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MULTICOLOR LIGHT CURVE ANALYSIS OF ECLIPSING CATACLYSMIC STAR OV BOO

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Abstract. We have studied in detail the photometric behavior of a dwarf nova OV Boo, undergoing outburst in the middle of March 2017. We show that it is possible to carry out qualitative observations and obtain new information about variable stars by using small telescopes with mirror diameters up to 1.25 m and even 6 cm photo lens.

Key words: Dwarf novae - eclipsing binaries - photometry

1. Introduction

Cataclysmic variables (CVs) are composed of a white dwarf and a red (or brown) dwarf supplying matter to the white dwarf, forming an accretion disk.

The WZ Sge-type stars are a rare subclass of cataclysmic variables (Smak, 1991; Kato, 2015; Kato et al, 2009) which possesses the properties of both: dwarf novae and recurrent novae. The WZ Sge stars have the shortest known orbital periods among the dwarf novae (typically 80 - 90 minutes) , a long recurrent time of outbursts (decades) with outburst amplitude of 8 magnitudes. During a superoutburst phase early, ordinary and late superhumps are observed. The presence of early superhumps, which show a double-humped orbital light curve in quiescence, is one of the significant features of WZ Sge stars (Kato, 2015).

The outburst amplitude of classic and recurrent novae ranges from 6 up to 19 magnitudes (Duerbeck, 1987; Harevich *et al.*, 1975; Hachisu & Kato, 2014, 2016) what makes the classification on the basis of light curve dificult and the studied star might be misclsasified in some cases. However, novae and recurrent novae do not exhibit the same superhump structure, as WZ Sge-type stars, and have other spectral features. But among Nova stars, which were classified long ago and still insufficiently studied, WZ Sge-type stars might be found, and vice-versa. Therefore, it is important to take into account possible misclassification while doing statistical studies.

Some of these stars show complex post-superoutburst rises of brightness called rebrightenings, or echo-outbursts (Kato, 2009b; Uemura *et al.*, 2008).

We have studied in detail the present photometric behavior of a dwarf nova OV Boo, undergoing outburst in the middle of March 2017.

2. Historical review of the object J150722.30+523039.8

Szkody *et al.* (2005) studied the star SDSS J150722.30+523039.8. Deep (more than 1 mag.) eclipses were observed, and the orbital period of 67 minutes was found. Additionaly, H_α emission whith half amplitude of radial velocities K = 69±15 km/s was found. The further observations suggested that J1507 is WZ Sge-type star with extremely short orbital period, but no outbursts typical for WZ Sge-type stars were observed.

Littlefair *et al.* (2007) have recalculated the value of orbital period: P=$0.^d04625829$ and give for physical characteristics of the system in quiescence: $i = 83^o.6, M_{wd} = 0.9M_\odot$, $M_{rd} = 0.056M_\odot$ and $R_{rd} = 0.096R_\odot$ for the secondary red star mass and radius, $a/R_\odot = 0.53$ for separation and $\sim 11000 \pm 500K$ for white dwarf temperature. The distance to the system was found to be 160±10 pc. High time resolution light curves were analyzed with ingress and egress of the components of the system, steps and other details found on the eclipse profile were explained by changing of visibility conditions or eclipses of white dwarf, bright spot, accretion disc and the secondary star. Patterson *et al.* (2008) found the value of orbital period as $P = 0.^d0462583411 \pm 7$, and also the values of masses, radii and other parameters close to those found by Littlefair *et al.* (2007). But the distance to the system was determined as 230 ± 40 pc. Besides of orbital variations of magnitude the authors studied also high frequency variations, the most high peaks were registered at $\sim 1/75$ day frequency.

This object may be similar to ASASSN-15po, which has an orbital period of 0.0509^d (Kato *et al.*, 2016; Namekata *et al.*, 2016).

Uthas *et al.* (2012) used the results of ultraviolet spectroscopy of J1507 obtained with the Hubble Space Telescope and suggested that the object was formed from a detached white dwarf – brown dwarf binary system. The authors determined the temperature $T_{eff} = 14200 \pm 500$ K and the distance to the system of 250 ± 50 pc.

3. Photometric observations

In March, 2017 the outburst occurred with an amplitude of 6 mag, and we started $UBV(RI)_C$ photometric observations of the object J1507, named OV Boo (Kazarovets *et al.*, 2011).

Observations were made by several different telescopes with mirror diameters ranging from 18 up to 125 cm of Slovak Academy of Sciences in Stara Lesna (SL), South Stations of Sternberg Astronomical Institute (SAI-Cr) in Nauchnyy and Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) in Caucasus. During one of the nights the observations were made at the 2.5 m telescope of SAI in Caucasus (SAI-KGO) in the U passband.

Observations near the maximum of the outburst were made also by using photolens 60/180 mm. We used the following CCD cameras: FLI ML3041, SBIG ST-10XME (SL); VersArray-1300 (SAI-Cr); EV-4240 (SAO-RAS); Niels Bohr Institute, E2V CCD44-82 (SAI-KGO).

Our primary comparison star GSC3868.1067 was calibrated using standard stars from Landolt (2013), its magnitudes are: $U = 11^m.95$; $B = 12^m.004; V = 11^m.529; R_C = 11^m.243; I_C = 10^m.96$.

4. Multicolor light curves

Fig. 1 shows the LC from March till May 2017 in the R_C and U passband. There is a brightness fading of $\sim$6 stellar magnitudes during two months time interval. The UV excess was growing with time during this interval.

During the outburst eclipses had a small amplitude (see the left inset on Fig. 1), but two months later we can see clear eclipses (the right inset).

To find the orbital ephemeris we have used our observations and a minimum from Patterson *et al.* (2008), our observations coincided with ephemeris found by Patterson:

$$MinI_{hel} = 2457901.5299 + 0.04625834 \cdot E.$$

It is obvious that during last 10 years the period doesn't change in spite of the outburst which occurred in 2017. Our observations allowed us to study the changes of light curve shape for the epoch from the outburst till almost quiescence. On Fig. 2 on the left plot of the evolution of the orbital wave and the eclipse is shown in R_C band. During the outburst (11.5 - 12.5

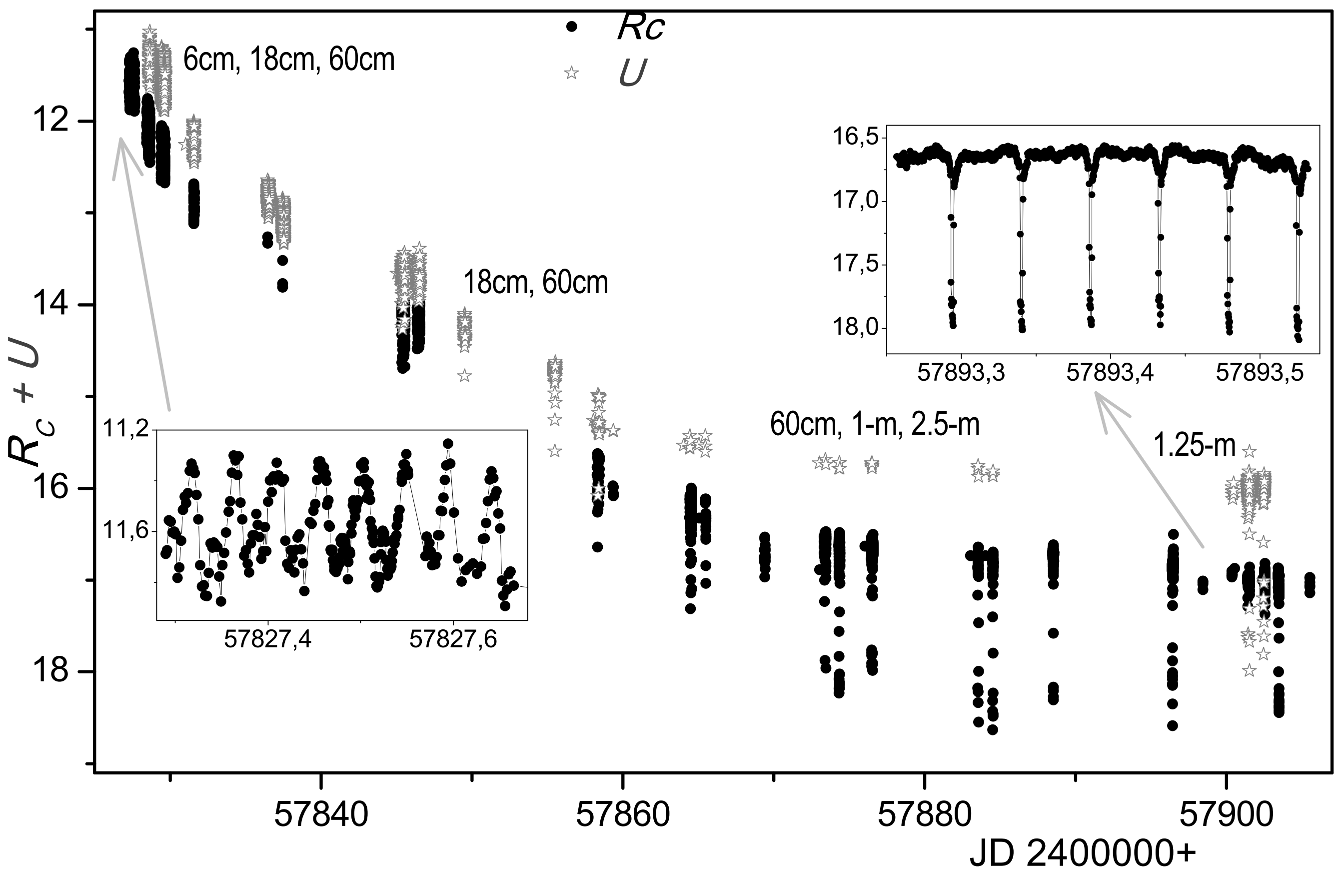

Figure 1: The LC from March till May, 2017 in the R_C, U bands. The insets show nightly LCs in the R_C band.

mag.) we see only two-humped orbital wave, the minimum of brightness coincides with zero orbital phase. We can suppose, that at this stage we see the partial eclipse of the accretion disk, which has increased its dimensions and undergone the outburst. As the brightness fades to 14 mag the clear eclipse with depth of 0.3 mag begins to appear, the pre-eclipse hump at the phase ~ 0.85 also appears. During the fading up to 16 mag the depth of the eclipse increases up to 0.5 mag, the pre-eclipse hump is still clearly seen (Fig. 2, the middle plot). During the further fading up to 16.5 - 17 mag the depth of the eclipse reaches 1.5 mag, but the height of the pre-eclipse hump decreases, and is not constant from cycle to cycle. In Fig. 2, right plot the fragment of the eclipse is shown. The increase of the amplitude of the eclipse during the fading of brightness is clearly visible.

Fig. 3 shows the analogous curves in the B band. Let us look in more detail on the eclipsing light curve at the right plot, Fig. 3. The rapid brightness depression coincides with phases 0.97-0.975. The rapid brightness fading is observed at the same phases, which is caused by the white dwarf eclipse. This can be observed also in the Fig. 2 of Littlefair *et al.* (2007). Then, during the eclipse, the slow fading of brightness continues till phase 0.005. It is caused both by the hot spot's surface area decreasing for the observer from Earth and also by ongoing eclipse of the disk. At the phase ~ 0.005 the rapid eclipse of hot spot occurs and there is the further brightness fading. But at the phase ~ 0.02 the brightness of the system sharply rises because of the end of white dwarf eclipse. At the phase ~ 0.07 (Littlefair *et al.*, 2007, Fig. 2) the hot spot eclipse ends and brightness slightly increases. In our observations this phenomenon is not seen. Our observations span also during the brightness depression after the outburst, the star does not reach the quiescence, as distinct from the observations of Littlefair *et al.* (2007). That is why the contribution from the accretion disk to the total luminosity of the system was more significant than the contribution from the hot spot. Because of this reason the additional brightness of the hot spot, appearing from the red star's limb, was not apparent in relation to still bright disk and was lost in the observational uncertainty. On the Figs. 4 and 5 the analogous light curves in the U and I_C bands are shown. We can see the flat fading and rising of brightness in I_C band (Fig. 5, right plot) and, on the contrary, the absence of flat wings before and after the eclipse for the U band (Fig. 4, right plot). We suppose, that the nature of these wings is caused by the eclipse of the accretion disk by the red star. In the U band only the inner

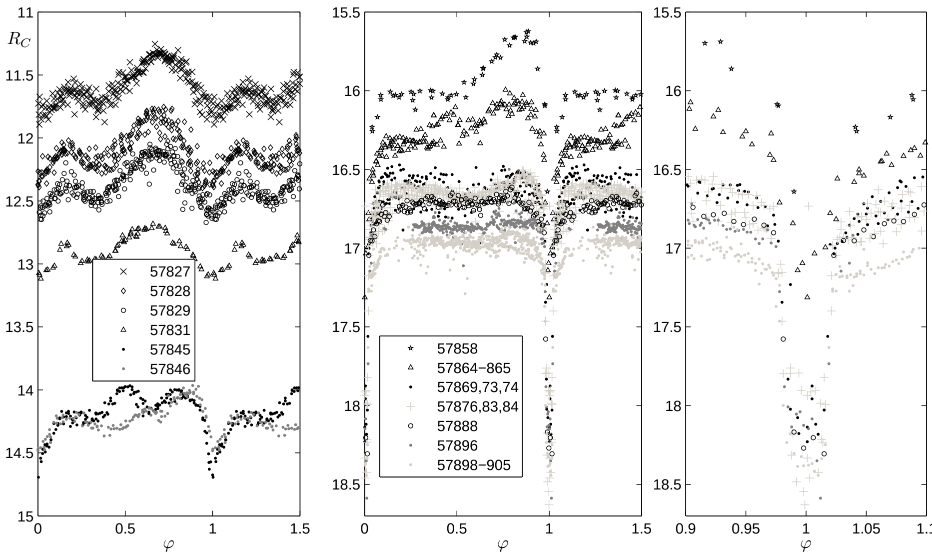

Figure 2: Phased light curves in R_C band. The left plot: LCs during the first 20 days after the outburst; the middle: LCs after the 30th day; the right: the fragment of the eclipse of the middle plot.

hot parts of the disk are emitting, which are close to the white dwarf. That is why the eclipse duration in UV light is shorter and sharper, than in I_C band. In near IR area on the contrary, the colder and more distant outer parts of the disk are emitting stronger, that is why the eclipse duration of the disk together with wings is longer than in UV.

In future we plan to do the mathematical modelling of light curves at all stages of brightness fading, from the outburst till quiescence, and obtain more exact values of different physical and geometrical parameters of the OV Boo system components.

5. Color indices changing of OV Boo

On Fig. 6 the track of OV Boo on the $U-B/B-V$ diagram is shown. On this figure the number of days since the outburst is given. It is visible that the color temperature has raised after the outburst and reached ∼13000 K in quiescence. Similar temperature before the outburst was obtained in other studies. Such temperature is observed in the majority of WZ-Sge-type stars.

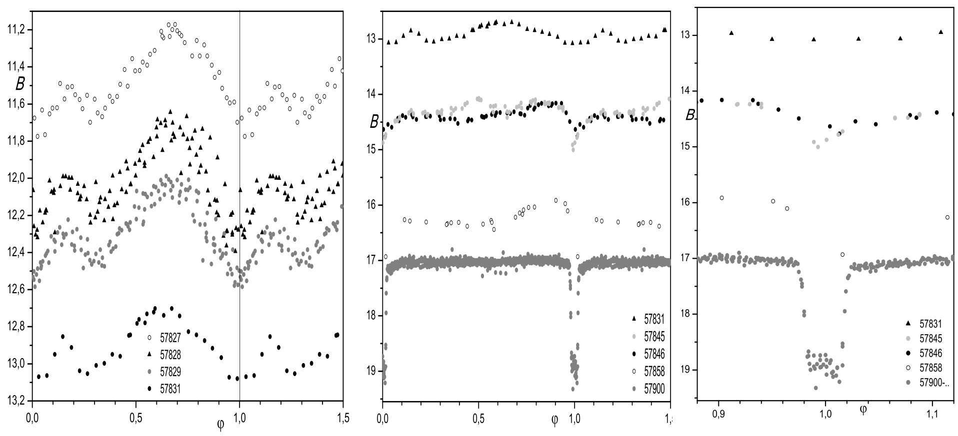

Figure 3: Left: Phased light curves in the B band. The left plot: LCs during the first 20 days after the outburst; the middle plot: LCs after the 30th day; the right plot: the fragment of the eclipse of the middle plot.

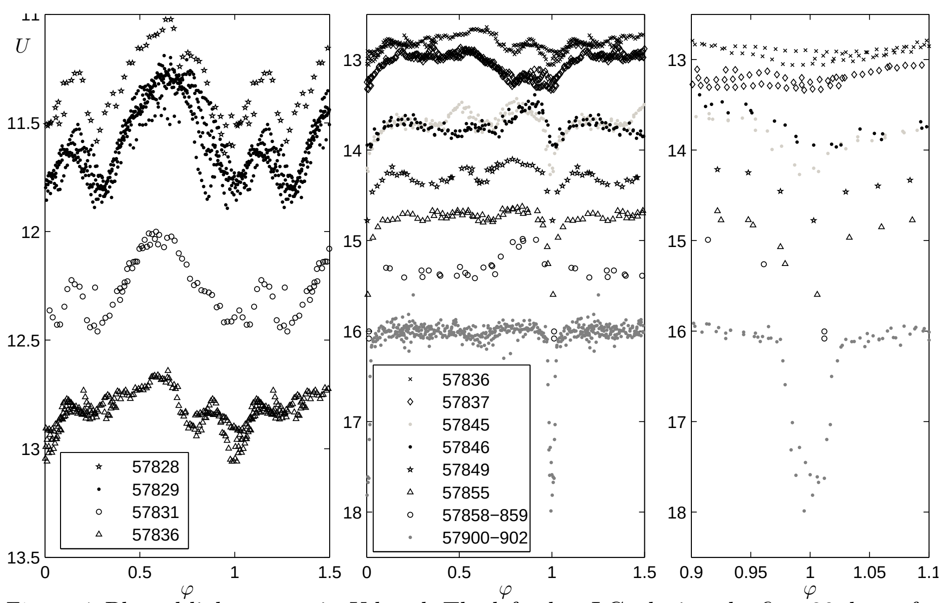

Figure 4: Phased light curves in U band. The left plot: LCs during the first 20 days after the outburst; the middle plot: LCs after the 30th day; the right plot: the fragment of the eclipse of the middle plot.

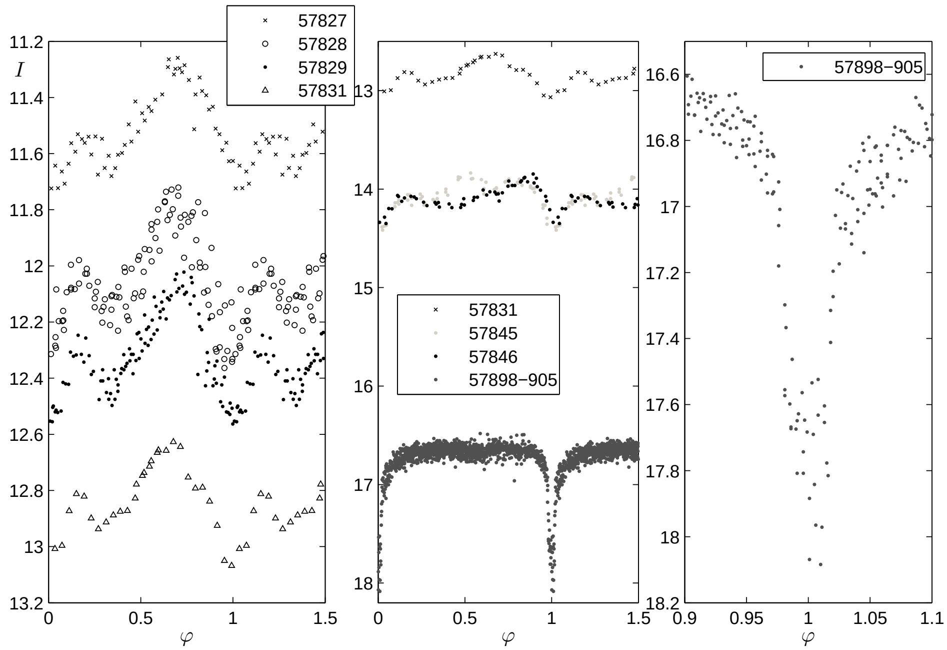

Figure 5: Phased light curves in I_C band. The left plot: LCs during the first 20 days after the outburst; the middle plot: LCs after the 30th day; the right plot: the fragment of the eclipse of the middle plot.

For comparison we can point that for the object CT Tri T∼ 13000 - 15000 K (Chochol *et al.*, 2009); for the star HS0218 we found T∼ 14000 K (Golysheva *et al.*, 2012); for the object J1915+07 (Golysheva Shugarov, 2014) T∼ 15000 K; for the star CSS130418 T∼ 10000K (Chochol *et al.*, 2015); for the star HR Her T∼ 15000 K (Shugarov *et al.*, 2015) and so on. At the beginning of the outburst the radiation of the accretion disk is close to star's or black body's, usually at this time in spectra the strong continuum radiation is observed with emission lines of hydrogen and helium. During the brightness fading the main contribution to the luminosity is provided by the inner parts of the disk and white dwarf, which have, as a rule, higher color temperature. That is why the UV excess begins to rise during the total brightness fading. Fig. 7 shows the color changing with phase.

During the eclipses the star becomes redder in color indices $B - R$ and $R - I$. But unexpectedly at this time the maximal UV excess $U - B$ is observed.

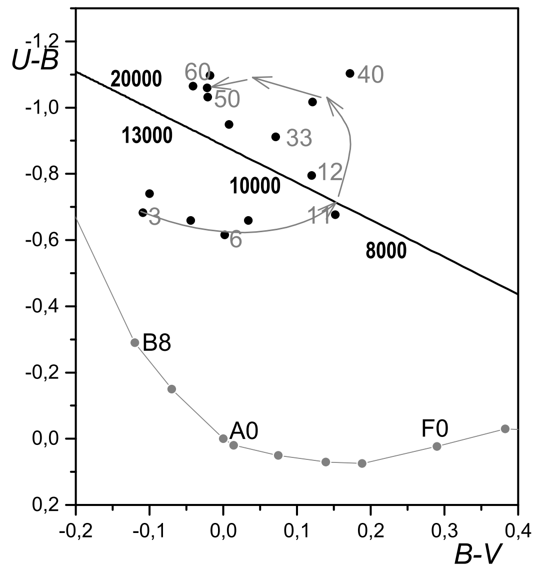

Figure 6: Two color $U-B/B-V$ diagram. The track of OV Boo is shown by grey arrows, the plotted number of days is occurred from the outburst. By black solid line is plotted black body line, by grey line – main sequence star line.

The fact that during the eclipse the color indices of the star increase, so, that there is reddening, is easily explained by the fact that hot WD is obscured by cold and red component. But the fact that during this time the UV excess is increasing needs to be carefully analyzed. It is possible that at this time in UV spectral region the hot outer edges of the disk, which are not fully obscured by the secondary component are emitting. The absence of clear eclipses is explained by the fact that the dimensions of hot accretion disk after the outburst exceeded the dimensions of red dwarf, and we have observed only partial eclipses of the disk. We hope, that the ongoing mathematical modeling will allow us to explain this phenomenon correctly. It should be noted, that during the eclipse some other CVs also show the increase of UV excess, for example V2051 Oph (SU UMa-type star with eclipses, see Cook & Brunt, 1983).

6. Concluding remarks

Different CVs have different shapes of eclipses. But it is possible to find the similar features for some objects. For example, novae KN Cet = PHL

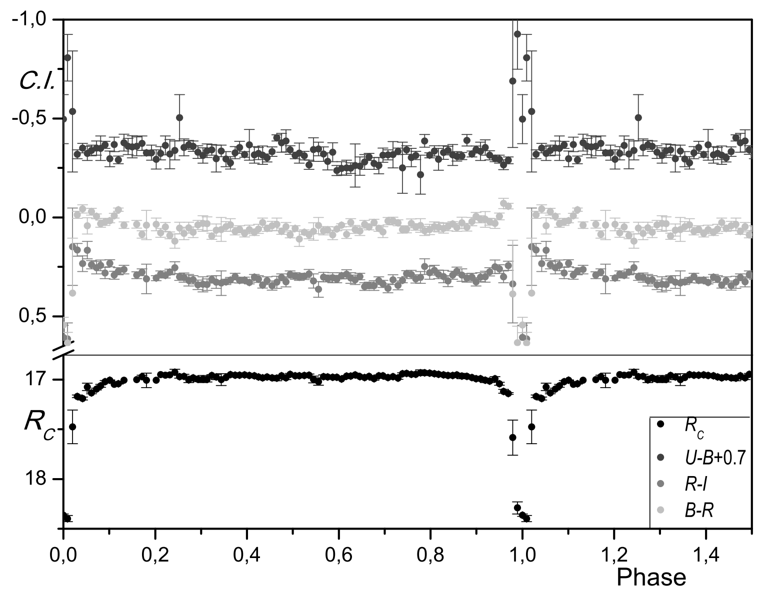

Figure 7: The color-phase dependence. The lower curve is phased LC in R_C band, the upper three curves are color dependences on phase.

1445 (McAllister *et al.*, 2015) or SDSS J143317.78+101123.3 (Gänsicke *et al.*, 2009) display the same brightness fading and rising during the eclipse, which are caused by the ingress and egress of the white dwarf and the hot spot, as OV Boo displays. Star GP CVn (SU UMa type, Gänsicke *et al.*, 2009) also exhibit similar steps, sharp brightness rising and fading. From the previously published studies can be seen that the superposition of four sources of light – white dwarf, red dwarf, accretion disk and hot line allows to make good approximation of the theoretical and the observed light curves (see also Khruzina *et al.*, 2015,b).

Our observations will provide an opportunity to estimate the dynamics of parameters changes of OV Boo during the different phases of outburst, from the maximum of brightness till its decline by using the methods of mathematical simulation developed by our co-authors. It is also shown that within the limits of errors the value of period doesn't change from the year 2006.

Finally, we have shown that the observations with small telescopes can be useful (see also Katysheva *et al.*, 2014), because obtained multicolor photometry is allowing to calculate many physical and geometrical parameters of close binary systems and to estimate sizes, temperatures and spatial location of the components in the system.

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References

Chochol, D., Katysheva, N. A., Shugarov, S. Yu., Volkov, I. M.: 2009, *Contributions of the Astronomical Observatory Skalnaté Pleso*, **39**, 43.

Chochol, D., Shugarov, S., Katysheva, N., Volkov, I., Zharova, A., Pavlenko, E., Pit, N., Zvagelsky, R., Antoniuk, O., Baklanov, A., Borisov, N., Gabdeev, M.: 2015, *Acta Polytechnica CTU proceedings*, **2**, 165.

Cook, M. C., Brunt, C. C.: 1983, *MNRAS*, **205**, 465

Duerbeck, H. W.: 1987, *Space Science Reviews* **45**, 1-2.

Gänsicke, B. T., Dillon, M., Southworth, J., Thorstensen, J. R., Rodríguez-Gil, P., Aungwerojwit, A., Marsh, T. R., Szkody, P., Barros, S. C. C., Casares, J. and 8 coauthors: 2009, *MNRAS*, **397**, 2170.

Golysheva, P. Yu., Antipin, S. V., Zharova, A. V., Katysheva, N. A., Chochol, D., Shugarov, S. Yu.: 2012, *Astrophysics*, **55**, 208.

Golysheva, P., Shugarov, S.: 2014, *Contributions of the Astronomical Observatory Skalnaté Pleso*, **43**, 312.

Hachisu, I., Kato, M.: 2014, *Astrophys. J.* **785**, 44.

Hachisu, I., Kato, M.: 2016, *Astrophys. J., Suppl. Ser.* **223**, 62.

Harevich, V., Bocharov, A. N., Shugarov, S. Yu., Vsekhsvyatskij, S. K., Shefer, Y., Kukarkin, B. V., Aksenov, E. P., Alksne, Z., Platais, I., Samus, N. N., and 15 coauthors: 1975, *IAU Circ.* **2839**, 1.

Kato, T.: 2015, *PASJ* **67**, 108.

Kato, T. Imada, A., Uemura, M. and 135 coauthors: 2009, *PASJ* **61**, 365.

Kato, T., Pavlenko, E. P., Maehara, H., Nakajima, K., Andreev, M., Shugarov, S. Yu., de Ponthiere, P., Brady, S., Klingenberg, G, Shears, J., Imada, A., Yanagisawa, K. : 2009, *PASJ* **61**, 601.

Kato, T., Hambsch, F., Monard, B. and 75 coauthors: 2016 *PASJ* **68**, 65.

Katysheva, N., Chochol, D., Shugarov, S.: 2014, *Contributions of the Astronomical Observatory Skalnaté Pleso*, **43**, 306.

Kazarovets, E., Samus, N., Durlevich, O., Kireeva, N., Pastukhova, N.: 2011 *Informational Bulletin on Variable Stars* No 6008, 1.

Khruzina, T., Katysheva, N., Golysheva, P., Shugarov, S.: 2015, *EAS Publications Series*, **71-72**, 149.

Khruzina, T. S., Golysheva, P. Yu., Katysheva, N. A., Shugarov, S. Yu., Shakura, N. I.: 2015, *Astronomy Reports*, **59**, 288.

Landolt, A.: 2013, *Astron. Astrophys.* **146**, 131.

Littlefair, S. P., Dhillon, V. S., Marsh, T. R., Gansicke, B. T., Baraffe, I., Watson, C. A.: 2007, *MNRAS* **381**, 827.

McAllister, M. J., Littlefair, S. P., Baraffe, I., Dhillon, V. S. and 13 coauthors: 2015, *MNRAS*, **451**, 114.

Namekata, K., Isogai, K., Kato, T. and 37 coauthors: 2016, *PASJ*, **69**, 2.

Patterson, J., Thorstensen, J. R., Knigge, C.: 2008, *PASP*, **120**, 867.

Shugarov, S., Katysheva, N., Gladilina, N.: 2015, *Contributions of the Astronomical Observatory Skalnaté Pleso*, **45**, 119.

Smak, J.: 1991, *Acta Astronomica* **41**, 269.

Szkody, P., Henden, A., Fraser, O. J. and 10 coauthors: 2005, *Astron. J.* **129**, 2386.

Uemura, M., Arai, A., Krajci, T., Pavlenko E. P. and 25 coauthors: 2008, *PASJ* **60**, 227.

Uthas, H., Patterson, J., Kemp, J., Knigge, C., Monard, B., Rea, R., Bolt, G., McCormick, J., Christie, G., Retter, A., Liu, A.: 2012, *MNRAS*, **420**, 379.