Detection of Change in Supercycles in ER Ursae Majoris

Polina ZEMKO,1,2 Taichi KATO,2 and Sergei Yu. SHUGAROV1,3
1 Sternberg Astronomical Institute, Moscow University, Universitetsky ave. 13, Moscow 119992, Russia
polina.zemko@gmail.com
2 Department of Astronomy, Kyoto University, Kitashirakawa-Oiwake-Chō, Sakyo-ku, Kyoto 606-8502
tkato@kasastro.kyoto-u.ac.jp
3 Astronomical Institute of the Slovak Academy of Sciences, 05960, Tatranska Lomnica, the Slovak Republic

Abstract

We examined data from observations of ER UMa during a period of ~20 years available in the AA VSO, VSNET, AFOEV, NSVS, and VSOLJ databases together with published light curves. The obtained O − C diagram revealed a systematic change of the supercycle (time interval between two successive superoutbursts) ranging from 43.6 to 59.2 d. The time-scale of this cycle variation is from 300 to ~1900 d. The number of normal outbursts within the supercycles also varied between 4 and 6, although no strong correlation between this number and the supercycle length was found. We suggest that the appearance of negative superhumps is responsible for the observed variations in the number of normal outbursts. Our results generally confirm the expectations based on the thermal-tidal instability theory.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (ER Ursae Majoris) — stars: novae, cataclysmic variables

1. Introduction

Dwarf novae (DNe) are a class of cataclysmic variables (CVs)—close binary systems consisting of a white dwarf as a primary component and a red- or brown-dwarf secondary transferring matter via Roche-lobe overflow. Because of the instabilities that take place in the accretion disks, normal outbursts and less-frequent superoutbursts with larger amplitudes take place (see Warner 1995; Hellier 2001). DNe that show both normal outbursts and superoutbursts are called SU UMa-type stars. These stars have one distinguishing property—light-curve modulations with the periods being close to, but different from, the orbital one that appear near the superoutburst maxima, and sometimes persist at other times (Vogt 1980). These modulations are called positive superhumps if their period is longer than the orbital one and negative if shorter. Positive superhumps are believed to arise from periodic viscous dissipation in a disk driven to resonant oscillation by the tidal field of the secondary star, and precessing slowly in the prograde direction (see Whitehurst 1988; Hirose & Osaki 1990; Lubow 1991; Smith et al. 2007; Wood et al. 2011); negative superhumps arise from the precession of a tilted accretion disk (Wood et al. 2009; Montgomery & Martin 2010).

SU UMa stars have two extreme subgroups with very long (about decades) and short (tens of days) supercycles. They are WZ Sge and ER UMa subtypes, respectively. There are five ER UMa-type stars already known: RZ LMi (Nogami et al. 1995), DI UMa (Kato et al. 1996), ER UMa (Kato & Kunjaya 1995), V1159 Ori (Robertson et al. 1995), and IX Dra (Ishioka et al. 2001); all of them show extremely short supercycles (18.9–54 d) and positive superhumps (Olech et al. 2008). Moreover, ER UMa-type stars were known to show a pronounced stability of the supercycle length and outburst pattern, which can be particularly seen in the folded light curves and O − C diagrams presented in Robertson, Honeycutt, and Turner (1995). This stability and short supercycles can be explained as the result of a very high and constant mass-transfer rate in the framework of a thermal-tidal instability (TTI) model (Osaki 1995a).

However, long-term monitoring of V1159 Ori revealed secular changes in the supercycle and a hint of the periodic behavior of such variations (Kato 2001). The TTI model suggests that this phenomenon is the consequence of a change in the mass-transfer rate in the binary system, although the origin of these changes is still an open question. The hibernation scenario, or the theory of cyclic evolution, suggested by Livio (1992), also assumes that the mass-transfer rate in CVs can vary secularly, and proposes the irradiation of the secondary by the white dwarf, which is still hot after the nova eruption, as being one of the possible mechanisms of an increased mass-transfer. However, the time-scale of the $M$ variation in this scenario is very long compared to these observations. On the other hand, for V1159 Ori, Kato (2001) proposed that solar-type cycles of the secondary, which are possibly observed in cataclysmic variables (Bianchini 1988; Ak et al. 2001), may be responsible for the phenomenon.

Here, we report that another ER UMa-type star—ER UMa itself—also shows variations of the supercycle. A discussion concerning the origin of this phenomenon is even more intriguing in the context of a recent discovery of persistent negative superhumps in this dwarf nova by Ōshima et al. (2012). The presence of negative superhumps was not taken into account in past studies of SU UMa-type stars, while this factor may strongly affect the outburst behavior. Osaki and Kato (2013) have also found that the presence of negative superhumps correlates with normal outbursts; thus, it is
Fig. 1. Long-term light curve of ER UMa from AAVSO, VSNET, AFOEV, NSVS, and VSOLJ observations.
reasonable to investigate the possibility of whether the presence of negative superhumps is related to the long-term variations of the outburst behavior.

A comprehensive study of long-term variations in ER UMa-type stars is therefore essential for better understanding the evolution of dwarf novae in general, and in particular changes in the mass-transfer rate, the mechanisms that lead to the appearance of negative superhumps, and their effect on the outburst behavior.

2. Observation and Data Analysis

2.1. Light Curves

We analyzed all of the data on ER UMa available in American Association of Variable Star Observers (AAVSO),1 Variable Star NETwork (VSNET),2 Association Francaise des Observateurs d’Etoiles Variables (AFOEV),3 Northern Sky Variability Survey (NSVS),4 and Variable Star Observers League in Japan (VSOLJ)5 databases, which cover more than 20 years of observations. The earliest superoutburst was on 1992 April 27 (JD 2448740) and the latest one on 2012 June 12 (JD 2456090.7). We also used observations obtained by one of the authors (S. Yu. Shugarov) in the Stará Lesná Observatory of Slovak Academy of Sciences, and by the group of E. Pavlenko in the Crimean Astrophysical Observatory. A long-term light curve of ER UMa from these observations is presented in figure 1.

2.2. Moments of the Superoutbursts and $O - C$ Diagram

In order to follow the supercycle change in ER UMa, we plotted an $O - C$ diagram using the data mentioned. The moments of the superoutbursts and normal outbursts were determined visually by the light curves. The mean period essential for plotting such a diagram was determined by summing up the cycle counts, and was chosen to be 48.7 d by the least-squares method. There were several gaps in observations, usually 3–4 cycles long, particularly around the solar conjunction, which can be also seen in figure 1. The time intervals between two subsequent detected superoutbursts in such cases were large enough to cause considerable uncertainties in calculations of the number of cycles in such gaps. For every uncertain moment of the superoutburst we checked the

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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/).
Table 1. Moments of the superoutbursts, supercycle lengths ($T_s$), and the number of normal outbursts within the supercycle ($N_{NO}$).*

| $E$ | Date      | JD     | $T_s$ (d) | $N_{NO}$ |
|-----|-----------|--------|-----------|----------|
| 0   | 1992/04/27| 2448740| 49.6      |          |
| 3   | 1992/09/05| 2448871| 49.0      |          |
| 6   | 1993/01/13| 2449001| 44.1      |          |
| 7   | 1993/02/27| 2449046| 44.5      |          |
| 8   | 1993/04/17| 2449095| 45.0      | >4       |
| 9   | 1993/05/29| 2449137| 43.6      | >4       |
| 10  | 1993/07/12| 2449181| 44.4      |          |
| 11  | 1993/08/22| 2449222| 43.9      |          |
| 12  | 1993/10/14| 2449275| 44.0      |          |
| 13  | 1993/11/18| 2449310| 43.6      |          |
| 14  | 1994/01/04| 2449357| 42.1      |          |
| 15  | 1994/02/15| 2449399| 43.1      |          |
| 16  | 1994/03/29| 2449441| 42.6      | >4       |
| 17  | 1994/05/11| 2449484| 42.5      | >4       |
| 18  | 1994/06/24| 2449528| 42.4      | 5–6      |
| 19  | 1994/08/03| 2449568| 42.1      |          |
| 20  | 1994/09/15| 2449611| 42.1      |          |
| 21  | 1994/10/27| 2449653| 43.5      |          |
| 22  | 1994/12/09| 2449696| 45.0      |          |
| 23  | 1995/01/25| 2449743| 46.9      | >3       |
| 24  | 1995/03/14| 2449791| 47.3      | 5        |
| 25  | 1995/05/02| 2449840| 48.71     | 5        |
| 27  | 1995/08/02| 2449932| 50.5      |          |
| 28  | 1995/09/29| 2449990| 54.4      | 5        |
| 29  | 1995/11/24| 2450046| 59.6      |          |
| 30  | 1996/01/31| 2450114| 59.4      |          |
| 31  | 1996/03/25| 2450168| 55.8      | >4       |
| 32  | 1996/05/22| 2450226| 48.9      |          |
| 33  | 1996/07/04| 2450269| 47.2      |          |
| 36  | 1996/11/22| 2450410| 47.0      |          |
| 37  | 1997/01/06| 2450455| 47.6      | 4        |
| 38  | 1997/03/02| 2450510| 48.1      |          |
| 39  | 1997/04/15| 2450554| 47.6      | 4        |
| 40  | 1997/06/01| 2450601| 46.2      | 4        |
| 42  | 1997/09/04| 2450696| 46.0      |          |
| 44  | 1997/12/03| 2450786| 45.8      | 3–4      |
| 45  | 1998/01/16| 2450830| 44.8      | 3–4      |
| 46  | 1998/03/05| 2450878| 44.9      | 3–4      |
| 47  | 1998/04/15| 2450919| 46.0      |          |
| 48  | 1998/06/01| 2450966| 49.7      | 5        |
| 49  | 1998/07/21| 2451016| 52.2      |          |
| 50  | 1998/09/21| 2451078| 52.8      |          |
| 51  | 1998/11/06| 2451124| 50.6      |          |
| 52  | 1998/12/28| 2451176| 49.2      |          |
| 53  | 1999/02/10| 2451220| 49.8      |          |
| 54  | 1999/04/07| 2451276| 51.6      | >4       |
| 55  | 1999/05/24| 2451323| 52.6      | 5        |
| 57  | 1999/09/11| 2451433| 51.0      |          |
| 58  | 1999/10/31| 2451483| 51.0      |          |
| 59  | 1999/12/13| 2451526| 47.6      | 4–5      |
| 60  | 2000/02/06| 2451581| 46.0      |          |
| 61  | 2000/03/18| 2451622| 46.2      | 5        |
| 62  | 2000/04/30| 2451665| 44.7      | 5        |
| 63  | 2000/06/19| 2451715| 46.7      | >5       |

*Note: $N_{NO}$ represents the number of normal outbursts within the supercycle.
Table 1. (Continued)

| \(E\) | Date       | JD   | \(T_s\) (d) | \(N_{NO}\) |
|-------|------------|------|-------------|------------|
| 114   | 2007/05/03 | 2454224 | 53.6       | 6          |
| 118   | 2007/12/03 | 2454438 | 52.9       |            |
| 118   | 2007/12/04 | 2454438 | 51.4       |            |
| 119   | 2008/01/20 | 2454486 | 45.6       |            |
| 120   | 2008/03/03 | 2454529 | 46.0       | 3–4        |
| 120   | 2008/03/04 | 2454530 | 47.0       |            |
| 121   | 2008/04/21 | 2454578 | 49.3       |            |
| 121   | 2008/04/23 | 2454580 | 49.2       | 3–4        |
| 122   | 2008/06/10 | 2454628 | 49.7       |            |
| 122   | 2008/06/11 | 2454629 | 49.6       |            |
| 125   | 2008/11/07 | 2454778 | 50.1       | 3–4        |
| 125   | 2008/11/08 | 2454778 | 49.8       |            |
| 126   | 2008/12/29 | 2454830 | 49.6       |            |
| 127   | 2009/02/14 | 2454877 | 48.9       |            |
| 127   | 2009/02/15 | 2454878 | 48.2       | 4          |
| 128   | 2009/04/04 | 2454926 | 51.2       |            |
| 128   | 2009/04/05 | 2454926 | 47.4       | 4          |
| 129   | 2009/05/29 | 2454981 | 47.0       | 5          |
| 134   | 2010/01/14 | 2455211 | 46.7       |            |
| 135   | 2010/03/01 | 2455257 | 45.8       |            |
| 135   | 2010/03/01 | 2455257 | 46.6       |            |
| 136   | 2010/04/14 | 2455301 | 47.7       | 4          |
| 136   | 2010/04/20 | 2455307 | 46.0       |            |
| 137   | 2010/06/05 | 2455353 | 45.6       | 3–4        |
| 141   | 2010/12/03 | 2455534 | 45.2       |            |
| 142   | 2011/01/16 | 2455578 | 45.2       |            |
| 143   | 2011/03/04 | 2455624 | 45.8       | 4          |
| 143   | 2011/03/04 | 2455625 | 48.1       | 4          |
| 144   | 2011/04/22 | 2455674 | 49.5       | 4          |
| 144   | 2011/04/23 | 2455675 | 49.0       | 4          |
| 144   | 2011/04/24 | 2455676 | 48.9       | 4          |
| 145   | 2011/06/11 | 2455724 | 48.3       |            |
| 145   | 2011/06/11 | 2455724 | 48.9       |            |
| 147   | 2011/09/16 | 2455820 | 50.6       |            |
| 148   | 2011/11/07 | 2455872 | 51.3       |            |
| 149   | 2012/01/02 | 2455929 | 53.0       |            |
| 149   | 2012/01/02 | 2455929 | 53.9       |            |
| 150   | 2012/02/20 | 2455978 | 53.4       |            |
| 150   | 2012/02/27 | 2455984 | 53.8       |            |
| 152   | 2012/06/11 | 2456089 | 54.4       |            |
| 152   | 2012/06/12 | 2456090 | 52.8       |            |

* Since the moments of superoutbursts were determined from several databases, multiple entries for the same \(E\) sometimes occur.

3. Discussion

3.1. \(O–C\) Behavior, Comparison with Other SU UMa-type DNe

An \(O–C\) diagram for the whole analyzed period is shown in figure 4. We can see that ER UMa underwent several stages with a relatively stable supercycle length (linear portion in the diagram), which lasted from 6 to 30 cycles and terminated with an abrupt period change. The local mean supercycle length was determined by a linear fit of each time interval with a relatively stable supercycle in the \(O–C\) diagram. It was shown that the supercycle varied from 43.7 at the very beginning of the \(O–C\) diagram to 59.2 d. The local values of the supercycle length are also presented in table 1.

The \(O–C\) behavior presented in figure 4 is reminiscent of that of V1159 Ori, shown in figure 2 in Kato (2001). Although one can see such a pattern, for example between the \(E = 60\) and \(E = 125\) cycles in figure 4, the time-scale of the variability is significantly longer in ER UMa. A detailed analysis of the supercycle variations in SU UMa-type stars was presented by Vogt (1980). Although only ordinary SU UMa-stars were discussed in Vogt (1980) (we do not consider comparison with SS Cyg-type DNe, since it is beyond the scope of this paper), the published \(O–C\) diagrams have the same features as ER UMa, particularly SU UMa, itself (figure 1 in Vogt 1980). Supercycles of SU UMa remained stable for the relatively long periods ranging from 10 to 20 cycles and switched randomly between several characteristic values. Nevertheless, while Vogt (1980) has shown that the supercycles in SU UMa possess 3 characteristic values, in ER UMa there are no preferable supercycle lengths, as can be seen in figure 5.
period derivative for IX Dra is 1.8. In Otulakowska-Hypka et al. (2013) it was shown that these formal estimates of error should not be taken seriously. Nevertheless, the possibility of the obtained trend. It yielded that the period increase is statistically significant with the 90% confidence. Nevertheless, these formal estimates of error should not be taken seriously. In Otulakowska-Hypka et al. (2013) it was shown that the period derivative for IX Dra is $d T_e / dE = 0.033(6) \text{d/cycle}$ and the period derivative is $d T_s / T_s = 6.7(6) \times 10^{-4}$. We used a half-delete jackknife method described in Shao and Tu (1995) to determine reliability of the obtained trend. It yielded that the period increase is statistically significant with the 90% confidence. Nevertheless, these formal estimates of error should not be taken seriously.

### 3.2. Supercycle-Length Change

We measured the local lengths of the supercycle by the linear fitting of $O - C$ diagram and plotted them against time. The results can be seen in figure 6, where the supercycle-length change is presented. Supercycle lengths ($T_s$) appeared to change discontinuously and show oscillations superimposed on a secular increasing trend. The rate of supercycle growth is $d T_s / dE = 0.033(6) \text{d/cycle}$ and the period derivative is $d T_s / T_s = 6.7(6) \times 10^{-4}$. We used a half-delete jackknife method described in Shao and Tu (1995) to determine reliability of the obtained trend. It yielded that the period increase is statistically significant with the 90% confidence. Nevertheless, these formal estimates of error should not be taken seriously. In Otulakowska-Hypka et al. (2013) it was shown that the period derivative for IX Dra is $1.8 \times 10^{-3}$, comparable with that found for ER UMa. We suppose that it is a typical value of supercycle-change rate for ER UMa-type stars. In figure 5 there is a hint of a bimodal distribution of the supercycle's lengths with maxima at 48 and 53 d. Osaki (1995a) proposed a model of ER UMa-type stars based on the TTI theory that successfully explained the light curves and short recurrence times of the superoutbursts, assuming an extremely high mass-transfer rate (about 10 times higher than that expected from the CV evolutionary scenario based on gravitational-wave radiation). It also provided a dependence of the period of the supercycle on the mass-transfer rate (presented in figure 1 in Osaki 1995a) and a possible minimum of supercycle lengths for ER UMa-type stars ($\sim 40 \text{d}$). According to this dependence, there are two possible values of $M$ for each $T_s$. These two possibilities are distinguishable by considering the duty cycle of the superoutbursts (ratio of the duration of superoutburst to the supercycle length). In this case, we can exclude the possibility of a larger $M$ because the observed duty cycles were much smaller than 0.5. The observed variations in the supercycle length of ER UMa correspond to the change of the mass-transfer rate from $3.8 M_{16}$ to $2 M_{16}$, where $M_{16}$ is the mass-transfer rate in units of $10^{16} \text{g s}^{-1}$, and the increasing trend in $T_s$ means that the mass-transfer rate in this system decreases secularly. It is also remarkable that the most significant change of the supercycle and the mass-transfer rate (almost twice) occurred in the first break in the $O - C$ diagram (JD 2449932) just after the initial long stable interval. All of the further supercycle changes were less dramatic. The period varied between 46.2 and 54.1 d, which corresponds to a $\sim 15\%$ change in the mass-transfer rate. It is also notable that the minimum value of the supercycle length was not below the shortest achievable supercycle in Osaki (1995a), and we therefore do not need to assume an additional mechanism, as in RZ LM$\phi$ (Osaki 1995b).

### 3.3. Normal Outbursts

Another important problem concerning the behavior of ER UMa is the correlation between the length of the supercycle and the number of normal outbursts within it. For systems with a high mass-transfer rate (like ER UMa), both the waiting time for normal outbursts ($T_n$) and the waiting time for superoutbursts ($T_s$) are approximately proportional to $M^{-1}$ (Osaki 1995b). In this case $T_n / T_s$ does not depend on $M$, and the number of normal outbursts between two successive superoutbursts should be constant according to the model of ER UMa stars proposed by Osaki (1995a). However, as mentioned in subsection 2.3, ER UMa shows two types of normal outburst phase: a phase with 3–4 normal outbursts observed and the other phase with more than 4. In the Type L phase presented in figure 2, ER UMa underwent four normal outbursts (marked with an arrow), which occurred once a week. In figure 3 five normal outbursts can be seen; moreover, in the second supercycle the 6-th normal outburst near JD 2449824 was likely to be unobserved because of the gap between the observations. The time intervals between two subsequent normal outbursts
were 4 days. In figures 4 and 6, filled circles correspond to the supercycles with the Type S normal outburst phase and open circles to supercycles with the Type L phase. If it was impossible to determine the type of the phase within the supercycle, we marked them with a cross. It can be seen from these plots that there is no strong correlation between the normal outburst phase and the length of the supercycle. Types L and S were observed in any value of the supercycle length. Bends on the $O-C$ diagram, or shifts of the supercycle period, did not affect the number of normal outbursts. Apparently, there should be some additional factor that is responsible for the change in the normal outburst phases. Osaki and Kato (2013) and Ohshima et al. (2012) suggested that the type of phase may depend on the absence or presence of negative superhumps. This possibility is discussed in the following subsection.

3.4. Negative Superhumps and Outburst Behavior

Negative superhumps are believed to arise from the precession of a tilted accretion disk; nevertheless, the origin of the disk tilt is still being debated. In such cases, the hot spot appears not only at the disk’s rim, but also deeper in the primary’s potential. Montgomery and Martin (2010) proposed a mechanism based on the hydrodynamic lift. Differences between the supersonic velocities of the accretion flow under and below the disk cause an appearance of the lift force, and make the disk tilted when the mass transfer is high. The accretion stream can thus reach the inner parts of the accretion disk. An interaction of the magnetic field with the rotating plasma was also suggested as a possible source of the disk tilt (Murray & Armitage 1998; Murray et al. 2002; Smak 2009). A disk tilt is likely to affect the outburst behavior of SU UMa stars, and it is very important to study the correlation between the presence of negative superhumps (as an indicator of the disk tilt) and the outburst activity. In 2011 it became clear that persistent negative superhumps in ER UMa were observed even during the superoutburst (Ohshima et al. 2012) while a retrospective search for the literature and for the available data suggests that they were absent in the past. Kato and Kunjaya (1995) in their discovery paper reported the detection of positive superhumps in ER UMa. No negative superhumps, which are considered as a characteristic feature of ER UMa in the present state, were observed by them in 1994. The first possible detection of negative superhumps in ER UMa was claimed by Gao et al. (1999), but their amplitudes were smaller than that given in Ohshima et al. (2012), and it is likely that, even if negative superhumps did exist in 1998, they were not as strong in 1998 as in 2011. Since then the presence of superhumps with a period less than the orbital one was confirmed by Zhao et al. (2006) and Kjurkchieva and Marchev (2010). In our retrospective study we also confirmed the presence of negative superhumps in 2010 in the AAVSO data. It appears likely that negative superhumps have been present since 2006.

3.5. Correlation with Normal Outburst Phase

The TTI theory suggests that a mass-transfer to a tilted disk is expected to reduce the number of normal outbursts (Osaki & Kato 2013). Since the accretion stream in such cases can reach the inner parts of the disk, material is accumulating not primarily on the disk’s rim. This leads to a reduction of “outside-in” outbursts. Here, we examine the correlation between the normal outburst phase and the presence of negative superhumps. In figure 4 we mark the type of superhumps observed by the above-mentioned authors. One can see that the presence of negative superhumps seems to depend strongly on the phase of the normal outbursts. The first possible detection of negative superhumps was near $E = 44$ in figure 4 when the first L stage was observed. The next one, claimed by Zhao et al. (2006), was on 2004 February 29, which corresponds to $E = 88$, just at the transition from the S to L phases. Negative superhumps observed by Kjurkchieva and Marchev (2010) in 2010 were in $E = 119$ on the diagram, and also at the beginning of the L phase. According to the detailed light curves of ER UMa, provided by the observational campaign of the VSNET collaboration (Kato et al. 2004), negative superhumps have been observed since the 2011 ($E = 135$), and four normal outbursts occurred within each supercycle. This confirms that the phase of the normal outbursts can be strongly affected by the presence of negative superhumps, which can indeed reduce the number of normal outbursts. We can thus now assume that the Type L phase can be regarded as a “negative superhump” phase.

3.6. Correlation with the Supercycle Length

According to figure 4, positive and negative superhumps were observed both on the descending and ascending branches of the $O-C$ diagram, and they do not correlate with the supercycle length. Negative superhumps have been without doubt observed since 2011. During this period $O - C$ took a bend near $E = 150$, but it had no effect on the presence of negative superhumps. In the TTI model, the next superoutburst occurs when the disk stores a certain amount of angular momentum ($J_{\text{crit}}$), and the supercycle is not expected to change if $J_{\text{crit}}$ from the secondary is constant, regardless of the point of the accretion on the disk. A disk tilt is therefore not expected to affect the supercycle length, and our analysis confirmed this expectation.

4. Conclusions

In the present work we examined data from observations of ER UMa during a period of ~20 years. We followed the evolution of the change in the supercycle length, the behavior of normal outbursts, and the type of superhumps observed. We found the oscillations of the supercycle length to be superimposed by a secular increasing trend, and associated it with a gradual change of the mass-transfer rate in the binary system. The estimated period derivative was $dT_s/T_s = 6.7(6) \times 10^{-4}$. We also found that ER UMa shows two types of normal outburst phase: 3–4 normal outbursts within the supercycle and 5 or more. We also examined possible correlations between the supercycle length, the normal outburst phase, and the presence of negative superhumps, and found a strong dependence of the last two on each other. A reduced number of normal outbursts was observed when negative superhumps were detected. This confirms an assumption of Osaki and Kato (2013), that negative superhumps tend to suppress the normal outbursts. No correlation between the length of the supercycle and other characteristics was found.
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