Photometric study of new southern SU UMa-type dwarf novae and candidates: V877 Ara, KK Tel and PU CMa

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ABSTRACT

We photometrically observed three dwarf novae V877 Ara, KK Tel and PU CMa. We discovered undisputed presence of superhumps in V877 Ara and KK Tel, with mean periods of 0.08411(2) d and 0.08808(3) d, respectively. Both V877 Ara and KK Tel are confirmed to belong to long-period SU UMa-type dwarf novae. In V877 Ara, we found a large decrease of the superhump period ($\dot{P}/P = -14.5 \pm 2.1 \times 10^{-5}$). There is evidence that the period of KK Tel decreased at a similar or a more exceptional rate. Coupled with the past studies of superhump period changes, these findings suggest that a previously neglected diversity of phenomena is present in long-period SU UMa-type dwarf novae. The present discovery of a diversity in long-period SU UMa-type systems would become an additional step toward a full understanding the dwarf nova phenomenon. PU CMa is shown to be an excellent candidate for an SU UMa-type dwarf nova. We examined the outburst properties of these dwarf novae, and derived characteristic outburst recurrence times. Combined with the recently published measurement of the orbital period of PU CMa, we propose that PU CMa is the first object filling the gap between the extreme WZ Sge-type and ER UMa-type stars.

Key words: accretion; accretion disks — stars: cataclysmic — stars: dwarf novae — stars: individual (V877 Ara, KK Tel, PU CMa)

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 (for recent reviews, see Warner (1995a); Hellier (2001a)). There exists a class of dwarf novae, called SU UMa-type dwarf novae. All 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 (1995a), respectively.] Superhumps are 0.1–0.5 mag modulations which have periods (superhump period: $P_{SH}$) a few percent longer than the system orbital period ($P_{orb}$). The difference between $P_{SH}$ and $P_{orb}$ is understood as a consequence of the apsidal motion Osaki (1983) of a tidally induced eccentric accretion disk Whitehurst (1988). The origin of superhumps is explained as increased viscous dissipation around periodic conjunctions between the major axis of the elongated accretion disk and the secondary star. This explanation has been recently confirmed with more
detailed hydrodynamical simulations [Murray 1998, 2000], Truss et al. (2000, 2001) indeed succeeded in reproducing the light curves of dwarf novae with hydrodynamical simulations within the thermal-tidal disk instability model (Osaki 1989, 1996).

Early development in study of SU UMa-type dwarf novae largely owed to southern bright objects (VW Hyi, Z Cha, OY Car etc., see e.g. Vogt (1974, 1980), Vogt et al. (1981), Warner & Brickhill (1974); Warner 1974, 1975, 1983; Cook & Warner 1981, 1984; O'Donoghue 1986; Smak 1979, 1983; Bailey & Ward (1981)) with dedicated telescopes. The recent advent of the wide availability of CCDs, however, has opened a new window to study of SU UMa-type dwarf novae. Excellent examples include (a) an extension to faint objects (e.g. Howell & Szkody 1988; Howell et al. 1990, 1991; Mukai et al. 1990; Szkody et al. 1989) and (b) timely observations of SU UMa-type outbursts. These new techniques have produced a number of striking discoveries or new concepts: e.g. recognition of a class of short-period, rarely outbursting SU UMa-type dwarf novae (Howell et al. 1993), establishment of the concept of WZ Sge-type dwarf novae (Kato et al. 1996, 1997, 2001), discovery of peculiar ER UMa-type stars (Kato & Kunjaya 1995; Robertson et al. 1995; Nogami et al. 1995a,b; Patterson et al. 1995; Kato et al. 1996), and discovery of ultra-short period SU UMa-type dwarf novae breaking the standard evolutionary sequence of short-period CVs (Uemura et al. 2002a, Skillman et al. 2002). These discoveries have dramatically changed our understanding of CVs. In recent years, Woudt & Warner (2001) applied a technique of time-resolved CCD photometry, which was largely introduced by Howell & Szkody (1988); Szkody et al. (1989), to the previously unexploited field of faint southern CVs, and has indeed proven the high productivity of such a study.

In the most recent years, the advent of the Internet, wide availability of CCDs and a global network of observers, best exemplified by the VSNET Collaboration (Osaki 1989, 1996), has enabled a rapid circulation of outburst alerts and opened a new window to globally and timely study the novel field of transient object astronomy. Combined with the established technique of time-resolved CCD photometry of outbursting dwarf novae, this kind of global collaboration has become a breakthrough in study of CVs (a wealth of scientific highlights is presented on the VSNET webpage). In this paper, we present the very first result of this global network on newly discovered outbursts of southern CVs.

2 CCD OBSERVATION

The observers, equipment and reduction software are summarized in Table 1. The Kyoto observations were analyzed using the Java-based PSF photometry package developed by one of the authors (TK). The other observers performed aperture photometry. The observations used unfiltered CCD systems having a response close to Kron-Cousins $R_c$ band for outbursting dwarf novae, except for the $V$-band observation by SK. The errors of single measurements are typically less than 0.01–0.03 mag unless otherwise specified.

Barycentric corrections to the observed times were applied before the following analysis.

3 V877 Ara = NSV 08383

3.1 Introduction

V877 Ara was originally discovered as a suspected variable star (CSV 7612 = NSV 08383). The star was selected as a possible dwarf nova in Vogt & Bateson (1982). From the finding chart presented in this literature, Lopez (1983) provided astrometry of the proposed quiescent counterpart at $17^h16^m58.s96, -65^\circ 33' 00''.2$ (precessed to J2000.0). The star has been intensively monitored by members of the VSNET Collaboration. The first outburst was detected by B. Monard on 1999 February 27 at visual magnitude 14.2 (vsnet-alert 2715). Monard further noticed that the outbursting object is different from the proposed quiescent counterpart (vsnet-alert 2727). Although no detailed time-resolved photometry was performed, the overall behavior of the 1999 February–March outburst resembles that of a superoutburst of an SU UMa-type dwarf nova (vsnet-alert 4110).

3.2 Long-term Light Curve

Figure 1 shows the long-term visual light curve of V877 Ara. Four major outbursts occurring at JD 2451236, 2451805, 2452129 and 2452433 are clearly seen. As shown in section 3.4, the major outburst around JD 2452433 is a superoutburst as demonstrated by the secure detection of superhumps, thereby establishing the SU UMa-type nature of V877 Ara. The earlier three outbursts had durations longer than 5 d (section 3.4), and comparable maximum magnitudes to that of the JD 2452433 outburst. Since all well-observed long (more than 5 d) outbursts of SU UMa-type dwarf novae have been confirmed to be superoutbursts (Vogt

Table 1. Observers and Equipment.

| Observer | Telescope | CCD | Software |
|----------|-----------|-----|----------|
| Santalho | 20-cm SCT | ST-7E | AIP4Win |
| Bolt     | 82-cm SCT | ST-7E | AIP4Win |
| Richards | 18-cm refractor | ST-7E | AIP4Win |
| Nelson   | 32-cm reflector | ST-8E | AIP4Win |
| Monard   | 30-cm SCT | ST-7E | AIP4Win |
| Kyoto    | 25-cm SCT | ST-7 | Java |
| Kiyota   | 25-cm SCT | AP-7 + V filter | MIRA A/P |

a http://munipack.astronomy.cz
b MaxIm/DL was used for KK Tel.
c See text.
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Figure 1. Long-term visual light curve of V877 Ara. Large and small dot represent positive and negative (upper limit) observations, respectively. Four major outbursts occurring at JD 2451236, 2451805, 2452129 and 2452433 are superoutbursts.

Table 2. Journal of the 2002 CCD photometry of V877 Ara.

| 2002 Date | Start–End | Exp(s) | N | Obs  |
|-----------|-----------|--------|---|------|
| June 9    | 52434.951–52435.110 | 50 | 194 | S   |
| 11        | 52436.959–52437.123 | 50 | 163 | S   |
| 11        | 52437.069–52437.283 | 60 | 273 | B   |
| 15        | 52441.010–52441.219 | 75 | 215 | B   |
| 17        | 52442.920–52443.222 | 240 | 93  | R   |
| 17        | 52443.105–52443.285 | 120 | 120 | B   |

\(^{a}\) BJD–2400000.

\(^{b}\) S (Santallo), B (Bolt), R (Richards)

We can safely conclude that these outbursts are indeed superoutbursts. Two shorter outbursts were detected between these outbursts. These outbursts are most likely normal outbursts. The overall characteristics of the long-term light curve is that of a typical SU UMa-type dwarf nova.

3.3 The 2002 June Superoutburst

The 2002 June outburst was detected by R. Stubbings on June 7 at visual magnitude 13.8. The object was reported to be below the detection limit on the previous night; the outburst must have been caught during its earliest stage. We undertook time-resolved CCD photometry campaign. The magnitudes were measured relative to GSC 9060.112, whose constancy during the observation was confirmed by a comparison with GSC 9060.610. The log of observations is given in Table 2.

Figures 2 and 3 are the overall and nightly light curves of V877 Ara. Gradually decaying superhumps are clearly visible on all nights; this confirms the SU UMa-type nature of V877 Ara. The overall light curve shows a linear decline with a rate of 0.12 mag d\(^{-1}\). This value is quite characteristic of a normal SU UMa-type dwarf nova. The dip-like structure near the end of the June 17 run may have been a result of slightly unfavorable observing condition.

Figure 2. Light curve of the 2002 June superoutburst of V877 Ara. The magnitudes are given relative to GSC 9060.112 and are on a system close to \(R_{c}\).

3.4 Superhump Period

Figure 4 shows the result of a period analysis using Phase Dispersion Minimization (PDM; Stellingwerf 1978) applied to the entire data set after removing the linear decline trend. The selection of the correct period among possible aliases was performed using an independent analysis of the longest run (June 11), which yielded a period of 0.0853(4) d.\(^{5}\) This selection was also confirmed by a comparison with the independently obtained period (0.0842 d) communicated from S. Walker based on his June 10 observation. The adopted mean period during the superoutburst is 0.08411(2) d. A relatively large difference between the mean

\(^{5}\) The quoted error from a single-night observation should be regarded as an approximation rather than the true error, since an estimated of such a period may have been affected by an uncorrected systematic variation of the observing condition or an intrinsic variation in the waveform. We therefore regard that the seeming difference between nightly-based periods on June 10 and June 11 is not significant. This error, however, safely rejected the longer possible alias by at least 6\(\sigma\).
Figure 3. Nightly light curves of V877 Ara. Gradually decaying superhumps are clearly visible on all nights.

Figure 4. Period analysis of V877 Ara. See text for the explanation of the selection of the correct alias ($P_{SH} = 0.08411$ d).

period and a period on a single-night basis may be ascribed to the large superhump period change described later. Figure 4 shows the phase-averaged profile of superhumps. The rapidly rising and slowly fading superhump profile is characteristic of an SU UMa-type dwarf nova (Vogt 1981, Warner 1983).

We extracted the maxima 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 maxima times. The errors of the maxima times are usually less than $\sim$0.002 d. The resultant superhump maxima are given in Table 3. 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 BJD 2452434.961. A linear regression to the observed superhump times gives the following ephemeris:

$$\text{BJD(maximum)} = 2452434.9715(31) + 0.084025(47)E.$$  \hspace{1cm} (1)

Figure 6 shows the ($O-C$)'s against the mean superhump period (0.084025 d) from a linear regression (equation 1). 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:

$$\text{BJD(maximum)} = 2452434.9633(18) + 0.084659(92)E - 6.12(87) \times 10^{-6}E^2.$$  \hspace{1cm} (2)

The quadratic term corresponds to $\dot{P} = -12.2\pm1.7 \times 10^{-6}$ d cycle$^{-1}$, or $\dot{P}/P = -14.5\pm2.1 \times 10^{-5}$. This measured quadratic term is one of the extremely negative values among all SU UMa-type dwarf novae (Kato et al. 2001).
Table 3. Times of superhump maxima of V877 Ara.

| $E^a$ | BJD−2400000 | $O - C^b$ |
|-------|-------------|-----------|
| 0     | 52434.9606  | -0.0109   |
| 1     | 52435.0482  | -0.0073   |
| 24    | 52436.9913  | 0.0032    |
| 25    | 52437.0784  | 0.0063    |
| 26    | 52437.1613  | 0.0051    |
| 27    | 52437.2469  | 0.0067    |
| 72    | 52441.0234  | 0.0021    |
| 73    | 52441.1086  | 0.0032    |
| 74    | 52441.1945  | 0.0051    |
| 75    | 52442.9510  | -0.0029   |
| 76    | 52443.0387  | 0.0008    |
| 77    | 52443.1145  | -0.0075   |
| 98    | 52443.2022  | -0.0038   |

$^a$ Cycle count since BJD 2452434.961.

$^b$ $O - C$ calculated against equation 1.

3.5 Astrometry and Quiescent Counterpart

Astrometry of the outbursting V877 Ara was performed on CCD images taken by R. Santallo and B. Monard. An average of measurements of seven images (UCAC1 system, 60 – 150 reference stars; internal dispersion of the measurements was $0''0.03$) has yielded a position of $17^h16^m53^s.936$, $-65^\circ32'51''4.9$ (J2000.0). The position agrees with the USNO−A2.0 star at $17^h16^m53^s.926$, $-65^\circ32'51''8.0$ (epoch 1979.891 and magnitudes $r = 17.8$, $b = 19.1$), which is most likely the quiescent counterpart of V877 Ara (Figure 7). Comparing with the USNO−A2.0 position and the DSS 1 images (epoch = 1975 – 1978), no apparent proper motion was detected; its upper limit is deduced to be $0''0.04$ yr$^{-1}$. No counterpart is recorded in GSC−2.2, UCAC and 2MASS catalogs.

3.6 V877 Ara as an SU UMa-type Dwarf Nova

Table 4 lists the recorded outbursts of V877 Ara. The durations of outbursts have a clear bimodal ($\leq 2$ d or $\geq 5$ d) distribution, which is very characteristic of an SU UMa-type star (Vogt 1980; Warner 1985). The observed intervals between superoutbursts implies the existence of a missed superoutburst around the solar conjunction between JD 2451236 and JD 2451805. The intervals between superoutbursts (supercycle length) are thus 285–374 d. The observed number of normal outbursts between superoutbursts does not seem to be exceptionally low for an SU UMa-type star (Warner 1995b; Nogami et al. 1997) considering the faintness (14.2–14.6 mag) of normal outbursts, which is close to the detection limit. Future deep monitoring is encouraged to determine the true cycle length of normal outbursts.

4 KK Tel

4.1 Introduction

KK Tel is a dwarf nova discovered by C. Hoffmeister. Vogt & Bateson (1982) provided a finding chart. Howell & Szkody (1990) suggested that KK Tel may be a member of high galactic latitude CVs, which were then considered to be...
a new population of CVs with large outburst amplitudes (Howell et al. 1995). Howell et al. (1991) obtained CCD time-resolved photometry of KK Tel in quiescence, and recorded regularly recurring humps with a period of 0.084 d. Among the CVs studied by Howell et al. (1991), KK Tel showed most prominent humps, which resembled those of a high-inclination eclipsing CV, DV UMa (Howell et al. 1987, 1988). Howell & Blanton (1994). The characteristics of the humps in KK Tel was further discussed in Howell et al. (1996). Zwitter & Munari (1995) obtained a spectrum in quiescence, and confirmed the presence of Balmer emission lines. This observation spectroscopically confirmed the CV nature of KK Tel. Since the reported period strongly suggests the SU UMa-type nature, we undertook a photometric campaign.

### 4.2 The 2002 June Superoutburst

The 2002 June outburst was detected by R. Stubbings on June 17 at visual magnitude 13.8. Due to a 4-d gap of observation before this detection, the exact epoch of the start of the outburst was not determined. We started a CCD photometric campaign following this detection. Each observer measured relative magnitudes against a constant star in the same field. Since different observers used different comparison stars and the accurate adjustment of the zero point is difficult because of the presence of a close visual companion to KK Tel, we simply subtracted a nightly average from each runs and the combined data were subject to period analyses. The log of observations is given in Table 5.

### 4.3 Superhump Period

Figure 8 shows nightly light curves of KK Tel. Superhumps are clearly visible on all nights. This observation has finally established the SU UMa-type nature of KK Tel. The relatively large scatter on June 20 may have been caused by an interference by the nearby companion. Figure 9 shows the result of PDM period analysis. The selection of the correct period among possible aliases was performed using an independent analysis of the longest run (June 20), which yielded a period of 0.0878(10) d. The identification of the superhump period is also confirmed by a comparison with the quiescent photometric period of 0.084 d (Howell et al. 1991). No other alias gives a reasonable match with this quiescent period. The best determined mean $P_{SH}$ is 0.08808(3) d.

We extracted the maxima times of superhumps from the light curve just as in section 3.4. The resultant superhump maxima are given in Table 6. A linear regression of the observed times is given in equation 3.
The times of the superhump maxima in this interval can be well represented by the following quadratic equation:

$$\text{BJD} \quad (\text{maximum}) = 245244.4018 + 0.08880 E - 1.69 \times 10^{-5} E^2.$$  \hfill (4)

Nominal errors of the fit are not shown because of the small degree of freedom in the data. Although further detailed observations are needed to exactly determine the period derivative, the presently measured period change corresponds to $P = 3.3 \times 10^{-5}$ d cycle$^{-1}$, or $P / P_0 = -3.7 \times 10^{-4}$. Even if we allow most pessimistic measurement errors of 0.01 d (14 min) for superhump maxima, the period derivative varies only by $\sim 10\%$. We thereby adopted $P / P_0 = -3.7(4) \times 10^{-4}$ for KK Tel.

### 4.4 Astrometry and Quiescent Counterpart

Astrometry of the outbursting KK Tel was performed on CCD images taken by P. Nelson and T. Richards. An average of measurements of two images (UCAC1 system, 26 – 70 reference stars; internal dispersion of the measurements was of measurements of two images (UCAC1 system, 26 – 70 CCD images taken by P. Nelson and T. Richards. An average of the outbursting KK Tel was performed on the identification by Howell et al. (1991) that the 0.084 d period is likely to be correct to $\pm 1\%$. Based on the detection at mag 11 on one ESO B plate, the object has been suspected to be a dwarf nova (cf. Downes et al. (1997)). The object is located at $06^h 40^m 47.691, -24^\circ 23^m 14.04$ (GSC–2.2, J2000.0, epoch=1996.131, $r = 14.87$, $b = 16.17$). The object was monitored by one of the authors (PS) using an AP-8 CCD camera attached to the 50-cm reflector at the Iowa Robotic Observatory (IRO), Schmeer (2000, vsnet-alert 3956) discovered a new outburst on 2000 January 6.348 UT at unfiltered CCD magnitude of 11.5, and established the dwarf nova classification. Upon this alert, we started time-resolved CCD photometry at Kyoto (TK and MU) and Tsukuba (SK). The Tsukuba observation further covered the later part of the 2000 February outburst, which was detected by one of the authors (R. Stubbings).

### 5 PU CMa = RX J0640–24

RX J0640–24 (=IRXS J064047.8-242305) is a ROSAT-selected cataclysmic variable, normally at $B = 15.4$. Based on the detection at mag 11 on one ESO B plate, the object has been suspected to be a dwarf nova (cf. Downes et al. (1997)). The object is located at $06^h 40^m 47.691, -24^\circ 23^m 14.04$ (GSC–2.2, J2000.0, epoch=1996.131, $r = 14.87$, $b = 16.17$). The object was monitored by one of the authors (PS) using an AP-8 CCD camera attached to the 50-cm reflector at the Iowa Robotic Observatory (IRO), Schmeer (2000, vsnet-alert 3956) discovered a new outburst on 2000 January 6.348 UT at unfiltered CCD magnitude of 11.5, and established the dwarf nova classification. Upon this alert, we started time-resolved CCD photometry at Kyoto (TK and MU) and Tsukuba (SK). The Tsukuba observation further covered the later part of the 2000 February outburst, which was detected by one of the authors (R. Stubbings).
Figure 10. Long-term visual light curve of KK Tel. Large and small dot represent positive and negative (upper limit) observations, respectively. Outbursts marked with vertical ticks are superoutbursts.

Table 8. Nightly averaged magnitudes of PU CMa

| BJD start | BJD end | Mean mag | Error | N | Obs. |
|-----------|---------|----------|-------|---|------|
| 51551.202 | 51551.257 | 1.544 | 0.013 | 137 | K   |
| 51552.065 | 51552.206 | 5.406 | 0.025 | 63  | T   |
| 51552.123 | 51552.268 | 2.516 | 0.028 | 342 | K   |
| 51554.187 | 51554.260 | 3.010 | 0.092 | 60  | K   |
| 51558.190 | 51558.196 | 3.106 | 0.100 | 14  | K   |
| 51559.181 | 51559.199 | 3.597 | 0.057 | 49  | K   |
| 51561.156 | 51561.202 | 3.417 | 0.049 | 342 | K   |
| 51599.003 | 51599.018 | 4.331 | 0.012 | 10  | T   |
| 51599.963 | 51600.009 | 5.399 | 0.029 | 31  | T   |
| 51831.261 | 51831.264 | 2.929 | 0.262 | 8   | K   |
| 52422.178 | 52422.224 | –     | –     | 99  | M   |

a BJD = 2400000.
b Magnitude relative to GSC 6512.166 (Kyoto), GSC 6512.908 (Tsukuba).
c Standard error of nightly average.
d Number of frames.
e K (Kyoto), T (Tsukuba), M (Monard).

The magnitudes of Kyoto CCD observations were determined relative to GSC 6512.166 (Tycho-2 magnitude: \( V = 12.43 \pm 0.17 \), \( B - V = +0.91 \pm 0.34 \)). The magnitudes of Tsukuba observations were determined relative to GSC 6512.908 (Tycho-2 magnitude: \( V = 9.10 \pm 0.01 \), \( B - V = +1.31 \pm 0.03 \)). The constancy of comparison star during the run was confirmed by comparison with GSC 6508.1168 at both observatories. The log of observations is given in Table 8. BM obtained another set of time-series photometry on 2002 May 27 (during the 2002 May long outburst). Because of the different comparison star system, average magnitude of BM’s observation is not listed in Table 8.

The upper panel of Figure 11 shows the light curve of the 2000 January outburst drawn from the Kyoto data. The light curve shows a rapid initial decline at a rate of \( \sim 1.0 \) mag d\(^{-1}\). The decline became slower as the object approached its minimum magnitude. The object returned to quiescence within 4 d of the initial detection of the rise. The object was observed at quiescence (15.4 mag) two days before the outburst detection. Such rapid evolution of the outburst suggests a normal outburst of an SU UMa-type dwarf nova. The lower panel of Figure 11 shows an enlarged light curve of the 2000 January outburst, drawn from Kyoto and Tsukuba observations. The Tsukuba observation on January 8 were shifted by 2.966 mag in order to get the best match. A smooth, slow modulation was observed on the first night (January 7), while it became more irregular on
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We also note that the second and third long outbursts were preceded by a precursor 13 d and 11 d, respectively, before each outbursts. Such appearance of precursors are relatively common in SU UMa-type superoutbursts (e.g. Marino & Walker (1970); Kato (1997)), and is naturally explained to reflect two-step ignitions (thermal instability and tidal instability) within the framework of the disk-instability model (Osaki 1989, 1996). If PU CMa would turn out to be an SS Cyg-type dwarf nova rather than an SU UMa-type dwarf nova, such a feature should require a different mechanism.

Although definitive classification requires further time-resolved photometry, we propose that PU CMa to be an excellent candidate for an SU UMa-type dwarf nova. This indication is also strengthened by the recently reported orbital period of 0.05669(4) d (Thorstensen & Fenton 2002). This period is one of the shortest periods among the known SU UMa-type dwarf novae (Thorstensen et al. 2002). Most of the systems with similar orbital periods show significant deviations (either related to WZ Sge-type dwarf novae or ER UMa-type dwarf novae) from normal SU UMa-type dwarf novae. PU CMa, with its outburst properties strongly resembling a normal SU UMa-type dwarf nova (Vogt 1980; Warner 1983; Warner 1985), may be the first object filling the gap between the extreme WZ Sge-type and ER UMa-type systems.

6 SUPERHUMP PERIOD CHANGES IN LONG-PERIOD SYSTEMS

We have shown that V877 Ara has a definitely large decrease of the superhump period. Even allowing for unusually large measurement errors of superhump times, an even more striking decrease is inferred in KK Tel. The periods of "textbook" superhumps in usual SU UMa-type dwarf novae have been known to decrease during a superoutburst (e.g. Warner 1983; Patterson et al. 1983). Warner (1983) showed that the period derivative (\(P_{\text{dot}} = P / P\)) has a rather common negative value (\(\sim -5 \times 10^{-5}\)). This period change has been generally attributed to decreasing apsidal motion due to a decreasing disk radius (Osaki 1989; inward propagation of the eccentricity wave (Lubow 1992); Kato et al. 2001) systematically studied \(P_{\text{dot}}\) in SU UMa-type dwarf novae. Within the survey by Kato et al. (2001), most of long-\(P_{\text{orb}}\) SU UMa-type dwarf novae have been confirmed to show a "textbook" decrease of the superhump periods. On the other hand, short-period systems or infrequently outbursting SU UMa-type systems have been found to predominantly show an increase in the superhump periods.

In recent years, some long-period SU UMa-type stars (V725 Aql; Uemura et al. 2001; EF Peg: K. Matsumoto et al, in preparation) have been known to show zero or marginally positive \(P_{\text{dot}}\). While this finding seems to give an impression that \(P_{\text{dot}}\) makes a minimum around the period of 0.07–0.08 d, the discovery of a large negative \(P_{\text{dot}}\) in long-period systems (V877 Ara and KK Tel) more implies a previously neglected diversity of \(P_{\text{dot}}\) in long-period SU UMa-type systems. Figure 4 shows \(P / P\) versus \(P_{\text{SH}}\) for SU UMa-type dwarf novae. This diagram clearly shows the present of different populations (i.e. systems with \(P_{\text{dot}} \sim 0\) and systems with definitely negative \(P_{\text{dot}}\) in long-period \(P_{\text{SH}} > 0.08\) d) systems.

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Figure 13. Long-term visual light curve of PU CMa. Large and small dot represent positive and negative (upper limit) observations, respectively. Three long outbursts (JD 2451677, 2452056, 2452418) were detected.

Figure 14. $\dot{P}/P$ versus $P_{\text{SH}}$ for SU UMa-type dwarf novae. The open circles are from Kato et al. (2001). The data points of 1RXS J232953.9+062814 and V725 Aql is from Uemura et al. (2002b) and Uemura et al. (2001).

Dwarf novae was first attributed to different tidal torques in different binary mass ratios ($q = M_2/M_1$) i.e. short-$P_{\text{SH}}$ WZ Sge stars have the lowest $q$, which could explain the small tidal effect on the accretion disk (Patterson et al. 1993). Kato et al. (1998) further proposed an idea that a large disk radius in superoutbursting WZ Sge-type dwarf novae (cf. Osaki & Meyer 2002) enables outward propagation of eccentricity waves, which is responsible for positive $P/P$ in WZ Sge-type stars. Recent discoveries of nearly zero $P/P$ in long-period, low mass-transfer rate ($\dot{M}$) systems (EF Peg and V725 Aql), however, seem to more favor a new interpretation that $\dot{P}/P$ more reflects $\dot{M}$ (see also Kato et al. 2001 for more discussion). If the latter possibility is the origin of different $P/P$, the present discovery of a diversity of $P/P$ provides new evidence of a wide variety of $\dot{M}$ in long-period SU UMa-type dwarf novae. In short-period SU UMa-type dwarf novae (and related systems), there is a well-established diversity [WZ Sge-type stars and ER UMa stars, permanent superhumpers (Dobrzycka & Howell 1992; Skillman & Patterson 1993; Ringwald et al. 1999)]. There have been two recent attempts to interpret this diversity by introducing an inner truncation of the accretion disk and irradiation on
the secondary star (Buat-Ménard et al. 2001, Buat-Ménard & Hameury 2002) and by considering a decoupling between the thermal and tidal instabilities in low q systems (Hellier 2001b). Both models are expected to show smaller effects which has led to new insights into fundamental problems of accretion disks (Osaki 1995a, Buat-Ménard et al. 2001, Buat-Ménard & Hameury 2002, Hellier 2001b). The present discovery of a diversity in long-period SU UMa-type systems would become an additional step toward full understanding the dwarf nova and CV phenomenon.

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