Grazing Eclipsing Dwarf Nova CW Monocerotis: Dwarf Nova-Type Outburst in a Possible Intermediate Polar?

Taichi KATO and Makoto UEMURA
Department of Astronomy, Kyoto University, Sakyo-ku, Kyoto 606-8502
tkato@kusastro.kyoto-u.ac.jp, uemura@kusastro.kyoto-u.ac.jp

Seiichiro KIYOTA
Variable Star Observers League in Japan (VSOLJ), 1-401-810 Azuma, Tsukuba 305-0031
skiyota@nias.affrc.go.jp

Kenji TANABE, Mitsuo KOZUMI, Mayumi KIDA, Yuichi NISHI, Sawa TANAKA, Rie UEOKA, Hideki YASUI
Department of Biosphere-Geosphere Systems, Faculty of Informatics, Okayama University of Science,
Ridaicho 1-1, Okayama 700-0005
tanabe@big.ous.ac.jp

Tonny VANMUNSTER
Center for Backyard Astrophysics (Belgium), Walhostraat 1A, B-3401 Landen, Belgium
Tonny.Vanmunster@cbabelgium.com

Daisaku NOGAMI
Hida Observatory, Kyoto University, Kamitakara, Gifu 506-1314
nogami@kwasan.kyoto-u.ac.jp

and

Hitoshi YAMAOKA
Faculty of Science, Kyushu University, Fukuoka 810-8560
yamaoka@rc.kyushu-u.ac.jp

(Received ; accepted )

Abstract

We observed the 2002 October–November outburst of the dwarf nova CW Mon. The outburst showed a clear signature of a premaximum halt, and a more rapid decline after reaching the outburst maximum. On two separate occasions, during the premaximum stage and near the outburst maximum, shallow eclipses were recorded. This finding confirms the previously suggested possibility of the grazing eclipsing nature of this system. The separate occurrence of the eclipses and the premaximum halt can be understood as a result of a combination of two-step ignition of an outburst and the inside-out propagation of the heating wave. We detected a coherent short-period (0.02549 d) signal on two subsequent nights around the optical maximum. This signal was likely present during the maximum phase of the 2000 January outburst. We interpret this signal as a signature of the intermediate polar (IP) type pulses. The rather strange outburst properties, strong and hard X-ray emission, and the low luminosity of the outburst maximum might be understood as consequences of the supposed IP nature. The ratio between the suggested spin period and the orbital period, however, is rather unusual for a system having an orbital period of ~0.176 d.

Key words: accretion, accretion disks — stars: binaries: eclipsing — stars: dwarf novae — stars: individual (CW Monocerotis) — stars: novae, cataclysmic variables — stars: oscillations

1. Introduction

Dwarf novae are a class of cataclysmic variables (Warner 1995). Dwarf novae show outbursts, which are believed to be a result of the disk-instabilities in the accretion disk (Osaki 1996). The eclipses in some high-inclination dwarf novae provide a unique tool in studying the time-evolution of the geometry and physical properties of the accretion disk (e.g. Horne 1985; Wood et al. 1989; Wolf et al. 1993; Webb et al. 1999; Ioannou et al. 1999). The appearance of eclipses in grazing eclipsing systems can provide a powerful tool in studying the radius change in an outbursting disk (e.g. Smak 1984a), which is essential for distinguishing the outburst mechanisms (Ichikawa, Osaki 1992).

CW Mon was originally discovered by Ahnert (1944), whose observation (also shown in Glasby 1970) demonstrated the dwarf nova-type variability. The object was photographically studied by Wachmann (1968). The exact identification was independently studied by several authors (Vogt, Bateson 1982; Lopez 1985; Skiff 1999; Kinnunen, Skiff 2000). Bateson (1989) reported that mean outburst cycle length is ~160 d, although many outbursts must have been missed due to unavoidable seasonal gaps. Stubbings, McIntosh (1997) further presented an analysis of the outburst statistics, and concluded that CW Mon has wide and narrow outbursts, the former being ~0.5 mag brighter than the latter. Stubbings,
McIntosh (1997) proposed a mean cycle length of $\sim 150$ d with a statistical assumption of missed outbursts.

Szkody, Mateo (1986) obtained time-resolved infrared photometry of this object, and detected ellipsoidal variations attributable to a binary motion with a period of $P_{\text{orb}} = 4.23 \pm 0.01$ hr. Szkody, Mateo (1986) further noted the possible presence of a shallow fading which could be attributed to a grazing eclipse of the accretion disk. Szkody, Mateo (1986) deduced an inclination angle of $i = 65^\circ$ from the infrared light curve and the profile analysis of the Balmer emission lines. Howell, Szkody (1988) obtained an optical time-series photometry and detected a possible dip, which may be associated with an eclipse. However, the identification of the nature of the dip remained unclear because of the lack of the clearly recurring nature of this phenomenon (Howell, Szkody 1988).

From high-speed CCD photometry, Stover, Allen (1987a) reported the possible presence of an eclipse lasting for $\sim 1900$ s. Although there is a report (Stover, Allen 1987b) that these eclipses sometimes occur, especially during the state following an outburst, neither detailed nor systematic observations have yet been published.

We conducted time-resolved CCD observing campaign through the VSNET Collaboration, upon the alerts of outburst detection in 2002 October–November by D. Taylor and M. Simonsen, vsnet-outburst 4679, 4683. We also obtained some data during the 2000 January outburst, which was detected by H. McGee, vsnet-alert 3952.

## 2. Observation

The CCD observations were carried out at several sites. The instruments are given in Table 1. We mainly used GSC 146.1617 ($V = 11.75, B - V = 0.65$, Misselt 1996) as the primary comparison star, whose constancy during the observation was confirmed by a comparison with GSC 146.1362 and several fainter check stars. The Belgian observation used GSC 146.1677 (Tycho-2 $V = 11.86, B - V$.

![CW Mon outburst (2002 October - November)](image)

**Fig. 2.** Overall light curve of the 2002 October–November outburst. The large filled circles and open squares represent CCD (this observation) and visual (reported to VSNET) observations, respectively. The small dots represent upper limit visual observations. The magnitude scale was adjusted to $V$. CCD observations represent averaged magnitude in 0.05-d bins. A 0.3 magnitude was added to the visual observations in order to correct the systematic difference.

![CW Mon (2002 November 3)](image)

**Fig. 3.** Eclipse caught on 2002 November 3, when CW Mon was still before the outburst maximum. The shallow depth (0.2 mag) and the eclipse shape indicate that the eclipse was a partial one.

### Table 1. Instruments.

| Site      | Telescope | CCD     | Software       |
|-----------|-----------|---------|----------------|
| Tsukuba (T) | 25-cm SCT | AP-7    | MIRA A/P       |
| Okayama (O) | 21-cm refl. | ST-7XE  | Java*          |
| Belgium (B) | 35-cm SCT | ST-7    | AIP4WIN        |
| Kyoto (K)  | 25-cm SCT | ST-7    | Java*          |
| Hida (H)   | 60-cm refl. | SITe003AB† | IRAF       |

* See text.
† PixCellent S/T 00-3194 camera.

### Table 2. Zero points added to each set of observations.

| Date (2002) | Okayama | Belgium |
|-------------|---------|---------|
| November 5  | 11.85   | ...    |
| November 6  | 11.78   | 11.74  |
| November 9  | 12.01   | ...    |
| November 10 | 12.64   | ...    |
| November 13 | 12.16   | ...    |

1 [http://www.kusastro.kyoto-u.ac.jp/vsnet/]
2 [http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/outburst4000/msg00679.html], [http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/outburst4000/msg00683.html]
3 [http://www.kusastro.kyoto-u.ac.jp/vsnet/Mail/alert3000/msg00952.html]
Fig. 1. Long-term visual light curve of CW Mon constructed from the observations reported to VSNET. Large and small dot represent positive and negative (upper limit) observations, respectively. Outbursts rather rarely occur once in 100–200 d.

Table 3. Journal of CCD photometry.

| Date          | Start–End | Filter | Exp(s) | N   | Mean mag† | Error | Obs‡ |
|---------------|-----------|--------|--------|-----|-----------|-------|------|
| 2000 January  | 7         | 51551.299–51551.314 | none   | 30  | 36 (0.91) | 0.02  | K    |
|               | 7         | 51551.401–51551.549 | none   | 40  | 285 (0.76) | 0.01  | B    |
|               | 8         | 51552.289–51552.328 | none   | 30  | 90 (1.08)  | 0.02  | K    |
|               | 10        | 51554.056–51554.196 | $V$    | 60  | 131 12.92  | 0.01  | T    |
|               | 11        | 51555.034–51555.162 | $V$    | 60  | 101 13.01  | 0.01  | T    |
| 2002 November | 3         | 52582.106–52582.290 | $V$    | 30  | 351 13.16  | 0.01  | T    |
|               | 4         | 52583.194–52583.287 | $V$    | 30  | 203 13.24  | 0.01  | T    |
|               | 5         | 52584.097–52584.311 | $V$    | 30  | 433 12.82  | 0.01  | T    |
|               | 5         | 52584.114–52584.360 | none   | 45  | 445 (0.97) | 0.01  | O    |
|               | 6         | 52584.567–52584.748 | none   | 40  | 190 (1.06) | 0.01  | B    |
|               | 6         | 52585.090–52585.361 | none   | 45  | 492 (0.98) | 0.01  | O    |
|               | 6         | 52585.104–52585.285 | $V$    | 30  | 382 12.76  | 0.01  | T    |
|               | 9         | 52588.114–52588.277 | $V$    | 30  | 348 13.78  | 0.01  | T    |
|               | 9         | 52588.117–52588.357 | none   | 45  | 367 (1.68) | 0.01  | O    |
|               | 10        | 52589.079–52589.366 | none   | 45  | 420 (2.33) | 0.01  | O    |
|               | 10        | 52589.132–52589.252 | $V$    | 30  | 265 14.95  | 0.01  | T    |
|               | 13        | 52591.776–52591.874 | $V$    | 30  | 216 16.07  | 0.03  | T    |
|               | 13        | 52592.095–52592.142 | none   | 90  | 45 (3.91)  | 0.02  | O    |
|               | 16        | 52595.099–52595.302 | none   | 90  | 183 (4.31) | 0.01  | O    |
|               | 16        | 52595.212–52595.214 | $V$    | 90  | 3 16.40    | 0.03  | H    |

* BJD−2400000.
† Differential magnitudes to the comparison star are given in parentheses except for the Tsukuba and Hida Observations.
‡ T (Tsukuba), O (Okayama), K (Kyoto), B (Belgium), H (Hida)
Figure 4. Nightly folded light curves with a period of 0.1766 d. The zero phase is taken as BJD 2452582.180. The November 10 data represent the averages of 0.005 phase bins in order to reduce the scatter. Because of the uncertainty of the adopted period, the phases have uncertainties of ∼0.07 (November 5) to ∼0.22 (November 10).



Figure 5. Short-term variations on 2002 November 6 (around the maximum light). The upper and lower panels represent V and unfiltered (close to R_c) observations, respectively. Linear trends within the night have been subtracted from the observation. The fadings around BJD 2452584.117 and 2452584.303 are eclipses described in subsection 3.3. The short-term variations are more prominent in the V-band, which indicates that a hotter region more contributes to the variations.

3. Results

3.1. Long-Term Light curve

Figure 1 shows a long-term visual light curve of CW Mon constructed from the observations (1996–2002) reported to VSNET. Large and small dots represent positive and negative (upper limit) observations, respectively. Outbursts rather rarely occur, typically once in 100–200 d. These observations generally confirmed the results by Stubbings, McIntosh (1997).

3.2. Course of the 2002 October–November Outburst

The 2002 October–November outburst was first detected on October 29.378 UT at a visual magnitude of 14.4. The object was not seen in outburst on October 28 by three independent observers (VSNET observations). The object further brightened to a visual magnitude of...
12.9 on October 31.315 UT. These observations indicate that the object was caught during its earliest rising stage. We define October 29.378 as $t = 0$.

Subsequent CCD observations (table 3) showed a “pre-maximum halt” until November 4 ($t = 5$ d). After this halt, the object further brightened to $V = 12.7–12.8$ on November 6 ($t = 7$ d). After reaching this maximum, the object rather rapidly faded. The rate of decline reached 0.7–1.2 mag d$^{-1}$ (between November 9 and 10). The present outburst is characterized by a rather slow rise, accompanied by a premaximum halt, and a more rapid decline. On November 13, the object almost reached the quiescence ($V = 16.1$), followed by a further 0.3 mag fade in three days.

The overall light curve of the 2002 October–November outburst is shown in figure 2.

3.3. Eclipse Detection

On 2002 November 3, we detected a shallow fading (depth 0.2 mag) lasting for $\sim 30$ min (figure 3). The light curve was otherwise relatively flat. Since the properties of the phenomenon closely agree with the description by Stover, Allen (1987a), we identified it to be an eclipse (hereafter we call these phenomena eclipses). The shallow depth and the eclipse shape indicate that the eclipse was a partial one, as suggested by Stover, Allen (1987b). Assuming a period of 0.1762 d (Szkyd, Mateo 1986), the phenomenon was confirmed to occur at the same phase on November 5 (cf. figure 4),$^5$ there was no comparable eclipse at the same phase on November 4, 6, 9, and 10. These observations indicate that the eclipses are essentially transient, i.e. the eclipses occur only when the accretion disk is large enough to be eclipsed. Because of this transient nature of the eclipse phenomenon, we have not attempted to refine the eclipse ephemeris by Szkody, Mateo (1986).

We determined the mid-eclipse times by minimizing the dispersions of eclipse light curves folded at the mid-eclipse times. The error of eclipse times were estimated using the Lafler–Kinman class of methods, as applied by Fernie (1989). Since the eclipse profiles and depths considerably varied, the resultant errors, however, should better be treated as a statistical measure of the observational errors. The times are given in table 4. A linear regression of the times yielded the following ephemeris. The errors correspond to the epoch at $E = 8$. The resultant period agrees with the value by Szkody, Mateo (1986) within their respective errors.

$$B JD_{\text{min}} = 2452582.1801(38) + 0.17659(69)E.$$  

$^5$ The quoted error in Szkody, Mateo (1986) corresponds to an uncertainty of $\sim 0.1$ hr in identifying the phases between November 3 and 5. This uncertainty will not affect the identification of the observed phenomena. A unique identification of the orbital phases based on Szkody, Mateo (1986) was impossible because of the lack of precision to make a long-term ephemeris.
Fig. 6. Nightly power spectra of the short-term variations. The data points around the expected eclipses ($|\text{phase}| < 0.1$ against equation 1) were removed before the analyses. There is a distinct power around a frequency of $40 \text{ d}^{-1}$ on November 5 and 6. The power of short-term variations was weak on the other nights. The power spectrum on November 10 more reflect a scatter in the light curve rather than true signals (cf. figure 8).

Fig. 8. Nightly pulse profile of the signal at the frequency $39.233 \text{ d}^{-1}$. The profile is almost sinusoidal on November 5 and 6.
3.4. Short-Term Variations

During the premaximum halt (2002 November 3), the light curve was rather flat except for the shallow eclipse. Strong short-term variations appeared when the object further brightened. The short-term variations have typical time-scales of \( \sim 40 \text{ min} \). The amplitude of the short-term variation reached a maximum around the outburst maximum, and then decayed as the system faded (2002 November 9 and after).

Figure 5 shows a comparison of \( V \) and unfiltered simultaneous observations of the short-term variations on 2002 November 6 (around the maximum light). The short-term variations are more prominent in the \( V \)-band, which indicates that a hotter region more contributes to the variations.

Figure 6 shows nightly power spectra of the short-term variations. The data points around the expected eclipses (\( \text{phase} < 0.1 \) against equation 1) were removed before the analyses. Linear trends within each night were also removed by fitting a line. There is a distinct power around a frequency of \( 40 \text{ d}^{-1} \) (\( \sim 40 \text{ min} \)) on November 5 and 6 (around the outburst maximum). The power of short-term variations was weak on the other nights.

Figure 7 shows a power spectrum of the combined data on November 5 and 6. A strong coherent signal at a frequency of 39.233 d\( \text{d} \) is clearly seen. Figure 8 shows nightly pulse profile of the signal at the frequency 39.233 d\( \text{d}^{-1} \). The profile was almost sinusoidal on November 5 and 6. The signal was not apparent on the other nights.

Although there was no premaximum observation during the 2000 January outburst, the existence of similar short-term variations was confirmed around or shortly after the maximum light. Figure 9 shows a power spectrum (upper) and a pulse profile (lower) from the 2000 January 7 data.\(^6\) The data were taken near the outburst maximum. Although clear distinction of the period is difficult because of the shortness of the run, the dominant frequency in the 2002 data was most likely present.\(^7\)

---

\(^6\) Since we do not have an applicable eclipse ephemeris, no rejection of the data was applied based on the phase.

\(^7\) Preliminary observations after 2000 January 7 (vsnet-alert 3977, L. Cook (http://www.kusastro.kyoto-u.ac.jp/vsnet-Mail/alert3000/msg009977.html) and vsnet-alert 3976, S. Walker (http://www.kusastro.kyoto-u.ac.jp/vsnet-Mail/alert3000/msg00976.html)) suggest that the short-term variations be-

---

4. Discussion

4.1. Outburst Properties

The outburst properties of CW Mon (subsection 3.2) are rather unique among dwarf novae with similar orbital parameters. As a comparison, U Gem (\( P_{\text{orb}} = 0.176906 \text{d} \), \( i = 69.7^\circ \) (Krzeminski 1965; Warner, Nather 1971; Zhang, Robinson 1987), mean cycle length = 118 d), rarely shows slowly rising outbursts (Smak 1993; Sion et al. 1997; Cannizzo et al. 2002). The premaximum halt more resembles those in the outbursts of long-period dwarf novae with long recurrence times: BV Cen (\( P_{\text{orb}} = 0.610108 \text{d} \) : Vogt, Breyvacher 1980; Gilliland 1982; Menzies et al. 1986, V1017 Sgr (\( P_{\text{orb}} = 5.714 \text{d} \) : Sekiguchi 1992), GK Per (\( P_{\text{orb}} = 1.996803 \text{d} \) : Bianchini et al. 1981; Bianchini et al. 1982; Bianchini et al. 1986; Cannizzo, Kenyon 1986; Crampton et al. 1986; Kim et al. 1992; Simon 2002; Nagami et al. 2002), V630 Cas (\( P_{\text{orb}} = 2.564 \text{d} \) : Whitney 1973; Honeycutt et al. 1993; Warner 1994; Orosz et al. 2001). Figure 10 presents a representative comparison of the outbursts of CW Mon and GK Per. The slow rise to the maximum and premaximum halts are common in these systems.

Some of infrequently outbursting dwarf novae, such as CH UMa (\( P_{\text{orb}} = 0.343 \text{d} \), Becker et al. 1982; Simon 2000b) and DX And (\( P_{\text{orb}} = 0.440502 \text{d} \) : Bruch et al. 1997; Simon 2000a) sometimes show similar outburst profiles.

As shown in Kim et al. (1992), these outbursts are classified as a variety of so-called ‘type B’ outbursts (Smak 1984b; Smak 1987). The existence of the premaximum halt can be well explained as a result of a combination of stagnation due to the increase of the specific heat associated with H and He ionization (Mineshige 1988; Mineshige et al. 1990) and slow inside-out propagation of the thermal instability starting at the inner region of the accretion disk. Kim et al. (1992) indeed showed a prolonged stagnation can be achieved in the condition of GK Per. Since low mass-transfer enables a sufficient quiescent diffusion to allow inside-out outbursts, and a larger disk radius effectively suppresses thermal instability to occur in the outer disk, such an condition of prolonged stagnation can be most easily achieved in long-\( P_{\text{orb}} \) low mass-transfer systems, which agrees with the above observational examples.

In many short-period dwarf novae with rather high mass-transfer rates, such a condition is difficult to achieve. Nevertheless, the same system is shown to undergo unusual outbursts, resembling those of GK Per, when the mass-transfer rate is temporarily reduced (RX And: Kato et al. 2002c). Many of the well-observed long outbursts of CW Mon (cf. figure 10) to some degree bear resemblance to the 2002 October–November outburst, especially in the initial rapid rise and the following phase of a slow rise to maximum, indicating that the stagnation-type progress of the outburst is very effective in CW Mon.
4.2. Eclipses

As shown in subsection 3.3, transient eclipses were only detected on 2002 November 3 (premaximum stage) and November 5 (near maximum). As is naturally expected from the binary configuration, these eclipses are interpreted to occur only when the accretion disk is sufficiently large to be eclipsed by the secondary. In the model calculation by Kim et al. (1992), the outward heating wave travels toward the outer disk twice: during the stagnation phase and the maximum phase. During these epochs, the outer disk can expand as a result of the heating wave and the resultant upward transition to a hot state (Ichikawa, Osaki 1992; Osaki 1996). The detection of the eclipses only during the premaximum halt (stagnation phase) and near the maximum light (maximum disk expansion) well agrees with the picture. We thus conclude that the present transient eclipse detections on two occasions are an additional observational support for the two-step ignition of the outburst, as proposed by Kim et al. (1992).

4.3. Wide and Narrow Outbursts

The reported magnitude difference of the wide and narrow outbursts (Stubbings, McIntosh 1997) also seems to support this stagnation-type interpretation, since no such a great, systematic difference of peak magnitudes between wide and narrow outbursts has been observed in usual SS Cyg-type dwarf novae, e.g. SS Cyg (Cannizzo, Mattei 1992; Cannizzo, Mattei 1998). Such a difference can be reasonably reproduced if narrow outbursts represent outbursts with early quenching of the outward heating wave (for an example of such a simulation, see Kim et al. 1992).

Among well-observed dwarf novae with similar orbital periods, TW Vir ($P_{\text{orb}} = 0.18267$ d) shows a similar pattern of outbursts. In long period systems, such as CH UMa (Simon 2000b), RU Peg ($P_{\text{orb}} = 0.3746$ d), this phenomenon is commonly seen, which is a natural consequence of the predominant inside-out type outbursts in these long-period systems.

See e.g. (http://www.kusastro.kyoto-u.ac.jp/vsnet/gcvs/VIRTW.html)
4.4. Short-Term Variations

From the apparent presence of a short-period coherent signal during the maximum phase of the 2002 November outburst, and the likely existence of the common period during the 2000 January outburst, CW Mon is likely an intermediate polar (IP; sometimes called a DQ Her star: for recent reviews, see e.g. King, Lasota 1990; Patterson 1994; Hellier 1996; Buckley 2000; chapters 8 and 9 in Hellier 2001). If this IP-nature is confirmed, CW Mon is a rare dwarf nova showing IP-type properties during their outbursts. The other IPs showing rather regular dwarf nova-like (or possibly dwarf nova-type) outbursts include DO Dra (Wenzel 1983; Szkody et al. 2002), HT Cam (Ishioka et al. 2002; Kemp et al. 2002) and GK Per. Other IPs showing outbursts include EX Hya (Hellier et al. 1989) and TV Col (Szkody, Mateo 1984; Hellier 1993). The outbursts of these objects are, however, more irregular than in DO Dra, HT Cam and GK Per.

Up to now, HT Cam is the best-known example which showed a dramatic increase of the IP pulse strength during the outburst phase (Ishioka et al. 2002). The pulses of this object are generally weaker in quiescence (Tovmassian et al. 1998; Kemp et al. 2002). Following this analogy, we tentatively identify the 0.025489(8) d as the spin period of the magnetized white dwarf. However, we must note that the observed period is not necessarily the spin period but may be some sort of quasi-periodic oscillations (QPOs) (e.g. GK Per, see Morales-Rueda et al. 1999; Nogami et al. 2002) or beat periods between the rotation of the white dwarf and the structure or wave in the accretion disk (Warner, Woudt 2002).

Following this interpretation, the dramatic increase of the pulse strength following the premaximum phase can be best understood as a result of the dramatic increase of the accretion rate in the inner disk following the stagnation stage, as is reasonably predicted by Kim et al. (1992).

4.5. Proper Motion and Distance

We examined the available astrometric catalogs (table 5). From a comparison of the positions in USNO A2.0 and 2MASS catalogs, we detected a probable proper motion of 0′′.57 ± 0′′.17 in 42.8 yr. The position of GSC 2.2.1 at an intermediate epoch supports its direction. The Astrographic Catalog (AC) happened to contain this object in outburst, whose position in the latest reduced version also supports the proper motion. The derived proper motion of 13 ± 4 mas yr\(^{-1}\) is consistent with the other estimates of 21.4 mas yr\(^{-1}\) (FONAC catalog) and 13.9 mas yr\(^{-1}\) (USNO B1.0 catalog).

At a distance of 290 pc (Verbunt et al. 1997), our proper motion corresponds to a reasonable transverse velocity of 19 ± 6 km s\(^{-1}\). The present proper motion study supports the 290 pc distance estimate. At this distance, the maximum absolute magnitude becomes \(M_V = +5.4\) (assuming the maximum apparent magnitude of \(V = 12.7\), present observation). This value is significantly fainter than the mean maximum absolute magnitude of \(M_V = +4.4\), of dwarf novae with similar orbital periods (Smak 1999). The value is fainter than \(M_V = +4.5\) expected from Warner’s relation (Warner 1987). Although the high inclination may be partly responsible for this faintness, the formulation by Warner (1986) indicates that this effect is less than 0.1 mag compared to an average inclination (\(i = 44°\)), or 0.4 mag compared to a pole-on system. The effect of inclination thus seems to be insufficient to explain the low maximum brightness of CW Mon.

As described in subsection 4.1, (at least some of) the outbursts of CW Mon are well represented by a combination of stagnation and inside-out type evolution. In such a situation, either heating wave may not fully reach the outermost disk, or the entire disk may not reach the critical surface density (\(\Sigma_{\text{max}}\)), which is a necessary condition that the maximum \(M_V\) follows Warner’s relation (Cannizzo 1998). The faintness of the outbursts of CW Mon can be thus naturally explained within the framework of the disk instability theory.

5. CW Mon as a Possible Intermediate Polar

As shown in subsection 4.4, CW Mon is a good IP candidate which shows transient IP pulses during the maximum phase of the outbursts. The supposed IP-nature would naturally explain the rather unusual properties in this system. The truncation of the inner disk by the magnetic field lines of the white dwarf can effectively suppress disk instabilities in the inner accretion disk, thereby lengthening outburst intervals (Angelini, Verbunt 1989; see also Kato et al. 2002a). The low maximum luminosity can be alternatively explained by the inner truncation of the accretion disk. A slight deviation from the Bailey relation during the late decline phase (subsection 4.1) may be a result of the inner truncation (cf. Ishioka et al. 2002; Kato et al. 2002a).

One of the most remarkable features of CW Mon would be the relatively strong X-ray emission. According to Verbunt et al. (1997), the X-ray luminosity of CW Mon is estimated to be \(L_X = 10^{31.1}\) erg s\(^{-1}\), which makes CW Mon one of the luminous sources among dwarf novae. This value is, however, a rather common X-ray luminosity among IPs (Verbunt et al. 1997). The hard spectrum of the X-ray emission (Richman 1996; Verbunt et al. 1997) is also consistent with the IP picture. The observed X-ray luminosity also fits the general relation between \(P_{\text{orb}}\) and \(L_X\) (Patterson 1994).

The ratio between the suggested spin period (\(P_{\text{spin}} = 0.0255\) d) and the orbital period (\(P_{\text{orb}} = 0.1766\) d) is close to the expected ratio (\(P_{\text{spin}}/P_{\text{orb}} = 0.1\)) for the equilibrium spin rate of the white dwarfs in IPs (King 1993; Wynn, King 1995). The observed ratio, however, is slightly above the equilibrium value; such a situation is relatively rare in IPs (cf. Wu, Wickramasinghe 1991; Patterson 1994; Hellier 1996). V1025 Cen (Buckley et al. 1998; Hellier et al. 1998) and EX Hya (Jablonksi, Busko 1985; Heise et al. 1987; Bond et al. 1988) are the best-known such ex-
The ratio of the white dwarf and the Lₑ point. King, Wynn (1999) suggested that such a condition should usually require an orbital period below the period gap (P_{orb} ≤ 2 hr). Since CW Mon apparently does not fit this picture, further confirmation of the suggested spin period is strongly recommended.

The weakness of the IP signature except during the outburst maxima may be a result of a lower magnetic field than in other IPs. A deep search for ultraviolet and X-ray pulses in quiescence (cf. Patterson et al. 1992; Patterson, Szkody 1993; Haswell et al. 1997; Norton et al. 1999; Szkody et al. 2002), as well as detailed optical coverage during future outbursts, is strongly recommended.

We are grateful to many VSNET observers who have reported vital observations. We are particularly grateful to Dan Taylor, Mike Simonson and Hazel McGee for promptly notifying the outbursts through VSNET, and to Lew Cook and Stan Walker for making their preliminary results quickly and publicly available. We are grateful to Rod Stubbings for making the relevant RASNZ VSS publications available to us. This work is partly supported by a Research Fellowship of the Japan Society for the Promotion of Science for Young Scientists (MU). This research has made use of the Digitized Sky Survey produced by STScI, the ESO Skycat tool, and the VizieR catalogue access tool.

References
Ahern, P. 1944, Comm. Obs. Berlin-Babelsburg and Sonneburg, 66
Angelini, L., & Verbunt, F. 1989, MNRAS, 238, 697
Bailey, J. 1975, J. British Astron. Assoc., 86, 30
Bateson, F. M. 1989, RASNZ Publ. of Var. Star Sect., 16, 89
Becker, R. H., Chanan, G. A., Wilson, A. S., & Pravdo, S. H. 1982, MNRAS, 201, 265
Bianchini, A., Sabbadin, F., Favero, G. C., & Dalmeri, I. 1986, A&A, 160, 367
Bianchini, A., Sabbadin, F., & Hamzaoglu, E. 1981, A&A, 99, 392
Bianchini, A., Sabbadin, F., & Hamzaoglu, E. 1982, A&A, 106, 176
Bond, I. A., Bond, I. A., & Freeth, R. V. 1988, MNRAS, 232, 753
Bruch, A., Vrielmann, S., Hessman, F. V., Kochsiek, A., & Schimpke, T. 1997, A&A, 327, 1107
Buckley, D. A. H. 2000, New Astron. Rev., 44, 63
Buckley, D. A. H., Cropper, M., Ramsay, G., & Wickramasinghe, D. T. 1998, MNRAS, 299, 83
Cannizzo, J. K. 1998, ApJ, 493, 426
Cannizzo, J. K., Gehrels, N., & Mattei, J. A. 2002, ApJ, 579, 760
Cannizzo, J. K., & Kenyon, S. J. 1986, ApJL, 309, L43
Cannizzo, J. K., & Mattei, J. A. 1992, ApJ, 401, 642
Cannizzo, J. K., & Mattei, J. A. 1998, ApJ, 505, 344
Crampton, D., Fisher, W. A., & Cowley, A. P. 1986, ApJ, 300, 758
Fernie, J. D. 1989, PASP, 101, 225
Gilliland, R. L. 1982, ApJ, 263, 302
Glasby, J. S. 1970, The Dwarf Novae (Constable: London)
Haswell, C. A., Patterson, J., Thorstensen, J. R., Hellier, C., & Skillman, D. R. 1997, ApJ, 476, 847
Heise, J., Mewe, R., Kruszewski, A., & Chlebowski, T. 1987, A&A, 183, 73
Hellier, C. 1993, MNRAS, 264, 132
Hellier, C. 1996, in IAU Colloq. 158, Cataclysmic Variables and Related Objects, ed. A. Evans & J. H. Wood (Dordrecht: Kluwer Academic Publishers), 143
Hellier, C. 2001, Cataclysmic Variable Stars: how and why they vary. (Berlin: Springer-Verlag)
Hellier, C., Beardsmore, A. P., & Buckley, D. A. H. 1998, MNRAS, 299, 851
Hellier, C., Mason, K. O., Smale, A. P., Corbet, R. H. D., O’Donoghue, D., Barrett, P. E., & Warner, B. 1989, MNRAS, 238, 1107
Honeycutt, R. K., Robertson, J. W., Turner, G. W., & Vesper, D. N. 1993, PASP, 105, 919
Horne, K. 1985, MNRAS, 213, 129
Howell, S., & Szkody, P. 1988, PASP, 100, 224
Ichikawa, S., & Osaki, Y. 1992, PASJ, 44, 17
Iono, Z., Naylor, T., Welsh, W. F., Catalán, M. S., Worraker, W. J., & James, N. D. 1999, MNRAS, 310, 398
Ishioka, R., Kato, T., Uemura, M., Billings, G. W., Morikawa, K., Torii, K., Tanabe, K., Oksanen, A., Hyvönen, H., & Itoh, H. 2002, PASJ, 54, 581
Jablonski, F., & Busko, I. C. 1985, MNRAS, 214, 219
Kato, T., Dubovsky, P. A., Stubbings, R., Simonson, M., Yamaoka, H., Nelson, P., Monard, B., Pearce, A., & Garradd, G. 2002a, A&A, 396, 929

Table 5. Astrometry of CW Mon.

| Source | R. A. (J2000.0) | Decl. | Epoch | Magnitude |
|--------|----------------|-------|-------|-----------|
| AC 2000.2 | 06 36 54.470 | +00 02 17.70 | 1909.083 | b = 12.58 |
| USNO A2.0 | 06 36 54.547 | +00 02 16.79 | 1955.881 | b = 16.4, r = 16.0 |
| GSC 2.2.1 | 06 36 54.572 | +00 02 17.19 | 1990.963 | b = 17.50, r = 15.94 |
| 2MASS | 06 36 54.579 | +00 02 17.39 | 1998.723 | ⋯ |

The ratio (P_{spin}/P_{orb}) would be closer to 0.1 if the observed periodicity corresponds to a beat period between the rotation of the white dwarf and the orbital motion or a slowly rotating portion of the accretion disk. We note, however, there is no established IP showing a beat period as the predominant signal during its outbursts.

788
760
753
745
720
689
675
660
612
595
588
576
561
542
529
517
508
490
479
461
440
429
419
408
398
388
379
368
359
349
340
329
318
309
300
290
281
272
263
254
245
236
227
218
210
201
192
183
174
165
156
147
138
129
120
111
102
93
84
75
66
57
48
39
30
21
12
3

9 The weakness of the IP signature except during the outburst maxima may be a result of a lower magnetic field than in other IPs. A deep search for ultraviolet and X-ray pulses in quiescence (cf. Patterson et al. 1992; Patterson, Szkody 1993; Haswell et al. 1997; Norton et al. 1999; Szkody et al. 2002), as well as detailed optical coverage during future outbursts, is strongly recommended.
