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Study of a long and short–term variability of ER Ursae Majoris

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Abstract. We present the results of our study of a long and short-term variability of ER UMa. Obtained light curves revealed presence of superhumps during the whole supercycle. The superhumps period was not stable but varying from night to night. The $O-C$ diagram suggests that both positive and negative superhumps were present. The form of the $O-C$ digram is consistent with recently presented *Kepler* data of another SU UMa-type star – V1504 Cyg.

We also examined data of about 20 years of observations of ER UMa from different databases. The $O-C$ diagram for the moments of superoutbursts revealed a systematic change of the supercycle within 43.6 and 59.2 d. We associate these variations with the changes of a mass transfer rate.

Key words: stars: dwarf novae – stars: individual (ER UMa)

1. Introduction

Dwarf novae (DNe) are a subclass of cataclysmic variable stars. These binary systems consist of a white dwarf and a late-type main sequence star accreting material via the Roche-lobe overflow.

SU UMa-type stars are DNe with very short orbital periods (80–180 min) that show normal outbursts together with superoutbursts with larger amplitudes. Another feature of these objects is presence of a light curve modulation with periods slightly longer than the orbital one - "positive superhumps". It appears near maxima of superoutbursts due to the precession of an elliptical accretion disk. In some systems the modulation with periods shorter than the orbital is observed, too. It presents "negative superhumps" and is believed to arise from the precession of a tilted accretion disk. Superhumps in SU UMa-type stars were discussed in details by Kato et al. (2009).

SU UMa stars have two extreme subgroups with very long (about decades) and short (tens of days) supercycles, which are time interval between two subsequent superoutbursts. They are: WZ Sge and ER UMa subtypes, respectively.

Short supercycles of ER UMa can be explained as a result of a very high

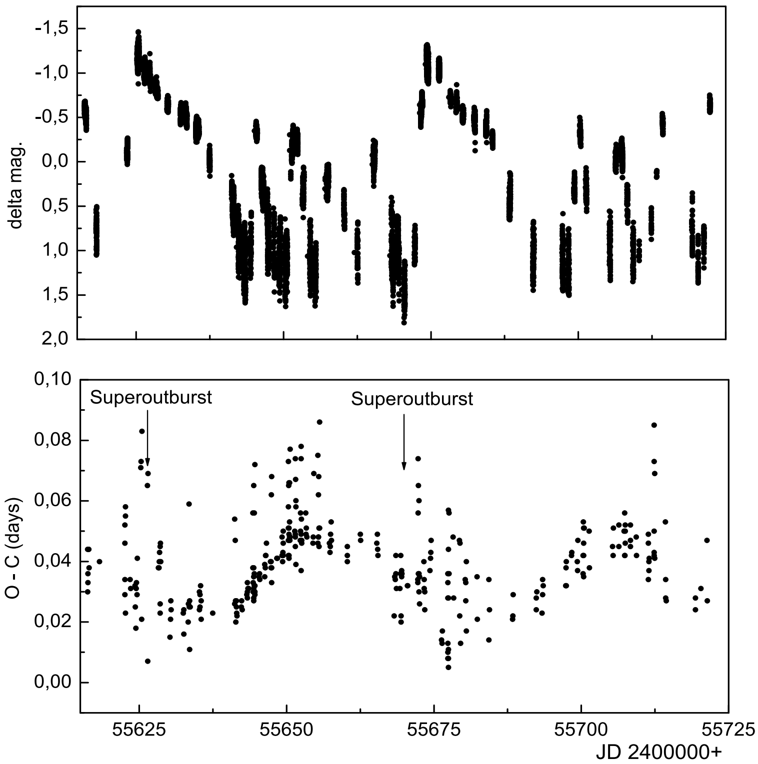

Figure 1. Top: A light curve of ER UMa in the photometric system, close to the R_c-band. Bottom: an $O - C$ diagram for the superhumps maxima.

and constant $\dot{M}$ in the framework of the thermal tidal instability (TTI) model (Osaki, 1995). Here we present the results of the photometric study of short and long term variability of ER UMa during the last 20 years and compare them with predictions of the TTI model.

2. Observations and data analyses

We started our observations of ER UMa in March 2011 at the Stará Lesná Observatory of the Slovak Academy of Sciences. We used an SBIG ST10-XME CCD camera, mounted in the Newton focus of the 0.5 m (0.5/2.5) reflector and in the Cassegrain focus of the 0.15 m (0.15/2.25) Maksutov telescope. All the data were reduced to the R_C passband. We also used data obtained by the group of E. Pavlenko at the Crimean Astrophysical Observatory, and corrected them for a systematic shift.

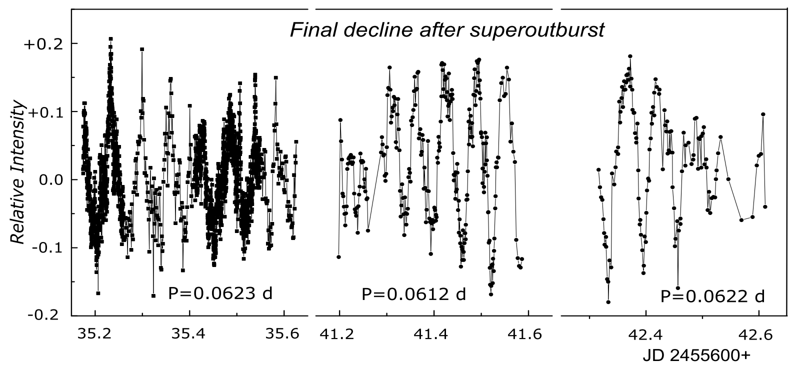

Figure 2. Negative superhumps, observed during the decline from the superoutburst. Because of the rapid fading of ER UMa, we plot the light curves in fluxes.

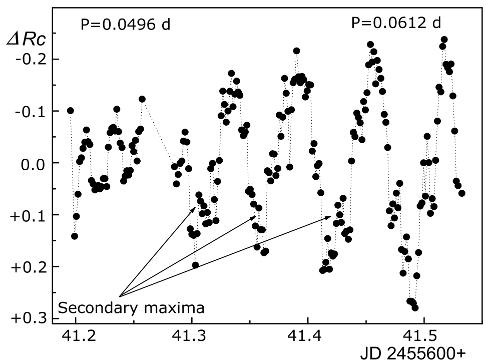

Figure 3. Negative superhumps at brightness minimum. Secondary maxima are marked with arrows.

The mean accuracy of our measurements is 0.01-0.04 mag. Time resolution is 30 − 120 s. In total we used more than 20 000 CCD images that cover two supercycles and three superoutbursts.

The final light curve is shown in the top plot of Fig. 1. Four normal outbursts were observed within each supercycle. The length of the supercycle was stable and equal to $\sim 49^d$. We found the following mean period of the observed light curve modulation – $P_{\rm Nsh} = 0.^d06225$ – and associated it with negative superhumps (taking into account the orbital period $P_{\rm orb} = 0.^d06366$, determined by Thorstensen et al. 1997, see Fig. 2 – 3). Positive superhumps in this system were detected only near the maxima of superoutbursts (see Fig. 4). The same value of $P_{\rm Nsh}$ was found by Ohshima et. al (2012): $0.^d06226$. It should be mentioned that presence of negative superhumps is not an inevitable feature of ER UMa. There are several detections of negative superhumps in this system (Gao et al., 1999; Kjurkchieva, Marchev, 2010; Zemko, Shugarov, 2012; Ohshima et. al, 2012) while a retrospective search for the literature suggests that they were absent in the past (see Kato, Kunjaya, 1995). A similar effect (disappearance of the negative superhumps) was found in V503 Cyg by Pavlenko et al. (2012) and Kato et al. (2013). It was suggested that there is a connection between the appearance and disappearance of the negative superhumps and the change of the normal outburst cycle.

At the minimum of brightness observed the profiles of negative superhumps sometimes have secondary peaks, shifted by 0.5 phase (see Fig. 3).

For the investigation of a long-term variability of ER UMa we analysed the data of AAVSO[1], VSNET[2], AFOEV[3], NSVS[4] and VSOLJ[5] databases, which represent more than 20 years of observations.

In order to follow the supercycle change in ER UMa we plotted an $O-C$ diagram for the moments of superoutbursts, using the data mentioned above, and then determined the local value of the supercycle by a linear fit of each 5 data points. The detailed methodology and results are presented in Zemko, Kato & Shugarov (2013). From the long-term light curve we found that the supercycle varied from 43.7 to 59.2 d. Supercycle lengths ($T_{\rm s}$) appeared to change discontinuously and show oscillations superimposed on a secular increasing trend. The rate of supercycle growth is $dT_{\rm s}/dE = 0.033(6)$ d/cycle and the period derivative is $dT_{\rm s}/T_{\rm s} = 6.7(6) \times 10^{-4}$, respectively.

3. Discussion

According to our data, the period of superhumps is not stable but varies from night to night. Moreover, it is longer than the orbital one at the beginning of a supercyle and shorter during the remaining part of it. We propose the following scenario. Positive superhumps in ER UMa appear about one day before a superoutburst and last until a rapid fading starts (for ~ 7 days).

Further, the light curve becomes irregular and the period of the modulation decreases – negative superhumps become clear. Negative superhumps, probably, are present during a whole supercycle, but are suppressed by positive superhumps around the maxima of superoutbursts. This behaviour resembles the case of the dwarf nova MN Dra, described by Pavlenko, Voloshina et al. (2010) and Pavlenko, Kato et al. (2010).

Negative superhumps profiles have an irregular form with dips and secondary peaks (see Fig. 2, 3). We suggest that secondary peaks, being observed near the minima of brightness which have a 0.5 phase shift with respect to the primary,

[1] http://www.aavso.org/
[2] http://www.kusastro.kyoto-u.ac.jp/vsnet/
[3] http://cdsarc.u-strasbg.fr/afoev/
[4] http://skydot.lanl.gov/nsvs/nsvs.php
[5] http://vsolj.cetus-net.org/

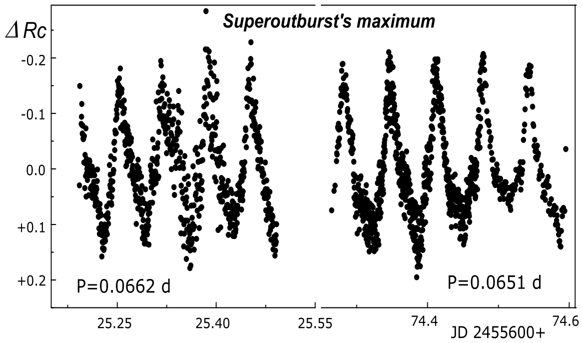

Figure 4. Positive superhumps at the maxima of the superoutbursts. Periods of superhumps are marked.

appear because the accretion disk is thin enough and the bright spot can be seen through it. Usually, in the case of negative superhumps, we see only one hump on a light-curve in a cycle, because of the opacity of a disk.

The $O-C$ diagram, presented in the bottom plot of Fig. 1, clearly shows a quasi-sinusoidal wave. A recent study of the *Kepler* data of V1504 Cyg has shown the same pattern of $O-C$ diagram behaviour (Warner, 2012). According to the TTI model, accretion onto a tilted disk would slow down the precession rate between outbursts and superutbursts, in turn, drain an accretion disk and speed up precession. Our $O-C$ diagram perfectly reflects this scenario.

A long term light curve of ER UMa revealed variations of the $T_{\rm s}$ from 43.7 to 59.2 d, superimposed with a secular increasing trend. Otulakowska-Hypka (2013) showed that the period derivative for IX Dra is 1.8×10^{-3}, comparable with that found for ER UMa. According to the dependence between $T_{\rm s}$ and $\dot{M}$ (Osaki, 1995), observed variations in the supercycle length of ER UMa correspond to the change of $\dot{M}$ from $3.8\dot{M}_{16}$ to $2\dot{M}_{16}$ ($\dot{M}_{16}$ is $\dot{M}$ in units of 10^{16} g s^{-1}). We assume that this value is typical for ER UMa type stars. An increasing trend in $T_{\rm s}$ means that $\dot{M}$ in this system decreases secularly and indicates that ER UMa could be a nova-like system 100 – 200 years ago. This result is even more intriguing in the context of the hibernation scenario proposed by Livio (1992).

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