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Observation and Light Curve Analysis of Three Eclipsing Dwarf Novae

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Abstract. We present the results of our photometric observations of the eclipsing dwarf novae V1239 Her, V2051 Oph, and EX Dra in quiescence. All light curves exhibit a deep main eclipse, a depression near the secondary minimum, and a hump before the eclipses. However, the light curves can vary from cycle to cycle. We have improved the orbital period of V1239 Her using the $O - C$ diagram over a long time interval. The combined "hot line + hot spot" model was used to analyze the light curves of V1239 Her. Some physical and geometrical parameters of the components, such as the temperature of inner and outer disk and the hot spot, have been derived.

1. Introduction

Cataclysmic variables (CVs) are highly evolved close binaries consisting of a red dwarf transferring matter to its companion, a white dwarf (WD). This matter creates an accretion disk around the WD. Dwarf novae (DNe) are a subclass of CVs.

For eclipsing CVs, when the WD, the disk, and the other emitting parts around the WD are overshadowed by the secondary, it is possible to calculate the physical parameters of the system from the light curves using numerical modeling. This type of work has been carried out by many groups for a number of years. In particular, we refer the reader to the observational and modeling papers on eclipsing CVs for IP Peg (Goranskii et al. 1985; Katysheva et al. 2002), AC Cnc (Shugarov 1981), UU Aqr (Volkov et al. 1986; Katysheva et al. 2002), GY Cnc, IR Com, HT Cas, and GSC 4560−02157 (Feline et al. 2005; Katysheva & Shugarov 2005; Khruslov et al. 2014), IY UMa (Shugarov et al. 2007; Khruzina et al. 2008), SDSS J090350+330036 (Voloshina & Khruzina 2012), SDSS J152419+220920 (Michel et al. 2013), SDSS J0756+0858 (Tovmassian et al. 2014), 13 stars in Savoury et al. (2013), and many others.

V1239 Her was discovered as an eclipsing CV in the Sloan Digital Sky Survey (SDSS) by Szkody et al. (2004). Its spectrum exhibited strong emissions in the Balmer lines and in neutral helium. Littlefair et al. (2006), Boyd et al. (2006), and Gänsicke et al. (2009) obtained a period of 0.1000821 day (2.4 hours), which falls in a known "period gap" for CVs (2–3 hours), and therefore the star warrants further study.

Kato et al. (2013) emphasized the four super-outbursts and three outbursts of V1239 Her between 2005 and 2013. During the 2005 (Boyd et al. 2006) and 2011 (Kato et al. 2013) super-outbursts, the super-hump period was determined to be roughly

0.1046–0.105 day. The period excess, $\epsilon = (P_{sh} - P_{orb})/P_{orb} = 0.05$, is typical for SU UMa stars.

Littlefair et al. (2006) and Savoury et al. (2013) presented the results of numerical modeling for this system. The authors determined the physical parameters of V1239 Her including the mass, radius, component temperatures, half-amplitude of the radial velocities, and also established the distance to the system and its orbital inclination angle.

2. Observations of V1239 Her

Our observations in the years 2005–2007 were obtained in the *R* and *V* bands at low time resolution and have been used only for the determination of the orbital period. The observations in 2013–2014 had a higher time resolution of 12 to 45 sec, when the object was in quiescence. All data were obtained unfiltered at the 60 cm telescope of the Slovak Academy of Science and the 125 cm telescope at the Crimean Station of the Sternberg Astronomical Institute.

In Figure 1 we show the individual nightly light curves, which are seen to change in shape from night to night and from cycle to cycle. Usually there is an orbital hump before the eclipse, but on some nights the hump disappears, as on the night of JD 2,456,746, when the brightness before and after the eclipse is the same. On some nights a weak secondary minimum is visible. Figure 2 presents six sections centered on the eclipses. A rather fast fading is seen that corresponds to the ingress of the WD and accretion disk, as well as a "step" feature in the ascending part of the eclipse. The fast increase in brightness is the egress of the WD, while the step feature is caused by the egress of the disk, and a small peak after this step (see Figure 2) marks the appearance of the hot spot area.

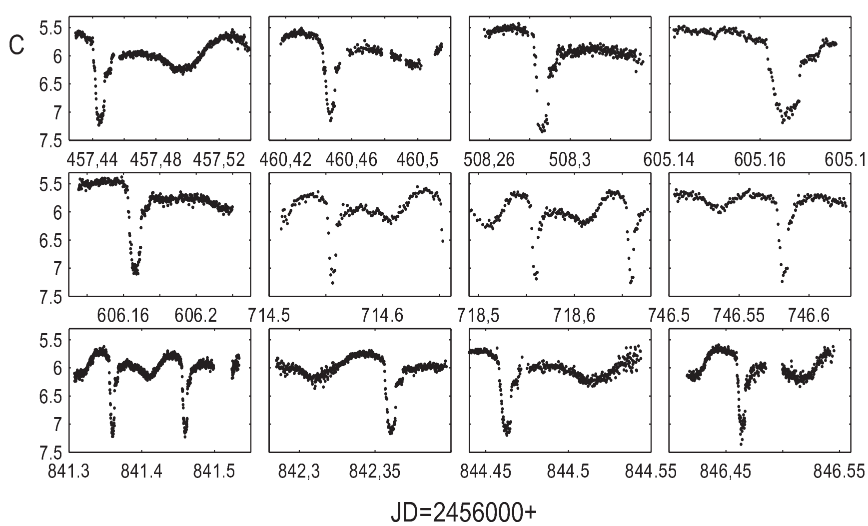

Figure 1.: Nightly light curves ov V1239 Her obtained in 2013–2014.

We measured 20 times of minimum for V1239 Her from 2006 June until 2014 July (see Khruzina et al. 2015), which combined with other measurements from the literature lead to the improved ephemeris $HJD_{min} = 2,456,508.28634(5) + 0.100082222(1) \cdot E$.

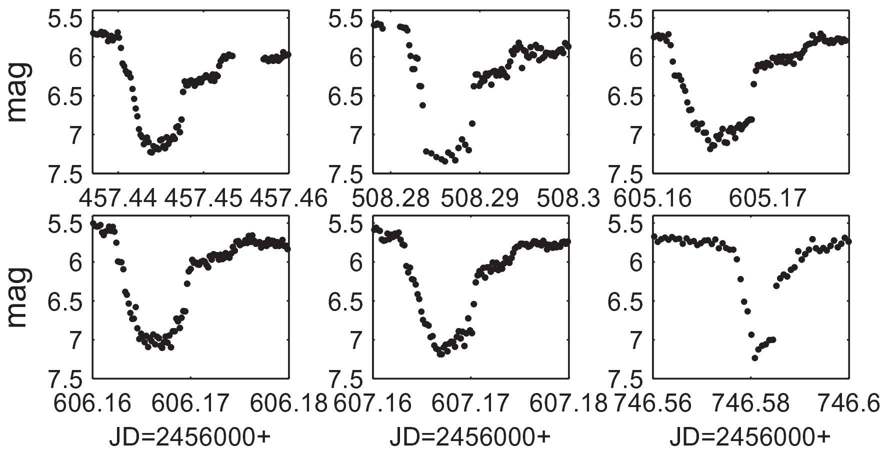

Figure 2.: The eclipse sections of the light curves of V1239 Her.

The $O-C$ residuals from this ephemeris (see Figure 3) are typically smaller than 40 sec and are caused by uncertainty in the definition of the times of mid-eclipse for the WD. Phase-averaged light curves in 0.01 P_{orb} increments during four nights (JD 2,456,457, 460, 714, and 718) are presented in Figure 4. We note the clear orbital hump, the fast ingress and egress of the WD, the delay in the egress of the accretion disk, and the asymmetrical eclipse shape near phase 0; an explanation of these features is given by Khruzina et al. (2015).

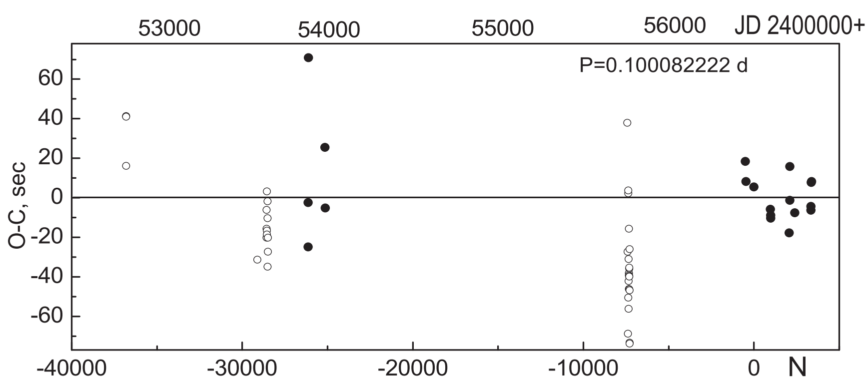

Figure 3.: $O-C$ diagram for V1239 Her. Our calculated minima are shown with black dots, and those taken from the literature with open circles.

3. Observations of EX Dra and V2051 Oph

We have begun studies of two another CVs with deep eclipses: EX Dra, with an orbital period of 0.2099 day, and V2051 Oph, with a period of 0.0624 day. The period-folded light curves are shown in Figures 5 and 6. The out-of-eclipse brightness of these systems is seen to vary from night to night, which is caused by changes in the luminosity of the accretion disk and other sources of radiation, as is the case for V1239 Her. However, the eclipse profiles of these two stars are smoother and more symmetric.

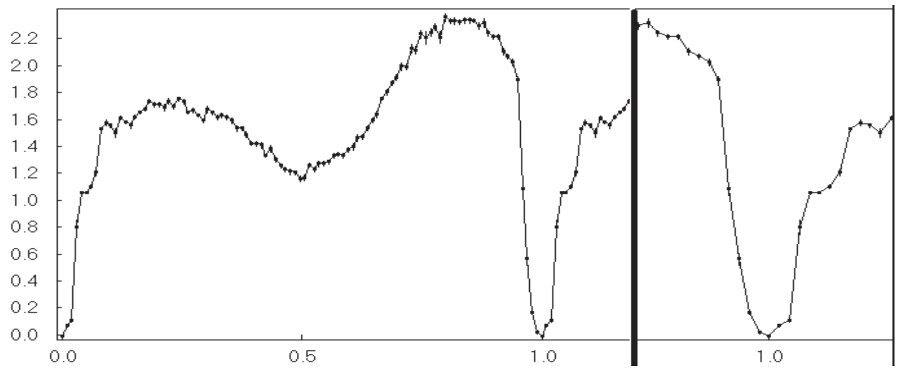

Figure 4.: The period-folded, average light curve of V1239 Her on an intensity scale. The shape of the eclipse is not symmetrical near zero phase (right panel) because of the partial eclipse of the accretion disk and the inhomogeneous brightness of the disk edges.

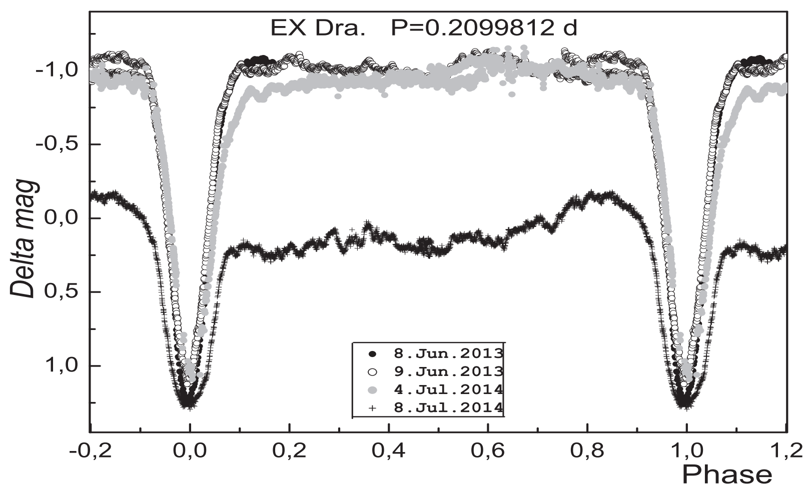

Figure 5.: Four period-folded light curves of EX Dra.

4. Numerical Modeling of V1239 Her

We have performed a numerical modeling of the light curves of V1239 Her and calculated the parameters of the disk in the combined "hot spot + hot line" model described by Bisikalo et al. (2004). For this task we used the Nelder & Mead method (see Press et al. 1986). The results of the modeling have recently been reported by Khruzina et al. (2015). Some of the parameters of the system such as the temperature and luminosity of the disk, its size, the location of the bright spot, and the hot line, can vary not only from night to night but also from cycle to cycle.

5. Conclusions

We have analyzed the light curves of V1239 Her in quiescence, and improved the orbital period by using the $O - C$ diagram. We have shown that although the system was in quiescence at the time, the light curves were highly variable.

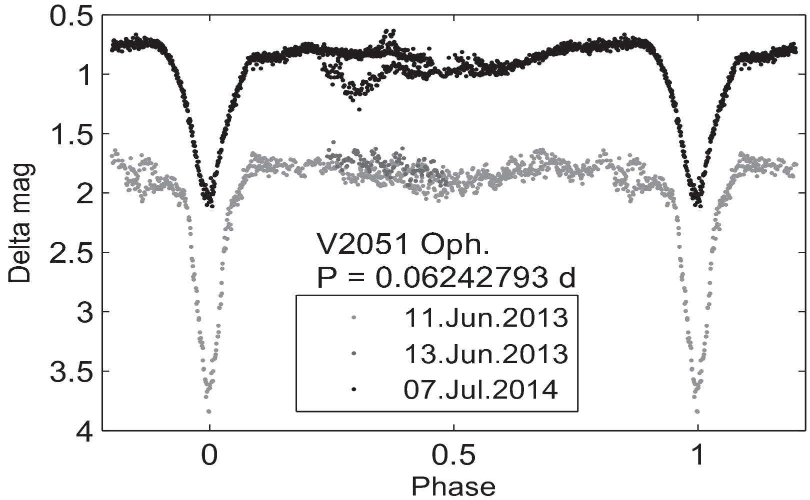

Figure 6.: Three period-folded light curves of V2051 Oph.

Our modeling and comparison with the observational data shows that the physical variability from night to night is caused by changes in the luminosity of the accretion disk, the hot spot, and the hot line, which might be due to a change in the rate of mass transfer. The modeling with the hot line and hot spot describes the system better than with only the hot spot. We also present preliminary results from our observations of two other eclipsing cataclysmic variables, EX Dra and V2051 Oph.

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