Mem. S.A.It. Vol. 83, 539

Memorie della

White dwarfs in cataclysmic variable stars: accretion physics and evolution

E.M. Sion[1] and P. Godon[1,2]

[1] Department of Astronomy & Astrophysics, Villanova University, 800 Lancaster Ave., Villanova, PA 19085, USA, e-mail: edward.sion@villanova.edu
[2] Visiting at the Henry A. Rowland Department of Physics & Astronomy, Johns Hopkins University, 3701 San Martin Drive, Baltimore, MD 21218, USA
e-mail: patrick.godon@villanova.edu

Abstract. A summary is presented of what is currently known about the surface temperatures, chemical abundances, and rotation velocities of accreting white dwarfs detected in non-magnetic and magnetic cataclysmic variables (CVs) based upon synthetic spectral analyses of far ultraviolet data. A special focus is placed on white dwarf temperatures above and below the CV period gap as a function of P_{orb} and the heating, and subsequent cooling in response, of a white dwarf to a dwarf nova accretion event. A simulation of the heating and cooling of the white dwarf in the eclipsing dwarf nova HT Cas is compared with observations of its observed response to an outburst accretion event.

1. Introduction

Hubble Space Telescope and FUSE far ultraviolet spectroscopy, along with X-ray and EUV spectroscopy using HUT, Orfeus, Chandra, XMM-Newton, EUVE, EXOSAT, ROSAT and ASCA have led to a windfall in our knowledge of the underlying white dwarfs in cataclysmic variables and how they are affected by the accretion process. These space observatories have made it possible to detect numerous white dwarf accretors, the boundary layer between the accretion disk and the WD surface, the accretion disk itself and wind outflow in the wavelength domains where they emit most of their energy (between ∼ 3 and 2000 Å). For the white dwarfs in CVs, space observations are obtained when the luminous accretion disks or bright accretion columns are absent during quiescence/low states of non-magnetic systems and low states of magnetic CVs. Thus, it has become possible to determine many poorly known basic physical properties of these systems both above and below the cataclysmic variable period gap, an orbital period range between two and three hours in which very few systems are found. Among the newly determined physical properties are surface temperatures T_{eff}, mass accretion rates, rotational velocities $V \sin i$, chemical abundances, the accretion energy budget and how accretion and thermonuclear runaways can drastically alter the structure, evolution and atmospheric chemistry of the accreting WD over time. In this paper, we focus on the surface temperatures of the white dwarfs in CVs, the heating and the subsequent observed cooling of white dwarfs in response to dwarf nova outbursts, the chemical abundances in their accreted atmosphere,

Send offprint requests to: E.M. Sion

their rotation velocities, and their distribution versus orbital period, P_{orb}, with implications for their long term evolution through comparison with evolutionary models.

2. Temperatures of CV white dwarfs

The photospheric temperatures of non-accreting white dwarfs in the field directly measure their cooling ages since their formation but for CV white dwarfs, their photospheric temperatures are relics of their history of long term average accretion and the effects of novae explosions. This makes their temperatures immensely important to understand their evolution. These temperatures have been derived from fitting their observed spectra during dwarf novae quiescence, nova-like low states and low states of Polars with white dwarf model atmospheres computed primarily with continually updated versions of the codes TLUSTY Hubeny (1988) and SYNSPEC Hubeny & Lanz (1995). In the simplest case of a dwarf nova below the period gap whose accretion rate during quiescence is extremely small and whose disk is in a cold state, single temperature white dwarf models have been successfully fit to the FUV and optical spectra (e.g. Slevinsky et al. 1999). The best fits are determined with standard χ^2 minimization techniques,and visual appearence of the fit to the continuum shape and profiles of absorption lines in the accreted atmosphere. In general, the best-fit is constrained by the minimum χ^2, the CV distance estimates, measurements or clues, physical plausibility, fitting-derived parameters and the constraint that the combined optical model flux of the WD + disk yields an optical magnitude no brighter that the observed V-magnitude of the CV, since the disk and other cooler emitting components contribute flux in the optical.

Unlike the temperature determinations for non-accreting single degenerates, which have typical precisions of ±100K or better, this precision cannot normally be achieved for CV WDs because of the typically poorly known white dwarf mass, and distance errors. These are the two largest, most important uncertainties. In FUV spectra of an exposed white dwarf in a CV, the derivation of the surface gravity is uncertain because Lyα with its ground state electron, is less sensitive to pressure broadening, hence gravity, than the Balmer lines, which are usually hidden due to disk/BL emission in the optical even during quiescence. There are also considerable uncertainties in the reddening, unidentified FUV flux contributors other than the WD, temporal changes due to time variable accretion heating and cooling, variations imposed by the aspect of orbital phase, intrinsic differences in the codes employed by workers in the field and even the specific ways in which different workers eliminate emission line regions and artifacts in the fitting. Added to these difficulties are missing atomic physics, for example, unknown oscillator strengths, unknown opacity sources and instrumental flux calibration problems. There is also the problem of consistency between temperatures derived from spectral fitting in different wavelength domains, both in the far UV down to the Lyman limit (FUSE, HUT) and the optical, and in the far UV (HST, IUE) and the optical. In some cases where quiescent dwarf nova spectra are obtained by two observatories, the flux levels in overlapping wavelength regions match and spectral fitting has been carried out for the combined spectra yielding a broader wavelength coverage. Experience has taught that temperature determinations of CV WDs approach, in successive approximations, an absolute value, but unlike the precision temperatures of single WDs, it is generally unrealistic to claim a unique value of surface temperature. Despite all of the above caveats, we analyze the best, most reliable temperatures, T_{eff} to date in Section 6 below, where we discuss the T_{eff} versus P_orb distribution. In Figs.1, 2, and 3, we display reasonable model atmosphere fits to the CV white dwarfs in the dwarf novae BZ UMa TU Men (Sion et al. 2008), and V442 Cen (Sion et al. 2008), respectively. BZ UMa exhibits the Nitrogen to Carbon abundance anomaly indicative of CNO-processing while TU Men is the only SU UMa-type dwarf nova above the lower boundary of the CV period gap and V442 Cen is a U Gem-type dwarf nova with a very hot white dwarf. As stated earlier, if quiescent/low state

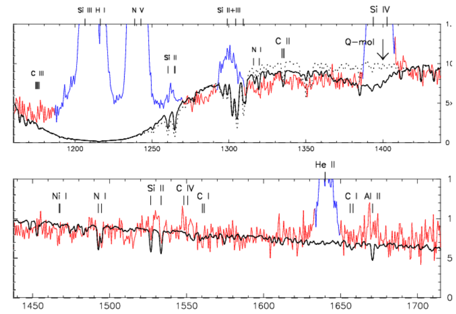

Fig. 1. The best-fitting single temperature WD fit to the *HST* STIS spectrum of the dwarf nova BZ UMa. The white dwarf model has temperature of 15,000K, log(g) = 7.5 for a distance of 156 pc. Note the extremely strong N v (1240) emission feature, the near absence of C IV (1550) and how the hydrogen quasi-molecular satellite lines opacity affects the spectrum around 1300-1400Å.

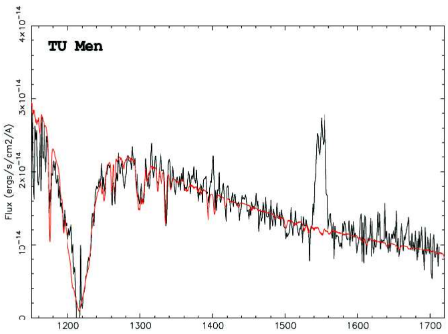

Fig. 2. The best-fitting single temperature WD fit to the *HST* STIS spectrum of TU Men, the longest period SU UMa-type dwarf nova. The white dwarf model has temperature of 28,000K for a distance of 288 pc. The model metal line profiles are a bit broader than the observed profiles implying $v_{rot} \sin i$ = 400km/s.

CV spectra are obtained by two different space observatories (e.g. FUSE and HST), and the flux levels in overlapping wavelength regions match, then spectral fitting can be carried out for the combined spectra yielding a broader wavelength coverage. An example of model fitting to merged FUSE and HST STIS spectra of the long period dwarf nova SS Aur during quiescence is displayed in Fig. 4. A single tem-

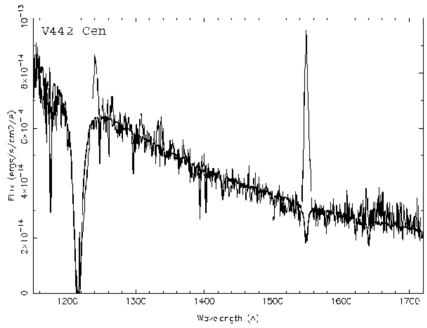

Fig. 3. The best-fitting single temperature WD fit to the *HST* STIS spectrum of V442 Cen, with E(B-V) = 0.10. This model is a 47,000K white dwarf with Log g= 8.3 with a distance of 328 pc.

perature white dwarf best fit cor responding to the parallax distance of 201 pc yields T_{eff} = 34,000K, log(g) = 9, $V_{\sin(i)}$ = 200km/s.

3. Chemical abundances of WDs in CVs

The chemical abundances of white dwarfs in cataclysmic variables have been derived largely from high quality HST and FUSE spectra. The observed metal lines are fitted with rotationally broadened theoretical line profiles. However, for the most part, the S/N is not high enough to determine reliable individual abundances. Moreover, the reliability of the chemical abundances could be compromised by underlying emission, an upper disk atmosphere (curtain), circumstellar absorption, interstellar absorption and variations of absorption features with orbital phase. In Table 3, we summarize the abundances determined to date for CV WDs to provide an overall picture of the abundance patterns characterizing the accreting WDs. However, as with the temperature data, the reader is cautioned to consult the individual references to get a sense of their individual reliability and a realistic assessment of their errors.

The most telling characteristic of the abundances in Table 3 is their sub-solar metallicity values. If the replacement time of the accreted atmosphere is shorter than the diffusion timescales of the accreted ions, then the surface abundances would tend to reflect the composition of the infalling matter from the donor star. There is no reason to expect the secondary mass donor stars to have sub-solar metallicity. Rather, one expects that effects of diffusion are responsible for these abundances. At temperatures below 20,000K, radiative forces levitation of the ions is unimportant. The problem is that in order for accretion-diffusion equilibrium to govern the surface abundances, the accretion rate must be low enough to permit accretion-diffusion equilibrium, otherwise, the accretion timescale is too short and the abundances tell us nothing about diffusion. The continually changing and unsettled atmosphere of a CV white dwarf where other forms of mixing and spreading of accreted matter are likely involved presents a challenging theoretical problem.

The two most reliable, straightforward cases are U Gem and VW Hyi where elevated N and depleted C are solidly established in their white dwarf atmospheres (Sion et al. 1998; Sion 1999; Long 1999). Large enhancements above solar of P, Al and Mn have been reported in VW Hyi (Sion et al. 1997; Sion et al. 2001). On the other hand, the photospheric origin of the metal lines in HST and FUSE spectra of the WD in WZ Sge are not as definitively established, especially the high ionization species whose formation requires a higher temperature than the photospheric temperature. Nevertheless, it has been sequence of HST STIS spectra over five HST orbits follow the orbital motion of the white dwarf and are gravitationally red-shifted.

It is interesting that P and Al abundances above solar have been reported (Szkody et al. 2002a) in three other systems shown in Table 3, BC UMa, BW Scl and SW UMa. Both of these odd-numbered elements can be enhanced via proton captures during CNO thermonuclear processing. The N abundance is elevated far above solar while the C abundance is depleted, also a result of CNO-processed gas in the white dwarf photosphere.

Large N/C ratios (discovered by their strong N V emission and weak or absent C IV emission) among 14 magnetic and non-magnetic systems have been reported (Gänsicke et al. 2003). The magnetic systems are AE Aqr, V1309 Orin, TX Col, MN Hay, and BY Cam while the non-magnetic CVs showing the N/C anomaly are BZ UMa EY Cyg, RX J2329, CE315, GP Com and CH UMa.

Since these N/C values were inferred from emission lines presumably forming in the disk or accretion column, they should originate in the secondary. Indeed, if CNO-processed material from the stripped-away core of the secondary flows through the accretion disk or column onto the WD, then the surface abundances of the WD should manifest the same N/C abundance which originated in the secondary core.

Two possibilities have emerged so far for the origin of this composition anomaly. First, the companion star may be contaminated by CNO-processed material from the nova shell ejected by the white dwarf during a classical nova explosion after repeated nova cycles over long timescales. During each nova explosion, there is a brief common envelope phase when the secondary is engulfed by the expanding WD surface layers. After many such nova episodes, it may be possible for the nova processing to have polluted the secondary's atmosphere. However, to date there has been no definitive theoretical calculations of the efficiency of the contamination process (?Sion et al. 1998). Hence, there have been no quantitative comparisons with the observations.

Second, Schenker et al. (2002) presented calculations suggesting that that the CV binary originally consisted of a mass donor more massive than the current white dwarf, resulting in a rapid phase of unstable thermal timescale mass transfer (TTSMT). Recent calculations by Schenker et al. (2002) show that systems with an initial donor mass of up to 2 $M_{\odot}$ may survive the TTSMT and subsequently evolve into a normal appearing CV. These objects would appear as the supersoft X-ray binaries which undergo steady nuclear burning and hence avoid classical nova explosions. Their descendants could thus be regarded as failed Type Ia supernovae. However, in this "normal" CV, the matter flowing over to the WD is CNO processed gas from the stripped core of

Table 1. Chemical Abundances of White Dwarfs in CVs

Object	Type	P_{orb}	Abundance	Ref
GW Lib	DN	76.8	Z ~0.1	Szkody et al. (2002a)
BW Scl	DN	78.2	Al 3.0±0.8, rest 0.5±0.2	Gänsicke et al. (2005)
LL And	DN	79.2	Z ≤~1	Howell et al. (2002)
WZ Sge	DN	81.6	C 0.5, Fe 0.1, S 0.1, Si 0.005	Sion et al. (1995a)
AL Com	DN	81.6	Z ~ 0.3	Szkody et al. (2003)
SW UMa	DN	81.8	Al 1.7±0.5, rest 0.2±0.1	Gänsicke et al. (2005)
HV Vir	DN	83.5	Z ~0.3	Szkody et al. (2002c)
WX Cet	DN	83.9	Z~0.1	Sion et al. (2003)
EG Cnc	DN	86.4	Z~0.3	Szkody et al. (2002c)
BC UMa	DN	90.2	Al 2.0±0.5, rest 0.3±0.1	Gänsicke et al. (2005)
VY Aqr	DN	90.8	Si 0.05, C 1.0	Sion et al. (2003)
EK Tra	DN	91.6	Z < 1	Gaänsicke (2001)
VW Hyi	DN	106.9	Si 0.3, C 0.3, N 3, O 3, Al 2, P 20, Mn 50	Sion et al. (1995b)
EF Peg	DN	123	Z 0.1 - 0.3	Howell et al. (2002)
MV Lyr	NL	191.0	C 0.5, N 0.5, Si 0.2	Hoard et al. (2004)
DW UMa	NL	198.0	Z ~0.47	Knigge et al. (2000)
WW Ceti	DN	253	C 0.1, N 2, Si 0.3	Godon et al. (2006b)
U Gem	DN	254.7	C 0.3-0.35, N 35 - 41, Si 1.4 - 4, 6.6 - 10	Long et al. (2006)
SS Aur	DN	263.2	C 0.1, Si 0.1, N 2.0	Sion et al. (2004)
RX And	DN	302.2	C 0.05, Si 0.1	Sion et al. (2001)
RU Peg	DN	539.4	C 0.1, Si 0.1, N < 8	Sion et al. (2004)

the previously more massive donor. Schenker et al. (2002) predict that the seondaries in such systems should be later than expected for their orbital periods. These TTSMT binaries should evolve into 10 to 30% of the present CVs. However, the absence of any known pre-cataclysmic, post-common enevelope binary containing a secondary displaying CNO processed abundances represents a major difficulty with the above scenario.

It remains unclear how systems containing white dwarfs with CNO-processed photospheric abundances (enhanced N and depleted C), as in VW Hyi, U Gem, and possibly others, fit into this picture. Do the CNO-processed surface abundances seen on the surfaces of the WDs in U Gem and VW Hyi arise from accreting disk gas rich in N and depleted in C or did the N/C surface abundance arise from processes intrinsic to the WD? Curiously, there is evidence that the secondary donor star in VW Hyi has normal C abundance while the secondary in U Gem has subsolar C (Hamilton et al. 2011). If the abundances in the accretion disk itself are solar, then the anomalous N/C abundance ratios observed in the WD's surface layers probably originated through CNO burning and dredgeup in the WD itself.

4. Rotation of WDs in CVs

On theoretical grounds, it was long suspected that white dwarfs in non-magnetic CVs should be rotating very rapidly and possibly near breakup due to the angular momentum transferred to the WD by disk accretion. In fact, rapid white dwarf rotation was considered a viable explanation for the weak boundary layer luminosities that were at odds with standard disk accretion theory. Surprisingly, the first rotation rates for white dwarfs in a non-magnetic CVs measured with HST GHRS data **?** were slow (<400 km/s). While this CV WD rotation is very rapid compared with the extremely slow rotation of single WDs (<40 km/s), it quickly became clear that rapid rotation of a CV WD could not account for the observed low boundary layer luminosities.

As the number of detected white dwarf accretors in CVs continued to grow, high quality HST and FUSE spectra of sufficient resolution enabled the measurement of over twenty WD rotational velocities, Vsini, or stringent upper limits on their rotation. These are listed in Table 4. The rotational velocities are derived from fitting the relatively sharp line profiles of ionized metals which form in the white dwarf photosphere. If the photospheric origin of the features is unmistakable, then the only difficulty arises when the rotation rate is rapid because then the chemical abundances of the ion species becomes intertwined with the rotation rate. Thus, different rotation rates will result for different metal abundance values. Moreover, interstellar and circumstellar absorption as well as underlying emission and absorbing curtains (in high inclination systems) may complicate the rotation determination. In view of these uncertainties, as with the temperature and abundance data, the reader is cautioned to consult the individual references for an assessment of their errors and to gain a sense of their individual reliability.

All of the velocities in Table 4 are well below 20% of the Keplerian velocity, far slower than predicted based upon the specific angular momentum transferred to the white dwarf during long term accretion. Livio & Pringle (1998) examined this question and proposed a model in which the accreted angular momentum is removed during nova outbursts. They showed that the most likely source of the needed torque is a shear-generated magnetic field during the envelope expansion of the nova. They found that the efficiency of transport of angular momentum between the white dwarf core and the extended nova envelope is rather low. Were this not the case, the rotation rates of CV white dwarfs would be even slower than what is observed. It is also clear that there is no apparent difference in rotation between CV WDs above and below gap which might be expected from differences in system age and hence differences in accretion history. Finally, since nova explosions appear to be the way to explain the slow rotation rates, then the fact that nearly all the white dwarfs in disk CVs for which we know the rotation are in dwarf novae supports the expectation that CVs cycle between dwarf nova states and classical nova systems (Gänsicke et al. 2005).

5. Compressional heating by a dwarf nova outburst

During a dwarf nova outburst, accretion onto the white dwarf occurs at a high rate as much of the disk mass falls inward. After heating by irradiation and compression, the WD cools. This cooling in response to the outburst was one of several possible explanations for the observed decline of UV flux observed with IUE during dwarf nova quiescence (Verbunt 1987). Indeed, these declines appeared to contradict the standard disk instability theory for the outbursts, which predicts an increasing far-UV flux during quiescence due to a gradual increase in the accretion rate. As more detections of the underlying WDs were made using the IUE and HST observations, (Sion 1991) showed that WDs in CVs were hotter than field WDs of comparable age, and showed that compressional heating by the accreted material was the source of the heating (Townsley & Bildsten (2003) derived a quantitative relationship between a key observable, the surface temperature, and the long term, time-averaged accretion rate.

There are a few systems which have some coverage at different times during quiescence. Thus, changes in their temperatures during quiescence as a function of time since the last outburst have been studied. One of the best cases is WZ Sge with the longest recurrence time and dense observational coverage of the flux decline for several years following the 1978 outburst by Slevinsky et al. (1999) and during and after the 10 years-early July 2004 outburst from space in ground-based. Since a precision parallax was known, intense HST STIS and FUSE coverage deepened our insights. The observed light curve and model atmosphere-derived temperature decline of the accretion-heated white dwarf were compared with the evolutionary simulations of (Godon et al. 2004, 2006b).

A recent eclipse mapping analysis of light curves of HT Cas by Baptista et al. (2012) revealed a very fast response of the underlying

Table 2. Rotational Velocities of White Dwarfs in CVs

Object	Type	P_{orb}	Vsini	Ref
GW Lib	DN	76.8	<300	Szkody et al. (2002a)
BW Scl	DN	78.2	<300	Gänsicke et al. (2005)
LL And	DN	79.2	< 500	Howell et al. (2002)
WZ Sge	DN	81.6	400/1200?	Sion et al. (1995a)
AL Com	DN	81.6	<800	Szkody et al. (2003)
SW UMa	DN	81.8	200	Gänsicke et al. (2005)
HV Vir	DN	83.5	400	Szkody et al. (2002c)
WX Cet	DN	83.9	400	Sion et al. (2003)
BC UMa	DN	90.2	300	Gänsicke et al. (2005)
VY Aqr	DN	90.8	400	Sion et al. (2003)
EK Tra	DN	91.6	200	Gaänsicke (2001)
VW Hyi	DN	106.9	400	Sion et al. (1995b)
EF Peg	DN	123	<300	Howell et al. (2002)
MV Lyr	NL	191.0	200	Hoard et al. (2004)
DW UMa	NL	198.0	370	Knigge et al. (2000)
WW Ceti	DN	253	600	Godon et al. (2006b)
U Gem	DN	254.7	150	Sion et al. (1998); Long (1999)
SS Aur	DN	263.2	400	Sion et al. (2004)
RX And	DN	302.2	500	Sion et al. (2001)
Z Cam	DN	417.4	330	Hartley et al. (2005)
RU Peg	DN	539.4	100	Sion et al. (2004)

white dwarf (which brightened by a factor of 2) to the increase in mass transfer rate, a simultaneous increase in the expansion rate of the accretion disk (which brightened by a factor of 3) and a relative amplitude of the high-frequency flickering which implies a high viscosity ($\alpha \sim 0.3 - 0.7$) for the quiescent disk and hence disagrees strongly with the key prediction of the disk instability model. This suggests that the outbursts of HT Cas may be due to bursts of enhanced mass transfer from the donor star. As a theoretical test of the observed fast response of the white dwarf in HT Cas, we carried out a simulation of the heating of the white dwarf by the dwarf nova outburst. For the basic parameters of the white dwarf in HT Cas, we took $M_{wd} = 0.61 M_\odot$ ($\log(R_{wd}) = 8.962$), $V_{sini} = 200$ km/s, $T_{eff} = 14,000$K (quiecsence), To simulate the heating from irradiation and compression, we took an accretion rate of $10^{-8} M_\odot$/yr switched on for 2 days, followed by cooling. In Fig.5, we have displayed the theoretical simulation. The white dwarf quickly reached a peak temperature of 18,600K in response to the outburst. After ~ 10 days the white dwarf cooled to its temperature in quiescence. This is in marked disagreement with the disc-instability model and implies that the outbursts of HT Cas are caused by bursts of enhanced mass-transfer rate from its donor star Baptista et al. (2012).

6. Surface temperature versus orbital period

In this section, we present a preliminary discussion of the distribution function of CV WD surface temperatures versus the orbital period, P_{orb}. In Fig.6, we display the distribution of CV white dwarf effective temperatures as a function of the orbital period. The references for the individual temperatures can be found in Sion et al. (2008); Townsley & Bildsten (2009); Araujo-Betancor et al. (2005) and references therein). We have also included temperatures determined from HST STIS spectra of CV white dwarf pulsators. The number of temperatures we have plotted, with separate symbols for each CV subclass, are 13 polars with known WD temperatures, 35 dwarf no-

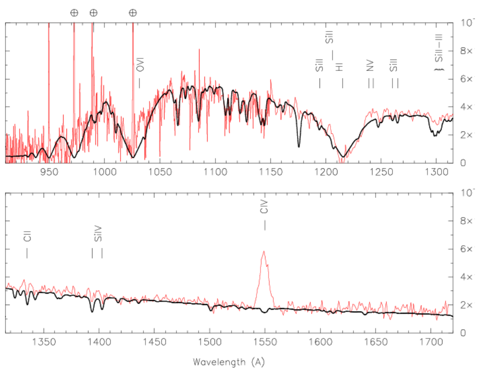

Fig. 4. Combined FUSE+STIS spectrum of SS Aur (light gray) together with the best-fit WD model (black). The regions that have been masked for the fitting are shown in dark gray. The synthetic stellar spectrum has a temperature of 34,000 K assuming $\log(g)$ = 8.93 and the parallax distance of 200 pc, a projected rotational velocity of 400 km s⁻1 and solar abundances. The spectrum has been dereddened assuming E(B-V) = 0.08.

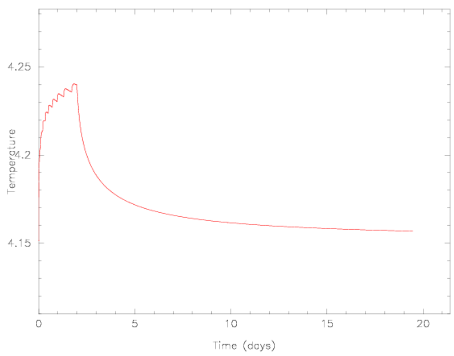

Fig. 5. Simulation of the heating and subsequent cooling of the white dwarf in the eclipsing dwarf nova HT Cas by a dwarf nova outburst. The surface temperature (Log scale) of the accreting white dwarf is displayed versus time (in days); see the text for details

vae below the period gap with known WD temperatures, 6 nova-like variables of the VY Scl subclass with known WD temperatures, 12 U Gem-Type dwarf novae above the period gap with known WD temperatures and 3 Z Cam-

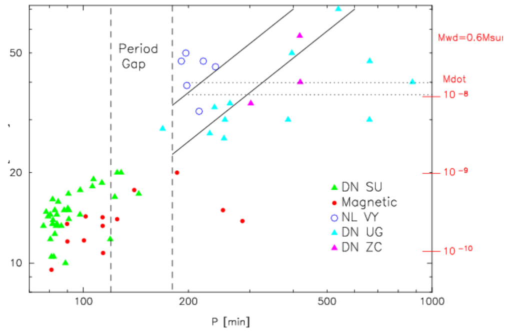

Fig. 6. Effective White Dwarf Temperature as a function of the orbital period. The references for the indivdual temperatures can be found in Sion et al. (2008); Townsley & Bildsten (2009); Araujo-Betancor et al. (2005) and references therein). The traditional magnetic braking above the period gap (Howell et al. 2001) is shown between the parallel diagonal solid lines. On the right hand side are the time-averaged accretion rates correpsonding to the temperature scale on the left hand side of the diagram based upon the $< T_{eff} >$ versus $< \dot{M} >$ relation of Townsley & Bildsten (2003) for a $0.6 M_\odot$ white dwarf. Shown for comparison between the dotted lines is the long term evolutionary path of a 0.8 solar mass white dwarf (with an initial core temperature of 30 million degrees K) which has undergone 1000 nova outburst cycles accreting at the long term rate of $10^{-8} M_\odot$/yr

Type dwarf novae with known WD temperatures.

In Fig.5, there is a well defined separation between Polars and DN below the gap, and apparently also above the gap. There remains a paucity of data points above the gap for Z Cam's, Polars and VY Scl's. There seems to be a separation in the $P_{orb} - T_{eff}$ parameter space between Polars, SU UMa's,U Gem's and possibly VY Scl's. The traditional magnetic braking above the period gap (Howell et al. 2001) is shown between the parallel diagonal solid lines. On the right hand side are the time-averaged accretion rates corresponding to the temperature scale on the left hand side of the diagram based upon the $< T_{eff} >$ versus $< \dot{M} >$ relation of Townsley & Bildsten (2003) for a $0.6 M_\odot$ white dwarf. Shown for comparison is the long term evolution (at a constant accretion rate) of a white dwarf which has undergone 1000 nova outburst cycles accreting at the long term rate of $10^{-8} M_{\odot}$/yr (Prialnik 2008).

The clustering of dwarf novae WDs around 15,000K was first evident from the results of the Medium HST program of Szkody et al. (2002b) ; see also Gänsicke et al. (2005); Townsley & Bildsten (2009). The temperatures of the WDs in the magnetic and non-magnetic systems below the period gap are roughly consistent with $< \dot{M} >$ values identifed with angular momentum loss due to gravitational radiation as the sole driver of mass transfer. For the WDs in CVs below the gap, hotter than 15,000K, up to ~20,000K, the implied $< \dot{M} >$ values are higher than that expected from gravitational wave emission alone. The WDs in magnetic CVs are cooler than the WDs in non-magnetic CVs at a given P_{orb}, a result first reported by Sion (1991) and later with a much larger number of magnetic WDs in CVs by Araujo-Betancor et al. (2005). Thus, their average $< \dot{M} >$ is lower than non-magnetic systems which may be related to a supression of magnetic wind outflow from the donor star. Above the period gap, the much greater dispersion of surface temperatures is clearly seen and speaks to a higher $< \dot{M} >$ than the characteristically lower $< \dot{M} >$ below the period gap. A more complete discussion of Fig.6 which includes more theoretical models will appear elsewhere (Sion et al. 2012, in preparation).

It is clear that large FUV surveys of CVs with IUE, HST, HUT and FUSE have yielded many insights into accreting WD properties, accretion physics and accreting WD evolution. At the same time the enlarged samples of magnetic and non-magnetic CV WDs have raised exciting questions and possibilities. Much of the progress to date has resulted from ground-based surveys like Hamburg-Schmidt, SPY and the Sloan Digital Sky Survey as well as space ultraviolet surveys of CVs carried out with HST and FUSE. These and other surveys have led to discoveries of new phenomena, enlargement of existing CV samples, and the existence of new types of CVs and pre-CVs. With the availability of having renewed FUV spectroscopy of CV WDs with HST COS as well as STIS, even greater progress and deeper insights into CV WDs and CV evolution should result. This will require the analysis of a much larger sample size, vitally important parallax data eventually from GAIA and greater light throughput to reach extremely faint objects, high resolution and broader UV wavelength coverage.

Acknowledgements. We are grateful to Dina Prialnik for providing us with evolutionary tracks of accreting white dwarfs with the inclusion of multiple nova explosion cycles. This work was supported by NSF grant AST0807892 to Villanova University. PG wishes to thank William Blair, for his kind hospitality at the Henry Augustus Rowland Department of Physics and Astronomy at the Johns Hopkins University, Baltimore, MD. PG was partly supported by the National Aeronautics and Space Administration (NASA) under grant number NNX08AJ39G issued through the Office of Astrophysics Data Analysis Program (ADP) to Villanova University.

References

Araujo-Betancor, S., et al. 2005, ApJ, 622, 589
Baptista, R., et al. 2012, To appear in the proceedings of "The Physics of Accreting Compact Binaries", Universal Academic Press Inc
Gänsicke et al. 2001, A&A, 374, 656
Gänsicke, B., et al. 2003, ApJ, 594, 443
Gänsicke, B., et al. 2005, ApJ, 629, 451
Godon, P., et al. 2006, ApJ, 612, 429
Godon et al. 2006b, AJ, 131, 2634
Hamilton, R.T., et al.2011, ApJ, 728, 16
Hartley, L., et al.2005, ApJ, 623, 425
Hoard et al. 2004, ApJ, 604, 346
Howell, S. et al. 2001, ApJ, 550, 897
Howell, S., Gänsicke, B. Szkody, P. 2002, ApJ, 575, 419
Hubeny, I. 1988, Comput. Phys. Comm., 52, 103
Hubeny, I., & Lanz, T. 1995, ApJ, 439, 875
Knigge, C. et al. 2000, ApJ, 539, L49
Livio, M.,& Pringle, J.1998, ApJ, 505, 339
Long, K.,& Gilliland, R. 1999, ApJ, 511, 916
Long, K., Brammer, G., Froning.C 2006, ApJ, 648, 541
Marks, P.B., Sarna,M.J., Prialnik, D. 1997, MNRAS, 290, 283

Marks, P.B., Sarna,M.J. 1998, MNRAS, 301, 691
Prialnik, D. 2008, private communication
K.Schenker et al.: MNRAS, 337, 1105
Sion et al. 1995a, ApJ, 439, 957
Sion et al. 1995b, ApJ, 444, 97
Sion et al. 2004, AJ, 128, 1834
Sion, E.M., et al. 2003, Ap.J. 583 907
Sion, E.M. 1991, AJ, 102, 295
Sion, E.M. 1995c, ApJ, 438, 876
Sion, E.M. 1999, PASP, 111, 532
Sion, E.M., Cheng, F., Szkody, P., Sparks, W.M., Gänsicke, B.T., Huang, M., & Mattei, J. 1998, ApJ, 496, 449
Sion, E.M., Cheng, F., Szkody, P., Sparks, W.M., Gänsicke, B.T., Huang, M., & Mattei, J. 1998, ApJ, 496, 449
Sion, E.M., Szkody, P., Gänsicke, B.T., Cheng, F., LaDous, Hassall, B. 2001, ApJ, 555, 834
Sion, E.M., et al. 2008, ApJ, 681, 543
Slevinsky R. et al. 1999, PASP, 111, 1292
Szkody, P. et al. 2002a, ASP Conf.Ser.261, 21
Szkody, P. et al. 2002b, ASP Conf.Ser.261, 21
Szkody et al. 2003, AJ, 126, 149
124
Szkody, P. et al. 2002c, ASP Conf.Ser.261, 21
Townsley, D.,& Bildsten, L. 2003, ApJ, 596, L227
Townsley, D., & Gaensicke, B. 2009, ApJ, 693, 1007
Verbunt, F. 1987, A&A, 71, 339