Long-Term Monitoring of the Short Period SU UMa-Type Dwarf Nova, V844 Herculis

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Abstract

We report on the time-resolved CCD photometry of four outbursts of a short-period SU UMa-type dwarf nova, V844 Herculis. We successfully determined the mean superhump periods to be 0.05584(64) d, and 0.055883(3) d for a 2002 May superoutburst, and a 2006 April–May superoutburst, respectively. During the 2002 October observations, we confirmed that the outburst was a normal outburst, which was the first recorded normal outburst in V844 Her. We also examined superhump period changes during the 2002 May and 2006 April–May superoutbursts, both of which showed an increasing superhump period over the course of the plateau stage. In order to examine the long-term behavior of V844 Her, we analyzed archival data over the past ten years since the discovery of this binary. Although photometry is not satisfactory for some superoutbursts, we found that V844 Her showed no precursors or rebrightenings. Based on the long-term light curve, we further confirmed that V844 Her has shown almost no normal outbursts despite the fact that the supercycle of the system is estimated to be about 300 d. In order to explain the long-term light curves of V844 Her, evaporation in the accretion disk may play a role in the avoidance of several normal outbursts, which does not contradict with the relatively large X-ray luminosity of V844 Her.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (V844 Herculis) — stars: novae, cataclysmic variables — stars: oscillations

1. Introduction

Dwarf novae belong to a subclass of cataclysmic variable stars that consist of a white dwarf (primary) and a late-type star (secondary). The secondary star fills its Roche lobe and transfers mass to the primary via the inner Lagrangian point (L1), and the transferred matter forms an accretion disk (for a review, see Warner 1995; Osaki 1996; Hellier 2001). Among dwarf novae, there exist three subtypes based on their light curves. SU UMa-type dwarf novae, whose orbital period are shorter than 0.1 d in most cases, are one of the subtypes, characteristic of exhibiting two types of outbursts. One is a normal outburst, continuing for a few days. The other is a superoutburst, lasting for about two weeks,
The time-resolved CCD photometry during the outburst was performed from 2002 May 20 to 2006 May 20 using 10–100 cm telescopes at 8 sites. The log of these observations is summarized in table 1. The list of observers is given in table 2.

In total, we observed V844 Her for 31 nights, during which modulations, called superhumps, occur. The periods of superhumps are a few percent longer than that of the orbital period of the system. This is well explained by a phase-dependent dissipation of a tidally deformed precessing accretion disk. The most acceptable model for SU UMa stars is a thermal–tidal instability model developed by Osaki (1989), well reproducing the majority of observations.

V844 Her was discovered by Antipin (1996) as a variable star near η Her. Antipin (1996) classified the variable, originally named Var 43 Her, as a dwarf nova based on the detection of a long outburst. The light curve in Antipin (1996) is reminiscent of a superoutburst of SU UMa-type dwarf novae. Time-resolved CCD photometry was performed by Kato and Uemura (2000) during the 1999 September outburst of V844 Her. Detecting superhumps with a period of 0.05392(2) d, they firstly confirmed the SU UMa nature of V844 Her. By radial velocity studies Thorstensen et al. (2002) determined 0.054643(7) d (78.69 min) as being the orbital period of the system. These results indicate that V844 Her is one of the shortest periods among dwarf novae ever known. In order to thoroughly investigate the short-period system, the VSNET Collaboration placed V844 Her as one of the highest priorities since the confirmation of the SU UMa nature of the system. In 2002 May, 2002 October, and 2003 October, V844 Her underwent an outburst and the VSNET Collaboration detected superhumps during these superoutbursts.

On 2004 April 26, Pavol A. Dubovsky reported a brightening of V844 Her (12.4 mag) to the VSNET ([vsnet-alert 8914]). Thanks to this prompt report, as well as to the seasonal condition of V844 Her (the precise coordinates are RA: 16°25′00.175, Dec: +39°09′26.4′, Adelman-McCarthy et al. 2006), we firstly succeeded to observe almost the whole superoutburst of V844 Her. The object is identical with USNO A2.0 1275-8931436 (B = 16.9, R = 16.2). The infrared counterpart of the binary is 2MASS J16250181+3909258 (Hoard et al. 2002; Imada et al. 2006a). V844 Her is also cataloged as a bright X-ray source by ROSAT, 1RXS J162501.2+390924 (Voges et al. 1999).

### Table 1. Log of observations.

| Date       | HDJ start* | HDJ end* | Exposure| N  | ID  |
|------------|------------|----------|---------|----|-----|
| 2002 May   | 52415.0264 | 52415.2657 | 10      | 1051 | KOYO |
| 2002 October | 52571.8704 | 52571.9989 | 30      | 122  | Kyoto |
| 2003 October | 52939.8714 | 52939.9845 | 30      | 185  | Kyoto |
| 2003 November | 52944.8663 | 52944.9188 | 30      | 65   | Kyoto |
| 2004 May   | 53851.0347 | 53851.1642 | 30      | 235  | Njh  |
| 2006 April | 53851.1864 | 53851.2948 | 30      | 278  | Kyoto |
| 2006 May   | 53851.2312 | 53851.3075 | 30      | 124  | Mih  |
| 2006 May   | 53853.0088 | 53853.3080 | 30      | 533  | Kyoto |
| 2006 May   | 53854.0403 | 53854.1606 | 30      | 221  | Njh  |
| 2006 May   | 53854.1103 | 53854.2534 | 30      | 408  | Mih  |
| 2006 May   | 53854.1183 | 53854.3170 | 30      | 373  | Kyoto |
| 2006 May   | 53855.4640 | 53855.5378 | 30      | 107  | PD   |
| 2006 May   | 53856.1070 | 53856.2445 | 30      | 506  | Mih  |
| 2006 May   | 53856.3050 | 53856.5867 | 30      | 343  | PD   |

### Table 2. List of observers.

| ID          | Observer     | Sites   | Telescopes |
|-------------|--------------|---------|------------|
| KM          | K. Morikawa  | Okayama | 25 cm      |
| KV          | S. Oizumi    | Kagoshima | Japan 100 cm |
| Kyoto       | A. Imada     | Tokyo   | 40 cm      |
| Mih         | H. Maehara   | Saitama | 25 cm      |
| Njh         | K. Nakajima  | Mie     | 25 cm      |
| OUS         | K. Tanabe    | Okayama | 10 cm      |
| PD          | P. A. Dubovsky | Kolonica Saddle, Slovakia | 15 cm |
| RIKEN       | K. Torii     | Saitama | 25 cm      |

* Start and end times of the observation, HDJ − 2400000.
† Exposure time in seconds.
§ Number of frames.
¶ ID of the observers. See table 2.

Footnotes:
- Observer S. Oizumi, H. Yamamoto, S. Tanada, T. Yasuda, Y. Arao, K. Kodama, M. Suzuki, and T. Matsuo.
- Observer A. Imada, K. Kubota, K. Sugiyasu, and T. Kato.

2. Observations
to 15037, which is the largest data ever obtained for V844 Her.

After subtracting a dark-current image from the original CCD frames, flat fielding was performed in the usual manner. The images obtained by Mhh and KU were processed by the task apphot in IRAF. 1 Kyoto, OUS, RIKEN, and Okayama data were analyzed by aperture photometry using Java-based software developed by one of the authors (TK). Data of Mie were analyzed using FitsPhot4.1.2 The Maxim DL 3 and the task apphot in IRAF. 1 Kyoto, OUS, RIKEN, and Okayama sites, the magnitude was adjusted to that of the Kyoto system, except for the 2006 observations, for which the magnitude was shifted by 0.3 mag. After correcting any systematic differences between sites, the magnitude was adjusted to that of the Saitama system. As comparison stars, USNO A2.0 1275-8932542 (RA: 16°25′31.25″, Dec: +39°12′07″/6, V = 12.334, B − V = 0.662) were used for the Kyoto and Saitama systems, respectively (Henden & Honeycutt 1997), 5 whose constancy was checked by the local stars in the same images. A heliocentric correction was applied to the observation times before the following analyses.

3. Results

3.1. 2002 May Outburst

The light curve obtained during the 2002 May outburst is presented in figure 1. The magnitude declined linearly at a rate of 0.13(1) mag d −1 until HJD 2452420, after which the system remained almost constant magnitude until the end of our run. Such a halt is sometimes observed in other SU UMa-type dwarf novae (e.g., V1028 Cyg, Baba et al. 2000. For a comprehensive review, see Kato et al. 2003). Regarding HJD 2452425, 12 d after the detection of the outburst, V844 Her likely entered a rapid decline stage, when the visual magnitude was fainter than 15.

Figure 2 shows representative light curves during the plateau phase after removing daily decline trends for each run. Rapid rises and slow declines, characteristic of superhumps, are visible. In order to estimate the superhump period, we applied the phase dispersion minimization (PDM, Stellingwerf 1978) method to the prewhitened light curves during the plateau stage. We determined 0.05584(64) d as being the best estimated period of the superhump. The error of the resulting period was estimated using the Lafter–Kinman class of methods as applied by Fernie (1989). The obtained superhump period was in good agreement with previous studies (Kato & Uemura 2000; Thorstensen et al. 2002).

We extracted the maximum times of superhumps calibrated mainly by eye. Table 3 shows the timings of the superhump maxima. A linear regression to the observed times yields the ephemeris in the following equation:

\[ \text{HJD}(\text{max}) = 2452415.0424(15) + 0.055857(23) \times E \]

where \( E \) is the cycle count of the maximum timings of the superhumps, and the values within the parentheses on the right

![Fig. 1. Obtained light curve during the 2002 May outburst. The abscissa and the ordinate denote the fractional HJD and the magnitude, respectively. The bottom triangle means the negative observation. The light curve shows no sign of a precursor.](https://academic.oup.com/pasj/article-abstract/59/3/643/1405680/fig1)

![Fig. 2. Representative light curves obtained during the 2002 May superoutburst. The vertical and the horizontal axes denote the fractional HJD and differential magnitude, respectively. For the purpose of a comparison between nights, the light curve on HJD 2452419 (May 24) was shifted by 0.3 mag.](https://academic.oup.com/pasj/article-abstract/59/3/643/1405680/fig2)

### Table 3. Timings of superhump maxima during the 2002 May superoutburst.

| E | HJD † | O − C | Error ‡ | ID |
|---|---|---|---|---|
| 0 | 2415.0431 | 0.000700 | 0.001 | KM |
| 1 | 2415.1019 | 0.003641 | 0.001 | KM |
| 3 | 2415.2110 | 0.001023 | 0.001 | KM |
| 22 | 2416.2681 | −0.003195 | 0.003 | Kyoto |
| 72 | 2419.0634 | −0.000839 | 0.001 | KM |
| 73 | 2419.1189 | −0.001198 | 0.002 | KM |
| 74 | 2419.1754 | −0.000557 | 0.002 | KM |
| 75 | 2419.2281 | −0.003716 | 0.002 | KM |
| 129 | 2422.2523 | 0.004105 | 0.003 | Kyoto |

† Cycle count.
‡ HJD−2450000.
§ In units of day.

1 IRAF (Image Reduction and Analysis Facility) is distributed by US National Optical Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with National Science Foundation.

2 [http://www.geocities.jp/nagai_kazuo/dload-1.html](http://www.geocities.jp/nagai_kazuo/dload-1.html).

3 [http://www.cyanogen.com/products/maxim_main.htm](http://www.cyanogen.com/products/maxim_main.htm).

4 [http://integral.physics.muni.cz/cmunipack/](http://integral.physics.muni.cz/cmunipack/).

5 [ftp://ftp.aavso.org/public/calib/](ftp://ftp.aavso.org/public/calib/).
Fig. 3. $O - C$ diagram of the superhump maxima. The $O - C$ was calculated against equation (1). The dashed curve is the best-fitting quadratic described in equation (2). Note that the superhump period increased as the superoutburst proceeded.

Fig. 4. Light curve during the 2002 October outburst. The vertical and the horizontal axes denote the magnitude and HJD, respectively. The filled circles show the nightly averaged magnitudes. The error bars mean the standard error for each day. The open circles show visual observations. The bottom triangles show the negative observations.

handed side of the equation denote the 1 $\sigma$ error, respectively. Using the above equation, we derived the $O - C$ diagram illustrated in figure 3, in which the dashed line means the best-fitting quadratic equation, as follows:

$$O - C = 1.52(0.99) \times 10^{-3} - 1.37(0.40) \times 10^{-4} \times E$$
$$+ 1.24(0.34) \times 10^{-6} \times E^2.$$  

The quadratic term yields $P_{\text{dot}} = \dot{P}/P = 4.4(1.2) \times 10^{-5}$, indicating that the superhump period increases throughout the superoutburst. Because of the apparent sparse data listed in table 3, it is likely that the obtained value might include a large uncertainty. Nevertheless, we can conclude that a conspicuous increase occurred in the superhump period during the plateau stage.

3.2. 2002 October Outburst

Figure 4 shows a light curve of our run during the 2002 October outburst. The outburst was caught on HJD 2452571, when the visual magnitude of V844 Her was about 12.5. Our observations started one night after a detection, when the mean magnitude was about 13.3. Using the data obtained on the first two nights, we determined the mean decline rate to be 1.20(1) mag d$^{-1}$. The value is large for the plateau stage of a superoutburst in SU UMa-type dwarf novae. On HJD 2452575, V844 Her faded to 17 mag, which is almost the same value as that of the quiescent magnitude. Based on the negative observation on HJD 2452570, we can estimate that the duration of the outburst was at most 5 d.

Figure 5 represents the de-trended, enlarged light curves taken on the first two nights. Interestingly, one can see hump-like profiles on 2002 October 25 (HJD 2452573) with an amplitude as large as 0.4 mag. They are, however, definitely not superhumps, since three peaks are detectable with an amplitude of $\sim$ 0.4 mag during the 0.06 d run. These results indicate that this outburst was the normal outburst. This is the first recorded normal outburst of V844 Her.
3.3. 2003 October Outburst

Figure 6 displays the overall light curves during the 2003 outburst of V844 Her. The duration of the outburst appeared to be about 2 weeks. The decline rate was 0.12(1) mag d\(^{-1}\) until HJD 2452945, which is a typical value for a SU UMa-type dwarf novae. Due to the absence of observations between HJD 2452945 and HJD 2452951, we cannot specify whether there was a phase of constant magnitude, as was observed in the 2002 May superoutburst. After the plateau stage, V844 Her entered a rapid decline phase around HJD 2452956, and the magnitude returned to its quiescent level on HJD 2452958. No rebrightenings were observed during our run. Due to lack of our observations, we were unable to trace the superhump period change and whether a precursor was present.

3.4. 2006 April Outburst

3.4.1. Light curve

The whole light curve of the 2006 April–May outburst is shown in figure 7. The duration of the plateau phase was about 2 weeks. The magnitude declined almost constantly at a rate of 0.15(1) mag d\(^{-1}\) from HJD 2453851 to HJD 2453860, after which a magnitude kept almost constant at the end of the plateau stage. On HJD 2453867, V844 Her became faint with the magnitude of 16.5. There were no evidence provided of any rebrightening during our run.

3.4.2. Superhump

Figure 8 shows enlarged light curves on the first two days of our observations. There were no signals of superhumps on HJD 2453851, while there were hump-like modulations on HJD 2453853. However, their profile suggested that superhumps had not yet fully grown. We thus suppose that the superhumps were detected from HJD 2453854.

We performed a period analysis using 7554 points between HJD 2453854 and HJD 2453864, after subtracting the linear declining trend. The theta diagram of the PDM analysis provides the best estimated period of 0.055883(3) d. This value is in good accordance with that obtained during the 2002 May superoutburst.

Figure 9 indicates the daily averaged light curves during the plateau phase folded by 0.055883(3) d. A rapid rise and slow decline are typical features of superhumps. The data obtained on April 28 (HJD 2453854) showed superhumps with an amplitude of 0.2 mag, and then the superhump amplitude gradually decreased. A hint of superhump regrowth can be
seen on May 5 (HJD 2453861).

3.4.3. Superhump period change

The superhump maximum timings measured by eye are listed in Table 4. A linear regression yields the following equation on the superhump maximum timings:

\[ \text{HJD}(\max) = 2453854.1284(14) + 0.055885(18) \times E. \] (3)

The obtained \( O - C \) diagram is exhibited in Figure 10. For \(-1 < E < 128\), the best fitting quadratic equation is given by

\[ O - C = 6.6(0.9) \times 10^{-3} - 3.88(0.34) \times 10^{-4} \times E \]
\[ + 3.05(0.27) \times 10^{-6} \times E^2. \] (4)

This equation yields \( P_{\text{d}} \approx 10.9(1.0) \times 10^{-3} \), meaning that the superhump period increases through the superoutburst.

3.5. Distance and X-Ray Luminosity

It is well known that an accurate estimation of the distance to the dwarf novae is not easy. Nevertheless, we can roughly estimate it using an empirical relation derived by Warner (1987) as follows:

\[ M_V = 5.64 - 0.259P, \] (5)

where \( M_V \) is the absolute magnitude at the maximum during a normal outburst, and \( P \) is the orbital period of the system in units of hour. The above equation could be applied for the systems which have a low inclination and do not reach the period minimum. Based on the previous investigations by Thorstensen et al. (2002), both conditions can be satisfied for V844 Her. Substituting \( P = 1.3115 \) into equation (5) and with a little algebra (here we assume that the maximum \( V \) magnitude of V844 Her is 12.6), we roughly derived \( d = 290(30) \) pc as an estimated distance.

Using the obtained distance, we can also estimate the X-ray luminosity of V844 Her following the same manner as Verbunt et al. (1997), who showed that the ROSAT PSPC countrate in channel 52–201 corresponds to a flux in the 0.5–2.5 keV bandpass given by

\[ \log F_{0.5-2.5}\text{keV} \left( \text{erg cm}^{-2}\text{s}^{-1} \right) \sim \log cr_{52-201}\left( \text{s}^{-1} \right) - 10.88, \] (6)

where \( cr_{52-201} \) denotes the countrate in channel 52–201. With a little algebra, we can obtain the X-ray luminosity between 0.5–2.5 keV is \( 10^{31.0 \pm 0.2} \) erg s\(^{-1}\). Although the observed X-ray luminosity will be affected by some effects, including the inclination of the system, the derived value is relatively

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Table 4. Timings of the superhump maxima during the 2006 April superoutburst.

| \( E^* \) | \( \text{HJD}^\dagger \) | \( O - C \) | Error$^\ddagger$ | ID |
|---|---|---|---|---|
| -18 | 3853.1201 | -0.002163 | 0.006 | Kyoto |
| -17 | 3853.1723 | -0.005885 | 0.007 | Kyoto |
| -16 | 3853.2292 | -0.004846 | 0.005 | Kyoto |
| -15 | 3853.2893 | -0.000638 | 0.005 | Kyoto |
| -1 | 3854.0782 | 0.005781 | 0.004 | Njh |
| 0 | 3854.1351 | 0.006789 | 0.001 | Mhh |
| 1 | 3854.1354 | 0.007089 | 0.002 | Njh |
| 1 | 3854.1356 | 0.007289 | 0.002 | Kyoto |
| 1 | 3854.1904 | 0.006298 | 0.002 | Kyoto |
| 2 | 3854.1905 | 0.006298 | 0.002 | Mhh |
| 2 | 3854.2495 | 0.009506 | 0.005 | Kyoto |
| 3 | 3854.3027 | 0.006815 | 0.003 | Kyoto |
| 36 | 3856.1368 | -0.003606 | 0.002 | Mhh |
| 37 | 3856.1901 | -0.006098 | 0.002 | Mhh |
| 41 | 3856.4149 | -0.004964 | 0.003 | PD |
| 42 | 3856.4693 | -0.006456 | 0.009 | PD |
| 43 | 3856.5204 | -0.011247 | 0.006 | PD |
| 70 | 3858.0322 | 0.008419 | 0.019 | Njh |
| 91 | 3859.0950 | -0.001610 | 0.009 | Njh |
| 72 | 3858.1442 | -0.008202 | 0.004 | Njh |
| 73 | 3858.1470 | -0.005502 | 0.004 | Kyoto |
| 74 | 3858.2022 | -0.006193 | 0.004 | Kyoto |
| 89 | 3859.0978 | -0.004858 | 0.005 | Mhh |
| 90 | 3859.0984 | -0.004158 | 0.005 | Njh |
| 91 | 3859.1539 | -0.004550 | 0.003 | Mhh |
| 92 | 3859.1570 | -0.001550 | 0.005 | Kyoto |
| 93 | 3859.2111 | -0.002837 | 0.003 | KU |
| 92 | 3859.2699 | -0.000078 | 0.002 | KU |
| 93 | 3859.3239 | 0.001807 | 0.005 | KU |
| 108 | 3860.1624 | -0.002097 | 0.008 | Kyoto |
| 109 | 3860.1670 | 0.003014 | 0.002 | KU |
| 110 | 3860.2242 | 0.003811 | 0.010 | Kyoto |
| 125 | 3861.1191 | 0.004446 | 0.007 | Kyoto |
| 126 | 3861.1212 | 0.007165 | 0.003 | KU |
| 108 | 3861.1706 | 0.000555 | 0.012 | Kyoto |
| 127 | 3861.1714 | 0.000755 | 0.003 | Mhh |
| 128 | 3861.2305 | 0.004063 | 0.004 | Mhh |
| 128 | 3861.2889 | 0.007209 | 0.003 | KU |

$^*$ Cycle count.
$^\dagger$ HJD–2450000.
$^\ddagger$ In units of day.
large compared to other SU UMa-type dwarf novae given by Verbunt et al. (1997).

4. Discussion

4.1. Superhump Period Change

Historically, the superhump period had been known to decrease during the course of a superoutburst before the tidal instability was discovered (Haefner et al. 1979; Vogt 1983). The decrease of the superhump period was ascribed to shrinkage of the disk radius, or simply a natural consequence of mass depletion from the accretion disk (Osaki 1985). Recently, particularly over the past decade, the picture has been altered since numerous systems showed an increase of the superhump period. Such systems are mainly WZ Sge-type dwarf novae, and SU UMa-type dwarf novae with short orbital periods (Semeniuk et al. 1997; Nogami et al. 1998; Baba et al. 2000; Ishioka et al. 2001; Uemura et al. 2002; Olech 2003; Nogami et al. 2004; Imada et al. 2005; Templeton et al. 2006). Observationally, there appears to be a borderline around $P_{\text{sh}} = 0.063$ d, below which the superhump period tends to increase (Imada et al. 2005).

Figure 11 illustrates the superhump period derivative against the mean superhump period of SU UMa-type dwarf novae. The value for V844 Her is pointed out with the filled circles. In figure 11, V844 Her is likely to lie in the general trend. Hence, we firstly confirmed that V844 Her showed the positive $P_{\text{dot}}$ derivative and became the shortest period SU UMa-type dwarf nova that was confirmed to exhibit an increase of the superhump period. Additionally, we should briefly note on figure 10, where one can see data points deviated from the quadratic equation (4), corresponding to $E \sim -20$. Recent CCD photometry indicates that this feature is observed not only for V844 Her, but also for other short-period SU UMa-type stars exhibiting a positive $P_{\text{dot}}$. The systems include ASAS 102522–1542.4 (H. Maehara et al. in preparation), FL TrA (Imada et al. 2006b), ASAS 160048–4846.2 (Imada & Monard 2006; A. Imada et al. in preparation). Theoretical models suggest a dramatic variation in the temperature or pressure in the accretion disk is a possible cause of the superhump period change in this stage (Murray 1998; Montgomery 2001; Pearson 2006). We require further samples in order to discuss the nature of the superhump period change at this early stage.

4.2. On the Nature of V844 Her

It is well known that SU UMa-type dwarf novae show two types of superoutbursts: superoutbursts with a precursor, and superoutbursts without a precursor, though a precursor-main superoutburst is hardly observed. For superoutbursts without a precursor, a handful of systems, especially archetype TOADs WX Cet and SW UMa, show three types of superoutburst: a short superoutburst with a duration as short as 10 days, an intermediate superoutburst continuing for 2 weeks, and a long superoutburst lasting longer than 20 d (Howell et al. 1995). In the case of V844 Her, all three superoutbursts reported here lasted about 2 weeks, suggesting that these superoutbursts belong to the intermediate category, or V844 Her simply lies in the majority of SU UMa-type dwarf novae.

In order to examine whether V844 Her shows other types of superoutbursts, we extracted the observations reported to AAVSO and VSNET since the 1996 discovery. Table 5 summarizes the recorded outbursts of V844 Her, from which we can properly give a constraint on the durations of outbursts. As can be noticed in table 5, no superoutburst provides evidence for a duration longer than 20 d, and the durations of the superoutbursts appear to converge to 2 weeks. From the archives, we newly discovered two facts. One is that V844 Her shows no precursor. Of course we have overlooked the onset of the superoutburst in a few cases, for which we cannot specify further evidence.

| Date          | Duration | Type | Precursor |
|---------------|----------|------|-----------|
| 1996 October  | $7 < T < 20$ | S   | ×         |
| 1997 May      | $T = 15$  | S   | ×         |
| 1998 December | $8 < T < 19$ | S   | ?         |
| 1999 September| $14 < T < 16$ | S   | Δ         |
| 2000 July     | $16 < T < 17$ | S   | ×         |
| 2001 August   | $16 < T < 18$ | S   | ×         |
| 2002 May      | $12 < T < 15$ | S   | ×         |
| 2002 October  | $5 < T < 6$  | N   | –         |
| 2002 December | $10 < T < 18$ | S   | ?         |
| 2003 May      | $3 < T < 5$  | N   | –         |
| 2003 October  | $12 < T < 16$ | S   | ?         |
| 2005 January  | $14 < T < 16$ | S   | Δ         |
| 2006 April    | $15 < T < 18$ | S   | ×         |

* S : Superoutburst. N : Normal outburst. × : No precursor. Δ : Probably no precursor. ? : Unable to discern the type of superoutburst.
the type of superoutburst. However, the absence of a precursor has been confirmed in the most cases of the superoutbursts by virtue of the amateur observers. The other is that no rebrightenings have been observed in V844 Her, despite careful monitoring of the system since the 1996 discovery (Antipin 1996). Recent extensive studies over the past decades suggest that rebrightenings tend to occur among SU UMa-type dwarf novae with short orbital periods (Kuulkers et al. 1996; Imada et al. 2006b).

The most interesting fact is, although it has been mentioned for a long time, that V844 Her shows almost no normal outbursts (Kato & Uemura 2000; Thorstensen et al. 2002). From the viewpoint of the original thermal–tidal instability model, normal outbursts occur more frequently as the mass-transfer rate from the secondary increases (Osaki 1989, 1995). Further, the optical spectrum of V844 Her suggests a relatively high mass-transfer rate (Szkody et al. 2005), which accelerates a circulation on the limit cycle in the $\Sigma$–$T$ diagram. From table 5, the supercycle of V844 Her is estimated to be about 300 d, which is in agreement with previous work (Kato & Uemura 2000). When compared to the other systems having similar supercycles, e.g., Z Cha, the peculiarity of V844 Her becomes very clear with respect to the absence of normal outbursts.

Although we cannot draw a firm conclusion against the infrequent normal outbursts, one possibility is that evaporation in the accretion disk is working well, so that a hole is created in the inner region of the disk and avoids an outburst (Meyer & Meyer-Hofmeister 1994; Liu et al. 1995; Lasota et al. 1995; Hameury et al. 1997; Mineshige et al. 1998). The model also suggests large X-ray luminosity (Lasota et al. 1995) and expansion of the accretion disk during quiescence (Mineshige et al. 1998). As for the former, the relatively large X-ray luminosity of V844 Her may be suggestive of evaporation. The latter should be investigated by peak-separation studies during quiescence.

5. Conclusions

In this paper, we have reported on time-resolved CCD photometry during 2002 May, 2002 October, 2003 October, and 2006 April outbursts, of which three were superoutburst. We estimated mean superhump periods of 0.05584(64) d for 2002 May and 0.055883(3) d for 2006 April superoutbursts, respectively. We successfully examined the superhump period change during the 2002 May and 2006 April superoutbursts. The resultant period derivatives showed an period increase of superhumps during the plateau stages in both superoutbursts, which we confirmed in V844 Her for the first time. We also derived the distance to V844 Her to be 290(30) pc. Using this value, the X-ray luminosity between 0.5 and 2.5 keV is estimated to be $10^{31.0\pm0.2}$ erg s$^{-1}$.

To appreciate the long-term behavior of V844 Her, we investigated the archival light curves since the discovery of the variable. Using the extensive data, we estimated a possible supercycle to be $\sim$ 300 d, which is in good agreement with Thorstensen et al. (2002). From the archives, it turned out that V844 Her shows neither precursors nor rebrightenings, although we cannot rule out the possibility that we missed a few events. We also confirmed that V844 Her shows almost no normal outbursts in spite of the intermediate supercycle among SU UMa-type dwarf novae. A possible explanation for the absence of a normal outburst is that the evaporation mechanism may play a role, which is consistent with the relatively large X-ray luminosity of V844 Her. In the future, the evolution of the disk radius during quiescence should be investigated in order to test our suggestion.

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References

Adelman-McCarthy, J. K., et al. 2006, ApJS, 162, 38
Antipin, S. V. 1996, IBVS, 4360
Baba, H., Kato, T., Nogami, D., Hirata, R., Matsumoto, K., & Sadakane, K. 2000, PASJ, 52, 429
Fernie, J. D. 1989, PASP, 101, 225
Haefner, R., Schoembs, R., & Vogt, N. 1979, A&A, 77, 7
Hameury, J.-M., Lasota, J.-P., & Huré, J.-M. 1997, MNras, 287, 937
Hellier, C. 2001, Cataclysmic Variable Stars: how and why they vary (New York: Springer)
Henden, A. A., & Honeycutt, R. K. 1997, PASP, 109, 441
Hoard, D. W., Wachter, S., Clark, L. L., & Bowers, T. P. 2002, ApJ, 565, 511
Howell, S. B., Szko, P., Sonneborn, G., Fried, R., Mattei, J., Oliversen, R. J., Ingram, D., & Hurst, G. M. 1995, ApJ, 453, 454
Imada, A., et al. 2005, PASJ, 57, 193
Imada, A., et al. 2006a, PASJ, 58, 143
Imada, A., Kubota, K., Kato, T., Nogami, D., Maehara, H., Nakajima, K., Uemura, M., & Ishioka, R. 2006b, PASJ, 58, L23
Imada, A., & Monard, L. A. G. B. 2006, PASJ, 58, L19
Ishioka, R., et al. 2001, PASJ, 53, 905
Kato, T., Uemura, M., Ishioka, R., Nogami, D., Kunjaya, C., Baba, H., & Yamaoka, H. 2003, PASJ, 55, 989
Kato, T., & Uemura, M. 2000, IBVS, 4902
Kato, T., Uemura, M., Ishioka, R., Nogami, D., Kunjaya, C., Baba, H., & Yamaoka, H. 2004, PASJ, 56, S1
Krzeminski, W., & Vogt, N. 1985, A&A, 144, 124
Kuulkers, E., Howell, S. B., & van Paradijs, J. 1996, ApJ, 462, L87
Lasota, J. P., Hameury, J. M., & Huré, J. M. 1995, A&A, 302, L29
Liu, F. K., Meyer, F., & Meyer-Hofmeister, E. 1995, A&A, 300, 823
Meyer, F., & Meyer-Hofmeister, E. 1994, A&A, 288, 175
Mineshige, S., Liu, B., Meyer, F., & Meyer-Hofmeister, E. 1998, PASJ, 50, L5
Montgomery, M. M. 2001, MNRAS, 325, 761
Murray, J. R. 1998, MNRAS, 297, 323
Nogami, D., Baba, H., Kato, T., & Novák, R. 1998, PASJ, 50, 297
Nogami, D., Uemura, M., Ishioka, R., Kato, T., & Pietz, J. 2004, PASJ, 56, S155
Olech, A. 2003, Acta Astron., 53, 85
Osaki, Y. 1985, A&A, 144, 369
Osaki, Y. 1989, PASJ, 41, 1005
Osaki, Y. 1995, PASJ, 47, L11
Osaki, Y. 1996, PASP, 108, 39
Pearson, K. J. 2006, MNRAS, 371, 235
Podsiadlowski, Ph., Han, Z., & Rappaport, S. 2003, MNRAS, 340, 1214
Semeniuk, I., Olech, A., Kwast, T., & Nalezyty, M. 1997, Acta Astron., 47, 201
Stellingwerf, R. F. 1978, ApJ, 224, 953
Szkody, P., et al. 2005, AJ, 129, 2386
Templeton, M. R., et al. 2006, PASP, 118, 226
Thorstensen, J. R., Patterson, J., Kemp, J., & Vennes, S. 2002, PASP, 114, 1108
Uemura, M., et al. 2002, PASJ, 54, 599
Uemura, M., et al. 2005, A&A, 432, 261
Verbunt, F., Bunk, W. H., Ritter, H., & Pfeffermann, E. 1997, A&A, 327, 602
Voges, W., et al. 1999, A&A, 349, 389
Vogt, N. 1983, A&A, 118, 95
Warner, B. 1987, MNRAS, 227, 23
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge University Press)