THE HOT COMPONENTS OF AM CVn HELIUM CATACLYSMICS

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ABSTRACT

We present the results of a multi-component synthetic spectral analysis of the archival far-ultraviolet spectra of the hot components of several AM CVn double degenerate interacting binaries with known distances from trigonometric parallaxes. Our analysis was carried out using the code BINSYN, which takes into account the donor companion star, the shock front which forms at the disk edge, and the FUV and NUV energy distribution. We fixed the distance of each system at its parallax-derived value and adopted appropriate values of orbital inclination and white dwarf (WD) mass. We find that the accretion-heated “DO/DB” WDs are contributing significantly to the FUV flux in five of the systems (ES Ceti, CR Boo, V803 Cen, HP Lib, GP Com). In three of the systems, GP Com, ES Ceti, and CR Boo, the WD dominates the FUV/NUV flux. We present model-derived accretion rates which agree with the low end of the range of accretion rates derived earlier from blackbody fits over the entire spectral energy distribution. We find that the WD in ES Ceti is very likely not a direct impact accretor but has a small disk. The WD in ES Ceti has $T_{\text{eff}} \sim 40,000 \pm 10,000$ K. This is far cooler than the previous estimate of Espaillat et al. We find that the WD in GP Com has $T_{\text{eff}} = 14,800 \pm 500$ K, which is hotter than the previously estimated temperature of 11,000 K. We present a comparison between our empirical results and current theoretical predictions for these systems.

Key words: accretion, accretion disks – novae, cataclysmic variables – white dwarfs

1. INTRODUCTION

A puzzling and exotic subset of all cataclysmic variables (CVs) are the nearly pure helium systems known as the AM CVn binaries. They have the shortest orbital periods (5 minutes to 1 hr) known for any interacting binary and hence are the most compact of any known interacting systems. Their spectra are dominated by helium spectral features arising from a helium accretion disk which has formed via mass transfer from a degenerate or semi-degenerate helium donor star filling its Roche lobe (Paczynski 1967; Deloye & Bildsten 2003). The basic model was originally proposed by Paczynski (1967) and Faulkner et al. (1972) with their binary nature first confirmed by Nather et al. (1981). The mass transfer is driven by angular momentum loss due to gravitational wave radiation (GWR). Because GWR depends very strongly on the orbital period, this suggests a rapidly dropping mass transfer rate as a function of orbital period. However, this hypothesis has never been tested with either actual realistic helium accretion disk models with vertical structure, or hot helium-rich, high-gravity photospheres, or combinations of photospheres and disks. Indeed, much of the effort has focused only upon the prototype system AM CVn itself (Nasser et al. 2001), which is always observed in its high state when the helium accretion disk is very luminous.

The spectroscopic, orbital, and physical properties of these systems are comprehensively reviewed by Warner (1995) and Solheim (2010). There are three types of AM CVn systems. Objects like AM CVn and HP Lib are in continuous high states and show apparent He disk spectra with absorption lines. Four objects have both outburst states and quiescence states as in dwarf novae (e.g., CR Boo, V803 Cen), and three objects are seen in continuous low states (e.g., GP Com). In their bright states, the AM CVns spectroscopically resemble the prototype AM CVn in its continual bright state in which the absorption lines of an optically thick helium disk and wind dominate their optical and FUV spectra (e.g., Groot et al. 2001 and references therein). It is unclear whether the helium accretion disk also dominates the light during the low states.

The AM CVn objects are fundamentally important because of their exotic evolutionary history which may have involved double common envelope evolution and led to their nearly pure helium composition in which the physics of helium accretion under extreme conditions can be explored. Most importantly, AM CVn systems may be a significant channel for the production of Type Ia supernovae (SNe Ia) and can contribute up to 25% of the galactic SN Ia rate (Nelemans et al. 2001). While some population synthesis calculations indicate they may not be a significant SN Ia progenitor channel (Solheim & Yungelson 2005), a recent discovery of the progenitor of the Type Ia supernova SN2007 as an AM CVn star strongly suggests that indeed some AM CVn stars may be Type Ia progenitors (Voss & Nelemans 2008). Further support from recent theoretical work suggests that AM CVn systems could indeed produce SN Ia (Bildsten et al. 2007). Interestingly, the final evolutionary state of these systems, if they do not explode as SN Ia when mass transfer has ceased, may be a DB white dwarf (WD; Nather 1985) with a planet or brown dwarf as companion. Furthermore, as their mass transfer is driven by general relativity, the AM CVns are predicted to be a significant source of the low-frequency gravitational radiation background (Warner 1995). Thus, they are important sources for any space-based GWR detector sensitive to these relatively rare short-period systems.

One major obstacle to synthetic spectral analysis has been the large uncertainty in their distances. Since trigonometric parallaxes have now been measured with the Hubble fine guidance sensor for several AM CVn systems (Roelofs et al. 2007a), it is possible to constrain the parameter space of model fits and attempt to disentangle the flux contributions of multiple emitting components. In this work, we exploit this newly available distance information to carry out extensive multi-component model fitting to the FUV/NUV spectra of
AM CVn systems in high states and in low states, in much the same way we have done for H-rich CVs (Sion et al. 2008; Urban & Sion 2006). In this paper, we confine our attention to five systems for which the distances are known from the parallax measurements of Roelofs et al. (2007) and for which archival IUE spectra exist.

The reddening of the systems was determined based upon all estimates listed in the literature. The three principal sources of reddening were the compilations of Verban (1987), La Doux (1991), and Bruch & Engel (1994) or from the Galaxy Evolution Explorer archive on Multimission Archive at Space Telescope (MAST). The spectra were dereddened with the IUE IDL routine UNRED.

Table 1: Summary of Observational Properties of AM CVn Stars

| Name     | $P_{\text{orb}}$ (s) | $M_{\text{WD}}$ ($M_\odot$) | $M_2$ ($M_\odot$) | $i$ (deg) | $E(B-V)$ | $d$ (pc) |
|----------|----------------------|-------------------------------|-------------------|-----------|-----------|-----------|
| ES Cet   | <0.8                 | 0.009-0.012                   | 0.026             | 75        |
| GP Com   | 1103                 | 0.048-0.088                   | 26-34             | 197       |
| HP Lib   | 1471                 | 0.044-0.088                   | 30                | 337       |
| V803 Cen | 1612                 | 0.059-0.109                   | 12-15             | 347       |

For ES Ceti and HP Lib, the archival IUE spectra are available in the high brightness state. Hence, the designation in Column 7 refers to the high (“outburst”) state.

2. FAR-ULTRAVIOLET ARCHIVAL SPECTRA

All the spectral data were obtained from the MAST. We restricted our selection to those systems with IUE SWP spectra, with resolution of 5 Å and a spectral range of 1170–2000 Å. After downloading all of the IUE spectra, we re-calibrated them according to the Massa and Fitzpatrick flux calibration correction, deleted bad pixels, and saved the spectra for plotting. All spectra were taken through the large aperture at low dispersion.

Table 2: IUE Observing Log

| System Name | Data ID | $t_{\text{exp}}$ (s) | Disp. | Ap. | Date of Obs. | State |
|-------------|--------|----------------------|-------|-----|--------------|-------|
| ES Ceti     | SWP30020 | 3600                | Low   | Large | 1987-01-04 21:46:25 | High  |
| GP Com      | SWP46900 | 19500               | Low   | 1993-02-08 06:04:06 | Low   |
| HP Lib      | LWP20586 | 14400               | Low   | 1991-06-13 00:20:25 | Low   |
| CR Boo      | SWP51283 | 3000                | Low   | Large | 1994-07-01 20:38:37 | Low   |
| V803 Cen    | LWP28520 | 2700                | Low   | 1994-07-01 23:12:25 | High  |
| CR Boo      | SWP33087 | 25200               | Low   | 1988-03-13 12:56:17 | Low   |
| GP Com      | SWP33086 | 37200               | Low   | 1988-03-13 01:45:44 | Low   |
| HP Lib      | SWP33077 | 3600                | Low   | 1988-03-10 20:10:40 | Low   |
| CR Boo      | LWP12836 | 3600                | Low   | 1988-03-10 21:16:53 | Low   |
| GP Com      | LWP12847 | 5400                | Low   | 1988-03-13 00:08:50 | Low   |
| V803 Cen    | SWP44085 | 7200                | Low   | 1992-03-01 05:03:16 | Low   |
| CR Boo      | LWP22482 | 3600                | Low   | 1992-03-01 03:58:46 | Low   |
| CR Boo      | SWP38270 | 5880                | Low   | 1990-02-28 10:32:21 | High  |
| CR Boo      | LWP17437 | 2400                | Low   | 1990-02-28 09:45:58 | High  |

In all synthetic spectra reported here the adopted number ratio $T_{\text{eff}}(r)$ proportional to $r^{-3/4}$ is a special case. The program calculates a synthetic spectrum of the primary star, the secondary star, the accretion disk face, the accretion disk rim, and the entire system at arbitrary orbital longitudes and orbital inclinations. The program allows for eclipse effects, mutual irradiation, and a hot spot (shock front) at the disk edge. The package also calculates light curves by synthetic photometry.

In all synthetic spectra reported here we adopted the number ratio $T_{\text{eff}}(r)$ proportional to $r^{-3/4}$. Since the spectra of stellar models closely approximate accretion disk annuli spectra of the same $T_{\text{eff}}$ (Hubeny 1990), we have used the same set of synthetic spectra for both the WD and accretion disk annuli. The radii of the WD models for a given input value of $g$ and $T_{\text{eff}}$ were

3. SYNTHETIC SPECTRAL ANALYSIS

We combined He-rich accretion disk models and He-rich WD models constructed with BINSYN, a comprehensive software package for simulating binary stars with or without accretion disks. In the case of accretion disk systems (Linnell & Hubeny 1996) the program constructs a generalized accretion disk with an assignable radial temperature gradient; the standard model case with $T_{\text{eff}}(r)$ proportional to $r^{-3/4}$ is a special case. The program calculates a synthetic spectrum of the primary star, the secondary star, the accretion disk face, the accretion disk rim, and the entire system at arbitrary orbital longitudes and orbital inclinations. The program allows for eclipse effects, mutual irradiation, and a hot spot (shock front) at the disk edge. The package also calculates light curves by synthetic photometry.

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read from Figure 4(a) in Panei et al. (2000). Using our synthetic spectra and successive trial parameters, we obtained the physical parameters for the five AM CVn systems listed in Table 3. The best-fitting combination of models was selected on the basis of consistency with the trigonometric parallax distances of Roelofs et al. (2007a), and visual estimates of the goodness of fit to the continuum slope and to any absorption features.

An important feature for all of the systems is that the observed IUE spectra, in each case, can be well fit by a source with a unique $T_{\text{eff}}$. The problem that arises is that a bare WD with the requisite $T_{\text{eff}}$ and any reasonable mass has a model flux too small to fit the observed spectra; an additional flux source of closely similar $T_{\text{eff}}$ must be added. We experimented with bare WDs distorted by rapid rotation and this led nowhere. An accretion disk was the only other option. Our initial experiments simply added an isothermal accretion disk of the requisite $T_{\text{eff}}$ with an outer radius adjusted to produce a good fit of the WD + accretion disk to the observed spectrum. The question then arises whether a standard model accretion disk can be substituted for the isothermal one. Since a standard model accretion disk has a range of $T_{\text{eff}}$, it is important to choose an accretion rate $M$ that produces an average accretion disk $T_{\text{eff}}$ that matches the requisite one. That is what we have done where we quote an accretion rate. As we discuss below, we found that a standard model disk never produces a combined WD + accretion disk synthetic spectrum whose fit to the observations is superior to the combination WD + isothermal accretion disk.

Some parameters such as the WD mass are not precisely known. Since the WD radius is fixed by its mass and the radius enters into the scale factor of a given fit, the WD contribution to the synthetic spectrum is affected appreciably. For our study, we have adopted values of the WD mass for each system that are published in the literature. We discuss each system in the subsections below.

### 3.1. ES Ceti

ES Ceti seems to remain in the same brightness state (a high state) by analogy with nova-like variables and has only one SWP spectrum (SWP30020) and no LWP spectrum. Thus, our wavelength coverage is not as wide as the other sources in this study. At its very short $P_{\text{orb}}$, ES Ceti has been considered a likely direct impact accretor. As we show below, in our model of the system, ES Ceti is not a direct impact accretor and an accretion disk is necessary to understand the FUV observational data. We have adopted a WD mass of 0.7 $M_\odot$ (Solheim 2010 and references therein). Assuming the low amplitude light variation (Espaillat et al. 2005) represents only the phase variation from the stream impact, not an eclipse, we have adopted a low inclination of 41 deg. Separate tests with a range of helium-rich WD $T_{\text{eff}}$ spectra, scaled to fit the SWP spectrum, established a source $T_{\text{eff}}$ close to 40,000 K. A nominal synchronously rotating 0.7 $M_\odot$ 40,000 K WD, without an accretion disk, must be at a distance of 213 pc to fit the observed spectrum, in disagreement with our adopted distance of 350 pc from Solheim (2010). In order to achieve better agreement with our adopted distance, we tried a standard accretion disk model. In Figure 1, we display a standard model helium accretion disk with 33 annuli (rings), an outer radius of 0.03 $R_\odot$, and an accretion rate 5 × 10$^{-10}$ $M_\odot$ yr$^{-1}$ (upper synthetic spectrum) and the WD contribution to the system spectrum (lower synthetic spectrum).

The calculated flux from both the WD and the system synthetic spectrum has been scaled by 1.16639E29, corresponding (exactly) to the distance of 350 pc (Solheim 2010). Note that the accretion disk flux lies significantly below the observed continuum level. In judging the quality of fit, we have used eye estimates of one-fifth of the peak-to-peak variation in the observed continuum spectrum, excepting emission lines. The synthetic spectrum displacement below the observed spectrum can be ameliorated by either decreasing the WD mass (making the WD larger) or increasing the accretion rate. We tried a hotter disk by increasing the accretion rate to 2.5 × 10$^{-9}$ $M_\odot$ yr$^{-1}$ and 5 × 10$^{-8}$ $M_\odot$ yr$^{-1}$. In the former case, the disk spectrum still looked too cool, while in the latter case the disk flux was too high relative to the observations. Increasing the outer disk radius to $R_{\text{disk}} = 0.035$ resulted in excess flux, based on our eye estimate criterion. Our optimal fit resulted when we increased the disk radius only slightly to $R_{\text{disk}} = 0.032$ $R_\odot$. This final fitting result is displayed in Figure 2. Thus, we find that the FUV spectrum of ES Ceti is best represented by a combination of an

| System       | $M_{\text{wd}}$ ($M_\odot$) | $i$ (deg) | $d_{\text{model}}$ (pc) | $R_{\text{disk}}$ ($R_\odot$) | $T_{\text{wd}}$ (1000 K) | $M$ ($M_\odot$ yr$^{-1}$) | Brightness State | Dominant FUV Source |
|--------------|-----------------------------|-----------|--------------------------|-----------------------------|--------------------------|--------------------------|-------------------|-------------------|
| ES Ceti      | 0.7                         | 41        | 350                      | 0.032                       | 40 ± 10                  | 2.5 × 10$^{-9}$          | High              | WD                |
| GP Com       | 0.7                         | 75        | 75                       | 0.030                       | 14 ± 0.5                 | 3 × 10$^{-11}$           | Low               | WD                |
| HP Lib       | 0.7                         | 30        | 197                      | 0.038                       | ...                     | 8 × 10$^{-10}$           | High              | He disk           |
| CR Boo       | 0.9                         | 30        | 337                      | 0.017                       | ...                     | 5 × 10$^{-10}$           | Low               | WD                |
| V803 Cen     | 0.9                         | 15        | 347                      | 0.030                       | ...                     | 5 × 10$^{-10}$           | Low               | He disk           |
| V803 Cen     | 0.9                         | 15        | 347                      | 0.035                       | ...                     | 5 × 10$^{-10}$           | High              | He disk           |
(adopted) 0.7 $M_\odot$ WD with $T_{\text{eff}} = 40,000$ K and an accretion disk dominating the FUV light with $M = 2.5 \times 10^{-9} M_\odot$ yr$^{-1}$. The empirically determined outer accretion disk radius is much smaller than the tidal truncation radius (Warner 1995). Figure 3 shows the orbital plane view of the system with the accretion disk marked by the diagonal line region. The mass transfer stream is shown, terminating on the accretion disk rim. Continuation of the stream shows that, in the absence of an accretion disk, the stream would miss the WD if one neglects stream spreading (Lubow & Shu 1975, 1976).

3.2. GP Com

GP Com is always seen in the same brightness state (a low state by analogy with low states of H-rich nova-like variables and dwarf novae during quiescence). The pair of IUE spectra that we selected for analysis are SWP46900 and LWP20586. As with ES Ceti, initial tests established a source $T_{\text{eff}} = 14,800$ K. Standard model accretion disks with median $T_{\text{eff}}$ values around $14,800$ K have $M$ values around $(3-4) \times 10^{-11} M_\odot$ yr$^{-1}$. We were constrained in this system analysis by the lack of convergence of TLUSTY for $T_{\text{eff}}$ values below 14,000 K. Nather suggests a low mass for the WD (Nather et al. 1981). The published range of WD masses is between 0.5 and 0.7 $M_\odot$ (see Table 1). Following Marsh (1999), we adopted $M_\odot = 0.7$. Marsh (1999) shows that the inclination is large; we adopt $i = 75$ deg. A standard model accretion disk with the $M$ just described requires annulus $T_{\text{eff}}$ values down to 11,000 K. Consequently we have forced the accretion disk to be isothermal at 14,800 K. In Figure 4, we display the best-fitting WD + disk model, with the 14,800 K WD seen at the bottom of the figure. The best synthetic spectral fit to the outer radius of the annulus is 0.030 $R_\odot$. The accretion disk is isothermal with $T_{\text{eff}} = 14,800$ K and the WD has the same $T_{\text{eff}}$. The accretion disk radius is 0.030 $R_\odot$ while the WD radius is 0.011 $R_\odot$. The WD contribution is about one-half the system flux or a bit less. The uncertainty in the WD temperature is $\pm 1500$ K.

3.3. HP Lib

HP Lib is also continually seen in the same brightness state, a high state with no known low state ever having been recorded. Thus, it was reasonable to try standard, steady state, helium accretion disk fits with standard model radial temperature gradients. As with previous systems, we first determined the source $T_{\text{eff}}$ and found it to be 30,000 K. There are no eclipses and we adopted $i = 30$ deg, a value in the middle of the range of published inclinations given in Table 1. Trying a standard model accretion disk, we obtained a fairly successful fit to the IUE spectra SWPS1283 + LWP28520. The $M$ is $8.0 \times 10^{-10} M_\odot$ yr$^{-1}$. The temperatures of the disk annuli range from 31,076 K to 22,304 K. In order to fit the observed fluxes, it was necessary to adjust the outer radius of the accretion disk. We tried outer radii of 0.0370 $R_\odot$, 0.0400 $R_\odot$, and 0.038 $R_\odot$. The best-fitting result was with $R_{\text{disk}} = 0.038 R_\odot$ and is shown in Figure 5. Note the small WD contribution (bottom plot) to the system synthetic spectrum.

3.4. CR Boo

CR Boo, like V803 Cen and CP Eri, has both high and low optical brightness states in analogy with H-rich dwarf novae and nova-like variables. We adopted $M_{\text{wd}} = 0.9 M_\odot$ (middle of the mass range in Roelofs et al. 2007a), inclination $i = 30^\circ$ (Nasser et al. 2001), the WD radius from Table 4a in Panei et al. (2000), $R_{\text{wd}} = \sim 0.095 R_\odot$, and the mass of the secondary, $M_2 \sim 0.023 M_\odot$, from Table 1 of Bildsten et al. (2006).
The outer radius of the accretion disk. The outer radius of

\[ R_{\text{disk}} = 0.35 R_\odot \]

is displayed in Figure 9.

The *IUE* spectra SWP33087 + LWP12847 were obtained
during the low state of CR Boo. The LWP spectrum is noisy
and was scaled by \(-0.05 \times 10^{-14}\) to combine it with the
SWP spectrum. We first tried fitting WD synthetic spectra with
log \( g = 8.0 \) and He/H = 1 \times 10^4, and a range of \( T_{\text{eff}} \) values to
the combination SWP33087 + LWP12847. This was followed
by standard accretion disk model fitting. The resulting best fits
were obtained with a combination of an accretion disk and WD
photosphere. The outer radius of the accretion disk during the
low state was \( R_{\text{disk}} = 0.017 R_\odot \). Figure 6 shows the best-fitting
combination of an He-rich WD plus accretion disk model to the
low state of CR Boo.

The *IUE* spectra SWP33077 + LWP12836 were obtained
during the high state of CR Boo. The difference in flux
levels between the high and low states of CR Boo is not
very large. The high-state spectrum has a flux level of \( \sim 5 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1} \) at 1280 Å compared with the low-state
flux level of \( \sim 1.5 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1} \). In Figure 7, we
display the best-fitting combination of WD plus disk SWP33077
+ LWP12836. The only difference between Figures 6 and 7
is the outer radius of the accretion disk. The outer radius of
the accretion disk fit to the high-state spectrum was \( R_{\text{disk}} = 0.035 R_\odot \), while it was \( R_{\text{disk}} = 0.017 \) in the low state. The WD
parameters and the derived accretion rate are exactly the same
in both figures. The change in flux between the two figures is
exclusively a result of the change in radius of the accretion disk.
Thus, the fractional contribution of the WD is larger for the
smaller accretion disk radius in Figure 6. Note that the solid
black line toward the bottom of the plot is the contribution of
the WD spectrum alone while the upper solid black line
fitting the observed spectrum itself is the combined synthetic
spectrum of the WD plus the accretion disk. We determined
\( M \) by running several BINSYN models, varying the adopted
\( M \) until the annulus temperature extremes were about equally
spaced around 30,000 K. The temperature extremes are 34,795 K
and 23,000 K with the former temperature characterizing only
the very narrow annuli at the inner edge of the accretion disk.

### 3.5. V803 Cen

For V803 Cen with its trigonometric parallax distance, we
adopted \( M_{\text{wd}} = 0.9 M_\odot \) (Roelofs et al. 2007a, 2007b) and
\( i = 15 \deg \) for the model fitting. The *IUE* spectra SWP44085 +
LWP22482 were obtained during the low state of V803 Cen.
The flux level at 1280 Å is \( \sim 7.5 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1} \).
The best fit to the low state of V803 Cen was a combination of
an accretion disk with an accretion disk outer radius of 0.030 \( R_\odot \)
and \( M = 5 \times 10^{-10} M_\odot \text{ yr}^{-1} \) and a WD with \( T_{\text{eff}} = 30,000 \text{ K} \)
contributing only \( \approx 10\% \) of the FUV light. The standard model
accretion disk has a \( T_{\text{eff}} \) range from 34,027 K to 24,909 K.
The fit with this model is fairly good but the best fit is with an
isothermal 30,000 K accretion disk with the same outer radius.
A plot of this result for the low state of V803 Cen is displayed
in Figure 8.

The *IUE* spectra SWP38270 + LWP17437 were obtained
during the high state of V803 Cen. The flux level at 1280 Å is
\( 2.5 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1} \). For this combination
of spectra, we found that by using an isothermal annulus with
\( T_{\text{eff}} = 30,000 \text{ K} \) with an outer radius of 0.055 \( R_\odot \), we obtained
a very good fit. On the other hand, when we used a full standard
model accretion disk + WD with an outer radius of \( R_{\text{disk}} = 0.050 \),
and an accretion rate \( M = 5 \times 10^{-10} M_\odot \text{ yr}^{-1} \), the fit was not as
good as the isothermal (\( T = 30,000 \text{ K} \)) annulus case. A plot of
the best fit to the high-state spectrum SWP38270 + LWP17437
of V803 Cen with an isothermal 30,000 K annulus with an outer
radius of 0.035 \( R_\odot \) is displayed in Figure 9.
Figure 8. Best-fitting accretion disk model to the IUE spectrum SWP44085 + LWP17482 of the nova-like system V803 Cen during its low state. The accretion disk corresponds to $\dot{M} = 5.0 \times 10^{-10} M_\odot \text{ yr}^{-1}$; see the text for details.

Figure 9. Best-fitting accretion disk model to the IUE spectrum SWP38270 of the nova-like system V803 Cen during its high state. The accretion disk corresponds to $\dot{M} = 3.0 \times 10^{-10} M_\odot \text{ yr}^{-1}$; see the text for details.

In Table 3, we summarize the best-fitting parameters of this selected sample of AM CVn systems where the entries by column are (1) the system name, (2) WD mass, (3) inclination angle, (4) best-fitting model distance in pc, (5) $T_{\text{wd}}$, (6) $M$, and (7) dominant FUV source.

4. CONCLUSIONS

Our synthetic spectral analysis of the far-ultraviolet spectra of AM CVn systems obtained with the IUE spacecraft reveals a number of new findings. First, we have found that in four of the systems (ES Ceti, CR Boo, V803 Cen, HP Lib, GP Com), the accretion-heated “DO/DB” WDs are contributing significantly to the FUV flux. This confirms the prediction by Sion et al. (2006) and Bildsten et al. (2006) that the accreting WD is a significant contributor to the FUV but not in the optical (with the exception of GP Com). Nevertheless, He-rich disks in the FUV with a range of temperatures dominate the FUV flux. In two of the systems, GP Com and ES Ceti, the WD dominates the FUV/NUV flux.

Our estimated accretion rates derived in the FUV/NUV alone from disk and photosphere models, using the accurate trigonometric parallax distances, are in agreement with the lowest value of the range of accretion rates derived for HP Lib, CR Boo, and V803 Cen from “blackbody” fits over the entire spectral energy distribution by Roelofs et al. (2007a). The system with the highest derived accretion rate is the shortest period system ES Ceti with $\dot{M} = 2.5 \times 10^{-9} M_\odot \text{ yr}^{-1}$, while our lowest derived accretion rate is for the longest period system, GP Com with $\dot{M} = (3-4) \times 10^{-11} M_\odot \text{ yr}^{-1}$.

For HP Lib, which remains at the same brightness level, and the “outbursting” systems, CR Boo and V803 Cen, all three of which have similar orbital periods, the derived accretion rates are also similar at $(3-5) \times 10^{-10} M_\odot \text{ yr}^{-1}$. In the case of CR Boo and V803 Cen, the variation in the flux level between the high state and the low state is not large and can be accounted for by a relatively small change in the size of the accretion disk between the two states rather than by an appreciable change in the accretion rate between the two states.

We have found that the WD in ES Ceti is very likely not a direct impact accretor, but instead has a small disk around the WD. The WD in ES Ceti has $T_{\text{eff}} \sim 40,000 \pm 10,000 \text{ K}$ and dominates the system’s FUV flux. Our derived temperature is far cooler than the previous estimate of Espaillat et al. (2005). We find that the WD in GP Com has $T_{\text{eff}} = 14,800 \pm 500 \text{ K}$, which is hotter than the previously estimated temperature of 11,000 K by Roelofs et al. (2007a), while the accretion rate that we estimate, $(3-4) \times 10^{-11} M_\odot \text{ yr}^{-1}$, is a factor of 10 higher than that derived by Roelofs et al. (2007a).

Finally, given the relatively poor quality and limited sensitivity of the spectra obtained with the small-aperture IUE telescope, it is clear that further progress on AM CVn systems requires higher quality spectra with Hubble Space Telescope, especially with the capabilities of the Cosmic Origin Spectrograph to reach the Lyman limit.

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