УДК 524.74-36 *Астрофиз.исслед. (Изв.САО),* 1991, 33, 114-124

GAS KINEMATICS IN THE CENTRAL REGIONS OF SEYFERT GALAXIES. III. MRK 79 AND MRK 1126

V. L. Afanasiev, O. K. Sil'chenko*

ABSTRACT. *The results of kinematic investigation of ionized gas in the central parts of Seyfert galaxies with large bars Mrk 79 and Mrk 1126 obtained with the 6-m telescope are presented. The peculiarities of the velocity fields (the turn of the kinematic major axis, the increase of angular rotation velocity with the distance from the centre) give evidences of the non-axisymmetrical potential form in the centres of the galaxies being non-similar to their large bars. There are some proofs of radial gas flows with the velocities to ≃200 km/s.*

Представлены результаты исследования кинематики ионизованного газа в околоядерных областях сейфертовских галактик с протяженными барами Mrk 79 и Mrk 1126, проведенного на 6-метровом телескопе. Особенности поля скоростей газа (поворот кинематической большой оси, рост угловой скорости вращения с удалением от центра) указывают на присутствие в центрах галактик неосесимметричного потенциала, не подобного большому бару. Имеются признаки радиальных течений газа со скоростями до 200 км/с.

INTRODUCTION

The studied galaxies Mrk 79 and Mrk 1126 of Seyfert 1.2 and 1.5 types respectively are interesting by their common morphology feature: a prominent component of their structure is the large bar, and the disks have low surface brightness. In Mrk 79 the bar of ≈ 15 kpc in length lies at P.A. ≈ 50° practically perpendicular to the line of nodes (P.A. ≈ 140°). In Mrk 1126 the bar of ≈ 6 kpc in length has a P.A. ≈ 20°, and the outer parts of the disk resemble the correct ring: according to them the galaxy is seen face-on (MCG).

The both galaxies have linear radio structures in the nuclei. In Mrk 79 it is aligned approximately from the north to the south (i.e. just between the directions of the large bar and the line of nodes) and includes three lobes:

* Sternberg State Astronomical Institute, USSR

central (coinciding with the nucleus), north, at 2″ from the nucleus and south, at 1″ from the nucleus (Ulvestad and Wilson, 1984a). Whittle et al. (1988) have found in the region of the north radio lobe a splitting of [OIII] λ5007 emission line with peak separation ≈ 150 km/s. In Mrk 1126 the radio structure is aligned along P.A. 100° (approximately perpendicular to the direction of the large bar); the distance between its two radio lobes is ≈ 1″; the location of the optical nucleus is roughly in the middle between them (Ulvestad and Wilson, 1984b). According to the structures, to the presence of strong triaxial potential associated with the large bar, these galaxies should resemble Mrk 3 (Paper II). However, according to the gas kinematics in the nucleus region, as we'll see below, they both resemble rather Mrk 573 (Paper I).

OBSERVATIONS

Mrk 79 and Mrk 1126 have been observed in the prime focus of the 6-m telescope using the long-slit spectrograph. The spectra have been registered by two-dimensional photon-counting system (Afanasiev et al., 1986). In October, 1986 we have obtained one spectrum of Mrk 79 in H_α region; unfortunately it was of bad quality, besides the slit was located almost along the minor disk axis, so no rotation was detected. In October, 1987 we obtained 7 spectra for each galaxy, approximately in every 30° at P.A., in the green spectral band including H_β and [OIII]λ4959,5007 emission lines; the seeing was ≈ 1″. These spectra are the basic data for studying kinematics of ionized gas in the centre of Mrk 79 and 1126. The spectrograph slit sizes were 100″×2″, a dispersion - 1.5 A/pix, the scale along the slit - 0.37″/pix, the spectral resolution - 3.5 A. The journals of observations are presented in the Table. The line-of-sight velocities have been determined from the H_β and [OIII] emission lines by two ways: for outer regions (r>3″) according to the emission line peak (this standard procedure of spectrum reduction obtained with the long slit is described by Alyavdin et al., 1988), for inner regions the interactive Gaussian component analysis of the line profiles was used. Thus three gaseous systems were distinguished differing by their line-of-sight velocities: central, high-velocity, and low-velocity. The example of such analysis for Mrk 573 is presented in Paper I. An accuracy of velocity determination for such a procedure depends upon the line intensity and varies from 10 km/s up to 50 km/s. Maximum emission extension along the slit for Mrk 79 was 14″ (6 kpc) and for Mrk 1126 - 8″ (1.7 kpc), i.e. our data concern gas kinematics in the innermost regions of galaxies which are a priori inside the large bars.

GAS ROTATION IN THE CENTRAL REGION OF MRK 79

Fig. 1 shows the line-of-sight velocity radial distributions for ionized gas in the centre of Mrk 79 taking into account the line component division by the Gaussian component analysis. First that should undoubtedly attracts attention while analyzing Fig. 1 is fast rigid-body galaxy rotation up to the distance $\approx 6''$ ($\approx$ 3 kpc) from the centre, which is demonstrated by the central component of [OIII] emission at P.A. being close to the line of nodes (P.A. = 139° and 169°). If suppose that in these cross-sections being perpendicular to the large bar we see the circular rotation of gaseous galaxy disk, then we can make two estimations.

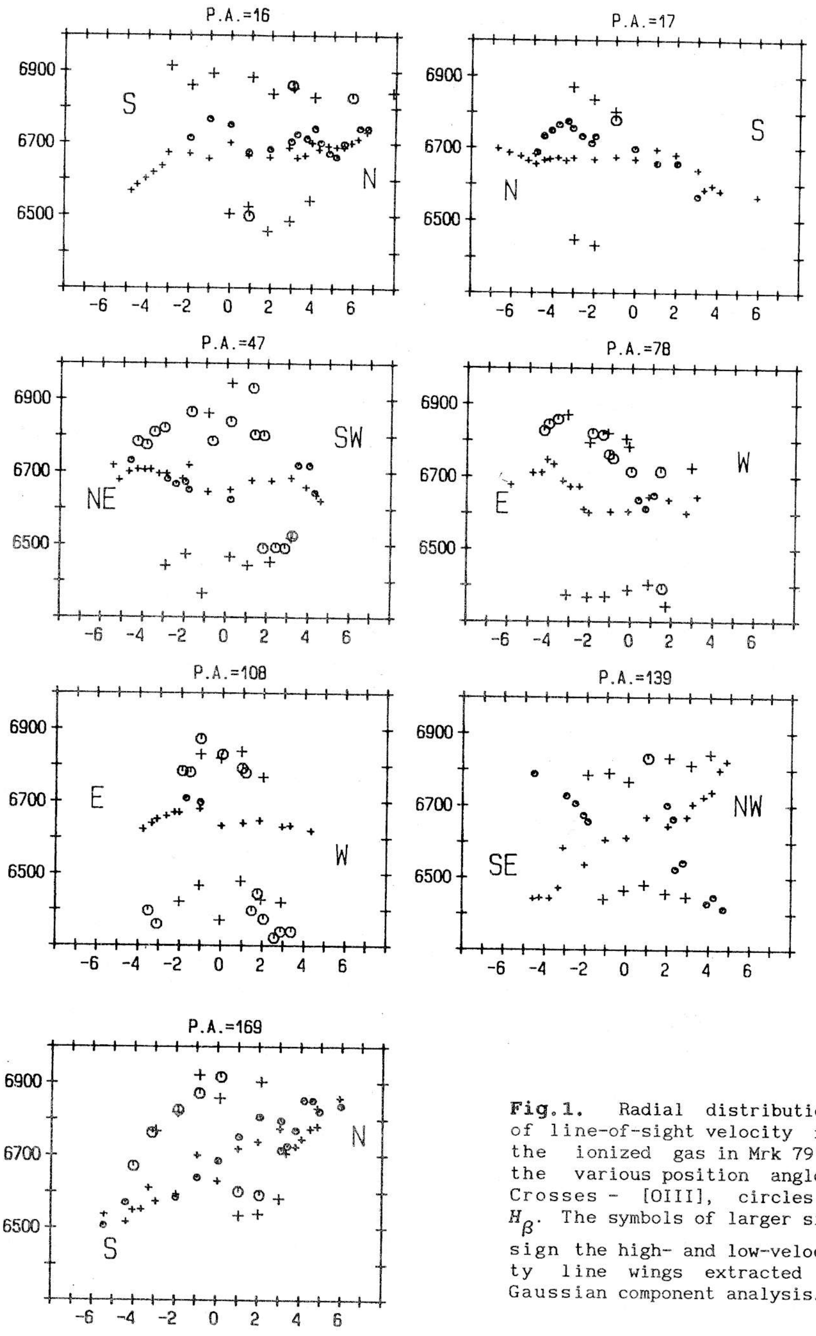

Fig. 1. Radial distributions of line-of-sight velocity for the ionized gas in Mrk 79 at the various position angles. Crosses - [OIII], circles - H_β. The symbols of larger size sign the high- and low-velocity line wings extracted by Gaussian component analysis.

First, according to two visible at P.A. 139° and 169° gradients of line-of-sight velocity, taking into account the fact that at the circular rotation

$$dV_r/dR \sim \cos\ (\text{P.A.} - \text{P.A.}_0),$$

we get the location of the line of nodes $\text{P.A.}_0 = 126°$, i.e. it is close to the estimation made by Ulvestad and Wilson (1984a): $\text{P.A.}_0 = 140°$. If in this case we assume the galaxy disk inclination angle to be $i \simeq 46°$ (Keel, 1980), we get the galaxy rotation velocity at a distance of 3 kpc from the centre to be of order of 400 km/s and the mass within this radius to be about $10^{11} M_{\odot}$.

Approximately at the same position angles which are close to the line of nodes and perpendicular to the large bar, that is at P.A. = 139° and 108°, an amazing phenomenon is observed that currently has no analogs. A narrow H_β emission line peak shows also rigid-body rotation (within the distance interval from the nucleus 2″ - 5″), but in opposite sense to the gas emitting in [OIII] rotation. Absolute values of angular rotation velocity for H_β and [OIII] are approximately equal. Here we should remember the paper of Oke and Lauer (1979) where line-of-sight velocities of stellar population at some points inside Mrk 79 were determined from Ca II *K* and *H* absorption lines. In the direction with P.A. = 0° a difference in line-of-sight velocities for stars locating 6″ to the north and 6″ to the south from the nucleus was 570 km/s, the northern part of the galaxy approaching the observer. Comparing this result with our cross-section at P.A. 169°, we see that stars rotate in the sense opposite to the rotation of gas emitting in [OIII]. Hence stellar rotation sense coincides with the one of gas emitting in H_β at P.A. 139°.

And at last the third, that we want to note as to the line-of-sight velocity distributions, is visible counter-rotation of the central region of Mrk 79 ($R \leqslant 2''$) relative to the more outer regions ($R = 2'' - 5''$) on the cross-sections with P.A. 47° and 78° ("plateau" in the centre of radial distribution V_r at P.A. 16°- 17° can apparently also be related to this phenomenon). Such shape of line-of-sight velocity distribution can be caused both by true counter-rotation (for an example see Mrk 3, Paper II) and by strong ellipticity of gaseous cloud orbits in the centre of the galaxy keeping the same rotation sense (an example - Mrk 573, see Paper I). To choose between these possibilities, it is necessary to consider azimuthal dependencies of gas line-of-sight velocity V_r at the fixed distances from the centre.

Fig. 2 shows azimuthal dependencies of the line-of-sight velocity V_r derived from the central component of [OIII] emission line, for several fixed distances from the centre. We see that at $R = 1''$ and $2''$ there is no any dependence of V_r upon the position angle: "counter-rotation" which has a diminished angular velocity displays only in the narrow range of position angles near the direction of the large bar; at P.A. 140° - 170° we observe fast rigid-body rotation of the galaxy disk. Apparently, the fact, that inside the 1″ (~seeing quality) there are seen different rotating systems, leads to full smoothing of azimuthal dependence of V_r. However at $R = 3''$ and $4''$ (where there is no "counter-rotating" component), having excluded the points at P.A. 139° and 169° referring to disk, we can construct cosinusoids using the least square method, which characterize probably gas rotation of the large bar:

$R=3''$ $V_r = (44\ \text{km/s})\cdot\cos\,(\text{P.A.} - 22^\circ) + 6642\ \text{km/s},$
$R=4''$ $V_r = (70\ \text{km/s})\cdot\cos\,(\text{P.A.} - 11^\circ) + 6648\ \text{km/s}.$

Analyzing the obtained cosine parameters we can conclude the followings:

a) the systemic velocity obtained for ionized gas of the large bar and being equal to 6645 km/s coincides with the known one obtained from observations at 21 cm - V_{sys} (*HI*) = 6643 km/s (Heckman et al., 1978);

b) the kinematic major axis at this distance interval from the centre is coincident neither with the line of nodes nor with the large bar direction, and turns while moving away from the centre;

c) angular rotation velocity grows noticeably with the distance from the centre (35 km/s·kpc → 42 km/s·kpc).

The latter two phenomena were already discussed while considering azimuthal dependence of V_r for Mrk 573 (Paper I) and it was noted that they evidence for a triaxial potential in the galaxy centre.

It is interesting that azimuthal dependence of line-of-sight velocity, obtained from H_β emission line does not show cosinusoid up to $R=4''$.

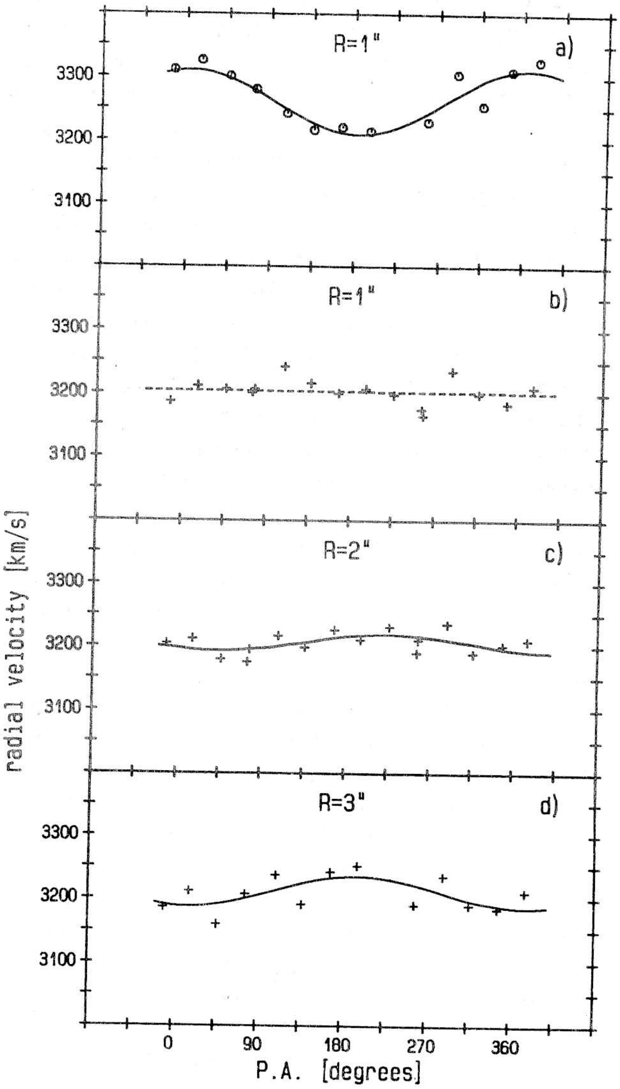

Fig.2. Azimuthal dependencies of line-of-sight velocity for the central emission line [OIII] component in Mrk 79 at various fixed distances from the nucleus.

RADIAL FLOWS IN MRK 79

Let us consider now high- and low-velocity components of [OIII] which line-of-sight velocity measurements are shown also in Fig. 2 with symbols of larger size. As for the difference of line-of-sight velocities between the wings and the central component (≃ 200 km/s) and for the tendency to trace the central component gradient (see e.g. high-velocity component at P.A. 169° or low-velocity one at P.A. 78°), [OIII] emission line wings resemble those in Mrk 573 (Paper I) and are probably caused by linear radial gas flows taking part in overall rotation. Whittle et al. (1988) made an inference on coincidence of radial gas flow locations with the radio lobes for several SyGs. To confirm this conclusion we have plotted distributions of [OIII] line wing intensity relative to the central component along the slit for different position angles (Fig.3).

Really, in the cross-section at P.A. 169° (close to the north-south direction, along which the radio structure is aligned) we see intensity maximum of the low-velocity component at 2″ to the south from the centre, and intensity maximum of the high-velocity component at 2″ to the north. Thus, it is likely that low-velocity component is associated with the north radio lobe, and the high-velocity one with the south radio lobe. However in the cross-section at P.A. 78°, perpendicular to the radio structure, we also see the spatial separation of the high- and low-velocity components; the high-velocity one locates at 2″ to the east and the low-velocity one at 1″ to the west from the nucleus. How can we explain this fact? Analyzing Fig. 2 we draw a conclusion that at P.A. 169° and 78° we observe different high- and low-velocity components. So, the high-velocity component at P.A. 169° traces the disk rotation, and at P.A. 78° it traces gas rotation in the large bar.

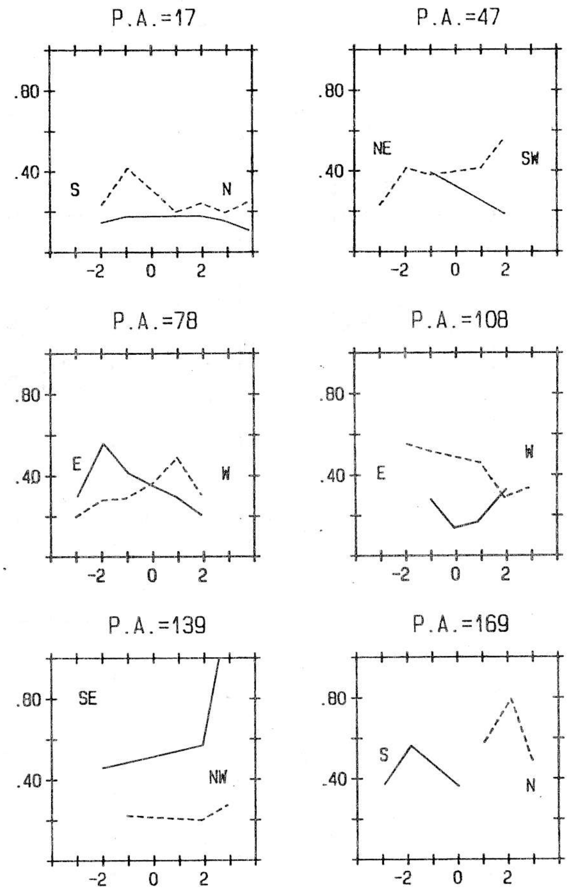

Fig.3. Radial distributions of relative intensity for high-velocity (solid lines) and low-velocity (dashed lines) wings of the emission line [OIII] in the central part of Mrk 79 at the various position angles.

The low-velocity component at P.A. 169° is rather compact and has V_r = 6560 km/s, and at P.A. 78° it is evidently extended, rotates and has average V_r =

6390 km/s. We think that in the central region of Mrk 79 there is a whole system of radial gas flows - more complicated than the radio structure at λ=6 cm and 20 cm.

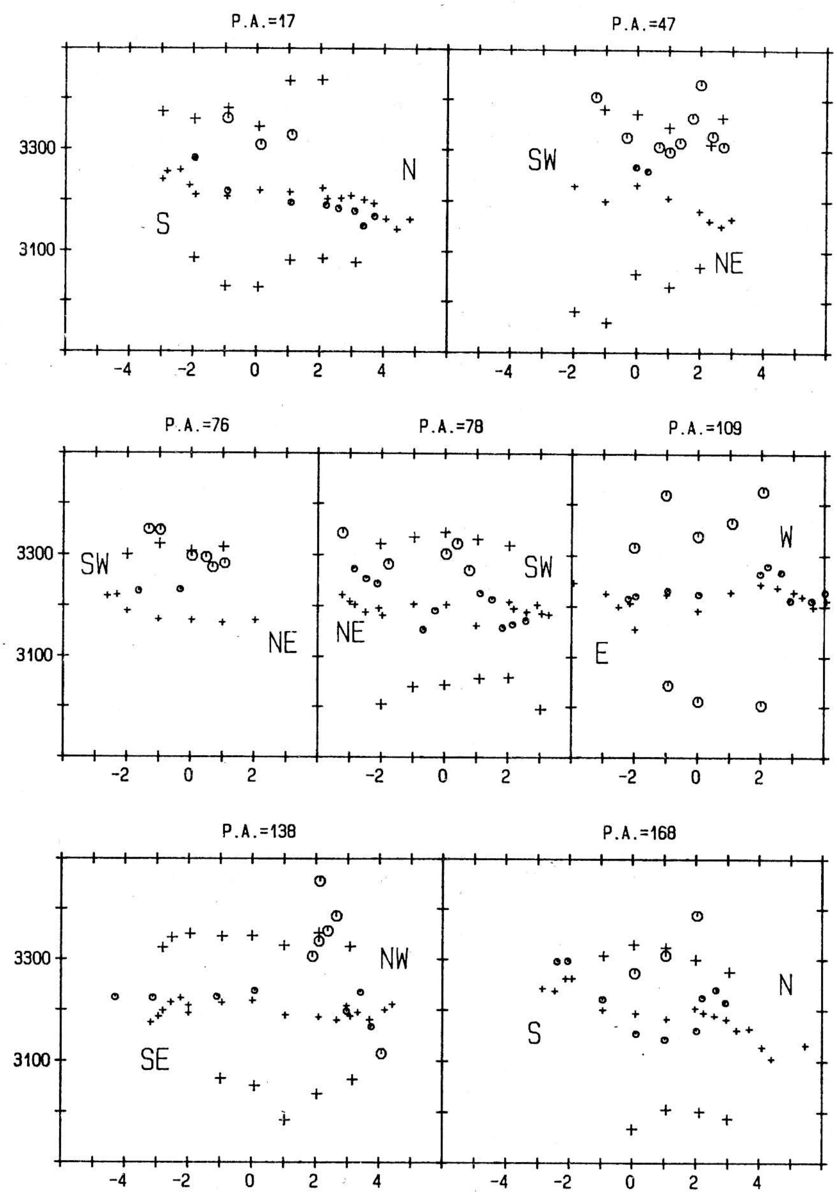

Fig. 4. Radial distributions of line-of-sight velocity for the ionized gas in Mrk 1126 at the various position angles. Crosses - [OIII], circles - H_{β}. The symbols of larger size sign the high- and low-velocity line wings extracted by Gaussian component analysis.

Fig. 4 presents radial distributions of ionized gas line-of-sight velocities at different position angles. Emission lines of Mrk 1126 are weaker than those of other Seyfert galaxies in our sample, therefore we can consider the gas motion only in the very central region of the galaxy - $r \leqslant 1$ kpc. Faint signs of rotation are seen near the north-south direction, but since the galaxy is seen almost face-on we do not know exactly the position angle of the line of nodes and sin i and so we cannot evaluate the real rotation velocity and mass of the observed region of the galaxy. In directions close to the north-south (at the cross-sections with P.A. 17° and 168°) we can note dynamical distinction of the very central ($r<2''$) galaxy region, where the line-of-sight velocity curves have a plateau. In such a case Mrk 1126 resembles absolutely Mrk 79: there are clear evidences for the potential shape variation in the very centre of the galaxy on scales much smaller than the size of the large bar.

Fig. 5 shows azimuthal variations of the observed V_r for different distances from the centre. Low rotation velocity, seen in Fig. 4, is confirmed. For the central component of [OIII] emission line we have obtained the following relations:

$R=1''$ $V_r \simeq$ const,
$R=2''$ $V_r = (13\ \mathrm{km/s}) \cdot \cos\,(\mathrm{P.A.} - 224^\circ) + 3205$ km/s (σ=15 km/s),
$R=3''$ $V_r = (24\ \mathrm{km/s}) \cdot \cos\,(\mathrm{P.A.} - 196^\circ) + 3210$ km/s (σ=23 km/s),

which are presented in Fig. 5b, c, d. Though cosinusoid amplitudes are on the level of point scattering relative to these curves, two facts, that is the growth of angular rotation velocity with moving away from the centre and the turn of kinematic major axis, are apparently real. Just to these features Mrk 1126 resembles Mrk 79. And the third striking resemblance is behaviour of H_β emission line. In contrast to [OIII] at $R = 1''$ H_β reveals a noticeable rotation:

$$V_r = (51\ \mathrm{km/s}) \cdot \cos(\mathrm{P.A.} - 6^\circ) + 3259\ \mathrm{km/s},$$

if we exclude the discordant points near P.A. 20° and 240° (i.e. at these P.A. there is a velocity component fitting the cosinusoid but it is more weak, compared with the discordant line peaks). Kinematic major axis is close to the north-south direction as it is for [OIII] at $R = 3''$ but the gas emitting in H_β rotates not only faster but in the sense opposite to that of gas emitting in [OIII]. It seems that the rotation in H_β is strongly localized, since already at $R = 2''$ we failed in observing any cosinusoid.

Radial gas flows seen as the high- and low-velocity emission components exist in Mrk 1126, however they do not reveal any rotation: with a small scatter (σ_v<30 km/s), within R=0-2″ the line-of-sight velocity of the high-velocity component is 3340 km/s, (i.e. the projection of the radial flow velocity on the line of sight is 130 km/s), and the line- of-sight velocity of the low-velocity component is 3035 km/s (i.e. the projection of radial flow velocity is 175 km/s). The observed lack of rotation can be explained either by the fact that there are only faint variations of V_r in the central region of Mrk 1126 (see Fig. 4) and due to the weakness of line wings they are difficult to be detected, or by the small separation of radial gas flow regions. The latter appears more probable, since an attempt to divide spatially the high-and low-velocity components according to radial distributions of the line wing intensities has failed. The radio structure in the centre of Mrk 1126 on the wavelength 20 cm (Ulvestad and Wilson, 1984b), which according to statistics of Whittle et al. (1988) must be associated with the regions of radial flows, is also very compact, the distance between the brightness centres being ≃ 1″. If the regions of radial flows are compact and located each at a distance of ≃ 0.5″ from the nucleus, then at any P.A. of the spectrograph slit (with the width of 2″) the both regions always fall into the slit completely, and, turning the spectrograph slit, we do not observe any notable velocity variations of the line components.

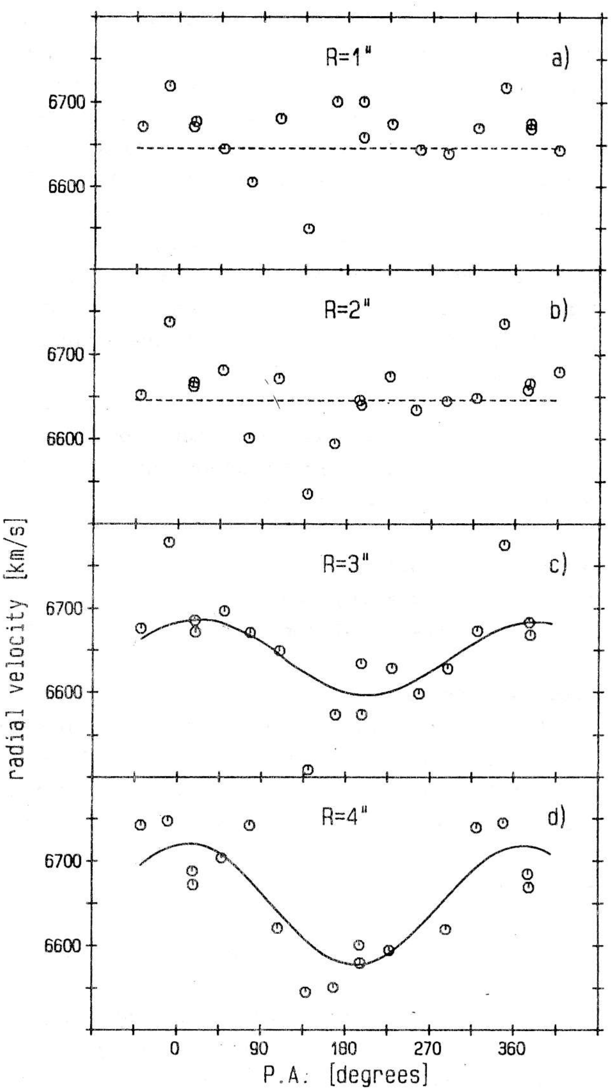

Fig.5. Azimuthal dependences of the line-of-sight velocity for the central component of emission line [OIII] at the various distances from the nucleus (b, c, d) and of emission line H_β at R=1″(a).

DISCUSSION

Similar in morphology, Mrk 79 and Mrk 1126 appeared to have also similar properties concerning kinematics of ionized gas in the central region. For instance, the central component of [OIII] emission in both galaxies reveals the growth of angular rotation velocity at moving away from the centre and the turn of kinematic major axis; and H_β emission shows a strongly localized (either by the angle or by the radius) counter-rotation. For Mrk 79 we have more observational data and can discuss a possible nature of these properties.

As we have already noted in Paper I, both the growth of angular rotation velocity and the turn of the kinematic major axis are characteristic for galaxies with bars: the first is the observed fact (Duval and Monnet, 1985), the second follows from consideration of gas rotation on elliptical orbits, aligned along the bar (Chevalier and Furenlid, 1978). However in case of Mrk 79 the large bar visible on the galaxy large-scale images cannot be the cause of the turn of kinematic major axis, since it is perpendicular to the line of nodes (for the corresponding formulae see the paper of Chevalier and Furenlid, 1978). A particular behaviour of line-of-sight velocity curves at $R \leqslant 2''$ (areas of reverse inclination or plateau) also is an evidence in favour of the fact that in the galaxy centre there is a small bar not associated with the large one and having other orientation in space. A confusing fact is that the image of the central region of Mrk 79 in continuum obtained by Haniff et al. (1988) has absolutely round isophotes.

Counter-rotation, visible in both galaxies in H_β line, makes us, first of all, to remember early analytical models of Vaucouleurs and Freeman (1973): according to them at position angles close to the minor axis of the bar (a degree of closeness which is necessary is determined by the bar axes ratio) stars and gas in the bar should rotate in opposite directions due to the fact that they have different velocity dispersions. Though later neither numerical models nor observations have confirmed this conclusion we must admit that Mrk 79 gas emitting in [OIII] rotates in one direction, and stars and gas emitting in H_β - in reverse direction, and in the centre of Mrk 1126 H_β and [OIII] lines have different widths: FWHM for H_β is 330 km/s, and for [OIII] - 200 km/s (Osterbrock and Pogge, 1985) and respectively the velocity dispersion of clouds emitting in H_β coincides with the typical velocity dispersion of stars in the bar. However, the most true explanation of the counter-rotation visible in [OIII] and H_β perhaps is the hypothesis of some "polar ring" around the large bar; this hypothesis is in a good agreement with the narrow location of the counter-rotation region. A source for this "polar ring" may be, for instance, a satellite merging.

REFERENCES

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.: 1990a, *Preprint SAO*, No.55, (Paper I).

Afanasiev, V.L., Sil'chenko, O.K.: 1990b, *Preprint SAO*, No.56, (Paper II).

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).

Chevalier, R.A., Furenlid, I.: 1978, *Astrophys. J.*, 225, p.67.

Duval, M.F., Monnet, G.: 1985, *Astron. Astrophys. Suppl.* Ser., 61, p.141.

Haniff, Ch.A., Wilson, A.S., Ward, M.J.: 1988, *Astrophys. J.*, **334**, p.104.
Heckman, T.M., Balick, B., Sullivan, W.T.: 1978, *Astrophys. J.*, **224**, p.745.
Keel, W.C.: 1980, *Astron. J.*, **85**, p.198.
Oke, J.B., Lauer, T.R.: 1979, *Astrophys. J.*, **230**, p.360.
Osterbrock, D.E., Pogge, R.W.: 1985, *Astrophys. J.*, **297**, p.166.
Ulvestad, J.S., Wilson, A.S.: 1984a, *Astrophys. J.*, **278**, p.544.
Ulvestad, J.S., Wilson, A.S.: 1984б, *Astrophys. J.*, **285**, p.439.
Vaucouleurs, G. de, Freeman, K.C.: 1973, *Vistas in Astron.*, **14**, p.163.
Vorontsov-Vel'yaminov, B.A., Arkhipova, V.P.: 1968, *Morfologicheskij katalog galaktik. Part IV.*, Moscow: Moscow University Press, (MCG).
Whittle, M., Pedlar, A., Meurs, E.J.A., Unger, S.W., Axon, D.J., Ward, M.J.: 1988, *Astrophys. J.*, **326**, p.125.

Поступила в редакцию
23 мая 1990 г.