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Velocity dispersion of stars and gas motion in double-barred galaxies [1]

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Abstract.
The current state of the problem of double-barred galaxies investigation is reviewed. The necessity for application of the panoramic spectroscopy methods to a detailed study of kinematics of these objects is being proved. The first results of observing double-barred galaxies at the 6m telescope using the multipupil spectrograph MPFS and the scanning interferometer Fabry-Perot are described.

Key words: galaxies: kinematics and dynamics — galaxies: spiral — galaxies: structure

1. Introduction

According to the latest statistical estimates (Selwood & Wilkinson, 1993; Knapen, 1999; Knapen et al., 2000b; Laine et al., 2001), galaxies with central bars account for 50–70% of the total number of nearby disk galaxies. Since the distribution of the gravitational potential in the region of the bar is not axisymmetric (one generally says of a triaxial potential), then the motion of stars and gas clouds is different from circular. This fact is confirmed by both direct observations of gas velocity fields in barred galaxies (see, for instance, Afanasiev & Shapovalova, 1981; Duval & Monnet, 1985; Knapen et al., 2000a) and numerous model calculations, (see, for example Athanassoula, 1992; Combes, 1994; Lindblad, 1996; Vauterin & Dejonghe, 1997). By now it can be considered to be proved that the bars are dynamically decoupled subsystems, where the motions of gas and stars being of different kind. Inside the bar there exist several "families" of stable periodic orbits that form an off-beat "backborn" of the bar (Contopouls & Grosbol, 1989). The main orbits that maintain the shape of the bar are elongated parallel to the bar and belong to family x_1. If two Inner Lindblad Resonances (hereafter ILR) are present in the galaxy then stable orbits of family x_2 are present between them, which are perpendicular to the main bar. The location of the resonances is defined by the relationship between angular velocity of differential rotation of the galaxy and angular velocity of the bar rotation.

Such motions are possible only in a collision-free stellar subsystems. The gas subsystem (where by the gas particles are implied individual clouds of interstellar gas) is collision. Therefore the stable existence of intersecting flows is impossible in it. Gas clouds follow "smoother" paths. The flows of gas onto a relatively slow rotating bar, which occurs at a velocity of 50–100 km/s, leads to formation of strong shock fronts at the leading edges of the bar (Athanassoula, 1992).

Numerous model calculations show that the bar takes up effectively angular moment from the gas of the disk, which results in formation of gas streams towards the galaxy centre. Although a detailed hydrodynamic modelling (Levy et al., 1996) shows that apart from the flows towards the centre (inflows) there exists a reverse motion (outflow) caused by the saddle point of the gravitational potential. However, it should be noted that the bar promotes increasing of gas concentration in the circumnuclear region. This is confirmed by the real observations. Sakamoto et al. (1999) showed that the molecular gas concentration inside the central kiloparsec in barred galaxies is by an order of magnitude higher than that in galaxies without bars. The bar is often treated as one of the basic mechanisms of transport of the interstellar gas to the circumnuclear region where it becomes a fuel for an active nucleus or a circumnuclear burst of star formation.

In the relation between the bar and the phenomenon of active (Seyfert) nucleus, two points should be noted. Firstly, according to the latest estimates of Knappen et al. (2000b), the relative proportion of bars in Seyfert galaxies is negligibly larger

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than one in galaxies of the control sample (80%±8% and 60%±9%, respectively). Also Laine et al. (2001) provide more contrast values of the bar percentage (73%±6% for Sy and 50%±7% for non-Sy galaxies). Knappen et al. and Laine et al. performed measurements using the data of surface photometry in the near IR range where the influence of dust is negligible, and the contribution of the old stellar population into luminosity is significant, which facilitates a more reliable detection of bars as compared to optical observations.

Secondly, the bar transports gas not to the centre, but to the ILR region where the gas is concentrated in a ring of radius of a few hundred parsec. Thus, there is a problem of taking up the angular rotation moment from the gas situated at a distance of 100–1000 pc from the centre and transportation of it to the region of effective gravitational forces of the central supermassive black hole (at a distance of $< 1 - 10$ pc). In particular detail, this problem is discussed in the survey "Fueling the AGN" (Combes, 2000)

2. Double-barred galaxies

2.1. The historical review

One of the refined performances of the task of matter transfer to the active nucleus was suggested by Shlosman et al. (1989). They showed that in the gas disk (ring) of radius of a few hundred pc (which is formed inside a large-scale bar), a new bar can be formed under the action of a bar-forming instability. And this bar again forms flows of gas towards the nucleus. The characteristic scale on which gas is concentrated is less than 0.1 R_{bar}, where R_{bar} is the bar radius. For this reason, the system of two bars is capable of "sweeping" the interstellar medium on scales of a few kiloparsec and concentrate it at distances of 1–10 pc from the centre. The process of angular moment transfer will further be defined by the turbulent viscosity of the accretion disk formed around the central supermassive object.

At nearly the same time with the paper by Shlosman et al. (1989), in which it was spoken only of a purely gaseous inner bar, Pfenninger & Norman (1990), using a numerical modeling, demonstrated the formation of the second bar as a result of development of instability in the stellar self-gravitating disk. Of particular interest is the conclusion that the internal bar does not necessarily rotate at the same angular velocity as the outer one does. The most stable is the configuration in which the corotation radius of the inner bar coincides with the position of the ILR of the main bar. Such an elaborate numerical modeling of the stellar-gaseous disks was carried out by Friedli & Martinet (1993), in which a double bar was treated as one of the stages of evolution of barred galaxies. In 2001 year new hydrodynamical simulations of the gas behaviour in double bars are presented by Heller et al.(2001), Maciejewski et al. (2001) and Shlosman & Heller (2001).

And what do the observations show? As early as in 1975, de Vaucouleurs found that an inner (stellar) circumnuclear bar (turned by 30° with respect to the outer one) was sharply decoupled on the optical images of NGC 1291 (de Vaucouleurs, 1975). The same galaxy was investigated by Jarvis et al. (1988) and they gave one more example of a double-barred galaxy, NGC 1543. However, the first attempt of systematic observational studies of this phenomenon was made by Buta & Crocker (1993) who published a list of 13 galaxies with "inner circumnuclear bars".

The observed position angle between the inner and outer bars in these galaxies varies over a wide range, from 20° to 90°. Since more than half of galaxies have a small inclination with respect to the line of sight, $i < 30°$, then a projection must have a minor effect on the estimate of the real angle between the bars in the galaxy plane. Therefore, in the opinion of Buta & Crocker (1993), the second bar can be oriented arbitrarily relative to the outer one. This question will be discussed in more detail in the next Section 2.2.

Wozniak et al. (1995) suggested a method of searching and classification of double bars, which is based on the isophote analysis of galactic images. By the turn of the position angle (PA) and by the change of ellipticity of the inner isophotes, the galaxies were divided into one-bar objects, double-bar ones, and containing a bar with a triaxial bulge. The latter term was applied to galaxies that demonstrate a smooth variation of the PA in contrast to a "pure" bar where the PA $\approx$ const. By applying this technique to the optical CCD images of 36 barred galaxies, Wozniak et al. (1995) found an "inner triaxial structure" in 2/3 of the cases, i.e. a second bar or a triaxial bulge. The galaxies of their sample (Friedli et al., 1996) are observed in the near IR range. Double bars were confirmed in all (excluding two, NGC 6951 and NGC 7479) objects. Similar observations made over the last few years in the IR range (where the influence of dust and young stars is small as compared with the optical range) have extended substantially the list of galaxies suspected to have double bars (Jungwiert et al., 1997; Greusard et al., 2000). An image of the double-bar galaxy NGC 2950 we have obtained with the 6m telescope is displayed in Fig. 1 for example.

Table 1 gives the list of all similar objects that we have found in references. The first column lists the name of the galaxy; the second column indicates the morphological type from the catalogue RC3; a_s and a_p are the sizes of the semiaxes of the inner and

Table 1: *A list of double-barred galaxies*

Name	Type	a_s	a_p	AGN	References	Notes
ESO 437-67	SBab	3	32		(15)	?
ESO 508-78	SBa				(7)	
ESO 215-31	SBb	10	47		(13)	
ESO 320-30	SABa	5	37		(13)	
ESO 443-17	SB0/a	6	15		(13)	
Mrk 573	SAB0	5	20	Sy2	(1), (3), (19)	
Mrk 1066	SB0	3	16	Sy2	(1)	
NGC 470	SAb	8	32		(12), (24)	$B+T$
NGC 613	SBbc	5	59	Sy	(15)	
NGC 1079	SABa	17	32		(15)	$T+B$
NGC 1097	SBb	10	80	Sy1	(7),(11),(12),(20),(24)	$B+T$
NGC 1291	SB0/a				(7), (14), (23)	
NGC 1300	SBbc				(4)	$T+B$
NGC 1317	SAB0/a	11	50		(17), (22)	
NGC 1326	SB0/a	10	50	LINER	(7), (24)	
NGC 1353	SAbc	4	14	LINER	(15)	?
NGC 1365	SBb	8	150	Sy1.8	(4),(15)	$T+B$
NGC 1371	SABa	10	60		(24)	
NGC 1398	SBab	14	36	Sy	(15)	$T+B$
NGC 1433	SBab	5	100	Sy2	(4),(5),(15),(24)	
NGC 1512	SBab	6	150		(15)	$T+B$
NGC 1543	SB0				(7),(14)	
NGC 1566	SABbc			Sy1	(4)	$T+B$
NGC 1672	SBbc			Sy2	(4)	$T+B$
NGC 1808	SABb	3	?	Sy2	(15)	
NGC 2217	SB0/a	8	37		(4), (15)	
NGC 2273	SBa	8	24	Sy2	(2), (17)	
NGC 2442	SABbc				(4)	$T+B$
NGC 2681	SAB0/a	5	29	LINER	(9), (24)	3β
NGC 2859	SB0	12	46		(8),(24)	
NGC 2880	SB0				(8)	?
NGC 2935	SABb	11	25		(15)	$T+B$?
NGC 2950	SB0	6	38		(12),(24)	
NGC 3081	SAB0/a	10	37	Sy2	(3),(6),(7),(12),(17),(24)	
NGC 3185	SBa	2	30	Sy2	(1), (8)	?
NGC 3275	SBa	5	34		(17)	
NGC 3358	SABab				(7)	
NGC 3368	SABab	4	24	LINER	(15)	$3B$
NGC 3393	SBab	2	13	Sy2	(3), (13), (15)	
NGC 3412	SB0				(8)	?
NGC 3516	SBO	6	22	Sy1	(16)	
NGC 3786	SABa	7	25	Sy1.8	(1)	
NGC 3941	SB0			Sy2	(8)	?
NGC 3945	SB0	20	42	LINER	(9),(24)	$3B$
NGC 4262	SB0	10	14		(21)	
NGC 4274	SBab	10	39		(21)	
NGC 4314	SBa	6	75	LINER	(8), (21)	
NGC 4321	SABbc	10	66		(18), (21)	
NGC 4340	SB0	5	52		(12), (24)	

Table 1: *A list of double-barred galaxies (continued)*

Name	Type	a_s	a_p	AGN	References	Notes
NGC 4371	SB0	24	43		(21), (24)	$3B$
NGC 4593	SBb	2	60	Sy1	(24)	$B+T$
NGC 4594	SAa	10	68	LINER	(10)	
NGC 4643	SB0/a	17	51	LINER	(8),(21)	
NGC 4736	SAab	10	26	LINER	(20)	
NGC 4754	SB0	7	21		(21)	
NGC 4984	SAB0	4	30		(15)	
NGC 5101	SB0/a	2	50	LINER	(15)	
NGC 5365	SB0	18	33		(17)	
NGC 5566	SBab	6	24	LINER	(15)	
NGC 5728	SABa	4	44	Sy2	(7),(20),(24)	
NGC 5850	SBb	9	84		(7),(24)	
NGC 5905	SBb	6	37		(12), (24)	
NGC 6300	SBb	4	44	Sy2	(17)	?
NGC 6782	SB0/a	3	26		(7),(12),(15),(24)	
NGC 6951	SABbc	5	44	Sy2	(12), (17)	?
NGC 7007	SA0	4	9		(17)	
NGC 7098	SABa	14	57		(12), (7), (24)	
NGC 7187	SAB0	9	28		(24)	$3B$
NGC 7479	SBc	?	46	LINER	(4), (12)	?
NGC 7702	SA0	10	?		(24)	$T+B$
NGC 7743	SB0	10	57	Sy2	(24)	$B+T$

Table 2: *References to Table 1*

(1)	VRI	Afanasiev et al. (1998a)
(2)	VRI	Afanasiev et al. (1998b)
(3)	JHKL′	Alongso-Herrero et al. (1998)
(4)	plates	Baumgart & Peterson (1986)
(5)	plates	Buta (1986)
(6)	I	Buta (1990)
(7)	BVI	Buta & Crocker (1993)
(8)	BR	Erwin & Sparke (1998)
(9)	HST	Erwin & Sparke (1999)
(10)	—	Emsellem & Ferruit (2000)
(11)	K	Forbes et al. (1992)
(12)	JHK	Friedli et al. (1996)
(13)	JK′	Greusard et al. (2000)
(14)	gr	Jarvis et al. (1988)
(15)	JHK	Jungwiert et al. (1997)
(16)	V	Moiseev et al. (2000)
(17)	K	Mulchaey et al. (1997)
(18)	I	Pierce (1986)
(19)	HST	Pogge & De Robertis (1995)
(20)	JHK	Shaw et al. (1993)
(21)	JHK	Shaw et al. (1995)
(22)	plates	Schweizer (1980)
(23)	plates	de Vaucouleurs (1975)
(24)	BVRI,H_α	Wozniak et al. (1995)

outer bar in arcseconds, respectively[2] (if these data were given by the authors). In the next columns are shown the type of nucleus activity (from the NED database) and the references. The symbol ? in the last column marks the uncertain data. $B+T$ denote the combination of the triaxial bar and the bulge; $3B$ is the "triple bar". In Table 2 is presented the list of literature sources with indication of the observational method (photographic, CCD or IR photometry in the bands). The case of NGC 4594 is distinguished.

This is a known nearby edge-on galaxy "Sombrero" in which Emsellem & Ferruit (2000) found as many as two bars on the basis of 2D spectroscopy with the integral field spectrograph TIGER.

Attention is attracted by the fact that 30% of all the galaxies in Table 1 are Seyfert, and 15% of LINER-type galaxies. However, such a number of active objects (an order of magnitude larger!) relative to the field galaxies is most likely caused by strong selection effects. Really, in the paper by Mulchaey & Regan (1997) no noticeable discrepancy in the relative number of double bars in the samples of Seyfert and normal (non-active) galaxies has been found; see also the discussion in Friedli (1999) and in Laine et al. (2001). The influence of selection effects can also explain the relatively large percentage (56%) of early-type (S0–Sa) galaxies because the second bar in such

[2] Hereafter indices "p" and "s" mark values which relate to the primary and secondary bars, respectively

galaxies can be easier defined. So, Erwin & Sparke (1998) argue that in no less than 20% of S0–Sa barred galaxies the second bar is observed as well.

Let us make some remarks concerning the terms used. Double-barred galaxies are termed also "bar-within-bar" systems. The outer bar is called "primary" while the inner one is named "secondary".

2.2. Relative orientation of bars

In the above mentioned paper Friedli & Martinet (1993) showed that if the two bars have the same angular velocity ($\Omega_p = \Omega_s$), only two stable configurations are then possible — the bars are parallel or perpendicular to one another. The former case is a trivial variation of radial distribution of surface brightness along the bar axis. The case of the perpendicular bars is more intriguing, however, it is difficult to confirm by observations, because only the position angle between the projections of the bars in the sky plane can actually be measured, and one has to introduce a correction for the inclination of the galaxy plane to the line of sight (i). The task is not trivial because the point in question is obviously the projection of three-dimensional structures. It is not always possible to unambiguously determine i from the ellipticity of the outer isophotes, because in the outer parts of barred galaxies rings are often observed, elliptical in the galaxy plane. Sometimes, the model of the mutually perpendicular bars describes well the observed surface brightness distribution (see, for instance, the paper of Moiseev (1998) about the 2D-decomposition of Mrk 573). However, in most of the galaxies observed nearly face-on, the angle between the bars differs substantially from 90° (Buta & Crocker, 1993). In the papers by Friedli & Martinet (1993), Friedli et al. (1996), Jungwiert et al. (1997), which were already discussed above, attempts were made to take account of the effect of projection of the bars onto the sky plane and, first of all, to test the hypothesis of mutually perpendicular bars. And all these authors came to the conclusion that there is no distinct characteristic value of the angle between the bars.

In the existing models this refers to the case of a dynamically independent inner bar. It is usually believed that from general considerations $\Omega_s > \Omega_p$ (but Heller et al. (2001) studied the secondary gaseous bar with $\Omega_s < \Omega_p$).

Since the stellar component in galaxies is collisionless, then this situation (a bar rotates inside a bar) is possible and is even reproduced in numerical experiments of Friedli & Martinet (1993). Maciejewski & Sparke (2000) showed that in a system of two dynamically independent bars, rotating one inside the other, there exist several families of orbital loops maintaining this configuration (similar to orbits x_1 and x_2 in a galaxy with a single bar). In accordance with the opinion of these and other authors, a configuration, in which the relation between angular velocities is not arbitrarily but such that the corotation radius of the inner bar lies near the resonance IRL of the outer bar, is stable (Pfenninger & Norman, 1990; Friedli & Martinet, 1993; Maciejewski & Sparke, 2000). If the rotation curve of the galaxy is such that there is no ILR in the primary bar, then, according to Maciejewski & Sparke (2000), the secondary stellar bar cannot to exist.

3. Two-dimensional spectroscopy of double bars

3.1. Necessity of 2D-methods

The numerous observational papers (see Table 2) point to the fact that in the case of double bars we are probably faced with some new structural feature of barred galaxies. However, all the papers enumerated above have a significant disadvantage, the presence of the secondary bar can be found only from photometric data, if on the galaxy image, some extended structure is observed inside the primary bar. The formal application of the results of isophote analysis, as described by Wozniak et al. (1995), allows even "triple bars" to be decoupled (Erwin & Sparke, 1998; 1999; Jungwiert et al., 1997; Friedli et al., 1996) without any reasoning for possible dynamic behaviour of such configurations. At the same time, the observed photometric structure can, in our opinion, be explained in a less exotic manner, without involvement of the secondary and the third bar. It is difficult to separate the following possibilities using only the data of the surface photometry:

- The dynamically independent secondary bar ($\Omega_s \neq \Omega_p$).
- The x_2-orbits (perpendicular to the primary bar) between two inner ILR resonances of the primary bar. In contrast to the previous case, this structure is not dynamically independent.
- The elliptical ring in the disk plane at the ILR resonance of the primary bar. A good example is the galaxy NGC 6951, the HST observations of which showed that the "secondary bar" is a ring resolved into separate star formation regions (Barth et al., 1995).
- The polar disk (ring) inside the primary bar. Similar structures have been found in a number of ordinary galaxies (Sil'chenko, 2001) such as NGC 2841 (Afanasiev & Sil'chenko, 1999), NGC 7280 (Afanasiev & Sil'chenko, 2000), and others.
- The projection of the central part of an oblate bulge inside the primary bar onto the sky plane. An illusion can be created of a "second bar", the major axis of which is virtually coincident with the line of

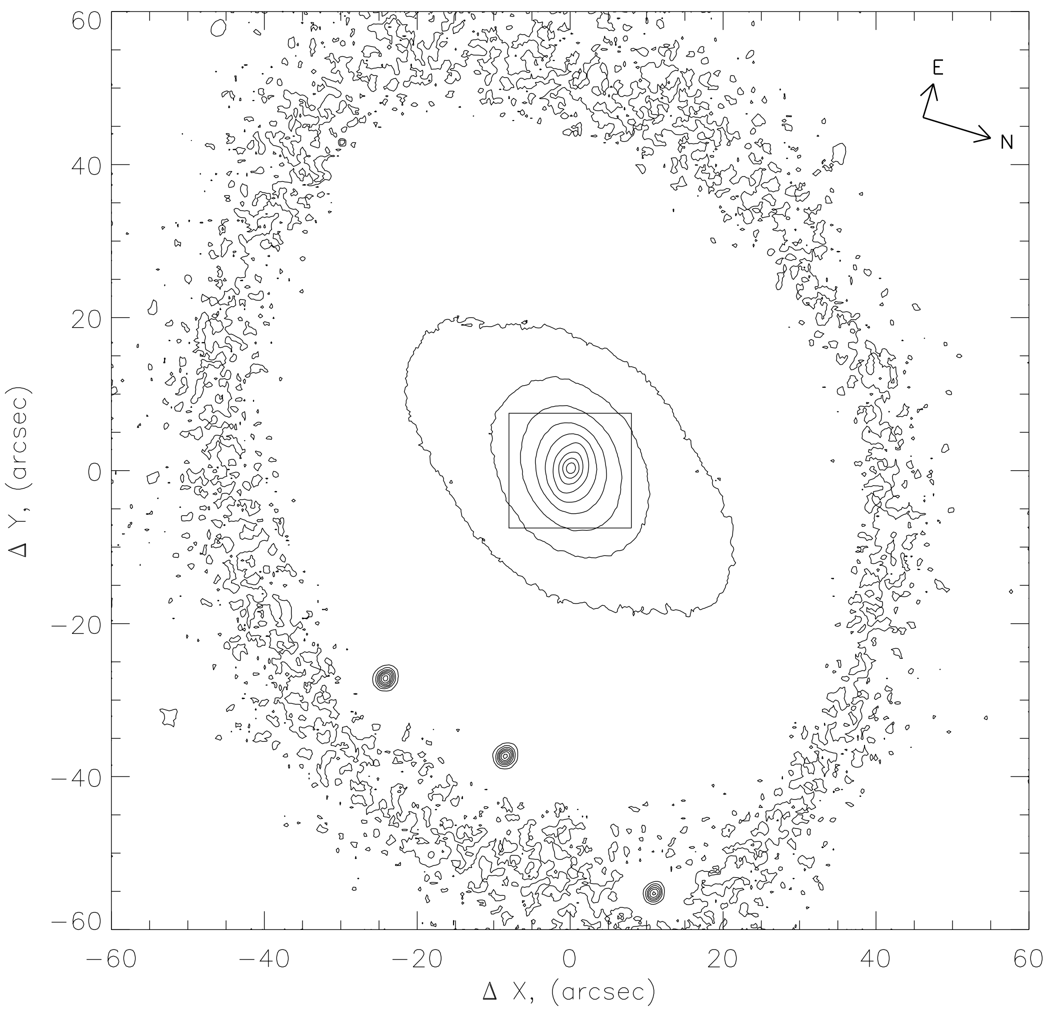

Figure 1: *The NGC 2950 image obtained with the BTA focal reducer SCORPIO in the medium-band filter centered on $\lambda = 7550Å$. The region of the secondary bar observed with the multipupil spectrograph (Fig. 2) is marked with the box.*

nodes of the disk.

- The complex distribution of dust and star formation regions inside the primary bar impedes the study of the circumnuclear region and can create illusion of the presence of a second bar. This problem is solved partly by observations in the near IR range.

That the interpretation of photometric observations of double bars is unambiguous is suggested by the fact that in the paper by Regan & Mulchaey (1999), the authors, using the colour distribution maps obtained with the HST (including those in the near IR), interpreted the structures observed in a number of galaxies (Mrk 573, Mrk 1066, NGC 3516) as circumnuclear spirals but not as second bars.

It seems to us that in order to understand if the second bar is readily a new dynamically isolated region of the galaxy, additional observational data on the kinematics of gas and stars in these strange objects are needed. Since the motion of matter in the regions of the bars differs markedly from circular (see Section 1), and the density distribution is different from axisymmetric, it is necessary to use the methods of panoramic 2D spectroscopy which makes it possible to obtain two-dimensional kinematic characteristics in the sky plane. In 2000 a programme was started at the 6m telescope with the goal of construction of radial velocity fields of stars and ionized gas and two-dimensional maps of velocity dispersion of stars in double-barred galaxies. These data will allow first of all the following kinematic features of bars to be revealed.

- The turn of the kinematic axis (the line of maximum radial velocity gradient) in the velocity fields of stars and gas. This is one of the easily measurable dynamical features of bars. For more details see the references in Moiseev & Mustsevoi (2000) and Sil'chenko (2001).

- The difference in the ionized gas radial velocities measured from Balmer (H_α, H_β) and forbidden ([OIII], [NII]) lines, which is associated with the presence of shock fronts at the edges of bars (Afanasiev & Shapovalova, 1996). We note that new models by Maciejewski et al.(2001) and Shlosman & Heller (2001) show that shock fronts may be absent in the secondary bar, but a observation tests of this fact is need.
- The distinction of the velocity dispersion distribution from axisymmetrical case (Miller & Smith, 1979; Vauterin & Dejonghe, 1997).

The author knows but a few papers concerned with a detailed study of kinematics of galaxies in the secondary bar region. Knapen et al. (2000a) analysed the velocity fields of ionized and molecular gas in NGC 4321 and obtained that only one bar exists in this galaxy contrary to photometric data. In a recent paper by Emsellem et al. (2001), data are presented on stellar kinematics of several double-barred galaxies. In three of them (NGC 1097, NGC 1808, NGC 5728) the secondary bar region turns out to be dynamically decoupled (the circumnuclear radial velocity peak in the sections obtained with a "long slit"). However, from the new data NGC 1365 is classified by the authors as a single bar galaxy with an inner circumnuclear disk. In a small note of Wozniak (1999) arguments are adduced that the "counterrotation" of stars which is observed in cross-sections through the circumnuclear region of NGC 5728 may be due to the influence of the secondary bar. It should, however, be noted that the peaks on the rotation curves and the "counterrotation" detected in one-dimensional sections are inadequate for proving the dynamic effect of the bar and can be explained by a number of other causes, such as merging with a companion or the accretion of intergalactic gas (see Kuijken et al.(1996) for the discussion of this point). The two-dimensional distributions of velocities and velocity dispersions can give more comprehensive information.

3.2. Observations

From the list given in Table 1 we constructed a sample of objects to be observed with 6m telescope BTA, basing on the following criteria: $\delta > 0°$, $a_s < 10''$ (the secondary bar is placed in the field of view of the multipupil spectrograph). During the year 2000 we observed 14 objects, which makes half of all double-barred galaxies in the northern sky. The circumnuclear regions were investigated with the multipupil spectrograph MPFS. The field of view was $16'' \times 15''$, the spatial scale was $1''$/lens. The spectral range $\lambda\lambda 4900-6100$Å included absorption features (MgI, NaI, CaI, FeI) characteristic of the old (G-K) stellar population. To construct the maps of radial velocities and velocity dispersion of stars (further σ_*), the cross-correlation method of the spectra of galaxies with the spectra of template stars was used. We adopted the method for working with the 2D spectroscopy data (Moiseev, 2001). With a dispersion of the spectrograph of 1.35 Å/px the radial velocity measurement accuracy was about 5–10 km/s, the radial velocity dispersion one was 10–20 km/s for $\sigma_* > 50-70$ km/s. The emission lines Hβ and [OIII] which we employed to construct velocity fields of ionized gas in the circumnuclear region are located within the spectral interval. Unfortunately, because most of the galaxies belong to old types (S0-Sa), the emission is far from being present in all the objects.

Galaxies with bright enough emission lines were observed with the scanning Fabry-Perot interferometer (FPI) in the 235th order (for the wavelength 6563 Å), the spectral resolution was about 120 km/s. Interference filter 10–15 Å wide separated the required spectral interval around the lines H$_\alpha$ or [NII]. From the observational data the velocity fields of ionized gas were constructed on considerably larger spatial scales than with the MPFS because the field of view of the FPI was about $5'$. The primary observational reduction and the wavelength scale calibration were performed with the software developed by the author in the IDL environment. The velocity fields were constructed with the ADHOC package [3].

The mean rotation curves and the radial relationships of the position angle PA (r) of the kinematic axis were defined from the velocity fields by the "tilted ring" method (Begeman, 1989). The velocity fields were broken up into elliptical rings of fixed width. The rotation velocity and PA values were determined in each ring as an approximation of circular rotation. Even the application of such a simple approximation allows one to draw a number of conclusions as to the character of non-circular motions in the bar region (see Moiseev & Mustsevoi, 2000 for discussion).

3.3. Some results

We will briefly describe the first results from the analysis of 2D spectroscopy data on the internal kinematics of the objects under study. One of the spectacular examples is NGC 2950, an S0 galaxy, on the images of which is clearly defined the secondary bar turned through approximately 60° with respect to the primary one (Fig. 1 and references in Table 1). The mismatch between the position angle of the kinematic ax-

[3] ADHOC software has been written by J. BOULESTEIX (Observatoire de Marseille). It is free of use http://www-obs.cnrs-mrs.fr/ADHOC/adhoc.html

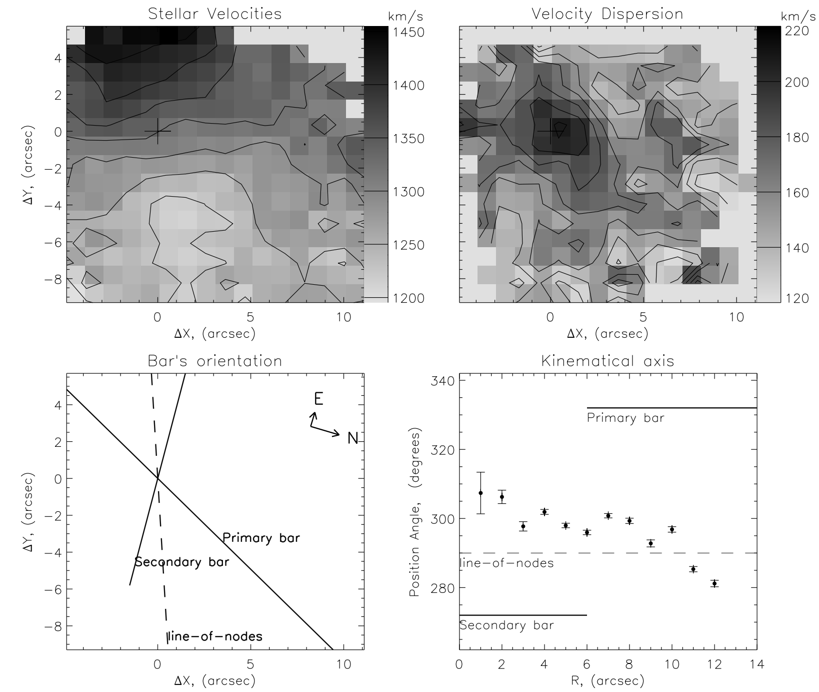

Figure 2: *Kinematics of stars in NGC 2950 from the MPFS observations. (top) — the radial velocity field and the map of the radial velocity dispersion. The cross marks the dynamic centre. The relative orientation of the bars in the image plane and the variations of the position angle of the kinematic axis ("moustached" dots) (bottom). The position angle of the bars and the outer isophotes (the line of nodes) is obtained from the photometric data of Friedli et al. (1996).*

is of the velocity field of stars (PA_{kin}) and the location of the line of nodes (defined from the outer isophotes) reaches $\Delta PA = 10 - 20^\circ$ at distances $r < 8''$ from the centre. The kinematic axis turns in the direction opposite with respect to the line of nodes, as compared to the position angle of the inner isophotes (Fig. 2). It is precisely this behaviour that is characteristic for the triaxial potential of the bar (Monnet et al., 1992; Moiseev & Mustsevoi, 2000). It can be seen from Fig. 2 that outside the secondary bar the kinematic axis intersects the line of nodes, and further at $r > 10''$ its position angle keeps decreasing, which is associated now with the influence of the primary bar.

Thus, the secondary bar, which is seen on the images of NGC 2950, shows itself in the velocity field as well. It is interesting, however, though a central ellipsoidal structure of $r \sim 5''$ in size is seen on the velocity dispersion map (Fig. 2), but its major axis coincides with the outer (not with the inner) bar. Note that in a galaxy consisting only of a disk and a bulge, the radial velocity dispersion of stars must be symmetric along the radius, i.e. the map σ_* has the pattern of concentric ellipses whose major axis is coincident with the line of nodes of the disk. In the presence of a bar, as it is shown in the papers dealing with numerical modeling (Miller & Smith, 1979; Vauterin & Dejonghe, 1997), the distribution of spatial components of the radial velocity dispersion changes so that the character of symmetry on the map of the radial velocity dispersion changes also. The distribution of σ_* in the region of the bar will be symmetric about the bar axis but not about the line of nodes of the disk.

However, the observed radial velocity dispersion distributions of stars in the galaxies explored are considerably more diversified (see Fig. 3). Apart from the expected elliptical structures (NGC 470, NGC 2950, NGC 2681) also peaks of σ_* are observed, which are displaced by a few arcseconds with respect to the dynamic centre (NGC 3368). These peaks have a more complex shape (NGC 5905). Two symmetric peaks are seen in the Seyfert galaxy NGC 3786 at a distance of $3 - 5''$ from the centre. The velocity dispersion gradient here is about ~ 50 km/s. Unfortunately, in literature there are absent any systematic observational data on the two-dimensional distributions of the velocity dispersions in the bars. All the papers are generally restricted to one or two long-slit cross-sections. The most consistent approach to observational studies of asymmetry of the distribution of the

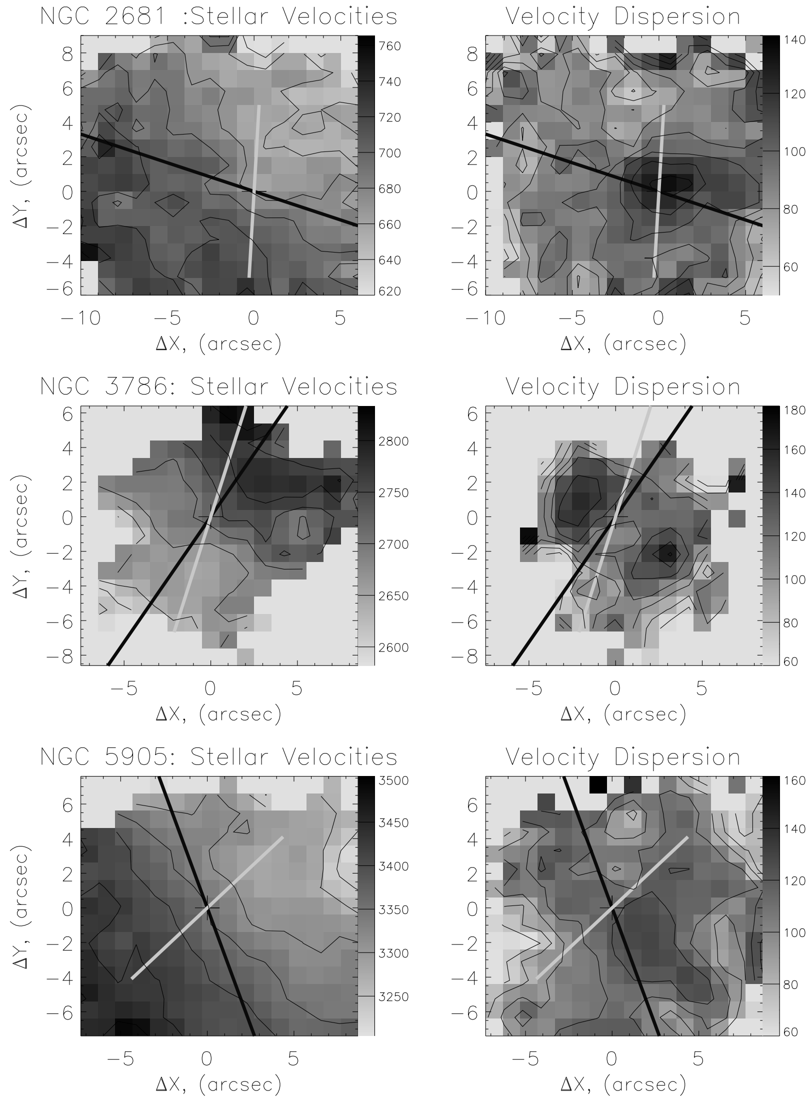

Figure 3: *Radial velocity fields of stars (left) and maps of velocity dispersion of stars (right) in the galaxies NGC 2681, NGC 3780 and NGC 5905. The scale in km/s. The solid black lines show the orientation of the outer bar and the white lines show that of the inner one (from photometry data, see Table. 2).*

radial velocity dispersion in the bars is presented in the paper by Kormendy (1983) by the example of NGC 936. Emsellem et al. (2001) have found "central drops" in the radial distributions of the radial velocity dispersion in several double-barred galaxies, but they did not explain them. Note, that if we had studied the stellar kinematics in NGC 3786 with a long-slit spectrograph, we should have discovered the "drops" in the σ_* distribution similar to those described by Emsellem et al. (2001).

Analysis of the velocity fields of gas and stars has shown that in all the galaxies the value of the PA_{kin} in the circumnuclear region is different from the position of the line of nodes by $10° - 25°$, which is suggestive of considerable non-circular motions. But only in a few galaxies (NGC 2950, NGC 3368 and less reliably in NGC 5850) the PA_{kin} changes on the scales of the secondary bar, and these changes being in opposite direction with respect to the PA of the inner isophotes. This may point to the dynamic decoupling of the inner bar. The turn of the PA_{kin} in the rest of the objects is likely to be related to the influence of the outer bar.

In the circumnuclear regions of NGC 3368, NGC 3768 and NGC 5905 the position of the kinematic axis of the PA_{kin} (stars), which is determined from the velocity field of stars, differs systematically by $10° - 20°$ from the PA_{kin} (gas) defined from the velocity fields of ionized gas. This feature is not related directly to the secondary bar but is the reflection of the fact that gas and stars move in the bar in different manner (see Section 1). The case of NGC 3368 is

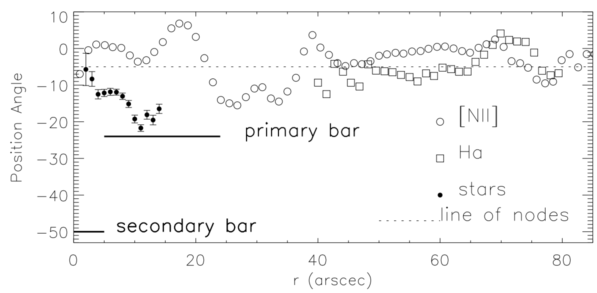

Figure 4: *Comparison of the kinematic axis orientation determined from the velocity field of stars (filled circles) and from the lines of ionized gas* H_α *(squares) and [NII] (circles) in the galaxy NGC 3368.*

of interest. Here the radial relationship of the PA_{kin} (stars) at $r = 2 - 15''$ copies the behaviour of the PA_{kin} (gas), but it displaced systematically with reference to the latter by $\sim 15^\circ$ (the measurement accuracy of the position angle being close to 1° everywhere (see Fig. 4). Note that, using the results of numerical modeling, Shaw et al. (1993) predicted a similar effect ("phase shift between gas and stars"), which must be observed in the central regions of the barred galaxies between two ILR resonances.

4. Conclusions

Thus we made the first attempt to study the internal kinematics of double-barred galaxies. In the central regions of all the investigated galaxies deviations from the purely circular rotation are being detected (turn of the kinematic axis in the velocity fields, different for stars and ionized gas, i.e. asymmetry in the observed distribution of the radial velocity dispersion of stars). However, the region of the inner bar seems to be dynamically decoupled from the outer bar but in a few cases (NGC 2950, NGC 3368, NGC 5850). It is not improbable that this is related to the fact that the dynamically independent secondary bar is a considerably rarer phenomenon than it follows from the analysis of images of galaxies. This conclusion is consistent with some theoretical models (Friedli & Martinet, 1993); Khoperskov et al., 2001) which suggest that the secondary bar is a relatively short-lived structure inside the long-lived large-scale bar. Moreover, Khoperskov et al. (2001) show that the three components of the velocity dispersion of stars in a galaxy with a bar have different shape of the distribution in the disk plane. The radial velocity dispersion σ_* will have then a rather complex distribution in the sky plane. The shape of distribution σ_* is first of all defined by the parameters of orientation of the bar and the disk relative to the observer. Changing these parameters, one can obtain the distribution σ_* with a drop at the centre (like in NGC 3786) or elongated perpendicularly to the inner bar, like in NGC 2950. We consider the dynamical three-dimensional modeling of particular galaxies with the use of all the kinematic data that we have acquired and with the involvement of the available photometric data to be the next step in the study of double bars. This is contemplated to be done in the next papers.

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