Superhumps of CC Cancri Revisited

Taichi Kato, Makoto Uemura, Ryoko Ishioka
Department of Astronomy, Kyoto University, Sakyoku, Kyoto 606-8502
(tkato,uemura,ishioka)@kusastro.kyoto-u.ac.jp

and

Jochen Pietz
Rostocker Str. 62, 50374 Erftstadt, Germany
Jochen.Pietz@t-online.de

(Received ; accepted )

Abstract
We observed the 2001 November superoutburst of CC Cnc. This observation makes the first detailed coverage of a superoutburst of this object. The best-determined mean superhump period is 0.075518±0.000018 d, which is 2.7% longer than the reported orbital period. This fractional superhump excess is a quite typical value for a normal SU UMa-type dwarf nova, excluding the previously raised possibility that CC Cnc may have an anomalously large fractional superhump excess. During the superoutburst plateau, the object showed a decrease of the superhump period at $P/P = -10.2±1.3 \times 10^{-5}$, which is one of the largest negative period derivative known in all SU UMa-type dwarf novae.

Key words: accretion, accretion disks — stars: dwarf novae — stars: novae, cataclysmic variables — stars: individual (CC Cancri)

1. Introduction

Dwarf novae are a class of cataclysmic variables (CVs), which are close binary systems consisting of a white dwarf and a red dwarf secondary transferring matter via the Roche lobe overflow. A class of dwarf novae, called SU UMa-type dwarf novae, show superhumps during their long, bright outbursts (superoutbursts). [For a recent review of dwarf novae and SU UMa-type dwarf novae, see Osaki (1996) and Warner (1995), respectively.] Superhumps have periods a few percent longer than the orbital periods (Vogt 1980; Warner 1985), which is believed to be a consequence of the apsidal motion of an eccentric accretion disk (Osaki 1985). The fractional superhump excess ($\epsilon = P_{\text{SH}}/P_{\text{orb}} - 1$, where $P_{\text{SH}}$ and $P_{\text{orb}}$ are superhump and orbital periods, respectively) is widely believed to be an excellent measure of the mass ratio ($q = M_2/M_1$) of the binary system both from theoretical calculations (Osaki 1985; Hirose, Osaki 1990; Lubow 1991a; Lubow 1991b; Murray 1998; Murray 2000; Wood et al. 2000; Montgomery 2001) and observations (Molnar, Kobulnicky 1992; Mineshige et al. 1992; Patterson 1998; O’Donoghue 2000). Most of SU UMa-type systems are on a tight relation (originally discovered by Stolz, Schoembs (1984) and extended by various authors, e.g. Thorstensen et al. 1996) between $P_{\text{SH}}$ and $\epsilon$, which is considered to be a natural consequence that most of CVs have non-evolved low-mass secondary stars (cf. Patterson 1984), i.e. $M_2$ is a strong function of $P_{\text{orb}}$, which mostly determines $q$.

Most recently, an SU UMa-type dwarf nova (1RXS J232953.9+062814: Uemura et al. 2001a) is found to conspicuously violate this relation (Uemura et al. 2002). Subsequent spectroscopy revealed that this object has a secondary star more massive and evolved than what is expected for the orbital period (Thorstensen et al. 2002). Departures from this $P_{\text{SH}}$ vs. $\epsilon$ relation are thus candidate systems with unusual stellar parameters.

CC Cnc [see Kato, Nogami (1997) for a historical review of this object] is one of such candidates which was reported to have a significantly large $\epsilon = 4.9 ± 0.5\%$ (Thorstenst 1997), who reported $P_{\text{orb}} = 0.07352(5)$ d. Since accurate determination of the superhump period of CC Cnc was difficult owing to unfavorable seasonal occurrences of the past superoutbursts (Kato, Nogami 1997), a further check of the superhump period throughout a superoutburst under favorable condition has been absolutely needed (Thorstenst 1997). An excellent opportunity arrived when the system underwent a superoutburst in 2001 November. This outburst enabled us to for the first time follow the entire superoutburst. The observation started within 2.5 d of the outburst detection by Mike Simonsen (visual magnitude 13.2 on November 10).

2. Observation

The observations were mainly done using an unfiltered ST-7E camera attached to a 25-cm Schmidt-Cassegrain telescope at Kyoto University. Some Kyoto observations were made using an unfiltered ST-7E camera attached to a 30-cm Schmidt-Cassegrain telescope. J. Pietz used an unfiltered ST-6B camera attached to a 20-cm reflector. All systems give magnitudes close to $R_c$. The exposure times were 30 s for Kyoto observations; Pietz used 60 s and 80 s for the November 14 and 15 observations, respectively. The images were dark-subtracted, flat-fielded, and ana-
analyzed using the Java\textsuperscript{TM}-based PSF photometry package developed by one of the authors (TK). The differential magnitudes of the variable were measured against GSC 1398.1399 (averaged GSC magnitude $V = 11.66$), whose constancy during the run was confirmed by comparison with fainter check stars in the same field. The effect of a nearby faint field star (cf. Misselt 1996) has been eliminated with the PSF fitting. The log of observations is summarized in table 1. The total number of useful frames was 5586. Barycentric corrections were applied before the period analysis. The overall light curve is shown in figure 1.

3. Results and Discussion

3.1. Mean Superhump Period and Profile

We performed period analysis using Phase Dispersion Minimization (Stellingwerf 1978) to all the data between 2001 November 12 and 19, after removing the systematic trend of decline. A correction of 0.220 mag has been added for the 2001 November 12 data in order to correct the systematic offset from the linear fit. This offset was most likely a result from a systematic difference caused by a different telescope only on this night. The resultant $\theta$-diagram and the phase averaged profile of superhumps are shown in figures 2 and 3, respectively. The best-determined superhump period is $0.075518 \pm 0.000018$ d.

3.2. Development of Superhumps

Figure 4 shows nightly averaged profiles of superhumps during the plateau stage of the superoutburst. The amplitude of superhumps reached a maximum (0.21–0.24 mag) around November 15–16, five days after the start of outburst. This development of superhumps is relatively slow compared to other SU UMa-type dwarf novae [one of the best examples can be found in Semeniuk (1980); see also Vogt (1980) and Warner (1985) for general descriptions; this delay is theoretically explained as a growth time of the tidal instability (Lubow 1991a)]. Although the phase coverage was not complete because of unfavorable sky condition, the amplitude of superhumps seems to have once decayed on November 17, and again grew on November 18. Such a regrowth of the superhump amplitude may be related to a phenomenon observed during the late stage of a superoutburst in V1028 Cyg (Baba et al. 2000). We must note that ER UMa stars (a small, peculiar subgroup of SU UMa-type dwarf novae with extremely short supercycles; presently known members being ER UMa, V1159 Ori, RZ LMi, DI UMa and IX Dra (Kato, Kunjaya 1995; Robertson et al. 1995; Nogami et al. 1995; Kato et al. 1996a; Ishioka et al. 2001a) show a similar pattern of decay and regrowth of superhumps (Kato et al. 1996b). CC Cnc, however, has a much longer supercycle ($\sim 400$ d) than those of ER UMa stars (19–45 d), indicating that CC Cnc has a much lower mass-transfer rate than in ER.
Table 1. Log of observations.

| Date            | BJD\(^*\) (start–end) | N\(^†\) | Mag\(‡\) | Error\(§\) | Inst\(∥\) |
|-----------------|------------------------|---------|----------|------------|----------|
| 2001 November 12| 52226.309–52226.368    | 90      | 1.950    | 0.010      | 1        |
| 2001 November 13| 52227.111–52227.368    | 404     | 2.315    | 0.005      | 2        |
| 2001 November 14| 52228.075–52228.369    | 690     | 2.380    | 0.004      | 2        |
| 2001 November 14| 52228.477–52228.556    | 68      | 2.401    | 0.012      | 3        |
| 2001 November 15| 52229.090–52229.366    | 475     | 2.481    | 0.004      | 2        |
| 2001 November 15| 52229.452–52229.542    | 86      | 2.362    | 0.008      | 3        |
| 2001 November 16| 52230.075–52230.375    | 476     | 2.591    | 0.005      | 2        |
| 2001 November 17| 52231.146–52231.372    | 206     | 2.663    | 0.006      | 2        |
| 2001 November 18| 52232.273–52232.377    | 245     | 2.822    | 0.007      | 2        |
| 2001 November 19| 52233.062–52233.369    | 701     | 2.979    | 0.004      | 2        |
| 2001 November 20| 52234.108–52234.375    | 625     | 3.406    | 0.005      | 2        |
| 2001 November 21| 52235.067–52235.362    | 688     | 4.383    | 0.011      | 2        |
| 2001 November 22| 52236.058–52236.375    | 747     | 5.221    | 0.029      | 2        |
| 2001 November 23| 52237.363–52237.371    | 19      | 4.969    | 0.227      | 2        |
| 2001 November 26| 52240.359–52240.377    | 43      | 5.190    | 0.086      | 2        |
| 2001 November 30| 52244.357–52244.363    | 13      | 6.783    | 1.086      | 2        |
| 2001 December 2 | 52246.323–52246.327    | 10      | 5.705    | 0.505      | 2        |

\(^*\) BJD\(−2400000\).

\(^†\) Number of frames.

\(^‡\) Averaged magnitude relative to GSC 1398.1399.

\(^§\) Standard error of the averaged magnitude.

\(∥\) 1: Kyoto (30-cm + ST-7E), 2: Kyoto (25-cm + ST-7E), 3: Pietz.

Alternately, this phenomenon seen in CC Cnc may be also interpreted as a result of the beat phenomenon between the superhump and orbital period (most evidently seen in eclipsing systems; e.g. Vogt 1982; Krzeminski, Vogt 1985), as was prominently seen even in a non-eclipsing system RZ Leo (Ishioka et al. 2001b). The calculated beat period

\[ P_{\text{beat}} = \frac{1}{1/P_{\text{orb}} - 1/P_{\text{SH}}} = 2.8 \text{ d} \]  

(1)

close to the observed time-scale of the regrowth may suggest a stronger possibility of the second interpretation. In this case, the orbital inclination of CC Cnc is expected to be high, which would provide an excellent opportunity in spectroscopically determining the component masses and other orbital parameters.

3.3. \(O-C\) Changes

We determined the maximum times of superhumps from the light curve by eye. The averaged times of a few to several points close to the maximum were used as representatives of the maximum times. The errors of the maximum times are usually less than \(\sim 0.004 \text{ d}\), which corresponds to the maximum lengths of the data bins (i.e. a few to several points) to deduce the maximum times. We did not use cross-correlation method to obtain individual maxima because the profile of superhumps was rather strongly variable (subsection 3.2). The resultant superhump maxima are given in table 2. The values are given to 0.0001 d in order to avoid the loss of significant digits in a later analysis. The cycle count \((E)\) is defined as the cycle number since Barycentric Julian Date (BJD) 2452226.322 (2001 November 12.822 UT).

A linear regression to the observed superhump times gives the following ephemeris:

\[ \text{BJD}(\text{max}) = 2452226.3315 + 0.0755135E. \]  

(2)

Figure 5 shows the \((O-C)\)’s against the mean superhump period (0.0755135 d). The diagram clearly shows the decrease in the superhump period throughout the superoutburst plateau. The times of the superhump maxima in this interval can be well represented by the following quadratic equation (the quoted errors represent 1-\(\sigma\) errors):

\[ \text{BJD}(\text{max}) = 2452230.4892(7) + 0.075531(13)(E - 55) - 3.86(50) \times 10^{-6}E^2. \]  

(3)

The quadratic term corresponds to \(P' = -7.7 \pm 1.0 \times 10^{-6} \text{ d cycle}^{-1}\), or \(P'/P = -10.2 \pm 1.3 \times 10^{-5}\). Kato et al. (2001) noted that short-period systems or infrequently outbursting SU UMa-type systems predominantly show an increase in the superhump periods in contrast to a “textbook” decrease of the superhump periods in usual SU UMa-type dwarf novae. However, observations of period changes in long \(P_{\text{orb}}\) systems are relatively lacking in the literature. Considering that the longer \(P_{\text{orb}}\) systems have larger (i.e. closer to zero) \(P'/P\) (Kato et al. 2001), or even

UMa stars. Although detailed mechanisms of regrowth is not yet identified, we consider that different mechanisms of superhump regrowth may be naturally taking place between ER UMa stars and other SU UMa-type dwarf novae.
Fig. 4. Evolution of CC Cnc superhumps during the plateau stage of the superoutburst. Each point represents an average of a 0.02 phase bin, except for November 12 data which used 0.04 phase bin. The phase zero corresponds to the zero-phase epoch of equation 2. The mean superhump period (0.075518 d) was used to calculate the phases.

virtually zero (e.g. V725 Aql: Uemura et al. 2001b; EF Peg: K. Matsumoto in preparation, see also Kato (2002)), there may be a possibility that \( \dot{P}/P \) makes a minimum around the period of CC Cnc. From a theoretical viewpoint, this decrease of superhump period is generally attributed to decreasing apsidal motion due to a decreasing disk radius (Osaki 1985), or inward propagation of the eccentricity wave (Lubow 1992). It may be possible these “intermediate period” systems like CC Cnc enable effective propagation of the eccentricity wave, although the possibility needs to be tested by future detailed fluid calculations.

3.4. Superhumps during the Rapid Decline Phase

In some SU UMa-type dwarf novae, what are called late superhumps appear during the final stage of superoutbursts. Late superhumps have similar periods with ordinary superhumps (i.e. superhumps observed during the plateau stage, subsections 3.1, 3.2), but have phases of \( \sim 0.5 \) different from those of ordinary superhumps (Haefner et al. 1979; Vogt 1983; van der Woerd et al. 1988; Hessman et al. 1992). Figure 6 shows the late-stage evolution of superhumps in CC Cnc. On November 20, the system started to decline rapidly. Ordinary superhumps were clearly present, without a hint of \( \sim 0.5 \) phase jump. On November 21, the system further faded by \( \sim 1.0 \) mag. Although the profile of variation became more irregular, the maximum phase remained close to zero, suggesting that late superhumps were weak in this system.
4. Summary

We observed the 2001 November superoutburst of the SU UMa-type dwarf nova CC Cnc. We obtained the mean superhump period of 0.075518 ± 0.000018 d, which is 2.7% longer than the orbital period. This observation excludes the previously suggested possibility that CC Cnc may have an anomalously large fractional superhump excess. The full growth of superhumps took ~5 d from the start of the superoutburst, which is relatively large for a long-period SU UMa-type dwarf nova. There was a suggestion of a regrowth of superhumps during the late plateau stage of the superoutburst, which may be interpreted as a result of the beat phenomenon. During the rapid decline stage, CC Cnc did not show prominent late superhumps. The observed superhump period change $\dot{P}/P = -10.2 \pm 1.3 \times 10^{-5}$ is one of the largest negative period derivative known in all SU UMa-type dwarf novae. This may be an indication that $\dot{P}/P$ makes a minimum around the period of CC Cnc.

We are grateful to Mike Simonsen for promptly notifying us of the outburst. This work is partly supported by a grant-in-aid (13640239) from the Japanese Ministry of Education, Culture, Sports, Science and Technology. Part of this work is supported by a Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists (MU).

References

Baba, H., Kato, T., Nogami, D., Hirata, R., Matsumoto, K., & Sadakane, K. 2000, PASJ, 52, 429
Hafner, R., Schoembs, R., & Vogt, N. 1979, A&A, 77, 7
Hessman, F. V., Mantel, K.-H., Barwig, H., & Schoembs, R. 1992, A&A, 263, 147
Hirose, M., & Osaki, Y. 1990, PASJ, 42, 135
Ishioika, R., Kato, T., Uemura, M., Iwamatsu, H., Matsumoto, K., Martin, B., Billings, G. W., & Novák, R. 2001a, PASJ, 53, L51
Ishioika, R., Kato, T., Uemura, M., Iwamatsu, H., Matsumoto, K., Stubbings, R., Mennickent, R., Billings, G. W., et al. 2001b, PASJ, 53, 905
Kato, T. 2002, PASJ, 54, 87
Kato, T., & Kunjaya, C. 1995, PASJ, 47, 163
Kato, T., & Nogami, D. 1997, PASJ, 49, 341
Kato, T., Nogami, D., & Baba, H. 1996a, PASJ, 48, L93
Kato, T., Nogami, D., & Masuda, S. 1996b, PASJ, 48, L5
Kato, T., Sekine, Y., & Hirata, R. 2001, PASJ, 53, 1191
Krzeminski, W., & Vogt, N. 1985, A&A, 144, 124
Lubow, S. H. 1991a, ApJ, 381, 239
Lubow, S. H. 1991b, ApJ, 381, 268
Lubow, S. H. 1992, ApJ, 401, 317
Mineshige, S., Hirose, M., & Osaki, Y. 1992, PASJ, 44, L15
Misaki, K. A. 1996, PASP, 108, 146
Molnar, L. A., & Kobulnicky, H. A. 1992, ApJ, 392, 678
Montgomery, M. M. 2001, MNRAS, 325, 761
Murray, J. R. 1998, MNRAS, 297, 323
Murray, J. R. 2000, MNRAS, 314, 1P
Nogami, D., Kato, T., Masuda, S., Hirata, R., Matsumoto, K., Tanabe, K., & Yokoo, T. 1995, PASJ, 47, 897
O'Donoghue, D. 2000, New Astron. Rev., 44, 45
Osaki, Y. 1985, A&A, 144, 369
Osaki, Y. 1996, PASP, 108, 39
Patterson, J. 1984, ApJS, 54, 443
Patterson, J. 1998, PASP, 110, 1132
Robertson, J. W., Honeycutt, R. K., & Turner, G. W. 1995, PASP, 107, 443
Semeniuk, I. 1980, A&AS, 39, 29
Stellingwerf, R. F. 1978, ApJ, 224, 953
Stolz, B., & Schoembs, R. 1984, A&A, 132, 187
Thorstensen, J. R. 1997, PASP, 109, 1241
Thorstensen, J. R., Fenton, W. H., Patterson, J. O., Kemp, J., Krajci, T., & Baraffe, I. 2002, ApJL, 567, L49
Thorstensen, J. R., Patterson, J. O., Shambrook, A., & Thomas, G. 1996, PASP, 108, 73
Uemura, M., Ishioika, R., Kato, T., Schmeer, P., Yamaoka, H., Starkey, D., Vannumster, T., & Pietz, J. 2001a, IAU Circ., 7747
Uemura, M., Kato, T., Ishioika, R., Yamaoka, H., Schmeer, P., Starkey, D. R., Torii, K., Kawai, N., et al. 2002, PASJ, 54, L15
Uemura, M., Kato, T., Pavlenko, E., Baklanov, A., & Pietz, J. 2001b, PASJ, 53, 539
van der Woerd, H., van der Klis, M., van Paradijs, J., Beuermann, K., & Motch, C. 1988, ApJ, 330, 911
Vogt, N. 1980, A&A, 88, 66
Vogt, N. 1982, ApJ, 252, 653
Vogt, N. 1983, A&A, 118, 95
Warner, B. 1985, in Interacting Binaries, ed. P. P. Eggelton, & J. E. Pringle (Dordrecht: D. Reidel Publishing Company), 367
Warner, B. 1995, Ap&SS, 226, 187
Wood, M. A., Montgomery, M. M., & Simpson, J. C. 2000, ApJL, 535, L39