THE LINE EMISSION REGION IN III Zw 2: KINEMATICS AND VARIABILITY

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ABSTRACT

We have studied the Lyα, Hβ, Hα, and Mg II λ2798 line profiles of the Seyfert 1 galaxy III Zw 2. The shapes of these broad emission lines show evidence of a multicomponent origin and also features that may be identified as the peaks due to a rotating disk. We have proposed a two-component broad-line region (BLR) model consisting of an inner Keplerian relativistic disk and an outer structure surrounding the disk. The results of the fitting of the four broad emission lines (BELs) considered here are highly consistent in both the inner and outer component parameters. Adopting a mass of \(\sim 2 \times 10^{8} \, M_\odot\) for the central object, we found that the outer radius of the disk is approximately equal for the four considered lines (\(\sim 0.01\) pc). However, the inner radius of the disk is not the same: 0.0018 pc for Lyα, 0.0027 pc for Mg II, and 0.0038 pc for the Balmer lines. This, as well as the relatively broad component present in the blue wings of the narrow [O III] lines, indicates stratification in the emission-line region. Using long-term Hβ observations (1972–1990, 1998) we found a flux variation of the BELs with respect to the [O III] lines.

Subject heading: accretion, accretion disks — galaxies: individual (Markarian 1501, III Zw 2) — galaxies: nuclei — galaxies: Seyfert — line: profiles

1. INTRODUCTION

The active galaxy III Zw 2 (Mrk 1501) appears to be essentially stellar-like, with faint wisps extending toward the northwest (Arp 1968; Zwicky 1971). III Zw 2 presents the classic broad emission line characteristic of a type 1 Seyfert galaxy or a quasar (Arp 1968; Sargent 1970; Khachikian & Weedman 1974; Osterbrock 1977). The emission lines of III Zw 2 have been studied in several papers (Osterbrock 1977; Kastra & Korte 1988; Corbin & Boroson 1996). Crenshaw et al. (1999) noted the presence of intrinsic absorption lines in the ultraviolet spectrum of III Zw 2 obtained with the Hubble Space Telescope (HST).

A disk model for the broad emission line region of III Zw 2 has been proposed in several papers (Kastra & Korte 1988; Corbin & Boroson 1996; Shimura & Takahara 1995; Rokaki & Boisson 1999). The rotating accretion disk model (van Groningen 1983; Kastra & Korte 1988; Perez et al. 1988; Chen, Halpern, & Filippenko 1989; Chen & Halpern 1989; Halpern 1990; Eracleous & Halpern 1994; Pariev & Bromley 1998; Rokaki & Boisson 1999; Shapovalova et al. 2001; Popović et al. 2002; Kollatschny & Bischoff 2002) has been very often discussed in order to explain the observed broad optical emission-line profiles in AGN. This model fits well the widely accepted AGN paradigm in that the “central engine” consists of a massive black hole fueled by an accretion disk. However, the fraction of AGNs with double-peaked lines (which may indicate the disk emission in a line) is small, and the observational evidence to support the existence of a disk is not statistically significant.

Observations in a wide band of wavelengths (X-ray, UV, optical) also indicate that an accretion disk could be present in III Zw 2. In particular, Kaastra & Korte (1988) gave some parameters for the central engine. They hold that the accretion disk has a large thickness in the central part, that it probably extends to 0.2 pc, and that the central black hole has a mass of about \(5 \times 10^7 \, M_\odot\). From the study of the emission lines, Kaastra & Korte inferred dimensions of \(\sim 7 \times 10^{18}\) and \(\sim 10^{16} \, m\) for the NLR and the BLR, respectively. Shimura & Takahara (1995) reproduced the specific UV and soft X-ray luminosities in III Zw 2 from a disk emission spectrum. More recently, Rokaki & Boisson (1999) show that the UV continuum and the Hβ line emission are compatible with an accretion disk model.

The aim of this paper is to analyze the shapes of the Hydrogen and Mg II λ2798 emission lines of III Zw 2 in order to identify features that might be associated with the emission from a rotating disk and try to find evidence that suggests that disk emission can contribute to line emission. We propose a structure for the BLR that can describe the shape of these lines. We also use a set of observations of the Hβ line, taken over a long period of time, to discuss the Hβ line shape variability.

2. OBSERVATIONS AND DATA REDUCTION

We use spectra of III Zw 2 taken from three sources: (1) 38 spectra including the Hβ line (wavelength interval 4700–5900 Å) observed at the Crimean Astrophysical Observatory (OAO) by K. K. Chuvacev with the 2.6 m Shain telescope during the period 1972–1990 (HJD 2441361 through 2448153), (2) spectra taken with the HST in 1992 that include the Lyα and Mg II λ2798 lines, and (3) three spectra taken in 1998 with the Isaac Newton Telescope (INT) at La Palma Observatory including the Hα and Hβ lines.

The spectra including the Lyα and Mg II λ2798 lines were also observed on 1992 January 18 with the HST Faint Object Spectrograph (FOS). Two different gratings were used to cover the wavelength range around the Lyα and Mg II λ2798 lines: (1) G130H in the spectral range from 1087.23 to 1605.52 Å with spectral resolution of 0.98 Å; and
(2) G270H in the spectral range from 2221.10 to 3300.10 Å with spectral resolution of 2.05 Å. Three spectra of Lyα and one of Mg ii 2798 were taken. The spectra have been reduced by the HST team, and are in the format intensity versus wavelength. We obtained an averaged spectrum of Lyα from the three observed.

At the CrAO, 38 spectra including the Hβ line (wavelength interval 4750–5900 Å) were obtained with the 2.6 m Shain telescope during the period 1972–1990. The spectral resolution was ~8 Å. The spectograph slit and seeing were in the 1′8–2′0, and 2′–3′ ranges, respectively. The spectra of Hβ were scanned with a two-coordinate CrAO microphotometer (as in the case of Ark 120; see, e.g., Stanić et al. 2000; Popović et al. 2001). The reduction procedure includes corrections for the film sensitivity, sky background, and instrumental spectral sensitivity. The wavelength and flux calibration were made using the SPE data reduction package, developed by S. G. Sergeev. The wavelength calibration was based on the night sky lines and narrow emission lines of the galaxy. The spectra have been normalized to the [O iii] 5007 emission line flux.

Hα and additional Hβ observations were performed on 1998 August 7 with the 2.5 m INT at La Palma. We used the Intermediate Dispersion Spectrograph (IDS) and the 235 camera in combination with the R1200Y grating. Two exposures of 1800 and 825 s, respectively, included Hβ, and another one of 1800 s included Hα. The seeing was 1′1 and the slit width 1′5. The spectral resolution was 1.8 Å. Standard reduction procedures including flat-fielding, wavelength calibration, spectral response, and sky subtraction were performed with the help of the IRAF software package.

The redshift of III Zw 2 was taken to be z = 0.0898 (Vérnon-Cetty & Vérnon 2000).

3. GAUSSIAN ANALYSIS

3.1. Line Profile Analysis

The first step in analyzing the emission lines was to define the continuum. In the case of Hβ the local continuum in four narrow zones around 4800, 4900, 5520, and 5600 Å was fitted with a second-order polynomial. For the Hα, Lyα and Mg ii 2798 lines the continuum was estimated using a straight line between two wavelengths: around 6900 and 7400 Å for Hα, 1200 and 1450 Å for Lyα, and 2900 and 3200 Å for the Mg ii line. We fitted each line with a sum of Gaussian components using a χ² minimization routine to obtain the best fit parameters. We have also assumed that the narrow emission lines can be represented by one or more Gaussian components (see text below). In the fitting procedure, we look for the minimal number of Gaussian components needed to fit the lines. It was found that using three broad Gaussian components provides a good fit to the profiles of the Lyα and Mg ii lines, while one additional narrow component was needed to fit the Balmer lines.

In Figures 1–5 we can recognize clear evidence of substructure in all the BELs. In the line profile with highest resolution (the Hβ spectrum from the INT; see Fig. 1), the narrow emission line is blueshifted with respect to the BEL that exhibits a gentle slope toward the red and a steeper drop toward the blue. Asymmetries are also present in the Hα, Lyα, and Mg ii BELs (Figs. 2–4). The absence of a narrow emission-line component in the Lyα and Mg ii lines indicates that the contribution of the NLR emission in these lines is minor.

3.1.1. Hβ

To study in more detail the presence of substructure we performed a multi-Gaussian fit to the INT high-resolution Hβ line profile. The low resolution and low S/N ratio of CrAO spectra could not be qualitatively decomposed into Gaussian components, and we use the spectra only for line variation investigation (see § 4). To limit the number of free parameters in the fit we have set some a priori constraints
In the first place, the three narrow Gaussians representing the two $[\text{O} \text{ iii}]$ λ4959, 5007 lines and the narrow Hβ component are fixed at the same redshift with Gaussian widths proportional to their wavelengths. Full width at half-maximum (FWHM) is connected with width of the Gaussian profile ($W$) as $\text{FWHM} = 2W(\ln 2)^{1/2}$. Second, we have linked the intensity ratio of the two $[\text{O} \text{ iii}]$ lines according to the line strengths, 1 : 3.03 (Wiese, Smith, & Glennon 1966). Finally, we have included in the fit a red shelf Fe ii template consisting of nine Fe ii lines belonging to the multiplets 25, 36, and 42 (Korista 1992). We took the relative strength of these lines from Korista (1992) and supposed that all the Fe ii lines originated in the same region; that is, all of them have the same redshift and widths proportional to their wavelengths.

We obtained reasonably good fits by considering the above-mentioned narrow and shelf components and three broad Hβ components with redshifts 0.0856 ($W = 2200 \text{ km s}^{-1}$), 0.0898 ($W = 1900 \text{ km s}^{-1}$), and 0.0950 ($W = 2800 \text{ km s}^{-1}$); see Figure 1. The central broad component is relatively weak, and, in principle, consistent fittings can be obtained with only two broad components on the basis of minimal Gaussian component assumption. Therefore, we used the F-test (Eadie et al. 1971) to compare the $\chi^2$ of two and three broad Gaussian models and find that the model with the central component leads to a significant improvement in fit quality at the 99.8% confidence level. On the other hand, as we will see, the central component is present in the other hydrogen and Mg ii lines in the same way.

We have also used the high-resolution spectra from the INT to study in detail the $[\text{O} \text{ iii}]$ lines. To do this we have subtracted from the original spectrum all the Hβ components (broad and narrow) and the Fe ii shelf, obtaining the spectrum shown in Figure 5. In this figure we note that both $[\text{O} \text{ iii}]$ lines show very extended wings and cannot properly be fitted by a Gaussian. We also notice that the wings are asymmetrical, being more gently sloped toward the blue. We have performed a multi-Gaussian fit to these lines, finding that at least one relatively broad ($W = 410 \text{ km s}^{-1}$) and blueshifted (0.0875) component should be included to account for the extended wings (see Fig. 5). One can expect that other narrow lines in the optical spectra have the same shape as the $[\text{O} \text{ iii}]$ ones and that the $[\text{O} \text{ iii}]$ line profile can be used as template to fit these lines. Taking into account that the other narrow lines are very weak compared to the corresponding broad one (see, e.g., $[\text{N} \text{ ii}]$ in the Hα wavelength region) the asymmetry seen in $[\text{O} \text{ iii}]$ will not significantly affect the line profile, and for the purposes of the paper the narrow lines can be satisfactorily fitted with one single

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**Fig. 3.**—Same as in Fig. 1, but for the averaged shape of the Lyα line. The dashed lines, at the bottom, represent the contribution of the narrow emission and absorption lines (see text for details).

**Fig. 4.**—Same as in Fig. 1, but for the Mg ii 2798 Å line. The dashed complex lines, at the bottom, represent the contribution of the Fe ii template.
Gaussian. On the other hand, we cannot be sure that all the narrow lines are emitted under the same kinematic and physical conditions.

### 3.1.2. H\(\alpha\)

To fit the H\(\alpha\) line, we have assumed that [N\(\text{ii}\)] \(\lambda\)6548, 6583 and the H\(\alpha\) narrow component have the same redshift and Gaussian widths proportional to their wavelengths. Taking into account that the two [N\(\text{ii}\)] lines belong to the transition within the same multiplet, we assume an intensity ratio of 1:2.96 (see, e.g., Wiese et al. 1966). However, a simple inspection of Figure 2 shows that the peak of the [N\(\text{ii}\)] \(\lambda\)6548 line is higher than the peak of the [N\(\text{ii}\)] \(\lambda\)6583 line. This may indicate the presence of a blueward asymmetric underlying component. We have been only partially successful in reproducing the narrow [N\(\text{ii}\)] \(\lambda\)6548 line. This is not very important at this stage, but we will need to clean it from the line profile to fit the disk model in § 5. For this reason we have considered an additional arbitrary narrow component at \(\lambda\)6548 to totally remove this line.

In this case we also found good fits, in addition to these narrow components, three broad components for H\(\alpha\) (see Fig. 2). As in the H\(\beta\) case, there is a central broad component (\(z = 0.0898\), \(W = 1250\) km s\(^{-1}\)) located between two other broad components, redshifted (\(z = 0.095\), \(W = 2500\) km s\(^{-1}\)) and blueshifted (\(z = 0.0861\), \(W = 2330\) km s\(^{-1}\)) ones. In the case of H\(\alpha\), the broad central component contributes a larger fraction of the integrated emission-line flux than does the corresponding component in H\(\beta\).

### 3.1.3. Ly\(\alpha\)

The complex Ly\(\alpha\) shape contains three absorption lines and two narrow emission lines; Figure 3. In order to clean the absorption lines as well as the emission satellite lines we assume that each one of them can be represented by a Gaussian. The central absorption line is redshifted around 0.0888 and probably arises from a Ly\(\alpha\) autoabsorption. The feature at \(\lambda \approx 1335\) \(\AA\) is possibly an intrinsic N\(\nu\) absorption (Crenshaw et al. 1999). The very weak absorption component in the blue wing might be the Si\(\text{iii}\) \(\lambda\)1207 line (see, e.g., Laor et al. 1994, 1995). The two narrow emission lines in the blue wing are very close to the Si\(\text{iii}\) \(\lambda\)1195, 1197 lines (Laor et al. 1994, 1995), but the observed line profiles are too narrow, which would not be expected for these permitted Si transitions. This feature can be identified as contribution of geocoronal O i \(\lambda\lambda 1302, 1306\) emission lines (see Eracleous 1998). The lines were fitted with two Gaussians and subtracted from the Ly\(\alpha\) blue wing.

In the red wing of the Ly\(\alpha\) line appear the N\(\nu\) \(\lambda\lambda 1239, 1243\) lines (Wilkes & Carswell 1982; Buson & Ulrich 1990; Laor et al. 1994, 1995). In order to subtract these lines we supposed that they come from the same emission region, i.e., that they have the same \(W/\lambda\) and intensity ratio \(I(1238)/I(1242) = 1.98\) (Wiese et al. 1966).

We needed three broad components to perform the multi-Gaussian fitting of the Ly\(\alpha\) line (Fig. 3) with parameters \(W \approx 3150\) km s\(^{-1}\), \(z \approx 0.083\); \(W \approx 1380\) km s\(^{-1}\), \(z \approx 0.0889\); and \(W \approx 3250\) km s\(^{-1}\), \(z \approx 0.0943\). The width and redshift of the Gaussians fitted to the N\(\nu\) lines were 2270 km s\(^{-1}\) and \(z \approx 0.0898\), respectively. The estimated ratio of \(I(\text{N}\nu)/I(\text{Ly}\alpha)\) is around 0.12, in a very good agreement with previous estimates (Laor et al. 1994, 1995).

### 3.1.4. Mg\(\text{ii}\) \(\lambda\)2798

The contribution of 33 Mg\(\text{ii}\) lines from multiplets 60, 61, 62, and 63 to the red and blue wing of Mg\(\text{ii}\) \(\lambda\)2798 has been taken into account. We assume that line intensities ratio within a multiplet is proportional to the ratio of corresponding line strengths. The atomic data for the line strength we took from the NIST website.\(^5\) We also assume that the Fe\(\text{ii}\) emission originates in the same region; i.e., the lines have the same width and shift. The decomposition of Mg\(\text{ii}\) \(\lambda\)2798 is shown in Figure 4. The scaled and broadened Fe\(\text{ii}\) template is indicated by the dashed lines (bottom). As in the case of the H\(\beta\), H\(\alpha\), and Ly\(\alpha\) lines, the Mg\(\text{ii}\) line can be decomposed into three broad Gaussian components (Fig. 4) with parameters \(W \approx 2700\) km s\(^{-1}\), \(z \approx 0.0843\); \(W \approx 1450\) km s\(^{-1}\), \(z \approx 0.0896\); and \(W \approx 3600\) km s\(^{-1}\), \(z \approx 0.0980\). The lines from the Fe\(\text{ii}\) template have \(W = 2100\) km s\(^{-1}\), \(z = 0.0898\).

### 3.2. Discussion of the Multi-Gaussian Analysis

In Figure 6 we present the width of the different broad components versus their centroid velocities (relative to the systemic one). The different components appear well separated in this diagram, showing the consistency of the multi-Gaussian decomposition. By inspection of the diagram we can derive the following conclusions:

1. The best fit with Gaussian functions can be obtained only if we use three broad Gaussians.
2. The Gaussian decomposition indicates the existence of a central broad component of redshift consistent with the systemic velocity.
3. The presence of red- and blueshifted broad components in the case of all considered lines suggests that part of the emission may originate in a different region, possibly a disk.

If we assume that a disk (or a disklike region) exists, we can roughly estimate the parameters of the disk using the results of Gaussian analysis and the relationship (see

\(^5\) See http://physics.nist.gov/PhysRefData/contents-atomic.html.

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**Fig. 6.**—Width, \(W\), of Gaussians as a function of the shift. The used notation is as follows: full squares for Ly\(\alpha\), full circles for H\(\beta\) observed with INT, asterisks for H\(\alpha\), and open squares for the Mg\(\text{ii}\) line.
Popović et al. 2002)

\[ \sin i \approx \Delta z \sqrt{R_{\text{out}}} \]

where \( i \) is the inclination of the disk, and \( R_{\text{out}} \) is the outer radius given in Schwarzschild radii \( (R_{\text{Sch}} = 2GM/c^2) \). Taking into account that \( \sin i \leq 1 \), we can estimate the maximal outer radius. From our analysis we find that \( \Delta z = z_p - z_R \) (where \( z_p \) and \( z_R \) are the shift of the red and blue Gaussians, respectively) is in the interval from 0.0086 (for H\( \alpha \)) to 0.014 (for Mg \( \text{n} 2798 \) line). Then we can estimate the maximal outer radius, \( R_{\text{out}}^{\text{max}} < 10^4 R_{\text{Sch}} \). On the other hand, if we accept from previous investigations (e.g., Wandel, Peterson, & Malkan 1999; Kaspi et al. 2000; Popović et al. 2001, 2002) that the outer radius of a BLR has typical dimensions of \(~1000R_{\text{Sch}}\), we estimate that \( i \sim 10^\circ - 20^\circ \). This can be used as a starting point in analyzing the line shapes using a more complex model of the BLR.

The inclination we obtain is significantly smaller than the one obtained by Rokaki & Boisson (1999) for III Zw 2, but at the same time it is in agreement with a mean value of disk inclination of 21 Seyfert 1 galaxies given by these authors, as well as with their conclusion that “we tend to observe the Seyfert 1 galaxies at a more face-on inclination” (Rokaki & Boisson 1999).

4. VARIABILITY

We have used the long-term H\( \beta \) observations to discuss the variability of the BELs. With this aim we have removed from each observed spectrum its continuum and used the emission in the narrow [O \text{ iii}] \( \lambda 5007 \) line to normalize the spectra. The high-resolution spectrum obtained with the INT has been smoothed to match spectral resolution of the CrAO spectra. Five spectra of low S/N were rejected from the whole set.

To find any variation in the H\( \beta \) line profile along the observed period we constructed profiles of the mean, the rms, and the rms divided by the square root of the mean (Figs. 7a–7c). As one can see in Figure 7a, the mean profile is single-peaked and asymmetric with traces of shoulders in the blue and red wings that might represent substructure connected with emission from a disk. The shoulders appear clearly enhanced in Figure 7b; a more prominent one is at \( X \sim -0.008 \) and the other two maxima at \( X \sim 0.006 \) and 0.012, respectively \([X = (\lambda - \lambda_0)/\lambda_0]\). According to Figure 7c, the highest variations are found in the region including these features between approximately \( X \sim -0.01 \) and \( X \sim 0.013 \). In principle, a part of the variability in the red part of the H\( \beta \) emission line might be attributable to changes in the Fe \( \Pi \) contribution; however, we do not find evidences of variability in the stronger Fe \( \Pi \) component beneath [O \text{ iii}] (see Figs. 7b and 7c). Leaving aside the H\( \beta \) profile, the strong dispersion in the residual He \( \Pi \) line at \( X \sim -0.018 \) is noticeable.

In order to study the line flux variation during the observed period, we present in Figure 8a the integrated flux (H\( \beta \) plus [O \text{ iii}], Fe \( \Pi \), and He \( \Pi \) lines) between 4750 Å and 5050 Å (rest wavelengths) for each one of the individual spectra. The resulting integrated light curve decreases \(~50\%\) from 1972 to 1998. To improve the S/N ratio we have considered seven sets of spectra (defined according to the observational gaps; see Fig. 8a) averaging the spectra within each set. The averaged light curve (Fig. 8b) reproduces the variation inferred from the individual spectra and is in good qualitative agreement with the slowly decreasing trend found by Salvi et al. in the optical B-band (see Fig. 7 in Salvi et al. 2002).

To study the flux variation of different parts of the line, we have applied to the seven averaged spectra the same Gaussian analysis made in § 3.1.1. To improve the fits we have, in the first place, fitted the mean H\( \beta \) profile obtaining centroids for the three broad Gaussians, central \((\sim 0.0893)\), blueshifted \((\sim 0.084)\), and redshifted \((\sim 0.0953)\), similar to the ones obtained from the INT H\( \beta \) profile (§ 3.1.1). In a second step we performed the Gaussian fit of the seven

![Fig. 7](image-url)

Fig. 7.—(a) Mean H\( \beta \) line profile obtained from 34 spectra (33 from CrAO and 1 from INT), (b) the corresponding rms profile, and (c) the rms divided by the square root of the mean profile. The intensity scale for H\( \beta \) line is from 0.0 to 0.5, for H\( \beta \) rms is from 0.0 to 0.06, and for rms divided by the square root of the mean profile is from 0.0 to 0.1 in units of [O \text{ iii}] \( \lambda 5007 \) line flux. The value \( X \) is \((\lambda - \lambda_0)/\lambda_0\).
averaged spectra fixing the Gaussian centroids to these values. The results of this analysis can be seen in Figures 8 and 9. In Figure 8c we present the variation of the sum of the three Gaussians. This light curve is practically the same as the one corresponding to the integrated flux (Fig. 8b). This confirms that the main contribution to the flux variation in the considered wavelength range is the variation of the H/β broad component. In Figures 9a–9c, the light curves corresponding to each of the three Gaussian components are presented. The variation in the blue and red Gaussians (with an amplitude greater than that of the central Gaussian) tends to be correlated, once again supporting the assumption of the existence of two regions contributing differently to the H/β broad emission line profile.

5. TWO-COMPONENT MODEL ANALYSIS

As mentioned in the introduction, the accretion disk model was taken into consideration for III Zw 2 in previous investigations (Kastra & Korte 1988; Shimura & Takahara 1995; Rokaki & Boisson 1999). The shape of the line profiles discussed in the present paper (two red- and blueshifted broad components) and our preliminary analysis also support this idea. Besides, the multi-Gaussian fitting also implies the presence of a central component with the systemic velocity. According to this result, in this section we fit the lines using a two-component model based on a disk and a central Gaussian component that can be interpreted as a region surrounding the disk.

For the disk we use the Keplerian relativistic model of Chen & Halpern (1989). The emissivity of the disk as a function of radius, R, is given by $c = c_0 R^{-p}$.

Considering that the illumination is due to an extended source from the center of the disk and that the radiation is isotropic, the flux from the outer disk at different radii should vary as $r^{-3}$ (Eracleous & Halpern 1994); i.e., $p = 3$, and that is value we adopt. We express the disk dimension in gravitational radii ($R_g = GM/c^2$, G being the gravitational constant, $M$ the mass of the central black hole, and $c$ the velocity of light). The local broadening ($\sigma$) and shift ($z_{Disk}$) within the disk have been taken into account (Chen & Halpern 1989); i.e., the $\delta$ function has been replaced by a Gaussian function (with the mentioned parameters).

Before performing the fitting we have “cleaned” the spectra by subtracting (1) the narrow lines from INT high-resolution H/β and H/α; (2) the absorption features, the narrow emission in the blue wing, and the N v lines from Ly/α; (3) the narrow [O iii] lines and the Fe ii template from H/β; and (4) the Fe ii template from the blue and red wings of the Mg ii line. It is striking that after this operation is done, the features associated with the disk are visible not only in the asymmetrical wings of Mg ii, but also in the red and blue shoulders of the Ly/α and H/α as well as in the triangular shape and the red shoulder of H/β (see Fig. 10). To compare the line profiles we present in Figure 10a the intensities normalized to the peak ones versus $X = (\lambda - \lambda_0)/\lambda_0$. As one can see from Figure 10a, the lines have similar shapes.

When a chi-square minimization including all the parameters at once is attempted, it is found that the results are very dependent on the initial values given to the parameters. To overcome this problem we have, in the first place, tried several values for the inclination using an averaged profile.

Fig. 8.—Variation of (a) the flux ($F_n$) of spectra in H/β line region (H/β plus [O iii] and Fe ii lines) normalized to the flux of mean spectra in H/β line region, (b) the same variation of averaged spectra of the seven considered groups, and (c) the total broad-line flux ($F_{blr}$ sum of fluxes of red, blue, and central components obtained from Gaussian analysis) of seven considered groups normalized to the corresponding broad-component flux of mean H/β line. The time is given in 100 JD, starting from the epoch 2,440,000 (1968 May 23).

Fig. 9.—Flux variations of (a) the blue, $F_b$, (b) the red, $F_r$, and (c) the central, $F_c$, H/β components normalized to the corresponding component from the mean H/β line. The time is given in 100 JD, starting from the epoch 2,440,000.
of all four lines (Fig. 10b). We found that the best by-eye fits can be obtained for values of $i \approx 12^\circ$. Accordingly we have fixed it to $i = 12^\circ$ and performed a $\chi^2$ fitting of the other parameters starting from suitable initial values. The fit of the BELs wings strongly restricts the value of the inner radius and additional “local” broadening, i.e., random velocity of emission gas in the disk. This fact (related to the emissivity dependence, $p \approx -3$) supports the validity of the determination of these parameter from the line profile fits. We note here that by changing the inner (outer) radius of

the disk and parameter $p$ we can obtain a satisfactory fit with inclination $12^\circ \pm 5^\circ$.

The results of the fit are presented in Figures 10b–10f, and the disk and Gaussian parameters in Table 1. This table enables us to point out the following results: (1) There is a very good consistency among the parameters ($z$ and $W$) of the broad components representing the region surrounding the disk. Their redshifts exhibit a very small difference with respect to the redshift of the [O III] narrow lines. (2) There is also a good consistency in the redshifts for the disk corresponding to Ly$\alpha$, H$\alpha$, H$\beta$, and Mg II. The average $z$ for these four disk lines appears to be slightly blueshifted (by about 600 km s$^{-1}$) with respect to the systemic one. (3) The inner radius of the Ly$\alpha$-emitting disk is clearly smaller than the others. H$\alpha$ and H$\beta$ exhibit a very good coincidence of the inner radii, but the inner edge of the Mg II emission ring seems to be closer to the disk center, although this point should be viewed with caution. (4) The disk emission component contributes more to the total flux than the low-velocity component of the BLR.

Taking into account the estimated mass of the central object in III Zw 2 ($M \sim 2 \times 10^8 M_\odot$) given by Vestergaard (2002), we can obtain the dimensions of the radiating disk: $R_{\text{in}} \approx 5 \times 10^{13}$ m, $R_{\text{out}} \approx 3 \times 10^{14}$ m. This last value is in agreement with the estimation given by Kaastra & Korte (1988; ~2 $\times 10^{14}$ m). The size of the whole BLR (disk + surrounding region) cannot be inferred from this analysis but it might be considerably larger (Collin & Hure 2001). On the other hand, the BLR surrounding the disk may originate from an accretion disk wind, that may be created because of several disturbances capable of producing shocks (e.g., Bondi-Hoyle flow, mutual stellar wind collisions, and turbulences, see, e.g., Fromerth & Melia 2001). Also, a Keplerian disk with disk wind can produce single peaked broad emission lines (Murray & Chiang 1997). Recently, Fromerth & Melia (2001) described a scenario of the formation of BLR in the accretion disk shocks, which can create a surrounding BLR.

We should mentioned here that other geometries can contribute to the substructure seen in III Zw 2 line shapes. Besides emission of the disk (or disklike region) or emission from spiral shock waves within a disk (Chen et al. 1989; Chen & Halpern 1989), the following geometries may cause substructures in line profiles: (1) emission from the oppositely-directed sides of a bipolar outflow (Zheng, Binette, & Sulentic 1990; Zheng, Veilleux, & Grandi 1991); (2) emission from a spherical system of clouds in randomly inclined Keplerian orbits, illuminated anisotropically from the

![Figure 10](image_url)

**Figure 10.**—Observed lines of III Zw 2 (dots), fitted with the disk model (double-peaked) and one Gaussian. (a) The comparison of all line profiles (dashed lines) with an averaged one (solid line). (b) Fit of the averaged line profile. Panels c, d, e, and f represent fits of Ly$\alpha$, Mg II, H$\beta$, and H$\alpha$ lines, respectively. The value $X$ is $(\lambda - \lambda_0)/\lambda_0$.  

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### Table 1

| Line        | $z_{\text{disk}}$ | $\sigma$ (km s$^{-1}$) | $R_{\text{in}} (R_g)$ | $R_{\text{out}} (R_g)$ | $z_G$ | $W_G$ (km s$^{-1}$) | $F_B/F_G$ |
|-------------|-------------------|-------------------------|------------------------|------------------------|-------|---------------------|-----------|
| Ly$\alpha$  | -800              | 850                     | 200                    | 900                    | -20   | 1280                | 1.11      |
| Mg II λ2789 | -350              | 920                     | 300                    | 1000                   | -30   | 1100                | 1.86      |
| H$\beta$    | -600              | 920                     | 400                    | 1300                   | -130  | 1100                | 3.14      |
| H$\alpha$   | -600              | 850                     | 450                    | 1300                   | -120  | 1170                | 1.52      |
| $\langle AV \rangle$ | -600 | 890 | 400 | 1200 | -120 | 1170 | 1.72 |

**Notes.**—Explanation of symbols: $z_{\text{disk}}$ is the shift, $\sigma$ is the Gaussian broadening term from disk indicating the random velocity in disk, $R_{\text{in}}$ is the inner radius, and $R_{\text{out}}$ is the outer radius. The $z_G$ and $W_G$ represent the parameters of the Gaussian component. $\langle AV \rangle$ is an averaged profile (see Fig. 10b). $F_B/F_G$ represents the ratio of the relative disk and Gaussian fluxes.
center (Goad & Wanders 1996); and (3) emission of the binary black hole system (Gaskell 1983, 1996). In any case, the two-component model should be taken into account, considering a low-velocity BLR and one additional emitting region.

6. CONCLUSIONS

We have analyzed UV spectra and a collection of optical spectra of III Zw 2 procured in over 20 years. The flux of Hβ spectra shows variability in the wings, as well as in the line core. The variation of the blue and red wing fluxes tends to correlate during the considered period. It indicates that line wings originate in the same region, while the line core arises from another emission-line region (low-velocity BLR). We have also discussed the possible contribution of a Keplerian disk of emitters to the BELs, finding the following results:

(1) The shape of the BELs (especially after removing the narrow and absorption lines) indicates a multicomponent origin, and certain features—like the shoulders in Lyα, Hα and Hβ and the slight profile asymmetries—that can be associated with a disk.

(2) The same two-component model (Keplerian relativistic disk + a surrounding emission region) can consistently fit the four BELs considered here (Lyα, Mg ii, Hβ, and Hα).

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