HIGH SPECTRAL RESOLUTION TIME-RESOLVED OPTICAL SPECTROSCOPY OF V893 SCORPII

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ABSTRACT

We present high-resolution time-resolved optical spectra of the high-inclination, short orbital period dwarf nova V893 Scorpii. We performed spectral analysis through radial velocity measurements, Doppler mapping, and ratioed Doppler maps. Our results indicate that V893 Sco’s accretion disk is dissimilar to WZ Sge’s accretion disk and does not fit any of the current accretion disk models. We derive the system parameters $M_1$ and $i$ and present evidence for V893 Sco as a very young cataclysmic variable and an ER UMa star. We advance the hypothesis that all ER UMa stars may be newly formed cataclysmic variables.

Subject headings: binaries: close — novae, cataclysmic variables — stars: dwarf novae — stars: individual (V893 Scorpii)

1. INTRODUCTION

Emission lines in high-inclination, short orbital period dwarf novae consist of strong hot spot emission superimposed on a double peaked profile from the accretion disk (Warner 1995). The hot spot emission, because of the binary system orbital motion, produces the characteristic S-wave motion seen in trailed spectrograms (Honeycutt, Kaitchuck, & Schlegel 1987). Doppler maps of dwarf nova emission lines show clear indications of both the hot spot and the accretion disk emission, the latter producing a ring-shaped bright region in velocity space (Kaitchuck et al. 1994). Emission lines from the accretion disk imply that part of the accretion disk gas is optically thin and has low density (Kaitchuck et al. 1994; Williams 1980; Tylenda 1981). Optically thin, low gas density accretion disks are predicted in short orbital period dwarf novae because of their low mass transfer rate ($M \lesssim 6.3 \times 10^{14}$ g s$^{-1}$; Howell, Skody, & Cannizzo 1995; Howell, Rappaport, & Polito 1997).

Photometric and spectroscopic studies of short orbital period dwarf novae at quiescence show accretion disks that do not fit in the standard optically thick x-disk model (e.g., WZ Sge [Mason et al. 2000; Skidmore et al. 2000], Z Cha and OY Car [Wood 1990]). In particular, recent works on WZ Sge (Mason et al. 2000; Skidmore et al. 2000) have shown evidence for an optically thin accretion disk in the emission lines and an optically thick hot spot elongated along the stream trajectory. Observational testing is fundamental to prove or disprove current accretion disk models and evolutionary theories. Thus, the authors have undertaken a project aimed at the study of the accretion disks in quiescent, short orbital period dwarf novae through time-resolved spectroscopy. V893 Sco was selected because it is a high orbital inclination system showing hot spot eclipse (Bruch, Steiner, & Gneiding 2000) and strong double-peaked Balmer emission lines (Thorstensen 1999) similar to WZ Sge.

We describe our new observations of V893 Sco and the data reduction in § 2. Results from trailed spectra, Doppler and ratioed Doppler maps, and radial velocity curves are presented in § 3. Section 4 discusses our understanding of V893 Sco’s accretion disk structure and compares it with that of WZ Sge, a similar looking short orbital period dwarf nova. The present evolutionary status of V893 Sco is also discussed. Section 5 summarizes our results.

2. OBSERVATION AND DATA REDUCTION

Observations were carried out on 2000 March 3 and 4 UT on the New Technology Telescope in La Silla. EMMI was used in medium-resolution mode, with gratings Grat 3 and Grat 6 mounted in the blue and red arms, respectively. Observations were performed simultaneously by the use of a dichroic with a central wavelength of 450 nm. A detailed log of the observations is summarized in Table 1.

Both nights were photometric and the seeing was always $\lesssim 0.8–0.9$; thus, the slit aperture was set to 0.9. Each night the standard star Feige 56 was observed before V893 Sco for flux calibration. HeAr and ThAr arc exposures were taken only at the beginning and the end of the object observations and were used for wavelength calibration of the blue and the red arms, respectively.

Data reduction was performed by one of us (E. Mason)
using the standard IRAF routines ccdred and onedspec. Each frame was bias subtracted and flat-field corrected using exposures taken on the morning following each observing night. Wavelength calibration was performed by extracting the matching arc for each spectrum and by fitting the arc emission lines with a spline of first or second order in both arms. The number of fitted lines varied between 55 and 60 in the blue and between 15 and 20 in the red; both fits were carried out keeping the residuals of the fitting function \( \leq 10^{-12} \text{ km s}^{-1} \), i.e., less than 0.25 \( \text{Å} \text{ pixel}^{-1} \). A sample of the reduced and phase-folded spectra is shown in Figure 1.

3. EMISSION-LINE ANALYSIS

3.1. Trailed Spectra and Doppler Maps

In V893 Sco, the emission-line profile evolution through an orbit (see Fig. 1) appears quite confusing at first glance. The three Balmer lines show different profiles and profile evolution. For example, the H\( \alpha \) line shows multipeaked profiles, which are never observed in the blue arm spectra and are not explained by the standard S-wave motion. The two He I emission lines \( \lambda 4026.3, 6678.1 \) seem to follow the profile evolution shown by the H\( \gamma \) and H\( \delta \) lines.

Trailed spectrograms (Fig. 2) for the five emission lines show a lack of the typical S-wave component, and the \( V/R \) ratio is \( \geq 1 \) at all phases. Since the lack of the S-wave component cannot be due to the time resolution of our spectra, the following two physical interpretations can be advanced: (1) there is not significant hot spot emission, and (2) the accretion disk gas is optically thick in the emission lines, thus, the line emissivity is strongly anisotropic. The line photons emerge more readily in directions along which the Keplerian velocity field provides a large Doppler-shifted gradient (Horne & Marsh 1986). The above two hypotheses are not mutually exclusive.

Doppler maps of the Balmer lines have been generated by using the back-projection algorithm in the data reduction package molly (written by T. Marsh; see Horne 1991 for...
details of the back-projection technique). The spectra were continuum subtracted (the continuum was fit by a first-order spline) and Fourier filtered before back projection (both blue and red arm spectra). Phasing of the spectra was made according to the photometric ephemeris given in Bruch et al. (2000). Spectra around phase ~0 were not excluded as we verified that the emission-line fluxes do not show any eclipse effects.

Figure 3 shows Doppler maps and reconstructed trailed spectrograms for the three Balmer lines. All three Doppler maps show a relatively strong emission at roughly the expected hot spot position. Indeed, trailed spectra in Figure 2 show enhanced emission in the blue and red accretion disk peak in the phase ranges 0.1–0.25 and 0.4–0.55, respectively, which may be evidence of some hot spot emission. The reconstructed trailed spectra show that such enhanced emission produces the hot spot region in the back-projected Doppler maps. However, the hot spot emission is stronger than the accretion disk emission by only, at most, 20% and ≤10% in the Hα and Hγ and Hδ lines, respectively.

In the Hα Doppler map, the hot spot emission is centered at $v_X \sim -800$ km s$^{-1}$ and $v_Y \sim 0$ km s$^{-1}$ and is quite elongated toward negative $v_X$ values. Previous Hα Doppler maps of V893 Sco (Matsumoto, Mennickent, & Kato 2000) show the hot spot centered at about the same position, but different in both size and orientation. The accretion disk emission appears to arise mainly from the leading side of the disk, being strong between phases 0.15 and 0.5 and weak otherwise. Nonuniform accretion disk emission was also pointed out by Matsumoto et al. (2000); however, their Doppler maps show the accretion disk inhomogeneities to dramatically vary in both extension and position from night to night. Our Hα Doppler map of V893 Sco provides evidence for emission from the secondary star being irradiated by the hot spot. Irradiation of the secondary star was noticed also by Matsumoto et al. (2000), but they observed it to disappear during one of their six nights of observation, just in the preoutburst stage. There is no evidence of irradiation in the Hγ and Hδ Doppler maps. Doppler maps for Hγ and Hδ show a quite extended hot spot region, centered slightly ahead of the Hα hot spot emission and possibly elongated along the $v_Y$ axis. The hot spot peak intensity appears at $v_X \sim -800$, $v_Y \sim -200$ km s$^{-1}$ and $v_X \sim -800$, $v_Y \sim -400$ km s$^{-1}$ for Hγ and Hδ, respectively, with a possibly double-peaked Hγ hot spot.

3.2 Radial Profiles, Ratioed Doppler Maps, Balmer Decrement, and Continuum Fitting

Ratioed Doppler maps (Fig. 4) show quite uniform gas densities in the accretion disk and roughly equal flux ratio at the hot spot position and the accretion disk. Radial profiles of the accretion disk emitting regions (Fig. 5, left panel) show the line flux smoothly increasing toward the center of the accretion disk in all three of the Balmer lines, while the disk, being strong between phases 0.15 and 0.5 and weak otherwise. Nonuniform accretion disk emission was also pointed out by Matsumoto et al. (2000); however, their Doppler maps show the accretion disk inhomogeneities to dramatically vary in both extension and position from night to night. Our Hα Doppler map of V893 Sco provides evidence for emission from the secondary star being irradiated by the hot spot. Irradiation of the secondary star was noticed also by Matsumoto et al. (2000), but they observed it to disappear during one of their six nights of observation, just in the preoutburst stage. There is no evidence of irradiation in the Hγ and Hδ Doppler maps. Doppler maps for Hγ and Hδ show a quite extended hot spot region, centered slightly ahead of the Hα hot spot emission and possibly elongated along the $v_Y$ axis. The hot spot peak intensity appears at $v_X \sim -800$, $v_Y \sim -200$ km s$^{-1}$ and $v_X \sim -800$, $v_Y \sim -400$ km s$^{-1}$ for Hγ and Hδ, respectively, with a possibly double-peaked Hγ hot spot.

Figure 2—Trailed spectrograms of the Balmer lines (Hα, Hγ, and Hδ) and the He i lines λ4026.3, 6678.1

[Image: Trailed spectrograms of the Balmer lines (Hα, Hγ, and Hδ) and the He i lines λ4026.3, 6678.1]
Fig. 3.—Top: Doppler maps of the three Balmer lines. Filtering of the spectra was performed with a FWHM of 0.5 in all three cases; velocity binning was made at the rest wavelength for each line, with the velocity dispersion corresponding to a 0.39 Å pixel\(^{-1}\) resolution. Input \(y\) velocity was different for each Doppler map and corresponds to the values determined for each radial velocity curve (see Table 3). Bottom: Trailed spectrograms reconstructed by inverting the back-projection process. By comparison with the trailed spectra in Fig. 2 it is evident that some smoothing (in the time/phase direction) has occurred as expected. However, the main features characterizing the input data have been reproduced in the reconstruction.

radial profiles of ratioed Doppler maps increase with the radius (Fig. 5, top of middle and right panels). The derived temperature profiles (Fig. 5, bottom of middle and right panels) are flatter than in an optically thick accretion disk. The innermost accretion disk region (0.1–0.2 \(R/L_1\)), which apparently matches the temperature profile of an optically thick \(x\)-disk having \(M \sim 10^{16} \text{ g s}^{-1}\), is too noisy to allow any definitive conclusion.

The Balmer decrements \(H\alpha/H\gamma\) and \(H\alpha/H\delta\) have been computed in three different ways: (1) by ratioing the emission-line fluxes, (2) by ratioing the emission-line peak intensity as described in Mason et al. (2000), and (3) by averaging either azimuthally and radially different segments in the ratioed Doppler maps. In methods 1 and 2, orbital average values were used, as we did not find phase-dependent modulations. The Balmer decrement at the hot spot position determined in method 3 is dubious, as the hot spot emission overlaps the accretion disk emission. However, despite the different assumptions involved, methods 1, 2, and 3 provide identical Balmer decrement values, within the uncertainties (see Table 2).

In order to derive information on the temperature (and possibly density) of the accretion disk line-emitting region, we averaged the three values for each Balmer decrement.

Fig. 4.—Ratioed Doppler maps. Scale bars show the ratio of fluxes in frequency units.
We found $D_l(H\alpha/H\delta) = 2.15 \pm 0.29$ and $D_l(H\alpha/H\delta) = 2.47 \pm 0.45$, which correspond to either a blackbody of temperature $\sim 4700 \pm 300$ K or an optically thin gas, with either temperature $T \sim 8000$ K and density $\log_{10} N_0 \sim 12.9$ or temperature $T \sim 10,000-15,000$ K and density $\log_{10} N_0 \sim 12.4$ (Fig. 6; Williams 1991). In the case of optically thick accretion disk emission lines, the hot spot gas cannot have the same Balmer decrement as the accretion disk, otherwise it would imply a hot spot gas temperature of $T < 5000$ K, which is far too low for the gas impact region.

The blackbody temperature was computed including a thermal and/or turbulent broadening correcting factor of $\lambda_0^{-1}$ (Williams 1980). Neglecting the thermal broadening, we find an upper limit of $\sim 5700 \pm 300$ K for the accretion disk temperature in the optically thick case.

We also investigated the continuum emission from both hot spot and accretion disk gas. We determined the hot spot continuum emission by subtracting the average of five spectra centered at phase $\sim 0$ (hot spot eclipse) from the average of five spectra around phase $\sim 0.8$ (hot spot facing the observer) and compared the result with a blackbody. The red and blue spectral differences could not be fit with a single blackbody function. We found $8550 \pm 150$ K and $10,450 \pm 50$ K blackbodies to match the continuum slopes in the red and blue arms, respectively, possibly indicating that there is a temperature structure in the optically thick hot spot continuum emission. The accretion disk continuum was derived by fitting the continuum in the blue and red arm spectra averaged over both nights. We checked to see if the continuum slope matches an optically thick $\alpha$-disk emission but found it to be shallower than $F_\lambda \propto \lambda^{-7/3}$.

| Method 1 | Method 2 | Method 3 |
|----------|----------|----------|
| $D_l$    | PEAK INTENSITY | RATIO MAPS AVERAGE RADIAL PROFILE |
|          | Emission Line | Disk | Hot Spot | Disk | Hot Spot |
| H$\alpha$/H$\gamma$ | 2.27 ± 0.45 | 2.03 ± 0.42 | 2.39 ± 0.76 | 2.25 ± 1.02 | 2.22 ± 0.93 |
| H$\alpha$/H$\delta$ | 3.05 ± 0.74 | 2.01 ± 0.62 | 2.34 ± 0.75 | 2.68 ± 1.34 | 2.61 ± 1.29 |

NOTE.—Balmer decrement values derived for the hot spot gas via method 3 (last column in table) are not subtracted of the accretion disk contribution. See text for further explanations.
matching a best-fit blackbody of 11,750 ± 250 K and 6400 ± 50 K in the blue and red arms, respectively. The hotter blue continuum possibly indicates a higher gas temperature in the inner accretion disk.

3.3. Radial Velocity Curves

Radial velocity measurements were made on each original spectrum following the Pogson-like method described in Mason et al. (2000). We measured the accretion disk emission-line wings by positioning the cursor at different levels above the continuum up to ~30% of the average line intensity \( I \). We verified that the wing measurements at intensity levels \( \lesssim 0.3 \times I \) were not biased by the hot spot S-wave motion, which is expected to blueshift the blue wing and redshift the red wing at phases 0.55 and 0.05, respectively. We observe such a hot spot bias to affect wing measurements at intensity levels of \( \gtrsim 0.5 \times I \). However, we still derived different radial velocity curve fitting parameters depending on the measured emission line. Thus, bias other than the hot spot must affect our radial velocity measurements.

In order to reduce the uncertainties of the radial velocities, we applied a running boxcar to our measurements before sine fitting the radial velocity curves. Boxcar smoothing of the radial velocity measurements was preferred to spectra binning before radial velocity measurements as it does not reduce the phase resolution of the data set. The three smoothed radial velocity curves were fitted with the fitting function as in formula (1) of Mason et al. (2000). The best-fitting parameters are summarized in Table 3, while the radial velocity curves and their correspondent fits are plotted in Figure 7. The He i lines were too weak to allow accurate radial velocity measurements.

The phase of the red-to-blue crossing, \( \phi_0 \) (Table 3), corresponds to the phase offset between the spectroscopic and the photometric time for the secondary star inferior conjunction, and it is believed to be proportional to the relative intensity of the hot spot emission with respect to the accretion disk emission and to the hot spot bias in the radial velocity measurements. In the V893 Sco radial velocity curves, the phase offset is small in all three of the Balmer lines, with an average value of \( \phi_0 = 0.0616 \pm 0.0090 \).

**TABLE 3**

| Line | Central Wavelength (Å) | \( V/R \) Crossing (\( \phi_0 \)) | \( K_1 \) Amplitude (km s\(^{-1}\)) | Systemic Velocity (\( \gamma \)) (km s\(^{-1}\)) |
|------|----------------------|-----------------|-----------------|-----------------|
| H\(_{a}\) | 6560.03745 | 0.0798 ± 0.012 | 80.6 ± 7.5 | -135.3 ± 4.8 |
| H\(_{e}\) | 4340.97680 | 0.0354 ± 0.007 | 54.6 ± 8.6 | 32.9 ± 7.7 |
| H\(_{d}\) | 4102.28000 | 0.0385 ± 0.016 | 83.7 ± 7.6 | 42.4 ± 5.4 |
also found the phase offset not to be proportional to the excitation potential energy of the H emission lines, in contrast with WZ Sge and VY Aqr (Mason et al. 2000 and references therein).

4. DISCUSSION

V893 Sco and WZ Sge are high-inclination, short orbital period dwarf novae, showing both a hot spot eclipse in photometric observations and strong double-peaked Balmer emission lines in their optical spectra. However, despite these similarities, our spectral analysis applied to V893 Sco and WZ Sge (Mason et al. 2000) provided contrasting results.

The emission lines in WZ Sge are dominated by the hot spot emission, which heavily affects the line profile evolution throughout the orbital period. In V893 Sco, the emission lines do not show strong evidence of hot spot emission in any of our spectra, with the exception of Hα, Hγ and Hδ and the two He i lines λ4026.3 and λ6678.1 show V-shaped profiles and V/R ratios of ≥1 throughout the orbit. Trailing spectrograms of WZ Sge are dominated by the S-wave component, while in V893 Sco the trailing spectrograms show a complete lack of such a component.

Doppler maps of both WZ Sge and V893 Sco show asymmetric accretion disk emission. However, in WZ Sge, the disk emission appears weak and is superposed by an extremely strong hot spot emission, while in the V893 Sco Doppler maps there is the same Balmer decrement at the hot spot position as in the accretion disk gas. Radial profiles of V893 Sco Doppler maps show increasing flux toward the center of the accretion disk, while in the case of WZ Sge the emission-line flux is observed to increase outward.

Ratiod Doppler maps of WZ Sge show a statistically significant larger Balmer decrement in the accretion disk than in the hot spot, while in V893 Sco ratiod Doppler maps the Balmer decrement at the hot spot position is larger than or equal to that in the accretion disk gas. Radial profiles of the ratiod Doppler maps and the derived temperature profiles in the cases of both V893 Sco and of WZ Sge do not match the profile predicted by an optically thick x-disk model. Both systems have flux ratio increasing outward and a quite flat temperature profile.

The radial velocity curves yield different values for the system parameters $K_1$, $\gamma$, and $\phi_0$, depending on the accretion disk emission line measured. This is true for both WZ Sge and V893 Sco. However, in the case of V893 Sco, the derived phase offsets are small and not proportional to the excitation potential energy of the emission lines.

In V893 Sco, the V-shaped profile of the emission lines and the V/R ratios of ≥1 are consistent with saturated emission lines (Horne & Marsh 1986), and anisotropic turbulence with positive correlation in the vertical and azimuthal velocity components (Horne 1995). Optically thick emission lines also explain the lack of S-wave components in trailed spectrograms. However, the accretion disk gas temperature of ~4700 K in the line-forming region does not match any of the current accretion disk models at the mass transfer rate expected in V893 Sco (Osaki 1996; also see below). Tylenda (1981) derives gas temperatures in the range 4000–5000 K only in the cases of either very low mass transfer rates ($M \sim 10^{13}$ g s$^{-1}$) or high mass transfer rate and extended accretion disks ($M \sim 10^{17}$ g s$^{-1}$, $R_d > 4 \times 10^{16}$ cm). Williams (1980) predicts a lower limit of 6000 K for the accretion disk line-forming region at any mass transfer rate. Both Tylenda (1981) and Williams (1980) predict emission lines to form in the outer accretion disk, while we observe the emission-line flux to mostly arise from the inner accretion region.

Our observed emission-line flux radial profiles fit the optically thin line hypothesis, where the line-forming region
is a hot corona or a gas layer above the accretion disk. Within such a hypothesis, we would expect the accretion disk continuum flux to be optically thick to explain the lack of S-wave component in trailed spectra and the photometric light curve (Bruch et al. 2000). However, our continuum analysis was not conclusive and two different blackbodies were found to match our spectra, rather than the expected flux distribution of the optically thick $a$-disk model. Furthermore, the optically thin emission-line model does not explain the V-shaped line profiles. The observed $V/R$ ratio of $\geq 1$ may be explained by a bipolar wind flowing perpendicularly to the disk plane with an outflow velocity of $v_{\text{wind}} \approx 2000$ km s$^{-1}$. However, wind in non-magnetic cataclysmic variables is typically observed in the UV band and in either outbursting dwarf novae or nova-like variables (Warner 1995). The only systems where wind has been detected in the optical are BZ Cam (Ringwald & Naylor 1998) and V592 Cas (Huber et al. 1998).

In order to better understand the physics of the ongoing accretion process and the binary system evolutionary status and to possibly constrain the accretion disk, we performed the following computations. We determined the secondary star mass, $M_2$, and radius, $R_2$, for a 1.82 hr orbital period system (see Howell & Skidmore 2000). We find $M_2 = 0.175 M_\odot$ and $R_2 = 0.196 M_\odot$. We then used this $R_2$, with a first guess for $M_1$, $R_1$, $r_\nu$, the hot spot radius (Smak 1993: $r_\nu = 3.1 \times 10^8$ cm), and azimuth ($\alpha = 30^\circ$), to geometrically constrain the orbital inclination $i$. Applying formula 2.79 in Warner (1995) with our $K_i(H\alpha)$ determination, we computed the white dwarf mass $M_1$. We iterated the computation of $i$ and $M_1$ until convergence, keeping constant all the other parameters. The results are $i = 72.5^\circ$ and $M_1 = 0.89 M_\odot$.

We measured the emission-line peak separation in the spectra averaged over both nights (see Table 4) to determine the accretion disk radius via the equation (2) in Mason et al. (2000). We found the accretion disk to extend to $\sim 0.5 R_\nu$ in H$_\gamma$ and H$\delta$ emission lines and to exceed the primary Roche lobe in H$\alpha$. We believe the H$\alpha$ average profile to be biased by both the hot spot and the secondary star emissions that reduce the accretion disk line peak separation.

We can calculate an evolutionary model for V893 Sco using the code described in Howell, Nelson, & Rappaport (2001), $P_{\text{orb}} = 1.82$ hr, $M_1 = 0.89 M_\odot$, and $M_2 = 0.175 M_\odot$. Figure 8 plots the model results for the mass transfer rate as a function of both the orbital period (left panel) and of the “evolutionary time” (right panel). Figure 8 indicates that for the determined parameters in V893 Sco, the system is likely to be a newly formed cataclysmic variable having just begun mass transfer. This “initial contact” evolutionary phase is relatively short ($\lesssim 10^8$ yr) and is characterized by an increased $M$ owing to the sudden onset of mass transfer from the secondary star as it tries to adjust itself toward a new equilibrium (Howell et al. 2001).

Based on the orbital period and optical appearance, V893 Sco is believed to be an SU UMa star, although none of its observed outbursts are time-resolved enough to provide evidence for the occurrence of superoutbursts with superhumps. However, the VSNET database shows outbursts every $\sim 30$ days spaced by possible “minoutbursts” ($\lesssim 1$ mag) every few days. Such a photometric signature characterizes V893 Sco as a high mass transfer rate system belonging to the ER UMa stars class. The outburst behavior observed in V893 Sco, i.e., short recurrence time ($\sim 30$ days) and small outburst amplitude ($\lesssim 2$ mag), is consistent with a cataclysmic variable having a high mass transfer rate and a hot accretion disk at or near constant outburst, similar to the nova-like variables.

Given the possible membership of V893 Sco as an ER UMa star and its probable status as a young cataclysmic variable, we examine the evolutionary code also for the ER UMa stars ER UMa, V1159 Ori, and RZ LMi. The masses of the two star components in each system were derived similarly to $M_1$ and $M_2$ in V893 Sco. However, given that none of the three ER UMa stars present any eclipse or partial eclipse, the imposed geometrical constraints were different. Formula (2.79) in Warner (1995) was applied using as input parameters $M_1 = M_1^* = (1.4 + M_2/0.25)/2$ (where $M_1 = 1.4 M_\odot$ is the Chandrasekhar upper limit and $M_1 = M_2/0.25$ is the lower limit derived by the constraint $q < 0.25$ in the superhumps theory; Whitehurst 1988), $i = i_{\text{max}}/2$ (where $i_{\text{max}}$ is the average of the two upper limits for no eclipse derived for either $M_1 = 1.4 M_\odot$ or $M_1 = M_2/0.25$), and $P_{\text{orb}}$ and $K_1$, determined by Thorstensen et al. (1997) and Szkody et al. (1996). In order to decrease the uncertainties on $M_1$, we then averaged the derived $M_1$ with results from observed white dwarf mass distributions in cataclysmic variables (Sion 1999; Webbink 1990). The input parameters for our evolutionary models corresponding to each ER UMa star are listed in Table 5. The model results show all three of the ER UMa stars to also be at the “$M$-spike” during initial contact, thus being very young cataclysmic variables, similar to V893 Sco. We tested the validity of such a result by making the evolutionary models also for some SU UMa stars with known $M_1$, $M_2$, and $P_{\text{orb}}$ (Ritter & Kolb 1998). The model results were contrary to the observations, predicting incorrect orbital periods for the input masses and vice versa. We believe that incorrect $M_1$ determinations may be the cause of this discrepancy as they depend, by up to 70%, on the input (from old, inaccurate $M_2$-$P_{\text{orb}}$ relations) in formula 2.79 in Warner (1995). The discrepant $M_1$ values derived for V893 Sco by Matsu-

### Table 4

| Emission Line | Half-Peak Separation (km s$^{-1}$) |
|--------------|-----------------------------------|
| Hz           | 393.3 $\pm$ 4.6                   |
| H$\gamma$    | 606.2 $\pm$ 6.9                   |
| H$\delta$    | 649.2 $\pm$ 7.3                   |

### Table 5

| Star Name      | $M_2$ ($M_\odot$) | $M_1$ ($M_\odot$) |
|----------------|------------------|------------------|
| ER UMa         | 0.14             | 0.86 $\pm$ 0.12  |
| V1159 Ori      | 0.14             | 0.86 $\pm$ 0.12  |
| RZ LMi         | 0.12             | 0.85 $\pm$ 0.10  |

Note: $M_1$ for RZ LMi is an upper limit. Szkody et al. (1996) could not fit any sine curve to their radial velocity curve. Thus, $K_1 = 20$ km s$^{-1}$ is estimated to be an upper limit for the white dwarf Keplerian velocity.
moto et al. (2000) and us arise from their use of an improper $M_2 P_{\text{orb}}$ relationship.

5. SUMMARY AND CONCLUSIONS

We analyzed high-resolution, time-resolved spectroscopy of V893 Sco and found the following results:

1. Trailed spectra of the emission lines Hα, Hγ, and Hδ and He I λλ4026.3, 6678.1 were presented. They all show a lack of the S-wave component and a $V/R$ ratio $\gtrsim 1$ (Hz being the exception) across the whole orbit. Doppler maps of the three Balmer lines were presented. They show a non-uniform accretion disk with the hot spot emission being only $\sim 20\%$ stronger than the accretion disk. Doppler maps and trailed spectra also show evidence for Hz emission from the secondary star irradiated by the hot spot.

2. The Balmer decrements, $D_i(\text{Hz}/\text{Hγ})$ and $D_i(\text{Hz}/\text{Hδ})$, were determined by three different methods, all of which provide similar values. Average Balmer decrements were used to determine the physical parameters of the accretion disk gas. Our computed values correspond to either an optically thin gas of $T \sim 8000$–15,000 K or an optically thick gas of $T \sim 4700$ K. None of the current models describing emission lines from accretion disks completely satisfy the details of our results; thus, a definitive conclusion about the accretion disk gas temperature can not be reached in the present paper.

3. Radial velocity curves for different emission lines yield an inconsistent set of systemic parameters $K_{\text{s}}$, $\gamma$, and $\phi_{\text{b}}$ (as already found in WZ Sge). However, the results are different with respect to WZ Sge as we find only a small phase offset in V893 Sco and no linear relationship between the orbital phase and the excitation potential energy for hydrogen. We conclude that the hot spot region is not elongated along the steam trajectory with gas temperature decreasing downstream. The hot spot line-forming region in V893 Sco is consistent with the gas stream impacting on a denser accretion disk gas.

4. The white dwarf mass was determined from the secondary star mass function and the measured $K_i(\text{Hz})$ amplitude. We find $M_{\text{WD}} = 0.89 M_\odot$ and a mass ratio of $q = 0.19$. These system parameters match those of a newly formed cataclysmic variable in our evolutionary models. The high mass transfer rate predicted by either the model or the long-term light curve of V893 Sco (VSNET database), together with the accretion disk properties we described in § 4, imply that V893 Sco is likely to be an ER UMa star. The evolutionary code of Howell et al. (2001) also predicts three other ER UMa stars to be newly formed cataclysmic variables.

The two high-inclination, short orbital period systems V893 Sco and WZ Sge appear to be spectroscopically similar yet are two completely different types of system. They not only differ in their accretion disk structure/physics as described in § 4 but also in their outburst behavior. WZ Sge has the longest recurrence time ($\sim 33$ yr) and the largest outburst amplitude ($A \gtrsim 8$ mag); V893 Sco has the smallest outburst amplitude ($A \sim 1.5$–$2.0$ mag) and a short outburst recurrence time ($\lesssim 30$ days). The derived properties for the accretion disks in these two stars appear consistent with
current evolutionary theory. WZ Sge has been shown to not fit the standard α-disk model (Skidmore et al. 2000; Mason et al. 2000), and it is expected to have an extremely low mass transfer rate ($M \lesssim 10^{15} \text{ g s}^{-1}$; Howell et al. 1995; Osaki 1995; Smak 1993) and to be near or past the orbital period minimum (Howell et al. 1995; Ciardi et al. 1998).

V893 Sco also does not fit the standard α-disk model, nor any of the models accounting for at least a partly optically thin disk. We show it to be a high mass transfer rate, short orbital period dwarf nova with $M$ in the range $10^{15} - 10^{16} \text{ g s}^{-1}$ and predict it to be an ER UMa star and a newly formed cataclysmic variable. The high mass transfer rate invoked to explain the outburst recurrence time would be a natural consequence of the sudden onset of the mass transfer process. However, time-resolved light curves and long-term monitoring are necessary to definitely prove or disprove our hypothesis that V893 Sco is an ER UMa star, by detecting superhumps and confirming minioutbursts.

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