Unveiling optical signatures of outflows in accreting white dwarfs

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ABSTRACT

Accreting white dwarfs are known to show signatures of wind-type outflows in the ultraviolet. However, at optical wavelengths, wind detections have only been reported for a few sources. We present GTC-10.4 m optical spectroscopy of four accreting white dwarfs (BZ Cam, V751 Cyg, MV Lyr, and V425 Cas) observed during luminous epochs, when their optical emission is expected to be dominated by the accretion disc. Our analysis focuses on four emission lines: H\textsc{\alpha} and He\textsc{i} 5876, 6678, and 7065. Line profiles are complex and variable on short (minutes) and long (days to weeks) timescales, with transient absorption and emission components. Among them, we detect strong blueshifted absorptions at $\gtrsim 1000$ km s\textsuperscript{-1}. These high-velocity components, present only in the blue wing of the emission lines, are observed in all four sources and could be associated with accretion disc winds. For MV Lyr and V425 Cas, these would represent the first detection of optical outflows in these objects, while in the cases of BZ Cam and V751 Cyg, the presence of outflows has been previously reported. This study suggests that, in addition to ultraviolet winds, optical outflows might also be common in accreting white dwarfs. We discuss the observational properties of these winds and their possible similarity to those detected in accreting black holes and neutrons stars.

Key words. novae, cataclysmic variables – accretion, accretion disks – stars: winds, outflows – stars: individual: V751 Cyg – stars: individual: MV Lyr – stars: individual: V425 Cas

1. Introduction

Accreting white dwarfs (AWDs; also known as cataclysmic variables) are binary systems typically composed of a non-degenerated companion star that is filling its Roche lobe and transferring matter onto a white dwarf through the inner Lagrangian point. In non-magnetic systems, the transferred material forms an accretion disc around the white dwarf, the relatively low magnetic field of which is not strong enough to disrupt it. Among the population of AWDs, nova-like systems are quasi-persistently accreting at high rates ($M \sim 10^{-8} M_\odot$ yr\textsuperscript{-1}) and have bright accretion discs. Nova-like AWDs can also show long-term variations in their optical light curves and exhibit sporadic low-activity periods characterised by drops of $\gtrsim 1$ mag (King & Cannizzo 1998).

Wind-type outflow features have been observed in AWDs. These are generally detected in ultraviolet resonant lines, such as C\textsc{iv} $\lambda\lambda$1548–1552, Si\textsc{iv} $\lambda\lambda$1393–1402, and N\textsc{iv} $\lambda\lambda$1238–1242 (e.g. Drew 1997; Prinja et al. 2000). The strong ultraviolet emission produced by AWDs is generally believed to power these winds via the line-driven mechanism (e.g. Froning et al. 2005). However, this is still a matter of debate (see Drew & Proga 2000, and references therein). These outflows have shown velocities of up to $\sim 5000$ km s\textsuperscript{-1}. Given that they have only been observed in non-eclipsing systems – that is, AWDs seen at low orbital inclinations ($\lesssim 60^\circ$) –, a bipolar wind geometry is generally favoured (e.g. Honeycutt et al. 1986; Drew 1987).

A handful of the AWDs with strong ultraviolet winds have also shown optical wind features, such as P Cygni profiles (a blueshifted absorption component superimposed on a broad emission feature; Castor & Lamers 1979) and broad emission line wings, both overlapping the emission lines formed in the accretion disc. These usually include the Balmer lines and He\textsc{i} triplet transitions (e.g. He\textsc{i} 5876), but not the less intense He\textsc{i} singlet transitions (such as He\textsc{i} 6678; e.g. Ringwald & Naylor 1998; Patterson et al. 2001; Kafka & Honeycutt 2004; Honeycutt et al. 2013). The presence of optical winds has also been suggested based on the detection of more indirect signatures. For example, Murray & Chiang (1996) showed that single-peaked emission lines might result from an accelerating accretion disc wind in high-luminosity AWDs. Likewise, Knigge et al. (1998) proposed that the Balmer jump in emission detected in the system UX UMa is evidence of the presence of an outflow.

Furthermore, it has been proposed that the visibility of wind features in AWDs has an orbital dependence (see Prinja et al. 2004 for an example of ultraviolet winds, and Kafka et al. 2009 for optical winds). It is worth noting that qualitatively similar optical wind features have been found in accreting black holes (e.g. Muñoz-Darias et al. 2016, 2019; Cúneo et al. 2020) and neutron stars (e.g. Muñoz-Darias et al. 2020) using high-signal-to-noise-ratio (S/N) spectroscopy. These are detected in several transitions (including the Balmer series and He\textsc{i} triplet transitions, but also the He\textsc{i} singlet transitions) and point towards wind velocities of up to a few thousand km s\textsuperscript{-1}, comparable to those measured in AWDs.

Optical spectroscopic studies of samples of nova-like AWDs are relatively limited and generally taken with low-to-moderate
Table 1. General properties of the AWDs sample.

<table>
<thead>
<tr>
<th>Source</th>
<th>Orbital period (h)</th>
<th>Inclination (°)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>BZ Cam</td>
<td>3.685 ± 0.001</td>
<td>12–40</td>
<td>1, 2</td>
</tr>
<tr>
<td>V751 Cyg</td>
<td>3.46714 ± 0.00002</td>
<td>&lt;50</td>
<td>3, 4</td>
</tr>
<tr>
<td>MV Lyr</td>
<td>3.19 ± 0.01</td>
<td>10–13; 7 ± 1</td>
<td>5, 6</td>
</tr>
<tr>
<td>V425 Cas</td>
<td>3.59 ± 0.01</td>
<td>25 ± 9</td>
<td>7, 8</td>
</tr>
</tbody>
</table>

References. (1) Ringwald & Naylor (1998); (2) Honeycutt et al. (2013); (3) Greiner et al. (1999); (4) Patterson et al. (2001); (5) Skillman et al. (1995); (6) Linnell et al. (2005); (7) Shafter & Ulrich (1982); (8) Ritter & Kolb (2003).

spectral resolution and S/N (e.g. Kafka & Honeycutt 2004; Aungwerojwit et al. 2005; Rodriguez-Gil et al. 2007a). In order to systematically search for optical outflows in AWDs, we started a multi-epoch observational campaign using the 10.4 m Gran Telescopio Canarias (GTC). In this paper, we present the first results obtained for four well-known systems that show complex and variable absorption components: BZ Cam, V751 Cyg, MV Lyr, and V425 Cas.

2. The sources

Table 1 contains the main properties of the sample relevant for our study. Figure 1 shows the light curves from American Association of Variable Star Observers (AAVSO) data in the V and Clear V bands, where we mark our observing epochs (see also Table 2). A description of the four systems of our sample is provided in the following paragraphs.

**BZ Cam** is one of the most studied AWDs. The system is surrounded by an optically resolved bow-shock nebula, photo-ionised by the AWD (e.g. Greiner et al. 2001). The V-band brightness of the system usually varies between 13.5 mag and 11.4 mag (see Fig. 1). BZ Cam is known to have strong and variable outflows (evident through P-Cygni profiles), which were first detected in ultraviolet low-resolution spectra provided by the International Ultraviolet Explorer (IUE; Woods et al. 1990; Griffith et al. 1995). Prinja et al. (2000) studied the outflow’s properties using *Hubble* Space Telescope (HST) high-resolution spectra and measured the blue edges of the blueshifted absorption features in the P-Cygni profiles – which is usually taken as a good proxy for the terminal velocity of the wind – of C, Si, and N lines. This resulted in wind velocities of up to ~5000 km s⁻¹. Furthermore, BZ Cam is one of the few AWDs with outflows detected at optical wavelengths (Patterson et al. 1996; Ringwald & Naylor 1998; Honeycutt et al. 2013). These optical outflows, revealed by strong P Cygni profiles in H and He emission lines, reach velocities of up to ~3000 km s⁻¹. In addition to the P Cygni profiles, both Patterson et al. (1996) and Ringwald & Naylor (1998) observed broad red emission wings in Hα up to 2400 km s⁻¹, features typically interpreted as evidence of outflows. Ringwald & Naylor (1998) estimated an orbital inclination of between 12° and 40°, which is consistent with the lack of eclipses.

**V751 Cyg** has a typical brightness of ~14–15 mag in the V band (see Fig. 1) but has been reported to show lower luminosity states down to V ~ 17.8 mag (see e.g. Greiner & di Stefano 1999). A shallow P Cygni profile (CIV λ1550) is the only reported detection of ultraviolet outflows (Zellem et al. 2009). Additionally, Patterson et al. (2001) detected transient P Cygni profiles in the Balmer and HeI λ5876 emission lines with terminal velocities of up to 2500 km s⁻¹. Based on the equivalent width (EW) of several ultraviolet spectral lines, Greiner et al. (1999) estimated an orbital inclination of <50°.

**MV Lyr** spends most of the time in a bright state, at V ~ 12.5 mag (see Fig. 1), but it also shows sporadic low states, when its brightness can drop down to ~19 mag. Although compelling outflow signatures have not yet been detected in the optical, Skillman et al. (1995) observed a red tail in the emission profile of Hα, with velocities of up to 1300 km s⁻¹. Likewise, Linnell et al. (2005) proposed the presence of a low-velocity (~165 km s⁻¹) ultraviolet wind through the detection of blueshifted (C, Si and He) absorption lines in HST spectra. Skillman et al. (1995) estimated a very low orbital inclination in the range of 10°–13°, while Linnell et al. (2005) proposed 7 ± 1°.

**V425 Cas** has been recurrently observed at V ~ 14.5 (Fig. 1), although it has been seen to drop down to V ~ 18 during low states (Wenzel 1987). To date, no wind-related features have been published at either optical or ultraviolet wavelengths (e.g. Szkody 1985; Mizusawa et al. 2010). An orbital inclination of 25 ± 9° was reported by Ritter & Kolb (2003, with reference to Shafter 1983).
We observed the sources during 2019 and 2020 using the Optical System for Imaging and low-Intermediate-Resolution Integrated Spectroscopy (OSIRIS; Cepa et al. 2000), which is attached to GTC at the Observatorio del Roque de los Muchachos in La Palma, Spain. We observed each source on three or four different nights over a timespan of 4 to 57 days, depending on the target. For each epoch, we obtained at least four spectra with a cadence of ~2–4 min. The observing log is detailed in Table 2. The exposure times ranged between 50 and 200 s. We used the R2500R (5575–7685 Å) grism and a slit-width of 1.2 arcsec. This configuration resulted in slit-limited velocity resolutions of 200–240 km s$^{-1}$, as derived from the full width at half-maximum (FWHM) of the O I λ6300 emission sky-line. The reduction, extraction, and wavelength calibration of the spectra were carried out with IRAF. We achieved S/N values ranging from 100 to 350.

We derived optical magnitudes from the acquisition images of each observing run. Flux calibration was performed against field stars catalogued in PanSTARRS (Magnier et al. 2020) and using routines based on ASTROPY-PHOTUTILS (Bradley et al. 2019). We report an averaged magnitude for each night in Table 2 (for epoch #3 of BZ Cam we report one average magnitude per observing run). The uncertainties were two percent or better.

### 4. Analysis and results

We analysed the optical spectra using MOLLY and custom software under PYTHON 3.7. Hα and the main He I transitions are present in emission in all four sources, as expected for systems with bright accretion discs. We focused our analysis on transitions that are notorious wind tracers: Hα and the triplets He I λ5876 and λ7065, but also on the singlet transition He I λ6678. We carefully normalised each line by fitting the adjacent continuum with a first-order polynomial. Both Hα and He I lines exhibit significant variability across the observing campaign. Their evolution can be seen in Figs. 2–5.

#### 4.1. Evolution of the main emission lines

Optical, double-peaked emission lines are commonly found in compact binaries and interpreted as arising in the accretion disc (Smak 1969). These can also be seen as single-peaked emission components in systems with low orbital inclination (as is presumably the case for the four sources studied here).

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1 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. under contract to the National Science Foundation.
Fig. 2. Evolution of the Hα, He I λ5876, λ6678, and λ7065 emission line profiles for BZ Cam along three different observing epochs (from top to bottom, respectively). All spectra are normalised to their continuum level and separated by an offset of 0.1 in the vertical axis for clarity. The time since our first observation, \( T \), is given in hours. The grey-shaded band indicates contamination by interstellar features.

the other hand, (intrinsic) single-peaked emission lines are also often detected during (presumably) disc-dominated phases (see e.g. Matthews et al. 2015, and references therein). However, as shown in Figs. 2–5, the optical lines of AWDs can be significantly more complex than single- or double-peaked emission components. In addition to the possible presence of wind-related features (e.g. P Cygni profiles), absorptions that shift in velocity throughout the orbit – producing variable components at both the red and blue side of the emission peak – are sometimes observed in AWDs (e.g. Casares et al. 1996; Hoard et al. 2000; Kára et al. 2023). Our study lacks the orbital coverage to properly single out these components. However, hints indicating the possible presence of underlying absorption features in the range of \(-1000\) to \(1000\) km s\(^{-1}\) can be seen in some of the sources, particularly in the He I transitions. Figure 6 (see also Sect. 4.3) shows an overlap of the Hα and He I λ5876 emission lines for the four sources in our sample. As an example of the multiple components that we detect, the He I λ5876 transition in epoch #3c of V751 Cyg (top right panel) presents a main emission component that seems to be embedded in a broad absorption, which is observed as both redshifted and blueshifted absorption features that reach velocities below \(1000\) km s\(^{-1}\). An additional blueshifted absorption component – that overlaps its analogue in Hα – reaches velocities higher than \(1000\) km s\(^{-1}\). Hereafter, we refer to the absorption features in the range of \(-1000\) to \(1000\) km s\(^{-1}\) as low-velocity absorptions, and those with velocities \(\geq1000\) km s\(^{-1}\) as high-velocity absorptions. The same phenomenology is observed in other epochs and sources (e.g. epochs #3a of MV Lyr and V425 Cas). Likewise, steady, broad absorption features overlapping the main emission profiles have also been observed in the Balmer transitions during active states of accreting black holes and neutron stars (i.e. X-ray binaries (XRBs); e.g. Casares et al. 1995; Callanan et al. 1995; Soria et al. 2000; Jiménez-Ibarra et al. 2019). For all these
Fig. 3. Evolution of the Hα, He i λ5876, λ6678, and λ7065 emission line profiles for V751 Cyg along four different observing epochs (from top to bottom, respectively). All spectra are normalised to their continuum level and separated by an offset of 0.1 in the vertical axis for clarity. The time since our first observation, T, is given in hours. The grey-shaded band indicates contamination by interstellar features. reasons, any absorption feature found in the data should be interpreted with caution.

**BZ Cam.** The spectral evolution of BZ Cam is depicted in Fig. 2. The profile of all the lines is single-peaked. We noticed that the core of Hα is saturated in epoch #1; however, this is not a major issue given that we focus our analysis on the wings of the line. Strong high-velocity blueshifted absorptions overlapping the central emission feature are evident in our spectra (more conspicuous in epoch #2) in all the transitions analysed. A variable low-velocity broad absorption component overlapping both the central emission and the blueshifted high-velocity absorption component is often also seen in the spectra (e.g. He i λ5876 in epoch #3). In addition to the absorption features, both the blue and red wings of the emission lines (e.g. Hα in epochs #1 and #3) show clear asymmetries.

**V751 Cyg.** We display the Hα and He i emission lines of V751 Cyg in Fig. 3. All the emission features have a single-peaked profile. The line profiles – in particular Hα and He i λ5876 – exhibit an overlap between the main emission core and several absorption components. In some cases, the presence of a variable low-velocity broad absorption component (producing red and blue absorptions) and a high-velocity blueshifted component can be resolved (e.g. He i λ5876 in most epochs; see also Fig. 6). The red wing of Hα shows additional asymmetries, particularly in epochs #3 and #4.

**MV Lyr.** This source also shows single-peaked line profiles (Fig. 4), with the main emission component blended with several absorption components. Low-velocity variable absorption features are observed in all the lines. An additional high-velocity blueshifted absorption component is particularly conspicuous in epoch #3 (Hα and He i λ5876; see also Fig. 6). Additional asymmetries are evident in the red wing of Hα, particularly in epochs #2 and #4.

**V425 Cas.** Figure 5 shows the evolution of the Hα and He i emission lines for V425 Cas. Most of the lines exhibit a single-peak profile. However, a double peak can be noticed in He i λ6678 in epoch #2d. The different absorption components detected for the previous sources are also visible in the spectra.
Fig. 4. Evolution of the Hα, He i λ5876, λ6678 and λ7065 emission line profiles for MV Lyr along four different observing epochs (from top to bottom, respectively). All spectra are normalised to their continuum level and separated by an offset of 0.1 in the vertical axis for clarity. The time since our first observation, $T$, is given in hours. The grey shaded band indicates contamination by interstellar features.

4.2. Hα excesses diagnostic diagram

In order to further investigate the origin of the complex emission line profiles described above, we computed the excesses diagnostic diagram (see Mata Sánchez et al. 2018; Muñoz-Darias et al. 2019; Panizo-Espinar et al. 2021 for details). Although the origin of the low-velocity absorption component in AWDs is unclear, the high-velocity blueshifted component is evident in Hα and He i λ5876 in epoch #3 (see also Fig. 6).

of V425 Cas. While the low-velocity absorption component is observed in the three He i lines, the high-velocity blueshifted component is evident in Hα and He i λ5876 in epoch #3 (see also Fig. 6).
EW of the residuals using the velocity masks that better account for the higher velocity features in the four sources: ±1000–2500 km s\(^{-1}\). This approach is conservative, and is designed to limit the impact of the aforementioned broad absorption features, either static (i.e. affecting both the blue and red wings of the profile) or dynamic (e.g. shifting in velocity, from blue to red and vice versa, following the orbit of the binary). The diagrams in Fig. 7 show that significant, high-velocity features are mostly located in the top- and bottom-right quadrants, including several >5\(\sigma\) significant residuals. The only exception might be V425 Cas, for which – using this approach – only two observations are consistent with the presence of winds. However, two clearly distinct blueshifted absorption features are also evident in this system (see bottom right panel of Fig. 6), although at lower velocities. We note that if we use a lower velocity mask for this source (±400–1500 km s\(^{-1}\)), we obtain similar results to those obtained for the other targets (Fig. A.1). This suggests that V425 Cas shows the same phenomenology, but at lower velocities.

Overall, the systematic presence of excesses in the right quadrants and not in the left ones (i.e. no redshifted absorptions as compared with a large number of blueshifted residuals) is consistent with the idea that at least the high-velocity features (≥1000 km s\(^{-1}\)) reflect the presence of outflows in these systems. We note that the limited coverage of our data prevents us from further testing the origin of these components, including their possible dependence on orbital phase.

### 4.3. Disc-wind signatures

As described above, the high-velocity (≥1000 km s\(^{-1}\)) blueshifted absorption components can be tentatively associated with signatures of wind-type outflows. In these cases, we fitted a Gaussian profile to the absorption feature and estimated...
the wind velocity as $3\sigma$ from the centre of the fitted Gaussian (i.e. where the blue edge meets the continuum). Hereafter, we quote this value as the wind velocity. In addition, the H$\alpha$ excesses diagnostic diagram reveals significant broad emission line wings, which are also a typical feature of outflowing objects. Taking all of the above into consideration, spectral features consistent with wind-type outflows are found in the four sources:

**BZ Cam.** The excesses diagnostic diagram in the top-left panel of Fig. 7 is consistent with the presence of wind in all epochs. In particular, epoch #2 shows massive P-Cygni-like absorption features (see also Fig. 2) reaching velocities of $\sim$2400 km s$^{-1}$ (epoch #2a). These absorption components are present even in He I $\lambda$6678, a transition in which wind-type features have not previously been observed for this object (e.g. Kafka & Honeycutt 2004; Honeycutt et al. 2013). In the top-left panel of Fig. 6, we show, as an example, the superposition of H$\alpha$ and He I $\lambda$5876 for epochs #2d and #3c. We observe how the high-velocity blueshifted absorption features of both lines are fully consistent for each epoch.

**V751 Cyg.** The excesses diagnostic diagram shown in the top-right panel of Fig. 7 suggests the presence of wind in all epochs but epoch #1. A particularly high-velocity blueshifted absorption feature in epoch #3 (see Fig. 4) implies a wind velocity of $\sim$2200 km s$^{-1}$ (epoch #3a). In the bottom-left panel of Fig. 6, we plot H$\alpha$ and He I $\lambda$5876 for epochs #2b and #3a, evidencing the match between the absorption components.

**MV Lyr.** The excesses diagnostic diagram in the bottom-left panel of Fig. 7 indicates significant wind-type features in all epochs but epoch #1. A particularly high-velocity blueshifted absorption feature in epoch #3 (see Fig. 4) implies a wind velocity of $\sim$1900 km s$^{-1}$ (epoch #3a). In the bottom-right panel of Fig. 6, we show an example of both the low- and high-velocity blueshifted absorption components of V425 Cas, visible in He I $\lambda$5876.

**V425 Cas.** P Cygni-like features evident in Figs. 5 and 7 (bottom-right panel) suggest the detection of a wind in epoch #3 ($\sim$1400 km s$^{-1}$ in epoch #3a). In the bottom-right panel of Fig. 6, we show an example of both the low- and high-velocity blueshifted absorption components of V425 Cas, visible in He I $\lambda$5876.

### 5. Discussion

We analysed optical spectra of four AWDs, namely BZ Cam, V751 Cyg, MV Lyr, and V425 Cas, taken over three to four different observing epochs (see Table 2). All the observations were obtained during bright states, when the optical emission is expected to be dominated by the accretion flow (see Fig. 1). We focused our analysis on the evolution of four relatively strong emission lines: H$\alpha$, He I $\lambda$5876, $\lambda$6678, and $\lambda$7065. These transitions are known to be sensitive to the presence of wind-type outflows in different classes of stellar objects (e.g. Prinja & Fullerton 1994; Kafka & Honeycutt 2004; Muñoz-Darias et al. 2019). In all four cases, the profiles of the emission lines are complex and variable over short (i.e. same time).
These components can be detected on both wings of the emission lines (Figs. 2–5) and although they are difficult to isolate from the aforementioned blueshifted absorption features that we associate with winds (and vice versa), there are clear cases where both absorption features are easily discriminated (e.g. see the He\textsc{i}\,$\lambda$5876 line in epoch #3c of the upper-right panel of Fig. 6). It is worth noting that several AWDs with orbital periods of 3–4 h have been classified as SW Sex stars (e.g. Rodriguez-Gil et al. 2007b; Dhillon et al. 2013). Among other properties, this class is characterised by spectra with complex and variable line profiles, including absorption features that are believed to have an orbital dependence, swinging between positive and negative velocities (e.g. Casares et al. 1996). These features, the origin of which is unknown, might be associated with the low-velocity absorption components that we see in our spectra. On the other hand, the high-velocity absorption components are only found in the blue wings, often accompanied by a red component in emission (see Fig. 7), as one would expect if they were associated with wind-type outflows.

5.1. Observational properties of the disc winds

We find that H\alpha and He\textsc{i}\,$\lambda$5876 are the most sensitive lines to the presence of winds. Outflow signatures at similar velocities are often observed simultaneously in both lines. This is consistent with previous observations of winds in both AWDs and XRBs (e.g. Kafka et al. 2003; Muñoz-Darias et al. 2019). The He\textsc{i}\,$\lambda$7065 line is usually a weaker version of He\textsc{i}\,$\lambda$5876.
might explain the differences across short (minutes) and long (>day) timescales. Although our results are (mostly) in good agreement with previous studies (see below), the aforementioned variability might explain the different wind velocities reported for some cases. The highest terminal velocity (blue edge) that we measured in BZ Cam is \( \sim 2400 \text{ km s}^{-1} \) (see Sect. 4.3), which is consistent with that obtained by Honeycutt et al. (2013, \( \sim 2350 \text{ km s}^{-1} \)). Ringwald & Naylor (1998) derived velocities of up to \( \sim 3000 \text{ km s}^{-1} \) for the same system (see Sect. 2). For V751 Cyg, we measure wind velocities of up to \( \sim 2500 \text{ km s}^{-1} \), in agreement with the same value reported by Patterson et al. (2001). In the cases of MV Lyr and V425 Cas, our highest wind velocity measurements are \( \sim 2200 \text{ km s}^{-1} \) and \( \sim 1400 \text{ km s}^{-1} \), respectively. All these values are consistent with those obtained by Kafka & Honeycutt (2004, 300–4600 \text{ km s}^{-1}; see their Table 4). Likewise, ultraviolet winds with a wide range of velocities have been reported in different studies (e.g. from \( \sim 165 \text{ km s}^{-1} \) to \( \sim 5000 \text{ km s}^{-1} \) for BZ Cam; Prinja et al. 2000), evidencing, once again, a high variability in the observational properties of the outflows from AWDs.

Finally, it has been suggested that the visibility of winds, both at ultraviolet and optical wavelengths, depends on the orbital phase (e.g. Kafka et al. 2009). We note that this scenario was observed for BZ Cam (Griffith et al. 1995; Honeycutt et al. 2013) and V751 Cyg (Patterson et al. 2001). However, Patterson et al. (1996) did not observe any clear correlation between the orbital phase and the presence of optical winds in BZ Cam. Likewise, no correlation was detected in ASAS J071404+7004.3 (Inight et al. 2022), while the phase coverage presented by Ringwald & Naylor (1998) and Kafka et al. (2003) in BZ Cam and Q Cyg, respectively, was not wide enough (poor overlapping coverage) to test the dependency scenario. The sampling of our database and the lack of absolute ephemeris prevent us from properly testing these claims. We simply note that a correlation between orbital phase and wind signatures is not obvious in our database (e.g. systems seem to show winds signatures at different orbital phases).

5.2. Outflows in AWDs versus XRBs

Optical wind signatures similar to those presented here (e.g. line profiles, variability properties, and terminal velocities) have been observed in XRBs with both black hole and neutron star accretors (e.g. Muñoz-Darias et al. 2016, 2020; Mata Sánchez et al. 2022). XRB winds are also observed in X-rays (e.g. Ponti et al. 2012) and in the ultraviolet (Castro Segura et al. 2022) and infrared (Sánchez-Sierras & Muñoz-Darias 2020) regimes with similar observational properties (e.g. velocities). Indeed, they have been proposed to be multi-phase in nature (see Muñoz-Darias & Ponti 2022 for a discussion on this topic). The mechanism(s) behind the launch of disc winds in XRBs is still strongly debated. In this context, the similarities between the observational properties of AWDs and XRBs might be relevant. For instance, AWD ultraviolet outflows are thought to be powered by the line-driven mechanism, where ultraviolet photons are absorbed by disc ions (metals), transferring enough momentum to launch a wind (e.g. Drew 1997; Froning et al. 2005; Honeycutt et al. 2013). Based on the similarities between ultraviolet and optical wind features in AWDs, it is tempting to consider that this mechanism also plays a role in XRBs, a conclusion that has some theoretical support (e.g. Higginbottom et al. 2020). As the strong X-ray emission produced in the inner disc would over-ionise the XRB wind (Proga & Kallman 2002), at least part of the outflow needs to be somehow shielded (see e.g. Motta et al. 2017; Muñoz-Darias & Ponti 2022). In addition, AWDs show significantly lower Eddingtonscaled luminosities than those of XRBs, which poses a challenge to the scenario where both AWD and XRB disc winds have a common physical origin.

Another interesting aspect to consider is the geometry of the wind. Given that P Cygni profiles have been preferentially observed in low-inclination systems (see, however, Inight et al. 2022), it is traditionally assumed that AWD winds are bipolar (e.g. Honeycutt et al. 1986; Drew 1987). In agreement with this, emission lines in MV Lyr, V425 Cas, and XRBs (e.g. Honeycutt et al. 1986; Drew 1987) have relatively low orbital inclinations (see Table 1). However, most of the optical wind detections in XRBs come from high-inclination systems, although there is a growing number of systems that show winds at lower inclinations (see Panizo-Espinar et al. 2021, 2022). Following on from the above, it seems clear that more observations of winds in both AWDs and XRBs are needed to properly understand their geometries as well as to constrain the mechanism(s) behind these outflows.

Also, hydrodynamical modelling of line-driven winds in CVs has provided some additional insights into the geometry of disc winds. Proga et al. (1998) found that the outflow geometry might be regulated by the geometry of the radiation field. If the disc luminosity were to dominate the radiation field, a polar wind geometry would be favoured. However, if the radiation comes mainly from the compact star, the wind would be more equatorial. In addition, it is worth noting that a number of numerical simulations were able to (roughly) reproduce the spectra of high-inclination AWDs by considering biconical outflow geometries (Knigge & Drew 1997; Noebauer et al. 2010; Matthews et al. 2015; Inight et al. 2022).

6. Conclusions

We present multi-epoch optical spectroscopy of four AWDs (BZ Cam, V751 Cyg, Mv Lyr, and V425 Cas). All of them show significant variability in their emission line profiles on both short (minutes) and long (days) timescales, with complex absorption and emission components. In particular, we report the detection of high-velocity (>1000 km s\(^{-1}\)) blueshifted absorption features that we argue can be associated with wind-type outflows. These possible wind features are detected in hydrogen (H\(_\alpha\)) and helium emission lines (He\(_\alpha\)) at about 1700 s, reinforcing the idea that, in addition to ultraviolet outflows, optical winds might also be common in AWDs. However, further observations are needed to fully constrain their observational properties and understand their origin and geometry, as well as their possible relation with the wind-type outflows detected in XRBs.

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Appendix A: Excesses diagnostic diagram of the H$_\alpha$ emission line for V425 Cas

Figure A.1 shows the excesses diagnostic diagram for H$_\alpha$ of V425 Cas, where residuals were calculated over the particular spectral region $\pm$400-1500 km s$^{-1}$. See Section 4.2 for more details.

Fig. A.1. Excesses diagnostic diagram of H$_\alpha$ wings of V425 Cas using the spectral region $\pm$400-1500 km s$^{-1}$ to estimate the residuals. The filled grey and dashed empty ellipses denote the 3$\sigma$ and 5$\sigma$ significance regions, respectively.