Spectroscopic Observations of V455 Andromedae Superoutburst in 2007: the Most Exotic Spectral Features in Dwarf Nova Outbursts

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Abstract

We present our spectroscopic observations of V455 Andromedae during the 2007 superoutburst. Our observations cover this superoutburst from around the optical peak of the outburst to the post-superoutburst stage. During the early superhump phase, the emission lines of Balmer series, He I, He II, Bowen blend, and C IV / N IV blend were detected. He II 4686 line exhibited a double-peaked emission profile, where Balmer emission lines were single-peaked, which is unexpected from its high inclination. In the ordinary superhump phase, Balmer series...
transitioned to double-peaked emission profiles, and high-ionization lines were significantly weakened. These transitions of the line profiles should be related to the structural transformation of the accretion disk, as expected between the early and ordinary superhump transition in the thermal-tidal instability model. The Doppler map of Hα during the early superhump phase exhibits a compact blob centered at the primary white dwarf. In analogy to SW Sex-type cataclysmic variables, this feature could emerge from the disk wind and/or the mass accretion column onto the magnetized white dwarf. The Doppler map of He II 4686 Å is dominated by the ring-like structure and imposed two flaring regions with the velocity of \( \sim 300 \text{ km/s} \), which is too slow for a Keplerian accretion disk. The phase of the flaring regions was coincident with the inner spiral arm structure identified during the early superhump phase. Our disk wind model with the enhanced emission from the inner arm structure successfully reproduced the observed properties of He II 4686 Å. Therefore, V455 And is the first case in dwarf nova outbursts that the presence of the disk wind is inferred from an optical spectrum.

**Key words:** accretion, accretion disk — novae, cataclysmic variables — stars: dwarf novae — stars: individual (V455 Andromedae)

### 1 Introduction

Cataclysmic variables (CVs) are close binary systems composed of a primary white dwarf (WD) and a Roche lobe-filling secondary low-mass star (for a review of CV, see Warner 1995; Hellier 2001). Dwarf nova (DN) is a subclass of CVs which possesses an accretion disk and exhibits recurrent outbursts triggered by the thermal-tidal instability (Osaki 1996). WZ Sge-type DNe are the most evolved class of DNe, and they show only large-amplitude and long-duration superoutbursts every 5 - 30 yr (for a review, see Kato 2015). Outbursts of WZ Sge-type DNe are characterised by both early superhumps and ordinary superhumps. Early superhumps are believed to be the result of double spiral structure in the disk that emerges from the 2:1 resonance (Lin and Papaloizou 1979; Osaki and Meyer 2002), whereas ordinary superhumps are induced by the eccentric disk through the 3:1 resonance (Whitehurst 1988; Osaki 1989). Early superhumps are a double-peaked variation with the period almost identical with the orbital period of the system (Ishioka et al. 2002; Kato 2002). Since a larger amplitude of early superhumps is observed in a system with higher inclination, the origin of early superhumps is believed to be the vertical deformation of the accretion disk (Nogami et al. 1997; Maehara et al. 2007; Matsui et al. 2009; Uemura et al. 2012). However, observationally, the exact system structures of the spiral arms during the early superhump phase are still not resolved. Baba et al. (2002); Kuulkers et al. (2002) studied the Doppler tomography of He II 4686 Å during the early superhump phase of WZ Sge. They revealed an asymmetric spiral structure in the accretion disk, which can be attributed to the 2:1 resonance.

Another important viewpoint on WZ Sge-type outburst is the evolution of the disk structure across the superhump stages. Since the 2:1 resonance suppresses the growth of the 3:1 resonance (Lubow 1991), early superhumps are always observed before the ordinary superhumps. The evolution of early and ordinary superhumps are well established in time-resolved photometric studies (e.g., Kato et al. 2009 and following series). Moreover, Neustroev et al. (2018) found that the X-ray flux in DN outbursts is correlated with the superhump stages, and Niijima et al. (2021) showed that the X-ray hard-soft transition in low-mass black hole X-ray binary ASASSN-18ey (=MAXI J1820+070) occurred simultaneously with the transition of optical superhump stages. Although the spectra during the outbursts of WZ Sge-type DNe dramatically changes as well (e.g., WZ Sge: Nogami and Iijima 2004, GW Lib: Hiroi et al. 2009), an association between the evolution of superhumps and the spectra has been less discussed. Nogami and Iijima (2004); Hiroi et al. (2009) revealed that before the outburst peaks, their spectra were dominated by Balmer and He I absorption lines, whereas after the maxima they turned into emission lines and high excitation lines such as He II and C III / N III Bowen blend lines appeared. These high excitation lines are then decayed out as the outburst proceeds, due to the decrease of irradiating UV photons and/or the disappearance of the spiral structure originating from the 2:1 resonance.

While most of the accreting objects accompany an outflow component in forms of a jet and a wind, CVs and DN outbursts have been believed that their outflow is negligible in optical studies. Indeed, optical spectra of DN outbursts are dominated by an emission from an accre-
tion disk (Horne and Cook 1985). Even though P Cygni profiles are observed in UV in some nova-like CVs (e.g., Prinja et al. 2000) and DN outbursts (e.g., Szkody et al. 1999; Froning et al. 2002; Sanad 2011), only a handful nova-like CVs show P Cygni profile in optical (Kafka and Honeycutt 2004 and reference therein) and never detected in the optical studies of DN outbursts in our best knowledge. Another possible implication of an outflow component in CVs is single-peaked Balmer and He emission lines in eclipsing nova-like CVs, called SW Sex-type CVs (Honeycutt et al. 1986). The theoretical studies by Honeycutt et al. (1986); Matthews et al. (2015) showed that these peculiar single-peaked emission lines from the eclipsing systems can originate from the wind component. Recent studies have detected a radio emission during the outburst of firstly SS Cyg (Körding et al. 2008) and then other systems (Coppejans et al. 2016). The suggested emission mechanisms include a synchrotron emission from the transient jet, while the discussion does not settled.

V455 And (= HS 2331+3905) was originally found by the Hamburg Quasar Survey (Hagen et al. 1995) as a CV candidate. Araujo-Betancor et al. (2005) studied its quiescence photometrically and spectroscopically, showing its great similarity with WZ Sge. V455 And showed grazing eclipses, therefore the orbital period is obtained as $P_{\text{orb}} = 0.05630921(1) \ \text{d}$, combining with the radial velocity observations. The existence of grazing eclipses suggests that V455 And is highly inclined as much as $i \sim 75^\circ$. Moreover, time resolved studies have found that V455 And shows a spin period (67.3 s) of the primary WD, establishing that V455 And is an intermediate polar (Araujo-Betancor et al. 2005; Silvestri et al. 2012; Szkody et al. 2013; Ghaderpour and Ghaderpour 2020). The first observed outburst of V455 And was discovered in 2007 by H. Maehara 1 and follow-up observations were conducted worldwide. The optical photometric observations of this 2007 superoutburst and the evolution of the superhumps are summarized in Kato et al. (2009); Matsui et al. (2009); Maehara et al. (2009). Using the period of early superhump and growing ordinary superhump (Stage-A superhump), the mass ratio of V455 And is dynamically estimated to be 0.080 (Kato and Osaki 2013). In Matsui et al. (2009), the multi-color photometry of the early superhump was performed for the first time, showing that the profile and color of early superhumps can be explained by the vertically extended outer disk. Moreover, Uemura et al. (2012) performed “early superhump modeling” using the multi-color light curve of early superhumps of V455 And. They successfully reconstructed the accretion disk with the two flaring patterns in the outermost region of the accretion disk, which are responsible for the maxima of early superhumps. Along with these patterns, the flaring patterns are also elongated into the inner part of the accretion disk. Uemura et al. (2012) interpreted these structures in the accretion disk as a double-spiral structure emerging from the 2:1 resonance.

In this paper, we present the spectroscopic observations of V455 And performed during the 2007 superoutburst and the subsequent post-superoutburst stage. Section 2 overviews our observations, and Section 3 shows the results of our spectroscopic observations. In Section 4, we performed Doppler tomography of the data obtained during the early superhump phase. We discuss the features and interpretations of our spectra in Section 5 and give a summary in Section 6.

2 Observations and Analysis

Our spectroscopic observations of V455 And were performed from around the optical peak to the post-superoutburst stage with various telescopes and equipment. The log of our observations is summarized in Table 1. In Figure 1, the light curve of the 2007 superoutburst of V455 And is presented with the black arrows indicating the epoch of our spectroscopic observations. The light curve data was taken from Kato et al. (2009). Most of our spectra were taken during the early superhump stage. We obtained some spectra during the ordinary superhump phase and during the post-superoutburst stage as well (see Section 3 for details). The data reduction was performed using IRAF in the standard manner (bias subtraction, flat fielding, aperture determination, spectral extraction, wavelength calibration with arc lamps, flux calibration with standard stars, and normalization by the continuum).

2.1 Bisei Astronomical Observatory

We took the low resolution spectra (R $\sim$1,400) with the spectrograph mounted on the 101-cm telescope at the Bisei Astronomical Observatory (BAO) on BJD 2454349.12, 2454350.04, 2454356.08, and 2454363.03. The exposure times were 300 s for the first two nights and 600 s for the last two nights, respectively.

2.2 Subaru telescope and the High Dispersion Spectrograph

On BJD 2454350.80, the high-resolution spectra (R $\sim$ 40,000) were obtained with the High Dispersion

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1 <http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/9530>
Table 1. Log of spectroscopic observations

| Mid BJD       | Exposure Time | Number of Spectra | Site         | Spectral Range |
|---------------|---------------|-------------------|--------------|----------------|
| (2454000+)    | (s)           |                   |              | (Å)            |
| 349.01        | 600           | 7                 | Fujii-Bisei  | 3800-8200      |
| 349.12        | 300           | 15                | Bisei        | 3700-8200      |
| 349.22        | 600           | 15                | Nishi-Harima | 4470-4900      |
| 350.04        | 300           | 3                 | Bisei        | 3700-8200      |
| 350.27        | 600           | 6                 | Fujii-Bisei  | 3800-8200      |
| 350.80        | 30            | 87                | Subaru       | 4200-5300      |
| 350.80        | 30            | 87                | Subaru       | 5600-6700      |
| 351.19        | 60            | 70                | Gunma        | 4000-8000      |
| 354.05        | 600           | 9                 | Fujii-Bisei  | 3800-8200      |
| 356.01        | 720           | 7                 | Fujii-Bisei  | 3800-8200      |
| 356.08        | 600           | 4                 | Bisei        | 3700-8200      |
| 363.03        | 600           | 3                 | Bisei        | 3700-8200      |
| 365.25        | 120           | 60                | Gunma        | 4000-8000      |
| 379.20        | 150           | 45                | Gunma        | 4000-8000      |
| 397.96        | 300           | 3                 | Gunma        | 4000-8000      |
| 416.19        | 180           | 15                | Gunma        | 4000-8000      |
| 425.17        | 180           | 22                | Gunma        | 4000-8000      |
| 429.13        | 180           | 35                | Gunma        | 4000-8000      |

Fig. 1. Light curve of V455 And during its 2007 superoutburst, binned in each 0.06 d. Data was taken from Kato et al. (2009). Arrows show the epoch of our spectroscopic observations. The upper right panel shows the enlarged light curve around the outburst peak. As shown at the bottom of this figure, we separate our observations into four periods (see Section 3).

Spectrograph (HDS; Noguchi et al. 2002; Sato et al. 2002) mounted on the 8.2-m Subaru telescope at the Maunakea Observatory. The exposure time was 30 s. We have obtained 87 exposures with the wavelength coverage of 4200-5300 Å and 5600-6700 Å, simultaneously covering both He II 4686 Å and Hα.

2.3 Fujii-Bisei Observatory

The low resolution spectra (R~600) were obtained on BJD 2454349.01, 2454350.27, 2454354.05, and 2454356.01, with the spectrograph, FBSPEC-2, mounted on a 28-cm Schmidt-Cassegrain telescope at the Fujii-Bisei Observatory. The exposure times were 600 s on the first three observation nights, and 720 s on the last night, respectively.
2.4 Gunma Astronomical Observatory
The low resolution spectra ($R \sim 500$) were taken with the Gunma LOW resolution Spectrograph (GLOWS) mounted on a 150-cm Ritchey-Chretien telescope at the Gunma Astronomical Observatory (GAO). Our observations were performed on BJD 2454351.19, 2454365.25, 2454379.20, 2454397.96, 2454416.19, 2454425.17, and 2454429.13, and the exposure times were 60, 120, 150, 300, 180, 180, 180 s, respectively. On the first two nights V455 And was in the superoutburst, and on the other nights it was in the post-superoutburst stage.

2.5 Nishi-Harima Astronomical Observatory
We obtained the mid-resolution spectra ($R \sim 7,500$) on BJD 2454349.22, using the Medium And Low-dispersion Long-slit Spectrograph (MALLS; Ozaki and Tokimasa 2005) mounted on the 2.0-m NAYUTA telescope of the Nishi-Harima Astronomical Observatory. The integration time was 600 s, and the wavelength coverage is 4470-4900 Å.

3 Result
In this section, we present the characteristics and evolution of our spectra of V455 And taken during the 2007 superoutburst and the following post-superoutburst stage. In Figure 2, we show all our normalized spectra taken during the superoutburst, and Figure 3 presents the spectra taken during the post-superoutburst stage. The equivalent widths (EWs) of our spectra are listed in Table 2 (Balmer series, He II, C IV / N IV blend) and Table 3 (He I series). Note that since EW is defined as a positive value for an absorption line, the negative value is given for an emission line.

In our analyses, our observations are divided into four periods based on both spectroscopic and photometric behaviour (Kato et al. 2009; Matsui et al. 2009). Period I corresponds to the early superhump phase, which is BJD 2454349.0 - 2454355.0. During this Period I, single-peaked Balmer emission lines were observed. Period II is BJD 2454355.0 - 2454357.3, during which the superposition of early and ordinary superhumps was observed. The spectra in Period II showed Balmer series with double-peaked emission, and the emission of He II 4686 Å was still stronger than Hβ. Period III covers the ordinary superhump phase, BJD 2454357.3 - 2454369. In Period III, the high excitation lines such as He II and C IV / N IV blend were significantly weaker than Period I and II. Period IV is during the post-superoutburst stage corresponding the observations after BJD 2454369.

3.1 Period I: early superhump phase
As described above, the spectra in Period I were observed during the early superhump phase. In Figure 4, the spectra on BJD 2454349.12 (upper red) and 2454350.04 (lower blue) obtained at BAO. Figure 5 presents the phase-resolved emission lines of Hα (left) and He II 4686 Å (right) on BJD 2454350.80 observed with HDS. In our analyses, 0.01 phase was added to the ephemeris of Araujo-Betancor et al. (2005), following the suggestion in Uemura et al. (2012). These spectra are binned in each 0.05 phase in Figure 5, and the phase 1.0 is corresponding to BJD 2454350.81583. Strong Balmer and He II 4686 Å emission lines are recognized in our spectra. Along with these lines, He I, Pickering series of He II 4200 Å, 4542 Å, 5411 Å, C III / N III Bowen blend, and C IV / N IV blend emission lines were detected. Although V455 And is a high-inclination system (Araujo-Betancor et al. 2005), Balmer series showed a single-peaked profile. The full width at zero intensity (FWZI) of Hα is about 4,000 km/s, which is comparable with the typical value in eclipsing CVs (Warner 1995). As seen in Figure 5, both in Hα and He II 4686 Å, the line profiles were almost stable around and in the eclipse (φ = 1), indicating the emission regions of both lines are vertically extended above the disk plane. On BJD 2454349, He I 6678 line is in double-peaked emission with the peak separation of ~ 430 km/s, while the other He I series are observed as absorption lines or not detected. One day after, on BJD 2454350, He I 4922 Å and 5015 Å are likely turned into emission. He II 5412 Å as well shows a double-peaked emission line, with the peak separation of ~ 700 km/s. In the right panel of Figure 5, He II 4686 Å emission line shows a double peak emission with the peak separation of ~ 440 km/s, which is much narrower than He II 5412 Å. The asymmetric bump on the blue side of He II 4686 Å emission line implies that Bowen blend line was in the emission. C IV / N IV blend and He II 5412 Å were also detected during the early superhump phase of WZ Sge (Nogami and Iijima 2004). On the other hand, He II 4200 and 4542 line are rarely detected in DN outbursts (e.g., HT Cas in outburst; Neustroev and Zharikov 2020), though often observed in intermediate polars (Schachter et al. 1991; Harlaftis and Horne 1999). Moreover, in the left panel of Figure 5, a small bump centered around 6560 Å is seen in Hα emission line. This bump is likely an emission line from Pickering series 6560 Å. Therefore, the other Balmer series can be contaminated with Pickering series as well.
Fig. 2. Normalized spectra taken during the superoutburst. For visibility, the data are vertically shifted.
Table 2. Averaged equivalent widths in Å of absorption lines (negative EW for an emission line).

| Mid BJD (2454000+) | Hα | Hβ | Hγ | He II | He II | He II | C IV |
|-------------------|----|----|----|-------|-------|-------|------|
|                   | 4542 Å | 4686 Å | 5411 Å | N IV |
| 349.01            | -65.22 (1.5) | -19.08 (0.52) | -8.55 (0.52) | -4.60 (0.46) | -39.05 (0.70) | -5.99 (0.22) | -4.55 (0.35) |
| 349.12            | -64.13 (1.24) | -19.17 (0.37) | -10.90 (0.39) | -1.88 (0.10) | -32.41 (0.34) | -7.68 (0.16) | -3.57 (0.23) |
| 349.22            | -24.40 (0.56) | -1.94 (0.28) | -43.63 (0.49) |       |       |       |      |
| 350.04            | -68.05 (1.43) | -25.15 (0.63) | -11.57 (0.47) | -2.66 (0.23) | -26.96 (0.33) | -6.15 (0.13) | -3.47 (0.22) |
| 350.27            | -73.31 (0.60) | -23.75 (0.52) | -11.32 (0.33) | -2.70 (0.31) | -39.54 (0.56) | -7.16 (0.31) | -4.47 (0.18) |
| 350.80            | -63.36 (1.06) | -22.60 (0.81) | -6.09 (0.40) | -1.24 (0.15) | -32.72 (0.65) | -1.27 (0.10) |       |
| 351.19            | -72.39 (0.58) | -21.21 (0.19) | -8.56 (0.47) | -1.29 (0.11) | -24.62 (0.11) | -4.83 (0.08) | -2.44 (0.29) |
| 354.05            | -34.74 (0.72) | -9.09 (0.24) | -3.15 (0.51) | -0.88 (0.31) | 15.58 (0.38) |       |      |
| 356.01            | -40.75 (0.6) | -10.16 (0.42) | -8.04 (0.22) |       | -17.56 (0.96) |       |      |
| 356.08            | -35.92 (0.5) | -11.46 (0.33) | -5.56 (0.11) | -0.62 (0.05) | -15.43 (0.14) | -2.51 (0.07) | -1.06 (0.15) |
| 363.03            | -14.36 (0.60) | -6.28 (0.29) | -3.59 (0.27) |       | -5.28 (0.20) |       |      |
| 365.25            | -12.27 (0.36) | -3.99 (0.13) | -1.50 (0.13) |       | -2.80 (0.10) |       |      |

∗ Can be contaminated with Bowen blend.

Table 3. Averaged equivalent widths in Å of absorption lines (negative EW for an emission line).

| Mid BJD (2454000+) | He I | He I | He I | He I | He I | He I |
|-------------------|------|------|------|------|------|------|
|                   | 4471 Å | 4922 Å | 5015 Å | 5876 Å | 6678 Å | 7065 Å |
| 349.01            | 1.09 (0.21) | —- | —- | 4.77 (0.23) | -0.43 (0.08) | —- |
| 349.12            | 0.51 (0.11) | —- | —- | 1.24 (0.14) | -1.86 (0.09) | —- |
| 349.22            | —- | —- | —- | —- | —- | —- |
| 350.04            | 0.08 (0.02) | -0.71 (0.04) | -0.19 (0.05) | —- | -2.95 (0.12) | —- |
| 350.27            | —- | -0.33 (0.17) | -0.30 (0.06) | -0.66 (0.06) | -2.86 (0.08) | -1.11 (0.1) |
| 350.80            | -1.07 (0.08) | -0.67 (0.07) | —- | -0.51 (0.09) | -1.82 (0.09) | —- |
| 351.19            | 0.07 (0.01) | -0.52 (0.03) | -0.32 (0.02) | -0.31 (0.02) | -3.25 (0.11) | -1.28 (0.2) |
| 354.05            | —- | —- | —- | —- | -1.90 (0.13) | —- |
| 356.01            | —- | —- | —- | —- | -1.05 (0.27) | —- |
| 356.08            | -0.4 (0.06) | —- | —- | -0.53 (0.08) | -3.33 (0.16) | -1.46 (0.07) |
| 363.03            | 0.59 (0.07) | 0.46 (0.06) | 0.19 (0.02) | —- | -0.99 (0.1) | —- |
| 365.25            | —- | —- | —- | —- | -1.82 (0.04) | —- |
| 379.20            | -8.50 (0.40) | —- | -6.28 (0.24) | -19.59 (0.26) | -10.93 (0.71) | -9.88 (0.59) |
| 397.96            | —- | —- | —- | —- | -31.74 (1.40) | —- |
| 416.19            | -9.85 (0.42) | —- | -8.88 (0.40) | -24.61 (0.64) | -12.82 (0.97) | -15.13 (0.80) |
| 425.17            | -19.97 (1.02) | -2.10 (0.89) | -5.04 (0.31) | -31.09 (0.87) | -16.63 (0.65) | -14.82 (0.87) |
| 429.13            | -17.63 (1.52) | —- | -12.31 (0.88) | -28.64 (1.55) | -27.25 (2.39) | —- |

3.2 Period II: early superhump - ordinary superhump transition

Period II is a transition phase from early superhumps to ordinary superhumps. The spectrum taken on BJD 2454356.08 at BAO is presented in Figure 6. Compared to Period I, the emission lines were significantly weakened and Balmer series turned into double-peaked emission. The peak separations of Hα, Hβ, and Hγ are ∼530 km/s, ∼660 km/s, and ∼600 km/s, respectively. He I lines are in emission, in contrast to Period I. He I 6678 Å is obviously in double-peak, with the peak separation of ∼750 km/s. He II Pickering series, Bowen blend and C IV / N IV emission lines are detected, and He II 4686 Å emission line is still stronger than Hβ. The peak separations of He
3.3 Period III: ordinary superhump phase

This Period III includes two spectra taken during the ordinary superhump phase. The spectrum taken on BJD 2454363.03 at BAO is presented in Figure 7. The spectra in this period show double-peaked emission lines from Balmer series and He II 4686 Å with much wider peak separations than Period II. The peak separations of Hα, Hβ, Hγ, and He II 4686 Å were ~740 km/s, ~810 km/s, ~990 km/s and ~1,200 km/s, respectively. The EW of He II 4686 Å emission line was smaller than that of Hβ in this Period III. He I lines are likely in absorption except He I 5876 Å and 6678 Å in weak emission. Bowen blend is weakened from Period I and II, however still detected. CIV / NIV blend nor He II 4200, 4542, 5411 lines were not detected in Period III.

3.4 Period IV: post-superoutburst stage

All spectra belonging to Period IV were obtained during the post-superoutburst stage at GAO. The corresponding optical magnitude is around 15.5 mag, which is still ~0.7 mag brighter than the quiescence brightness before the superoutburst (Araujo-Betancor et al. 2005). The normalized spectrum taken on BJD 2454425.17 is presented in Figure 8. The spectra during Period IV show double-peaked emission lines of Balmer series and He I. The mean of peak separations of Hβ, Hγ, and He I 6678 Å are ~950 km/s, ~1,085 km/s, and ~1,140 km/s, respectively. These values are broader than Period III, consistent with the spectrum of quiescence. He II, Bowen blend nor CIV / NIV lines, observed during the superoutburst, were not detected in Period IV.

4 Doppler Tomography

Doppler tomography is a method to reconstruct a brightness map of a certain line in the velocity plane firstly developed by Marsh and Horne (1988). In this paper, we used a code developed in Uemura et al. (2015), which applies the total variation minimization technique to reconstruct the Doppler map. For the system parameters to perform Doppler tomography, we used the following value from Araujo-Betancor et al. (2005); Kato and Osaki (2013); orbital period $P_{\text{orb}} = 0.0.05630921$ d, inclination $i = 75^\circ$, mass ratio $q = 0.80$, primary WD mass $M_{\text{WD}} = 0.6 M_\odot$. As described in Section 3, 0.01 phase was added to the orbital ephemeris of Araujo-Betancor et al. (2005) as suggested by Uemura et al. (2012). We note that, the data before/after 0.05 phase of the mid-eclipse are not used in performing Doppler Tomography following the usual manner. In Figure 9, we show the Doppler map of Hα (upper) and He II 4686 Å (lower) using the data on BJD 2454350 obtained with HDS. In the Doppler map we show the secondary Roche lobe (inner distorted circle), and a mass transfer trajectory using the same system parameters. The corresponding velocity of the tidal truncation radius ($R_{\text{max}} \sim 0.6a$ where $a$ is a binary separation; Paczyński 1977) under the assumption of Kepler rotation around the primary WD is plotted as the outer ring (~600 km/s).

In the Doppler map of both Hα and He II 4686 Å, we do not see any structure likely related to a hot spot along the mass stream trajectory. Therefore, a mass transfer burst was not taking place at this stage of the superoutburst. The Doppler tomography of Hα exhibits a rather compact blob centered at the primary WD. The blob in the Doppler tomography of Hα does not likely originate from an accretion disk, which would create a ring-like structure outside the tidal truncation radius in the Doppler map. This view is consistent with the spectra presented in the left panel of Figure 5, which show single-peaked emission with no variation of its center wavelength.

On the other hand, the Doppler map of He II 4684 line shows a ring-like structure with two bright spots in the

Fig. 3. Normalized spectra taken during the post-superoutburst stage. For visibility, the data are vertically shifted.

II 4686 Å and 5412 Å are ~610 km/s and ~660 km/s, respectively.
upper left ($V_x \sim -250$ km/s and $V_y \sim 200$ km/s) and right ($V_x \sim 250$ km/s and $V_y \sim 100$ km/s) quadrant (lower panel of Figure 9). The bright annuli has the velocity (200-400 km/s) significantly lower than the rotation velocity at the tidal truncation radius under Kepler rotation. Therefore, He II 4686 Å might not originate from the accretion disk as well as Hα. We note that, as we described in Section 3, the Hα and He II 4686 emission line can be blended with Pickering series 6560 Å and Bowen blend, respectively. However, a blended line only creates a ring-like structure (Marsh and Schwope 2016; Neustroev and Zharikov 2020), and hence we simply ignored the contribution from these lines.

5 Discussion

5.1 Doppler tomography of Hα: origin of single-peaked emission

In Doppler tomography of Hα (upper panel of Figure 9), V455 And showed a compact blob centered at the primary WD. On the other hand, that of WZ Sge, which has very similar binary parameters as V455 And (Smak 1993; Araujo-Betancor et al. 2005), showed almost flat emission from the accretion disk in Hα during the early superhump phase (Baba et al. 2002). This fact is consistent that WZ Sge showed a double-peaked emission of Hα, whereas V455 And showed a single-peaked emission profile during the early superhump phase.

This remarkable compact blob observed in V455 And clearly does not originate from the accretion disk, since the accretion disk is projected as a ring structure in Doppler map (Marsh and Horne 1988). The line profile of Hα is stable across the orbital phase even during the eclipse (left panel of Figure 5), suggesting that the emitting region of Hα is above the orbital plane. A similar compact blob centered at the primary WD in Doppler maps is observed in some SW Sex-type CVs (e.g., Hellier 1996; Rodríguez-Gil et al. 2001; Hernandez et al. 2017). SW Sex-type CVs are classically defined as an eclipsing nova-like system showing single-peaked emission lines (Thorstensen et al. 1991). Nowadays they include some non-eclipsing objects sharing similar spectroscopic properties (e.g., Rodríguez-Gil et al. 2007). Since a DN around outburst peak has a high mass-accretion rate comparable to nova-like systems and SW Sex-type CVs, the disk condition and the projected observational properties of eclipsing V455 And can be similar to SW Sex-type CVs, while the mass transfer rate is significantly different. In SW Sex-type CVs, the compact blob centered on the primary WD is the most prominent in high-excitation lines such as He II 4686 Å. The Doppler maps in Balmer lines of SW Sex-type CVs are, on the other hand, usually dominated by an emission from the accretion disk and the superimposed feature on the lower left quadrant, which is regarded as an emission from the re-impact region of the mass stream overflow (Hoare and Drew 1993; Hellier 1996). In case of V455 And, as WZ Sge-type DNe are known as CVs with the lowest mass-transfer rate (e.g.,
Fig. 5. Phase-averaged spectra of H\alpha (left panel) and He II 4686 Å (right panel) taken with HDS mounted on Subaru Telescope on BJD 2454350.80. $\phi = 1.0$ is defined as BJD 2454350.81583 (Araujo-Betancor et al. 2005).
Knigge et al. 2011) and as Doppler map does not show the evidence of the mass transfer burst, these re-impact region should not be formed even during the peak of a superoutburst and single-peaked component was not obscured even in Hα.

Even though the compact blob observed in V455 And can be an analogy of that in SW Sex-type CVs, the origin of this feature in SW Sex-type CVs is still not settled (Warner 1995). One possibility is the accreting material along the magnetic field of the primary WD. Some of SW Sex-type CVs are known as intermediate polars through optical, X-ray and polarimetric studies (e.g., Lima et al. 2021 and references therein). Williams (1989) proposed that the single-peaked emission lines in SW Sex-type CVs can attribute to the magnetic accretion curtain around the primary WD. As the accreting materials follow the magnetic field lines above the disk plane, little eclipses of emission lines are observed (Williams 1989; Casares et al. 1996; Hoard et al. 2003). V455 And is also known as an intermediate polar (Araujo-Betancor et al. 2005; Silvestri et al. 2012; Szkody et al. 2013; Ghaderpour and Ghaderpour 2020), hence the accretion along the magnetic fields can take place and a similar spectrum can be observed in V455 And. We note, in the ordinary superhump phase of V455 And superoutburst Balmer lines exhibited a double-peaked profile. Later phase of the outburst means the lower mass-accretion rate as well as the fainter the accretion disk itself is, hence the magnetic accretion could be more prominent in the ordinary superhump phase than during the early superhump phase. This respect suggests
that the magnetic accretion column might not be responsible for the single-peaked emission line of Hα during the early superhump phase.

Another possibility is the disk wind component. Honeycutt et al. (1986); Hoare (1994); Hellier (1996); Murray and Chiang (1997) interpret the stable single-peaked emission as a wind component. As calculated by Honeycutt et al. (1986); Matthews et al. (2015), considering the wind component other than the accretion disk generally makes the line profile much narrower, while the exact emission line profile depends on the applied model of the disk wind. Since the wind should locate above the orbital plane, they would not be eclipsed so much. However, the presence of an outflow in DN outbursts is still not established. Kafka and Honeycutt (2004) reported optical P Cygni profiles in He I lines (5876 Å and 7065 Å) and Hα of some nova-like stars, indicating the presence of an outflow in CVs. More recently, radio detections during some DN outbursts (Körding et al. 2008; Coppejans et al. 2016) gives a hint of a transient jet in an early stage of DN outbursts, while the mechanism of radio emission in CVs is still not fully understood. Even though the presence of wind or outflow has not been confirmed during the DN outburst in optical observations so far, combining the discussion on the origin of He II 4686 Å, we propose that the emission from the wind components can be an alternative interpretation of the compact blob in Doppler map of Hα.

Even if this single-peaked emission originated either from a magnetic accretion column or a wind component, the reason WZ Sge and more generally other eclipsing DNe in outburst did not show a similar feature is still controversial. The face-on WZ Sge-type DN GW Lib showed a strong narrow emission in Hα during its early superhump phase (Hiroi et al. 2009). Since the emission component of GW Lib did not show any blue-shift, Hα emission should not likely originate from an outflow in the case of GW Lib. Therefore, the emission components observed in V455 And and GW Lib may have a different origin. More other sample of time-resolved spectrum during the early superhump phase of WZ Sge-type DNe, as well as multi-wavelength observations to seek the impact of an outflow are needed to test the diversity of DN outbursts.

5.2 Doppler map of He II 4686 Å: not originate from the accretion disk

Since the discovery of the spiral structure in Doppler map of WZ Sge during the early superhump phase by Baba et al. (2002); Kuulkers et al. (2002), He II 4686 Å emission line is regarded as a tracer of the spiral arms emerging from the 2:1 resonance and causing early superhumps.
Recently, Tampo et al. (2021) studied both the optical spectra taken during the early superhump phase and the time-resolved photometry data of WZ Sge-type DNe. They showed that the strength of He II 4686 Å emission line is positively correlated with the amplitude of early superhump amplitude, therefore likely with the inclination of the system. This result is consistent with the view that the spiral arms are responsible for both the early superhumps and the strong emission of He II 4686 Å in WZ Sge-type DN outbursts.

The Doppler tomography of He II 4686 Å in both V455 And and WZ Sge shows a ring-like structure plus the two flaring patterns. The phases of the flaring spots are slightly different between WZ Sge and V455 And (Baba et al. 2002). The upper left spot in V455 And is shifted to the left quadrant ($V_x < 0$ and $V_y ~ 0$) in WZ Sge, although the right spot locates in almost same phase ($V_x > 0$ and $V_y ~ 0$) in V455 And and WZ Sge. Along with that, in the case of WZ Sge, the right spot is brighter than the left spot. These differences of the flaring spots might reflect the exact structure of the spiral arms depending on the mass ratio of the systems, as well as the observation date since the outburst peak. More interestingly, the velocity of the ring structure is significantly different between WZ Sge and V455 And. The ring structure of V455 And has the velocity significantly lower than 400 km/s, even though the one of WZ Sge has 500-600 km/s, which is consistent with Kepler velocity around the tidal truncation radius (Paczyński 1977). Therefore, the emitting region of He II 4686 Å in V455 And should differ from the Keplerian accretion disk, as observed in WZ Sge.

We note that the spiral structure in the accretion disk is not only observed in WZ Sge-type DNe, but also in some U Gem-type DNe (e.g., Harlaftis et al. 1999; Steeghs 2001; Groot 2001). However, the phase and structure of spiral waves seen in U Gem-type DNe and WZ Sge-type DNe are significantly different, suggesting that the origin of the spiral waves in these two types of DNe would be different.

5.3 Comparison with the height map of the accretion disk

In order to further examine the origin of the peculiarity of He II 4686 Å emission in V455 And, we compare our Doppler map with the disk height map obtained during the early superhump of V455 And in Uemura et al. (2012). Uemura et al. (2012) is the first case in which the height structure of the accretion disk during the early superhump phase was successfully reconstructed. They revealed two flaring patterns in the outermost part of the disk along with the elongated structure into the inner disk. In this context, this is the first case that, in a single object, we can directly compare both the height structure of the accretion disk and Doppler tomography. We note our data were not obtained on the same night as Uemura et al. (2012). We mainly compared our results with the reconstructed map using the data on BJD 2454352 (Day 3 in Uemura et al. 2012), which is 2 days after our observations with HDS. The flaring regions at the upper right quadrant ($V_x ~ 250$ km/s and $V_y ~ 200$ km/s) and the right quadrant ($V_x ~ 250$ km/s and $V_y ~ 100$ km/s) in Doppler tomography correspond to the upper left part and bottom part of the accretion disk in the height map of Uemura et al. (2012), respectively. In these phases of the accretion disk, the inner arm structures which elongated relatively
inside of the disk are located, suggesting a relation between He II 4686 Å emission and the spiral arm structure.

Even though He II 4686 Å was not dominated by the emission from the accretion disk, this coincidence should be attributed to a type of asymmetry in the system. Considering the fact that the profile of the emission lines was not affect by the eclipses and the peak separation of He II 4686 Å was too small for the emission from the accretion disk, we propose that the wind component can be the origin of this peculiar He II 4686 Å emission line during the early superhump stage of V455 And. The peak separation of a few hundred km/s is expected in the emission line from a wind component (Matthews et al. 2015). In this context, the asymmetry in the Doppler tomography is understood as the difference of the line emissivity on the phase of the wind, which could be related to the disk phase dependence of the mass flow rate of the wind. Since the local escape velocity \( V_{\text{escape}} = \sqrt{\frac{2GM_{\text{WD}}}{R}} \) is faster than the local Kepler rotation velocity \( V_{\text{kepler}} = \sqrt{\frac{GM_{\text{WD}}}{R^3}} \), and the conservation of angular momentum of the wind results in the slower rotational velocity at outer radius along the wind trajectory, the little difference of phases of the flaring spot in the disk height map and the Doppler tomography can be understood.

We note that the reconstructed disk height map of OT J012059.6+325545 during the early superhump does not show the inner part of the spiral arms (Nakagawa et al. 2013). While the spectrum of OT J012059.6+325545 was not reported in literature, the uniqueness of V455 And can be understood as the presence of the inner spiral arms and resulting the disk wind emission. We would need more samples of both the early superhump light curves and time-resolved spectroscopic observations to verify the nature of the wind in DNe outbursts.

As discussed in Section 5.1, the single-peaked emission of Hα also possibly arose from the wind component. In SW Sex-type CVs, a single-peaked profile is usually observed in He II 4686 Å, while the double peaked profile was observed in V455 And. This is likely because our data was obtained with HDS mounted on Subaru telescope with very high wavelength and time resolution enough to resolve a more compact structure in the emission line variation. By changing the total variation parameter of the Doppler tomography in Uemura et al. (2015), more featureless map with a compact blob centered on the primary WD is generated even in He II 4686 Å. Since the excitation level of Hα is much lower than He II 4686 Å, Hα line is emitted from more above the disk plane where the wind might reach slower velocity and hence show a narrower emission line. Therefore, both Hα and He II 4686 Å emission lines can be simultaneously emitted from the disk wind component with different peak separations.

5.4 Wind model

To verify whether the wind component can explain the narrow peak separation and non-axisymmetricity in He II 4686 Å emission line, we constructed a simple model of an accretion disk wind. In our model, we more focused on to reproduce the emission line with the peak separation of < 500 km/s and the variation of the emission profile across the orbital phase applying the non axisymmetric structure of the wind. In our model, we assumed that the wind component is launched from the inner part of the accretion disk \( 0.05a < R < 0.35a \). This radius corresponds to the inner arm structure reconstructed in Uemura et al. (2012). The initial velocity is 1.1 times of the local escape velocity (typically 1,000 km s\(^{-1}\)) from the primary WD to the radial direction and then the wind is decelerated by the gravitational force of the primary WD. As the emission line of He II 4686 Å showed double-peaked profile across all the phases, the symmetric components should be presented in the wind component. The non-rotational velocity field of the wind \( v_{\phi} \) is given as Equation 2,

\[
v_{\phi}(R) = 1.1 \sqrt{\frac{2GM_{\text{WD}}}{R_0}} - \sqrt{2GM_{\text{WD}} \left( \frac{1}{R_0} - \frac{1}{R} \right)},
\]

where \( R_0 \) is the launch radius of the wind. We note that the factor of 1.1 is a marginal value, and we chose this value to best reproduce the observed peak separation of He II 4686 Å. At the same time, the rotational velocity field of the wind \( v_{\theta} \) is obtained assuming conservation of specific angular momentum (Equation 3; Matthews et al. 2015).

\[
v_{\theta}(R) = \sqrt{\frac{GM_{\text{WD}}}{R_0}} \frac{R_0}{R}
\]

As discussed in the previous section, the phases in which two flaring spots are observed in Doppler map correspond to those of the inner spiral arm structure in the disk height map. We applied a non-axisymmetric structure in the wind by considering the additional emission from the wind originally launched from \((x,y) = (-0.10,-0.20)\) and \((x,y) = (0.15, 0.25)\), corresponding to the inner arm structure on Day 3 in Uemura et al. (2012). More specifically, the size of the inner arm structure is modeled with two-dimensional Gaussian (FWHM=0.1a), and at the peak of Gaussian the emission is twice enhanced compared to the other part of the disk. Since considering the physical structure of the disk wind and the detailed emission mechanism of each line is beyond
the scope of this paper, we assumed that the emissivity decreases with the proportion of $1/R^2$ and summed all the wind components on the velocity toward the observer with the inclination of 75° (Araujo-Betancor et al. 2005).

In Figure 10, the synthesised emission line profile (left panel) and Doppler map (right panel) using our model are presented. The peak separation of the emission profiles is $\sim 500$ km/s and observed in all orbital phases, consistent with our observations of He II 4686 Å presented in the right panel of Figure 5. In Doppler map, two flaring spots are seen, which locate in the upper left quadrant ($V_x < 0$ and $V_y > 0$) and lower left quadrant ($V_x > 0$ and $V_y < 0$). The phase of flaring spots are slightly different from our observation. This is likely due to the dependence of the launching speed of the wind ($V_0$) and more importantly, the lack of modeling the physical mechanism of the disk wind and radiative transfer. This difference of flaring spot phases also might attribute the difference of the spiral arm structure to the date of spectroscopic observation and photometric observation. Even with these respects, general properties are well reproduced, inferring that this narrow emission line of He II 4686 Å is attributed to the accretion disk wind with two flaring spots. More detailed analyses applying radiative transfer calculation and physical structure of the wind are required to confirm our results. It is worth noting that the FWZI of our model emission profile is $\sim 2,000$ km/s, which is smaller than the observed value of $\sim 4,000$ km/s. This is due to the fact that our model does not include the emission from the accretion disk, and therefore the observed broader profile should be accounted for the emission from the inner disk.

5.5 The time evolution of spectra

As described in Section 3, V455 And showed a significant evolution of its spectrum throughout the 2007 superoutburst and post-outburst stage. Figure 11 presents the zoomed spectral evolution of Hα (left), Hβ (middle), and He II 4686 Å (right) lines during the 2007 superoutburst. In this subsection, we more focused on these spectral evolutions compared with WZ Sge (Baba et al. 2002; Kuulkers et al. 2002; Nogami and Iijima 2004) and GW Lib (Hiroi et al. 2009). WZ Sge is a proto-type object of WZ Sge-type DNe, and WZ Sge and V455 And are thought to share similar binary parameters (e.g., short orbital period near the period minimum, high inclination showing grazing eclipse: Smak 1993; Araujo-Betancor et al. 2005). GW Lib is, on the other hand, a well-known low inclination WZ Sge-type DN which does not show detectable early superhumps (Thorstensen et al. 2002; Kato et al. 2009). All WZ Sge, GW Lib and V455 And are spectroscopically ob-
served during both the early superhump phase and ordinary superhump phase.

During the early superhump phase after the maximum light, V455 And showed double-peaked He II 4686 and single-peaked Balmer line emission lines. WZ Sge during the early superhump phase, on the other hand, showed double-peaked emission lines of He II 4686 Å and Hα, while other Balmer series are in absorption (Nogami and Iijima 2004). This single-peaked Balmer lines in V455 And should be attributed to the component other than an rotating accretion disk as described in Section 5.1, while the double-peaked profile of WZ Sge should be understood as the emission from the accretion disk.

High excitation lines such as Bowen blend, C IV / N IV blend, Pickering He II 5412 Å emission lines were detected in both V455 And and WZ Sge during the early superhump phase, while Pickering He II 4200 Å and 4542 Å were detected only in V455 And. Former high excitation lines are indeed detected in various DN outbursts including WZ Sge-type DNe (Tampo et al. 2021 and the reference therein). Contrast to that, stronger Pickering series is rarely observed in DN outburst and those in V455 And can be related to its nature as a intermediate polar (Harlaftis and Horne 1999). Concerning the emission line strength, the EWs of V455 And is about order of magnitude stronger than those of WZ Sge, and the peak separation of He II 4686 Å in V455 And (~375 km/s) is much narrower than those in WZ Sge (~1,000 km/s; Baba et al. 2002; Nogami and Iijima 2004) as discussed in Section 5.2. Therefore, the emission lines of V455 And other than Hα and He II 4686 Å were also affected by the possible wind components. These respects tell that even though WZ Sge and V455 And have very similar binary parameters, the system structure and conditions during the early superhump phase of the superoutburst were significantly different. These differences between V455 And and WZ Sge should attribute to the nature of V455 And as a intermediate polar, and the possible presence of an outflow component as discussed in previous sections.

In the case of GW Lib, He II 4686 Å and Hα were observed as single-peaked emission lines and the higher Balmer series are observed as an absorption line accompanying single-peaked weak emission core. Even though the single-peaked emission profiles are consistent with its low inclination, face-on systems should show stronger absorption arose from the face-on optically thick accretion disk during the outburst (Marsh and Horne 1990). In fact, even WZ Sge-type DNe with detectable low-amplitude early superhumps, which should have larger inclinations than GW Lib, show Hα line in absorption during the early superhump phase (Tampo et al. 2021). Therefore, the emission component of Balmer series in GW Lib could originate from other than the accretion disk, and may have a similar mechanism as V455 And. We note that again, since no blue-shifts of emission lines are observed in GW Lib (Hiroi et al. 2009), this additional component observed in GW Lib might not be an outflow. To summarize, the larger variety of spectra was observed even among these three systems in the early superhump phase, which is highlighted by the spiral structure and hence a high accretion rate, suggesting a more complex disk and system structure during the early superhump phase in WZ Sge-type DN outbursts.

In the ordinary superhump phase, V455 And and WZ Sge showed similar strength and species of the lines (Nogami and Iijima 2004) in the viewpoints of EWs and peak separations. Hα, He I 5876 Å, 6678 Å and He II 4686 Å have double-peaked emission profile in WZ Sge and V455 And, and both showed He I 4387 Å, 4471 Å, and 4912 Å in absorption. Bowen blend was detected, while C IV / N IV were decayed out in both systems during the ordinary superhump phase. Pickering series were not observed in this phase of V455 And as well. In contrast to those lines, Hβ was observed as emission in V455 And, while as absorption in WZ Sge. The peak separations became larger from the early superhump phase to the ordinary superhump phase in V455 And and WZ Sge, suggesting that the decrease of the accretion rate and high-energy irradiating photon. The spectra of GW Lib in the ordinary superhump period showed absorption lines of Balmer and He I, with a weak emission core in Hα. Such a similarity between V455 And and WZ Sge, and the cookie-cutter spectra of GW Lib as a low-inclination DN during the ordinary superhump phase suggests that the disk and system conditions were also much more similar in the ordinary superhump phase than those in the early superhump phase.

As discussed above, great spectral evolutions were happened in all three systems during the early - ordinary superhump phase transition, attributing a significant transformation of the disk and system structure between these phases (Osaki and Meyer 2002). The decays of high ionization lines are happened during the early-ordinary superhump phase transition and either because of the decay of the mass accretion rate and the resulted decay of high energy photons to irradiate, and/or because of the disappearance of the spiral structure and resulted cooling of the accretion disk, as interpreted by Nogami and Iijima (2004); Hiroi et al. (2009). As discussed in Section 5.4, if the single-peaked emission of Hα and narrow-separation He II 4686 Å during the early superhump phase in V455 And were the evidence of the
wind component, the disk wind was present only during the early superhump phase. While Hα of GW Lib and V455 And was decayed after the early-ordinary superhump transition, one of WZ Sge strengthened. According to Hiroi et al. (2009), this difference can be understood as the presence of the mass reservoir, which are the outer gas of the accretion disk and result in the mass donor for rebrightenings (Kato et al. 1998). As V455 And also did not show any rebrightenings along with GW Lib (Type-D rebrightening; Kato et al. 2009; Imada et al. 2006), this interpretation still holds among V455 And, GW Lib and WZ Sge.

In the post-superoutburst stage, our spectra are resembled to the spectra observed in the quiescence before the 2007 superoutburst (Araujo-Betancor et al. 2005) and after the superoutburst (Szkody et al. 2013) in the context of line series and profiles. The EWs of the emission lines in our spectra are slightly weaker than those in quiescence, due to the brighter magnitude which attributes to the enhanced emission from the cooling primary WD and the accretion disk (Araujo-Betancor et al. 2005; Szkody et al. 2013). WZ Sge in the quiescence between rebrightenings and GW Lib in the post superoutburst stage as well showed the emission of Balmer and He I (Nogami and Iijima 2004; Hiroi et al. 2009).

6 Summary

We report on the spectroscopic observations of V455 And taken during its 2007 superoutburst and following post-superoutburst stages. Our key findings are summarized as follows.

- During the early superhump stage, Balmer series showed a single-peaked emission profile, which is inconsistent with the high inclination of V455 And and did not likely originate from an accretion disk. High excitation lines such as He II 4686 Å, Bowen blend, C IV / N IV blend were observed, and those were also detected in the early superhump stage of WZ Sge. He II 4686 Å had a double-peaked profile with a peak separation of ~ 440 km/s; however, this value is too low for emerging from an accretion disk during a DN superoutburst of V455 And. Pickering series were observed during the early superhump stage as well. As they are often observed in magnetic CVs, Pickering series can be related to the nature of V455 And as an intermediate polar.

- We performed Doppler tomography using the time-resolved spectroscopic data observed with HDS mounted on the Subaru telescope. The Doppler map of Hα showed a compact blob centered on the primary WD. In analogy to SW Sex-type CVs, this feature can be arisen either from the disk wind component and/or the magnetic accretion column onto the primary WD. However, it is an open question why other eclipsing DNe in outbursts do not show similar Doppler maps.

- Our Doppler map of He II 4686 Å is dominated by a low velocity ring-like structure with two superimposed flaring regions. The velocity of the ring-like structure is too slow to present the emission from an accretion disk with Kepler rotation. The flaring regions in Doppler map share the same phase with the inner spiral arms formed by the 2:1 resonance, suggesting that the spiral arms are responsible for the non-axisymmetric emis-
section of He II 4686 Å, as well as early superhumps in the light curve. One possible scenario for such a narrow but double-peaked emission line is to originate from a disk wind component. Our simple model of an accretion disk wind with two non-axisymmetric flaring directions successfully reproduced the narrow peak separation and two flaring patterns on Doppler map. This is the first case among DN outbursts that the presence of an outflow component is inferred from an optical spectrum.

- While V455 And and WZ Sge are thought to share similar binary parameters, their system structures during the early superhump phase should be significantly different, especially in the respect of the magnetic activity of the primary WD and an additional component to produce the narrower strong emission lines in V455 And.

- During the ordinary superhump phase, V455 And exhibited Balmer series and He II lines in double-peaked emission profile, whose peak separations can be explained by a Keplerian accretion disk. Pickering series and C IV / N IV lines were not observed during this phase, suggesting that their origin is related to the high accretion rate during the early phase of the outburst. In the viewpoint of line species and strength, V455 And and WZ Sge showed a very similar spectrum. Therefore, the system and disk structure during the ordinary superhump phase are much similar than those in the early superhump phase.

- The remarkable transitions of optical spectra in WZ Sge and GW Lib, and more dramatically in V455 And have happened in the early-ordinary superhump transition. This spectral evolution between superhump stages should attribute to the evolution of the disk condition during the superoutburst of a WZ Sge-type DN, as predicted in the thermal-tidal disk instability model.

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