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FS Aurigae: A New Class of Cataclysmic Variables or the Missing Link between Intermediate Polars and SW Sextantis Objects?

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ABSTRACT. FS Aur is a known dwarf nova with an orbital period of about 85.7 minutes. It has been assumed to be a member of the SU UMa subclass of cataclysmic variables, but previous searches for superhumps and superoutbursts have been unsuccessful. We conducted a series of photometric and spectroscopic observations of FS Aur during quiescence. We confirmed its short orbital period from radial velocity measurements. However, the long-term photometry revealed an unexpected result: the system also shows a distinct 0.24 mag modulation in the *BVR* photometric bands with a period of 205.5 minutes, which is 2.4 times longer than the orbital period. We discuss various possible causes for such a peculiar behavior.

1. INTRODUCTION

FS Aur was discovered back in 1949 (Hoffmeister 1949) as a dwarf nova. Howell & Szkody (1988) made an attempt to determine its orbital period, among several other systems, by means of CCD photometry. They cite a spectroscopic period of 85 minutes, but they failed to find any definite period from photometry, although they have detected 0.15 mag variations that could be consistent with 87–105 minute periods. Later, Thorstensen et al. (1996) refined the orbital period from spectroscopy and suggested an SU UMa classification based on the short orbital period of 0.0595 days (85.7 minutes).

Nevertheless, long-term monitoring of the system by several groups failed to detect any superoutburst/superhumps in its light curve. The publicly available VSOLJ and AAVSO light curves show instead a steady-cyclic outburst pattern that is more similar to a SS Cyg–type dwarf nova light curve. Andronov (1991) found 12 outbursts on 180 archival photographic plates of the Sternberg State Astronomical Institute. But he also failed to find any superoutbursts in the archival data and notes the regular character of the outbursts, similar to dwarf novae. Neustroev (2002, hereafter N02), among others, for a long time hunted for superoutbursts and also conducted a new study of the system in quiescence. In his paper, he noted several interesting spectral characteristics of the object, roughly determined the system parameters, and also discovered variability with a period longer than the orbital period.

Here we present the results of a new long-term photometric campaign and additional spectroscopic observations of FS Aur (§ 2). They are combined with data previously obtained by N02, separated by a 3 yr time gap. We compare the properties of FS Aur with SW Sex stars (§ 3.2) and describe our discovery of the existence of a 3.42 hr photometric period in the light curve of FS Aur (§ 3.3). Finally, we discuss possible causes of this unusual behavior of the system (§ 4) and possible implications on the classification of cataclysmic variables (CVs) (§ 5).

2. OBSERVATIONS

2.1. Optical Observations

New observations of FS Aur were obtained at the Observatorio Astronomico Nacional (OAN SPM) in Mexico. The 2.1 m telescope with the B&Ch spectrograph, equipped with an SITe 1024 × 1024 pixel CCD with a pixel size of 24 μm, was used for the spectroscopic observations. Spectra were obtained in the second order of a 400 line mm^{-1} grating, covering the 3800–5200 Å region and reaching 2.5 Å FWHM spectral resolution with the used slit width of 1$''$.5. Spectral observations were done in two consecutive nights (2001 January 31/February 1) with a total coverage of 12 hr, consisting of 10 minute duration individual exposures. He-Ar arc lamp exposures were taken before and after the object observations for wavelength calibration, and the standard spectrophotometric star G191-B2B (Oke 1990) was observed each night for flux calibration. The reduction of the images and the extraction of the spectra were

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done using standard IRAF[8] routines customarily used for long-slit spectra.

Photometric observations were performed with the 1.5 m telescope of OAN SPM and cover a longer time span. Differential photometry was obtained with the three broadband Johnson-Cousins filters *B*, *V*, *R* in long time series with individual exposures ranging from 20 to 180 s. Selected comparison and check stars from the field were used for differential photometry performed using the DAOPHOT package within IRAF.

Additional photometry was acquired by members of the Center for Backyard Astrophysics (CBA).[9] For details of their activity and procedures used to obtain and reduce the data, we refer readers to Patterson et al. (2000). The log of all optical observations is presented in Table 1.

2.2. *ROSAT* X-Ray Observations

We also retrieved all FS Aur X-ray observations from the *ROSAT* archive at MPE Garching. FS Aur was observed in the course of the all-sky survey in 1990 August/September for a total exposure time of 441 s and is listed in the *ROSAT* All-Sky Survey Bright Source Catalog as 1RXS J054748.5+283512. It is detected at a count rate of 0.13 ± 0.02 counts s^{-1}.

FS Aur was serendipitously observed again in pointed mode on 1993 September 23 with the position-sensitive proportional counter (PSPC; Pfeffermann et al. 1986) with a total exposure time of 9509 s. As a result of its off-axis angle, the effective exposure of FS Aur is 6130 s. The mean count rate is 0.128 ± 0.005 counts s^{-1}, identical to that of the all-sky survey observation in 1990.

The spectrum is identical in shape and brightness during both observations. The hardness ratios (HRs) of the object inferred from these observations are HR1 = 0.911 ± 0.027 and HR2 = 0.371 ± 0.034. These hardness ratios are defined as $\mathrm{HR1} = (B - A)/(B + A)$ and $\mathrm{HR2} = (D - C)/(D + C)$, where *A*(0.1–0.4 keV), *B*(0.5–2.0 keV), *C*(0.5–0.9 keV), and *D*(0.9–2.0 keV) are the counts in the given energy range. Given the Galactic coordinates of FS Aur of $l_{\mathrm{II}} = 180\overset{\circ}{.}55$, $b_{\mathrm{II}} = +0\overset{\circ}{.}23$, these hardness ratios can be interpreted as a rather hard source spectrum, with strong interstellar absorption that practically leaves no counts below 0.5 keV.

As a result of this strong absorption and the restricted spectral coverage, several spectral models fit the data. The spectral fit using a thermal bremsstrahlung model is presented in Figure 1 and gives the following parameters: absorbing column $N_{\mathrm{H}} = (3.0 \pm 0.3) \times 10^{21}$ cm^{-2}, temperature $kT = 0.59 \pm 0.30$ keV, and a normalization of $(1.3 \pm 0.1) \times 10^{-3}$ photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{keV}^{-1}$. The absorbing column corresponds to about half the total Galactic column in this direction (Dickey & Lockman 1990). The unabsorbed bolometric flux for this model is 1.0×10^{-11} ergs $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, and the luminosity is 1.2×10^{31} $(D/100\ \mathrm{pc})^2$ ergs s^{-1}.

[8] IRAF is distributed by the National Optical Astronomical Observatory, which is operated by the Associated Universities for Research in Astronomy, Inc., in cooperative agreement with the National Science Foundation.

[9] http://cba.phys.columbia.edu.

TABLE 1
LOG OF OPTICAL OBSERVATIONS OF FS AUR

HJD Start (2,450,000+)	Duration (minutes)	Time of Exposure (s)	Band	Telescope
1165.72	193	60	White	CBA
1170.59	350	60	White	CBA
1174.51	82	60	White	CBA
1178.50	222	60	White	CBA
1179.50	378	60	White	CBA
1182.47	476	60	White	CBA
1184.57	313	60	White	CBA
1185.64	482	60	*R*	CBA
1186.64	506	60	*R*	CBA
1187.74	345	60	*R*	CBA
1188.58	472	60	*R*	CBA
1194.52	304	60	White	CBA
1510.68	283	60	White	CBA
1512.58	425	60	White	CBA
1513.59	430	60	White	CBA
1563.62	113	60	White	CBA
1571.60	123	15	*V*	1.3 m MDM-CBA
1575.62	417	60	White	CBA
1584.60	49	15	bg38	2.4 m MDM-CBA
1585.40	238	80	White	0.35 m CBA
1586.24	94	80	White	0.35 m CBA
1619.68	116	180	*R*	1.5 m SPM
1621.65	164	100	*R*	1.5 m SPM
1622.64	184	180	*V*	1.5 m SPM
1864.84	322	150	*V*	1.5 m SPM
1865.80	298	150	*V*	1.5 m SPM
1928.63	409	180	*B*	1.5 m SPM
1941.63	368	600	3800–5200 Å	2.1 m SPM
1942.62	299	600	3800–5200 Å	2.1 m SPM
1946.65	315	30, 20	*B*, *R*	1.5 m SPM
2206.84	289	30	*B*	1.5 m SPM
2259.78	157	30	*B*	1.5 m SPM
2260.76	178	30	*B*	1.5 m SPM

NOTE.—CBA: Center for Backyard Astrophysics; MDM-CBA: MDM Observatory telescope operated by members of CBA; SPM: San Piedro Martir Observatory, Mexico.

3. RESULTS

3.1. Spectroscopy

Our spectroscopic data basically repeat all characteristics described by N02. For radial velocity (RV) measurements, we simply did one Gaussian fitting to the mostly single-peaked Hβ emission-line profiles. Using RV measurements from our observations and combining them with the measurements from N02, we derived the spectroscopic (orbital) period of FS Aur. We used the discrete Fourier transform (DFT) method to obtain the power spectrum, the spectral window corresponding to the data, and the time distribution of our observations.

The period analysis resulted in a strong peak confirming

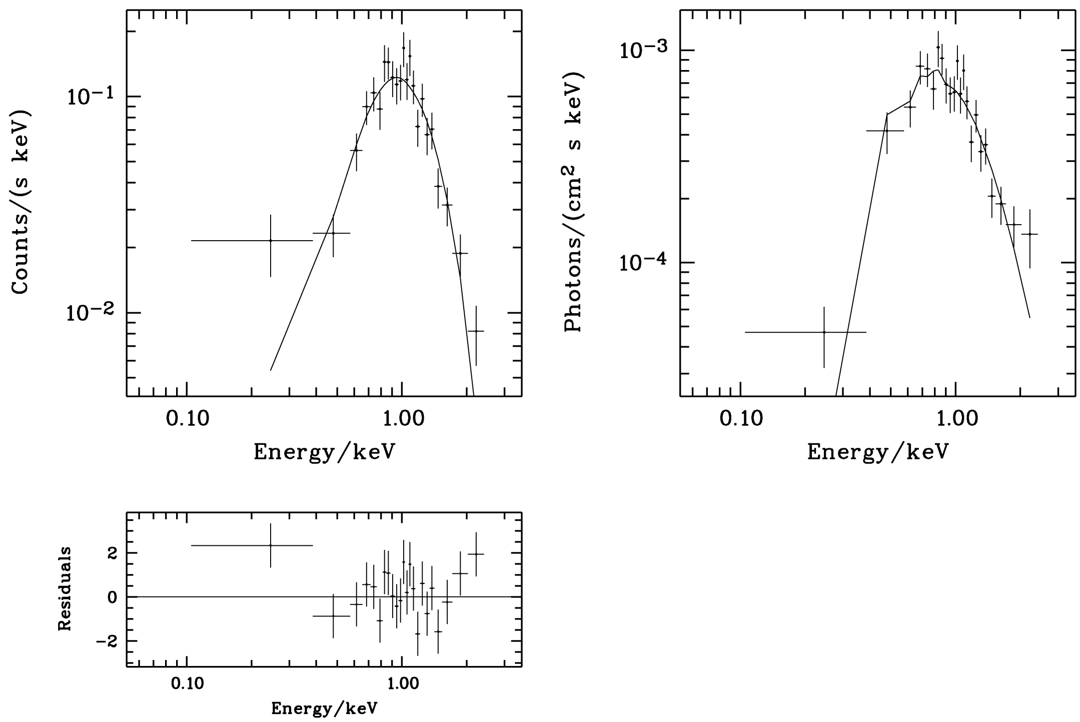

FIG. 1.—*ROSAT* PSPC X-ray spectrum of FS Aur derived from the pointed observation from 1993 September 23, fitted with a thermal bremsstrahlung model (see text for fit parameters). The lower left panel shows the deviation between data and model in units of χ^2.

previous determination of the orbital period. Using the CLEAN procedure (Roberts, Lehar, & Dreher 1987), which allows us to suppress alias frequency peaks caused by uneven data sampling, we obtained the strongest peak at the frequency corresponding to 85.65 minutes (0.059479 days). This estimate is within the range of periods and margins of error cited by previous authors (Thorstensen et al. 1996). There is another peak at around 10 day^{-1}. We will discuss this later in the text after considering our photometric data (§ 4). The superior conjunction of the emission-line source (i.e., red-blue crossing) corresponds to T_0 = HJD 2,450,101.2656. However, since the source of emission is not defined, it is not clear whether it is a superior conjunction of the white dwarf (WD) or not. Other emission lines show similar results with no significant phase shifts between the lines.

N02 estimates the inclination angle of the system to be within 51°–65°. While it is based on dynamical interpretation of emission lines that might be a highly unreliable indicator of the motions of the underlying stars, it is in good agreement with the velocities obtained from our new observations. It is surprising, though, not to see broad double-peaked emission lines from this short-period system (dwarf nova) at this inclination. It is noteworthy that He II λ4686 shows up strongly. It is unusual to have He II this strong in an ordinary dwarf nova. It appears that the emission lines of higher excitation show central absorption cores at some phases while Hβ remains mostly single peaked. Probably because there is no systematics behind this behavior, we could not find any firm phase-dependent pattern. We averaged the spectrum of FS Aur by co-adding all spectra after correcting for the orbital radial velocity (Fig. 2). Individual lines are enlarged in separate panels to display the above-mentioned features. These and some other characteristics noted in FS Aur bring us to the idea that it may belong to the class of SW Sex objects.

3.2. Is FS Aur an SW Sex Object?

Careful examination of spectra of FS Aur shows several things:

1. In spite of the estimate of a relatively high inclination angle of the binary system of $51° < i < 65°$, emission lines of FS Aur are single peaked. However, distorted wings can be seen in the form of blueshifted shoulders around phase 0.8 (N02).
2. Central small absorption can be seen in the higher Balmer lines starting from Hγ and in the He I λ4471 and He II lines at some phases. The absorption core of He lines can be seen even in the integrated spectrum (see Fig. 2).
3. Although there are no eclipses, high-excitation lines do notably diminish at some phases (N02).

These features are characteristic of SW Sex objects (Thor-

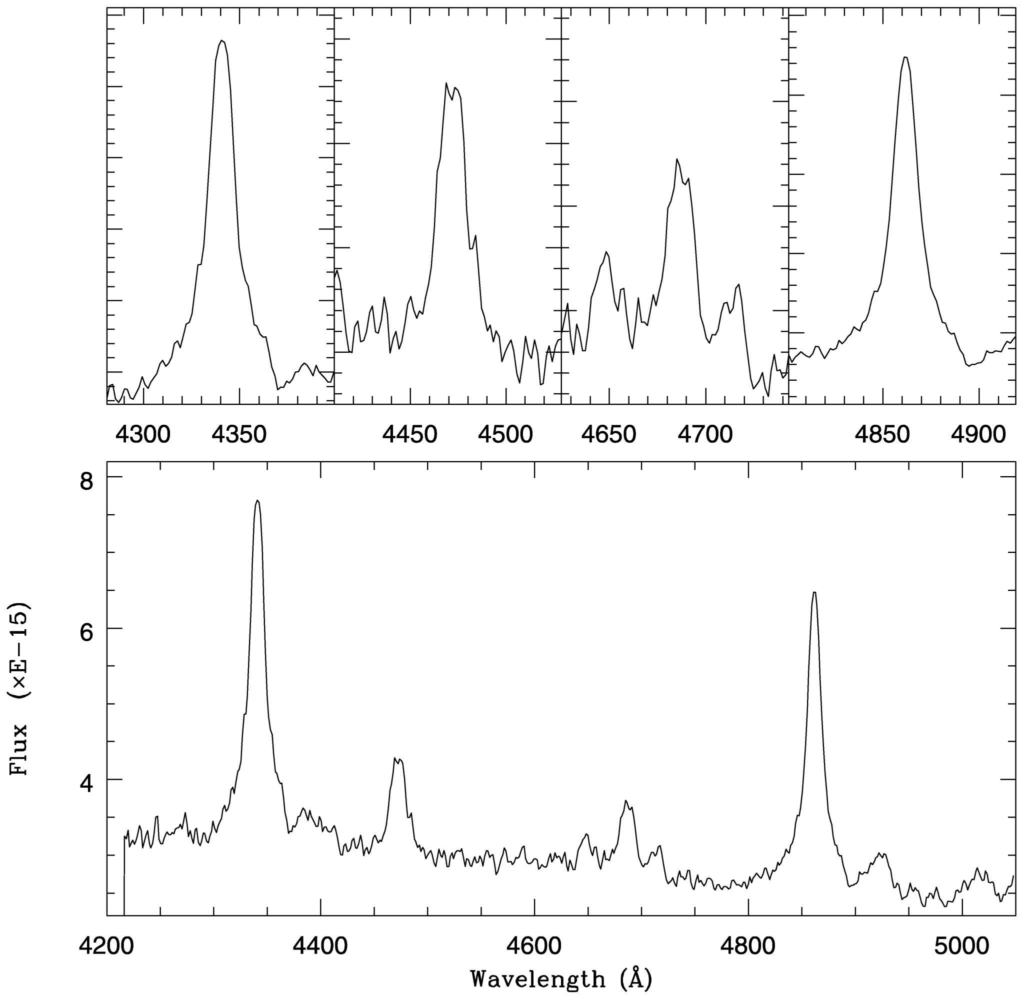

FIG. 2.—Averaged spectrum of FS Aur, obtained by co-adding all obtained spectra after correcting for orbital radial velocities changes.

stensen et al. 1991; Hellier 2000). Although most of the SW Sex stars are eclipsing systems (having been one of the original class identifiers), low-inclination systems were recently discovered pertaining to that class. In particular, FS Aur shows remarkable similarities to the line profiles of LS Peg (Taylor, Thorstensen, & Patterson 1999) and V442 Oph (Hoard, Thorstensen, & Szkody 2000). The shoulder in the blue wing of Hβ around phase 0.8 is similar to those observed in LS Peg and V442 Oph, where it is identified with the high-velocity component in these systems. We were not able to separate the high-velocity component, probably because of the low signal-to-noise ratio of our data. Also worth mentioning is the relatively small intensity of the He II line in both of these low-inclination systems. Finally, there is a striking resemblance of the Doppler tomograms of FS Aur to those of SW Sex stars. The ring in the maps, corresponding to the accretion disk, is rarely seen in SW Sex systems. Instead, bright spots are often detected in the lower left quadrant or below the location of the WD, and they may vary from line to line. The velocity maps and the trailed and reconstructed spectra of Hβ and Hγ of FS Aur are presented in Figure 3. Similar tomograms were obtained by N02. Since the phasing in the absence of eclipses or any other clear indication of zero phase is arbitrary, the locations of the spots on velocity map are arbitrary too.

Nevertheless, it should be noted that other characteristics of FS Aur do not fit well into the SW Sex definition. The latter are mostly nova-like systems exhibiting high and low states of luminosity, while FS Aur undergoes ≈2 mag dwarf nova–like outbursts. Another significant difference between FS Aur and the SW Sex stars is its short orbital period. However, the spectral (orbital) period, unambiguously detected in FS Aur, appears to be in large contrast with the photometric period discovered by us.

3.3. Photometric Period

The extensive photometric coverage reveals a most unexpected result. The long-term variability noted in N02 in reality

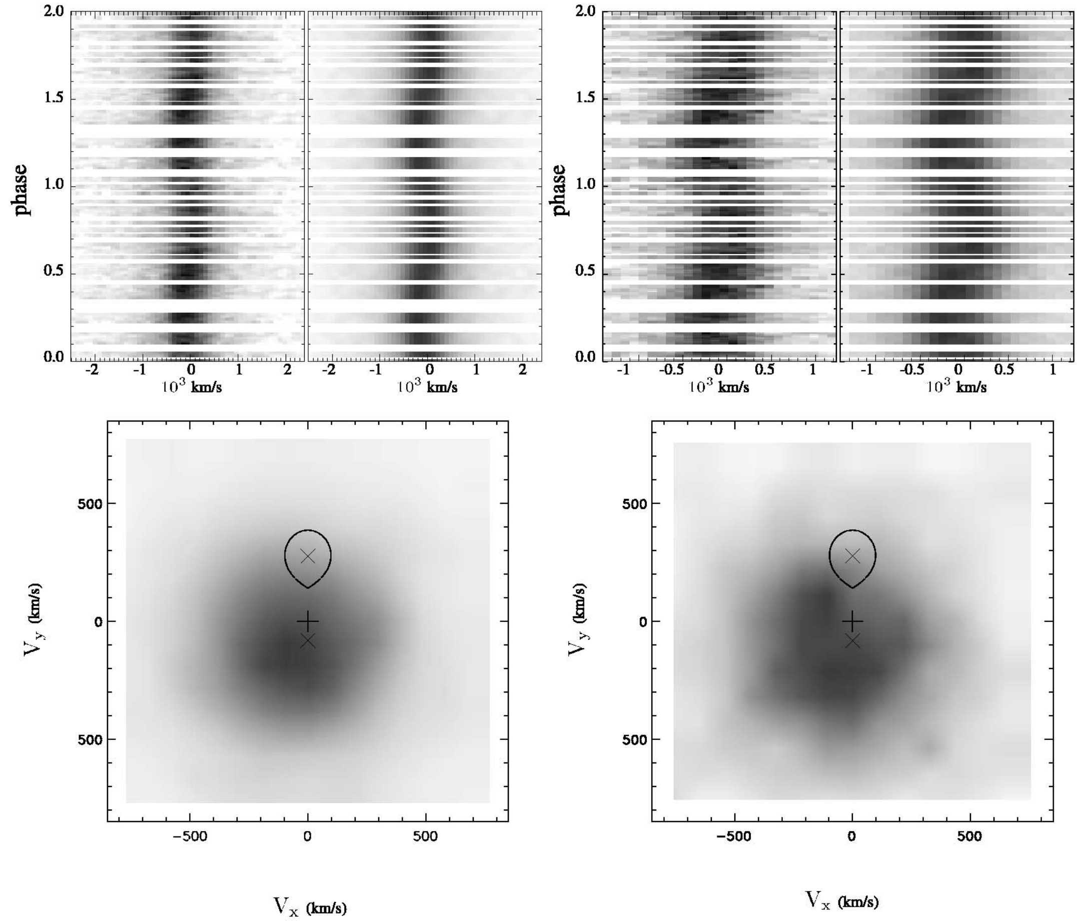

FIG. 3.—Velocity maps and trailed and reconstructed spectra of Hβ and Hγ.

appears to be strictly periodic. All data that we were able to collect since then show the same period of 3.4 hr and can easily be phase-folded over the time exceeding 3 yr of observations. In Figure 4, we present several thousand measurements collected from a variety of CBA small telescopes, in addition to SPM observations reported earlier in Tovmassian et al. (2002) and folded with the photometric period. The data were normalized to each night's mean magnitude, since they were obtained with various detectors and comparison stars. In spite of the large 0.2 mag scatter, the sinusoidal shape of the light curve is mostly undisturbed. Neither the phase nor the amplitude of variations seems to be altered by the cyclic outbursts that the system underwent between the different sets of observations. This demonstrates the very coherent nature of the periodic signal in the light curves.

However, when we look closely at each night's data, we can see that the abovementioned periodic signal in the light curve varies in its strength and appearance. Since the observed phenomenon is of unusual nature, we decided to present them all for clarity. In Figure 5, each night's data are presented in its corresponding panel. The overlaid solid curve represents the photometric period. On nights when the photometric period is not seen clearly or there are faster variations present, we have marked also the spectroscopic period with a dashed line. Its phase was estimated by a least-squares fitting of the curve to the moment of minima and maxima measured on these nights. We are not sure that these rapid variations are the result of orbital modulations, and these curves are presented solely for demonstration purposes.

In the broadband filters obtained at the 1.5 m telescope of OAN SPM, the system shows smooth sinusoidal light curves. The data collected from a variety of CBA small telescopes are not as smooth, and additionally spontaneous wiggles are detected in the light curves of individual nights. However, the 3.4 hr periodic signal can be clearly distinguished in the light curves and unambiguously stands up in the power spectrum. The most important characteristics of the light curves are as follows:

1. The period of variation in the light curve is 3.4247 ± 0.0005 hr as estimated from the combined data (differential magnitudes of all dates and colors were mean subtracted and combined in one large data set). The power spectra of individual

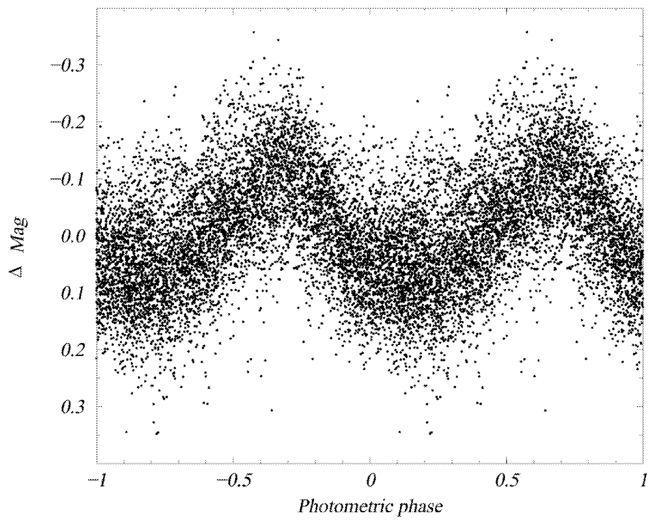

FIG. 4.—Several thousand photometric measurements collected from a variety of CBA small telescopes in addition to the SPM observations reported earlier in Tovmassian et al. (2002), folded with the photometric period. The data were normalized to each night's mean magnitude, since they were obtained with various detectors and comparison stars.

nights were also calculated and checked for consistency. Depending on the duration and data quality, they all show a similar pattern within errors between individual nights. The CLEANed power spectrum of the combined data and a blowout of the most prominent peak are presented in Figure 6.

2. The *BVR* light curves from OAN SPM are smooth and almost perfectly sinusoidal (see Fig. 7).

3. The amplitude of 0.24 mag is approximately equal in all three bands (*B*, *V*, *R*).

4. The individual light curves from the unfiltered CBA observations are more "noisy." By this, we do not mean photon statistics or a data scatter due to the flickering that is usual for CVs. Instead, the light curves just show more erratic wiggling imposed on a longer term variation due to the 3.4 hr period. However, the period is coherent over about 3 yr. The phase-folded light curve of all combined data, presented in Figure 4, clearly demonstrates this coherence.

5. The examination of other peaks in the power spectrum of the radial velocities shows an unidentified peak at 9.88 day^{-1}, which is very close to the sideband frequency of

$$\frac{1}{P_{\rm sb}} = \frac{1}{P_{\rm orb}} - \frac{1}{P_{\rm phot}}. \tag{1}$$

The photometric period exceeds the spectroscopic by 2.4 times! This is an unprecedented case for a low-mass binary system unambiguously identified as a cataclysmic variable. In order to show that the two periods do not match, we plotted the combined photometric data folded with the spectroscopic (orbital) period (Fig. 8), along with the RV curve obtained from measurements of the Hβ line from our observations. The zero point for spectroscopic as well as photometric phase, the ± crossing of the radial velocity, was taken from N02.

4. POSSIBLE CAUSES OF THE LARGE PHOTOMETRIC PERIOD

1. The possibility of rotational effects in the reference frame of the secondary star as well as a triple/multiple component system can be effectively ruled out on the basis of the canonical sinusoidal shape of the light curves, the equality of the amplitude of variation in the three bands, and the absence of any spectral evidence of such kind.

2. As a dwarf nova with an orbital period below the period gap, FS Aur was expected to be an SU UMa–type object and show superhumps due to an eccentric disk (see the extensive discussion in Patterson 2001 and references therein). The number of superhumpers is statistically significant; theory and models of superhumps are well developed. On the basis of our knowledge of this phenomenon, one would expect to detect superhumps with periods exceeding the orbital only by a few percent. Noting that permanent superhumps were detected in nova-like systems with short periods, a dwarf nova of SU UMa type produces superhumps only during superoutbursts. FS Aur in turn never showed superhumps during decades of optical monitoring. We think that it is extremely unlikely that the photometric period in FS Aur is due to an eccentric disk precession because the period difference is much too large.

3. The long period could be the precession period of a warped disk. One possible model to explain the difference between spectral (orbital) period and the photometric variations in FS Aur is the presence of a tilted accretion disk that is rigidly precessing with the observed photometric period. Similar models have been proposed to explain long-term variations in X-ray binaries. The analytical estimates of the induced precession period are given by Papaloizou & Terquem (1995) and Larwood (1998). The ratio between the binary orbital period and the forced precession period is

$$\frac{P}{P_p} = \frac{3}{7}\, q \left(\frac{1}{1+q}\right)^{1/2} \left(\frac{R_o}{a}\right)^{3/2} \cos\delta, \tag{2}$$

where $q = M_s/M_p$ is the mass ratio, R_o is the outer radius of the disk, a is the orbital separation, and δ is the orbital inclination with respect to the disk. For mass ratios $q = 0.2$–20, Larwood found that period ratios for precessing tilted disks is in the range $P_p/P \approx 18$–40. If the mean Papaloizou & Pringle (1977) disk truncation radius applies, then the lower value is ≈10.

From the absence of superoutbursts in FS Aur, we are not bound to the 3 : 1 resonance criterion, so the mass ratio can be different from the $0.05 < q < 0.25$ requirement for the eccentric disk resonance. However, it is hard to find reasonable

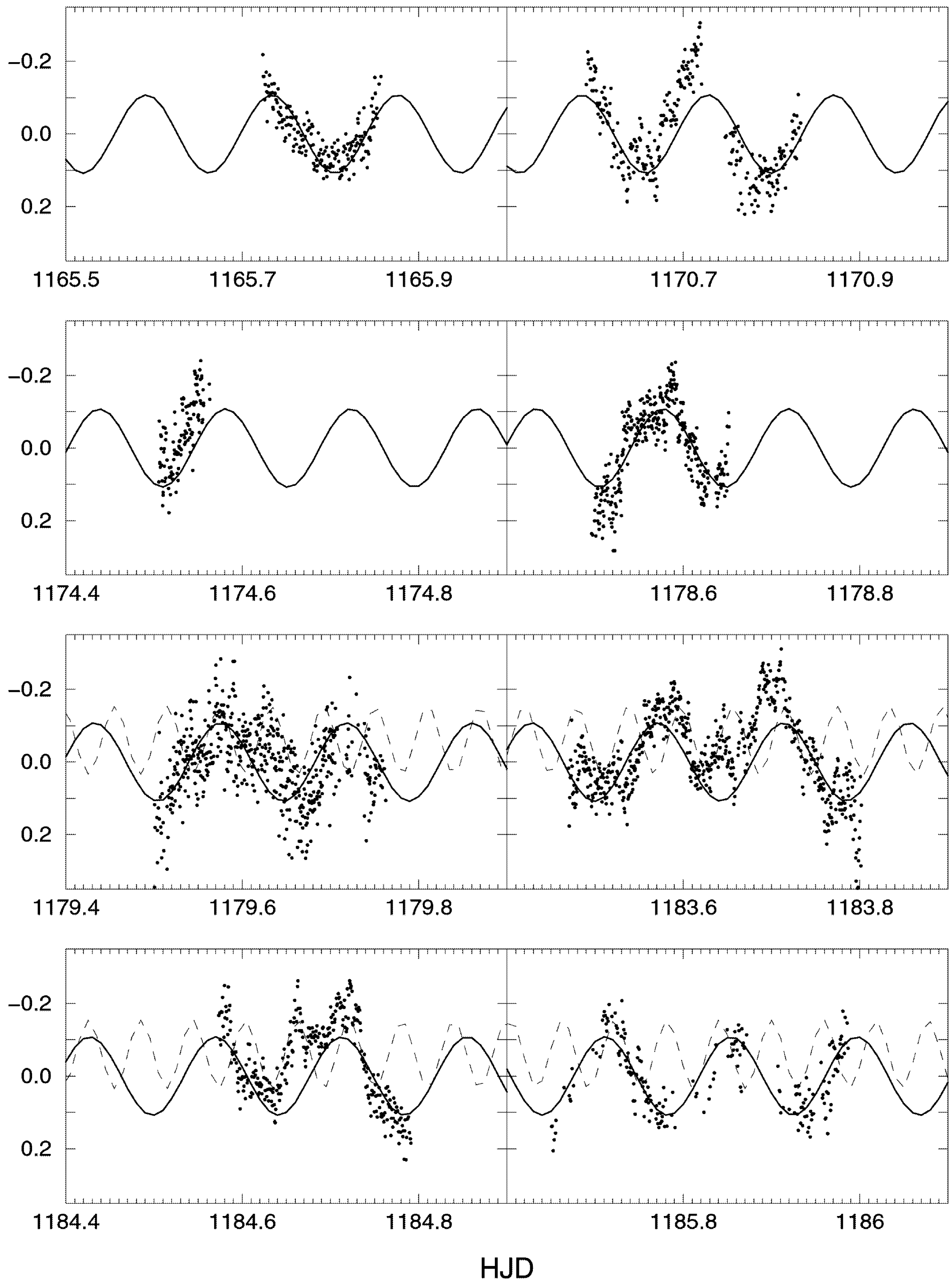

FIG. 5.—FS Aur light curves are presented. The epoch of observations is HJD 2,450,000+. The overlaid solid curve represents the photometric period. The dashed line corresponds to the spectroscopic period and is described in the text. The last panel shows all data together.

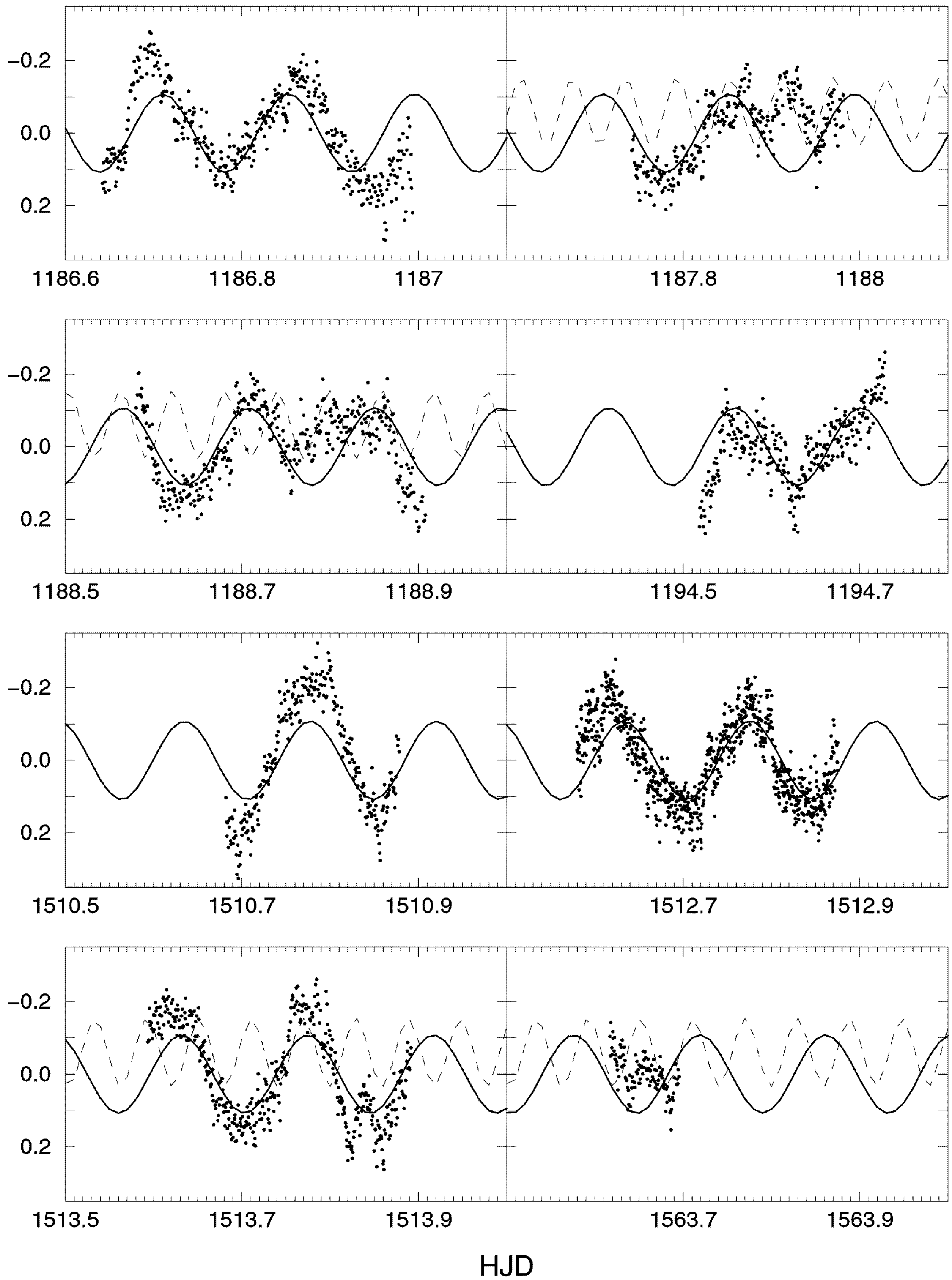

FIG. 5.—*Continued*

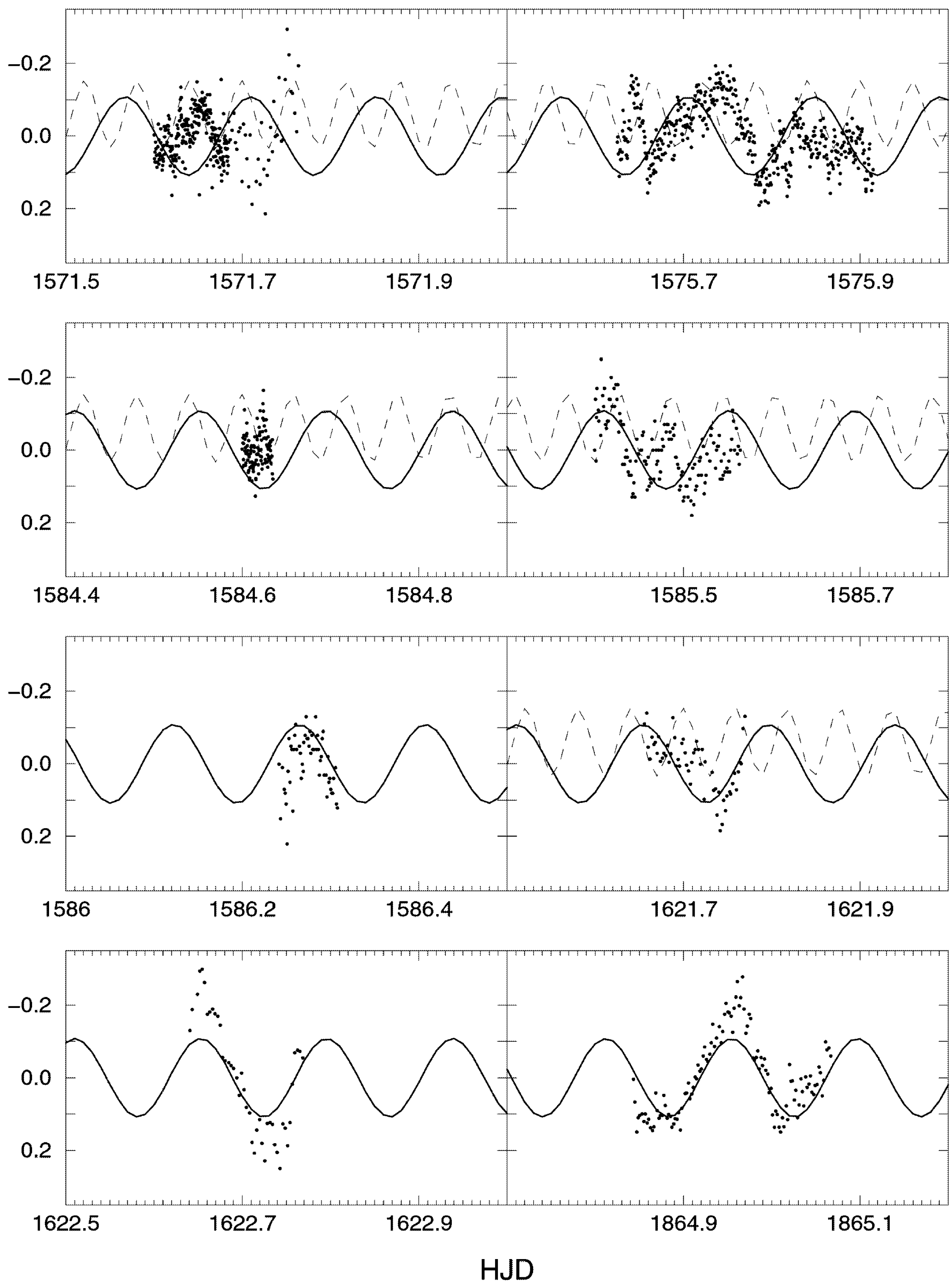

FIG. 5.—*Continued*

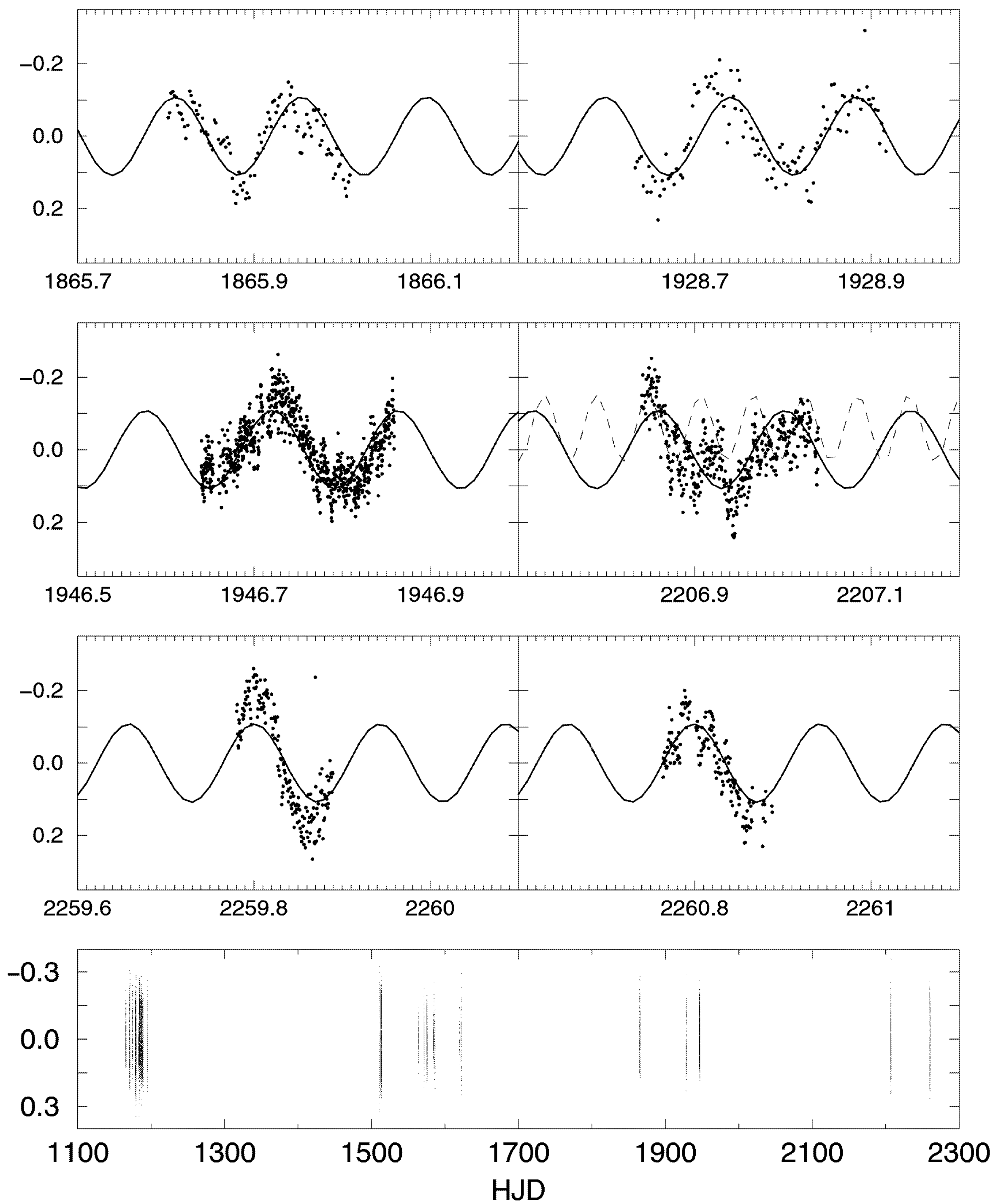

Fig. 5.—*Continued*

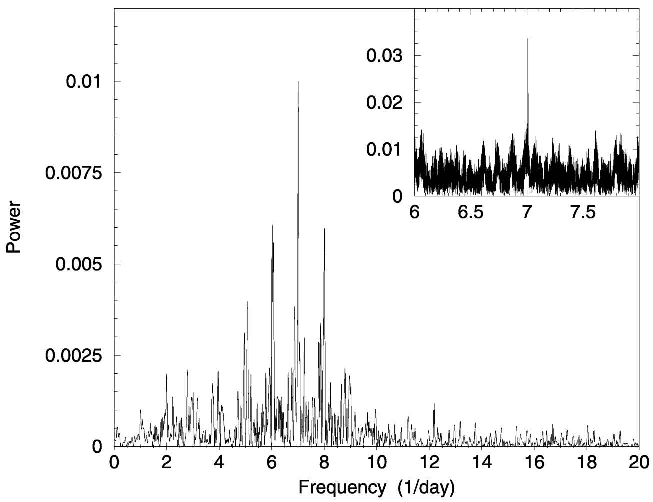

FIG. 6.—CLEANed power spectrum of the combined photometric data and blowout of the most prominent peak.

values of masses in order to reach a rigid precession of a gaseous Keplerian disk in a system similar to FS Aur. The secondary in the system should be a late M dwarf according to the relation between orbital period and spectral class of the secondary. The absence of any contribution in the near-IR spectrum from the secondary confirms that it is at least later than M0 with $M_2 < 0.5\ M_\odot$. On the other hand, rough estimates of M_1 yield values somewhere between $0.34 < M_1 < 0.46$ (N02). Thus, the mass ratio q can reach at maximum 1.5, if we assume an M0 secondary with $0.5\ M_\odot$ and the lower limit on M_1. With these parameters, $P_p/P_{\rm orb} > 14$ according to Larwood (1998), and the precession period in FS Aur should have been on the order of 1 day (≥20 hr).

Radiation-driven warping of accretion disks (Oglive & Dubus 2001) imposes additional restrictions on the parameters of binary systems in order to maintain stable precessing disks.

Thus, from a purely theoretical point of view, it is very difficult to justify a disk precession model. From the observational point of view, the contribution of the disk in emission is inferior to the spot, whatever the origin of the spot is. Thus, the spectroscopic data do not provide strong evidence of a luminous disk whose precession could lead to the observed photometric variations.

4. Could it be due to the rotation of the magnetic poles of the WD? The colors and shapes of the optical light curve strongly support the magnetic-spin version of the photometric period; there are numerous similar light curves in the literature on intermediate polars (IPs). For example, we refer to Norton (1999) and references therein. The intermediate polar scenario is so far the most plausible interpretation.

With this interpretation, we run basically into one important issue: Why is the period of rotation so slow? None of the dozens of known intermediate polars show WD spin periods less than the orbital one. Yet there are no theoretical restrictions on the velocity of rotation of the WD in CVs. Generally, one would expect the rotation periods of WDs in binary systems not to be very different from single WDs. According to Spruit (2001), the distribution of rotational velocities of WDs permits periods such as the one observed in FS Aur.

However, the presence of a magnetic field anchored on a WD makes almost impossible the existence of a stable spin periods less than $0.68P_{\rm orb}$, according to King & Wynn (1999), unless the magnetic field is high enough so that the magnetosphere of the WD overfills its respective Roche lobe and locks the system into synchronous rotation. Somerscales et al. (2002) considered the spin periods of magnetic CVs and show that there are very strong restrictions on the spin periods in magnetic CVs. But we should note here that there are a few examples of asynchronous polars that are supposed to be jolted out of synchronism by a nova explosion. The period difference is again not as big as in the case of FS Aur, and any system would rapidly tend to establish synchronization, but little is known about what happens during such cataclysms and how far it may take the spin period. Therefore, it is difficult to directly apply the IP scenario to the case of FS Aur in this pretext.

An alternative assumption to the longer than orbital spin period might be the possibility that the real WD spin period is of the order of 50–100 s and FS Aur is a fast rotator as AE Aqr and DQ Her. If we assume also that the WD in FS Aur freely precesses, then such fast rotation will result in the wobbling of the X-ray projector together with the WD. In a certain orientation of the magnetic pole angle to the orbital plane (colatitude β), the X-ray beam may or may not sweep across the disk or its inner edge. What or how much that fan beam perpendicular to the magnetic field lines will illuminate may explain the nature of this so far mysterious photometric period. The idea of free precession of WD was explored by Leins et al. (1992). They mention IPs as a possible laboratory to test it. According to Leins et al. (1992), Euler's frequency of free precession $\omega_{\rm E}$ of a rigid and axially symmetric body will be

$$\omega_{\rm E} = \alpha(\rho_c)\Omega^3. \tag{3}$$

In case of an elastic body, the Chandler frequency $\omega_{\rm C}$ is used instead:

$$\omega_{\rm C} = \beta(\rho_c)\Omega^3, \tag{4}$$

where $\alpha(\rho_c)$ and $\beta(\rho)$ are coefficients that are determined by the central density ρ_c or a mass M, radius R, and moment of inertia A of the WD. The results of numerical calculations for the realistic models of a WD with different central densities are presented in Table 2 of Leins et al. (1992). For a WD mass between 0.55 and 0.63 $M_\odot$, $\alpha(\rho_c)$ ranges between 2.109 and 1.299, while $\beta(\rho)$ varies from 0.219 to 0.124, correspondingly. Thus, a WD rotating with $50\ {\rm s} \le P_{\rm spin} \le 100$ s would have a free precession period of $P_{\rm prec} = 205$ minutes depending on which model (Euler or Chandler) we adopt.

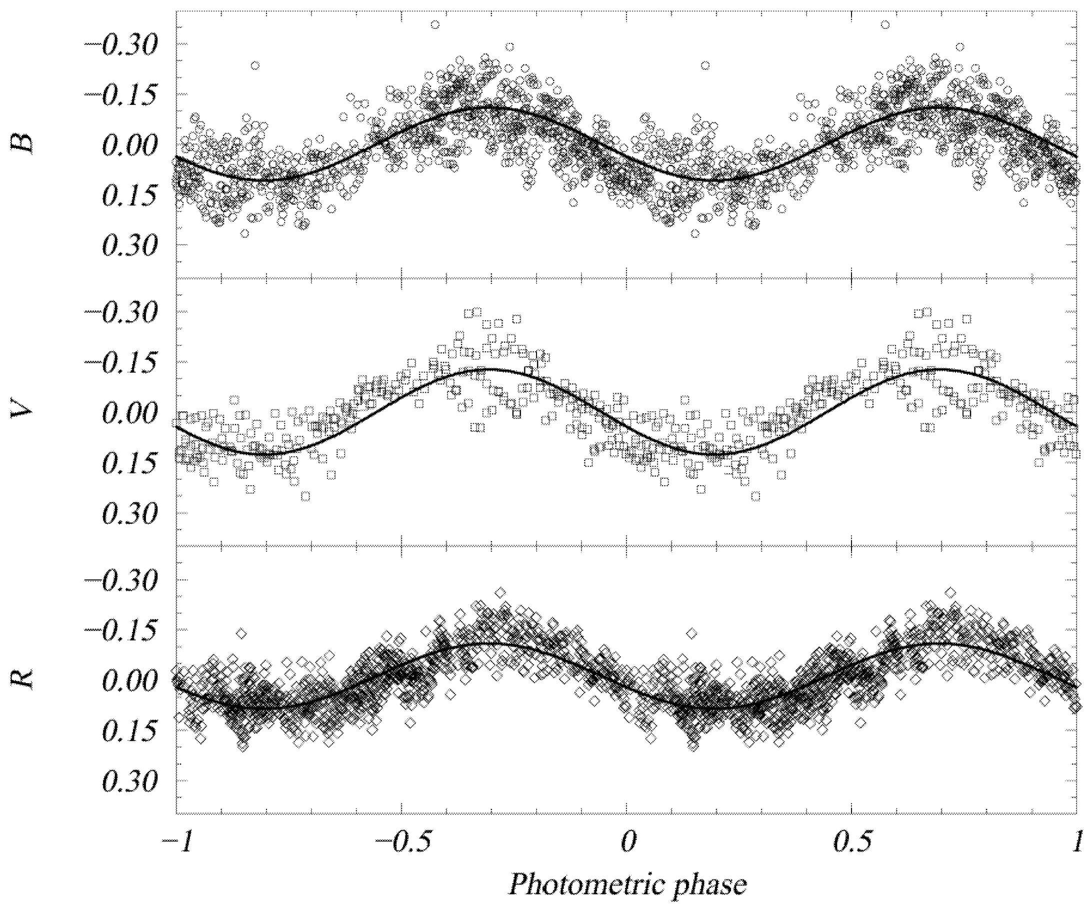

FIG. 7.—*BVR* light curves of FS Aur folded with the photometric period 205.5 minutes.

A good test for this intermediate polar scenario is the X-ray light curve. The spectral hardness ratio is in agreement with X-ray spectra from other known IPs. We have folded the X-ray data of the *ROSAT* pointed observation with the photometric and spectroscopic period, respectively. The corresponding curves are shown in Figure 9. Neither of the two figures contradicts the presence of a periodic signal with the corresponding period in the light curve. FS Aur was observed five times with 10–20 minutes each at time intervals of 3–4 hr. The periodic pattern in both panels most probably is the observing window. This is what causes the left panel in the image to show the "coherent" pattern: it is just the observing window pattern. The statistics are very poor, and the limit on the pulse fraction is less than 80%. Therefore, depending on the binning of a handful of photons, one can reach misleading results. New X-ray observations are needed and may help to sort this out.

5. CONCLUSIONS

There were arguments in the literature as to whether SW Sex objects owe their unusual characteristics to the phenomenon known as intermediate polars (Warner 1995). V795 Her has been proposed to be an intermediate polar and an SW Sex object at the same time (see Casares et al. 1996). The newly discovered KUV 03580+0614 (Szkody et al. 2001) is a good candidate for both categories. There are other, less obvious examples. These objects lack the detection of a stable, clearly detectable spin period. In FS Aur, we were able to observe two distinct, unrelated periods similar to the intermediate polars. There are very firm restrictions on upper limits of the spin periods of IPs, and 205 minutes is certainly excluded for FS Aur as the rotation period of the WD. Therefore, we propose that the WD in FS Aur is a fast rotator with $P_{\rm spin}$ around 50–100 s and freely precesses with $P_{\rm prec} = 205$ minutes. The cause of optical modulations with spin and sideband periods in IPs is still a matter of debate, but regardless of its nature the amplitude of the modulation is simply a geometrical effect of the orientation of the X-ray beam relative to the line of sight and/or orbital plane. Therefore, it may also explain why the observed phenomenon is unique so far. The number of IPs is still statistically small, and the detection of this effect might be merely a matter of a distinct magnetic pole colatitude. We

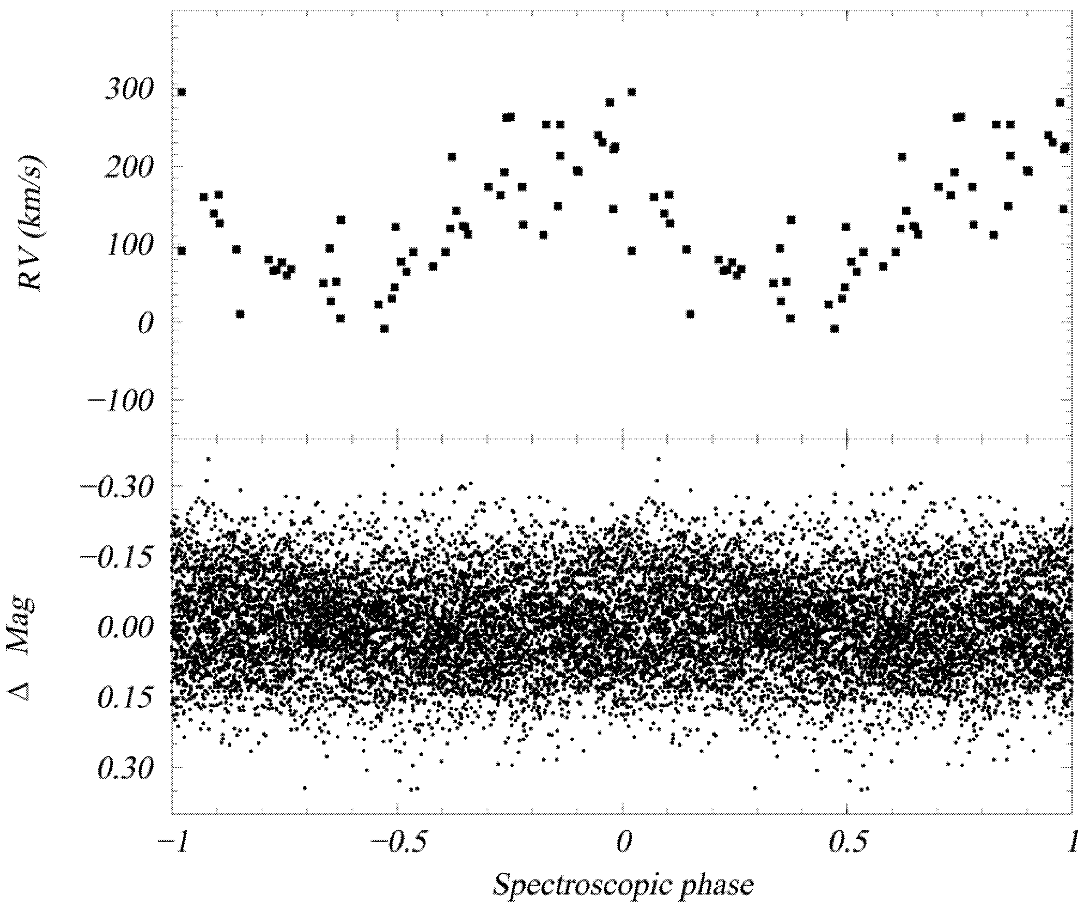

FIG. 8.—Combined photometric data folded with the spectroscopic (orbital) period.

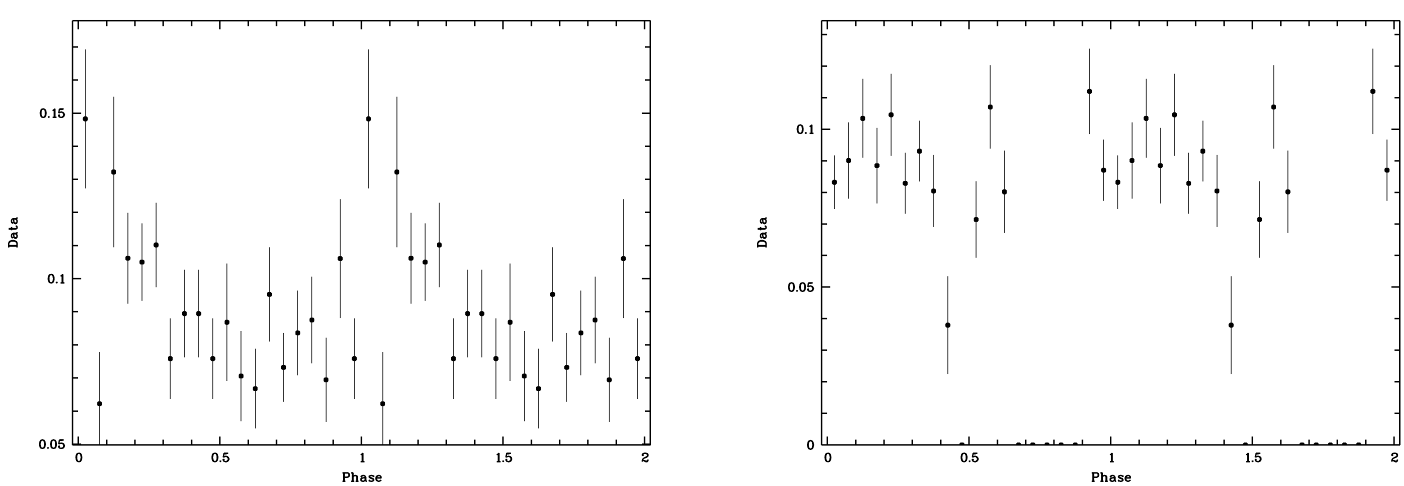

FIG. 9.—Folded X-ray light curves of FS Aur, obtained from the *ROSAT* PSPC observation of 1993 September 23 and folded with the spectroscopic (i.e., orbital; *left panel*) and photometric (205 minutes) period (*right panel*).

suggest that this phenomenological model can be observationally tested with fast optical photometry and/or more sensitive X-ray observations (*Chandra*/*XMM*).

While the combination of the SW Sex and IP models is appealing, there are big difficulties in squeezing FS Aur into each of these. Thus, FS Aur may be a rare, new kind of cataclysmic variable that can be defined as a dwarf nova, which in addition to its orbital period shows a photometric period that is 2–3 times longer in its light curve. Recently, Woudt & Warner (2002) discovered another similar system. GW Lib is another short-period CV that, apart from its 1.28 hr spectroscopic period, shows a well-defined photometric modulation of light with 2.09 hr periodicity. As is the case with FS Aur, the reasons for such behavior are not yet clear. However, we can talk of a new phenomenon within cataclysmic variables. FS Aur and GW Lib can be classified as a new type of CV, which still needs an explanation of its nature.

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REFERENCES

Andronov, I. L. 1991, Inf. Bull. Variable Stars, 3614, 1
Casares, J., Martinez-Pais, I. G., Marsh, T., Charles, P. A., & Lazaro, C. 1996, MNRAS, 278, 219
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Hellier, C. 2000, NewA Rev., 44, 131
Hoard, D. W., Thorstensen, J. R., & Szkody, P. 2000, ApJ, 537, 936
Hoffmeister, C. 1949, Veröff. Sternw. Sonneberg, 1, 3
Howell, S. B., & Szkody, P. 1988, PASP, 100, 224
King, A. R., & Wynn, G. A. 1999, MNRAS, 310, 203
Larwood, J. 1998, MNRAS, 299, L32
Leins, M., Soffel, M. H., Lay, W., & Ruder, H. 1992, A&A, 261, 658
Neustroev, V. V. 2002, A&A, 382, 974 (N02)
Norton, A. 1999, in AIP Conf. Proc. 599, X-Ray Astronomy: Stellar Endpoints, AGN, and the Diffuse X-Ray Background, ed. N. E. White, G. Malaguti, & G. G. C. Palumbo (Melville: AIP), 806
Oglive, G. I., & Dubus, G. 2001, MNRAS, 320, 485
Oke, J. B. 1990, AJ, 99, 1621
Papaloizou, J., & Pringle, J. E. 1977, MNRAS, 181, 441
Papaloizou, J., & Terquem, C. 1995, MNRAS, 274, 987
Patterson, J. 2001, PASP, 113, 736
Patterson, J., et al. 2000, AAS, 196, 1003
Pfeffermann, E., et al. 1986, Proc. SPIE, 733, 519
Roberts, D. H., Lehar, J., & Dreher, J. W. 1987, AJ, 93, 968
Somerscales, R. V., Norton, A. J., Wynn, G. A., & West, R. G. 2002, in ASP Conf. Ser. 261, The Physics of Cataclysmic Variables and Related Objects, ed. B. T. Gänsicke, K. Beuermann, & K. Reinsch (San Francisco: ASP), 171
Spruit, H. C. 2001, in ASP Conf. Ser. 229, Evolution of Binary and Multiple Star Systems: A Meeting in Celebration of Peter Eggleton's 60th Birthday, ed. Ph. Podsiadlowski, S. Rappaport, A. R. King, F. D'Antona, & L. Burder (San Francisco: ASP), 43
Szkody, P., Gansicke, B., Fried, R., Heber, U., & Erb, D. 2001, PASP, 113, 1215
Taylor, C., Thorstensen, J., & Patterson, J. 1999, PASP, 111, 184
Thorstensen, J. R., Patterson, J., Shambrook, A., & Thomas, G. 1996, PASP, 108, 73
Thorstensen, J. R., Ringwald, F., Wade, R., Schmidt, G., & Norsworthy, J. 1991, AJ, 102, 272
Tovmassian, G., Zharikov, S., Neustroev, V. V., Michel, R., & Greiner, J. 2002, in ASP Conf. Ser. 261, The Physics of Cataclysmic Variables and Related Objects, ed. B. T. Gänsicke, K. Beuermann, & K. Reinsch (San Francisco: ASP), 557
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge Univ. Press)
Woudt, P. A., & Warner, B. 2002, Ap&SS, 282, 433