Curious Variables Experiment (CURVE).
Superhump Period Change Pattern in KS UMa and
Other Dwarf Novae

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Abstract

We report extensive photometry of the dwarf nova KS UMa throughout its 2003 superoutburst
till quiescence. During the superoutburst the star displayed clear superhumps with a mean period
of $P_{\text{sh}} = 0.070092(23)$ days. In the middle stage of superoutburst the period was increasing with a
rate of $\dot{P}/P = (21 \pm 12) \times 10^{-5}$ and later was decreasing with a rate of $\dot{P}/P = -(21 \pm 8) \times 10^{-5}$.

At the end of superoutburst and during first dozen days of quiescence the star was showing
late superhumps with a mean period of $P_{\text{late}} = 0.06926(2)$ days. This phenomenon was observed
even 30 days after beginning of the superoutburst.

In quiescence the star shows quasi-periodic modulations with amplitude reaching 0.5 mag.
The most common structure observed during this stage was sinusoidal wave characterized by a
period of about 0.1 days.

Comparing KS UMa to other SU UMa stars we conclude that this group of dwarf novae shows
decreasing superhump periods at the beginning and the end of superoutburst but increasing period
in the middle phase.

\textbf{Key words:} Stars: individual: KS UMa – binaries: close – novae, cataclysmic variables
1 Introduction

Balayan (1997) identified 10 cataclysmic variables among the stars of the Second Buryakan Sky Survey (Makarian and Stepanian 1983). Seven of these variables were already known, but three were new. One of these new objects was KS UMa (SBS 1017+533).

Figure 1: Finding chart for KS UMa covering a region of $6.5 \times 6.5$ arcminutes. The position of the comparison star is shown. North is up, east is left.

Figure 2: The general photometric behavior of KS UMa during its 2003 superoutburst. Visual estimates collected in the VSNET archive are shown as open squares and CCD observations described in this paper as dots.
In 1998 the star was observed in the bright state. Detection of the superhumps with period of 0.0697 day during this event by T. Vanmunster proved that KS UMa belongs to the group of SU UMa type dwarf novae.

Historical light curve of the star based on the Harvard College Observatory photographic plates was obtained by Hazen and Garnavich (1999).

KS UMa most probably coincides with the ROSAT X-ray source J1020.4+5304 (Snowden et al. 1995) located only 10 arc sec away from the variable.

On 2003 February 18/19 KS UMa went into the superoutburst again as was announced by Eddy Muylleart and Gary Poyner. Because of the excellent visibility, and because of the lack of the entire coverage of a superoutburst in the past, we performed extensive CCD photometry of the star both in the superoutburst and quiescence.

2 Observations

Observations of KS UMa reported in the present paper were obtained during 23 nights from 2003 February 21 to April 1 at the Ostrowik station of the Warsaw University Observatory. They were collected using the 60-cm Cassegrain telescope equipped with a Tektronics TK512CB back illuminated CCD camera. The scale of the camera was 0.76"/pixel providing a 6.5′ × 6.5′ field of view. The full description of the telescope and camera was given by Udalski and Pych (1992).

We monitored the star in “white light”. This was due to the lack of an autoguiding system, not yet implemented after recent telescope renovation. Thus we did not use any filter to shorten the exposures in order to minimize guiding errors.

The exposure times were from 30 to 90 seconds during the bright state and from 150 to 300 seconds in the minimum light.

A full journal of our CCD observations of KS UMa is given in Table 1. In total, we monitored the star during 110.18 hours and obtained 3150 exposures.

2.1 Data Reduction

All the data reductions were performed using a standard procedure based on the IRAF package and the profile photometry has been derived using the DAOphotII package (Stetson 1987).

Relative unfiltered magnitudes of KS UMa were determined as the difference between the magnitude of the variable and the magnitude of the comparison star GSC 3815:610 (R.A. = 10h 20m 28.25s, Decl. = +53° 06′ 36.6″) located 2.2′ to the north of the variable. This comparison star is marked in the chart displayed in Fig. 1.

Note that a faint companion of magnitude V ≈ 18 located few seconds to the east of the variable does not affect our profile photometry in any substantial way.

The typical accuracy of our measurements varied between 0.001 and 0.012 mag in the bright state and between 0.006 and 0.055 mag in the minimum light. The median value of the photometry errors was 0.005 and 0.014 mag, respectively.

1VSNET alert no. 1448
2VSNET-superoutburst 1919 alert
3IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.
Table 1: JOURNAL OF THE CCD OBSERVATIONS OF KS UMA

| Date of 2003 | Time of start 2452000. + | Time of end 2452000. + | Length of run [hr] | Number of frames |
|-------------|--------------------------|------------------------|-------------------|-----------------|
| Feb. 21/22  | 692.30016                | 692.69672              | 6.313             | 284             |
| Feb. 22/23  | 693.21151                | 693.69672              | 11.596            | 624             |
| Feb. 23/24  | 694.22142                | 694.52265              | 6.230             | 365             |
| Feb. 24/25  | 695.21588                | 695.49997              | 6.818             | 285             |
| Feb. 25/26  | 696.23725                | 696.54021              | 7.271             | 425             |
| Feb. 26/27  | 697.37482                | 697.52844              | 3.687             | 219             |
| Feb. 27/28  | 698.23340                | 698.67746              | 6.931             | 139             |
| Mar. 05/06  | 704.44387                | 704.46670              | 0.548             | 20              |
| Mar. 06/07  | 705.22579                | 705.31920              | 2.242             | 75              |
| Mar. 07/08  | 706.26975                | 706.51688              | 5.931             | 122             |
| Mar. 15/16  | 714.37474                | 714.46856              | 2.252             | 45              |
| Mar. 21/22  | 720.25577                | 720.58496              | 7.901             | 76              |
| Mar. 22/23  | 721.26472                | 721.50796              | 3.032             | 30              |
| Mar. 23/24  | 722.38846                | 722.56662              | 4.276             | 36              |
| Mar. 24/25  | 723.42628                | 723.47508              | 5.491             | 78              |
| Mar. 25/26  | 724.42984                | 724.60743              | 4.262             | 62              |
| Mar. 26/27  | 725.38228                | 725.44741              | 1.563             | 16              |
| Mar. 27/28  | 726.25305                | 726.57153              | 7.644             | 92              |
| Mar. 28/29  | 727.39841                | 727.43791              | 0.948             | 12              |
| Mar. 29/30  | 728.28647                | 728.45990              | 4.162             | 44              |
| Mar. 30/31  | 729.28010                | 729.33608              | 1.344             | 16              |
| Mar. 31/01  | 730.27469                | 730.46936              | 4.672             | 39              |
| Apr. 01/02  | 731.29169                | 731.46109              | 4.066             | 46              |
| Total       | –                        | –                      | 110.18            | 3150            |

2.2 Light curves

Fig. 2 presents the photometric behavior of KS UMa as observed between February and April 2003. Relative differential magnitudes of the variable were transformed to the visual magnitudes using visual estimates of the brightness of the star made by astronomy amateurs and published in VSNET archive (these observations are marked using open squares). Photographic magnitude of our comparison star, according to GSC catalogue is $14.59 \pm 0.21$ mag. With respect to that the visual scale on Fig. 2 appears to be shifted by 0.3 mag down.

The superoutburst of KS UMa started on Feb. 18/19. Subsequent CCD photometry made by Tonny Vanmunster showed no short term modulations apart from general brightening. Full development of the superhumps took place on Feb. 19.

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4 VSNET-superoutburst 1919 alert  
5 VSNET-superoutburst 1921 and 1923 alerts  
6 VSNET-superoutburst 1927 alert
Figure 3: The light curves of KS UMa observed during seven consecutive nights in February 2003.
Figure 4: The light curves of KS UMa observed between Mar. 05/06 and Mar. 23/24.
Figure 5: The light curves of KS UMa observed between Mar. 24/25 and Apr. 01/02.
Our observations started with fourth night of the superoutburst and with the third night of the presence of the superhumps. We observed the superoutburst during seven consecutive nights from Feb. 21/22 to Feb. 27/28. During this time the star faded by 0.85 mag giving the mean decrease of 0.13 mag per day. Our observing run from Mar. 05/06 shows that the star was still 0.5 mag brighter than in the quiescence. During the night of Mar. 06/07 this difference was only 0.1 mag. Thus we conclude that the superoutburst lasted until Mar. 06/07 i.e. 16 days.

Fig. 3 shows the light curves of KS UMa during seven consecutive nights of February 2003. The superhumps are clearly visible in each run.

The light curves from period Mar. 05/06 to Mar. 23/24 are shown in Fig. 4. Clear periodic light variations are present even until Mar. 22/23.

Fig. 5 shows the lights curves of seven longest runs from period Mar. 24/25 to Apr 01/02. The magnitude of the star varied during this interval with amplitude of 0.5 mag but the changes were more chaotic and there is no trace of strictly periodic signal as in Figs. 3 and 4.

3 Superhumps

3.1 Amplitude

In a typical SU UMa star the amplitude of the superhumps reaches its maximum around third day of the superoutburst. Starting from this moment the amplitude monotonically decreases. Few days later superhumps evolve from the tooth-shape light curve to more complicated shape showing more scatter and secondary maxima called interpulses. Around the end of the superoutburst low amplitude superhumps switch into late humps characterized by the same period but phase shift of $\sim 0.5$ cycles.

As was described in the VSNET e-mail list $^7$ the peak-to-peak amplitude of the superhumps in KS UMa reached a maximum of 0.30 mag on Feb. 20. During the first night of our run i.e. on Feb. 21/22 the amplitude was 0.21 mag as is clearly visible in our Fig. 6 where we show the mean superhump profiles for each night. These profiles were obtained by phasing our observations with the superhump period for each night and averaging them in 0.02 - 0.05 phase bins.

Our longest run obtained on Feb. 22/23 lasting almost 12 hours shows gradual change in the superhump profile. During this interval the amplitude of the superhumps decreased from 0.20 mag (first four humps) to 0.16 mag (last 3 humps). Additionally, the main superhump maxima became weaker, while other peaks became stronger.

During the night of Feb. 23/24 the light curve was quite noisy with amplitude of the modulations equal to 0.13 mag. Surprisingly, on Feb. 24/25 the amplitude increased to 0.17 mag and the shape of the superhumps became sharp and smooth again as during the first days of the superoutburst.

Increase of the amplitude of the superhumps has been continued until Feb. 25/26 when it reached its local maximum with 0.18 mag. However the shape of the light curve during this night changed markedly in comparison with Feb. 24/25. The interpulses and other secondary humps were also clearly visible in the light curves from Feb. 26/27 and 27/28 and during these nights amplitude was 0.16 and 0.12 mag, respectively.

$^7$ VSNET-superoutburst 1929
3.2 Period

From each light curve of KS UMa in superoutburst we removed the first or second order polynomial and then analyzed them using ANOVA statistics and two harmonics Fourier series (Schwarzenberg-Czerny 1996). The resulting periodogram is shown in Fig. 7. The most prominent peak is found at a frequency of $f = 14.263 \pm 0.010$ c/d, which corresponds to the period $P_{sh} = 0.07011(5)$ days (100.96 ± 0.07 min). The peak visible at 7.13 c/d is a ghost of main frequency arising due to use of two harmonics. The harmonic peak at 28.53 c/d appears to be real. The inset in Fig. 7 shows the magnification of the power spectrum around main frequency. Apart from this main peak and its aliases the inset shows no other significant periodicities.

![Figure 6: Amplitude and profile changes of superhumps during 2003 superoutburst of KS UMa.](image)

The light curve of KS UMa in superoutburst was prewhitened with the main period and its first harmonic. The power spectrum of the resulting light curve shows no clear peaks except second, third and fourth harmonics of the main frequency.
For nights from Feb. 21 to 27 we determined 27 times of maxima of superhumps. They are shown in Table 2 together with their cycle numbers $E$. The least squares linear fit to the data from Table 2 gives the following ephemeris:

$$HJD_{\text{max}} = 2452692.3279(12) + 0.070087(26) \cdot E$$

indicating that the mean value of the superhump period $P_{sh}$ is equal to $0.070087(26)$ days ($100.93 \pm 0.04$ min). This is in good agreement with the value obtained from the power spectrum analysis.

Combination of both our determinations gives the mean value of superhump period as equal to $P_{sh} = 0.070092(23)$ days.

The $O-C$ departures from the ephemeris (1) are given also in Table 2 and shown in the lower panel of Fig. 8. The best fit to these data shown as a solid line corresponds to the ephemeris:

$$HJD_{\text{max}} = 2452692.3279 + 0.069804E + 1.25 \times 10^{-5} E^2 - 1.15 \times 10^{-7} E^3$$

$$\pm 0.0022 \quad \pm 0.000233 \quad \pm 0.63 \quad \pm 0.47$$

### 3.3 Is KS UMa untypical?

The upper panel of Fig. 8 shows the evolution of the peak-to-peak amplitude of the superhumps during 2003 superoutburst of KS UMa. It resembles in all details evolution of the superhump period shown in the lower panel. Both the amplitude and the superhump period behavior looks untypical for SU UMa stars. As we wrote earlier the amplitude of the superhumps usually decreases monotonically during the superoutburst.
Table 2: Times of maxima observed in the light curve of KS UMa during its 2003 superoutburst

| E  | HJD$_{max}$ | O − C  
|----|-------------|---------|
| 0  | 2452692.328 | 0.0014  |
| 3  | 2452692.538 | −0.0024 |
| 5  | 2452692.676 | −0.0335 |
| 13 | 2452693.238 | −0.0153 |
| 14 | 2452693.307 | −0.0308 |
| 15 | 2452693.377 | −0.0321 |
| 16 | 2452693.446 | −0.0477 |
| 17 | 2452693.517 | −0.0347 |
| 18 | 2452693.589 | −0.0074 |
| 19 | 2452693.658 | −0.0230 |
| 28 | 2452694.290 | −0.0060 |
| 29 | 2452694.360 | −0.0073 |
| 31 | 2452694.499 | −0.0241 |
| 42 | 2452695.273 | 0.0188 |
| 43 | 2452695.342 | 0.0104  |
| 44 | 2452695.414 | 0.0305  |
| 45 | 2452695.486 | 0.0578  |
| 56 | 2452696.258 | 0.0722  |
| 57 | 2452696.326 | 0.0424  |
| 58 | 2452696.392 | −0.0088 |
| 59 | 2452696.464 | 0.0113  |
| 60 | 2452696.536 | 0.0385  |
| 73 | 2452697.448 | 0.0504  |
| 74 | 2452697.514 | −0.0009 |
| 85 | 2452698.280 | −0.0721 |
| 86 | 2452698.350 | −0.0805 |
| 87 | 2452698.420 | −0.0818 |

Till the mid of 1990ties all members of SU UMa group seemed to show only negative superhump period derivatives (Warner 1985, 1995, Patterson et al. 1993). It was interpreted as a result of disk shrinkage during the superoutburst and thus lengthening its precession rate (Lubow 1992). This picture become more complicated when the first stars with $\dot{P} > 0$ were discovered. Positive period derivatives were observed only in stars with short superhump periods close to the minimum orbital period for hydrogen rich secondary (e.g. SW UMa - Semeniuk et al. 1997a, WX Cet - Kato et al. 2001a, HV Vir - Kato et. al. 2001b) or for stars below this boundary (e.g. V485 Cen - Olech 1997, 1RXS J232953.9+062814 - Uemura et al. 2002).

The diversity of $\dot{P}$ behavior is well represented in the $\dot{P}/P$ versus $P_{sh}$ diagram shown in Fig. 9. This diagram is taken from Kato et al. (2003a) with additional point for V1141 Aql (Olech 2003). It shows also the position of the periodic gap and minimum period for dwarf nova systems with hydrogen rich secondaries (Paczyński 1981). The outliers such as V485 Cen, 1RXS J232953.9+062814, KK Tel and TU Men are also marked.

Recently, Nogami et al. (2003) reported observations of Var73 Dra - the new SU UMa dwarf nova in the period gap. They found that the star having mean superhump period of $P_{sh} = 0.10623(16)$ days showed its change rate of $\dot{P}/P = -1.7 \pm 0.2 \times 10^{-3}$ which is one order of magnitude larger than the largest values known. For clarity we do not plot the position of Var73 Dra in our Fig. 9.

There are however few dwarf novae in which the superhump period derivative is not constant and changes its sign. The first case of the complex period behavior was observed during 1995 superoutburst of AL Com (Howell et al. 1996) when during the first stage of superoutburst the period was increasing with a rate of $\dot{P}/P = 2.1 \times 10^{-5}$ and later decreased quite rapidly.

Complex behavior of period and amplitude of the superhumps was observed recently in ER UMa (Kato et al. 2003b) and V1028 Cyg (Baba et al. 2000). In the first stage of the outburst, superhump
period of ER UMa was increasing and around 5th day after superoutburst maximum ordinary superhumps were switched into late superhumps which was connected with change of the amplitude of the modulation and sign of the period derivative. In the case of KS UMa the superhump period was also increasing and changed its derivative between third and fourth night of our observations (i.e. around fifth day after the maximum light as in case of ER UMa). But as it is clearly visible from our Fig. 8 change of the sign of period derivative in KS UMa was not connected with transition to the late superhumps because we did not observe the ~0.5 phase shift in the superhumps maxima.

Figure 8: *Upper panel*: Peak-to-peak amplitude changes of the superhumps in KS UMa. *Lower panel*: O – C diagram for 24 times of superhump maxima of KS UMa. The solid line shows the relation computed using ephemieris (2) and dotted line is a quadratic fit to the points starting form cycle number 28.
Figure 9: $\dot{P}/P$ versus $P_{sh}$ for SU UMa-type dwarf novae. The figure is taken from Kato et al. (2003a). Black dot shows the position of KS UMa corresponding to the ephemeris shown by the dotted line in Fig. 8. $P_{\text{min}}$ denotes the boundary for hydrogen rich secondary.

Period and amplitude changes of KS UMa resemble closely those of V1028 Cyg during its 1995 superoutburst (Baba et al. 2000). In that case the superhumps were fully developed on 1995 July 31. During the next six days the amplitude decreased from 0.25 to 0.05 mag and the period was increasing with the rate of $\dot{P}/P = 8.7 \times 10^{-5}$. Starting from 1995 Aug. 6 amplitude of the superhumps was larger again and period was decreasing. The $O-C$ diagram shown by Baba et al. (2000) shows no signs of 0.5 phase shift around Aug. 6 thus periodic light curve modulations observed after this date are still ordinary not late superhumps.

According to Baba et al. (2000) V1028 Cyg may be a link between ordinary SU UMa stars and WZ Sge subgroup of these variables. WZ Sge stars are characterized by very long supercycles, large amplitudes of superoutbursts and short orbital periods (close to 80 min boundary). V1028 Cyg with orbital period around 87 min, supercycle over 400 days and amplitude of the superoutburst around 6 mag is placed exactly between ordinary SU UMa stars and WZ Sge variables. On the other hand it this not the case of KS UMa whose supercycle is around one year, orbital period around 98 min and amplitude of the outburst around 4 mag.

A possible explanation of the untypical behavior of KS UMa is assumption that it is in fact quite typical. If we would start our observations from night of Feb. 23/24, not two days earlier, we would conclude that the period of the superhumps was decreasing with a rate of $\dot{P}/P = -20 \pm 8 \times 10^{-5}$ (as is shown by dotted line in Fig. 8 and filled circle in Fig. 9).

Recent progress in development of cheap but quite sensitive CCD detectors allowed astronomy amateurs to observe outbursts and detect superhumps of many dwarf novae and collaborate with professional astronomers. The excellent examples of such a fruitfull collaboration are Center fo
Backyard Astrophysics (CBA) run by Joseph Patterson from Columbia University and also VSNET run by Taichi Kato and Daisaku Nogami. Thus during last years we had usually very good coverage of superoutburst of interesting objects and we have started to discover such "peculiarities" as in case of KS UMa, V1028 Cyg, ER UMa or AL Com. The question is when the number of such "peculiar" objects become so large that we will begin to consider such a behavior as typical.

To check this hypothesis we reviewed the literature in search for reported period variations in stars with $P_{sh}$ close to period of KS UMa. The results of our search are summarized in Table 3 when we show designation of the star, its mean superhump period, period derivative in units of $10^{-5}$ and corresponding reference.

| Object     | $P_{sh}$  | $\dot{P}/P$ | Reference                |
|------------|-----------|--------------|--------------------------|
| V1028 Cyg  | 0.06154   | +8.7(0.9)    | Baba et al. (2000)       |
| V1159 Ori  | 0.0642    | −3.2(1)      | Patterson et al. (1995)  |
| CT Hya     | 0.06643   | −2(8)        | Kato et al. (1999)       |
| SX LMi     | 0.0685    | −8(2)        | Nogami et al. (1997)     |
| RZ Sge     | 0.07039   | −11.5(1)     | Semeniuk et al. (1997b)  |
| CY UMa     | 0.0724    | −5.8(1.4)    | Harvey & Patterson (1995) |

The $O - C$ diagrams for stars from the papers listed in Table 3 are shown in Fig. 10. The cycle numbers $E$ were renumerated to have $E \approx 0$ corresponding approximately to the moment of birth of the superhump in the light curve of the star.

What can we learn from Fig. 10? The most interesting thing is that this figure forces us to revise previous statements on the superhump period behavior. Warner (1985, 1995) and Patterson et al. (1993) argued that the period derivative in SU UMa stars has a rather common negative value of $\dot{P}/P \sim -5 \times 10^{-5}$. From our Figs. 8 and 10 we can clearly see that this is not true. Recently Kato et al. (2001b, 2003a) indicated that most of long-period systems show a "textbook" decrease of the superhump periods but short-period systems or infrequently outbursting SU UMa type systems predominantly show an increase in the superhump period. The transition between short and long period systems is around period of 0.062 day thus V1028 Cyg with $P_{sh} = 0.06154$ day was short-period system and its $\dot{P}/P$ was positive while V1159 Ori with $P_{sh} = 0.0642$ day was included into a group of long-period systems with negative $\dot{P}/P$ (as shown in Table 3).

Fortunately, observational coverage of the superoutbursts of V1028 Cyg (Baba et al. 2000) and V1159 Ori (Patterson et al. 1995) was excellent and comparison of the both $O - C$ shown in Fig. 10 indicates that in fact at the beginning of the superoutburst the superhump period was decreasing, in the middle phase of superoutburst was increasing and in the third - the longest phase was again decreasing. Baba et al. (2002) selected middle phase as representative for whole superoutburst of V1028 Cyg and obtained positive $\dot{P}/P$. On the other hand, Patterson et al. (1995) simply fitted the parabola to all determined maxima of V1159 Ori and therefore obtained negative value of $\dot{P}/P$.

The final conclusion of this section is that most probably all SU UMa stars, both short and long period, show decreasing superhump period in the beginning and in the end of the superoutburst but increasing period in the middle phase. Our Fig. 10 proves it for medium and long period systems.
Recent observations of short period stars such as WZ Sge (see Fig. 17 of Patterson et al. 2002), WX Cet (Fig. 7 of Kato et al. 2001a), ER UMa (Fig. 2 of Kato et al. 2003b), EG Cnc (Fig. 5 of Patterson et al. 1998) and AL Com (Fig. 9 of Howell et al. 1996) suggest that it is also true for this subgroup of SU UMa-type variables.

![Figure 10: O – C diagrams for SU UMa-type dwarf novae with superhump period close to 0.07 days.](chart)

15
In the case of KS UMa during the first four days of our observations (days 4 – 7 of superoutburst) the period of superhumps was increasing with a rate of \( \dot{P}/P = (21 \pm 12) \times 10^{-5} \) and later (days 7 – 12 of superoutburst) was decreasing with a rate of \( \dot{P}/P = -(21 \pm 8) \times 10^{-5} \).

4 Late superhumps

The 2003 superoutburst of KS UMa lasted until March 06/07 but modulations with period close to \( P_{sh} \) were observed even till March 22/23 (see Fig. 4). The shape and amplitude of these modulations was changing very quickly, sometimes from cycle to cycle, thus for searching for periodicities we decided to use ordinary Fourier transform. The power spectrum for period from March 05/06 to 21/22 is shown in Fig. 11. The highest peak is found at the frequency of 14.38 ± 0.020 which corresponds to the period of 0.0695 ± 0.0001 days.

![KS UMa 5.03–21.03](image)

Figure 11: Power spectrum of the light curves of KS UMa from March 05/06 to 21/22

In the case of these late superhumps the minima were more clear and sharp than maxima thus were much better for \( O - C \) analysis. Finally, in period Mar. 06 – 22 we determined 11 times of minima, which are listed in Table 4 together with their cycle counts \( E \) and \( O - C \) values computed according to the following ephemeris:

\[
\text{HJD}_{\text{min}} = 2452706.4341(20) + 0.06925(2) \cdot E
\] (3)
Table 4: TIMES OF MINIMA OBSERVED IN THE LIGHT CURVE OF KS UMa DURING LATE SUPERHUMP STAGE

| $E$ | HJD$_{min}$ | $O-C$ [cycles] | $E$ | HJD$_{min}$ | $O-C$ [cycles] |
|-----|-------------|----------------|-----|-------------|----------------|
| −17 | 2452705.258 | 0.0166         | 201 | 2452720.353 | −0.0051        |
| −2  | 2452706.295 | −0.0086        | 202 | 2452720.415 | −0.1097        |
| −1  | 2452706.364 | −0.0124        | 203 | 2452720.474 | −0.2577        |
| 0   | 2452706.435 | 0.0130         | 204 | 2452720.564 | 0.0419         |
| 1   | 2452706.504 | 0.0094         | 217 | 2452721.480 | 0.2693         |
| 200 | 2452720.277 | −0.1025        | 17  | 2452720.277 | −0.1025        |

$O-C$ deviations are sometimes large but show no clear trend. We thus conclude that period of the late superhumps was roughly constant and its value was (combination of $O-C$ and power spectrum estimates): $P_{\text{late}} = 0.06926(2)$ days.

Figure 12: O – C diagram for common (filled circles) and late (open circles) superhump maxima of KS UMa. O – C departures are computed using ephemeris (1).

Despite of the five day break in observations between Feb. 28 and Mar. 4 we decided to determine the values of the maxima in the light curve of KS UMa in early March and connect them with the
maxima observed in February. The March maxima are listed in Table 5 together with cycle numbers
$E$ and $O - C$ departures computed according to the ephemeris (1). The $O - C$ values are shifted in
phase by 0.5.

Table 5: TIMES OF MAXIMA OBSERVED IN THE LIGHT CURVE OF KS UMa DURING LATE SUPER-
HUMP STAGE

| $E$ | HJD$_{max}$     | $O - C$  |
|----|----------------|----------|
|    | [cycles]       |          |
| 173| 2452704.450    | -0.5421  |
| 185| 2452705.282    | -0.6711  |
| 200| 2452706.329    | -0.7326  |
| 201| 2452716.395    | -0.1709  |
| 202| 2452716.466    | -0.7779  |

The $O - C$ departures for common and late superhumps are shown in Fig. 12. Provided our
cycle count is correct, we can conclude that in the second stage of the superoutburst and during late
superhump phase the superhump period decreased with a rate of $\dot{P}/P = -(6.0 \pm 1.1 \times 10^{-5}$ i.e. value
quite typical for medium and long period SU UMa stars.

5 Quiescence

As displayed in Fig. 5 KS UMa in quiescence shows quasi-periodic modulations with amplitude
reaching even 0.5 mag. The most characteristic feature observed in this stage was sinusoidal wave
with period around 0.1 days clearly visible during late March nights.

The Fourier power spectrum for nights Mar. 24/25 – Apr. 01/02 is shown in Fig. 13. Before
calculation the light curves were prewhitened using second order polynomial.

The periodogram yields no specific frequency of these modulations. The highest peak found in
Fig. 13 corresponds to the frequency $10.20 \pm 0.02$ c/d i.e. to the period of $0.0980 \pm 0.0002$ days and
exceeds only marginally competing features.

6 Summary

We reported extensive photometry of the dwarf nova KS UMa in its 2003 superoutburst and quies-
cence. The amplitude of the superoutburst was 3.9 mag. The maximal brightness of the star was 12.3
mag and the mean magnitude in quiescence was 16.2.

The 2003 superoutburst of KS UMa lasted from Feb. 18/19 to Mar. 06/07 i.e. 16 days. During
this interval the star showed clear superhumps with a mean period of $P_{sh} = 0.070092(23)$ days.

On Feb. 21/22 the amplitude of the superhumps was 0.21 mag and decreased to 0.13 mag on Feb.
23/24. Surprisingly, later amplitude increased reaching its local maximum with 0.18 mag on Feb.
25/26.

In the middle stage of superoutburst the period of superhumps was increasing with a rate of $\dot{P}/P =
(21 \pm 12) \times 10^{-5}$ and later was decreasing with a rate of $\dot{P}/P = -(21 \pm 8) \times 10^{-5}$. Comparing
KS UMa to other SU UMa stars we concluded that this group of dwarf novae shows decreasing superhump periods at the beginning and the end of superoutburst but increasing period in the middle phase. This is contrary to the original suggestion of Warner (1985, 1995) and Patterson et al. (1993) that superhump periods usually decrease with a rate around $-5 \times 10^{-5}$ and also in contrast with a recent investigation of Kato et al. (2001a) who concluded that short period systems shows increasing periods but long period SU UMa stars are characterized by decreasing periods.

\[
\text{KS UMa } 24.03-1.04
\]

![Power spectrum of the light curves of KS UMa from Mar. 24/25 to Apr. 01/02](image)

At the end of the superoutburst and during first dozen days of quiescence the star showed late superhumps with a mean period of $P_{\text{late}} = 0.06926(2)$ days. This phenomenon was observed even 30 days after beginning of the superoutburst.

In quiescence the star shows quasi-periodic modulations with amplitude reaching 0.5 mag. The most common structure observed during this stage was sinusoidal wave characterized by period of 0.098 days.

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