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DETECTION OF SUPERHUMPS AND QUASI-PERIODIC OSCILLATIONS IN THE LIGHT CURVE OF THE DWARF NOVA SW URSAE MAJORIS

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ABSTRACT

The dwarf nova SW UMa erupted in 1986 March. The eruption lasted more than 3 weeks and had an amplitude greater than 7 mag. We obtained high-speed photometry of SW UMa on 10 nights during the eruption. Superhumps with a period of 84.0 ± 0.1 minutes and peak-to-peak amplitudes of up to 11% appeared in the light curve for at least 7 days of the eruption, proving conclusively that the eruption was a supermaximum and, therefore, that SW UMa is a member of the SU UMa subclass of dwarf novae. The superhumps in SW UMa have a period 2.7% longer than the 81.8 minute orbital period of the system, a difference typical of the superhumps of SU UMa stars. Quasi-periodic oscillations with a period near 5 minutes, a mean semiamplitude of 0.4%, and a coherence time of roughly 2 cycles appeared in the light curve on at least two nights of the eruption. Low-amplitude quasi-periodic oscillations with a mean period of 22.3 s were also present on several nights. This is the shortest period found so far for any bona fide quasi-periodic oscillation in a dwarf nova. The addition of SW UMa to the list of short-period dwarf novae with supermaxima lends further support to the hypothesis that all dwarf novae with periods less than 3 hr are SU UMa stars and that all SU UMa stars have orbital periods less than 3 hr. SW UMa is probably an intermediate polar. If so, it is the only one with unambiguous dwarf nova eruptions and now the first to show supermaxima and superhumps. If the 15.9 minute rotation period deduced for the white dwarf by Shafter *et al.* is correct, the intermediate polar model for superhumps cannot be correct.

Subject headings: stars: dwarf novae — stars: individual

I. INTRODUCTION

The only extensive observational study of the dwarf nova SW UMa was made by Shafter, Szkody, and Thorstensen (1986) when SW UMa was at minimum light. They found that, like all cataclysmic variables, SW UMa is a close binary star. Its orbital period is 81.8 minutes and it consists of an (unseen) late-type star transferring mass to a white dwarf. The optical light curve of SW UMa varied with a period of 15.9 minutes on two of the three nights which they obtained photometric data; the X-ray light curve was also modulated at this period during the single run they obtained with *EXOSAT*. From these data they concluded that SW UMa is a likely member of the intermediate polar subclass of the cataclysmic variables; that is, they concluded that the white dwarf is magnetized and rotates with a period of 15.9 minutes (for reviews of the intermediate polars, sometimes called the long-period DQ Her stars, see Lamb 1983 and Warner 1983). The matter accreting onto the white dwarf is entrained by the magnetic field and falls onto the white dwarf at its magnetic poles. The magnetic poles are hot and luminous and are, therefore, strong sources of X-ray emission. The rotation of the white dwarf brings the magnetic poles successively into view, modulating the X-rays at the 15.9 minute rotation period. We accept the identification of SW UMa as an intermediate polar, but since transient periodicities due to other causes often appear in the light curves of cataclysmic variables, the identification will not be firm until the 15.9 minute periodicity has been observed more extensively. The profiles of the emission lines in the spectrum of SW UMa show that there is a well-developed accretion disk around the white dwarf. The magnetic field is not, therefore, strong enough to dominate the flow of the transferred mass except in the near vicinity of the white dwarf.

The eruptions of SW UMa are rare but unusually pronounced. Every 460 days on average, SW UMa rises 6 mag or more from its magnitude at minimum light, $V = 16.5$–17.0, and remains bright for 2 weeks or more (Wellman 1952). The amplitude and recurrence time of these eruptions fall outside the normal range for ordinary eruptions of dwarf novae. The SU UMa stars, a subclass of the dwarf novae, have unusually bright and long eruptions called supermaxima in addition to or instead of their normal eruptions. They also have extremely short orbital periods. The strong eruptions and short orbital period of SW UMa suggested to us that it might be a member of this sublass.

Several kinds of rapid photometric activity can be present during the eruptions of dwarf novae, including quasi-periodic oscillations, coherent oscillations, superhumps, and the ever-present rapid flickering. The rapid flickering consists of random and unpredictable variations in brightness with amplitudes less than a few tenths of a magnitude and time scales of a few minutes. The power spectrum of flickering shows only a slow increase toward low frequencies, i.e., it is red noise. The quasi-periodic oscillations typically have periods between 24 s and 400 s, amplitudes of $\sim 1\%$, and a coherence time of a few cycles (Warner and Brickhill 1978; Robinson and Nather 1979; Robinson and Warner 1984). Power spectra of quasi-periodic oscillations typically show a broad region of enhanced power centered on the period of the oscillation. The coherent oscillations have periods between 7 s and 40 s, amplitudes between 0.05% and 1%, and coherence times of 20–100 cycles or more

(Patterson 1981). For a synopsis of the many, many models that have been proposed for the quasi-periodic and coherent oscillations, see Córdova and Mason (1982) and van der Klis *et al.* (1985). Superhumps appear only during supermaxima of dwarf novae. They have maximum amplitudes between 10% and 30%, they are periodic, and their period is a few percent longer than the orbital period (Vogt 1980). There is no consensus on the physical mechanism producing the superhumps (see Warner 1985), but their properties are so distinctive that they have become a diagnostic for supermaxima: if superhumps are present, the eruption must be a supermaximum.

SW UMa is unusual in several respects and deserves further attention. Its orbital period is extremely short. Among the cataclysmic variables, only WZ Sge and EF Eri have shorter periods, and their periods are shorter by only a few seconds (Robinson, Nather, and Patterson 1978; Schneider and Young 1980). The surface of the accretion disk in SW UMa is brightest in the quadrant facing away from the late-type star and preceding the white dwarf in its orbit. This is exactly opposite the position of the hot spot caused, in other cataclysmic variables, by the impact of the stream of transferred material with the disk (see Robinson 1976; Warner 1976). There is no convincing explanation for the anomalous position of the bright region. The only two intermediate polars that have also been classified as dwarf novae are SW UMa and EX Hya. We question whether EX Hya is properly classified as a dwarf nova. According to Bateson, Jones, and Menzies (1970) the eruptions of EX Hya have an amplitude of only 2.5 mag, last only ~4 days, and recur irregularly at a mean interval of ~465 days. Nearly half the "eruptions" tabulated by them had amplitudes less than ~1 mag in amplitude, however, leaving only seven substantial brightenings in 17 years of observation. In recent years EX Hya has failed to show any large increase in brightness at all (Bateson 1986). Such weak and rare increases in brightness are totally unlike the eruptions of any dwarf nova but are comparable to the behavior of many novalike variables. SW UMa may, therefore, be the only dwarf nova that is also an intermediate polar.

We were at McDonald Observatory observing with a high-speed photometer in 1986 March when SW UMa erupted. When notified by the observers of the AAVSO that the eruption had begun, we modified our program to include observations of the eruption. We present the results of our observations in this paper.

II. OBSERVATIONAL DATA

The visual light curve of the 1986 March eruption of SW UMa, compiled from observations by members of the AAVSO, is shown in Figure 1. We obtained high-speed photometry of SW UMa on 10 nights between March 8 (UT), 6 days after the beginning of the eruption, and March 23 (UT), when SW UMa was declining rapidly to minimum light. The specific nights are listed in Table 1 and are marked in Figure 1 by tick marks above the AAVSO light curve. The high-speed photometry was obtained on the 2.1 m and 0.92 m telescopes at McDonald Observatory at integration times ranging from 1 s to 10 s. Except for the data obtained on 1986 March 8 (UT), the observations were made in white light (no filters) with a RCA 8850 photomultiplier tube. The March 8 data were obtained both in white light and through Johnson *UBV* filters. The data were reduced by subtracting sky background and dark noise and then correcting, crudely, for the effects of atmospheric extinction. Since standard stars could not be observed for the *UBV*

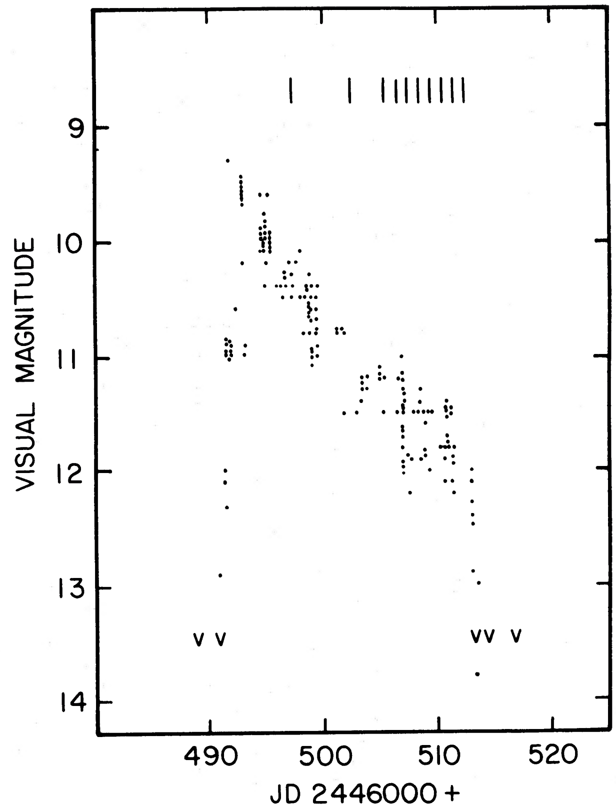

FIG. 1.—Visual light curve of 1986 March eruption of SW UMa as compiled by the observers of the AAVSO. The times when we obtained high-speed photometry of the eruption are shown by tick marks above the light curve. At minimum light SW UMa falls to V = 16.5–17.0.

TABLE 1

PHOTOMETRIC OBSERVATIONS OF SW URSAE MAJORIS

Run Number	UT Date (1986)	Start Time (JD 2,446,000.+)	Length (hr)	Telescope (m)	Integration Time (s)	Filters
3118..........	March 8	497.61898	1.84	0.9	1	*U, B, V*
122..........	March 13	502.59883	4.60	0.9	5	None
123..........	March 16	505.60293	4.88	2.1	3	None
125..........	March 17	506.60020	1.25	2.1	3	None
126..........	March 18	507.74289	1.39	2.1	3	None
3128..........	March 19	508.60370	1.53	0.9	10	None
3129..........	March 20	509.67245	2.62	0.9	10	None
3132..........	March 21	510.60301	2.61	0.9	10	None
3134..........	March 22	511.60104	3.92	0.9	10	None
3137..........	March 23	512.59734	3.71	0.9	10	None

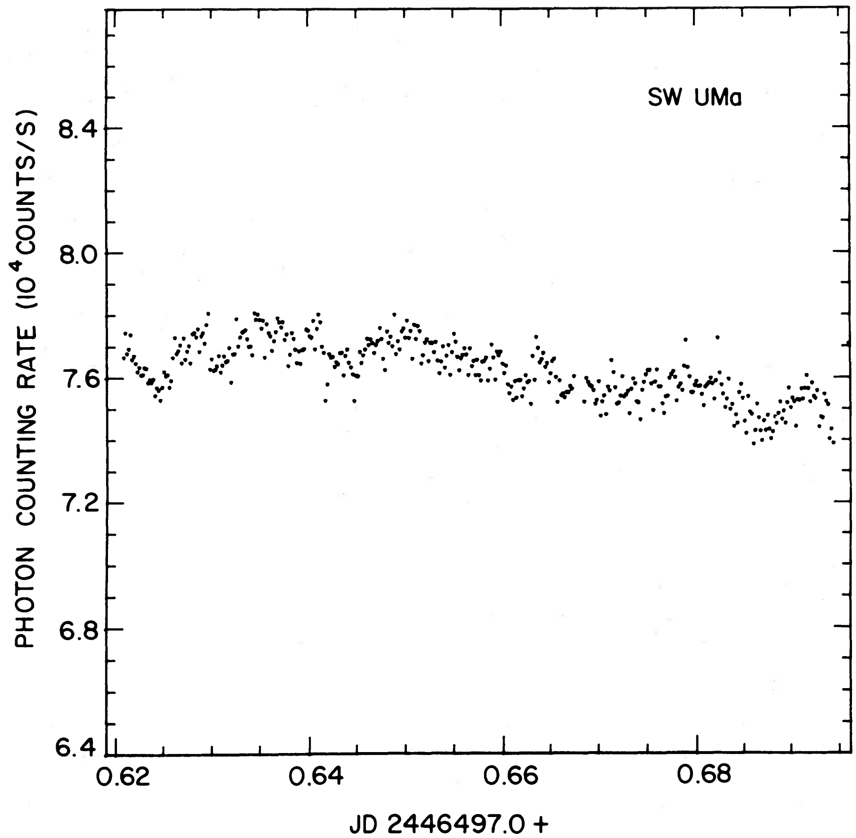

FIG. 2.—White-light light curve on the nights of 1986 March 8. Each point is the average of four 1 s integrations separated by 4 s and is therefore roughly equal to the mean brightness averaged over 16 s. The amplitude of the flickering was low and neither the superhumps nor the 5 minute quasi-periodic oscillations had appeared yet.

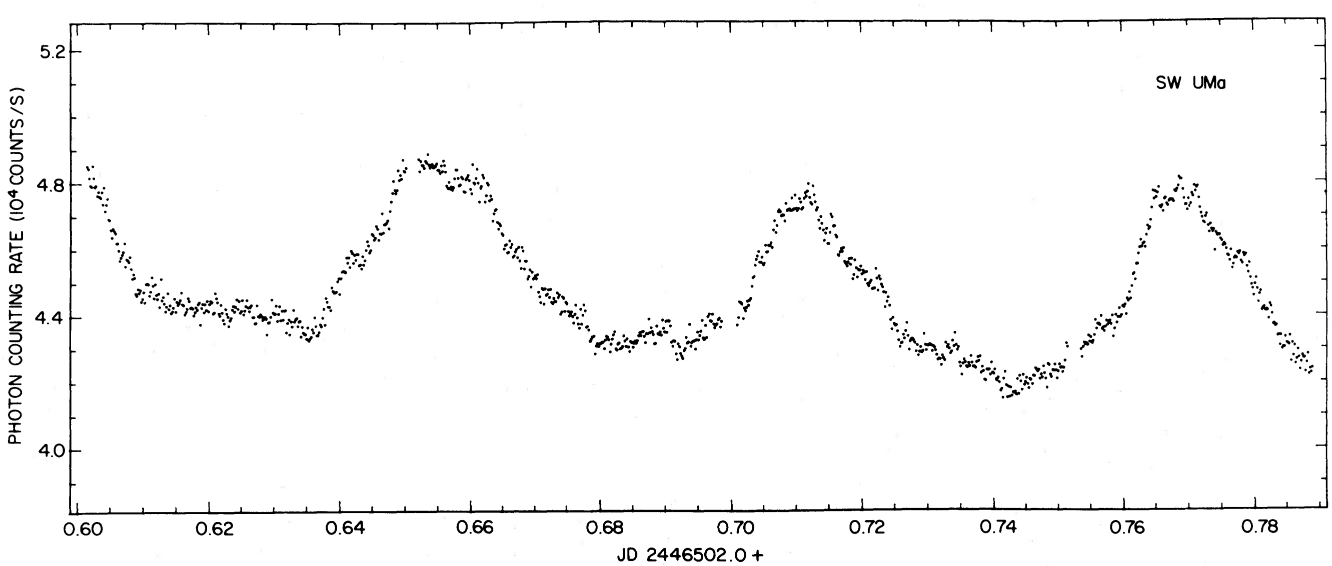

FIG. 3.—White-light light curve on the night of 1986 March 13. Each point is the mean brightness averaged over 15 s. The superhumps were clearly present and had an amplitude of nearly 11%, but the 5 minute quasi-periodic oscillations had not yet appeared.

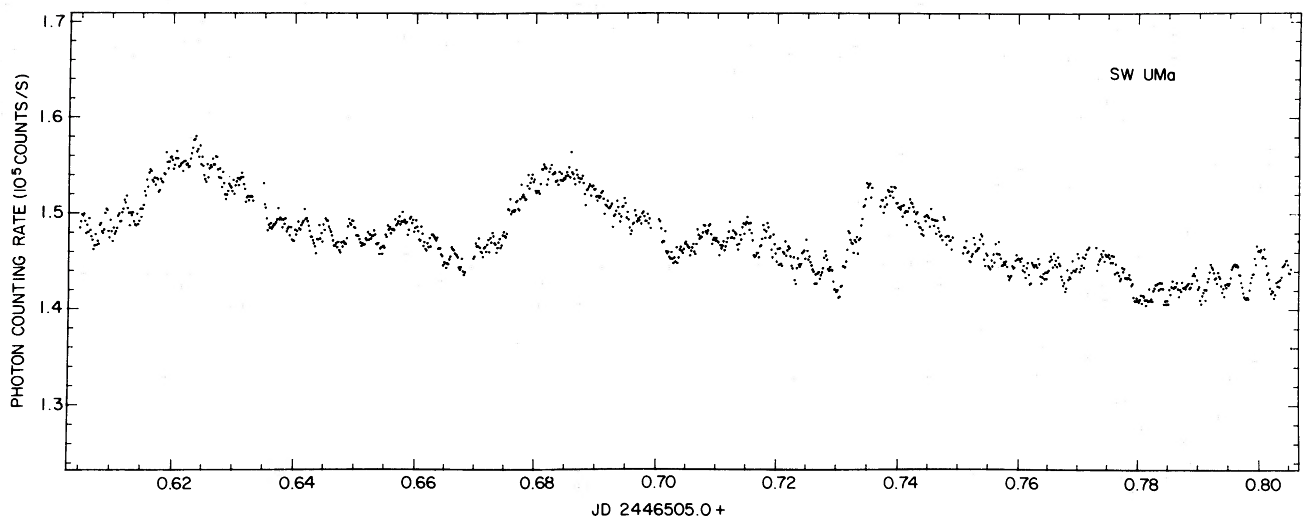

FIG. 4.—White-light light curve on the night of 1986 March 16. Each point is the mean brightness averaged over 15 s. Both the superhumps and the 5 minute quasi-periodic oscillations were clearly present. The 22 s quasi-periodic oscillations were probably present on this night also, but their amplitude was far too low to be visible.

data and since the white-light light curves are uncalibratable, we rely on the AAVSO light curve for the mean magnitudes of SW UMa during the high-speed observations.

The eruption of SW UMa lasted more than 3 weeks, and its amplitude was greater than 7 mag. The amplitude and length of the eruption are greater than those of normal eruptions of dwarf novae, but they are typical of the supermaxima of SU UMa–type dwarf novae. The high-speed light curves from the nights of 1986 March 8, 13, 16, 20, and 23 (UT) are shown in Figures 2–6. Superhumps, quasi-periodic oscillations, and flickering were all present at least part of the time, and their properties changed dramatically from night to night. The light curves show the evolution in the behavior of this rapid activity over the course of the eruption unusually well. We first describe the light curves and then discuss the various periodicities individually.

SW UMa reached maximum brightness on March 3. By March 8 (Fig. 2), the data of our first observation, it had faded to $V = 10.4$, ~ 1 mag below maximum brightness. There was almost no flickering in the light curve, and neither

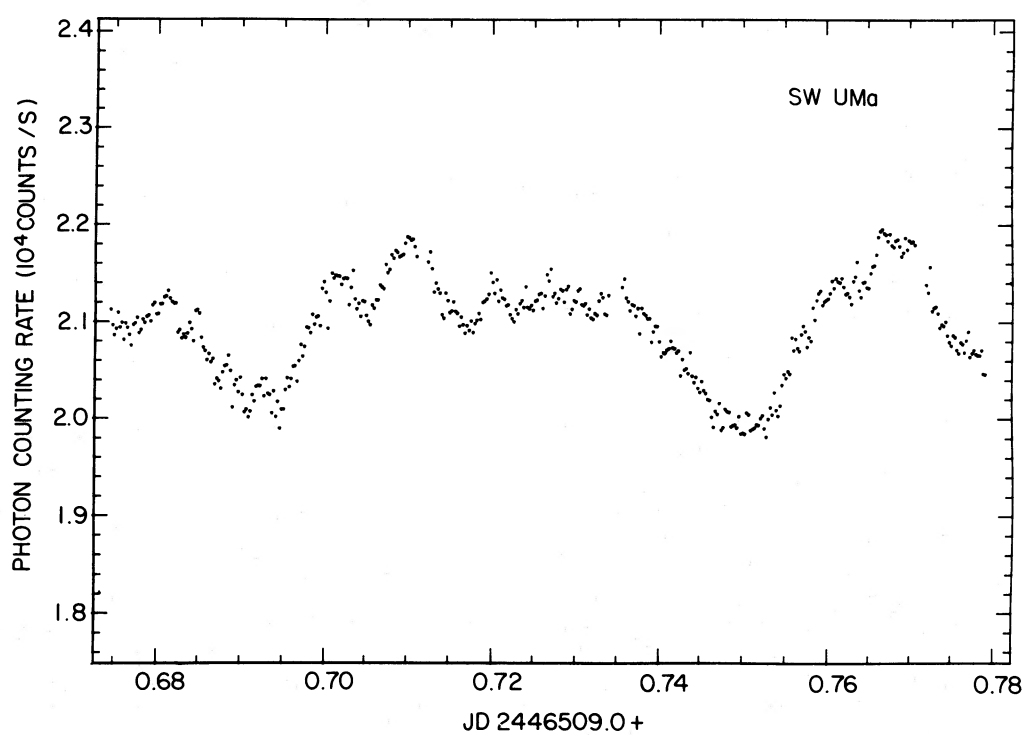

FIG. 5.—White-light light curve on the night of 1986 March 20. Each point is the mean brightness averaged over 20 s. The flickering had reappeared and partly masked the superhumps, but the superhumps were clearly present. This was the last night on which the superhumps could be detected with certainty. The 5 minute quasi-periodic oscillations were no longer present

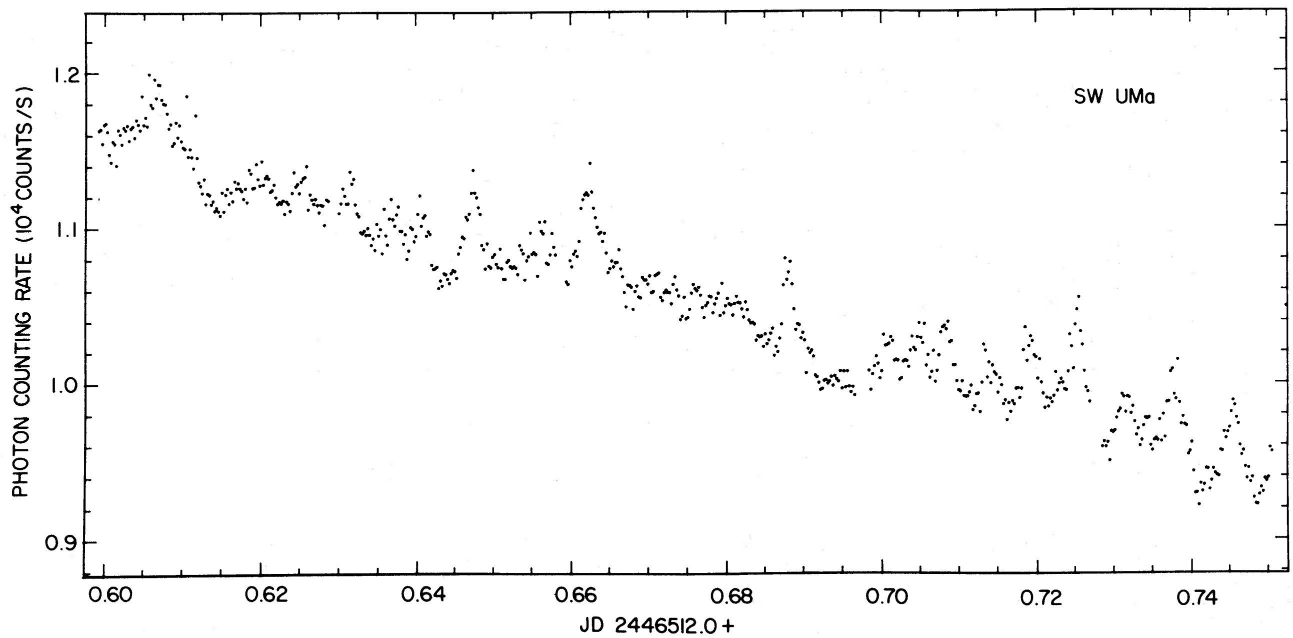

FIG. 6.—White-light light curve on the night of 1986 March 23. Each point is the mean brightness averaged over 20 s. SW UMa was fading rapidly back to minimum light, causing the decrease in brightness during the observation. The flickering was pronounced and the superhumps had disappeared.

the superhumps not the 5 minute quasi-periodic oscillations had yet appeared.

By March 13 (Fig. 3), SW UMa had faded to $V = 11.1$. Superhumps appeared in the light curve some time after March 8 and were well developed by March 13. The humps had a period roughly equal to the orbital period, an amplitude of 11%, and a shape similar to the shapes of the superhumps in other SU UMa stars (e.g., Zhang, Robinson, and Nather 1986; Szkody, Shafter, and Cowley 1984). The 5 minute quasi-periodic oscillations were absent, and the amplitude of the flickering was low.

By March 16 (Fig. 4), SW UMa had faded to $V = 11.3$. The superhumps were still present. Some time between March 13 and March 16, quasi-periodic oscillations appeared in the light curve. Their period was roughly 5 minutes and their peak-to-peak amplitude could be up to 1%, but both the amplitude and the phase of the oscillation changed on time scales as short as a cycle or so. The 5 minute quasi-periodic oscillations were clearly visible in the light curve only on March 16 and March 17. The amplitude of the flickering was still low.

By March 20 (Fig. 5), SW UMa had faded to $V = 11.8$, 2.4 mag below maximum brightness. The superhumps were still present in the light curve but their shape had changed considerably, becoming broader and less pronounced. The 5 minute quasi-periodic oscillations had disappeared, but the amplitude of the flickering had grown to a few percent.

By March 23 (Fig. 6), SW UMa had faded to $V = 12.5$. It had begun a precipitous decline to minimum light that was rapid enough to be visible in the 3.7 hr light curve shown in Figure 6 and took SW UMa to $V = 13.8$ on the next night. The superhumps and the quasi-periodic oscillations had disappeared completely. The rapid flickering had grown to a peak-to-peak amplitude of nearly 10%.

The superhumps.—The superhumps began some time between March 8 and March 13, lasted until March 20 or possibly March 21, and thus were present for 7–12 days. The superhumps did not begin until at least 5 days after maximum light. The humps consisted of an almost triangular main pulse plus an interpulse that grew from near invisibility on March 13 to an amplitude nearly equal to that of the main pulse by March 20. The peak-to-peak amplitude of the humps decreased only slowly from 11% on March 13 to 8% on March 20 but then dropped to nearly zero within 24 hr thereafter. Although the amplitude of the humps remained large until their final disappearance, the humps become much less obvious several days before they disappeared because the interpulse smeared the pulse shape and because the flickering reappeared and masked the pulses. The shape of the humps and the changes in the shape are remarkably similar to those of the superhumps in the well-observed SU UMa star VW Hyi (Haefner, Schoembs, and Vogt 1979). Even before the period of the superhumps in SW UMa had been established, the humps were easily recognized as superhumps.

The following ephemeris describes the times of the peaks in the humps from March 13 to March 20 with an accuracy of ± 3 minutes:

$$T_{\max} = JD_{\odot}\ 2,446,502.654 \pm 0.001 + 0.05833 \pm 0.00006E\ .$$

One alias period for the superhumps could not be eliminated with absolute certainty. This period, 0.0573 days, fits the times of the superhumps but with much greater scatter than a period of 0.05833 days. The period given in the ephemeris is strongly preferred. It is 2.7% longer than the orbital period of SW UMa, proving conclusively that the humps are superhumps and proving that SW UMa is an SU UMa star.

The 15.9 minute periodicity.—The 15.9 minute periodicity present in the X-ray and optical light curves of SW UMa at minimum light could not be detected in any of our data. The most stringent limits on its amplitude come from power spectra of the long light curves obtained on March 13, 16, 22, and 23. On the nights of March 13 and 16 the semi-amplitude of the 15.9 minute periodicity was less than $2 \times 10^{-3}\%$, and on the nights of March 22 and 23 its semi-amplitude was less than $4 \times 10^{-3}\%$.

The 5 minute quasi-periodic oscillations.—The 5 minute quasi-periodic oscillations were most clearly visible in the light curve on March 16, but even on this night their mean semi-amplitude was only ~0.4%. The low-frequency portion of the power spectrum of the light curve from that night is shown in Figure 7. The power at frequencies less than 0.0015 Hz is caused by the superhump and is restricted to the superhump period and its harmonics. The broad region of enhanced power peaking near 0.0033 Hz is caused by the 5 minute quasi-periodic oscillations. The breadth of the region of enhanced power demonstrates that the oscillation has a low coherence and is only quasi-periodic, not periodic. The 5 minute quasi-periodic oscillations were visible in both the light curves and the power spectra of the light curves on March 16 and 17. They were not visible in the light curves on March 18 and 19, but the power spectra of those light curves show enhanced power at periods near 6 minutes. The quasi-periodic oscillations may, therefore, have been present but at a lower amplitude and longer period.

Robinson and Nather (1979) have developed a formalism for describing the properties of the quasi-periodic oscillations. In this formalism, the oscillations are described as a single damped harmonic oscillator excited by white noise. The oscillations are characterized by their mean amplitude, by their mean period or frequency, which equals the resonant frequency of the oscillator, and by their coherence time, which equals the damping time scale of the oscillator. The power spectrum of the oscillations has a Lorentz distribution. The center of the Lorentz distribution gives the mean period of the oscillations, and the half-width at half maximum of the Lorentzian gives $1/2\pi\tau$, where τ is the *e*-folding coherence time of the oscillation. The formalism gives excellent fits to the observed power spectra and autocorrelation functions of quasi-periodic oscillations (Robinson and Nather 1979; Robinson and Warner 1984).

It is difficult to extract reliable properties for the 5 minute quasi-periodic oscillations in SW UMa, because the power spectrum of the oscillations is noisy and poorly defined. Nevertheless, we find a mean period of 305 ± 15 s and a coherence time between 1.5 and 2 cycles. This coherence time is short, but a visual inspection of the original light curve confirms that the oscillations can show extremely rapid changes in amplitude and phase, supporting the short coherence time given by the power spectrum.

The 22 s quasi-periodic oscillations.—The power spectra of the light curves revealed a region of enhanced power near 0.045 Hz on the nights of March 16, 17, and 18, although the presence of the enhanced power is really convincing only in the power spectrum from March 18. Figure 8 shows a portion of that power spectrum. The region of enhanced power extends from 0.043 to 0.047 Hz, showing that the oscillation causing the excess power is quasi-periodic, not periodic. The mean period of the oscillation is 22.3 ± 0.3 s. The coherence time of the oscillation is difficult to estimate reliably, because the power spectrum is so noisy, but lies somewhere between 1 and 2 cycles.

The 22 s quasi-periodic oscillation is generally invisible in the light curve because its amplitude is so low, only a few tenths of a percent. Figure 9 shows one of the few times when it can be seen. Even on this occasion the oscillation is hardly dramatic, and without the tick marks in the figure to point out the peaks of the oscillations, it would be easy to miss them.

III. DISCUSSION

Thanks to the observers of the AAVSO, we were able to obtain unusually complete coverage of the 1986 March eruption of SW UMa. We have shown that the eruption was a supermaximum and, therefore, that SW UMa is an SU UMa star.

The similarities between SW UMa and VW Hyi, another well observed SU UMa star, are striking. Both are dwarf novae with short orbital periods, 107 minutes in VW Hyi and 81.8 minutes in SW UMa (Vogt 1974); the amplitudes and lengths

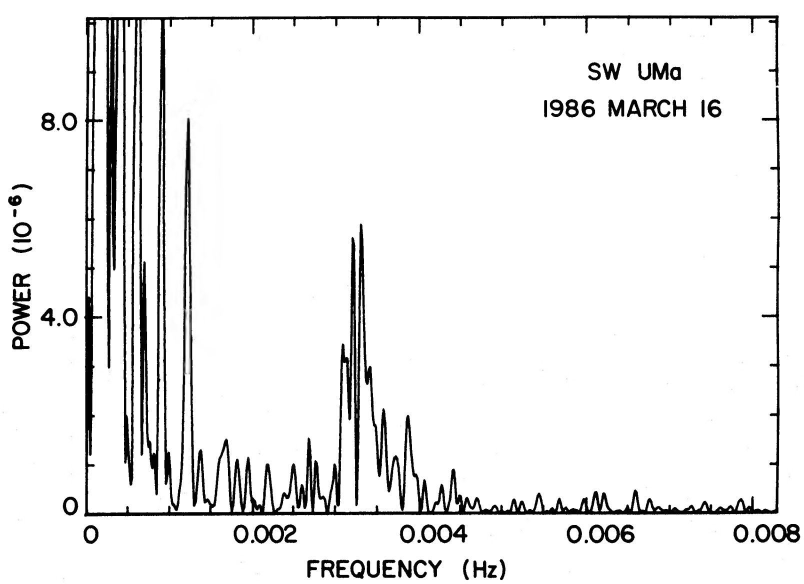

FIG. 7.—Low-frequency portion of the power spectrum of the light curve on the night of March 16. The power at frequencies less than 0.0015 Hz is caused by the superhumps and is restricted to the superhump period and harmonics of the superhump period. The broad region of enhanced power peaking at roughly 0.0033 Hz is caused by the 5 minute quasi-periodic oscillations.

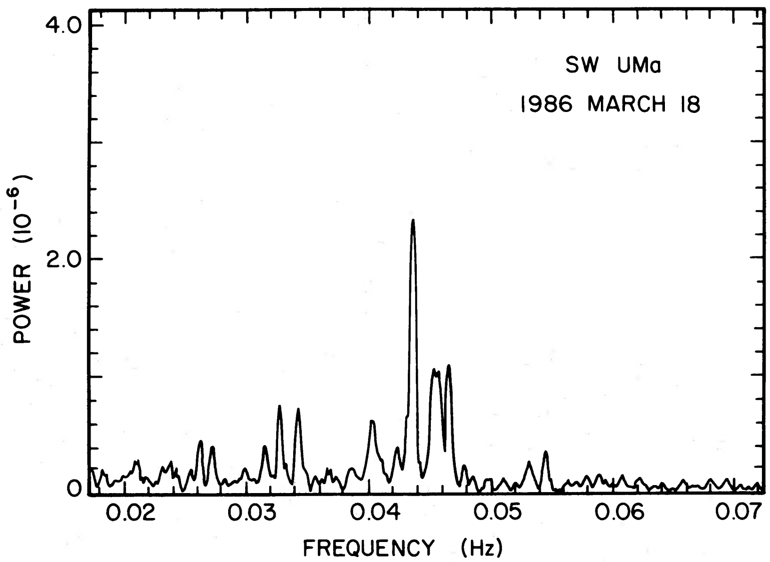

FIG. 8.—A portion of the power spectrum of the light curve on the night of March 18. The broad region of enhanced power between 0.043 Hz and 0.047 Hz is caused by the 22 s quasi-periodic oscillation.

of their supermaxima are nearly the same; both show superhumps with periods slightly longer than their orbital periods, 3.4% longer in VW Hyi and 2.7% longer in SW UMa (Vogt 1983); both have long-period quasi-periodic oscillations during their eruptions, a 4 minute quasi-periodic oscillation in VW Hyi and a 5 minute oscillation in SW UMa; and both have a short-period quasi-periodic oscillation, a 23.6 s quasi-periodic oscillation in VW Hyi and a 22.3 s oscillation in SW UMa (Robinson and Warner 1984). The 22.3 s and 23.6 s quasi-periodic oscillations have the shortest periods of any quasi-periodic oscillations discovered up to now. The similarities extend to many of their detailed properties. The shapes of the superhumps, for example, are nearly identical in VW Hyi and SW UMa, and the coherence times of the 23.6 s and 22.3 s quasi-periodic oscillations are both ~ 2 cycles.

There are some differences between the two systems. VW Hyi has frequent normal eruptions in addition to its supermaxima, but normal eruptions of SW UMa are rare or nonexistent. Only four possible normal eruptions of SW UMa have been detected by the AAVSO observers since 1942, and all four consisted of one or two isolated observations. The interval between the eruptions of SW UMa is ~ 3 times longer than the interval between the supermaxima of VW Hyi (Bateson 1977). The 4 minute and 23.6 s quasi-periodic oscillations in VW Hyi were observed during a normal eruption, while the quasi-periodic oscillations in SW UMa were observed during a supermaximum. The coherence time of the 4 minute oscillation was perhaps 5 times longer than the coherence time of the 5 minute oscillation. The superhumps in SW UMa started longer after the peak of the eruption than the

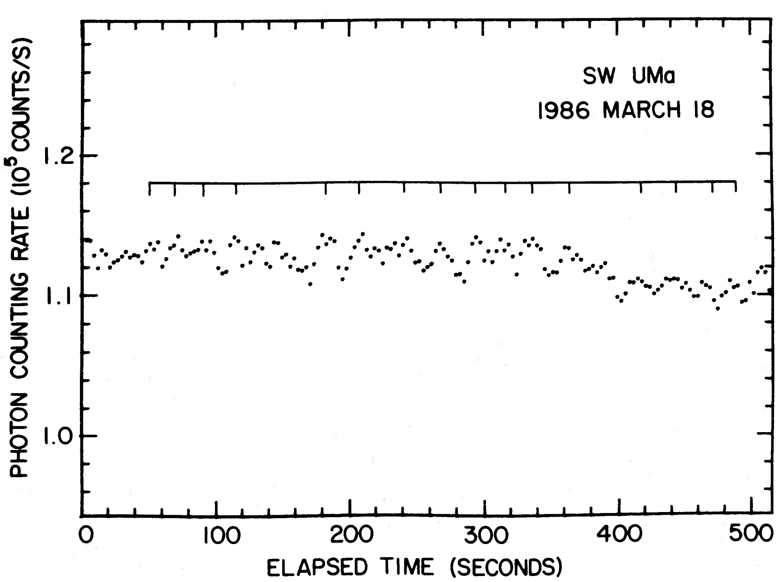

FIG. 9.—An expanded portion of the light curve on the night of March 18 retaining the 3 s sampling interval of the original data. This portion is one of the few times when the 22 s quasi-periodic oscillation is visible to the eye in the original data. The peaks of the oscillation are marked by the tick marks.

superhumps in VW Hyi—or any other SU UMa star—and had a lower amplitude. Most of these differences are superficial, however. Quasi-periodic oscillations, for example, have been observed in both normal eruptions and supermaxima of VW Hyi and of dwarf novae generally, and their properties do not seem to depend on the type of eruption in which they appear (Córdova and Mason 1982; Robinson and Warner 1984). The failure of SW UMa to show normal eruptions may be significant, but the remaining differences are mostly minor quantitative differences. We conclude that the properties of SW UMa during its eruption were normal and in no way unusual for the supermaxima of SU UMa stars.

This conclusion is important because there is a major difference between SW UMa and all other SU UMa stars: SW UMa is the only one which may be an intermediate polar. Conversely, SW UMa is the first intermediate polar to show supermaxima and superhumps. Perhaps surprisingly, the 15.9 minute periodicity caused by rotation of the magnetized white dwarf was not present in the optical light curve of SW UMa at any time during its eruption. According to Szkody (1986), the 15.9 minute periodicity also disappeared from the X-ray light curve during the 1986 March eruption, demonstrating that the accretion onto the white dwarf was no longer dominated by the magnetic field. We can use the known rotation period of the white dwarf in SW UMa to eliminate an entire class of models for the superhumps. In these models the superhumps are caused by illumination of some component of the binary system by the poles of the rotating white dwarf. For these models to work, the white dwarf must be rotating at nearly the orbital period of the binary or it must rotate extremely slowly—once in a few days (Warner 1985). The white dwarf SW UMa rotates at neither of these two periods, and therefore its rotation cannot be causing the superhumps.

We have previously noted that all SU UMa stars have orbital periods less than 3 hr and that most dwarf novae with orbital periods less than 3 hr are SU UMa stars (Robinson 1983). Orbital and superhump periods have become available for many more SU UMa stars since then, and the correlation with orbital period has become even more striking. All dwarf novae with orbital or superhump periods less than 3 hr are listed in Table 2 along with their periods. The table also gives the subclass to which the dwarf nova belongs, UG for normal dwarf novae and SU UMa stars. We have been conservative in assigning stars to the SU UMa class. Except for SU UMa itself, we have classified a dwarf nova as an SU UMa star only if superhumps have been observed in its light curve. Although many supermaxima have been recorded for SU UMa, it stopped erupting altogether from the end of 1980 to the beginning of 1983, preventing any search for superhumps until recently. Because its supermaxima are well established (it is, after all, the prototype of the class), we classify SU UMa as an SU UMa star. V2051 Oph has been called a dwarf nova (Watts *et al.* 1986). Although this classification may eventually prove to be correct, the only support for it at present is a single measurement showing the star to be roughly 2 mag above minimum light. It is, therefore, premature to include V2051 Oph in Table 2. We have included EX Hya in the table but with a prominent question mark appended to its UG classification.

There are 22 stars in the table, of which 18 are confirmed SU

TABLE 2

Dwarf Novae with Orbital or Superhump Periods Less Than 3 Hours

Star	Subclass	Orbital Period (hr)	Reference	Superhump Period (hr)	Reference
YZ Cnc	SU	2.1:	1	2.21	2
OY Car	SU	1.51	3	1.55	4
HT Cas	SU	1.77	5	1.83	5
V436 Cen	SU	1.50	6	1.53	7
Z Cha	SU	1.79	8	1.85	9
IR Gem	SU	1.64	10	1.70	10
EX Hya	UG?	1.64	11	...	
VW Hyi	SU	1.78	12	1.84	13
WX Hyi	SU	1.80	14	1.86	15
T Leo	UG	1.41	16	...	
AY Lyr	SU	...		1.81	2
TU Men	SU	2.82	17	3.04	18
TY Psc	SU	...		1.9:	19
TY PsA	SU	...		2.02	20
RZ Sge	SU	...		1.68	21
WZ Sge	SU	1.36	22	1.37	23
EK TrA	SU	...		1.56	24
SU UMa	SU	1.83	25	...	
SW UMa	SU	1.36	26	1.40	27
CU Vel	SU	...		1.92	28
VW Vul	UG	1.8:	29	...	
NSV 12615	UG	1.47	30	...	

References.—(1) Shafter 1983. (2) Patterson 1979. (3) Vogt *et al.* 1981. (4) Krzeminski and Vogt 1985. (5) Zhang *et al.* 1986. (6) Gilliland 1982*a*. (7) Semeniuk 1980. (8) Cook and Warner 1981. (9) Vogt 1981*a*. (10) Szkody *et al.* 1984. (11) Gilliland 1982*b*. (12) Vogt 1974. (13) Vogt 1983. (14) Schoembs and Vogt 1981. (15) Bailey 1979. (16) Shafter and Szkody 1984. (17) Stolz and Schoembs 1981*b*. (18) Stolz and Schoembs 1981*a*. (19) Patterson 1984. (20) Barwig *et al.* 1982. (21) Bond *et al.* 1982. (22) Robinson *et al.* 1978. (23) Patterson *et al.* 1981. (24) Vogt and Semeniuk 1980. (25) Thorstensen *et al.* 1986. (26) Shafter *et al.* 1986, (27) This paper. (28) Vogt 1981*b*. (29) Shafter 1985. (30) Jablonski and Steiner 1986.

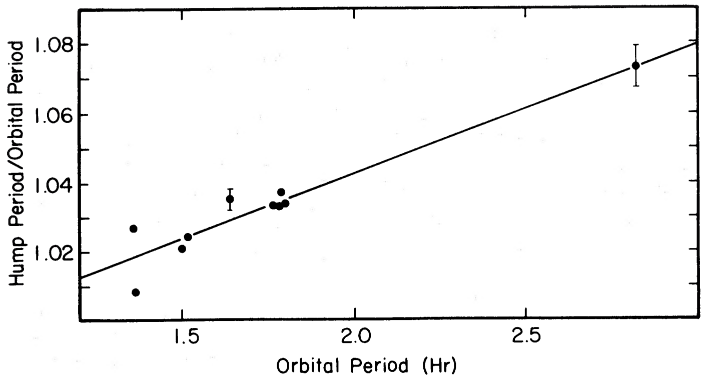

FIG. 10.—Ratio of superhump period to orbital period vs. orbital periods for those SU UMa stars for which both are known accurately. Although there is considerable scatter in the relation, the ratio is correlated with the orbital period.

UMa stars. Thus, 82% of all dwarf novae with orbital periods less than 3 hr are SU UMa stars. The four stars that are not known to be SU UMa stars are EX Hya, T Leo, VW Vul, and NSV 12615. We have already mentioned our doubt that EX Hya is a dwarf nova. AAVSO records show that T Leo has shown an anomalously long and bright eruption in 1982 June and is likely to be an SU UMa star. VW Vul and NSV 12615 are so poorly observed that their exact classification is not known with certainty. Thus, it is not only possible but even likely that all the true dwarf novae in Table 2 are SU UMa stars. More generally, the hypothesis that all dwarf novae with orbital periods less than 3 hr are SU UMa stars and that all SU UMa stars have orbital periods less than 3 hr seems to have every chance of being correct.

The data in Table 2 can be used to update a correlation first noted by Stolz and Schoembs (1981*b*). They found that the ratio of the superhump period to the orbital period in SU UMa stars increases with orbital period. There are now 10 SU UMa stars for which both superhump and orbital periods are known (the orbital period of YZ Cnc is not known accurately enough for this exercise). The ratio of the periods is plotted against orbital period in Figure 10. Two representative error bars have also been plotted in the figure. The errors in the period ratios are sometimes caused by measurement errors, but there is a real variation in the superhump periods from eruption to eruption for individual systems, and this variation is usually larger than the measurement errors. The representative error bar for the systems with periods less than 2 hr corresponds to the range of superhump periods displayed by VW Hyi (Vogt, 1983). The correlation between the period ratio and the orbital period is not perfect, and, indeed, if the point for TU Men at 2.82 hr were removed, it is not obvious that the correlation would be recognized. The correlation is present nevertheless. In the range of periods for which data exists, the correlation may be approximated by

$$\frac{P_{\text{hump}}}{P_{\text{orb}}} = 0.0367(P_{\text{orb}} - 2.00) + 1.043 ,$$

where P_{orb} is in hours. Although there is no generally acceptable explanation for this relation, it does show that the physical mechanism responsible for the superhumps strongly couples the superhump period to the orbital period.

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