TABLE 3. Coefficients in Linear Approximations to the Dependences Shown in Fig. 11: $Y = a_1*X + a_0$

X	Y	Equation with coefficients a_1 and a_0	Correlation coefficient	Error in coefficient a_1
$V - R$	$B - V$	$Y = -1.00*X + 2.02$	0.65	0.42
$B - V$	V	$Y = -1.02*X + 16.98$	0.63	0.23
$R - I_C$	V	$Y = 3.39*X + 14.15$	0.69	0.94
$V - R_C$	V	$Y = 5.47*X + 12.61$	0.78	1.17

star, while the emission from the secondary component is dominant at longer wavelengths.

Table 3 lists the coefficients in a linear approximation (a_1, a_0) for the data plotted in these curves (Fig. 10). The errors in the coefficients a_1, which characterize the slope of the line, are clearly a factor of 3-5 times smaller than the coefficients themselves. The correlation coefficients range from 0.63-0.78. Thus, we may conclude that the dependences we have described are real.

4.2. The phase light curve before and after an outburst. Phase light curves before and after an outburst are shown in Fig. 11. Before the outburst the maximum peaks and minimum depths are observed to be different, but after the outburst a double wave over an orbital period with almost equal amplitudes of the bumps can be seen. This can be explained by the fact that, immediately before an outburst, the saturated accretion disk makes a larger contribution to the luminosity of the system than afterward, when it is exhausted. The heights of the maxima in the pre-outburst state are different because we view the region where the stream and the outer parts of the disk interact from different angles. On the other hand, the depths of the minima are different because the “nose” of the red star, which is turned toward the white dwarf, is heated by radiation from the disk. After an outburst the luminosity of the disk and the spot on it decrease, and these effects are less marked. These same features of the light curve can be seen in Fig. 3 of Ref. 2. During January-February 2001, the heights of both maxima and the depths of the minima were essentially the same, but in October 2005, differences between them could be seen. These curves are very similar to our curves constructed using data obtained prior to the outburst of 2007. It can be assumed that at the end of October 2005 or just after that, the star underwent an outburst that was missed.

5. Classification of the variable star

Without observing even a single outburst, Rodriguez-Gil, et al. [2], classified the star as a cataclysmic variable. At present, three outbursts of this variable are known (see Section 3.1), so we can reliably assign HS 0218+3229 to the dwarf novae. Our star does not belong to the SU UMa stars, since during an outburst superhumps are not observed

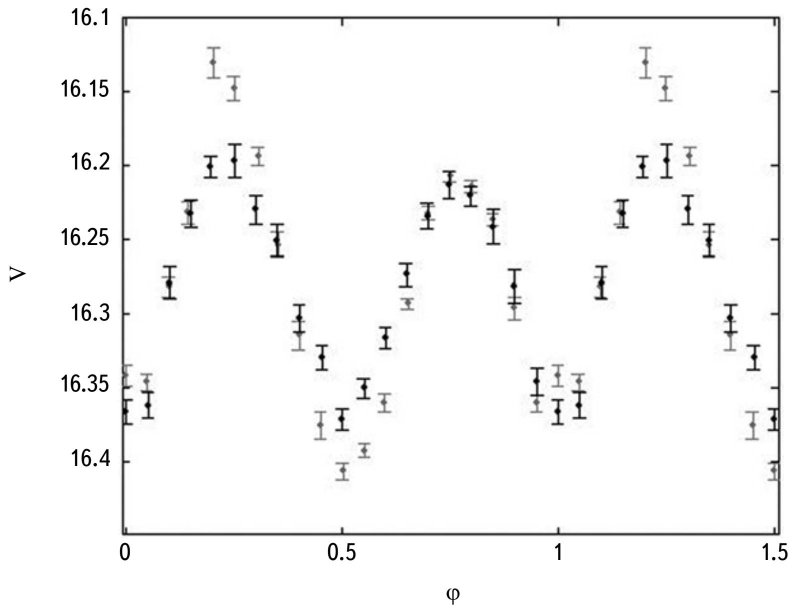

Fig. 11. V-band phase light curves before and after an outburst. The grey points indicate observations prior to the outburst and the black points, after the outburst. The error corresponding to 1σ is indicated.

and its period of ~$0^d.3$ is not typical of stars of this type. According to the classification in the General Catalog of Variable Stars (e.g., Ref. 11), type UGSS dwarf novae include stars that "increase their brightnesses over 1-2 days by 2-6^m ... . The cycles range from 10^d to several thousand days."

The classification of cataclysmic variables and dwarf novae, which are usually divided into several subclasses (see, for example, the catalog of Cherepashchuk, et al. [12]), is sometimes a complicated problem, since in the course of studying them, researchers can change their initial classification. We classify the star as belonging to a rare subclass of UGSS-type systems (U Gem or SS Cyg dwarf nova stars) with a low rate of material flow and rare, more symmetric ("inside-out") outbursts than in ordinary UGSS stars.

6. Estimates of several parameters of the system

In the quiescent state radiation from the red dwarf dominates in the V, R_J and I_J bands, as can be seen from the position of the star in the $V-R_J$, $(R-I)_J$ two-color diagram (Fig. 7). Its position is near that of a Main Sequence star of spectral class K5V-K6V. The absolute stellar magnitude of the stars in the class is $7^m.1$ in the V band, while the total luminosity of the red dwarf is roughly equal to $L_{bol} \sim 10^{32}$ erg/s [13]. The interstellar reddening is estimated to be $E(B-V) = 0^m.07$ [2]. Thus, the interstellar absorption, $A_V = 3E(B-V)$, is equal to $0^m.2$. The minimum stellar magnitude we recorded (see Table 2) was $V = 16^m.4$. From this we obtain a distance modulus of $-9^m.1$, including the interstellar absorption, and the distance to the system is d ~ 660 pc. (Rodriguez-Gil, et al. [2], have d = 870-1000 pc.)

During the outburst the brightness of the system reached $V = 12^m.3$ (Table 2). Knowing the distance modulus, we find that the absolute stellar magnitude of HS 0218+3229 during an outburst was $12^m.3 - 9^m.1 = +3^m.2$. Assuming that the major contribution to the emission during the outburst is from the accretion disk, we can estimate its total radiant energy. To do this, the bolometric correction, which depends on the temperature and the energy distribution of the bursting disk, must be taken into account. The *U-B, B-V* and *B-V, V-R* color diagrams show that the color indices of the disk during an outburst lie near the curves for an absolute black body with a temperature of about 15000 K.

The tables of Refs. 13 and 14 show that a star in spectral class B5 also has a color temperature of 15000 K and a bolometric correction of $-1^m.5$. Dodin [9] has calculated the bolometric corrections for an absolute black body. The correction was somewhat smaller, $-1^m.0$, for a temperature of 15000 K. Taking the bolometric flux from a star of 0-th magnitude to be $F = 2.48 \cdot 10^{-5}$ erg/cm^2/s [11], the visible bolometric magnitude of the disk to be $11^m.3$, and the distance to the system to be 660 pc, we find the total luminosity of the disk during an outburst to be $L_{bol} = 4 \cdot 10^{34}$ erg/s.

The average mass of a red dwarf in spectral class K5V is ~0.6 $M_\odot$ [11]. Rodriguez-Gil, et al. [2], have, however, estimated the mass of the red dwarf to be 0.23-0.44 $M_\odot$ and that of the white dwarf, 0.44-0.65 $M_\odot$. Knowing the period of the system, using Kepler's third law we estimate the distance between the components to be in the range $1.5 < a < 1.9\, R_\odot$.

As noted above, at the brightness minimum, the emission from the red dwarf dominates in the *VRI* bands. Thus, the luminosity of the accretion disk during this time is $<10^{32}$ erg/s (see the estimate at the beginning of this section), while the value for most dwarf novae is one or two orders of magnitude larger. Therefore, using the formula $L \sim G\dot{M}M/R$ (G is the gravitation constant, M is the mass of the white dwarf, and R is the inner radius of the accretion disk), we find a low rate of accretion in our system. This conclusion also follows from the more symmetric shape of the outburst (see Section 3.2) compared to most SS Cyg stars.

Although our calculations and estimates of several of the physical parameters differ somewhat from the analogous values obtained in Ref. 2, on the whole these differences are not fundamental and do not require a change in the model for the system.

7. Major results

In all, we have obtained more than 2000 CCD frames and about 200 photographic estimates of the brightness of HS 0218+3229 over the period from 1963 through 2010. An analysis of the data yielded the following:

(1) Three outbursts were observed over the entire time and we recorded two of them (1980 from photographic plates at GAISh and 2007 from our CCD observations). The duration of the outburst in October 2007 was about 15 days and its amplitude was 4^m in the V band.

(2) Two-color diagrams show that during an outburst the star becomes bluer than in the quiescent state; this is related to a larger contribution from the brightened disk to the luminosity of the system. The color temperature of the hot component was about 15000 K during the outburst.

(3) The orbital period of the system was determined more accurately ($P_{orb} = 7^h 8^m 11^s.5$) and the following

elements for the brightness variation were found:

$$\mathrm{JD}_{\mathrm{hel}}^{\mathrm{min}} = 2453653.0286 + (0.2973559 \pm 0.0000010) \cdot \mathrm{E}.$$

Because of the ellipsoidal shape of the cold red component, two waves are observed over the period in the light curve. The differences in the heights of the maxima in the phase curves for the variation in the color indices are explained by different seeing conditions for the hot spot on the disk, while the differences in the depths of the minima are explained by gravitational darkening and a reflection effect. During an outburst, the changes in brightness caused by the ellipsoidal shape of the red component are not noticeable against the background of the bright flaring disk.

(4) Emission from the accretion disk predominates in the *U* and *B* bands. The ellipsoidal wave shows up weakly or is not seen at all; however, a slight, partial eclipsing of the accretion disk is probably seen in the *U* band. A short-period variability associated with flickering of the hot region on the accretion disk is also noticeable. Emission from the cold component predominates in the brightness minimum in the *V, R*, and *I* bands. The color indices that we found correspond to a star in spectral class K5V. The shape of the orbital light curve is slightly different before and after an outburst. Before an outburst, the orbital light curve owing to the ellipsoidal shape of the secondary component is distorted by additional light from the saturated accretion disk.

(5) Based on our data on the characteristics of the outbursts, we have classified the star as a UGSS dwarf nova. For most stars of this type the shape of the light curve during an outburst is more asymmetric than in the case of our object. This behavior of HS 0218+3229 can be explained by a low rate of mass flow in the system. In this case, an outburst is born in the inner regions of the disk and propagates to the outer regions, i.e., it is an "inside-out" outburst.

(6) The average brightness of the system outside an outburst varies with a characteristic time of a few tens of days and an amplitude of $\sim 0^m.2$.

(7) We estimate the size of the orbit of the system to be $a = (1.5 - 1.9)R_\odot$ and the distance to it to be d = 0.66 kpc. For a *V*-band luminosity of the accretion disk of $1.6 \cdot 10^{34}$ erg/s during an outburst, we estimate the bolometric luminosity of the disk during an outburst to be $L_{bol} \sim 4 \cdot 10^{34}$ erg/s.

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