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GAS KINEMATICS IN THE CENTRAL REGIONS OF SEYFERT GALAXIES. II. MRK 3

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ABSTRACT. *For the central part of Seyfert galaxy Mrk 3 we present the observations of the line-of-sight velocity field of the ionized gas and the surface brightness distributions as in continuum as well in emission line [OIII], obtained at the 6-m telescope. These data suggest an existence of gaseous disk perpendicular to the major axis of the galaxy ellipsoid; the inner part of the disk counter-rotates relative to the outer parts. There are some evidences of the radial gas inflow having the velocity near 450 km/s.*

На 6-м телескопе исследовано поле скоростей ионизованного газа и распределения поверхностной яркости в континууме и в эмиссионной линии [OIII] в центральной области размером 10″×10″ сейфертовской галактики Mrk 3. Полученные данные позволяют констатировать существование газового диска, перпендикулярного большой оси эллиптического тела галактики, причем внутренняя часть диска вращается в направлении, противоположном направлению вращения внешних частей. Имеются указания на существование радиальных потоков газа, направленных к ядру со скоростью ≃ 450 км/с .

INTRODUCTION

Mrk 3 is a known Seyfert 2 galaxy. A lot of papers have presented investigations of this galaxy, so it is difficult to summarize everything in one short introduction. We draw our attention only at the latest works where the galaxy morphology was studied.

Morphological type of Mrk 3 is not determined confidently yet. First it was classified as S0, and if more exactly, as SB0 (Adams, 1977): apparently, an essential influence on this assumption was exerted by the idea that Seyfert nuclei are found mainly in disk galaxies. However, Jenkins (1981) has carried out spectral observations and did not found any noticeable gas rotation in Mrk 3 at distances from the centre of order of some kiloparsecs. And what is more, the gas velocity dispersion determined according to the emission line width is at constant, relatively high level (≃ 350-450 km/s), up to 5 kpc both to west and east, and north and south from the nucleus, that does not agree with the

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hypothesis of thin gaseous disk seen face-on. Jenkins made an inference that Mrk 3 is an ellipsoid in which gas was dropped by stars during their evolution and therefore its velocity dispersion is similar to that of stars. And at last Wagner (1987) has investigated the surface brightness radial distribution and showed that it corresponds to Vaucouleurs law. Thus, Mrk 3 is a triaxial ellipsoid whose major axis has P.A. $\simeq 20^{\circ}$ on the celestial sphere. Though according to radial distribution of the shape parameter called as "boxiness", Wagner has drawn a conclusion that nevertheless in Mrk 3 there is a weak stellar disk with the radius of $\simeq 20''$ and its line of nodes has P.A. 22°, i.e. practically aligned with the major axis of ellipsoid.

A question on gas distribution in Mrk 3 is more complicated. Wagner (1987) asserted that along the east-west direction he observed a strongly inclined gaseous disk through the whole galaxy width, but his assumption is based only on the colour maps where a blue band along P.A. 112° is seen. However on R-map the position angle of the major axis changes suddenly from 90° to 20° with r increase larger than $4''$. Haniff et al. (1988) presented the maps of Mrk 3 central region in [OIII] and H_{α} emission lines as well as in green and red continuum band. The inner isophotes in continuum are elongated along P.A. 20° (except the innermost, $r \leqslant 2''$) i.e. so as the most outer ones. In emission lines there are observed ellipsoidal isophotes with a position angle of the major axis 82°. However the diameter of this structure is not larger than $9''$, and it is associated with the linear radio structure discovered first by Wilson et al. (1980) and aligned along P.A. 85°. Recently Wagner and Anton (1989) obtained [OIII] line map of more extended region around Mrk 3 nucleus and it turned out that at $r \simeq 5''$ the isophote elongation changes from 90° to approximately 120°. Thus existence of gaseous disk in Mrk 3 whose major axis is aligned along P.A. $\cong 110$-120° may be considered as proved.

The linear radio structure in Mrk 3 nucleus has been studied recently in detail. Pedlar et al. (1984) have found a jet-like feature at 18 cm with an unresolved jet "core" in $\simeq 1''$ to the west from the Seyfert nucleus (the authors admit incorrect location of the optical nucleus) and on the weak radio background with two more radio lobes at $0.6''$ and $1.5''$ to the east from the jet "core". Ulvestad and Wilson (1984) presented 2 cm observations of two separate radio lobes - at $0.3''$ to the east, and at $1''$ to the west from the optical nucleus. Neff and Ulvestad (1988) have obtained at 18 cm and 21 cm the same results, but they reported that there is a third lobe between these two as was presented by Pedlar et al. (1984). The west and brightest lobe is not resolved with VLA - its size is smaller than 12 kpc; the other two are resolved with sizes $\simeq$ 100 pc. Note that in the place where the optical centre, i.e. Seyfert nucleus, is there are no any noticeable radio details.

We have carried out a detailed spectral study of Mrk 3 in optical region with the aim to investigate kinematics of ionized gas and the structure of the innermost ($r \leqslant$ 1 kpc) galaxy region in continuum and emission lines. For more details of the problem setting - see the previous paper of this cycle (Afanasiev and Sil'chenko, 1990).

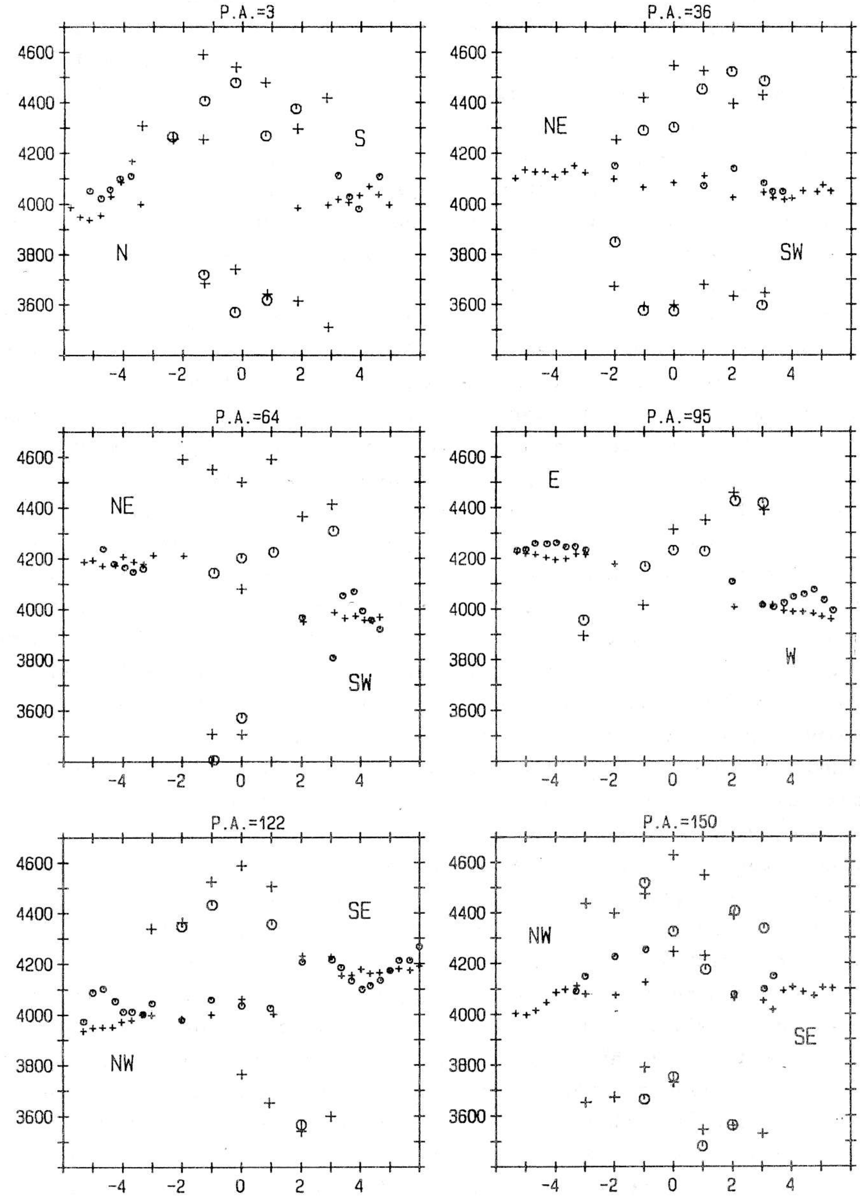

Fig. 1. The line-of-sight velocity radial distributions of ionized gas of Mrk 3 for various position angles.

OBSERVATIONS

Observations were made in 1986-1987 in the prime focus of the 6-m telescope using the long-slit spectrograph. The spectra were registered with the two-dimensional photon-counting system (for description of the equipment see Afanasiev et al., 1986). 13 spectra of Mrk 3 were obtained: one in the red band (October, 1986) and 12, two at each position angle, in [OIII] λ5007 emission line, the seeing being ≃ 1″. A journal of observations is presented in Table 1. For the green spectra a dispersion was 1.5 A/pix, the scale along the slit - 0.37″/pix; the slit size - 100″×2″ that corresponded to the spectral resolution of 3.5 A. To obtain gas line-of-sight velocities we followed two ways in spectrum reduction: the first, standard one (Alyavdin et al., 1988) allowing to obtain V_r according to the emission line peak, we used for rather distant from the nucleus regions ($r>3''$), and the second, interactive Gaussian component analysis of the line profiles was employed for the central region of Mrk 3 ($r\leqslant3''$) whose emission lines possess complicated multicomponent profiles. An example of such analysis is presented in the previous paper (Afanasiev and Sil'chenko, 1990). Using this method we have distinguished 3 (the fourth with uncertainty) kinematic gas subsystems in the central region of Mrk 3. Fig. 1 shows line-of-sight velocity distributions obtained from the emission lines [OIII] (crosses) and H_β (circles) in the central region along different P.A. in every 30° on the average. The larger symbols indicate the component measurements strongly differing in line-of-sight velocity from the velocity of mass centre V_{sys}. Three gas subsystems are well seen on the obtained distributions: low-velocity, central, and high-velocity; at P.A. 64° and 150° a "very high-velocity" system is also seen. In the central region of the galaxy the brightest in [OIII] component is the high-velocity one.

Table 1. A journal of observations with a long slit for Mrk 3

Spectrum	Date	Exposure	(P.A.) of slit	Spectral range (A)
M03705	9/10.X.86	5885^s	42°	6300-7000
M06420	16/17.X.87	300	95	4700-5400
M06421	16/17.X.87	300	95	4700-5400
M06422	16/17.X.87	300	64	4700-5400
M06423	16/17.X.87	300	64	4700-5400
M06424	16/17.X.87	300	36	4700-5400
M06425	16/17.X.87	300	36	4700-5400
M06426	16/17.X.87	300	3	4700-5400
M06427	16/17.X.87	300	3	4700-5400
M06428	16/17.X.87	300	150	4700-5400
M06429	16/17.X.87	300	150	4700-5400
M06430	16/17.X.87	300	122	4700-5400
M06431	16/17.X.87	300	122	4700-5400

In 1989, August we observed again the central Mrk 3 region using the multi-pupil fiber spectrograph MPFS - two-dimensional spectrophotometer with a digital registration in the prime focus of the 6-m telescope. The observation and reduction procedure are described by Afanasiev et al. (1990). Observations were made with the seeing of 1″, an exposure time was 20 min. Fig. 2a shows the central galaxy region of 10″×10″ in continuum (the central wavelength λ_0 = =5110 A, spectral window is 40 A), Fig.2b presents the same in [OIII] λ5007 with the continuum subtraction. Vertical P.A. is 90°, east is at the top, north - to the right. To obtain a map we used 78 individual spectra of each square (1.25″ × 1.25″) surface element within the central galaxy region of 10″ × 12″ in size.

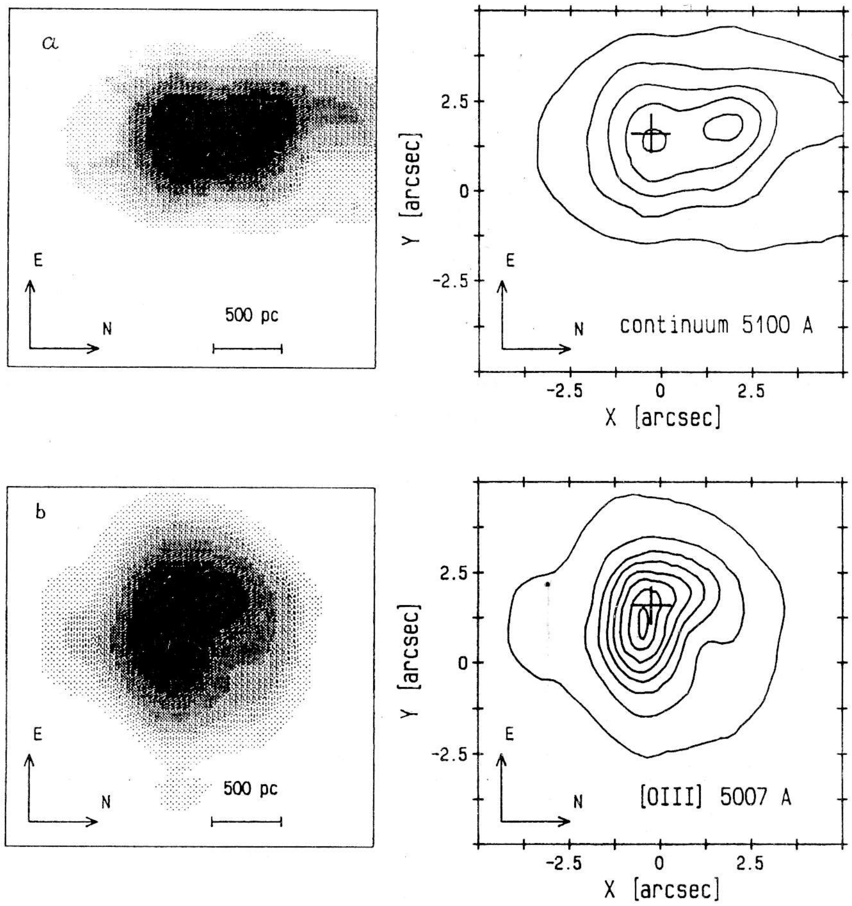

Fig. 2. a) The surface brightness map of the central region of Mrk 3 in the continuum band at the λ_0=5110A ($\Delta\lambda$=40A) obtained with MPFS. The isophote layers are: 14, 17, 20, 23, 26 in relative units. The centre of the galaxy is marked with a cross;

b) the surface brightness map of the central region of Mrk 3 in the emission line [OIII] λ5007 obtained with MPFS. The isophote layers are: 11, 32, 53, 74, 95, 116, 137, 158 in relative units. The centre of the galaxy is marked with a cross.

GAS ROTATION IN THE CIRCUMNUCLEAR REGION OF MRK 3

Only one sight at the line-of-sight velocity curve at P.A. 95° is enough to note different location of the "central" and "high-velocity" gas systems. Their boundary is at $r \simeq 3''$ ($\simeq$800 pc). Both exhibit rigid-body rotation, but in opposite sense: the east side of the "outer disk" recedes us, and that of the "inner disk" approaches us. For both systems we use the term "disk" according to Wagner (1987) who reported on gas disk visible practically edge-on with line-of-nodes P.A. 110°. However the morphology of the "outer" and "inner" disks is apparently different: if the "inner disk" is fully visible only at P.A. 95° and hence represents a narrow stripe in its projection , i.e. is oriented edge-on, then the "outer disk" has a smaller amplitude ΔV_r and its extension is equal at all position angles, so its inclination to the sky plane is small.

In general counter-rotating nuclei have been already detected in some giant elliptical galaxies from absorption lines, i.e. according to stellar kinematics (Bender, 1988; Franx and Illingworth, 1988). However the authors of these papers made their conclusions according to one, maximum to two reciprocally perpendicular cross-sections of the studied galaxies. In such a case even if on the line-of-sight velocity curve there is a region of inverse inclination it is impossible to speak about counter-rotation: such region may result from strongly elliptical orbits if the large axis of ellipses is slightly inclined to the line of nodes. Only one reliable case is known of counter-rotating nucleus - it is NGC 6621 (Reshetnikov and Sil'chenko, 1990), however this is a close interacting pair with NGC 6622.

Fig. 3 shows azimuthal dependencies of V_r for the central, high- and low-velocity components. The central component measured at a distance of R=3″ from the centre (points in Fig. 3) is well approximated with a cosine law:

$$V_r = (98 \text{ km/s})\cdot\cos\,(\text{P.A.} - 73^\circ) + 4095 \text{ km/s},$$

which is shown by a solid line. Hence we can conclude the following. First, the systemic galaxy velocity from the central component appears to be 4095±8 km/s that agrees well with V_{sys} measured from absorption lines (i.e. from stellar component) by Wagner (1987): 4057±50 km/s. Second, the angular velocity of the outer disk rotation is (122/sin$i$) km/s·kpc. Third, maximum of cosinusoid is reached at P.A. 73° which coincides neither with the direction of the large axis of the outer ellipsoid (20°) nor with the P.A. in which gaseous disk (110°) was detected by Wagner, nor with the direction of nuclear radio structure (85°), though it is rather close to this. The only, but paradoxical, association appearing in such a case: according to Haniff et al. (1988) the innermost isophotes of surface brightness in optical continuum ($r \leqslant 2''$) are elongated in the direction ≃ 70°.

However at R=5″ (small crosses in Fig. 3) the outer disk shows cosine law (it is shown with a dashed line)

$$V_r = (122 \text{ km/s})\cdot\cos\,(\text{P.A.} - 104^\circ) + 4061 \text{ km/s},$$

which kinematic major axis fits the position of Wagner gaseous disk. The angular rotation velocity at this distance from the centre is equal to (91/sin$i$) km/s·kpc, i.e. a little less than at R=3″; the systemic velocity coincides even better with that obtained by Wagner from stellar component. As to the turn of the kinematic major axis it is not surprising if we take into consideration the fact that the gas rotates in triaxial gravitational potential of elliptical galaxy.

We failed in obtaining cosine law for the high-velocity component since it is located in azimuth: beyond the interval P.A. 180°-360° it is impossible to detect it. However the picture that we see in Fig. 3 (large crosses at the top of the figure) resembles well the half of cosinusoid with P.A. ≃280° and ω

= (650/sin$i$) km/s·kpc (if the systemic velocity is assumed to be 4095 km/s). In this case $P.A._0$ is close to the P.A. of the gaseous disk obtained by Wagner but the "inner" disk rotates faster than the "outer" one (or its inclination to the sky plane is larger) and in opposite sense.

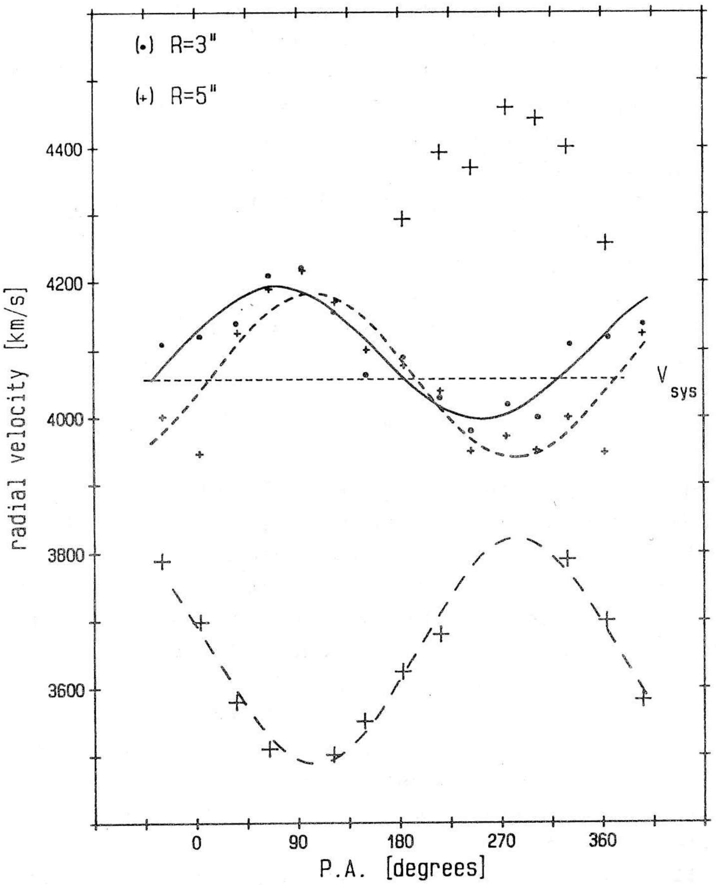

Fig. 3. The line-of-sight velocity azimuthal dependencies for the central (points and small crosses), high-velocity, R=2″, and low-velocity R=1″, (large crosses) components of the emission line [OIII] λ5007.

The most interesting is the cosine law obtained for the low-velocity component (large crosses at the bottom of Fig. 3). At $R = 1''$ an accuracy of approximation with the cosinusoid appeared to be two times better than for the central component: we see obvious rotation. After approximation we have:

$$V_r = (167\ \text{km/s})\cdot\cos\ (\text{P.A.} - 286^\circ) + 3653\ \text{km/s}.$$

I.e. the position of cosine maximum $P.A._0$ 286° is coincident with that for the high-velocity component and fits fully the picture of Wagner gaseous disk with P.A.(line-of-nodes)≃110°; angular rotation velocity (620/sin$i$) km/s·kpc indicates also the association of this component with the "inner disk". However the galaxy systemic velocity determined from the low-velocity component is equal to 3653 km/s!

The detected phenomenon can be explained as the followings: in the central region of Mrk 3 we observe radial gas flow which rotates with the "inner disk". Something like this we observed in Mrk 573 (Afanasiev and Sil'chenko, 1990), but there the radial flow velocity was 200 km/s and in Mrk 3 it reaches 450 km/s. Apparently the symmetrical flow with the redshift of ≃500 km/s is what we see on the line-of-sight velocity curves at P.A. 64° (direction to the flow location) and 150° (perpendicular to the direction on the flow location - the region falls onto the slit by its edge, opposite the galaxy nucleus): this is the fact that we called in the previous Section "very high-velocity" component, its $V_r \simeq 4600$ km/s. However it is seen worse than the low-velocity component and can be an artifact. From the angular rotation velocity of the "inner disk", in the assumption that it is observed "edge-on" and accepting its extension along the radius to be equal to 2″ (0.5 kpc), we estimate the mass of the Mrk 3 central region to be $1.1 \cdot 10^{10} M_\odot$.

THE GASEOUS DISK STRUCTURE

The inner disk brightness in [OIII], to all appearances, is distributed asymmetrically relative to the dynamic centre. For instance, at P.A. 64° the maximum intensity in [OIII] is reached by the high-velocity component at 2″ to the west from the dynamic centre. The fact that the brightness centre of the high-velocity component is noticeably shifted relative to the nucleus, is confirmed by the comparison of two spectra obtained at P.A. ≃ 40° in 1986 and 1987. Since this cross-section is at the large angle to the inner disk, the high-velocity component should project onto the spectrograph slit near r≃0″. Having compared Mrk 3 spectra at P.A. ≅ 40°, obtained in red and green bands in 1986 and 1987 respectively we see that the line-of-sight velocity of the galaxy nucleus determined from the emission line peak is 4290 km/s from H_β (due to high-velocity component) and 4070 km/s from H_α (close to the systemic velocity of the galaxy). The only difference between the spectra was the slit width: 1.7″ in 1986 and 2.1″ in 1987, i.e. when the slit width was diminished by 0.5″ the influence of the high-velocity component on the profile shape of hydrogen emission line decreased greatly. Hence we can conclude that the region of gas radiation in the high-velocity component is very condensed and its brightness centre locates at a distance of ≃2″ from the nucleus. Thus the Whittle et al.'s (1988) result on identification of the high-velocity component with the west radio-lobe, the brightest one at 2 - 20 cm wavelengths and according to Pedlar et al. (1984) being practically stellar-like, is confirmed. We think this lobe to be the shock wave region appearing at the boundary of two counter-rotating disks.

It is interesting also to consider the question of low-velocity component location. At 1″ from the centre it is seen over the whole sphere (except the angles where it is eclipsed by the high-velocity component), but at P.A. 3° and 36° to the south it extends up to r≃3″, and on the north it cuts off at ≃ 1″. An inference can be drawn that this radial flow is located mainly to the south from the nucleus. If the south side of gaseous disk is far one (Wagner, 1987), then we can speak on the gas falling onto the nucleus with a velocity of order of rotation velocity. Wagner (1987) noted also the radial gas motion to the nucleus.

In Fig. 2, where we presented the map of the central region of Mrk 3 obtained with the spectrograph MPFS, the inner disk, whose major axis is aligned approximately in the west-east direction, is well visible both in continuum and in [OIII] emission line. However its extension is only about 2″. The more outer isophotes are elongated in the direction P.A. $\simeq 20^{\circ}$, that fits the major axis of the global ellipsoid and is in a good agreement with the maps of Haniff et al. (1988). The brightness centres of the inner disk in [OIII] and in continuum are separated by about 1″, that confirms our inference on the brightness centre in [OIII] shifted relative to the kinematic centre. But the absolute brightness centre in continuum is shifted to the north from the inner disk. Probably it is explained by the fact that the inner gaseous disk is rich in dust and then obscures the south part of the nucleus region of Mrk 3.

DISCUSSION

Summing up all the presented above we note that since Mrk 3 is probably an elliptical galaxy and all its structures are three-dimensional, then according to observations of line-of-sight gas velocities we cannot restore the whole dynamical picture. However rather noticeable rotation detected in the west-east direction allows to assume the existence of gaseous disk perpendicular to the major axis of the global ellipsoid, the inner ($r \leqslant 0.5$ kpc) part of the disk being rotating in the direction opposite the rotation of the outer parts of the disk. It is not clear how this gaseous disk is supported by the stellar distribution. In general, since it locates in one of the main planes of ellipsoid (perpendicular to the major axis), it is stable and so may be a gaseous one only. But in the central parts of the gaseous disk both our results (Fig. 2) and the results of Haniff et al. (1988) show a turn of the continuum isophotes characterizing distribution of surface density of stellar population. Wagner (1987), basing on the spatial Fourier analysis, reported on the existence of disk component in distribution of surface brightness in filter I; and from the fact that at a distance of $r \simeq 5-20''$ from the centre isophote ellipticity at P.A. $\simeq 22^{\circ}$ is strongly increased, he made an inference that the major axis of the disk lies in this position angle. But one can imagine another explanation of this fact. Probably at $r \simeq 5''$ the disk with a major axis perpendicular to the P.A. 22° cuts off and hence isophote ellipticity increases. Then we could speak on the weak stellar-gaseous disk perpendicular to the major axis of the global ellipsoid and on gasodynamical effects in this disk.

Recently in literature there appeared the data on the object similar to Mrk 3 according to gas kinematics and morphology in the central region (Wagner and Appenzeller, 1989). In the Seyfert 2 galaxy IC 5063 the gas in the centre shows also counter-rotation relative to the outer parts; and at 1.8″ (0.6 kpc) from the nucleus there is observed the brightness centre in emission lines, the second NLR, the lines of which are 2.5 times wider than of the nucleus itself. The authors explain this phenomenon by merging other galaxy rich in gas. Probably the same has happened with Mrk 3.

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REFERENCES

Adams, T.F.: 1977, *Astrophys. J. Suppl. Ser.*, **33**, p.19.

Afanasiev, V.L., Grudzinsky, M.A., Katz, B.M., Noshchenko, V.S., Zukkerman, I.I.: 1986, in: *Avtomatizirovannye sistemy obrabotki izobragenij.* Moscow: Nauka, p.182 (in Russian).

Afanasiev, V.L., Sil'chenko, O.K.: 1990, *Preprint SAO,* No.**55** (Paper 1).

Afanasiev, V.L., Vlasiuk, V.V., Dodonov, S.N., Sil'chenko, O.K.: 1990, *Preprint SAO,* No.**54**.

Alyavdin, M.S., Afanasiev, V.L., Berlin, A.B., Burenkov, A.N., Zavadskaya, O.O.: 1988, *Soobshch. Spets. Astrofiz. Obs.*, **59**, p.68 (in Russian).

Bender, R.: 1988, Astron. Astrophys., **202**, p.L5.

Franx, M., Illingworth, G.D.: 1988, Astrophys. J., **327**, p.L55.

Haniff, Ch.A., Wilson, A.S., Ward, M.J.: 1988, *Astrophys. J.*, **334**, p.104.

Jenkins, C.R.: 1981, *Mon. Not. R. Astron. Soc.*, **197**, p.1049.

Neff, S.G., Ulvestad, J.S.: 1988, *Astron. J.*, **96**, p.841.

Pedlar, A., Unger, S.W., Booler, R.V.: 1984, *Mon. Not. R. Astron. Soc.*, **207**, p.193.

Reshetnikov, V.P., Sil'chenko, O.K.: 1990, *Astron. Tsirk.* No.**1542** (in Russian)

Ulvestad, J.S., Wilson, A.S.: 1984, *Astrophys. J.*, **278**, p.544.

Wagner, S.J.: 1987, *Astron. Astrophys.*, **185**, p.77.

Wagner, S.J., Anton, K.: 1989, in: *ESO Workshop on Extranuclear Activity in Galaxies - Proc.* No. **32**, Eds.: E.J.A. Meurs and R.A.E. Fosbury, p.195.

Wagner, S.J., Appenzeller, I.: 1989, *Astron. Astrophys.*, **225**, p.L13.

Whittle, M., Pedlar, A., Meurs, E.J.A., Unger, S.W., Axon, D.J., Ward, M.J.: 1988, *Astrophys. J.*, **326**, p.125.

Wilson, A.S., Pooley, G.G., Willis, A.G., Clements, E.D.: 1980, *Astrophys. J.*, **237**, p.L61.

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