Astron. Astrophys. 346, 151–157 (1999)

ASTRONOMY AND ASTROPHYSICS

SW Ursae Majoris, CU Velorum and AH Mensae: three more accreting white dwarfs unveiled?*

B.T. Gänsicke[1] **and D. Koester**[2]

[1] Universitäts-Sternwarte, Geismarlandstr. 11, D-37083 Göttingen, Germany
[2] Institut für Theoretische Physik und Astrophysik der Universität Kiel, D-24098 Kiel, Germany

Received 2 February 1999 / Accepted 12 March 1999

Abstract. We present IUE spectroscopy of the three cataclysmic variables SW UMa, CU Vel, and AH Men. In all three systems, a broad $\mathrm{Ly}\alpha$ absorption profile is observed. In the two short-period dwarf novae SW UMa and CU Vel, the SWP flux is interpreted as photospheric emission from white dwarfs with effective temperatures of 16 000 K and 18 500 K, respectively, similar to the well-studied systems WZ Sge and VW Hyi. From the white dwarf temperatures derived in short period dwarf novae to date, there is no significant difference between the supposedly old, low-mass-transfer TOADs and the "normal" SU UMa dwarf novae.

In the case of the novalike variable AH Men, the interpretation of the IUE data is not unambiguous. The SWP spectrum closely resembles that of a 19 000 K white dwarf, but this interpretation is in conflict with the distance $d \gtrsim 150$ pc which we derive from the published optical spectrum. The SWP spectrum can alternatively be explained by emission from an accretion disc with a moderate mass transfer rate ($\sim 10^{-9.5}\,M_{\odot}\,\mathrm{yr}^{-1}$) seen at a low inclination ($\sim 20°$). The possible contribution of the white dwarf to the observed UV flux cannot be determined quantitatively from the poor IUE spectrum, but may be as high as 50 %.

Key words: stars: novae, cataclysmic variables – stars: white dwarfs – stars: atmospheres – stars: individual: SW UMa – stars: individual: CU Vel – stars: individual: AH Men

1. Introduction

In cataclysmic variables (CVs), a white dwarf in a semi-detached close binary accretes matter from a Roche-lobe filling late-type main-sequence star. In the absence of a noticeable magnetic field on the white dwarf, the matter lost from the secondary will spiral through an accretion disc before being accreted at the white dwarf equator. It is clear that the physical parameters of the white dwarf, such as mass, temperature, and rotation rate, influence the structure of the accretion disc and the details of the accretion process itself. For instance, the mass determines the amount of energy released per unit mass accreted, and, hence, the total luminosity of the system. The rotation rate of the white dwarf is a critical parameter which determines the structure of the boundary layer, the interface between disc and star, where up to half of the accretion energy is released. In addition, hot white dwarfs may affect larger parts of the accretion discs via irradiation (King 1997). Though the properties of the white dwarfs are critical to a full understanding of CVs, the white dwarf has been identified only in some 30 out of the ~ 1000 CVs listed by Downes et al. 1997, with in-depth studies performed for a handful of them (Gänsicke 1997, 1999; Sion 1991, 1998).

2. CVs in the IUE final archive

We have initiated a systematic search of the IUE Final Archive (IUE FA) for hitherto unrecognized exposed CV white dwarfs. The aim of this search is to produce candidates for future in-depth studies of accreting white dwarfs with HST and/or FUSE. Here, we report the first results obtained for the sample of non-magnetic CVs from the Ritter & Kolb (1998) catalogue.

In order to be able to detect the white dwarf in a CV, the system has to have been observed during a phase of low accretion activity. As any emission from the accretion stream, an accretion disc remnant, or the hot spot where the stream impacts the disc contributes most dominantly in the near-UV, we restricted our analysis to the available SWP spectra. Using a coordinate list of 235 non-magnetic CVs (including those with an uncertain classification) as input for the archive search, we located 1980 SWP spectra of 136 systems in the IUE FA. All 1980 spectra were plotted and inspected by eye for any spectral evidence of photospheric white dwarf emission. The strongest indication is considered to be a broad $\mathrm{Ly}\alpha$ absorption profile, superimposed by absorption lines of carbon or silicon. This criterion may exclude some systems with hotter ($T_{\mathrm{eff}} \geq 50\,000$) white dwarfs, which have a narrower $\mathrm{Ly}\alpha$ absorption. However, the flux level of most observations obtained during a low state or quiescence is so poor that any narrow $\mathrm{Ly}\alpha$ absorption possibly present in the intrinsic spectrum will be completely filled in by the geocoronal emission. Thus, our search is biased towards the detection of low-temperature white dwarfs.

Send offprint requests to: B. Gänsicke (boris@uni-sw.gwdg.de)

* Based on observations made with the International Ultraviolet Explorer, retrieved from the IUE FA.

Table 1. IUE observations of SW UMa, CU Vel and AH Men retrieved from the IUE FA. Listed are the IUE frame numbers, the observation dates, and the exposure times.

Image No.	Exp. start (UT)	Exp. time (sec)
CU Vel		
LWP30314L	27 Mar 1995 08:33:23	6720
SWP54235L	27 Mar 1995 04:25:57	14400
SW UMa		
LWP31797L	05 Dec 1995 09:34:30	1800
LWP31798L	05 Dec 1995 23:03:00	5400
SWP56268L[a]	05 Dec 1995 10:53:41	12600
SWP56269L	05 Dec 1995 15:44:33	21600
AH Men		
LWP21666L	08 Nov 1991 17:23:25	2880
SWP43038L	08 Nov 1991 18:17:57	1680

[a] Severely affected by cosmic rays

Our systematic search resulted in the detection of a broad $\mathrm{Ly}\alpha$ absorption feature in three further CVs: the dwarf novae SW UMa[1] and CU Vel, and the novalike variable AH Men.

3. The data

Two SWP and two LWP spectra of SW UMa were obtained on December 5, 1995, when the system was in quiescence (Table 1). These data show the system fainter by a factor of $10-25$ than in previous IUE observations obtained during outburst (Szkody et al. 1988; Howell et al. 1995b). CU Vel was observed with IUE for the first time in March 1995, when a single pair of SWP/LWP spectra was obtained (Table 1). Even though we have no information on the optical magnitude during the IUE observations, it appears likely that CU Vel was in quiescence as the spectrum is very similar to that of, e.g., VW Hyi in quiescence (Gänsicke & Beuermann 1996), with weak C IV emission and a broad $\mathrm{Ly}\alpha$ absorption line. AH Men was observed with IUE on three occasions in April 1990, April 1991, and November 1991, resulting in a total of 9 SWP and 7 LWP spectra. These data have been previously presented by Mouchet et al. (1996, hereafter M96). The close-by K-star (see Buckley et al. 1993; hereafter B93) was included in the IUE aperture, but does not contribute to the UV flux. It does, however, affect the FES magnitude. M96 report an FES magnitude of $V = 15.2$ for the Nov. 1991 observations, 1.7 magnitudes fainter than typically observed ($V \approx 13.5$, B93). M96 disregarded this low FES measurement as being due to contamination by scattered light. We recomputed the FES magnitudes for the Nov. 1991 observations, finding $V_{\mathrm{FES}} = 13.8$ for $B - V = 0.27$, the typically observed colour of AH Men, and $V_{\mathrm{FES}} = 13.6$ for $B - V = 0.73$, the colour of the K-companion alone. It appears that AH Men was, indeed, somewhat fainter than normal during the Nov. 1991 observations, but not as much as reported by M96. Comparison of the Nov. 1991 data with April 1990 spectra taken at the same orbital phases shows, as noted already by M96, that the UV brightness does not change drastically throughout the different IUE runs. However, in Nov. 1991 the C IV λ 1550 emission was somewhat reduced and the $\mathrm{Ly}\alpha$ absorption was more pronounced. We re-analyse here only the SWP spectrum which most clearly shows the $\mathrm{Ly}\alpha$ absorption (Table 1).

All the IUE spectra discussed here were obtained in the low resolution mode and through the large aperture, resulting in a spectral resolution of FWHM$\sim$6 Å. The data were retrieved from the IUE Final Archive at the NASA Data Archive and Distribution Service. We inspected the two-dimensional images for the presence of cosmic ray hits. One spectrum of SW UMa (SWP56268L) was strongly affected at ~ 1400 Å, and was consequently excluded from the analysis.

[1] Optical spectroscopy of SW UMa revealed "a hint of broad absorption at Hβ and possibly Hγ", which was interpreted as weak evidence for emission from the white dwarf (Shafter et al. 1986). However, no unequivocal detection of the white dwarf at UV wavelengths has been published so far.

4. Analysis and results

4.1. The model spectra

The secondary stars in CVs show, on average, no signs of subsolar abundances (Beuermann et al. 1998). Therefore, in a state of steady accretion at rates typical for CVs, the accreted matter will enrich the white dwarf photosphere with heavy elements to approximatively solar abundances. The chemical surface abundances derived so far for white dwarfs in non-magnetic systems have been shown to deviate in some cases from solar values, possibly due to dredge-up of core material or to re-accretion of nuclearly processed material (Sion et al. 1995a; 1997). However, considering the low signal-to-noise ratio of the IUE spectra discussed here, we decided to compute a grid of model spectra with the abundances being fixed to solar values. As we are mainly interested in determining the white dwarf effective temperatures, the assumption of solar abundances will not significantly alter our results.

As a further simplification, we fix the surface gravity to $\log g = 8$, corresponding to $M_{\mathrm{wd}} \approx 0.6\,M_{\odot}$, the canonical mass of single white dwarfs. This is appropriate, as the low-quality IUE data do not permit a spectroscopic determination of the actual white dwarf mass, and as there is no strong evidence that the mass spectrum of white dwarfs in CVs differs significantly from that of field white dwarfs (e.g. Gänsicke 1999). The model atmospheres were calculated with our code for white dwarf atmospheres (for a recent description see Finley et al. 1997) including blanketing by hydrogen and helium lines and the quasimolecular features in the wing of $\mathrm{Ly}\alpha$. From these model atmospheres, spectra were generated which include all relevant metal absorption lines from the Kurucz & Bell (1995) list. The grid of model spectra covers $T_{\mathrm{eff}} = 10\,000$–$100\,000$ K with appropriate steps in T_{eff}.

This grid was used to fit the IUE SWP spectra of SW UMa, CU Vel and AH Men in the range $1225-1900$ Å. For SW UMa and CU Vel, where strong emission of C IV λ 1550 is visible, we included a Gaussian fit to the emission line.

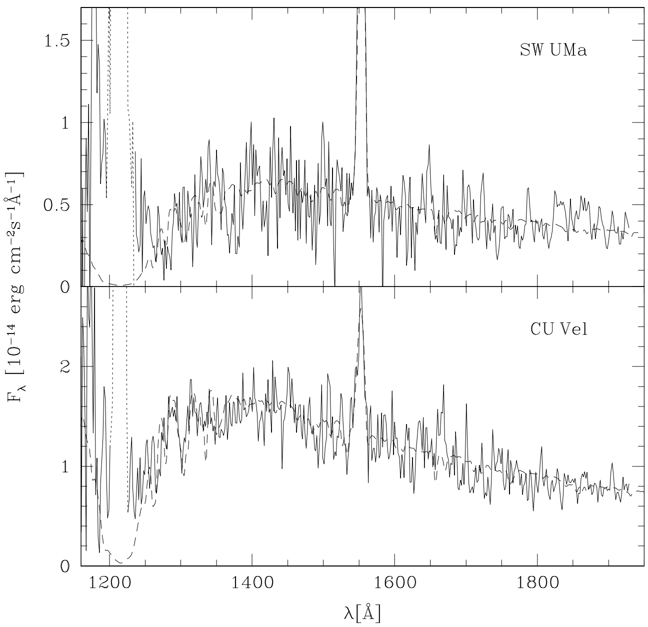

Fig. 1. IUE SWP spectra of SW UMa (*top*) and CU Vel (*bottom*). The Lyα emission (dotted) is of geocoronal origin. Plotted as dashed lines are the best-fit solar abundance white dwarf models, $T_{\rm eff} = 16\,000$ K for SW UMa and $T_{\rm eff} = 18\,500$ K for CU Vel.

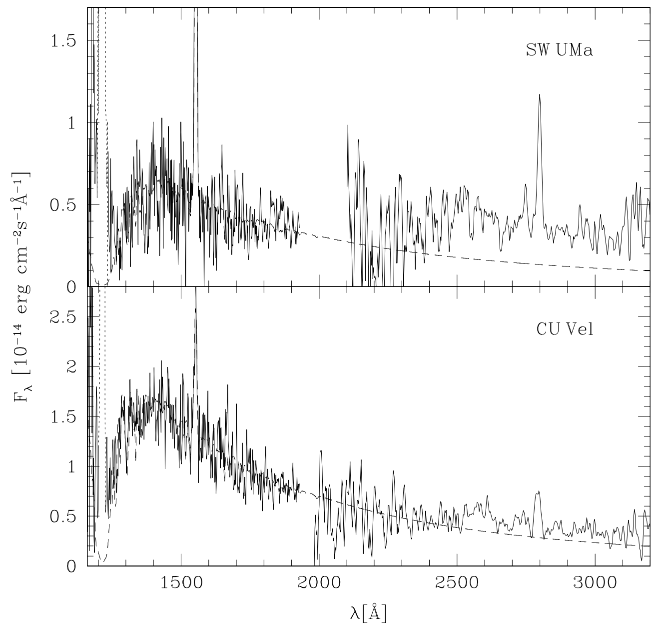

Fig. 2. As Fig. 1, but the LWP spectra listed in Table 1 are included. In SW UMa disc or hot spot emission significantly contribute at longer wavelengths. The LWP spectra of SW UMa and CU Vel contain emission of Mg II λ 2800.

4.2. SW UMa

The best fit to the SWP spectrum of SW UMa results in a white dwarf temperature of $T_{\rm eff} = 16000 \pm 1500$ K. The observed spectrum is shown in Fig. 1, top panel, along with the model spectrum. The IUE spectrum contains absorption features at ~ 1367, 1381, and 1417 Å that are not reproduced by the solar-abundance model. Elevated photospheric abundances of individual elements have been detected in a few CV white dwarfs. WZ Sge, for instance, contains a $T_{\rm eff} \approx 15\,000$ K white dwarf which shows a large overabundance of carbon with respect to the other elements (Sion et al. 1990; 1995a). We computed a few model spectra with $10\times$solar abundances in the temperature range $10\,000-20\,000$ K, which, however, also fail to explain the observed absorption features. The inspection of the list of transitions used to generate the model spectra did not provide any plausible identification. We note that a number of Phosphorus and Sulfur transitions coincide with the observed features, and that a very elevated Phosphorus abundance has been observed in the dwarf nova VW Hyi (Sion et al. 1997). However, the signal-to-noise ratio and spectral resolution of the IUE data does not permit to further investigate this possibility.

The scaling factor between the observed flux and that of the model spectrum can be used to estimate a distance of SW UMa,

$$d = \sqrt{{R_{\rm wd}}^2 \frac{\pi F}{f}} \times \frac{1}{3.086 \times 10^{18}} \,[\rm pc] \qquad (1)$$

where F is the astrophysical flux of the model spectrum and f is the observed flux. The derived distance depends obviously on the white dwarf radius, and, therefore, on the assumed white dwarf mass. As described above, we have fixed the surface gravity to $\log g = 8$, i.e. $M_{\rm wd} \approx 0.6\,M_\odot$, the canonical mass for field white dwarfs (e.g. Bergeron et al. 1992; Finley et al. 1997). As the white dwarf masses determined in CVs are generally rather unreliable, we assume a large range of possible masses for the white dwarf in SW UMa, 0.35, 0.6, and 1.2 $M_\odot$, and find corresponding distances of 243, 182, and 84 pc, respectively. In this estimate, we used for all three white dwarf masses/radii the same flux scaling factor, obtained from the best fit ($\log g = 8$ $\Leftrightarrow M_{\rm wd} \approx 0.6\,M_\odot$ and $T_{\rm eff} = 16\,000$ K). This introduces an additional uncertainty, as changing the white dwarf mass will affect the best-fit temperature derived from the Lyα profile due to different amounts of pressure broadening. Increasing (decreasing) the white dwarf mass generally results in a somewhat higher (lower) best-fit temperature. A higher (lower) temperature will result in a larger (smaller) flux scaling factor, and, hence in a larger (lower) distance estimate. We conclude that $d = 84$–243 pc is a conservative range. For comparison, Warner (1987) estimates the absolute magnitude of SW UMa and derives $d = 140$ pc.

The optical magnitude of the best-fit model is $V = 17.6$, which is below and, therefore, consistent with the observed quiescent magnitude of $V \approx 17.0$ (Ritter & Kolb 1998). We show the white dwarf model spectrum along with the average of the two LWP exposures in Fig. 2, top. Apparently, an additional component contributes in the near-UV, presumably the accretion disc and/or the hot spot.

4.3. CU Vel

For CU Vel, the best fit to the IUE SWP spectrum yields $T_{\rm eff} = 18\,500 \pm 1500$ K (Fig. 1, bottom). The distance, estimated in the

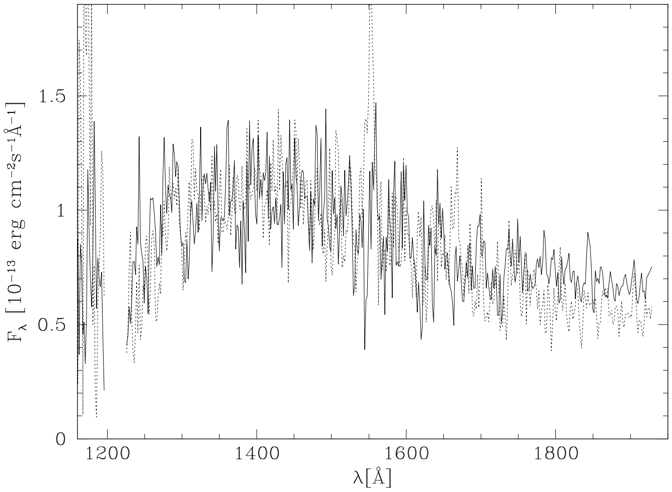

Fig. 3. Comparison between the SWP spectra of AH Men (solid line) of CU Vel (dotted line, multiplied by 7). AH Men shows emission of N V λ 1240, in CU Vel, C IV λ 1550 is relatively strong. Apart from these emission lines, the spectra are very similar.

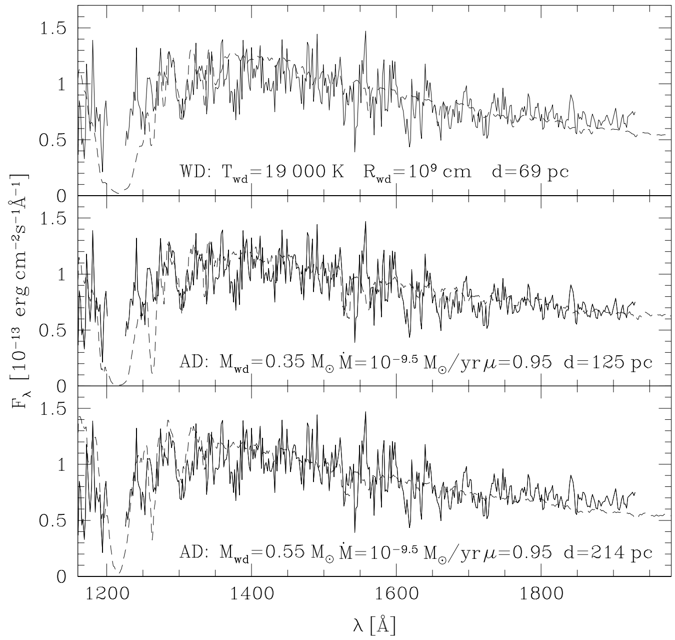

Fig. 4. Model fits (dashed lines) to the SWP spectrum of AH Men (solid lines). Top panel: Photospheric white dwarf emission. Middle and bottom panel: Accretion disc spectra from Wade & Hubeny (1998). Note that the excess flux at $\sim$ 1240 Å is likely due to emission of N V.

same way as for SW UMa, is 209, 157, and 72 pc for white dwarf masses of 0.35, 0.6, and 1.2 $M_\odot$, respectively. For comparison, Warner's (1987) estimate is $d \approx 200$ pc. The best-fit white dwarf has $V = 17.6$, which is consistent with the observed $V = 16.6$ during quiescence (Mennickent & Diaz 1996). Fig. 2, bottom, demonstrates that the white dwarf dominates the UV emission also in the LWP range.

4.4. AH Men

AH Men has been classified as a novalike variable and possibly an intermediate polar (B93). In both types of systems, the accretion rate is normally too high to allow the detection of the white dwarf even at UV wavelengths. The broad Lyα line observed in AH Men is, therefore, somewhat surprising. We consider several models that could account for the broad Lyα absorption.

Photospheric white dwarf emission: Fig. 3 compares the SWP spectrum of AH Men to that of CU Vel. Considering that the SWP spectrum closely resembles that of a typical CV white dwarf (see also e.g. VW Hyi, Gänsicke & Beuermann 1996), our first hope was that the exposed white dwarf also dominates the UV emission in AH Men. The best fit using the white dwarf models described above results in $T_{\rm eff} = 19\,000 \pm 1500$ K (Fig. 4, top panel). There are two broad absorption features centred at 1380 Å and 1425 Å, which our model spectra fail to explain. As for SW UMa, we computed spectra with 10× solar abundances, which do, however, not improve the fit in these absorption features. The distance derived from the white dwarf fit is, again assuming $M_{\rm wd} = 0.35$, 0.6, and 1.2 $M_\odot$, 92, 69, and 32 pc, respectively. The white dwarf has $V = 15.1$, which is far below $V \approx 13.5$ typically observed in AH Men. As in SW UMa, the white dwarf model spectrum underpredicts the flux in the LWP range, clearly indicating that at least the near-UV is dominated by emission from another component than the white dwarf.

If the interpretation of the SWP spectrum as being due to photospheric white dwarf emission were true, the hitherto poorly studied AH Men would be one of the nearest CVs! We checked this possibility using the published optical spectra of AH Men (B93; Zwitter & Munari 1995). With an orbital period of 2.95 h (Patterson 1995), the assumed spectral type of the secondary is ~M 4.5−M 5.5 (Beuermann et al. 1998). The radius of the secondary star can approximatively be calculated as $R_2/R_\odot = 0.234(M/M_\odot)^{1/3} P_{\rm h}^{2/3}$ with $P_{\rm h}$ the orbital period in hours (Patterson 1984). Scaling the optical spectrum of the field M 5.5 dwarf Gl473ab ($R = 0.164\,R_\odot$, Beuermann et al. 1999, and $d = 4.38$ pc, Jenkins 1952) to R_2, we estimate a lower limit on the distance of $d \approx 150$ pc at which the TiO absorption features of the secondary would pass unnoticed in the spectrum of AH Men presented by Zwitter & Munari (1995). For $d = 150$ pc it is clear, however, that the white dwarf alone cannot be the source of the entire observed SWP flux.

Accretion disc emission: M96 interpreted the UV/optical continuum as emission from an optically thick accretion disc, ignoring any possible contribution from the white dwarf, the secondary star or the hot spot where the accretion stream impacts the accretion disc. They modeled the IUE observations with blackbody-radiating standard accretion discs, deriving an upper limit for the distance of $d = 360$ pc and an accretion rate of $\dot{M} = 5 \times 10^{-9}\,M_\odot\,{\rm yr}^{-1}$. From comparison with objects of similar orbital period (Patterson 1984), an accretion rate of $5 \times 10^{-9}\,M_\odot\,{\rm yr}^{-1}$ seems too high. The authors noted a flux excess at shortest wavelengths which they tentatively attributed to the emission from a hot, $T_{\rm eff} \sim 85\,000$ K, white dwarf.

Here, we use the accretion disc spectra published by Wade & Hubeny (1998) to analyse the IUE data of AH Men. The grid includes accretion disc model spectra for a wide range of white dwarf masses $M_{\rm wd}$, mass transfer rates $\dot{M}$, and inclinations $\mu = \cos i$. The models fully take into account limb darkening and rotational broadening, which are very important effects for the spectrum of a flat disc. Basically, the three parameters act on the shape of the model spectra as follows. Increasing $M_{\rm wd}$ or $\dot{M}$ increases the amount of energy dissipated in the disc, raises its temperature, and, hence, steepens the emitted spectrum. Increasing μ, i.e. decreasing the inclination i, also increases the flux and the steepness of the spectrum due to a weaker limb darkening. The actual line profiles are complicated functions of the radial temperature, density, and velocity gradients in the disc. As a rule of thumb, the lines get broader with decreasing μ, i.e. higher inclinations, due to the larger projection of the Keplerian velocities in the disc, and with increasing $M_{\rm wd}$ due to the higher Keplerian velocities around a more compact central object. For a detailed discussion of the spectral dependencies on $M_{\rm wd}$, $\dot{M}$, and μ, see Wade & Hubeny (1998).

Comparing the accretion disc model spectra to the SWP data of AH Men, it turns out that only a small number of combinations of $[M_{\rm wd}, \dot{M}, \mu]$ can reproduce the observed spectrum and satisfy the constraints $d \gtrsim 150$ pc (as discussed above) and $i > 70°$ (as no eclipse is observed, B93). High inclinations or white dwarf masses are excluded by the relatively sharp and deep Si III $\lambda\lambda$ 1300 complex. High mass transfer rates match neither the broad Lyα absorption nor the slope of the SWP continuum. Finally, the models with low white dwarf mass and low mass transfer rates require $d \ll 150$ pc. The two disc models which yield the best fits are shown in the middle and bottom panel of Fig. 4. Both models have $\dot{M} = 10^{-9.5}\,M_{\odot}\,{\rm yr}^{-1}$ and $i = 18.2°$, but differ in $M_{\rm wd} = 0.35\,M_{\odot}$, and $M_{\rm wd} = 0.55\,M_{\odot}$, respectively. The $M_{\rm wd} = 0.35\,M_{\odot}$ model only barely satisfies our lower distance limit.

An essential drawback of the Wade & Hubeny (1998) disc models is that they are tabulated only up to 2000 Å. It is, hence, not possible to compare the models to the LWP spectrum of AH Men and to the observed V-magnitude. In order to obtain a rough estimate of the V-magnitude of a $[M_{\rm wd} = 0.55\,M_{\odot}$, $\dot{M} = 10^{-9.5}\,M_{\odot}\,{\rm yr}^{-1}$, $\mu = 0.95]$ accretion disc, we computed a standard optically thick disc (e.g. Pringle 1981), summing blackbody spectra over 50 rings logarithmically equidistant distributed in radius. For $\dot{M} = 10^{-9.5}\,M_{\odot}\,{\rm yr}^{-1}$, $M_{\rm wd} = 0.55\,M_{\odot}$, $i = 18.2°$, and $d = 214$ pc, the accretion disc has $V = 13.3$, somewhat brighter than the typical magnitude of 13.5. As in the analysis of M96, our fit with this simple blackbody disc model spectrum results in an excess flux observed in the SWP range.

Concluding, the SWP spectrum of AH Men can be interpreted by emission from a stationary accretion disc, a self-consistent modeling of the entire UV/optical spectrum is, however, not possible due to the lack of appropriate models.

Interstellar absorption: M96 give a formal reddening of 0.12 (even though they state that no strong reddening is immediately apparent from the data), which corresponds, assuming an average gas-to-dust ratio (e.g. Diplas & Savage 1994), to a neutral hydrogen column density of $N_{\rm H} \approx 6 \times 10^{20}\,{\rm cm}^{-2}$. The corresponding interstellar absorption line, using a pure damping profile (Bohlin 1975), has a width comparable to that of the geocoronal Lyα emission, and is completely negligible in the interpretation of the IUE observations. To match the width of the observed Lyα absorption line a column density $N_{\rm H} \approx 6 \times 10^{21}\,{\rm cm}^{-2}$ is required. This value is a factor 4 higher than the total galactic column density towards AH Men (Dickey & Lockman 1990; as implemented in EXSAS, Zimmermann et al. 1994). Such a high neutral column density is in principle possible if AH Men is, as suggested by B93, an intermediate polar. Large intrinsic absorption columns obscuring the central object are indeed often observed in this class of CVs at X-ray wavelengths. Since no dust can form/survive in the strong radiation field within the binary system, $N_{\rm H}$ can be higher than the value derived from the strength of the 2200 Å absorption bump.

In order to cause the observed broad flux depression towards Lyα the hypothetical interstellar Lyα absorption has to be superimposed on the blue spectrum of a hot white dwarf or accretion disc with an intrinsically narrow Lyα line. This interpretation encounters, however, two major difficulties: the continuum slope of the SWP spectrum is too flat for a hot ($\gtrsim 30\,000$ K) source; and the Si III λ 1300 complex is too weak in a hot white dwarf or accretion disc. It appears more likely that the observed Lyα absorption is intrinsic to the emitted spectrum of an only moderately hot source.

5. Discussion

5.1. The effective temperature of white dwarfs in dwarf novae

In Table 2 we summarized the effective temperatures of white dwarfs in dwarf novae derived so far. More extensive compilations are given by Sion (1991; 1998) and Warner (1995), but we have restricted ourselves to systems in which the white dwarf has unequivocally been identified by photospheric absorption lines in optical or UV spectroscopy.

As has been discussed by Gänsicke (1998), Sion (1991, 1998) and Warner (1995), the white dwarf temperatures in CVs are determined by a balance between core cooling and accretion heating. The crucial parameters for interpreting the temperature distribution of CV white dwarfs are, hence, the ages of the CVs and their accretion histories.

Among the dwarf novae listed in Table 2, AL Com, WZ Sge and SW UMa are members of a class of short-period dwarf novae with extremely long outburst cycles and very large ($\Delta V \geq 6$) outburst amplitudes, the TOADs[2]. It has been suggested that TOADs are very old CVs with low mass transfer rates (Howell et al. 1997; Meyer-Hofmeister et al. 1998). OY Car, HT Cas, VW Hyi, Z Cha, and CU Vel all belong to the large group of "normal" SU UMa-type dwarf novae, which show quasi-regular

[2] Tremendous Outburst Amplitude Dwarf novae; Howell et al. 1995a

outbursts plus, less often, longer-lasting and brighter superoutbursts. Taking the outburst frequency as a measure for the accretion rate, VW Hyi has the highest accretion rate of the five systems, which is consistent with its white dwarf being the hottest of this group.

One might have expected that TOADs, given their age and low accretion rates, would harbour cooler white dwarfs than the "normal" SU UMa systems. The observed evidence is, so far, meagre. A significant difference appears only when dwarf novae below the period gap are compared with those above the gap: the white dwarf in U Gem is hotter by $\sim 10\,000$ K than those in the short-period systems. Alas, U Gem is the only long-period dwarf novae with a reliable white dwarf temperature published so far.

5.2. *AH Men*

AH Men has been identified by B93 to be the optical counterpart of an X-ray source detected during the HEAO-1 survey. B93 derived a photometric period of $P_{\rm phot} = 3.34$ h, which they identified with the binary's orbital period. The presence of quasi-periodic oscillations with periods of 600−2400 s and the relatively large X-ray-to-optical flux ratio lead B93 to suggest that AH Men may be an intermediate polar. Patterson (1995) obtained further photometry and refined the photometric period to $P_{\rm phot} = 2.95$ h. Also he concluded from the presence of stable signals in the power spectra computed from his photometry that AH Men may be an intermediate polar with a white dwarf spin period of 1040.4 or 2080.8 s.

We have shown that the SWP spectrum of AH Men resembles that of a typical exposed CV white dwarf, but that this interpretation conflicts with the lower distance limit of $d = 150$ pc derived from the non-detection of the secondary star in the optical spectrum of Zwitter & Munari (1995). Unless the secondary star is atypically (and unrealistically) underluminous, with a spectral type later than M 5.5, the white dwarf alone cannot account for the observed SWP spectrum. The SWP spectrum can principally be explained entirely by the emission from an accretion disc with a moderate mass transfer rate in a CV with a average white dwarf mass and a low inclination.

In reality, however, the observed UV spectrum will be the sum of disc and white dwarf emission. The quality of the IUE spectrum makes it impossible to quantitatively disentangle the contributions of these two components. However, we estimate that a $\sim 20\,000$ K white dwarf could contribute up to 1/3−1/2 of the observed UV flux. This opens the tantalizing possibility of deriving the characteristics of the white dwarf in the intermediate polar candidate AH Men from future high-resolution spectroscopy.

6. Conclusions

We have searched the complete IUE Final Archive data set of all non-magnetic CVs from Ritter & Kolb (1998) for spectroscopic evidence of exposed white dwarfs. A broad Lyα absorption line, considered typical of the photospheric emission of a CV white dwarf, is detected in three systems hitherto not discussed in this context.

Table 2. White dwarf temperatures in dwarf novae.

System	$P_{\rm orb}$	$T_{\rm eff}$ [K]	Reference
AL Com	81.6	20 000	1
WZ Sge	81.6	15 000	2
SW UMa	81.8	16 000	3
OY Car	90.9	15–17 000	4, 5
HT Cas	106.1	14–17 000	6
VW Hyi	107.0	20–22 000	7, 8
Z Cha	107.3	15 000	9, 10
CU Vel	113.0	18 500	3
U Gem	254.8	30–32 000	11, 12, 13

(1) Szkody et al. 1998, (2) Sion et al. 1995a, (3) This work, (4) Hessman et al. 1989, (5) Horne et al. 1994, (6) Wood et al. 1992, (7) Gänsicke & Beuermann 1996, (8) Sion et al. 1995b, (9) Marsh et al. 1987, (10) Robinson et al. 1995, (11) Kiplinger et al. 1991, (12) Long et al. 1994, (13) Sion et al. 1998.

The SWP spectra of the two short-period dwarf novae SW UMa and CU Vel can be fitted with white dwarf model spectra, yielding $T_{\rm eff} = 16\,000$ K and 18 500 K, respectively. These values are in the range of temperatures previously determined for several other dwarf novae. The present data show no significant difference between the white dwarf temperatures in TOADs, presumably very old dwarf novae with extremely low accretion rates, and those in "normal" SU UMa dwarf novae. Assuming a canonical white dwarf mass of 0.6 $M_{\rm wd}$, the distances to SW UMa and CU Vel are ~ 180 pc and ~ 160 pc, respectively, roughly consistent with previous estimates.

In the intermediate polar candidate AH Men, the white-dwarf interpretation of the SWP spectrum is irreconcilable with the distance $d \gtrsim 150$ pc estimated from the optical spectrum. The SWP spectrum can broadly be fitted with state-of-the-art accretion disc model spectra, indicating a moderate accretion rate and a low inclination. The low quality of the IUE data prevents a more realistic decomposition of the UV spectrum into white dwarf and disc contribution.

The case of AH Men underlines that a broad Lyα absorption line is not sufficient to unmistakably identify the photospheric emission of the white dwarf in a cataclysmic variable.

Acknowledgements. This work was supported in part by the BMBF/DLR under project number 50 OR 9210 1. We thank Klaus Beuermann for helpful comments on the manuscript, Cathy Imhoff for checking the FES counts and computing the $V_{\rm FES}$ values, Tomaz Zwitter and Ulisse Munari for communicating the optical spectrum of AH Men, Rick Hessman for improving the language of the manuscript, and the referee Michael Friedjung for helpful remarks.

References

Beuermann K., Baraffe I., Kolb U., Weichhold M., 1998, A&A 339, 518
Beuermann K., Baraffe I., Hauschildt P., 1999, A&A, submitted

Bergeron P., Saffer R.A., Liebert J., 1992, ApJ 394, 228
Buckley D.A.H., Remillard R.A., Tuohy I.R., Warner B., Sullivan D.J., 1993, MNRAS 265, 926
Bohlin R.C., 1975, ApJ 200, 402
Dickey J.M., Lockman F.J., 1990, ARA&A 28, 215
Diplas A., Savage B.D., 1994, ApJS 427, 274
Downes R., Webbink R. F., Shara M. M., 1997, PASP 109, 345
Finley D.S., Koester D., Basri G., 1997, ApJ 488, 375
Gänsicke B.T., 1997, Ph.D. dissertation, University of Göttingen
Gänsicke B.T., 1999, In: Solheim J.-E., Meistas E.G. (eds.) Proceedings of the 11th European Workshop on White Dwarf. ASP conf. series 169, p. 315
Gänsicke B.T., Beuermann K., 1996, A&A 309, L47
Hessman F.V., Koester D., Schoembs R., Barwig H., 1989, A&A 213, 167
Horne K., Marsh T.R., Cheng F.H., Hubeny I., Lany T., 1994, ApJ 426, 294
Howell S.B., Szkody P., Cannizzo J.K., 1995a, ApJ 439, 337
Howell S.B., Szkody P., Sonneborn G., et al., 1995b, ApJ 453
Howell S.B., Rappaport S., Politano M., 1997, MNRAS 287, 929
Jenkins L.F., 1952, General Catalogue of Trigonometric Stellar Parallaxes. Compiled at the Yale Univ. Obs.
King A.R., 1997, MNRAS 288, L16
Kiplinger A.L., Sion E.M., Szkody P., 1991, ApJ 366, 569
Kurucz R.L., Bell B., 1995, CD-ROM 23, Atomic Line List. Smithsonian Astrophys. Obs., Cambridge
Long K.S., Sion E.M., Huang M., Szkody P., 1994, ApJ 424, L49
Marsh T.R., Horne K., Shipman H.L., 1987, MNRAS 225, 551
Mennickent R.E., Diaz M., 1996, A&A 309, 147
Meyer-Hofmeister E., Meyer F., Liu B.F., 1998, A&A 339, 507
Mouchet M., Siess L., Drew J., et al., 1996, A&A 306
Patterson J., 1984, ApJS 54, 443
Patterson J., 1995, PASP 107, 657
Pringle J.E., 1981, ARA&A 19, 137
Ritter H., Kolb U., 1998, A&AS 128, 83
Robinson E.L., Wood J.H., Bless R.C., et al., 1995, ApJ 443, 295
Shafter A.W., Szkody P., Thortensen J.R., 1986, ApJ 765
Sion E.M., 1991, AJ 102, 295
Sion E.M. 1998, In: Howell S., et al. (eds.) Proceedings of the 13th North American Workshop on CVs and Related Objects. ASP conf. series 137, p. 62
Sion E.M., Leckenby H.M., Szkody P., 1990, ApJ 364, L41
Sion E.M., Cheng F.H., Long K., et al., 1995a, ApJ 439, 957
Sion E.M., Szkody P., Cheng F.H., Huang M., 1995b, ApJ 444, L97
Sion E.M., Cheng F.H., Sparks W.M., et al., 1997, ApJ 480, L17
Sion E.M., Cheng F.H., Szkody P., et al., 1998, ApJ 496, 449
Szkody P., Osborne J., Hassall B.J.M., 1988, ApJ 328, 243
Szkody P., Hoard D.W., Sion E.M., et al., 1998, ApJ 497, 928
Wade R.A., Hubeny I., 1998, ApJ 509, 350
Warner B., 1987, MNRAS 227, 23
Warner B., 1995, Cataclysmic Variable Stars. Cambridge University Press
Wood J.H., Horne K., Vennes S., 1992, ApJ 385, 294
Zimmermann H.U., Becker W., Belloni T., et al., 1994, MPE Report 257
Zwitter T., Munari U., 1995, A&AS 114, 575