ANOMALOUS ULTRAVIOLET LINE FLUX RATIOS IN THE CATACLYSMIC VARIABLES 1RXS J232953.9+062814, CE315, BZ UMA AND EY CYG OBSERVED WITH HST/STIS

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ABSTRACT

Brief HST/STIS spectroscopic snapshot exposures of the cataclysmic variables 1RXS J232953.9+062814, CE315, BZ UMa and EY Cyg reveal very large N V/C IV line flux ratios, similar to those observed in AE Aqr. Such anomalous line flux ratios have so far been observed in 10 systems, and presumably reflect a different composition of the accreted material compared to the majority of cataclysmic variables. We discuss the properties of this small sample in the context of the recent proposal by Schenker et al. (2002) that a significant fraction of the present-day population of cataclysmic variables may have passed through a phase of thermal time-scale mass transfer.

1. INTRODUCTION

Spectroscopic studies of cataclysmic variables (CVs) are exceptionally rewarding in the far-ultraviolet (FUV), as this wavelength range contains transitions of diagnostically important metals (e.g. C, N, O, Si) in various ionization stages that are not accessible from the ground. Analyzing the observed ultraviolet lines provides information on both the ionizing spectrum emitted by the hot accretion region on/near the white dwarf, as well as on the abundances of the material in the accretion flow. Unfortunately, high-quality ultraviolet spectroscopy is rather difficult to obtain, and all large-scale statistical studies have so far been based on data obtained with IUE (e.g. Verbunt 1987; La Dous 1991; de Martino 1995; Mauche et al. 1997).

We have initiated a FUV spectroscopic survey of CVs using the Space Telescope Imaging Spectrograph (STIS) on-board the Hubble Space Telescope (HST). The observations are carried out as snapshots, gaps in the HST schedule that can not be filled with regular observations. This survey will eventually produce a homogenous database of modern high-quality ultraviolet spectra for a large number of CVs. Here we report the first results obtained from this program, namely the measurement of an extreme N V/C IV emission line flux ratio in 1RXS J232953.9+062814 (henceforth RX J2329), a recently discovered dwarf nova with an unusually short orbital period of 66 min (Thorstensen et al. 2002b), and in CE315, an AMCVn type CV (Ruiz
et al. 2001). In addition, we confirm the unusually large N\textsc{v}/C\textsc{iv} emission line flux ratios in the dwarf novae BZ UMa and EY Cyg, first detected in \textit{IUE} data by Winter & Sion (2001) and Sion (2002).

2. FUV SPECTROSCOPY

\textit{HST}/STIS FUV spectroscopy of RX J2329, CE315, BZ UMa and EY Cyg was obtained using the G140L grating and the 52′′ × 0.2′′ aperture (Table 1). This instrumental setup provides a spectral resolution of \( R \approx 1000 \). The data were processed with the latest release of CALSTIS (V2.13b), which takes into account the decaying sensitivity of the G140L grating. The STIS spectra of RX J2329, CE315, BZ UMa and EY Cyg are displayed in Fig. 1. An apparent similarity between all four systems is the unusually large strength of N\textsc{iv}, as well as the lack of noticeable C\textsc{iii} λ1176, C\textsc{ii} λ1335 or C\textsc{iv} λ1550 emission.

Despite the short exposure times, the quality of our STIS spectra exceeds that of the previous \textit{IUE} observations of BZ UMa and EY Cyg by large factors. The continuum FUV spectrum of BZ UMa is typical for a short-period dwarf nova, being most likely a mixture of emission from the accretion disc and the white dwarf. The fact that the broad Ly\textalpha absorption originating in the white dwarf photosphere is largely filled in with emission suggests that the disc contributes significantly in the FUV. In contrast to this, the FUV continuum of RX J2329 is extremely red, suggesting that the white dwarf in this system is very cold (reddening is negligible for the distance of \( \sim 200 \) pc determined by Thorstensen et al. 2002b). The continuum slope and Ly\textalpha absorption observed in EY Cyg is reminiscent of the photospheric emission of a white dwarf with \( T_\text{wd} \sim 25000 \) K. A detailed modelling of the continuum spectra of RX J2329, BZ UMa and EY Cyg, will be presented along with the data of additional objects from our snapshot survey in a separate paper.

The STIS spectrum of CE315 differs from that of the other three systems in that practically no continuum emission is detected. Furthermore, none of the usual emission lines of silicon are present in the spectrum. Most of the weak emission lines are likely due to N\textsc{i}. The identifications of emission features at \( \sim 1170\AA, \sim 1300\AA, \sim 1490\AA \) and \( \sim 1560\AA \) remain somewhat uncertain. With respect to the last line, we stress, however, that this feature is clearly not related to emission of C\textsc{iv}.

3. EMISSION LINE FLUX RATIOS

We have measured the emission line fluxes of N\textsc{v} λ1240, Si\textsc{iv} λλ1394,1403, C\textsc{iv} λ1550, and He\textsc{ii} λ1640 in RX J2329, CE315, BZ UMa and EY Cyg adopting the following two methods: (1) We fitted a small interval around the central wavelength with a linear function plus a Gaussian line (in the case of Si\textsc{iv} two Gaussians), and computed the line flux from the Gaussian fit parameters; (2) we used the \texttt{integrate/line} command in the ESO/MIDAS suite to interactively determine the continuum level and integrate the flux of the emission line(s) above this continuum. The results from these two methods were found to be in good agreement, and the average of the line fluxes from both measurements are reported in Table 2. Note that we did not detect C\textsc{iv} λ1550 at a statistically significant level in any of the four stars. In addition, Si\textsc{iv} λ1394,1403 were not detected in CE315. In order to constrain the C\textsc{iv} and Si\textsc{iv} line fluxes we have added to the STIS spectra Gaussian profiles of similar width as the observed lines and analysed the synthetic emission lines as described above. We repeated this process, decreasing the line fluxes of the added Gaussian lines, until reaching the detection threshold. The upper limits on the line fluxes derived in that way are given in Table 2.

For completeness, we compare the N\textsc{v} emission line fluxes obtained from our STIS spectra of BZ UMa and EY Cyg with the values derived from archival \textit{IUE} observations (the other lines are too weak in the \textit{IUE} spectra to permit any useful measurement). In the case of BZ UMa, two SWP spectra are available (32778, 32783), which contain N\textsc{v} at a similar flux level as our STIS spectrum \( \sim 0.5 \times 10^{-18} \) erg cm\(^{-2}\) s\(^{-1}\). In the case of EY Cyg, the two available SWP spectra that have a sufficient signal-to-noise ratio suggest that in this system the N\textsc{v} line may vary significantly \( (33428: 20 \pm 4 \times 10^{-14} \text{erg cm}^{-2}\text{s}^{-1}; 31034: 10 \pm 3 \times 10^{-14} \text{erg cm}^{-2}\text{s}^{-1}) \). Second-epoch STIS observations of EY Cyg would be desirable to confirm the variability.

4. DISCUSSION

To our knowledge, 10 CVs have so far been reported to display anomalously high N\textsc{v}/C\textsc{iv} emission line flux ratios: AE Aqr (Jameson et al. 1980), BY Cam (Bonnet-Bidaud & Mouchet 1987), TX Col (Mouchet et al. 1991), V1309 Ori (Szkody & Silber 1996), MN Hya (Schmidt & Stockman 2001), EY Cyg (Winter & Sion 2001; Sion 2002), BZ UMa (Winter & Sion 2001; Sion 2002), GP Com (Lambert & Slovak 1981; Marsh et al. 1995), RX J2329, and CE315. We show in Figure 2 the line flux ratios N\textsc{v}/C\textsc{iv} vs. Si\textsc{iv}/C\textsc{iv} and He\textsc{ii}/C\textsc{iv} vs. Si\textsc{iv}/C\textsc{iv} of these “anomalous” CVs, except for CE315 (in which neither C\textsc{iv} nor Si\textsc{iv} are detected, Fig. 1) and GP Com (in which Si\textsc{iv} is not detected, and He\textsc{ii} is not included in the wavelength range covered by the \textit{HST}/FOS observations). The line flux measurements are taken from the \textit{IUE} study of Mauche et al. (1997), except for V1309 Ori (Szkody & Silber 1996; Schmidt & Stockman 2001), MN Hya (Schmidt & Stockman 2001), TX Col (Mouchet et al. 1991), the line ratios were measured as described above from the \textit{IUE} spectra SWP00502L and SWP34129L, and RX J2329, BZ UMa, and EY Cyg (Table 2).

The largest N\textsc{v}/C\textsc{iv} (Fig. 2, Table 2) ratios are observed in AE Aqr during quiescence, RX J2329, CE315, BZ UMa and EY Cyg, followed by BY Cam, V1309 Ori, MN Hya and GP Com and finally by TX Col with a moderate enhancement of this line flux ratio with respect to “normal” CVs. Figure 3 shows the period distribution of the “anomalous” systems, and indicates whether the accreting white dwarf possesses a significant magnetic field or not. A number of possible explanations for the observed anomalous line ratios have been proposed. After the first \textit{IUE} detection of an inverse N\textsc{v}/C\textsc{iv} emission line flux ratio in BY Cam, Bonnet-Bidaud & Mouchet (1987) discussed peculiar ionization conditions of the emitting region, and the possibility of anomalous abundances in the accreting material, either as the consequence of a (moderately recent) nova outburst or related to the nuclear evolution of the donor star. Mauche et al. (1997) have cast
some doubt on the hypothesis of anomalous abundances, and suggested that confusion of N\textsc{v} λλ 1238.8,1242.8 doublet with Mg \textsc{ii} λλ 1239.9,1240.4, combined with a low ionization parameter could explain the observed line ratios. However, Mauche et al. (1997) also noted that none of their photoionization models was able to reproduce the strong correlation between the observed N\textsc{v}/C\textsc{iv} and Si\textsc{iv}/C\textsc{iv} line flux ratios.

The systems displaying the most “anomalous” line flux ratios span a very large range in orbital periods (Fig.3), corresponding to a large range in binary sizes and accretion rates. In addition, the white dwarfs contained in these systems cover a wide range in magnetic field strength. Considering this large range of variety, it appears rather coincidental that the ionization conditions in all those systems could be similar enough to favour the observed extreme line ratios. We note in passing that an extreme N/C abundance in the donor star in this system may have undergone significant nuclear evolution.

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Are the spectral types of the “anomalous line ratio” CVs “anomalous”? Schenker et al. (2002) predict that the donor stars in CVs which went through a phase of TTSMT should have spectral types too late for their orbital period. This is indeed the case for AE Aqr and V1309 Ori. The M5.5 \pm 0.5V and M3 – 4V donors in BZ UMa (Ringwald et al. 1994) and MN Hya (Ramsay & Wheatley 1998), respectively, are, however, rather “normal” for the orbital periods of the two systems. The donor in RX J2329 is much too early for the 64 min period (Thorstensen et al. 2002b) – but it has the excuse that the concept of “normal” spectral type does not apply to this period range. Tovmassian et al. (2002) recently determined the spectral type of the donor in EY Cyg to be K0, but with a radius 1.6 times larger than a main sequence star. Interestingly, Tovmassian et al. (2002) suspected that EY Cyg has recently gone through a classical nova explosion, however, their Hα images of the system do not unambiguously reveal signs of a nova shell. The spectral type of the donor star in TX Col is only poorly constrained, and nothing is known about the donor in BY Cam.

How many CVs display a N/C enhancement? Schenker et al. (2002) suggest that a large fraction, up to one third, of the CV population might be descended from supersoft X-ray binaries. The sample of CVs analyzed by Mauche et al. (1997) contained data for 20 systems, of which two (BY Cam and AE Aqr) display unusually large N\textsc{v}/C\textsc{iv} line ratios. At the time of writing, we have obtained HST/STIS snapshot spectra of 31 CVs with strong emission lines, and found four systems with extremely enhanced N\textsc{v}/C\textsc{iv} ratios. While the presently available sample is still too small for any definite conclusion, it suggests that the fraction of CVs that have gone through a phase of thermal time-scale mass transfer and that display large abundance anomalies could well be of the order of 10 – 15%.

While Fig. 3 may suggest that the occurrence of “anoma-

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2 Thorstensen et al. (2002a) have recently identified a second short-period dwarf nova, QZ Ser, which contains a secondary with a spectral type too early for its orbital period. The authors detected enhanced sodium absorption in the optical spectrum of QZ Ser and argue that the donor star in this system may have undergone significant nuclear evolution.
lous” CVs is higher among magnetic systems, we stress that such a conclusion has to be treated with great care because of the involved selection effects. The study of Mauche et al. (1997) contains 7 magnetic CVs in a total sample of 20 systems, which suggests that the fraction of magnetic CVs with sufficiently good IUE observations is larger than that of non-magnetic CVs. Our STIS sample contains 5 magnetic CVs out of 31 emission-line systems, and all systems displaying large \( N^V/C^IV \) line flux ratios within this sample are non-magnetic.

As a final note, we recall that evidence for carbon-depletion and nitrogen-enhancement has also been found in FUV observations of the accreting white dwarfs in several dwarf novae (e.g. U Gem: Sion et al. 1998; Long & Gilliland 1999 and VWHyi: Sion et al. 2001), and have so far been discussed primarily in the context of the aftermath of a (recent) nova explosion.

5. SUMMARY

Our HST/STIS snapshot spectra of RX J2329, CE315, BZ UMa, and EY Cyg reveal extremely large \( N^V/C^IV \) and \( Si^IV/C^IV \) line flux ratios, similar to those observed in AE Aqr. Such anomalous line flux ratios are expected in CVs that went through a phase of thermal timescale mass transfer and now accrete CNO processed material from a companion stripped of its external layers. A full understanding of the possible links between the observed anomalous line ratios and the evolution of CVs requires a significantly larger sample of systems for which high-quality ultraviolet spectroscopy is available. Our Cycle 11 snapshot program and its approved continuation in Cycle 12 will eventually provide such a data base.

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Table 1

**Log of the HST Observations**

| Object  | UT          | Dataset | Exp. time |
|---------|-------------|---------|-----------|
| RX J2329 | 2002-11-28 17:20:11 | o6li06010 | 730s      |
| BZ UMa  | 2002-10-25 04:37:52 | o6li24010 | 700s      |
| EY Cyg | 2003-02-10 09:06:48 | o6li0v010 | 700s      |
| CE315   | 2003-04-10 19:14:41 | o6li05010 | 900s      |

Table 2

**Emission Line Fluxes**

| Line       | RX J2329 | CE315 | BZ UMa | EY Cyg |
|------------|----------|-------|--------|--------|
| $\text{N v} \lambda 1240$ | $45 \pm 5$ | $58 \pm 4$ | $63 \pm 3$ | $57 \pm 5$ |
| $\text{Si iv} \lambda 1400$ | $35 \pm 5$ | $< 3$ | $25 \pm 3$ | $21 \pm 2$ |
| $\text{C iv} \lambda 1550$ | $< 5$ | $< 4$ | $< 4$ | $< 4$ |
| $\text{He ii} \lambda 1640$ | $17 \pm 6$ | $20 \pm 3$ | $11 \pm 4$ | $10 \pm 3$ |

Fig. 1.— *HST/STIS* G140L snapshot spectra of RX J2329, CE315, BZ UMa, and EY Cyg.
Fig. 2.— Far ultraviolet line flux ratios in CVs. Most “normal” CVs, in which the white dwarf presumably accretes from a donor star with (nearly) solar-abundances, fall within a limited parameter space (roughly indicated by the dotted ellipses). The “anomalous” line flux ratios observed in BZ UMa, EY Cyg, RX J2329, AE Aqr, BY Cam, V1309 Ori, MN Hya, and TX Col suggest that the white dwarfs in these systems accrete material with an enhanced N/C abundance ratio. The line flux ratios of RX J2329, BZ UMa and EY Cyg have been measured from our HST/STIS snapshot spectra. The line flux ratios of V1309 Ori and MN Hya are taken from Szkody & Silber (1996) and Schmidt & Stockman (2001), that of TX Col was obtained from archival IUE data. All other line ratio data are based on IUE observations and were kindly supplied by C. Mauche, see Fig. 8 in Mauche et al. (1997).

Fig. 3.— Properties of the seven CVs known to display significantly enhanced N V/C IV line flux ratios.