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OBSERVATIONS OF THE DWARF NOVA VW HYDRI IN QUIESCENCE WITH THE HOPKINS ULTRAVIOLET TELESCOPE

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ABSTRACT

The dwarf nova VW Hydri was in quiescence when it was observed in 1995 March with the Hopkins Ultraviolet Telescope on the Astro-2 space shuttle mission. The far-UV (820–1840 Å) spectra are punctuated by broad Lyα and Lyβ absorption profiles and narrow absorption lines which can be identified with transitions expected in the atmosphere of a moderate-temperature white dwarf. There is no detectable emission shortward of 980 Å. The only emission line seen is C IV λλ1548, 1551. If the emission from VW Hyi is due to a uniform-temperature white dwarf, then our spectra suggest that the temperature of the white dwarf was ~17,000 K at the time of our observations and that abundances in the atmosphere were subsolar. Improved fits to the data are obtained using models in which the far-UV emission arises in part from a white dwarf with near-solar abundances and in part from the accretion disk. However, given the uncertainties in model spectra of metal-enriched atmospheres in this temperature range and our limited knowledge of quiescent accretion disks, higher S/N spectra are needed to unambiguously assess the disk contribution to the far-UV spectrum of VW Hyi in quiescence.

Subject headings: binaries: close — novae, cataclysmic variables — stars: individual (VW Hydri) — ultraviolet: stars

1. INTRODUCTION

Dwarf novae (DNs) are binary star systems, consisting of a white dwarf (WD) and a late-type, low-mass companion. Material flowing from the secondary star through the inner Lagrangian point feeds an accretion disk around the WD. Changes in the structure of the accretion disk trigger quasi-periodic outbursts in these systems.

VW Hydri, with an orbital period of 107 minutes and a quiescent optical magnitude of 13.8, is a well-studied example of the dwarf nova phenomenon. Distance estimates to VW Hyi range from ~65 pc (Warner 1987) to ~91 pc (Bailey 1981), which imply that VW Hyi is among the closest of DNs. It is a member of the SU UMa class of DNs which exhibit both "normal outbursts" and "superoutbursts" (Bateson 1977; Mohanty & Schlegel 1995). During normal outbursts, which occur every 20–30 days and last 1–3 days, its magnitude peaks at 9.5. During superoutbursts, which occur every 160–180 days and last 10–15 days, it peaks at 8.5. Estimates of the mass of the white dwarf and the normal companion of 0.63 and 0.11 $M_\odot$ are typical (Schoembs & Vogt 1981). The companion star has never been observed directly.

The "standard" theory of dwarf nova accretion disks predicts that half the accretion energy is radiated away, primarily at UV and optical wavelengths, as material traverses the disk, and that the remainder is lost, primarily at X-ray and extreme-UV (EUV) wavelengths, in a transition region between inner edge of the accretion disk and the WD (see, e.g., Pringle & Savonije 1979). However, observations have generally indicated that the boundary layer luminosity is lower, particularly in outburst, than the standard theory predicts. VW Hyi is a pivotal object in the discussion of the "boundary layer problem" because absorption is extremely low along the line of sight to VW Hyi ($N_{\rm H} \sim 6 \times 10^{17}$ cm^{-2}; Polidan, Mauche, & Wade 1990), and it is difficult therefore to hide soft X-ray and EUV photons in this system. The recent data on VW Hyi suggest that the ratio of boundary layer to disk luminosity is (a troublesome) 0.04 in outburst (Mauche et al. 1991) and (less worrisome) 0.25 in quiescence (Belloni et al. 1991).

In quiescence, *IUE* spectra of VW Hyi show a relatively smooth continuum with a broad Lyα absorption feature. Mateo & Szkody (1984) first showed that the spectrum could be interpreted as emission from the WD in the system and derived a temperature of 18,000 ± 2000 K. Their interpretation was consistent with the "standard" theory of dwarf nova outbursts, which requires that the midplane temperature of the quiescent disk be of order 5000 K or less, and suggests that the disk is faint in the far-UV (FUV; Meyer & Meyer-Hofmeister 1982; Cannizzo, Ghosh, & Wheeler 1982). However, Pringle et al. (1987) noted that it was difficult to exclude a contribution from the disk observationally using *IUE* data, since plausible disk models also yield relatively broad Lyα absorption profiles. Nevertheless, they felt that Mateo & Szkody were correct in arguing that the WD contributes significantly to the FUV flux. The FUV flux from VW Hyi in quiescence is not in fact constant, but declines significantly through the first half of the quiescent interval (Verbunt et al. 1987). Pringle (1988) suggested that the decline might be interpreted as cooling of the WD after the outburst, but other possibilities have also been suggested (Meyer & Meyer-Hofmeister 1994).

More recently, Sion et al. (1995a, 1995b) observed VW Hyi in quiescence with *HST*. The Faint Object Spectrograph (FOS) spectra were notable because they were the first to show the narrow metal absorption lines in FUV spectra that are expected from a WD with accretion, but not from an accretion disk. Sion et al. (1995b) found they could interpret their data in terms of a 22,000 ± 1000 K WD, as long as the abundances of most elements were ~0.15 solar. The intermediate-resolution Goddard High Resolution Spectograph (GHRS) spectra of the Si IV region were also interesting because they suggested that the WD in VW Hyi is rotating with $v \sin i = 600$ km s^{-1}, which is almost 20% of the breakup velocity of the WD (Sion et al. 1995a).

In this paper, we describe two observations of VW Hyi in quiescence made with the Hopkins Ultraviolet Telescope. While *Voyager* has observed VW Hyi in outburst (Polidan et al. 1990), the HUT spectra are the first FUV observations of VW Hyi in quiescence to extend to the Lyman limit.

2. OBSERVATIONS

The Hopkins Ultraviolet Telescope was flown as part of the Astro-1 and Astro-2 space shuttle missions to obtain moderate-resolution (2–4 Å) spectra of wide range of astrophysical objects in the wavelength range 820–1840 Å (Davidsen et al. 1992). It consists of a 0.9 m f/2 primary feeding a prime focus Rowland spectrograph and a photon-counting microchannel plate-intensified detector. The observations described here were obtained on Astro-2 in 1995 March. Kruk et al. (1995) have described the performance of HUT on that mission.

VW Hyi was observed twice during the mission, first on 1995 March 4 beginning at GMT 12:47 and then on 1995 March 6 beginning at GMT 13:34. As evidenced by the visible light curve of VW Hyi compiled by the AAVSO during this period and shown in Figure 1, VW Hyi was in quiescence during both observations. A normal outburst of the system had ended 13 days before the first observation, and the next outburst (also a normal outburst) would occur about 21 days after the second observation.

Both observations were carried out with the 20″ circular aperture. Except for brief periods (mostly during the acquisition) when the object was clearly outside the slit, pointing appears to have been stable throughout the observations. Approximately 2000 and 1280 s of high-quality data were obtained in the first and second observation, respectively. The source counting rate during both observations was about 85 s^{-1}.

The summed, flux-calibrated spectrum from the two observations is shown in Figure 2. To obtain this spectrum we eliminated bad data intervals, and then used a standard calibration procedure to convert each count rate spectrum to a flux-calibrated spectrum. The steps in the flux calibration process involve a dark count subtraction (based on the count rate in an airglow-free region of the spectrum shortward of Lyα), a correction for doubly counted photons (due to persistence in the phosphor of the HUT detector), a correction for second-order photons (affecting the spectrum longward of 1824 Å), and finally a flux calibration using a time-dependent sensitivity curve. This sensitivity curve, which was derived from a series of WDs observed during Astro-2, is believed to be accurate to 5%. The two spectra were almost identical, except for small differences in the strength of the airglow lines. To improve the statistics, we then combined the two spectra, weighting the data according to the exposure times.

The flux-calibrated spectrum of VW Hyi, shown in Figure 2, consists of a relatively flat continuum longward of 1300 Å, a very broad Lyα absorption trough, little if any emission from VW Hyi below 980 Å, and, unfortunately, a

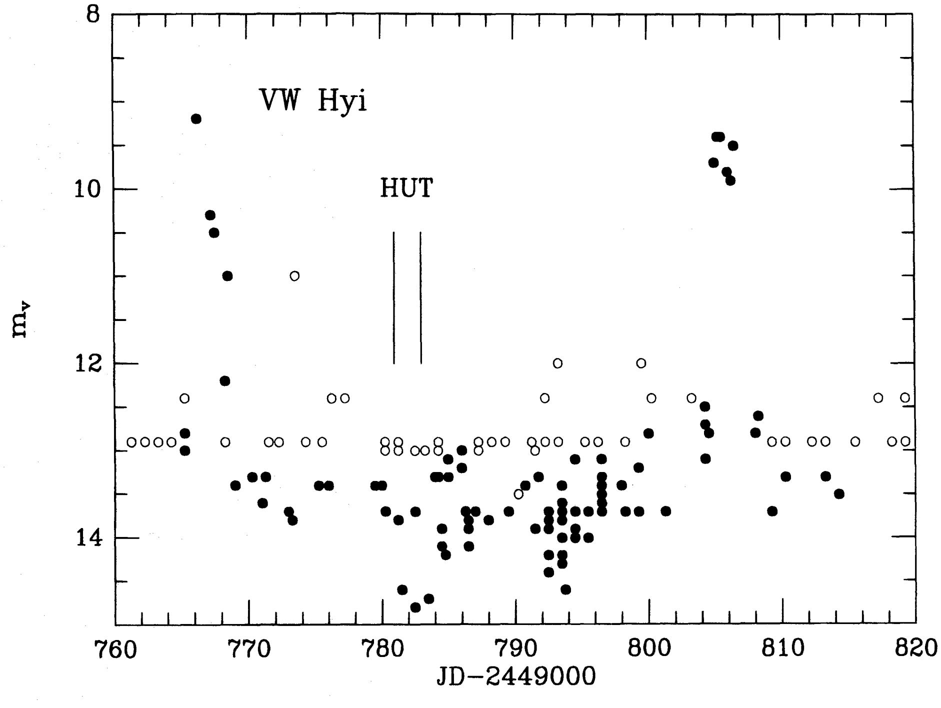

FIG. 1.—Visible light curve of VW Hyi as reported by the AAVSO during the time period of the HUT observations. Solid circles are measured magnitudes; open circles are upper limits. The HUT observation times are indicated.

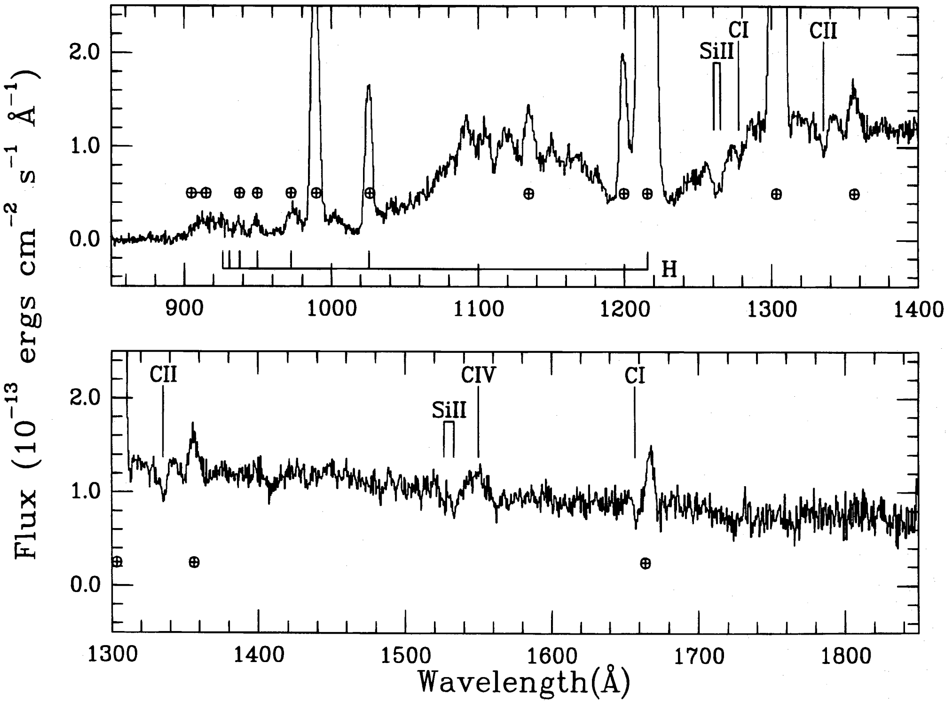

FIG. 2.—Summed flux-calibrated 830–1860 Å spectrum of VW Hyi as observed with HUT. Prominent absorption lines in the spectrum are labeled, as are airglow lines in the spectrum.

significant amount of airglow. The flux at 1400 Å, 1.1×10^{-13} ergs cm^{-2} s^{-1} Å^{-1}, is almost identical to that reported by Sion et al. (1995b).

Airglow is a significant problem in the HUT spectra of VW Hyi because most of the observing time was during the daytime portion of the orbit. The stronger airglow features are indicated in Figure 2. For the most part, the problems associated with airglow are limited to specific regions of the spectrum. The problems are most severe at the shortest wavelengths, primarily as a result of contributions from the Lyman series. There is no completely satisfactory way to address this problem. The HUT detector is a one-dimensional detector, and therefore we do not have a background spectrum obtained at the same time.

We have attempted to construct an airglow-subtracted spectrum using off-source measurements obtained before the first observation, scaling the airglow data so that Lyα, the strongest airglow line, is best subtracted. The result is

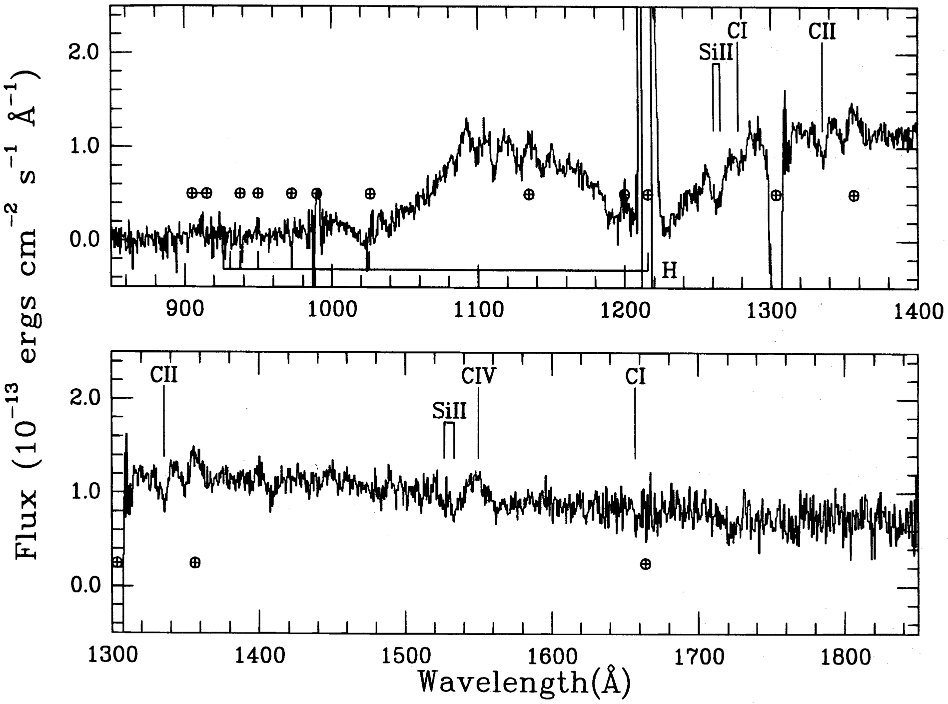

FIG. 3.—Airglow-subtracted spectrum of VW Hyi. The airglow spectrum was obtained prior to the first observation and multiplied by 0.7 to match approximately the fluxes of Lyα, Lyβ, and O I λλ988.6–990.8 before subtraction. The subtracted spectrum indicates VW Hyi has little or no flux below 980 Å.

displayed in Figure 3 and shows fairly clearly that there is no detectable emission from VW Hyi below 980 Å. In particular, the pseudocontinuum due to the higher order Lyman lines, the very strong O I λλ988.6–990.8 feature, and the O I recombination feature near the Lyman limit (Feldman et al. 1992) have been subtracted away. Figure 3 also shows the limitations of this background subtraction technique, since some lines, such as O I λ1304, do not scale accurately with Lyα. There does appear to be faint emission near 1000 Å, shortward of Lyβ.

There is one unambiguously detected emission feature in both the original and airglow-subtracted spectra, namely C IV λλ1548, 1551. It has an equivalent width of 3.7 Å and a flux of $\sim 3.5 \times 10^{-13}$ ergs cm^{-2} s^{-1}. The doublet is considerably broader (13.9 Å FWHM) than the expected resolution of HUT (2.8 Å) at that wavelength and can plausibly be identified with the disk in VW Hyi. In addition to Lyα and Lyβ, the spectrum contains a number of narrow absorption features which at wavelengths longer than Lyα are identifiable with relatively low ionization states of Si or C. Shortward of Lyα line identifications are more difficult, though the WD models presented below suggest that C I and Fe II features are particularly important.

3. ANALYSIS

In regions where the wavelength ranges overlap, the HUT spectra of VW Hyi in quiescence resemble those obtained with *IUE* and *HST*, which Mateo & Szkody (1984) and later Sion et al. (1995b) interpreted as arising from the WD in the system. In particular, the HUT data, like the FOS data, show the narrow absorption lines that are the signature of the WD. (These lines have much larger EWs than the interstellar absorption lines used by Polidan et al. 1990 to determine the line-of-sight absorption.)

To carry out a more quantitative analysis, we first compared the HUT spectra to a set of model WD spectra created with the model atmosphere program TLUSTY (Hubeny 1988; Hubeny & Lanz 1995) and companion spectral synthesis code SYNSPEC (Hubeny, Lanz, & Jeffrey 1994), which we have used previously to study the WD in U Gem (Long et al. 1993; Long, Blair, & Raymond 1995), and which Sion et al. (1995b) had used to analyze the FOS data. We began by calculating several sets of LTE $\log g = 8$ models covering the temperature range 14,000–25,000 K in 1000 K intervals. (The lower limit to our model grid is set by the fact that TLUSTY is not designed to handle atmospheres that have convection zones.) The structure calculations explicitly include opacities due to H, He I, C I, C II, and Mg II. Additional continuum opacities and lines are added as part of the spectral synthesis. We created models in which all the abundances were solar, models in which all the abundances, including helium, were 0.3 solar, 0.15 solar, 0.1 solar, and 0.01 solar, and models in which only the metal abundances were reduced. Each model was calculated initially on a wavelength grid with a maximum wavelength separation of 0.015 Å and then convolved with a Gaussian with a FWHM of 3.5 Å to match the average HUT wavelength resolution.

We fit the models to the data using SPECFIT, the IRAF-based spectral fitting program that is part of the HUT data analysis suite (Kriss 1994). The important parameters in these fits were the temperature and the solid angle of the source. Our final fits were produced using the wavelength ranges 1050–1124, 1144–1195, 1226–1294, 1314–1346, 1366–1651, and 1671–1840 Å in order to minimize the effect of airglow on the model fits. The holographically generated HUT grating scatters relatively little flux into the wings of its response function, so excluding 10 Å on either side of the line center of a typical airglow line is a very conservative way to mitigate the effects of the lines on a fit. However, Lyα and O I λ1304 are stronger than the typical airglow line, and therefore we explicitly included these two lines and N I λ1200 in our fitting procedure. In modeling these lines, we used the in-flight profile of Lyα as observed through the 20″ circular aperture during a nighttime airglow observation. Our approach to the final fit was iterative. We first fit the HUT spectra to a model consisting of a stellar spectrum plus airglow. For these preliminary fits, we used wavelength ranges around Lyα and O I λ1304 which excluded only the line cores of Lyα and O I λ1304. (We excluded about 3 Å on either side of the line cores because there are nonlinearities in the response function at very high count rates and because these heavily exposed regions of the photocathode suffered more sensitivity loss than other regions of the detector.) We then fixed the flux and line centers for these airglow lines and refit the spectrum using the wavelength regions specified above. In practice there was very little change between the parameters derived in the initial and final fits. However, in the initial fits, the resulting χ_ν^2 reflected primarily the quality of the fit within 10 Å of the airglow lines, rather than the overall spectrum, and therefore we have elected to use the χ_ν^2 from the line-free regions above to quantify the goodness of fit of individual models. Results from the model fits are summarized in Table 1.

None of the fits with single-temperature WD models was wholly satisfactory. The best-fitting solar abundance model had a temperature of 18,100 K and a reduced χ_ν^2 of 1.41 for 1330 degrees of freedom (dof). As shown in Figure 4, this model fits the overall slope of the spectrum fairly well, but the absorption lines are too strong and the model underestimates the flux within 50 Å of Lyα (and to a lesser degree Lyβ). Fits with abundances in the range one-third to one-tenth solar match the depths of individual lines more closely, especially longward of Lyα, but do not overcome the basic problem with single-temperature $\log g = 8$ models, which is that one cannot reconcile the Lyα profile with the slope of the spectrum as defined by the fluxes at 1100 and 1400 Å. The values of χ_ν^2 are actually worse for the models with subsolar abundances because these models do not fit the short-wavelength (1000–1200 Å) portion of the spectrum very well, as is indicated in Figure 5. It does not seem to matter, in terms of χ_ν^2 or in terms of one's qualitative impression of the fits, whether the helium abundance is assumed to be solar or is allowed to decline with the metal abundances. Generally speaking, the best-fit temperature reflects the slope of the spectrum as defined by the fluxes at 1100 Å and 1400 Å. At a fixed temperature, reducing heavy element abundances reduces the opacity in the 1100 Å region and results in a bluer model spectrum. To compensate for this effect, the best-fit temperatures decrease, but this increases the depth of the Lyα profile. The net result is that the best-fit χ^2 is worse for subsolar abundances than for solar abundances and the temperature is lower, 16,400 K for models in which both the helium and metal abundances were 0.1 solar.

Our qualified success in modeling the HUT spectra with $\log g = 8$ subsolar atmospheres appears to contrast the success enjoyed by Sion et al. (1995b) in modeling the FOS

TABLE 1

MODEL FITS TO HUT AND FOS VW HYI DATA

Instrument	χ_ν^2	N[a]	T or $\dot{m}$[b]	Model Parameters
HUT	1.41	3.51×10^{-22}	18,100	WD (solar)
HUT	1.49	3.75×10^{-22}	16,900	WD (He = 1/3 solar; metals = 1/3 solar)
HUT	1.49	3.83×10^{-22}	17,500	WD (He = solar; metals = 1/3 solar)
HUT	1.62	3.81×10^{-22}	16,400	WD (He = 1/10 solar; metals = 1/10 solar)
HUT	1.63	3.91×10^{-22}	17,300	WD (He = solar; metals = 1/10 solar)
HUT	1.58	3.02×10^{-22}	18,600	WD (solar), FOS region
HUT	1.04	3.43×10^{-22}	17,900	WD (He = 1/10 solar; metals = 1/10 solar), FOS region
FOS	2.20	1.62×10^{-22}	21,500	WD (solar)
FOS	1.58	1.81×10^{-22}	21,100	WD (He = 1/15 solar; metals = 1/15 solar)
FOS	1.60	1.89×10^{-22}	20,800	WD (He = 1/10 solar; metals = 1/10 solar)
HUT	1.21	4.06×10^{-22}	17,200	2 T WD (solar)
	...	1.09×10^{-24}	49,600	...
HUT	0.98	1.83×10^{-22}	18,700	Composite [WD (solar) &
	...	9.01×10^{-1}	2.4×10^{15}	Disk (solar)]
FOS	1.84	9.58×10^{-23}	21,700	Composite [WD (solar) &
	...	4.70×10^{-1}	3.7×10^{15}	Disk (solar)]

[a] For WD models, $N = 4\pi(R_{\rm WD}/D)^2$; for disks $N = (D/65\ {\rm pc})^{-2}$.

[b] T in K or $\dot{m}$ in g s^{-1}.

spectra. It is clearly important to understand to what extent the apparent differences reflect differences in the spectra observed at different epochs and to what extent they reflect differences between the FOS and HUT.

The analysis procedures and the models we used in our WD fits to the HUT data are very similar to those used by Sion et al. (1995b) to interpret the FOS data. Nevertheless, since the models are not exactly the same, we did retrieve the FOS VW Hyi data from the *HST* archive and carry out fits to assure ourselves that we could reproduce, at least approximately, the Sion et al. (1995b) analysis. And indeed, our best-fit log $g = 8$ model with 0.15 solar abundances does reproduce the FOS data well, although our best fits tended to have temperatures of 20,000–21,000 K, instead of the 22,000 ± 1000 K reported by Sion et al. (1995b). For the FOS data, models with subsolar abundances produced markedly lower χ_ν^2 than do solar abundance models. The fact that our best-fit temperatures to the FOS data are somewhat lower than those of Sion et al. (1995b) can probably be attributed to detailed differences in the opacities used in generating the WD model spectra. As a result, we do not believe that the specific models or analysis procedures explains the differences between the two spectra.

The HUT spectra extend over a wider wavelength range than the FOS spectra. When we restricted our analysis to the FOS (1160–1600 Å) portion of the HUT spectrum, or more specifically the wavelength ranges 1160–1195, 1226–1294, 1314–1346, and 1366–1600 Å, we found a best-fit temperature of 17,900 and an improved χ_ν^2 of 1.04 for 687 dof for models with 0.1 solar abundances. The problems associ-

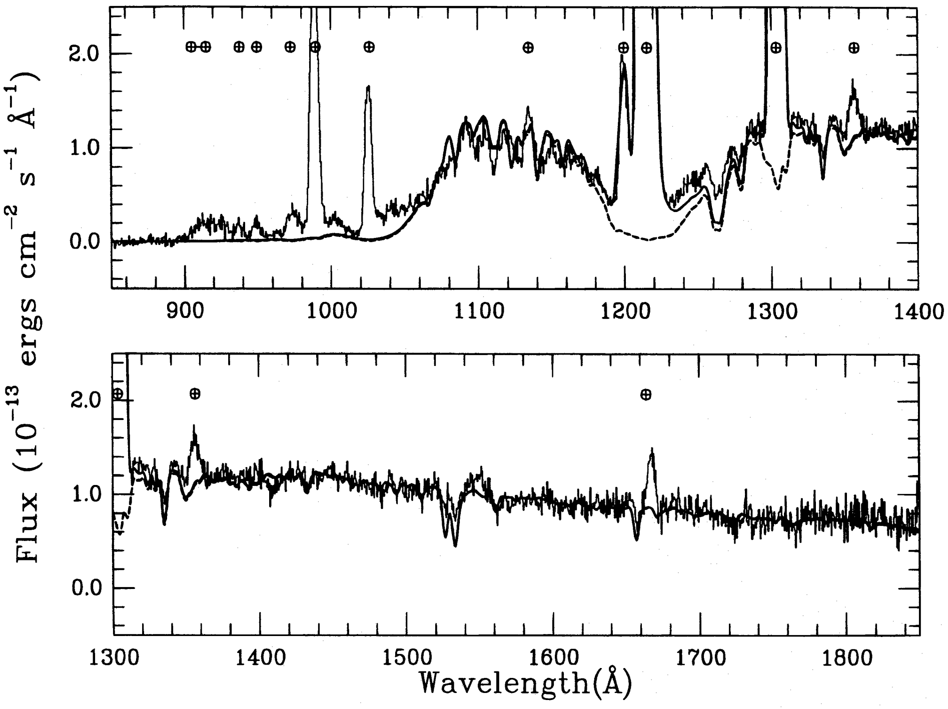

FIG. 4.—Comparison between the HUT spectrum of VW Hyi and the best-fitting log $g = 8$ solar-abundance WD model. Dashed curve is the WD contribution to the spectrum. Solid curve includes the contributions of the airglow lines at Lyα, N I λ1200, and O I λ1304.

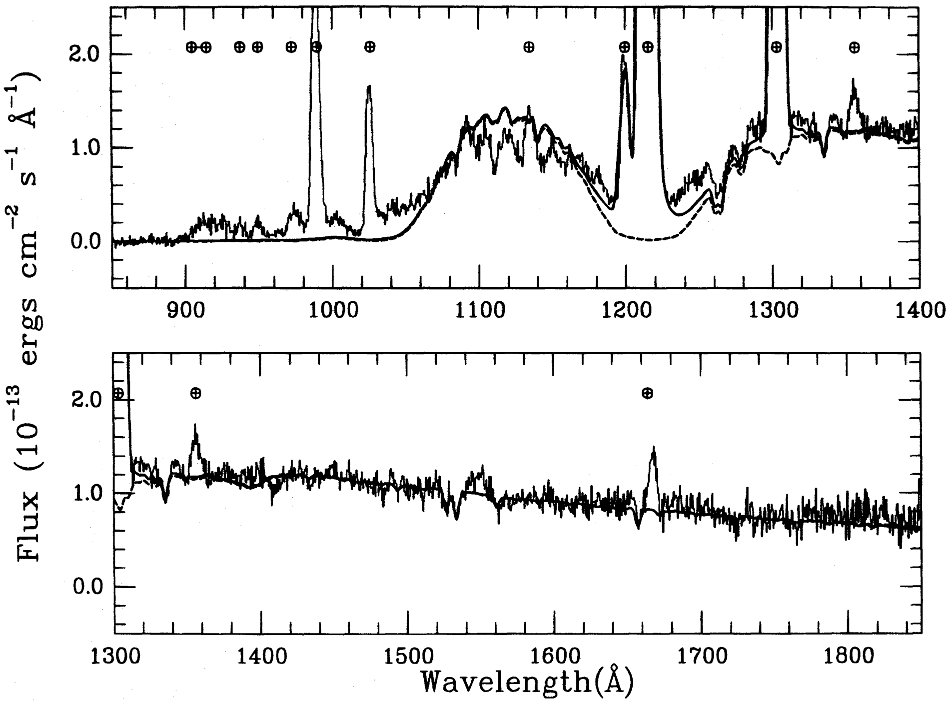

FIG. 5.—Comparison between the HUT spectrum of VW Hyi and the best-fitting WD model with helium and metal abundances which are 0.1 solar. Although the metal absorption lines observed in VW Hyi longward of Lyα are better approximated by this model, the overall fit to the spectrum is worse.

ated with reconciling the depth of the Lyα profile and the continuum shape were less severe in this case than they were when we tried to fit the "full" HUT range. Furthermore, although the temperature was about 3000 K lower than Sion et al. (1995b) had inferred from the FOS data, models with reduced abundances fit the "restricted" HUT data better than those with solar abundances. This suggests that at least part of the difficulty/opportunity we have encountered with the HUT data is due to HUT's more extended spectral range.

In our earlier analyses of the HUT spectra of U Gem in quiescence from Astro-1 and Astro-2 (Long et al. 1993, 1995), we found improved fits to the data using models constructed from the sum of two $\log g = 8$ atmospheres. We suggested that an accretion belt produced on the WD surface during the preceding outburst might generate a nonuniform temperature distribution on the surface of the WD and that the gradual disappearance of the belt in quiescence might explain the decline in the UV flux observed through the quiescent interval (Kiplinger, Sion, & Szkody 1991; Long et al. 1994a). In U Gem, we found that this accretion belt occupied about 15% of the WD surface shortly after an outburst. Since the UV flux from VW Hyi also declines by 20%–30% during the first half of a quiescent interval (Verbunt et al. 1987), we have experimented with two-temperature $\log g = 8$ model fits to the HUT spectrum of VW Hyi. Formally, two-temperature fits did improve the fits somewhat. For example, for $\log g = 8$, solar abundance models, we obtained $\chi_\nu^2 = 1.21$ compared to 1.41 for our best-fitting single-temperature model. If a belt existed in VW Hyi, the heated area was about 0.3% of the WD surface, and its temperature was of order 50,000 K. The two-temperature model fits the data better in terms of χ_ν^2 because it has a shallower Lyα profile. However, the improvement in χ_ν^2 is misleading in VW Hyi because we excluded the shortest wavelength portion of the spectrum, and in fact the two-temperature model fluxes exceed the observed (source plus airglow) flux from VW Hyi shortward of Lyβ considerably. Therefore, we do not believe two-temperature models are a real solution to the problem of fitting the HUT VW Hyi data. Instead, we would argue that the observed spectrum places a fairly restrictive limit on the size of any significantly hotter region on the WD surface.

Although the presence of narrow absorption lines is, we believe, an extremely strong argument for a significant WD contribution to the FUV spectrum, other possible sources of emission are the disk and hot spot. As was pointed out by Pringle et al. (1987), and more recently by Wade, Hubeny, & Polidan (1994), it is difficult to distinguish with moderate-resolution spectra between a low accretion rate, optically thick disk and a WD, since both have broad Lyα absorption profiles and similar color temperatures in the FUV. To explore the possibility that the disk contributes to the spectra in the HUT spectral range, we have constructed models for steady state accretion disks from a set of appropriately summed Doppler-broadened stellar atmospheres using the procedure described by Long et al. (1994b). (Long et al. also discuss the suitability of models based on stellar atmospheres models rather than proper disk atmospheres.) For VW Hyi, we assumed a WD mass of 0.63 $M_\odot$, an inclination angle of 60°, and inner and outer disk radii of 8.3×10^8 cm and 2×10^{10} cm, respectively. The inner radius corresponds to the radius of a 0.63 $M_\odot$ WD; the outer radius is completely unimportant for the FUV spectrum of VW Hyi. We calculated models for a variety of accretion rates ranging from 10^{14} to 10^{17} g s^{-1}.

We then fit the data to models consisting of a WD with $\log g = 8$ and a disk, assuming solar abundances for both components. The free parameters in these model fits were the temperature of the WD, the mass accretion rate $\dot{m}$, and the overall normalization of the composite model (effectively the distance to VW Hyi). As indicated in Figure

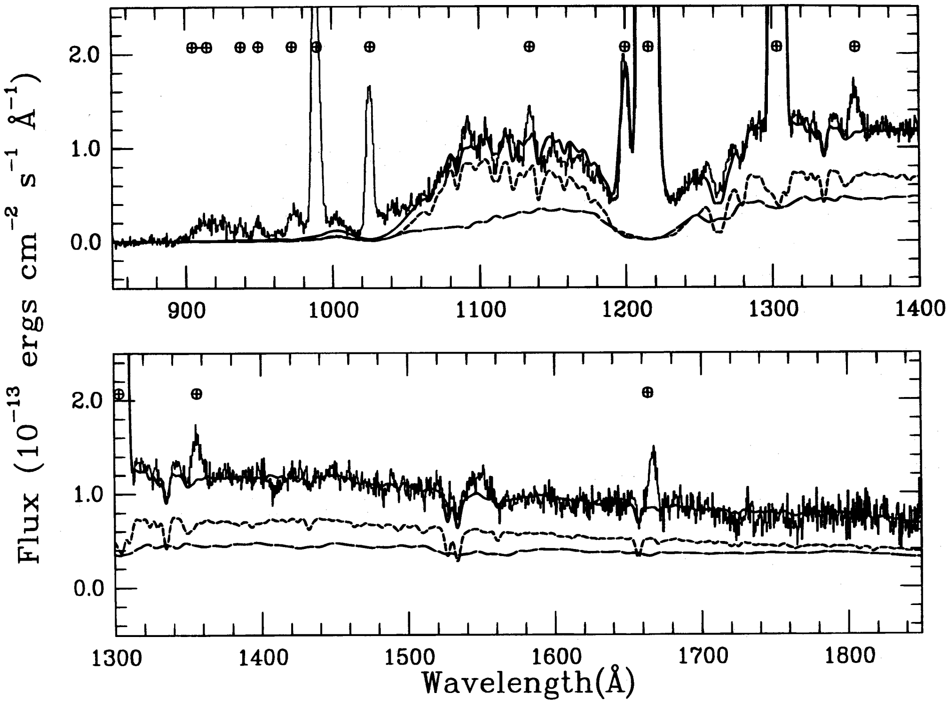

FIG. 6.—Comparison between the HUT spectrum of VW Hyi and the best-fitting composite WD/disk model. The contribution from the WD and the disk are shown as the dashed and long-dashed curves. As in earlier figures, the overall fit, which includes contributions from Lyα, N I λ1200, and O I λ1304, is shown as the solid curve.

6, a model of this type provides a far better representation of the data than do any of the simple WD models we constructed.

The best fit has $\chi_\nu^2 = 0.98$ for 1333 data points, a WD temperature of 18,700 K, $\dot{m} = 2.4 \times 10^{15}$ g s^{-1}, and an implied distance of 69 pc. The combined WD/disk model has shallower Lyman line profiles and less pronounced metal absorption lines than do solar abundance WD models. The Lyman line profiles are not as deep because the effective gravity of the disk ($\log g = 3$–5) is much lower than that of the WD ($\log g = 8$). Narrow metal lines are absent in the disk because the lines are smeared out by Doppler shifts due to Keplerian rotation.

There are theoretical and observational arguments against the reality of an optically thick accretion disk with this accretion rate in quiescence. The accepted theory of dwarf nova outbursts is predicated on an instability which develops when the effective temperature of the disk rises above ~10,000 K (Meyer & Meyer-Hofmeister 1982; Cannizzo et al. 1982). This theory has been quite successful in accounting for many, if not all, of the properties of DN outbursts, including the shape of, duration of, and period between outbursts. (See, e.g., the review by Osaki 1996 and references therein.) In the disk models that best fit the HUT data, the peak temperature is ~14,000 K and exceeds 10,000 K in the inner 3 WD radii. In the standard theory, such a disk would quickly move to the outburst state (which did not happen). In addition, radial surface brightness and color temperature profiles of the quiescent disks constructed from ground-based observations of eclipsing DNs, e.g., HT Cas (Wood, Horne, & Vennes 1992), generally show color temperatures of ~5000 K throughout the disk. And recent *HST* observations of eclipsing DN OY Car indicate that its disk contributes less than 1/30 of the FUV of the WD (Horne et al. 1994).

VW Hyi is not an eclipsing system so it is far more difficult to separate the various components of the system, but we do know that measurements of Hα profiles in quiescence suggest that the inner accretion disk is missing out to a distance of about $10R_{\rm WD}$ (Schoembs & Vogt 1981). VW Hyi is also a fairly bright X-ray source, even in quiescence. According to Belloni et al. (1991), the "bolometric" luminosity of the X-ray emission of VW Hyi in quiescence is $9.6 \times 10^{30}(D/65\ {\rm pc})^2$ ergs s^{-1}. If the X-ray luminosity arises from a boundary layer and if $L_{\rm BL} = GM\dot{m}/2R_{\rm WD}$, then the quiescent accretion rate for VW Hyi is $\sim 1.3 \times 10^{14}(D/65\ {\rm pc})^2$ g s^{-1}. In that case, the peak effective temperature of an optically thick disk would be ~7000 K, which is too low to produce a significant continuum in the FUV. However, the essence of the "boundary layer problem" is that we are uncertain that most of the energy we expect from the boundary layer is detected as X-rays, and therefore our estimates of $\dot{m}$ and the peak temperature are really lower limits.

Even if we are disinclined to believe that a standard steady state disk with an accretion rate of 2.4×10^{15} g s^{-1} exists in VW Hyi in quiescence, it is important to remember that this does not necessarily rule out a significant disk contribution in the FUV, since (with the recent exception of Ko et al. 1996) there have been few attempts to calculate in detail the spectra of quiescent disks in the FUV and since there are other DNs, such as SS Cyg, which exhibit none of the obvious characteristics of the WD in the FUV (Long 1996).

The other possible source of FUV emission in the VW Hyi system is the bright spot where the accretion stream interacts with the disk. VW Hyi has an orbital hump which modulates the quiescent optical light curve by ~30% (van Amerongen et al. 1987). The anisotropic portion of the emission has a $U-B$ color of -0.070 ± 0.014 (van Amerongen et al. 1987), which corresponds to an effective temperature of about 10,000 K. *IUE* spectra of VW Hyi in quiescence (see, e.g., Fig. 3 of Pringle et al. 1987) show a clear break at ~2000 Å, which is most likely due to this bright spot. It is possible that a higher temperature region of the bright spot contributes to the FUV flux. However, if the hot spot is a major contributor to the FUV emission of VW Hyi, one might expect to see changes in the flux from VW Hyi as a function of orbital phase. Using van Amerongen et al.'s (1987) orbital ephemeris for VW Hyi, in which phase 0 corresponds to the peak of the orbital hump, the first and second HUT observations covered phases 0.02–0.37 and 0.39–0.59, respectively. Since HUT was operated in a mode which transmitted the accumulated spectrum every 2 s, it is straightforward to search for temporal variability. None was observed, even though changes of greater than 10% should have been easy to detect. The anisotropic portion of any bright spot emission is weak, which suggests that the bright spot does not contribute very much to the HUT spectrum of VW Hyi.

The C IV λλ1548, 1551 emission doublet is 2600 km s^{-1} wide (FWHM), somewhat broader than the Hα emission line which, according to Schoembs & Vogt (1981), has a FWZI of ~2100 km s^{-1}, indicating that C IV must be formed in the inner accretion disk. One possible source of UV emission lines in cataclysmic variables is X-ray illumination of the accretion disk. By comparing the C IV emission-line flux with the X-ray flux reported by Belloni et al. (1991), we find that it would be necessary to fluoresce 2.5% of the X-ray luminosity to produce the observed C IV. If we include the geometrical corrections proposed by Patterson & Raymond (1985), the efficiency requirement is reduced to 0.6%. This is about the efficiency expected from photoionization models of emission lines in the disk (Ko et al. 1996). Hence, we conclude that the observed C IV emission could arise from X-ray reprocessing in the inner disk.

4. SUMMARY AND CONCLUSIONS

We have obtained the first spectra of VW Hyi in quiescence which extend significantly shortward of Lyα toward the Lyman limit. The existence of narrow absorption lines in these spectra confirm that the WD contributes significantly to the FUV light from VW Hyi. Our observations indicate that the WD was considerably cooler (~17,000 K) than when VW Hyi was observed with the FOS by Sion et al. (1995b). This may not be surprising in view of the fact that cooling of the WD following outbursts has been reported in the WDs in some other DN systems, most notably U Gem (Long et al. 1993). The FOS observations of VW Hyi were made approximately 10 days after a superoutburst. During the superoutburst, VW Hyi had been brighter than 10th magnitude for ~10 days, and therefore there was plenty of time for substantial heating of the WD. In contrast, the HUT observations took place 13–15 days after a normal outburst during which VW Hyi had been brighter than 10th magnitude for only 1 day. If sources of FUV emission other than the WD are insignificant in VW Hyi in quiescence, then abundances on the surface of WD at the time of our observation were subsolar and uncertainties in the temperature of the WD of about 1000 K are dominated by limitations in the stellar models we have constructed.

The HUT data can also be fitted to composite models consisting of a WD and an optically thick accretion disk. The disk emission dilutes the light from a 18,700 K WD, accounting naturally for the apparent weakness of the metal absorption lines, which had led Sion et al. (1995b) to argue for subsolar abundances. In fact, in terms of χ_ν^2, the composite models fit the data better than do simple WD models. The accretion rate of 2.4×10^{15} g s^{-1}, inferred by fitting standard steady state disk (plus a WD) to the spectrum, is higher than the (minimum) accretion rate derived from X-ray observations.

At present, we do not believe one can choose using the existing observations between a low-metallicity WD and a solar-abundance composite WD/disk model for VW Hyi in quiescence. The WD model spectra are sensitive to the specific opacity sources that are available (and our models do not, for example, include the continuum opacity of Fe). The art of calculating metal-enriched spectra of relatively low-temperature WDs is simply at an elementary state. We are in an even more parlous state in terms of an ability to calculate accurate models of quiescent accretion disks. However, it would be possible to choose between the two basic models for FUV emission if higher S/N spectra than the existing *HST* or HUT spectra were obtained. One needs simply to study the ratios of equivalent widths of lines of one ion with very different oscillator strengths, rather than the equivalent widths themselves.

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