THREE-DIMENSIONAL SPECTROSCOPIC STUDY OF THE LINE-EMITTING REGIONS OF Mrk 493

L. Č. POPOVIĆ1,2, A. A. SMIRNOVA3, J. KOVAČEVIĆ1,2, A. V. MOISEEV3, AND V. L. AFANASIEV3

1 Astronomical Observatory, Volgina 7, 11160 Belgrade, Serbia
2 Isaac Newton Institute, Yugoslavia Branch, Yugoslavia
3 Special Astrophysical Observatory, Nizhnii Arkhyz, Karachaevo-Cherkesia 369167, Russia

Received 2008 August 10; accepted 2008 December 26; published 2009 February 17

ABSTRACT

We report the results of three-dimensional spectroscopic observations of Mrk 493 (narrow-line Seyfert 1 galaxy) with the integral-field spectrograph MultiPupil Fiber Spectrograph of the Special Astrophysical Observatory of the Russian Academy of Sciences 6 m telescope. The difference in the slope of the optical continuum emission intensity across the nucleus part and an extensive continuum emission region is detected. The emission in lines (Hα, Hβ, [O iii], etc.) coincides with a composite nuclear region: an active galactic nucleus plus a circumnuclear star-forming region observed in the Hubble Space Telescope UV/optical images. The [S ii] emission region tends to be up to 1 kpc around the center. The Hα and Hβ could be decomposed into three components (broad ~2000 km s\(^{-1}\), intermediate ~700 km s\(^{-1}\), and narrow ~250 km s\(^{-1}\)). We found that the width (~750 km s\(^{-1}\)) of the Fe ii lines corresponds to the intermediate component that may indicate a non-wide-line region (non-BLR) origin of the Fe ii lines, or that a large fraction of the Fe ii emission arises in the outer parts of the BLR.

1 INTRODUCTION

Mrk 493, a narrow-line Seyfert 1 galaxy (NLS1), is known as an active galactic nucleus (AGN) with a strong Fe ii emission (Osterbrock & Pogge 1985; Crenshaw et al. 1991). NLS1s have been recognized as a distinct type of Seyfert nuclei. The optical emission-line properties of NLS1s can be summarized as (e.g., Osterbrock & Pogge 1985; Komossa 2008) follows: (1) the Balmer lines are only slightly broader than the forbidden lines such as [O iii]\(\lambda\lambda 5007\) (typically less than 2000 km s\(^{-1}\)). The [O iii]\(\lambda 5007\)/Hβ intensity ratio is smaller than 3. (3) They present the strong Fe ii emission that is often seen in Sy 1’s but generally not in Sy 2’s. Moreover, the X-ray spectra of NLS1’s are very steep (e.g., Boller et al. 1996; Leighly 1999a, 1999b) and highly variable (Boller et al. 1996; Leighly 1999a; Gliozzi et al. 2007). Also, it was found that NLS1s have less-massive black hole masses than Sy 1s (Mathur 2000; Wang & Zhang 2007) and could be young Sy 1s (Botte et al. 2004). Even though NLS1s have been known for almost more than 20 years, it is still not clearly understood what NLS1s are in the context of the current AGN-unified model (Nagao et al. 2001).

One of the interesting observational facts connected with NLS1 is that in their spectra a strong Fe ii emission is present. It was shown by Boroson & Green (1992) that a strong anticorrelation between the strengths of the [O iii] and Fe ii line intensities exists in the optical spectra, where NLS1s are showing the strongest Fe ii and weakest [O iii] emission. The observed line widths and the absence of the forbidden emission suggest that the Fe ii lines are formed in the dense broad-line region (BLR), but photoionization models cannot account for all of the Fe ii emission. The “Fe ii discrepancy” remains unsolved, though models which consider nonradiative heating with an overabundance of iron are promising (Joly 1993; Collin & Joly 2000). Also Mathur (2000) proposed that the strong Fe ii emission observed in NLS1s may be connected with their large accretion rates and that a collisional ionization origin of Fe ii is possible.

Here, we report three-dimensional spectroscopic observations of Mrk 493. The aims of the observations were (1) to investigate the characteristics of the Fe ii emitting region and their possible connection with other emitting regions (Hα, Hβ, [O iii], . . .) and (2) to map the circumnuclear emitting gas in this type of AGN. In this paper, we accepted a distance to Mrk 493 of 125.2 Mpc (for \(H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}\)), where 1″ on the sky corresponds to 610 pc at the galaxy distance.

2 OBSERVATIONS AND DATA REDUCTION

The observational data were obtained at the prime focus of the Russian 6 m telescope of the Special Astrophysical Observatory (SAO). The central region of the galaxy was observed with the MultiPupil Fiber Spectrograph (MPFS). MPFS (Afanasiev et al. 2001) takes simultaneous spectra from 256 spatial elements (constructed in the shape of square lenses) that form on the sky an array of 16 × 16 elements with the angular size 1″ per element. A bundle of 17 fibers placed at the distance about 3.5 from the lens array provides the night-sky background spectra simultaneously with object’s exposition. We have observed Mrk 493 twice in the years 2004 and 2007, in the low- and high-resolution spectral modes (see Table 1).

The spectral ranges included numerous emission lines of ionized gas ([O i]\(\lambda\lambda 6300, [O III]\lambda\lambda 4959, 5007, [N II]\lambda\lambda 6548, 6583, [S II]\lambda\lambda 6717, 6731, \) the Balmer Hα and Hβ lines). The spectra were reduced using the IDL-based software developed at the SAO of the Russian Academy of Sciences (RAS), and the data reduction sequence is briefly described in Moiseev et al. (2004). Namely, the primary reduction included bias subtraction, flat-fielding, cosmic-ray hits removal, extraction of individual spectra from the CCD frames, and their wavelength calibration using
The spatial element of a three-dimensional spectra.

...algorithm similar to that described by Arribas et al. (1999). The data of galactic images at different wavelengths) by using the algorithm similar to that described by Arribas et al. (1999). The data reduction results in a data cube in which a spectrum corresponds to each image “spaxel” in two-dimensional field 16′ × 16′. The seeing values shown in Table 1 were estimated from the MPFS observations of stars right before the object observations. Here, we fitted by two-dimensional Moffat function the star images in their data cubes. Additionally, we observed broadband direct images of the galaxy in the filters B, V, and Rc with the focal reducer SCORPIO (Afanasiev & Moiseev 2005). The seeing was 1′′/3, the total expositions were 400 s in B and 360 s in V and Rc bands, respectively. These images seem slightly deeper than POSS and Sloan Digital Sky Survey (SDSS) archival data; we confidently detected outer low-brightness grand-design structure in this barred galaxy (Figure 1).

3. RESULTS AND DISCUSSION

3.1. The Continuum and Line Fluxes Distribution Across Mrk 493 Nucleus

First, we explore the brightness distribution across Mrk 493 nucleus in different wavelength bands. In Figure 2, we presented the maps of emission lines. Each pixel on these maps corresponds to the flux obtained by Gaussian fitting of the lines or simple by integration around 6200 Å in the continuum. The maps of the [O iii]λ5007 and [S ii]λλ6717, 6731 were constructed using a single-Gaussian fitting, while the maps in the Hβ and Hα regions are separately constructed for the narrow as well as for the broad Gaussian components of these lines.

Also, we made a map of the Fe ii features (left and right from Hβ+[O iii] lines), integrating the all emission (after subtracting the continuum) in the wavelength range from 4600 to 4800 Å (blue shelf) and 5200 to 5500 Å (red shelf). The maximum of the Fe ii emission corresponds to the optical center of Mrk 493 (i.e., the continuum emission).

In order to investigate the spatial extension of the emission-line regions, we fitted the images of the starlike nucleus with two-dimensional Moffat function. We assumed that the full width at half-maximum (FWHM) of the two-dimensional Moffat function represents the dimension of the regions. The results of the fitting are shown in Figure 2. We should note here that the sizes (FWHM) of the nuclear emission-line region (except [S ii] lines) are almost the same or slightly larger (2′′) than was the seeing during the observations (1.7 ± 0.2′′). Therefore, the dimension of the Fe ii, [O iii], and the narrow and broad Balmer line-emitting regions seems to be practically the same. It might be caused by the spatial resolution of the instrument, but in any case there is a compact [O iii] region, smaller than the continuum and [S ii] one (see Figure 2). The [S ii]-emission region tends to be up to 1 kpc around the center.

Also, we found that the continuum slope and the Hα/Hβ line flux ratio are changing across the circumnuclear region (an example is shown in Figure 3). It indicates (as well as the dimension of the continuum source, see Figure 2) that the contribution to the continuum is coming not only from the nucleus but also from the circumnuclear region. The blue bump (see Figure 3) in the continuum flux may be caused by the UV radiation from an accretion disk or by the violent star formation in the circumnuclear ring. Note that a similar effect can be caused by the different dust absorption (inartistic reddening) across the central part.

3.2. Fe ii Emission Region in Mrk 493

As can be seen in Table 1, three-dimensional spectra of Mrk 493 were observed in two epochs, in 2004 and 2007. Consequently, first we were looking for the line/continuum changes between these epochs. To do that, we found a summary spectra for both epochs around the central part. To avoid errors caused by the procedure of spectra elaboration (flux calibration, different number of spaxels taken in summary spectra in different epochs, etc.) we normalized both spectra on the maximal intensity of the Hβ line. In Figure 4, we presented the normalized spectra to the maximal intensity of the Hβ line. As can be seen in Figure 4, there is no significant difference between the spectra (in the lines and continuum) observed in these two epochs (a three-year period). Only a slight difference can be noted in the He ii λ 4686 Å wavelength range (see Figure 4, bottom) that is probably caused by changing in this line. A marginal difference between the spectra (see Figure 4 bottom, for λc < 4750 Å) is caused by different spectral resolution (see Table 1). Note here that Klimek et al. (2004) found a slight long-term variation in the V-band of Mrk 493 (~ ±0.15, see their Figure 18).

Table 1

| Date     | Texp (s) | Sp. Range (Å) | Sp. Res. (Å) | Seeing (arcsec) |
|----------|----------|---------------|--------------|-----------------|
| 2004 May 21 | 4800     | 4150–5650     | 4            | 1.5 ± 0.2      |
| 2007 May 18 | 7200     | 4300–7200     | 8            | 1.7 ± 0.2      |

Figure 1. Composite BVR′C color image obtained with SCORPIO at 6 m telescope. The large red box shows the region observed with MPFS. The small green box marks the field shown in the bottom right corner. It is the HST WFPC2 image in the optical band with F606W filter. (A color version of this figure is available in the online journal.)

Figure 4. (Top) Emission-region map for the [O iii]λλ5007, 5270 emission line. The green box marks the field shown in the bottom right corner. (Bottom) Emission-region map for the Hβ emission line. As can be seen in Figure 4, there is no significant difference between the spectra (in the lines and continuum) observed in these two epochs (a three-year period). Only a slight difference can be noted in the He ii λ 4686 Å wavelength range (see Figure 4, bottom) that is probably caused by changing in this line. A marginal difference between the spectra (see Figure 4 bottom, for λc < 4750 Å) is caused by different spectral resolution (see Table 1). Note here that Klimek et al. (2004) found a slight long-term variation in the V-band of Mrk 493 (~ ±0.15, see their Figure 18).
In order to find the parameters of the Fe \(\text{II}\) line-emitting region and its possible correlation with the H\(\beta\) line-emitting one, we use the high-resolution spectra. We fitted the Fe \(\text{II}\) and H\(\beta\) lines in the nucleus region in order to compare the kinematic parameters of the Fe \(\text{II}\) and H\(\beta\) line-emitting regions (Figure 5). Also, we fitted the H\(\alpha\)+[N \(\text{II}\)] wavelength band (Figure 6) in the low-resolution spectral data cube in order to compare kinematics of the H\(\beta\)- and H\(\alpha\)-emitting regions.

There are several ways to fit the Fe \(\text{II}\) template (red and blue shelf, see, e.g., Boroson & Green 1992; Popović et al. 2004; Veron-Cetty et al. 2006). We use a template of 53 most intensive Fe \(\text{II}\) lines in the spectral interval from 4400 Å to 5400 Å from five types of transitions with 3\(d^6\)\((3\,F_2)4s\,^4F,\ 3d^54s^2\,^6S,\ 3d^6\(3G\)4s\,^4G,\ 3p^63d^7\,^2D,\ and\ 3d^6(5D)4s\,^6D\) lower-level configurations. Each of the 53 lines is assumed to have Gaussian profile.
To constrain the number of fitting parameters, we assumed the following.

1. All Fe ii lines are coming from the same emitting region, therefore the widths \( W \) and shifts \( d \) of the Gaussians representing the lines are the same.

2. The line intensities within one transition defined by low-level configuration have been connected with the relation (J. Kovačević et al. 2008, in preparation):

\[
\frac{I_1}{I_2} \approx \left( \frac{\lambda_2}{\lambda_1} \right)^3 f_1 f_2 g_1 g_2.
\]

where \( I_1 \) and \( I_2 \) are the intensities of the lines with the same lower level of a transition, \( \lambda_1 \) and \( \lambda_2 \) are the line-transition wavelengths, \( f_1 \) and \( f_2 \) are the corresponding statistical weights, \( g_1 \) and \( g_2 \) are the oscillator strengths, and \( E_1 \) and \( E_2 \) are the energies of the upper level of transitions.

3. The intensity ratio of the \([\text{O} \, \text{iii}] \lambda 4959, 5007 \) \( \AA \) lines was fixed as 1:3 (see Dimitrijević et al. 2007), and we also assumed that all narrow lines (\([\text{O} \, \text{iii}] \) and narrow \( \text{H} \beta \)) have the same width and shift.

4. In summary, we fitted the wavelength region \( \text{Fe} \, \text{ii}+\text{H} \beta+\text{[O} \, \text{iii}] \) with a sum of Gaussian functions (Figure 5(A)), from which 53 represent the Fe ii template (heaving the same widths and shifts, Figure 5(C)). To find the best fit, we use \( \chi^2 \) minimization routine.

Also, we used low-resolution spectra to fit (with the same sum of Gaussian functions) the \( \text{H} \alpha \) and \( \text{H} \beta \) lines. We were able to find a good and consistent fit (having the similar parameters for the corresponding Gaussian function in both lines) using three-Gaussian fitting (see Figures 5 and 6). Two-Gaussian model for broad \( \text{H} \alpha \) and \( \text{H} \beta \) cannot properly fit the line profiles, since there are far wings in these lines (especially in \( \text{H} \alpha \), see Figure 6). Moreover, an \( F \)-test shows that the three-Gaussian assumption is statistically better than the two-Gaussian one. Note here that often three regions in AGN have been considered (see, e.g., Sulentic et al. 2000). Consequently, we fitted \( \text{H} \alpha \) and \( \text{H} \beta \) with three Gaussian functions, aiming that the parameters of Gaussian for the same spectrum (obtained from one spaxel) have similar values for both lines (fitting the spectra observed in 2007). Note here that recently Hu et al. (2008a) reported that the BLR of AGN is composed from two emitting regions.

We were able to fit the emission lines from 16 and 21 spaxels of high- (observed in 2004) and low- (observed in 2007) resolution spectra, respectively. In both cases, we selected only spectra around the center where each of them, the \( \text{H} \beta \) or/and \( \text{H} \alpha \), can be decomposed into three components (broad \( W_B \), intermediate \( W_I \), and narrow \( W_{\text{NLR}} \)) and where the signal-to-noise ratio \((S/N)\) was good enough that the far wings are well defined. The parameters of the best fit of spectra from each spaxel are given in Tables 2–4. In Tables 2 and 3, the parameters of the best fit for 16 high-resolution spectra are presented. As can be seen from Tables 2 and 3, the obtained parameter values for different spaxels are consistent, and differences between the parameters from different spaxels are probably caused by the accuracy of the fitting procedure. The same is in the case of the low-resolution spectra (Table 4). As one can see from Tables 2 and 3, the averaged values of widths of the \( \text{H} \beta \) line components are \( W_R = (2380 \pm 200) \) km s\(^{-1}\), \( W_I = (790 \pm 80) \) km s\(^{-1}\), and \( W_{\text{NLR}} = (250 \pm 40) \) km s\(^{-15}\) \((W_{\text{NLR}}) \) is assumed to be the same as the narrow \([\text{O} \, \text{iii}] \) line width). The broadest component is weak and it is interesting that it is slightly more intensive than the \( \text{He} \lambda 4686 \) line (Gaussian represented with the solid line left from the \( \text{H} \beta \) in Figure 5(B)). In all spectra the broadest component shows the blueshift of \((-429 \pm 133) \) km s\(^{-1}\) with respect to the narrow \([\text{O} \, \text{iii}] \) lines, while the intermediate component shows a slight redshift, in average \((156 \pm 47) \) km s\(^{-1}\) that is in the frame of fitting errors. Also, there is no significant difference between the Gaussian parameters across the nucleus part; the difference is probably caused by the

\[ W = \sqrt{2} \sigma = \text{FWHM}/2\sqrt{n/2}. \]
accuracy of the fitting with three Gaussian functions. It means
that we were not able to find significant differences in gas
kinematics across the nuclear part.

Also, we fitted the Hβ and Hα lines from the low-resolution
spectra (observed in 2007, 21 spaxels). The parameters of the
best fit for Hα are given in Table 4. The obtained parameters
for Hβ from this spectra are similar to the parameters shown in
Tables 2 and 3 (for high-resolution spectra), but showing
systematically slight larger widths caused by lower resolution.
As one can see from Table 4, the Hα (W_{BLR} \approx 1800 \text{ km s}^{-1}
and W_{ILR} \sim 650 \text{ km s}^{-1}) has a smaller width and shift
than Hβ. The difference in the shift and width between the
broad and intermediate Hα and Hβ may be caused partly by fitting procedure and partly by different spectral
resolution.

The Fe ii line widths from different spaxels indicate the velocity
gas in the Fe ii emission region around W_{FeII} \approx 800 \text{ km s}^{-1}
(an averaged value 760 \pm 50 \text{ km s}^{-1}, see Table 2) that
corresponds to the random velocity in the intermediate region
(as well as the shift, see Tables 2–4). This fact suggests that the
Fe ii line could originate in an intermediate-line region (ILR)
as was mentioned in Popović et al. (2004). Moreover, recently
Kuehn et al. (2008) suggested that the optical Fe ii emission of
Ark 120 does not come from a photoionization-powered region

similar in size to the Hβ (broad component) emitting region, i.e.,
they conclude that Fe ii emission comes from a photoionized region severally times larger than the Hβ one, or from gas heated
by some other mechanism (not by photoionization). Moreover,
Hu et al. (2008b) found that the line width of Fe ii is
significantly narrower than that of the broad component of Hβ in
a sample of 4037 AGNs. All of the results mentioned above as
well as our fitting results for the Fe ii lines suggest that a large
fraction of the Fe ii emission arises in the outer parts of the
BLR, i.e., Fe ii emission may be originated in the ILR, which
may be the transition from the torus to the BLR (or an accretion
disk, see, e.g., Popović et al. 2004). From these observations, it is
hard to say if the portion of the Fe ii emission is formed in the
BLR, since the BLR component is too weak even in the Balmer
lines (Figures 5 and 6) and contributes around 25%–40% to the
total line flux of Balmer lines (see Tables 3 and 4). The Fe ii
emission is strong and the flux ratio of the Fe ii emission (in-
tegrated in the interval 4400–5500 Å) and Hβ-total line flux is
1.72 \pm 0.21.

The Fe ii emission spectra formation from AGN is still poorly
understood (Joly 1993; Hamann & Ferland 1999; Collin & Joly
2000). Typically, photoionization cloud models for the BLR fail
to account for the observed strength of the Fe ii emission. The
mechanism that is responsible for Fe ii origin is supposed to be
the collisional excitation (see, e.g., Sigut & Pradhan 2003), i.e.,
inelastic collisions with electrons excite the odd parity levels
near 5 \text{ eV} which then decay into the optical and UV lines. This
mechanism is efficient whenever the gas temperature is above
7000 K, temperatures which are generally found in photoionized
models of the BLR. Excitation is irrespective of the local optical
depth in the Fe ii lines, and thus this mechanism does not
suffer limitations of the continuum fluorescence. It is generally
believed that collisional excitation is responsible for the bulk of the
Fe ii emission. Also, Collin & Joly (2000) proposed that Fe ii
emission can be explained by a nonradiative heating mechanism,
e.g., shocks, as with an overabundance of iron. Comparison of

\begin{table}
| Position | w [O iii] | [O iii]λ4959, 5007 Å Lines and Fe ii Template (λλ 4400–5400 Å) for Each Spaxel (16 Spectra from 2004 Observations) |
|----------|----------|--------------------------------------------------|
| (0, 0)   | 310      | 0.058 780 79 1.80 |
| (+1, 0)  | 290      | 0.057 720 83 1.57 |
| (−1, 0)  | 280      | 0.061 840 24 2.22 |
| (0, +1)  | 270      | 0.045 770 48 1.58 |
| (0, −1)  | 270      | 0.051 840 50 1.93 |
| (+1, −1) | 260      | 0.055 870 18 1.91 |
| (+1, +1) | 270      | 0.060 810 67 1.64 |
| (−1, +1) | 250      | 0.054 720 80 1.56 |
| (−1, −1) | 250      | 0.048 720 48 1.90 |
| (0, −2)  | 290      | 0.069 720 40 1.98 |
| (+1, −2) | 260      | 0.061 720 78 1.59 |
| (−1, −2) | 190      | 0.045 720 23 1.66 |
| (0, +2)  | 230      | 0.058 720 50 1.38 |
| (+1, +2) | 240      | 0.071 720 96 1.63 |
| (−2, 0)  | 200      | 0.059 750 52 1.58 |
| (+2, −1) | 170      | 0.051 750 67 1.66 |
| Average value | 250 ± 40 | 0.056 ± 0.007 760 ± 50 42 ± 46 1.72 ± 0.21 |
\end{table}
AGN with other objects emitting strong Fe II lines is in favor of the presence of strong outflows and shocks. It is interesting here that we could not register significant outflow in the Fe II emitting region of Mrk 493, but there is a systematic blueshift of the broad Hα and Hβ components. This asymmetry can indicate some kind of the outflow. Note here that Hu et al. (2008b) found that the majority of quasars (from a sample of 4037 quasars) show redshifted Fe II emission toward to red around 400 km s⁻¹.

3.3. The Source of Ionization of the NLR of Mrk 493

In order to identify the nature of the gas ionization source in Mrk 493, we constructed diagnostic diagrams using the narrow emission-line intensity ratios. In Figure 7, we present [O III]/Hβ versus [N II]/Hα and [O III]/Hβ versus [S II]/Hα. In accordance with Veilleux & Osterbrock (1987), we separated the regions corresponding to the ionization by AGN, young OB-stars (H II regions), and shock waves (LINERS) on the diagrams.

It was surprising that all points are only in the H II region, implying that the main source of ionization should be young hot stars from violent star formation in the center of Mrk 493. From these diagrams we can conclude that the low-ionization lines are primarily excited by star formation. No contribution to line ionization from the AGN continuum is seen in Figure 7.

In the analysis a possible absorption in the Hα and Hβ lines is not taken into account. In any case, the stellar absorption reduction would increase the Hα and Hβ fluxes, consequently the [O III]/Hβ ratio would be lower; and points presented in Figure 7 would be deeper in the H II section of the graph. Therefore, we can point out that the star-forming process is
probably a dominant source of ionization in the central part of Mrk 493.

3.4. The Circumnuclear Ring

As can be seen in Figure 1, in the central part of the Mrk 493, a circumnuclear ring of star formation is present, already mentioned by Deo et al. (2006); see also new Hubble Space Telescope (HST)/ACS observations in the UV domain (Muñoz-Maríne et al. 2007). As can be seen in Figure 1, this is a prototypical galaxy with a strong large-scale bar with leading edge dust lanes feeding a central nuclear ring and a grand-design spiral toward the center. From the HST images, the presence of multiple dust spiral arms outside the nuclear ring can be seen. Note here that the radius of the ring (0.6–0.8 corresponding to 350–500 pc) is under the spatial resolution of our MPFS data, but there is also an extensive continuum emission (elliptical shape, see Figure 2) that is probably coming from emission gas around this ring.

All properties of the ring (its size, location inside the strong bar, morphology of dust lanes) indicate the resonance origin of this structure. It seems to be a nuclear ring formed near the Inner Lindblad Resonance (ILRe) of a large-scale bar (see Buta & Combes 1996, for details). According to the common point of view, a large-scale bar efficiently drives gas from the outer disk into the inner region where the gas flow stops near the ILRe where the powerful starburst (SB) is commonly observed (for instance, see review by Jogee 2006).

We roughly estimated the total rate of star formation in the circumnuclear region using the formula from Kennicutt (1998) which connects the star formation rate (SFR) with the Hα luminosity \( L_{\text{H}\alpha} \). From MPFS data we estimated the \( L_{\text{H}\alpha} = 6.7 \times 10^{41} \text{ erg s}^{-1} \) in an aperture radius of 21″5. This luminosity corresponds to SFR = 5 \( M_{\odot} \text{ yr}^{-1} \). Of course, the total \( L_{\text{H}\alpha} \) also includes the nuclear AGN contribution and therefore the SFR value is overestimated. In Table 4, we give the estimated contribution of the broad Hα component (and intermediate one) to the total flux of Hα (Columns 7 and 8), and as can be seen from Table 4 around 40% of Hα is emitted in the narrow Hα line. Consequently, it can indicate SFR = 2 \( M_{\odot} \text{ yr}^{-1} \), which is unusually large for such compact region (less than 1 kpc in diameter).

In such a system, it is interesting to see the spectra further from the center. Even we have very weak spectra outside 3″ × 3″, we were able to see the weak Hα and Hβ lines in the spaxels located at 4″ from the center (Figure 8, upper panel). In Figure 8 (upper panel), we show the spectrum extracted from three spaxels: at the center ((0, 0), top), 2″ far from the center ((0, 2), middle), and 4″ far from the center ((0, 4), bottom). To compare these three spectra, the last two spectra are magnified by 3 and 27 times, respectively. Although the spectra at (0, 4) are very noisy we were able to compare the Hα line profile from this spectrum (solid line in Figure 8, bottom panel) with the two closer to the center (dashed and dashed-dotted line for spectra from 0″ and 2″, respectively—see Figure 8, bottom panel). Also, we normalized the Hα lines to 1. As can be seen from Figure 8, the line profiles of Hα from 0″ and 2″ are almost identical, while Hα from (0,4) tends to have stronger [N II] emission, but it should be taken with caution since S/N is small in this spectrum. It is interesting that the Hα line profiles are similar, i.e., that broad wings are present in the Hα line at 4″ from the center. It may also indicate that some other mechanism can contribute to the origin of the broad Balmer line component in Mrk 493 (non-AGN component).

Since the stellar ring is located in the central part of the line-emission regions one can speculate that the ring may be in the principle star-forming region. It is interesting that the radiation of young stars from the ring probably represents the source of ionization of the line-emitting regions in Mrk 493. Moreover, the strong Fe II emission and weak [O III] one can be explained with a model that contains massive SB plus an AGN (see, e.g., Lipari & Terlevich 2006). The SB+AGN can lead to large-scale expanding supergiant shells (see, e.g., Lipari et al. 1994; Lawrence et al. 1997; Canalizo et al. 1998; Lipari & Terlevich 2006). In the case of Mrk 493, it might be that the Fe II lines are also formed in the gas located in (or around) the ring. The question is why the Fe II lines are broad around 800 km s\(^{-1}\). Note here that bloated stars’ extended envelopes are similar, in many ways, to the low-density gas. Close to the center they will show typical BLR spectrum and further away a typical NLR spectrum (Netzer 2006). Since violent star formation processes are in the central part of Mrk 493, and our analysis of ionizing diagrams shows that the ionization source is only thermal, we cannot exclude a possibility that the star formation process is
Figure 7. Diagnostic diagrams of Mrk 493 nucleus. Only the narrow Balmer line component is included. The dot presents the line flux ratio obtained from the same spaxel.

Table 4

| Position | w BLR Hα | w ILR Hα | w NLR Hα | sh BLR Hα | sh ILR Hα | HαBLR Hα | HαILR Hα | HαNLR Hα |
|----------|----------|----------|----------|-----------|-----------|-----------|-----------|-----------|
| (0, 0)   | 2460     | 700      | 300      | −196      | −16       | 0.24      | 0.35      | 0.41      |
| (+1, 0)  | 1980     | 750      | 300      | −352      | 13        | 0.18      | 0.42      | 0.39      |
| (−1, 0)  | 1980     | 690      | 300      | −359      | 14        | 0.23      | 0.32      | 0.45      |
| (0, +1)  | 2040     | 700      | 290      | −184      | 5         | 0.25      | 0.32      | 0.43      |
| (+1, +1) | 2040     | 650      | 280      | −169      | 13        | 0.27      | 0.36      | 0.37      |
| (−1, −1) | 2040     | 680      | 270      | −181      | 14        | 0.26      | 0.33      | 0.42      |
| (+1, −1) | 2040     | 640      | 280      | −139      | 10        | 0.26      | 0.34      | 0.40      |
| (−1, +2) | 2040     | 820      | 300      | −143      | −90       | 0.22      | 0.23      | 0.55      |
| (0, +2)  | 1770     | 700      | 290      | −129      | −15       | 0.23      | 0.29      | 0.48      |
| (+1, +2) | 1770     | 650      | 270      | −121      | 22        | 0.30      | 0.28      | 0.42      |
| (−2, +1) | 1770     | 560      | 300      | −135      | −24       | 0.23      | 0.24      | 0.54      |
| (+2, +1) | 1770     | 640      | 250      | −139      | 25        | 0.29      | 0.34      | 0.37      |
| (−2, 0)  | 1560     | 580      | 250      | −142      | 16        | 0.29      | 0.36      | 0.35      |
| (+2, 0)  | 1560     | 580      | 230      | −138      | 26        | 0.25      | 0.42      | 0.33      |
| (−2, −1) | 1560     | 630      | 250      | −128      | 33        | 0.27      | 0.34      | 0.39      |
| (+2, −1) | 1560     | 660      | 260      | −136      | 24        | 0.33      | 0.28      | 0.40      |
| (−1, −2) | 1530     | 610      | 220      | −139      | 51        | 0.29      | 0.37      | 0.35      |
| (+1, −2) | 1530     | 570      | 250      | −137      | 46        | 0.29      | 0.34      | 0.37      |
| (−1, +2) | 1530     | 560      | 230      | −126      | 31        | 0.31      | 0.40      | 0.29      |

Average value | 1820 ± 250 | 650 ± 70 | 270 ± 30 | −175 ± 70 | 10 ± 30 | 0.26 ± 0.03 | 0.33 ± 0.05 | 0.41 ± 0.06 |

the main mechanism of radiation in the center of this galaxy. Moreover, the active star formation regions have been found in Seyfert galaxies (see, e.g., Davies et al. 2004, 2007; Muñoz-Marín et al. 2007, and references therein). For example, Davies et al. (2007) found that in the case of nine Seyfert galaxies, on a kpc scale, the stellar luminosity is comparable with AGN one.

4. CONCLUSION

In this paper, we report the three-dimensional spectrophotometric observations of the Mrk 493. From our investigation we can give the following conclusions.

1. The continuum and [S II] line emitting regions in Mrk 493 seem to be very extensive ([S II] up to 1 kpc, and continuum >1 kpc), and they are larger than the [O III], Fe II, and Balmer emission line regions.

2. It seems that the strong Fe II emission is not coming from the BLR (W_BLR ~ 2000 km s^{-1}), but from a region with velocity dispersion around 800 km s^{-1}. This is in agreement with some earlier investigation given by Popović et al. (2004) and recent ones given by Kuehn et al. (2008) and Hu et al. (2008) that a large fraction of the Fe II emission may come from an ILR.

3. There are no changes of the continuum and emission lines (instead He II λ4686) between two observations (in the three years period) that may also indicate non-BLR origin of lines. Otherwise, the BLR in Mrk 493 should be (a) very extensive ~1 pc and/or (b) very stable.

4. The source of ionization of the narrow Balmer and [O III] line emitting regions in Mrk 493 seems not to be the nucleus, but the star-forming processes.

5. The position of the line and continuum regions coincides with a composite nuclear region: an AGN plus a circumnu-
clear star-forming ring observed in the HST UV/optical images, but it seems that the emitting source of the narrow line and continuum is probably the circumnuclear star-forming ring, but here remains a question about the mechanism of the Fe \text{II} production in such a ring.

This work is based on the observational data obtained with the 6 m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences funded by the Ministry of Science of the Russian Federation (registration number 01-43) and from the data archive of the NASA/ESA *Hubble Space Telescope* at the Space Telescope Science Institute. This work was supported by the Ministry of Science of Serbia through the project (14002) “Astrophysical Spectroscopy of Extragalactic Objects.” Also, the work has been financed by the Russian Foundation for Basic Research (project 06-02-16825). A.V.M. acknowledges a grant from the President of the Russian Federation. We thank the referee for very useful comments.

**REFERENCES**

Afanasiev, V. L., Dodonov, S. N., & Moiseev, A. V. 2001, in Proc. Int. Conf. Stellar Dynamics: From Classic to Modern, ed. L. L. Ossipkov & I. I. Nikiforov (St. Petersburg: Sobolev Astron. Inst.), 103

Afanasiev, V. L., & Moiseev, A. V. 2005, *Astron. Lett.*, 31, 194
Arribas, S., Mediavilla, E., García-Lorenzo, B., del Burgo, C., & Fuensalida, J. J. 1999, A&AS, 136, 189
Boller, T., Brandt, W. N., & Fink, H. 1996, A&A, 305, 53
Boroson, T. A., & Green, R. F. 1992, ApJS, 80, 109
Botte, V., Ciroi, S., Rafanelli, P., & Di Mille, F. 2004, AJ, 127, 3168
Buta, R., & Combes, F. 1996, Fundam. Cosm. Phys., 17, 95
Canalizo, G., Stockton, A., & Roth, K. 1998, AJ, 115, 890
Collin, S., & Joly, M. 2000, New Astron. Rev., 44, 531
Crenshaw, D. M., Peterson, B. M., Korista, K. T., Wagner, R. M., & Aufdenberg, J. P. 1991, AJ, 101, 1202
Davies, R. I., Mueller Sánchez, F., Genzel, R., Tacconi, L. J., Hicks, E. K. S., & Friedrich, S. 2007, ApJ, 671, 1388
Davies, R. I., Tacconi, L. J., & Genzel, R. 2004, ApJ, 613, 781
Deo, R. P., Crenshaw, D. M., & Kraemer, S. B 2006, AJ, 132, 321
Dimitrijević, M. Ć., Popović, L. ˇC., Kovacević, J., Dačić, M., & Ilić, D. 2007, MNRAS, 374, 1181
Gliozzi, M., Papadakis, I. E., & Brinkmann, W. P. 2007, ApJ, 656, 691
Hamann, F., & Ferland, G. 1999, ARA&A, 37, 487
Hu, C., Wang, J. M., Chen, Y. M., Bian, W. H., & Xue, S. J. 2008a, ApJ, 683, L115
Hu, C., Wang, J-M., Ho, L. C., Chen, Y.-M., Zhang, H.-T., Bian, W.-H., & Xue, S.-J. 2008b, ApJ, 687, 78
Jogee, S. 2006, Lect. Notes Phys., 693, 143
Joly, M. 1993, Ann. Phys. Fr., 18, 241
Kennicutt, R. C. 1998, ARA&A, 36, 189
Klimek, E. S., Gaskell, M. C., & Hedrick, C. H. 2004, ApJ, 609, 69
Komossa, S. 2008, RevMexAA C, 32, 86
Kuehn, C. A., Baldwin, J. A., Peterson, B. M., & Korista, K. T. 2008, ApJ, 673, 69
Lawrence, A., Elvis, M., Wilkes, B., McHardy, I., & Brandt, N. 1997, MNRAS, 285, 879
Leighly, K. M. 1999a, ApJS, 125, 317
Leighly, K. M. 1999b, ApJS, 125, 297
Lipari, S., Colina, L., & Macchetto, F. 1994, ApJ, 427, 174
Lipari, S. L., & Terlevich, R. J. 2006, MNRAS, 368, 1001
Mathur, S. 2000, New Astron. Rev., 44, 469
Moisseev, A. V., Valdés, J. R., & Chavushyan, V. H. 2004, A&A, 421, 433
Muñoz-Marí-Méndez, V. M., et al. 2007, AJ, 134, 648
Nagao, T., Murayama, T., & Taniguchi, Y. 2001, ApJ, 546, 744
Netzer, H. 2006, in Lecture Notes in Physics 693, Physics of Active Galactic Nuclei at all Scales, ed. D. Alloin, R. Johnson, & P. Lira (Berlin: Springer), 1
Osterbrock, D. E., & Pogge, R. W. 1985, ApJ, 297, 166
Popović, L. Ć., Mediavilla, E., Bon, E., & Ilić, D. 2004, A&A, 423, 909
Sigut, T. A. A., & Pradhan, A. K. 2003, ApJS, 145, 15
Sulentic, J. W., Marziani, P., & Dultzin-Hacyan, D. 2000, ARA&A, 38, 521
Veilleux, S., & Osterbrock, D. M. 1987, ApJS, 63, 295
Veron-Cetty, M.-P., Joly, M., Veron, P., Boroson, T., Lipari, S., & Ogle, P. 2006, A&A, 451, 851
Wang, J.-M., & Zhang, E.-P. 2007, ApJ, 660, 1072