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Minibars in the Centers of Normal Galaxies

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Abstract. Analysis of ionized gas velocity fields in the circumnuclear regions of 13 normal spiral galaxies has shown that about a half of them reveal discrepancy between kinematical axis at $R < 2"$ and photometric or kinematical axes of outer regions. It evidences for high frequency of non-axisymmetric gravitational potential occurence in inner few hundred parsecs of galaxies. The possible nature of these minibars is discussed.

Nuclear bars, or minibars observed in the very centers of some spiral galaxies, are poorly understood features of the galactic structure. A majority of them were found by visual inspection of galaxy images (see Buta and Crocker 1993 and references therein). It is generally accepted that they are related to the nuclear rings formed in barred galaxies at the inner Linblad resonance (ILR), although according to Buta and Crocker (1993), in some cases they were found in non-barred spirals, so in general a presence of large-scale non-axisymmetric gravitational potential is not a rigid condition for the nuclear bar to be formed. Typical length of nuclear bars is 1 - 2 kpc for $H_0 = 75 km/s/Mpc$. But the shape of the nuclear bar size distribution over small lengths ($L < 1$ kpc) is certainly strongly affected by selecton effects. Here we consider the presence of the smallest bar-like configurations which we call minibars in the centers of galaxies.

Perhaps the most direct way to reveal bar-like pattern in the central regions of galaxies is to analyse velocity data instead of brightness distribution to be sure that the rotation of gas (or stars) bears signs of non-axisymmetrical potential. Below we describe results of our measurements of ionized gas line-of-sight velocities in the inner ($R < 10"$) regions of nearby spiral galaxies obtained at 6m reflector of the Special Astrophysical observatory of Russian Academy of Sciences mainly in 1993-1994 with two-dimensional spectral devices which allow to investigate simultameously velocity fields and morphology (isophote ellipticity and orientation).

Our observational program included 13 barred and non-barred nearby galaxies without noticeable nuclear activity. All galaxies were chosen after preliminary analysis of our long-slit data obtained earlier which has revealed presence of local features on their rotation curves in the circumnuclear regions such as local maxima or small plateau in the center. Three different spectral devices were used: Long-Slit Spectrograph (LS), Multi-Pupil Field Spectrograph (MPFS) and Fabri-Perot scanning interferometer (FPI). Raw spectra were detected by TV Photon Counting System 512×512 pixels ($1px = 0.7" - 1.2"$). Typical seeing during the observations was $1.5" - 2"$. Line-of sight velocity gradients along different position angles (PA) were measured from the positions of $H\alpha$ and [NII] emission lines in the range $R = 1.5" - 2.3"$ from the nucleus. We have used these estimates to verify kinematical symmetry of velocity field with respect to the kinematical or photometric major axes found for the outer parts. Central line-of-sight velocity gradient of circularly rotating gas alters with the PA following cosine-like law and reaching its extrema at the line of nodes. Presence of bar or oval orbit distortion results in the shift of the PA_o.

Table 1. Program galaxies

NGC	Type	Spectral device	Presence of minibar
23	SBb	LS, MPFS, FP	No
497	SBbc	LS, MPFS, FP	Yes
615	Sb	LS, MPFS	No
895	Sc	LS, MPFS	Yes
972	Sb	LS, MPFS	Yes
4100	Sc	LS	Yes
4536	SBc	LS, MPFS	No
6181	SBc	LS, MPFS, FP	Yes
6643	Sc	LS	No
7013	SO/a	LS	No
7171	SBb	LS, MPFS	Yes (?)
7217	Sb	MPFS	Yes
7331	Sbc	LS	No

crrrr

Minibar is assumed to be detected if the discrepancy between kinematical major axis positions in the inner and in the outer regions exceeds $5-7°$. As one can see from Table 1, about half of the galaxies under consideration might have minibars. They may not to be real optical high-contrast bars: we state only the gas motions on elliptical orbits due to barred potential. Only three of these seven galaxies possess large-scale bars, so we may guess that there is no direct relation between two features. In general, although our results are not free from observational selection, they give first evidence of high frequency of minibar occurence among normal spiral galaxies.

Table 2. Galaxies with bar-like distortions of circumnuclear velocity fields

NGC	ΔPA_o	R, kpc	Comments	$(\frac{M_b}{M_d})_{R=1kpc}$
497	202°	1	counterrotation?	1.7
895	44°	0.3	inclined disk?	>1
972	45°	0.2		8
	10°	0.9		
4100	26°	0.15	nuclear ring $R=6$"	>1
6181	28°	0.3		1.4
	8°	1.0		
7171	190° ::	0.35	counterrotation?	2.3
7217	130°	0.15	nuclear ring $R=10$"	2.0

Differences between the inner and outer kinematical major axes are presented in Table 2. Linear radii corresponding to the given inner PA_o are also given. The scales of the bar-like orbit distortions in these galaxies are among the smallest ever observed in galaxies beyond the Local Group (in most cases they are less than 0.5 kpc). Optical images of all these galaxies look quite normal in their inner parts. Two of them (NGC 4100 and NGC 7217) have nuclear rings less than 1 kpc by radius (Buta and Crocker, 1993), but none has optical nuclear bar mentioned in the literature (although detailed photometry of their nuclear regions is still highly desirable). In some cases (NGC 497, NGC 7171, NGC 7217) the difference of PA_o's is between $90°$ and $270°$ that mimics nuclear gas counterrotation under long-slit spectral observations.

Fig. 1 presents azimuthal dependencies of line-of-sight velocity gradients in the nuclear regions of some galaxies which are found to have minibars. Their maxima are noticeably shifted from the lines of nodes defined by the outer parts. Angular differences between the expected and the observed maxima depend both on the amplitude of bar potential and on its orientation - parameters which are unknown. In principle, the observed shift of cosine-like curve maxima may be caused not only by an oval orbit distortion, but also by the inclination of inner disc with respect to the main disk of galaxy. For several galaxies whose inner isophotes demonstrate orientations of the major axis in agreement with the kinematical central PA_o (NGC 497, NGC 895, and NGC 972) this possibility cannot be excluded. However the azimuthal dependence of central velocity gradient for NGC 972 (Fig. 1) resemble poorly cosine law looking asymmetrical, so in this galaxy the presence of inclined, circularly rotating nuclear disk is quite improbable. In addition there are other cases, e.g. NGC 6181 and 7217, where the inner isophotes are turned with respect to the line of nodes in the sense opposite to that of kinematical major axis twist (Fig. 2 - our broad-band observations for NGC 6181 and combined data for NGC 7217), and here the presence of bar-like distortions is obvious. For two galaxies which were observed with FPI (NGC 972 and NGC 6181) we could retrace the change of kinematical major axis orientation along the R to obtain a boundary of the abnormal axis orientation region. In both cases it appears to be well resolved. The radius where $(PA)_o$ slows down or stops its variation is about $5" - 8"$ (0.6-0.9 kpc) for NGC 972 and about 5" (0.8 kpc) for NGC 6181. Beyond these radial distances the influence of minibar on the gaseous disk rotation is negligible.

The galaxies where minibars are found do not differ much from non-barred galaxies by the general shapes of their rotation curves. No colour peculiarities of nuclear regions were also found for galaxies where multiaperture UBV-data are available (Longo and Vaucouleurs, 1983, 1985).

One may expect that the main stellar disc does not control gravitational potential of galaxies under consideration at $R < 1$ kpc. To verify it we modelled rotation curves of the galaxies within their growing parts (several kpc from the center) in a frame of two-component model (exponential disc + sphere) to separate these components (the extended rotation curve of NGC 7217 was taken from Rubin et al., 1985, others are ours). Photometric scale-lengths of the discs were taken from the literature, then we extrapolated density distribution law of the disc onto the central region. Note that in many cases this procedure may lead to overestimation of the central density, because discs often show photometric profile flattening near the centers or central density depressions (see for example Kent, 1986, 1987). Presence of dark haloes does not influence the results because we restricted ourselves by the inner regions of galaxies. The masses ratios of spherical and disc components for $R = 1$ kpc are shown in the last column of the Table 2. It follows that in the central regions of the galaxies gravitation of the stellar disc is suppressed by the bulge. This circumstance allows to restrict possible mechanisms of minibar formation.

Large relative mass of spherical component prevents the development of classical bar-mode disc instability. Two possibilities left instead. The first one is the presence of massive and dynamically cool nuclear discs in the inner several hundred parsecs, which are independent from the main stellar discs being far more dense. The similar subsystems were found by us earlier in some galaxies with axisymmetric central rotation (Afanasiev, Sil'chenko, and Zasov, 1989).

The second possibility is to consider the observed inner bars as slowly rotating bars developed from the hot stellar population through the elongated orbit instability (the mechanism proposed by Lynden-Bell, 1979, and later developed by Polyachenko with coauthors - see Polyachenko, 1994, or Polyachenko and Polyachenko, 1994). In this case the process of sticking of elongated orbits together leads to the formation of bar from hot stellar population of inner bulge or nuclear stellar disc. It is expected that slow bar ends up at the ILR, so it may naturally explain the position of nuclear rings where they encircle nuclear bars. If both - normal and slow bar - coexist in a galaxy, there must not be any correlation between their orientations because of the different angular velocities, which agrees with observations of galaxies with nuclear bars.

In both cases the presence of large-scale "normal" bars is not necessary for minibars to be formed, although indirectly a large bar may provoke a creation of inner one owing to the accumulation of a bar-driven interstellar gas onto the central disc (if it exists) or to the dynamical heating of stars in the central region of galaxy, which is essential for the formation of slow bar.

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References

Afanasiev, V. L., Sil'chenko O. K., and Zasov, A. V. 1989, A&A, 213, L9

Buta, R. and Crocker, D. A. 1993, AJ, 105, 1344

Kent, S.M. 1986, AJ, 91, 1301

Kent, S.M. 1987, AJ, 93, 816

Longo, G., and de Vaucouleurs, A. 1983, A General Catalogue of Photoelectric Magnitudes and Colors in the U, B, V System. Austin: Univ. Texas Press

Longo, G., and de Vaucouleurs, A. 1985, Supplement to the General Catalogue of Photoelectric Magnitudes and Colors of Galaxies in the U, B, V System. Austin: Univ. Texas Press

Lynden-Bell, D. 1979, MNRAS, 187, 101

Polyachenko, V.L. 1994, in Physics of the Gaseous and Stellar Disks of the Galaxy, I. R. King, ASP Conf. Ser., 66, 103

Polyachenko, V.L. and Polyachenko, E.V. 1994, Pis'ma v Astron. Zh., 20, 491

Rubin, V. C., Burstein, D., Ford, W. K., and Thonnard, N. 1985, ApJ, 289, 81

Sil'chenko, O. K., and Vlasyuk, V. V. 1992, Pis'ma v Astron. Zh., 18, 643

Zaritsky, D., and Lo, K. Y. 1986, ApJ, 303, 66