AN INTERNATIONAL ULTRAVIOLET EXPLORER ARCHIVAL STUDY
OF DWARF NOVAE IN OUTBURST

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ABSTRACT

We present a synthetic spectral analysis of nearly the entire far-ultraviolet International Ultraviolet Explorer (IUE) archive of spectra of dwarf novae in or near outburst. The study includes 46 systems of all dwarf nova subtypes, both above and below the period gap. The spectra were uniformly analyzed using synthetic spectral codes for optically thick accretion disks and stellar photospheres, along with the best available distance measurements or estimates. We present newly estimated accretion rates and discuss the implications of our study for disk accretion physics and CV evolution.

Subject headings: accretion, accretion disks — stars: dwarf novae — white dwarfs

1. INTRODUCTION

Dwarf novae (DNe) are a subclass of cataclysmic variables (CVs), composed of a low-mass, main-sequence secondary star and a white dwarf (WD) primary. They are characterized by their quasi-periodic outburst episodes, which are typically 2–6 mag in amplitude. The Roche lobe–filling secondary loses gas through the inner Lagrangian point, carrying substantial angular momentum that leads to the formation of a disk around the accreting white dwarf. A thermal-viscous instability known as the disk instability model (Osaki 2005 and references therein) causes the accretion disk to transition from a cool, quiescent, optically thin state to a stable state where the disk is much hotter, more luminous, optically thick, and approaching a steady state. The disk is heated by the release of gravitational potential energy as the accreted material spirals through the optically thick disk toward the WD surface. The energy released can heat the disk to temperatures on the order of 100,000 K. This heating of the disk accounts for the increase in luminosity during a dwarf nova (DN) outburst and should dominate the system’s luminosity in outburst. When the outburst concludes, the disk should, theoretically, be relatively empty of material in its hotter inner regions and optically thin. At this time, the disk luminosity should be a negligible contributor to the system’s luminosity. This period of low mass transfer is known as quiescence.

In dwarf novae, it has long been noted that the systems generally undergo a transition from emission-line–dominated spectra in the optical and UV (in quiescence) to absorption-line spectra as the continuum gradually increases in strength up to outburst maximum, with the development of broad absorption troughs and, in the UV, P Cygni profile structure in the resonance lines. In the optical, emission-line cores remain, but have narrower widths than their counterparts in quiescence (Warner 1995 and references therein). The spectra in outburst and quiescence exhibit a mix of H and He lines, as well as metals, unlike the dichotomy between the DA (H-rich) and DB (He-rich) composition sequences of the isolated white dwarfs.

Two types of dwarf nova outbursts have been recognized, type A, which have a fast optical rise, delay progressively at shorter wavelengths, and describe a wide loop in the two-color diagram as the system progresses from quiescence to outburst, then back to quiescence, and type B, in which the optical rise is slower and the cycle describes a narrow loop in the two-color diagram, with only a small or zero delay between the UV and optical (Smak 1984a, 1984b). On the decline from outburst, systems of both types show fluxes that fall simultaneously at all wavelengths, but with the UV declining fastest near the end of the decline. Pringle & Verbunt (1984) and Verbunt (1987) found that the UV flux distributions evolve similarly for a given kind of outburst.

Early attempts to theoretically interpret the spectral energy distributions of dwarf novae in outburst relied on comparisons of the ratios of continuum fluxes in emission-line–free regions with model predictions. The UV flux distributions of DNe in outburst have been mostly fitted with $F_{\lambda} \sim \lambda^\alpha$ flux distributions, where $\alpha \sim -2$ (Verbunt 1987). Moderately good agreement was achieved for systems expected to approximate steady state disks. The largest uncertainty in the disk model fitting is the sensitivity to the WD mass (Verbunt 1987). The outburst spectra in both the optical and UV have overall flux distributions that resemble the flux distribution of a B$_2$–B3 V–III star ($T_{\text{eff}} \sim 20,000$ K).

La Dous (1991) noted in her archival study of 32 dwarf novae in outburst that the UV continuum flux distributions were virtually identical, regardless of inclination angle, except for the systems OY Car, Z Cha, AB Dra, WW Cet, CM Del, RX And, VW Vul (with increasingly bluer distributions, but all redder than the bulk of objects), and UZ Ser, which is much bluer than the other objects. La Dous (1991) used the published flux plots from an earlier generation of accretion disk models to conclude that the inner disk radius, inclination angle, and mass transfer rate at a fixed WD mass of 1 $M_\odot$ are the most critical factors in modeling the observed energy distribution. In particular, the appearance of the UV spectra at outburst is strongly correlated with the orbital inclination. In lower inclination systems the outburst spectra appear in pure absorption, while for higher inclinations ($70^\circ < i < 80^\circ$) the spectra are continuous, and finally for $i > 80^\circ$, strong emission lines are present (La Dous 1991).

Accretion rates have been obtained from absolute magnitudes $M_p$ (requiring distances) for various subgroups of CVs with due account for the sensitivity to system parameters such as the inclination angle (Smak 1989, 1994). Generally, during dwarf nova maximum, outburst accretion rates have been estimated in the range $M = 3 \times 10^{-9}$ to $1 \times 10^{-8} M_\odot$ yr$^{-1}$, while during the rise to outburst among dwarf novae, accretion rates in
the range $\dot{M} = 5 \times 10^{-10}$ to $3 \times 10^{-9} M_\odot \text{yr}^{-1}$ have been derived (Warner 1995). However, relatively few individual accretion rates have been published for dwarf novae in outburst based on detailed accretion disk model fitting. There is a comprehensive atlas of optical spectra of dwarf novae in outburst (Morales-Rueda & Marsh 2002), but none for UV spectra in which the data have been modeled and parameters derived. Some examples of early derivations of accretion rates in outburst from disk model fitting are for VW Hyi, Z Cha, OY Car, and SS Cyg. For VW Hyi, an accretion rate $\dot{M} = 5 \times 10^{-9} M_\odot \text{yr}^{-1}$ was obtained by Polidan et al. (1990) and Polidan & Holberg (1984). For Z Cha, Horne & Cook (1995) obtained $\dot{M} = 2.5 \times 10^{-9} M_\odot \text{yr}^{-1}$, and for OY Car, Rutten et al. (1992) obtained $\dot{M} = 1.6 \times 10^{-9} M_\odot \text{yr}^{-1}$. For SS Cyg at maximum, Kiplinger (1979) found excellent agreement between a model accretion disk with $\dot{M} = 3 \times 10^{-8} M_\odot \text{yr}^{-1}$ and the observed flux distribution from the IR through the far-ultraviolet (FUV) regions. If $\dot{M}$ is not constant throughout the disk, then steady state disk model fitting in outburst will yield discrepancies due to a non–steady state radial temperature distribution, $T(r)$, in the disk.

Of course, there is a strong sensitivity to the white dwarf mass, which is poorly known for the majority of systems. Orbital

| System     | Data ID | Observation Date (yyyy-mm-dd) | Observation Time (UT) | Exposure Time (s) | Outburst-Quiescence Cycle |
|------------|---------|--------------------------------|-----------------------|------------------|---------------------------|
| WZ Sge      | SWP03507 | 1978-12-01                      | 19:21:00              | 24               | Peak outburst             |
| SW UMa      | SWP94791 | 1986-03-08                      | 04:32:00              | 210              | Outburst                  |
| WX Cet      | SWP36511 | 1989-06-15                      | 10:41:00              | 3300             | Late decline              |
| T Leo       | SWP33642 | 1988-05-25                      | 20:53:00              | 300              | Outburst                  |
| V1159 Ori   | SWP56889 | 1996-03-03                      | 17:01:00              | 5400             | Rise to outburst          |
| V436 Cen    | SWP54264 | 1995-03-28                      | 10:09:00              | 2400             | Outburst\*                |
| BC UMa      | SWP50668 | 1994-05-01                      | 21:09:00              | 3000             | Peak outburst             |
| EK Trig     | SWP90705 | 1980-08-05                      | 22:20:00              | 1140             | Outburst\*                |
| TV Crv      | SWP41842 | 1991-06-14                      | 14:25:00              | 1800             | Outburst\*                |
| OY Car      | SWP25838 | 1985-05-02                      | 17:34:00              | 720              | Rise to outburst          |
| VY Aqr      | SWP21720 | 1983-12-08                      | 03:22:00              | 600              | Outburst                  |
| ER UMa      | SWP40947 | 1991-02-27                      | 22:20:00              | 4500             | Outburst\*                |
| IR Gem      | SWP38524 | 1990-04-05                      | 02:03:00              | 1068             | Outburst                  |
| AY Lyr      | SWP09342 | 1980-06-22                      | 06:46:00              | 3600             | Late outburst             |
| VZ Pyx      | SWP44129 | 1992-03-07                      | 05:36:00              | 2400             | Outburst\*                |
| VW Hya      | SWP40045 | 1990-11-04                      | 10:45:00              | 150              | Peak outburst             |
| Z Cha       | SWP30670 | 1987-03-31                      | 17:03:00              | 600              | Peak outburst             |
| WX Hya      | SWP23952 | 1984-09-13                      | 19:22:00              | 3600             | Outburst\*                |
| SU UMa      | SWP35261 | 1989-01-05                      | 08:58:00              | 1800             | Peak outburst             |
| YZ Cnc      | SWP15560 | 1981-11-24                      | 10:07:00              | 540              | Outburst                  |
| TU Men      | SWP10665 | 1980-11-23                      | 17:58:00              | 1800             | Outburst\*                |
| AB Dra      | SWP07413 | 1979-12-15                      | 18:51:00              | 4500             | Rise to outburst          |
| CY Lyr      | SWP21030 | 1983-09-12                      | 22:09:00              | 3600             | Outburst                  |
| KT Per      | SWP07382 | 1979-12-13                      | 01:19:00              | 2700             | Early decline             |
| AR And      | SWP15445 | 1981-11-07                      | 12:34:00              | 2100             | Outburst                  |
| CN Ori      | SWP15950 | 1982-01-04                      | 08:36:00              | 2400             | Outburst                  |
| X Leo       | SWP15985 | 1982-01-06                      | 14:03:00              | 6240             | Outburst                  |
| VW Vul      | SWP18875 | 1982-12-23                      | 19:08:00              | 7200             | Transition\*             |
| UZ Ser      | SWP15078 | 1981-09-22                      | 18:41:00              | 2400             | Outburst                  |
| U Gem       | SWP10327 | 1980-10-10                      | 13:28:00              | 353              | Peak outburst             |
| TW Vir      | SWP10951 | 1981-01-03                      | 06:47:00              | 3600             | Outburst\*                |
| SS Aur      | SWP18610 | 1982-11-20                      | 17:33:00              | 1560             | Rise to outburst          |
| HX Peg      | SWP37459 | 1989-10-25                      | 19:31:00              | 3600             | Outburst\*                |
| RX And      | SWP17678 | 1982-08-13                      | 22:59:00              | 600              | Peak outburst             |
| CZ Ori      | SWP16039 | 1982-01-14                      | 03:18:00              | 2700             | Outburst                  |
| AH Her      | SWP17662 | 1982-08-11                      | 22:12:00              | 1200             | Outburst                  |
| TZ Per      | SWP17643 | 1982-08-09                      | 19:37:00              | 2580             | Outburst                  |
| TT Crt      | SWP47805 | 1993-06-04                      | 19:54:00              | 3300             | Outburst                  |
| SS Cyg      | SWP47746 | 1993-05-27                      | 07:57:00              | 180              | Outburst                  |
| Z Cam       | SWP21721 | 1983-12-08                      | 05:41:00              | 240              | Early decline             |
| EM Cyg      | SWP907297| 1979-12-02                      | 22:45:00              | 1500             | Outburst                  |
| RU Peg      | SWP15079 | 1981-09-22                      | 20:43:00              | 840              | Decline                   |
| SY Cnc      | SWP07313 | 1979-12-05                      | 00:40:00              | 1200             | Mid-decline               |
| DX And      | SWP37687 | 1989-11-26                      | 15:25:00              | 2700             | Rise to outburst          |
| WW Cen      | SWP10664 | 1980-11-23                      | 16:21:00              | 1800             | Transition\*             |
| BV Cen      | SWP24867 | 1985-01-08                      | 20:48:00              | 3600             | Transition\*             |

Note.—Sample stars and associated SWP spectra are listed by increasing orbital period.

* The cycle state was determined in the absence of an optical light curve as described in § 2.
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\text{most part, rough estimates, except for less than two dozen sys-
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tems that have reliable trigonometric parallaxes. Thus, even for a
given inclination angle and distance, the accretion disk fits to be
described in § 3 yield inferred white dwarf masses uncertain by

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\text{at least 0.3 M. While our spectral coverage is restricted and}
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excludes the regions where the boundary layer and the white
dwarf probably contribute to the FUV flux, the International

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\text{Ultra violet Explorer (IUE) spectra do cover the range of wave-
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lengths where accretion disks during outburst are emitting a large

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of their light. In view of all these caveats, our disk model
fits should be regarded only as first approximations to the real ac-
cretion rates during outburst. Moreover, these spectra nicely com-
plement the compilation of optical spectra of dwarf novae in
outburst described by Morales-Rueda & Marsh (2002).

2. ARCHIVAL IUE SPECTRAL DATA

All the spectral data that were obtained from the Multimission
Archive at the Space Telescope (MAST) IUE archive are in a
high activity state, very near or at outburst. We restricted our
selection to those systems with short-wavelength prime (SWP)
spectra, with resolution of 5 Å and a spectral range of 1170 to

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\text{in Table 2. System Parameters are given for each system to locate the}
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associated fit in the accompanying figures. 

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\text{Notes.—Sample stars listed by increasing orbital period. A reference number is given to each system to locate the associated fit in the accompanying figures.}
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All spectra were taken through the large aperture at low dispersion. The Massa & Fitzpatrick (2000) flux calibration–correction algorithm was applied to all the IUE data used; please see their paper for a description of the corrections it makes to the data. When more than one spectrum with adequate signal-to-noise ratio was available, the two best spectra were analyzed. An observing log of the observations is given in Table 1, where we list (1) the system name, (2) data ID, (3) date of observation, (4) universal time of observation, (5) exposure time, and (6) activity state. “Transition” refers to an intermediate state between outburst and quiescence, and in column (6) footnotes indicate that an outburst state was determined without a ground-based optical light curve at the time of the IUE observation.

The activity state of the spectra was determined by examining the AAVSO light curves for each system, as well as the flux level of the IUE spectrum that typically made it obvious that the spectrum was obtained in outburst. Unfortunately, we were unable to cross-reference this AAVSO data with data from VSNET during the preparation of this paper due to their archives being offline. In the case of those systems not covered by the AAVSO, their activity state was assessed based on either mean photometric magnitudes taken from the Ritter & Kolb (2003) catalog or IUE Fine Error Sensor (FES) measurements at the time of the IUE observation. The FES counts, when available, were converted to optical magnitudes to help ascertain the brightness state at the time of the IUE observation and used as consistency checks on our model fitting, since the model-predicted optical magnitude from a best-fitting model should always be fainter than the observed optical magnitude of the system. This is because of the contribution of the secondary to the optical. In addition, the presence of P Cygni profiles and absorption lines and comparison with spectral data and flux levels for the systems during other activity states were used to ascertain the state of the system.

The reddening of the systems was determined based on all estimates listed in the literature. The three principal sources of reddening were the compilations of la Dous (1991), Verbunt (1987), and Bruch & Engel (1994). If there was a range of values found, then the value we assume in our analyses follows the range shown in column (5) of Table 2, and the ranges and assumed values are separated by a semicolon. If only one value was listed in the literature, then we adopted that value, and if there was none listed,
we took the reddening to be zero. The spectra were then dereddened with the IUERDAF routine UNRED.

3. SYNTHETIC SPECTRAL FITTING PROCEDURE

3.1. Distance Constraints on the Fitting

As a constraint on the goodness of a particular model fit, we adopted a distance from either a trigonometric parallax, the Warner (1995) and Harrison et al. (2004) relations, or the scale factor of the best-fitting WD model to Hubble Space Telescope (HST) spectra of dwarf novae during quiescence. The adopted distance was used as a basis for comparison with distances yielded by the accretion disk model fitting. The most direct means of knowing the distance is to have trigonometric parallaxes such as those measured by Thorstensen (2003) for 14 dwarf novae. But dwarf novae and nova-like variables also offer the advantage of estimating distances from correlations between their absolute magnitudes at maximum brightness and their orbital periods. Distance estimates were obtained from either the absolute magnitude at outburst $M_V(\text{max})$ versus orbital period $P_{\text{orb}}$ relation of Warner (1995) or from a more recent relationship by Harrison et al. (2004) based on their recent HST FGS parallaxes of dwarf novae. The Warner (1995) relation is

$$M_V(\text{max}) = 5.74 - 0.259 P_{\text{orb}} \text{(hr)}.$$  \(1\)

and the Harrison et al. (2004) relation is

$$M_V(\text{max}) = 5.92 - 0.383 P_{\text{orb}} \text{(hr)}.$$  \(2\)

At the outset of the modeling process, we applied both of these relationships to each system. Then, we conducted an exhaustive search of the literature for previous distance estimates. If the literature search revealed other estimates, then we adopted some reasonable mean based on the different methods used to obtain each distance estimate and the distance computed from the two calibrated $M_V(\text{max})$-$P_{\text{orb}}$ relations. If no other distance estimates existed, then we simply adopted a reasonable mean of the two $M_V(\text{max})$-$P_{\text{orb}}$ relations. If a trigonometric parallax was available, then we adopted it for the distance. In the case of two systems (U Gem and YZ Cnc), there was more than one parallax. For U Gem, all were identical. For YZ Cnc, they were slightly different, so we took a mean of the parallax values. For SU UMa, the parallax obtained was unreliable, so we combined it in a mean with other distance estimates and the $M_V(\text{max})$-$P_{\text{orb}}$ relations. The adopted distances used as constraints in the synthetic spectral fitting procedure are shown in Table 2.

3.2. Synthetic Spectral Fitting

We adopted model accretion disks from the optically thick disk model grid of Wade & Hubeny (1998). In these accretion
disk models, the innermost disk radius, $R_{in}$, is fixed at a fractional white dwarf radius of $x = R_{in}/R_{WD} = 1.05$. The outermost disk radius, $R_{out}$, was chosen so that $T_{eff}(R_{out})$ is near 10,000 K, since disk annuli beyond this point, which are cooler zones with larger radii, would provide only a very small contribution to the mid- and far-UV disk flux, particularly the SWP FUV bandpass. The mass transfer rate is assumed to be the same for all radii. Thus, the run of disk temperature with radius is taken to be

$$T_{eff}(r) = T_{s} x^{-3/4}(1 - x^{-1/2})^{1/4},$$

(3)

where $x = r/R_{WD}$ and $\sigma T_{s}^4 = 3GM_{WD}M/8\pi R_{WD}^3$.

Limb darkening of the disk is fully taken into account in the manner described by Diaz et al. (1996) involving the Eddington-Barbier relation, the increase of kinetic temperature with depth in the disk, and the wavelength and temperature dependence of the Planck function. The boundary layer contribution to the model flux is not included. However, the boundary layer is expected to contribute primarily in the extreme ultraviolet below the Lyman limit.

After masking emission lines, artifacts, and poor-quality data in the spectra, we determined, separately for each system, the best-fitting accretion disk model using IUEFIT, a $\chi^2$ minimization routine. In virtually every dwarf nova system in our IUE sample, the accretion disk by itself provided very good agreement with the outburst spectra. However, if the accretion disk fit to the outburst spectrum was not entirely satisfactory over the entire wavelength range, despite the disk providing nearly 100% of the flux, then an attempt was made to slightly improve the fit by adding the flux contribution of a hot white dwarf. For this minority of cases, WD model spectra with solar abundances were created for high-gravity stellar atmospheres using TLUSTY (Hubeny 1988) and SYNSPEC (Hubeny & Lanz 1995). We took a range of gravities in the fitting from log $g = 7.0$ to 9.0 in steps of 0.5. For the white dwarf radii, we use the mass-radius relation from the evolutionary model grid of Matt Wood (2006, private communication). These models have realistic nondegenerate H-rich envelopes, use the Lamb and Van Horn equation of state, and include the effect of nonzero temperature on the WD radius.

We took the best-fitting accretion disk model and combined it with a hot WD model, using a $\chi^2$ minimization routine called DISKFIT. The best-fitting composite accretion disk plus white dwarf was determined based on the minimum $\chi^2$ value achieved and consistency of the scale factor–derived distance with the adopted distance for each system. The scale factor, $S$, normalized to 1 pc and the solar radius, can be related to the white dwarf radius $R$ through $F_{\lambda(\text{obs})} = SH_{\lambda(\text{model})}$, where $S = 4\pi R^2d^{-2}$, and $d$ is the distance to the source.

Fig. 3.—Same as Fig. 1, but for (13) IR Gem, (14) AY Lyr, (15) VZ Pyx, (16) VW Hyi, (17) Z Cha, and (18) WX Hyi.
An illustration of the accuracy we can obtain in a formal error analysis with confidence contours is given in Winter & Sion (2003). In that paper we presented accretion rates of EM Cyg, CZ Ori, and WW Ceti in quiescence, in which 1, 2, and 3 \( \sigma \) confidence contours are given. In Table 2, we list the final composite-fitting results for all systems as follows: column (1), a reference number; column (2), the system name; column (3), the system type (and subtype, if applicable); column (4), \( P_{\text{orb}} \); column (5), \( E(B-V) \); column (6), the adopted distance; column (7), the inclination; column (8), the mass accretion rate \( \dot{M} \); column (9), the percent flux contribution of the WD; and column (10), the percent flux contribution of the disk.

The best-fitting accretion disk model for each system is shown in the accompanying Figures 1–8, listed in order of increasing orbital period as in Table 2. The thick solid line is for the best-fitting accretion disk. The accretion disk is the overwhelmingly dominant contributor in the FUV. If in rare cases a hot white dwarf flux contribution was added in an attempt to slightly improve the fits, then the thick solid line represents their combination, the dashed curve represents the accretion disk alone, and the dotted curve represents the white dwarf. Also included are a reference number and name given in Table 2 to clearly identify each system. To discuss a particular system, the figures are labeled, e.g., Figure N.nn, where N is the figure number and nn is the reference number of a particular dwarf nova.

There are several distances listed in column (6) of Table 2 that are followed by either a \( \pi \) or \( \pm \pi \) in parentheses. If the distance is followed by a \( \pi \), that distance is taken from a parallax (or parallaxes in the case of U Gem). If the distance is followed by a \( \pm \pi \) in parentheses, then it is an adopted distance that incorporates a parallax (see the explanation in § 3.1). All parallaxes are taken from either Harrison et al. (2004) or Thorstensen (2003). A colon in column (8) denotes an uncertain result.

Although the eclipsing dwarf novae OY Car and Z Cha are part of the IUE archival sample, these systems are not included in the statistics of this study, and their derived accretion rates cannot be taken seriously. This is because the accretion disk in these systems is self-eclipsed (i.e., the outer disk obscures the inner disk). Hence, any derived parameters (for example, the accretion rate or the percentage of disk flux contribution) are systematically affected.

In Table 2 it is seen that virtually all of the accretion rates derived from the FUV flux distribution with steady state, optically thick disk models fall within the range \( 1 \times 10^{-8} \) to \( 1 \times 10^{-9} \, M_{\odot} \, \text{yr}^{-1} \) for the distances, white dwarf masses, orbital inclinations, and interstellar reddening values we have adopted. This is no great surprise, although the range of accretion rates that we derive is somewhat broader than the range derived by Warner (1995), whose accretion rates were based on the absolute magnitudes of the accretion disk corrected for inclination and limb darkening.
effects. It should be acknowledged, however, that some of the distances for the 44 dwarf novae in our study involved the use of the Warner (1995) relation. Hence, the rough agreement with the range of accretion rates found by Warner (1995) from his optical study is biased to some degree in favor of such an agreement. Moreover, as is well known, in all of the outburst spectra, almost without exception, N\textsubscript{v} (1238 and 1242 Å), C\textsubscript{iv} (1548 and 1550 Å), and Si\textsubscript{iv} (1393 and 1402 Å), the hallmark resonance doublets are seen in prominent blueshifted absorption and originate in the CV wind. In many of the hotter disk models, one sees synthetic Si\textsubscript{iv} absorption, but the disk temperatures are not high enough for significant nonwind C\textsubscript{iv}, N\textsubscript{v}, or O\textsubscript{v}. The strongest metallic absorption seen in the spectra, aside from the wind resonance doublets, is due to a blend of multiplet 2 of Si\textsubscript{iii} (1300 Å), Si\textsubscript{ii}, and O\textsubscript{i} (1302 Å). In virtually all of the model accretion disk fits, the observed absorption centered at 1300 Å is reasonably well represented by the synthetic Si\textsubscript{iii} absorption at the solar abundance of silicon. One difficulty in fitting the width of the Ly\textsubscript{α} profiles in most of the outburst spectra is the presence of N\textsubscript{v}, which complicates discerning the longward wing of Ly\textsubscript{α}. Fortunately, the shortward wing is usually quite apparent, and one can assume, as a first approximation, that the two wings show mirror symmetry. Nonetheless, in some cases the N\textsubscript{v} looks suspiciously like a pseudo–absorption feature created by the geocoronal emission reversal seen in the core of Ly\textsubscript{α}.

Several individual spectra are noteworthy for reasons other than just the goodness of their fit with steady state, optically thick accretion disk energy distributions. Figure 1.02 presents the outburst spectrum of the SU UMa system SW UMa, along with the best-fitting accretion disk model. There are profiles (e.g., C\textsubscript{iv} 1550 Å and Si\textsubscript{ii} 1260 Å) that appear to have emission-flanking absorption on both the shortward and longward sides of the absorption. Similar profile shapes were seen during the early stages of the 2001 July superoutburst of WZ Sge (Sion et al. 2003). The emission seen near C\textsubscript{iv} could well be due to the Si\textsubscript{ii} (1526 and 1533 Å) doublet, which would match the same structure seen at Si\textsubscript{ii} (1260 Å). If this is the case, then C\textsubscript{iv} is barely seen and may be very weak relative to nitrogen.

In Figures 1.04, 3.18, 4.20, 6.35, 7.37, 7.41, 7.42, 8.43, 8.44, 8.45, and 8.46, the outburst spectra of T Leo, WX Hyi, YZ Cnc, RX And, AH Her, Z Cam, EM Cyg, RU Peg, SY Cnc, DX And, and BV Cen, respectively, reveal a deviation from a steady state flux distribution longward of 1700 Å. In every case, the disk model flux is lower than the observed flux. The deviation tends to be more pronounced among Z Cam–type systems. An anonymous referee suggests this may be due to the secondary star or possibly a shortfall of flux due to the temperature of the outermost disk boundary being set at 10,000 K. In our sample, except for T Leo, this deviation is seen primarily in systems above the period gap.
As stated earlier, one difficulty with fitting the width of the Lyα profiles in this and other outburst spectra is the presence of N v (1238 and 1242 Å), which in some cases may actually be a pseudo-feature created by the geocoronal emission reversal seen in the core of Lyα. In Figure 2.09, TV Crv has an unusually strong Si iv (1393 and 1402 Å) absorption, suggesting possible supersolar Si abundance or a higher Si iv ionization fraction in the outflowing wind material.

4. DISCUSSION

Our analyses represent the first detailed look at all of the dwarf novae observed with the IUE SWP in outburst in a systematic way. We have applied a uniform analysis to the largest spectroscopic sample of FUV spectra of dwarf novae, obtained during the same brightness state with the same telescope and the same instrumental setup, taking into account the best available distance information. Accordingly, this large body of accretion rates will serve as a basis for comparison with accretion rates derived by other independent methods in other wavelength regions. Moreover, the FUV-derived accretion rates of individual systems can be compared with FUV-derived accretion rates of other systems in the same dwarf nova subclass or across subclasses. A number of implications and conclusions arise from this analysis.

Overall, the steady state, optically thick disk model fits to the outburst spectra shown in Figures 1–8 are quite acceptable and in some cases excellent. All of the accretion rates derived from the FUV fall within the range $1 \times 10^{-8}$ to $1 \times 10^{-9} M_\odot$ yr$^{-1}$ for the distances, white dwarf masses, orbital inclinations, and reddening values we have adopted. Therefore, the main uncertainties in the derived accretion rates, or in constraining the outburst accretion rates, arise from the uncertainties in the published values of the white dwarf masses, the orbital inclinations, and the reliability of the distances.

On the other hand, there are several systems with outburst spectra in the IUE archive that merit attention because they differ significantly from the FUV energy distribution of steady state accretion disks. Aside from the eclipsing systems Z Cha and OY Car, which reside below the period gap and are seen nearly edge-on with absorbing curtains, all of the systems that depart from a steady state disk distribution do so longward of 1600 Å, and all of these systems lie above the period gap, except for T Leo. The U Gem–type and Z Cam–type systems are WX Hya, YZ Cnc, RX And, AH Her, Z Cam, EM Cyg, RU Peg, SY Cnc, DX And, and BV Cen.

If one takes our FUV-derived accretion rates in outburst at face value, then in principle they can be used in combination with accretion rates derived for dwarf nova quiescence, and the
Fig. 7.—Same as Fig. 1, for (37) AH Her, (38) TZ Per, (39) TT Crt, (40) SS Cyg, (41) Z Cam, and (42) EM Cyg.

Fig. 8.—Same as Fig. 1, but for (43) RU Peg, (44) SY Cnc, (45) DX And, and (46) BV Cen.
timescales of outburst and quiescence can be used to estimate the

the duty cycle–averaged averaged $\dot{M}$ is given by

$$
\langle \dot{M} \rangle = (\dot{M}_{\text{ob}} t_{\text{ob}} + \dot{M}_{\text{q}} t_{\text{q}}) / t_{\text{tot}},
$$

(5)

Now it appears that all dwarf novae both above and below the
gap have $M = 10^{-8}$ to $10^{-9} M_\odot$ yr$^{-1}$ in outburst. Suppose we
assume the outburst times and quiescence times, as well as the WD masses of all dwarf novae, are the same. Then the only possible
causes for a difference in accretion heating of a WD in a DN
above the gap compared with a WD below the gap are (1) a difference in WD ages due to evolution age, (2) a different amount of
disk accretion during the outburst (i.e., more mass from the disk accreted above the gap vs. the mass fraction of the disk accreted below the gap), or (3) a significantly higher accretion rate during quiescence for DNS above the gap than below the gap. Looking at the above equation, if $M_{\text{ob}}$ is sufficiently high and

the outburst duration is short enough, that is, if $M_{\text{ob}}$ is lower, say, less than $10^{-9} M_\odot$ yr$^{-1}$, then

if the accretion rate during quiescence is higher than the nominal $1 \times 10^{-11} M_\odot$ yr$^{-1}$ that we assume in this paper.

While the above time-averaged accretion rate are gotten di-
rectly from model-derived accretion rates, the time-averaged accretion rates derived for selected dwarf novae by Patterson (1984)
were obtained for the most part from a mean optical brightness level in AAVSO light curves on the assumption that the accretion disk is the sole source of the system light. By converting the mean magnitude to a flux and combining it with an estimated distance, a luminosity was obtained. The accretion rate providing that luminos-
ity was derived for a given assumed or known white dwarf mass.

It is of interest to carry out a quantitative comparison of the
two approaches to estimating $\langle \dot{M} \rangle$. To illustrate, we take sample

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