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Search for chemically decoupled galactic nuclei with the Multi-Pupil Field Spectrograph of the 6 m telescope

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1. Scientific history

One who has ever looked at any early-type galaxy by the unaided eye knows that a nucleus often looks like a star; namely, early-type galaxies often possess point-like nuclei. Our nearest neighbours, M 31, a giant spiral, and M 32, a dwarf elliptical galaxy, present excellent examples of such bright point-like nuclei. So, the surface brightness distinctness of galactic nuclei has long been known. After digital detectors of large dynamic range became to be extensively used, the photometrical distinctness of nuclei has been demonstrated quantitatively (e. g. Kormendy, 1985).

In 1988 a series of papers stated the existence of dynamically decoupled galactic nuclei. Jedrzejewski & Schechter (1988) and Bender (1988) investigated rotation of elliptical galaxies; they found several galaxies with fast rotating nuclei, whereas the main bodies of these galaxies rotated much slower. There were also some quite surprising examples (e. g. NGC 4406) where the nuclei rotated around the major axes, and the main bodies — around the minor ones. The first idea was that the dynamically decoupled nuclei of elliptical galaxies belonged earlier to smaller disk galaxies merged some time ago. But later Bender & Surma (1992) have found that dynamically decoupled nuclei in four elliptical galaxies are also distinguished by a higher magnesium absorption line strength, so the dynamically decoupled nuclei possess a particular metal-rich stellar population. It means that they could not belong earlier to dwarf galaxies because dwarf galaxies are metal-poor objects. Bender's favourite idea is that the decoupled nuclei in elliptical galaxies are formed as a result of accretion of a large amount of gas ("dissipative merger") and subsequent star formation burst in the centres. Due to the dissipative nature of accreted gas, decoupled nuclei must be disks. Indeed, a search for weak stellar disks in centres of elliptical galaxies with the Hubble Space Telescope was successful, a lot of such disks have been discovered, but only not in galaxies with dynamically decoupled nuclei (Van den Bosch et al., 1994; but see an alternative conclusion in Carollo et al., 1997). The relation between decoupled nuclei and nuclear stellar disks in elliptical galaxies remains still unclear.

A dissipationless merging can be excluded in the case of spiral galaxies with decoupled nuclei because of inevitable disk heating during merging. That is why when Kormendy (1988a) and Dressler & Richstone (1988) found a dynamically decoupled nucleus in M 31, and Kormendy (1988b) and Jarvis & Dubath (1988) reported its existence in NGC 4594, there was no supposition about merging. The presence of supermassive black holes in the centres of some early-type disk galaxies was claimed instead (later NGC 3115, a quiescent S0 galaxy, was added to M 31 and NGC 4594 by Kormendy & Richstone, 1992), though some opponents tried to draw attention to apparently composite profiles of absorption lines in the spectra of dynamically decoupled nuclei (Rix 1993): the existence of multiple stellar subsystems in the centres of these galaxies made senseless any attempt to apply a spherically symmetrical dynamic model to decoupled nuclei.

In 1988 we had digital long-slit spectroscopic data taken in several position angles for three dozen nearby spiral galaxies (Afanasiev et al., 1988a,b). This fund allowed us to react immediately to the discovery of the first dynamically decoupled nuclei. Using the data on ionized gas velocity distribution near the centres, we not only reported the discovery of another six dynamically decoupled nuclei in spiral galaxies, but proved axisymmetry of the central mass distributions in four of them having thus excluded imitation of dynamically decoupled nuclei by a minibar (Afanasiev et al., 1989). In contrast to Kormendy and others, we assumed the dynamically decoupled nuclei to be dense stellar clusters; and if so, the properties of their stars, namely, age and metallicity, may be quite different from the properties of the surrounding bulges. Having this idea in mind, we included three spiral galaxies with dynamically decoupled nuclei, NGC 615, 7013, and 7331, in the list of galaxies which were to be observed during the first run undertaken with the new Multi-Pupil Field Spectrograph (MPFS) of the 6 m telescope of the Special Astrophysical Observatory of RAS in August of 1989. We were lucky:

7 out of 12 nearby galaxies of various morphological types observed with the MPFS in 1989, demonstrated a prominent break of magnesium absorption-line strength between the nuclei and the surrounding bulges, the three of them being spiral galaxies with dynamically decoupled nuclei. So the dynamically decoupled galactic nuclei in spiral galaxies appear to be also chemically decoupled. Our paper with this result (Sil'chenko et al., 1992) was published in the same year as the paper of Bender & Surma (1992) on chemically decoupled nuclei in elliptical galaxies. It became clear that decoupled nuclei in galaxies of various morphological types may be of similar origin.

In 1992 high-resolution spectral observations of the centres of galaxies were sparse (and now they remain the same). We needed an effective way of search for decoupled nuclei in galaxies. So we appealed to the most numerous observational data – aperture photoelectric photometry of galaxies. By applying a unique statistical method to a sample of 237 galaxies for which there are more than 10 multi-aperture measurements in the catalogues of Longo & Vaucouleurs (1983, 1985) I have compared $B-V$ colours of the innermost parts and of extended bulges in early-type galaxies (earlier than Sc). As a result it has been obtained that 25%–30% of all elliptical and lenticular galaxies and more than 50% of early-type spirals possess nuclei which are considerably redder than the surrounding bulges (Sil'chenko, 1994). Surely, the red colour of a nucleus may result from a dust concentration, not from the stellar population difference, so spectral observations are quite necessary to prove the chemical distinctness of a nucleus. Bidimensional spectroscopy is particularly effective in search for decoupled nuclei: firstly, when co-adding of individual element spectra in rings, the resulting signal-to-noise ratio remains constant along the radius, providing high-quality radial profiles of absorption-line strengths, and, secondly, two-dimensional maps of brightness and velocity usually allow one to select an unambiguous dynamical interpretation, i. e. to verify if the nucleus is really the high-density site but not a triaxial structure. In 1993 I started an observational program of searching for decoupled galactic nuclei with the Multi-Pupil Field Spectrograph of the 6 m telescope; a list of 34 northern galaxies of various morphological types which demonstrate photometrically distinct red nuclei (Sil'chenko, 1994) is used to choose the most probable candidates for galaxies possessing a decoupled nucleus. To date more than half of all candidates have been studied, a dozen of new certain chemically decoupled nuclei have been found, and in this paper some preliminary judgements about their possible nature and origin are made.

2. Instrumental history

Our program of searching for decoupled galactic nuclei is fully based on advantages of a new approach to bidimensional spectroscopic investigations which are engaged by Dr. Afanasiev and his coworkers to create a Multi-Pupil Field Spectrograph of the Special Astrophysical Observatory of RAS. Systematic observations with the MPFS were started in 1989, and since that time the spectrograph has been essentially improved. A long history of all improvements can be briefly described as follows.

The main idea of the MPFS invented by G. Courtes in the early 80th involves construction of a pupil for each spatial element of a two-dimensional region of an extended astronomical object (e. g. a galaxy) by using a microlens array in the focal plane of the telescope and subsequent simultaneous registration of several dozens (hundreds) of spectra from all these elements. The French version of the multi-pupil field spectrograph – TIGER – was created in Lyon by Bacon with coworkers (Bacon et al., 1995) and is now in operation at the CFHT. The first variant of the MPFS of SAO RAS (Afanasiev et al., 1990) was created in 1989 and was operated at the 6 m telescope from 1989 to 1991. It contained fibers that transferred light from microlenses to the entrance of a classical long-slit spectrograph: 96 fiber outputs corresponding to the input 8×12 square spatial elements, each with a side of $1''.25$, were densely packed along the slit, and therefore spectra were located one under another taking advantage of full coverage of the detector format. The detector used was IPCS 512×512. This configuration had a large common spectral range, all the 512 pixels. But the fibers absorbed a lot of light; moreover, perhaps due to the fibers, the instrumental profile was essentially non-Gaussian, with extended low-contrast wings which humpered velocity measurements with an accuracy better than ≈ 70 km/s. In 1992 the fibers were removed, the microlense array was turned by some $10°–15°$ with respect to the dispersion direction, so that individual spectra became to be separated on the detector without any fibers; but the common spectral range was reduced to approximately 300 pixels. To obtain spectra as long as 500–700 Å we were forced to use dispersions of 1.7–2.5 Å per pixel, providing a spectral resolution of 8–10 Å. It is not good enough even for stellar population analysis; as for kinematical studies of ionized gas, they became possible, but even by selecting very intense emission lines we reached an accuracy not better than 30 km/s. In October of 1994 we began observations with a new detector — CCD 520×580 with an element of $18 \times 24\,\mu m$. It was an important improvement: firstly, the quantum efficiency of the new registration system was much higher than that of the previous one, and, secondly, the instrumental

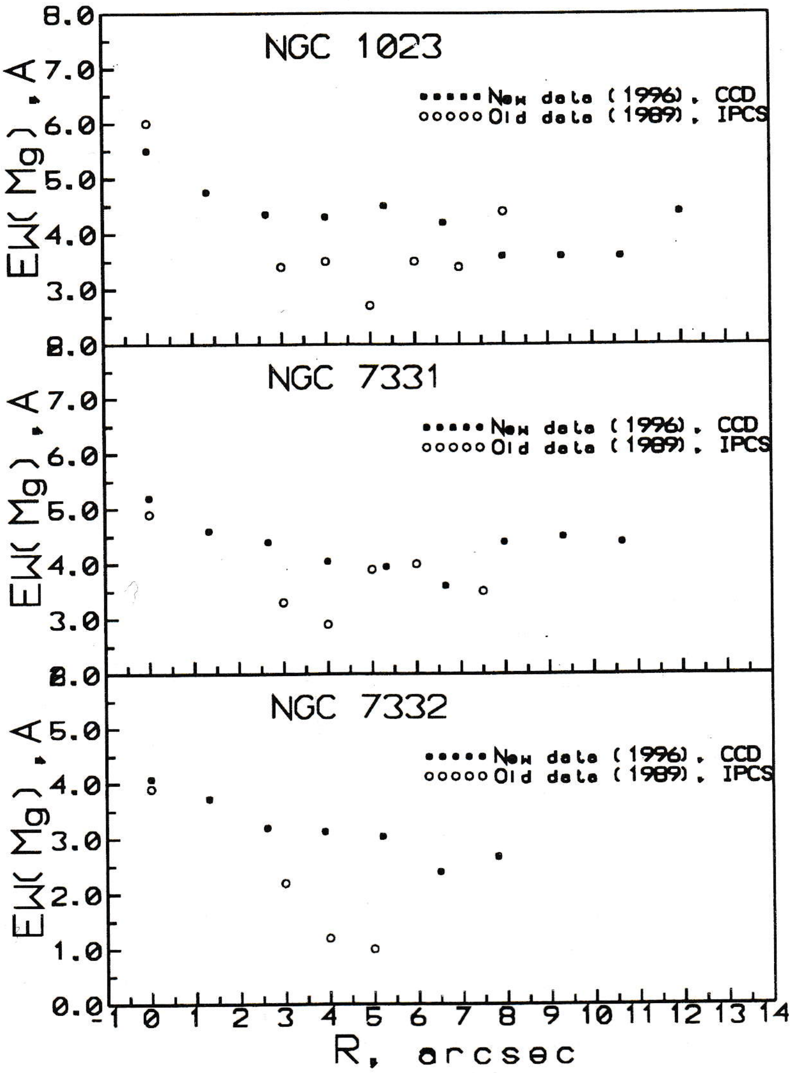

Figure 1: *Comparison of the equivalent widths of the magnesium absorption line MgI*λ5175 *measured along the radius in three galaxies in 1989 when the MPFS was equipped with the IPCS* 512 × 512 *and in 1996 when it was equipped with a CCD*

profile became much narrower with the FWHM reduced from 4–5 pixels to 2 pixels. This variant of the MPFS was used in two modes: when the dispersion was directed along the short side of the detector, we had 1.2 Å per pixel (a spectral resolution of 2.5 Å) and a field of 10 × 16 elements (later 8 × 16 elements), but a spectral range of only 300 Å – a good configuration for kinematical studies of ionized gas in the red spectral range. For stellar component investigations in the green spectral range we directed the dispersion along the long side of the detector and obtained 1.6 Å per pixel and a field of 10×12 elements (later 8×12 elements). This configuration allowed simultaneous detection of several strong absorption lines, from H_β (λ4861) to FeI ($\lambda\lambda$ 5270, 5328, 5406). After the CCD appearance we were able to measure stellar velocity fields by cross-correlation of the green spectrum of a galaxy element ($\lambda\lambda$ 4800–5400) with a similar spectrum of a template star which was usually a K0–K3 giant. The typical accuracy of wavelength calibration was improved to better than 5 km/s, and as a consequence, that of an individual velocity estimates, both for gas and stars, reached 20 km/s. The accuracy of equivalent widths of absorption lines was improved from 0.3 Å (IPCS) to 0.1 Å (CCD). This set of properties of two-dimensional spectroscopic data obtained with the MPFS equipped with the CCD has made it possible to undertake a complete and high-quality investigation of the proposed candidates for possessing decoupled nuclei, so since 1994 we have begun to claim findings of really new phenomena. In 1996 a large-format CCD 1040 × 1160 was installed on the

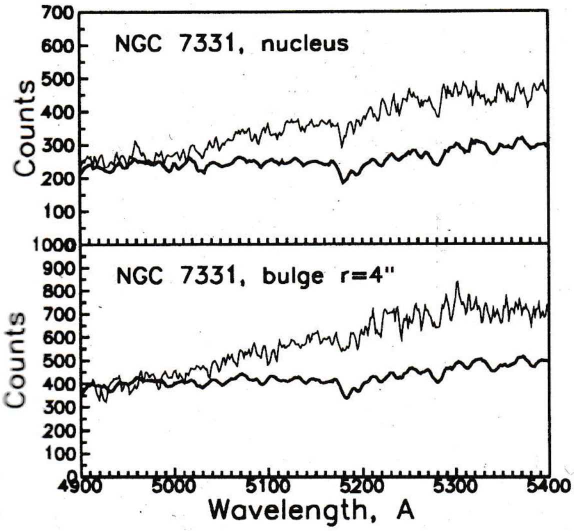

Figure 2: Comparison of nuclear and bulge ($r = 4''$) spectra, which were obtained for NGC 7331 in 1989 when the MPFS was equipped with the IPCS 512×512 *(thin lines) and in 1996 when it was equipped with CCD (thick lines)*

MPFS. This increased slightly the field of view registered during one exposure: now the field of 8 × 16 square elements, each with a side of 1.3″, can be combined with a 900-pixel common spectral range. As the instrumental improvement over the past seven years has been enormous, we have re-observed some of our first galaxies with the decoupled nuclei by using the last variant of the MPFS equipped with the large-format CCD. A comparison of azimuthally-averaged magnesium-line profiles obtained in 1989 and in 1996 is presented for three bright early-type disk galaxies in Fig. 1 and that of nuclear and bulge spectra (taken for NGC 7331) – in Fig. 2. One can see that despite very different noise level, equivalent-width accuracies and larger extension of the profiles of 1996, the main conclusion about the presence of chemically decoupled nuclei in NGC 1023, 7331, and 7332 has remained unchanged.

The whole procedure of the decoupled nucleus investigation now includes observations with the MPFS in the green (λλ 4800–5400) and in the red (λλ 6200–6900) spectral ranges with subsequent construction of two-dimensional maps of continuum and emission-line surface brightnesses, of ionized-gas and stellar line-of-sight velocities, and also of azimuthally-averaged profiles of equivalent widths of strong absorption lines. The primary reduction is made with the help of the software developed in the Special Astrophysical Observatory (Vlasyuk, 1993). The further analysis of two-dimensional velocity fields consists, firstly, of looking for local velocity extrema within a few arcseconds from the nuclei, and, secondly, of verifying the circular character of rotation. The latter point is usually carried out by examining the azimuthal dependence of observed central line-of-sight velocity gradients and by fitting this dependence by a cosine law. In the case of pure circular rotation

$$dv_r/dr(PA) = \omega \sin i \cos(PA - PA_0),$$

where ω is the deprojected central angular rotation velocity, i is an inclination of the rotation plane to the sky plane, and PA_0 is the orientation of the line of nodes on the sky. Hence if the rotation is circular and the brightness (mass) distribution is axisymmetric, the maximum of the fitted cosine curve must be located exactly at the position angle of isophote major axis. It is just for the purpose of measuring the orientation of the major axis of the innermost isophote that we use the maps of continuum and emission surface brightnesses. If such a verification has revealed the circular character of rotation, we should interpret the existence of symmetrically located circumnuclear velocity extrema as evidence of the central mass concentration, or of the so-called "dynamically decoupled" nucleus. As for chemically decoupled nuclei, we search for their manifestation in the form of abrupt drop of absorption-line strengths on the radial profiles when passing from a bright, mostly unresolved nucleus to a surrounding bulge. The present-day models of integrated spectra of stellar populations, such as those of Worthey (1994), allow us not only to calibrate this drop in terms of mean metallicity of the stellar population, but also, by comparing absorption-line indices of various chemical elements, to evaluate the mean age of the stellar populations and the duration of the epoch of basic star formation. As a rule, we detect a presence of chemically decoupled nucleus, if the magnesium-index break between the nucleus and the bulge is more than 2σ (let me remind that a mean σ of absorption-line index measurements is now about 0.1 Å). Sometimes we observe an intrinsic linear magnesium-line gradient in a bulge; in this case we extrapolate it to $r = 0''$ and after that compare the value of Mgb calculated for the centre of the bulge and the value measured in the nucleus. Below I briefly review the results of such an investigation for several galaxies studied in detail. A summary of the main characteristics of the galaxies is given in the Table.

3. Results

3.1. NGC 4826, 5533, and 7331

NGC 7331 is one of our first findings with a kinematically and chemically decoupled nucleus, and we have studied it in detail. We have reported the presence

Table 1: *Main characteristics of galaxies*

NGC/IC	Type	M_B	D (Mpc)	Metal. break (dex)	R of nucl. ($''$)	Reference
I1689	S0?	−19.6	63	0.7	< 2	Sil'chenko, 1998
1052	E4	−20.4	19	$\gtrsim 0.6$	3–4	Sil'chenko, 1995
2685	(R)SB0+pec	−19.1	14	0.7	< 2	Sil'chenko, 1998
2841	SA(r)b:	−20.7	10	0.36	< 2	Sil'chenko et al., 1997
4564	E6	−19.3	17 (Virgo)	0.8	4–5	Sil'chenko, 1997
4621	E5	−19.6	17 (Virgo)	0.5	4–6	Sil'chenko, 1997
4826	(R)SA(rs)ab	−20.6	7	$\gtrsim 0.23$	< 2	Sil'chenko, 1996
5533	SA(rs)ab	−21.4	53	0.24	< 2	Sil'chenko et al., 1998
5576	E3	−20.1	20	0.6	< 2	Sil'chenko, 1997
7331	SA(s)b	−21.4	14	0.8	< 2	

of a fast-rotating unresolved ($R \lesssim 1.5''$) mass concentration at the centre of NGC 7331 based on our long-slit observations of the emission line [NII]λ6583; moreover, four cross-sections at various position angles have allowed us to state that the rotation of the ionized gas in the centre is circular (Afanasiev et al., 1989). After the first observations with the MPFS we have reported a chemical distinctness of the unresolved nucleus of NGC 7331 (Sil'chenko et al., 1992). Many people have reported that in this galaxy there is no isophote twist beyond 10°, and we have checked this fact with our own data (Sil'chenko & Vlasyuk, 1992). To summarize briefly, we are sure that NGC 7331 represents a regular, axisymmetric, relatively isolated and absolutely undisturbed early-type spiral galaxy with a distinct unresolved nuclear disk characterized by a high mass density and by a high metallicity. This prototype has forced us to look for internal mechanisms of producing decoupled nuclei. But the picture has completely changed after the appearance of the paper of Prada et al. (1996) where the discovery of a counterrotating bulge in NGC 7331 was claimed. They analysed the behaviour of the infrared CaII absorption triplet along the major axis, and in the radius range of $5''$–$15''$ they found two counterrotating stellar subsystems. One of them (a truly counterrotating one with respect to gas rotation) was treated as a bulge (though a negative boxiness is revealed only within $R = 5''$), and the other – as the central part of the global disk. The presence of the unresolved fast-rotating nuclear disk has been tentatively confirmed. But what we thought earlier to be an extended co-rotating bulge is now treated as a cold inner disk. So, the overall structure of NGC 7331 looks now as follows: starting from the centre, we first see a nuclear fast-corotating dense disk with $R \lesssim 1''$, then a counterrotating bulge extending not farther than $R \approx 15''$ from the centre, then the first large corotating disk, and after $R \approx 60''$ – the second large disk with an unknown rotation sense detected only from a discontinuity of the surface brightness profile. This structure seems to be too complex for a classical spiral galaxy, and the presence of a counterrotating stellar component implies some accretion or merging event in the past.

NGC 4826 is another regular isolated spiral galaxy. It became famous several years ago when a counterrotating outer gaseous disk was found in it – first from observations of neutral hydrogen emission line 21 cm (Braun et al., 1992, 1994) and later from observations of ionized gas emission line H_α (Rubin, 1994, Rix et al., 1995). The inner gas, $R \lesssim 1$ kpc, rotates together with stars, and farther away from the centre neutral and ionized gas changes abruptly the sense of rotation remaining coplanar with the inner gaseous and stellar disks. The stellar disk conserves its rotation sense up to his boundary being quite cold ($\sigma_* \lesssim 40$ km/s), and no counterrotating stellar component was found (Rix et al., 1995). The galaxy looks quite normal except for a very high gas density in the central kiloparsec region. We have found the unresolved nucleus of NGC 4826 to be distinct by an increased magnesium-line strength (Sil'chenko, 1996) though the exact metallicity break cannot be surely estimated due to recent star formation in the vicinity of the nucleus (two supernova remnants are identified within $5''$ from the nucleus). The innermost dynamical major axis at $R \lesssim 2''$ coincides with the innermost isophote major axis according to HST data – this coincidence certainly points to a circular character of gas rotation at the centre of NGC 4826; however both are turned by 16° with respect to the global disk line of nodes defined by the orientation of the outermost isophotes. So the decoupled nuclear disk may be slightly inclined to the main galactic plane.

The last isolated regular early-type spiral galaxy that must be discussed in this Subsection is NGC 5533 (Sil'chenko et al., 1998). As NGC 7331, it has been found to have a chemically decoupled nucleus. As in NGC 7331, we have noted that both the stellar and the gaseous rotation curves of the central part of NGC 5533 demonstrate prominent circumnuclear local maxima. There is no significant isophote twist in any part of this galaxy; a dynamical line of nodes of the nuclear gas is exactly coincident with the orientation of the major axis of the innermost (and outer) isophotes, so we conclude that rotation is circular in the centre of NGC 5533 and circumnuclear rotation velocity maxima can be interpreted as evidence of a strong central mass concentration. Hence, the nucleus of NGC 5533 is chemically and dynamically decoupled, just as that of NGC 7331. The stellar kinematics far from the centre has not yet been studied in NGC 5533, and we can say nothing about the presence or absence of the counterrotating stellar component in the disk or in the bulge. But one more feature of resemblance between NGC 5533 and NGC 7331 forces us to suspect a possible intrinsic peculiarity of the stellar component in this galaxy: surface photometry, we have carried out with the CCD camera of the 1m telescope of SAO RAS has revealed the presence of two embedded stellar disks, an inner and an outer, with different central brightnesses and exponential scales.

We have reported here about three isolated regular spiral galaxies which demonstrate chemical distinctness of their unresolved nuclei in combination with circular planar corotation of gas and stars of the centres. But in all three cases – in NGC 4826 and 7331 for certain and in NGC 5533 probably – the global kinematics and structure have kept some relics of the past interaction accompanied by gas accretion.

3.2. NGC 2841

NGC 2841 is a nearby early-type isolated regular spiral galaxy, like NGC 7331 and 5533, but its detailed investigation with the 6 m and 1 m telescopes of SAO RAS has revealed quite particular properties of its central part (Sil'chenko et al., 1997). First of all, it possesses an unresolved chemically distinct nucleus, and the abundance break between the nucleus and the surrounding bulge has been detected not only in the magnesium-line profile, but also in the profiles of two iron lines and even in the CaII IR triplet profile (Delisle & Hardy, 1992). But the second, truly outstanding feature is that ionized gas at the centre rotates orthogonally to rotation of stars! Emission lines in the centre of NGC 2841 are rather weak, and though the galaxy is nearby and well-studied, its nuclear rotation was earlier observed only in absorption lines. We are the first to obtain the gas velocity field for the inner 15″ of NGC 2841. The dynamical major axis of the ionized gas within $R = 4\overset{''}{.}5$ has appeared to be orthogonal to the dynamical major axis of the nuclear stellar component, to the major axis of the innermost isophotes and, after all, to the global line of nodes of the galaxy. This looks like a small nuclear polar disk. Inclined gaseous disks were earlier found in some lenticular galaxies devoid of their own global gaseous disks (Bertola et al., 1992). But the neutral-hydrogen global disk of NGC 2841 is regular and coplanar to the galactic plane (Rots, 1980). Recently a nuclear orthogonal gaseous disk has been found in the starburst galaxy NGC 253 (Anantharamaiah & Goss, 1996). But NGC 2841 has no substantial star formation at the centre – it is a rather weak LINER. Perhaps, we have found a new phenomenon. When we undertook supplementary long-slit spectroscopic observations of NGC 2841 in the green spectral range at the 1 m telescope, in two cross-sections out of four, namely, along the minor axis and at 30° to the minor axis, we detected a switch of stellar rotation sense in the radius range of 5″–12″. A counterrotating stellar component dominates in this radius range at position angles close to the minor axis, perhaps, because the contribution of the stellar disk is minimal here. If the spectral resolution had been better, we should have detected a double-peaked LOSVD (Line-Of-Sight Velocity Distribution) along the major axis, as in NGC 7331. Since the dynamical major axis of the dynamically decoupled stellar component is obviously highly inclined to the global line of nodes, it may be related to the nuclear gaseous polar disk.

3.3. Polar-ring galaxies

Since in NGC 2841 the chemically decoupled nucleus is accompanied by the gaseous polar disk phenomenon, the natural development of this result is to look for chemically decoupled nuclei in *bona fide* polar-ring galaxies. NGC 2685 is the most nearby polar-ring galaxy, and as a result, the brightest one; its structure and kinematics have repeatedly been studied, but till now there exist doubts as to axisymmetry and rotation character of the galaxy (Peletier & Christodoulou, 1993). IC 1689 was studied in detail by Hagen-Thorn, Reshetnikov and their coworkers (Reshetnikov et al., 1995, Hagen-Thorn & Reshetnikov, 1997). They have reported the existence of the inner blue polar ring with a radius of only 3 kpc which represents the outer border of the gaseous polar disk rotating orthogonally to stars. But Hagen-Thorn & Reshetnikov (1997) have used only long-slit observations of two position angles, along the major and the minor axes, so the result on exact rotation plane orientations was somewhat preliminary. We have found chemically decoupled nuclei in both polar-ring galaxies under consideration (Sil'chenko, 1998). Moreover, the mean age of the nuclear stellar population in IC 1689 may be no longer than 5 billion years; this fact is direct evidence of a secondary star formation burst having produced a decoupled nucleus. In the case of polar-ring galaxies we can relate this secondary star formation burst with a gas accretion event that formed the polar rings themselves. As for circularity of rotation, axisymmetry of the structure and orientation of rotation planes, our investigation made with the MPFS has removed all doubts as to NGC 2685: the rotation planes of ionized gas and stars are strictly orthogonal, and the mass (light) distribution at the centre looks axisymmetrical implying that NGC 2685 is a regular lenticular galaxy. The case of IC 1689 is less certain: the dynamical major axis of the ionized gas at the centre is turned with respect to the isophote elongation, to the line-of-nodes orientation and to the stellar dynamical major axis which leaves a possibility of triaxiality or/and strong radial motions (gas inflow into the nucleus).

3.4. NGC 1052

In course of the investigation my impression that decoupled nuclei in disk galaxies and elliptical galaxies are of the same origin has permanently consolidated. To demonstrate the grounds, I mention here NGC 1052 – an elliptical galaxy of moderate luminosity, extremely gas-rich for its morphological type. Being of regular structure, this galaxy possesses meantime a polar ring "made" from neutral hydrogen (Van Gorkom et al., 1986). The radius of the HI polar ring is twice that of the stellar body, it rotates circularly and is highly inclined (seen almost edge-on). The inner ionized gas at radii of several hundred parsecs seems to co-rotate with the outer polar ring, namely, rotates orthogonally to a stellar component (Davies & Illingworth, 1986). But when I studied the central part of NGC 1052 by using the MPFS with a good enough spatial resolution – under a seeing of 1″.5 (Sil'chenko, 1995), I found that, firstly, the core with a radius of 3″–4″ is chemically distinct with a metallicity drop of 0.6 dex beyond it, and, secondly, that the ionized gas inside this core rotates together with stars in the main plane of the galaxy, in contrast to the gas farther away from the outer, both ionized and neutral. So, the resolved core of NGC 1052 which has a radius of 300–400 pc is decoupled both by higher metallicity of stars and by unrelated kinematics (and, obviously, origin) of ionized gas. It is the first case of resolved decoupled nucleus; in other relations, the case of NGC 1052 is quite similar to that of NGC 2685.

3.5. Elliptical galaxies NGC 4564, 4621, and 5576

If, as I think, decoupled nuclei have formed during secondary star formation bursts at the centres of galaxies, the mean age of their stellar populations must be less than that of surrounding bulges. But a decrease in age affects the spectrum of a stellar system the same way as a decrease in metallicity: metal absorption lines become weaker and the colour becomes bluer. The problem of age-metallicity disentangling is difficult enough, but simulations of Worthey (1994) have shown that on the diagram (H_β, Mgb) these effects can be separated. Unfortunately, most galaxies discussed above demonstrate intense H_α emission; it means that H_β absorption is strongly contaminated by emission and cannot be used as an indicator of age. The class of galaxies, among which Balmer emissions are rare, is ellipticals. I have studied three elliptical galaxies without emission, which were also included into the list of candidates for possessing a chemically decoupled nucleus (Sil'chenko, 1997). Chemically decoupled nuclei have been found in all three galaxies; in NGC 4564 and 4621 the chemically decoupled nuclei have been resolved, with a radius of 400–600 pc, and in NGC 5576 it is point-like. It is interesting that NGC 4564 and 4621 possess stellar disks, the former – a large-scale one and the latter – a nuclear one; NGC 5576, on the contrary, has only boxy isophotes, but a neutral-hydrogen halo is observed around it. And just in these galaxies I have succeeded in finding an age difference between the chemically decoupled nuclei (cores) and their nearest outskirts. The resolved, chemically distinct stellar cores of NGC 4564 and NGC 4621 being placed on the diagram (H_β, Mgb) and compared to the single-age models of Worthey (1994) have appeared to be of 8 billion years, while outside the cores the mean age of the stellar population is larger than 12 billion years. The chemically distinct nucleus of NGC 5576 looks even younger: the mean age of its stellar population is not larger than 5 billion years. In this particular case we have detected young cores in 100% elliptical galaxies with chemically distinct nuclei (3 out of 3). Meanwhile de Jong & Davies (1997) reports the discovery of a correlation between H_β index and diskiness of isophotes in elliptical galaxies: galaxies with weak inner disks look often younger than boxy ones. The examples of NGC 4564 and 4621 reveal some relation between the presence of stellar disk (of any size) and the chemical distinctness of the nucleus, so our result and the result of de Jong and Davies may be of the same nature. But I think that the relationship between the chemical distinctness and the young age of the cores in elliptical galaxies must be more straightforward than between the age and the isophote shape.

4. Summary

In this brief report I present results of a detailed investigation with the MPFS of the 6 m telescope of the central parts of 10 galaxies in which chemically distinct nuclei have been found. Among these 10 galaxies we see 4 regular spirals, 2 peculiar lenticulars (please note, that regular lenticulars are not touched upon yet), and also 4 ellipticals. Among the ellipticals, two are Virgo cluster members and two belong to groups.

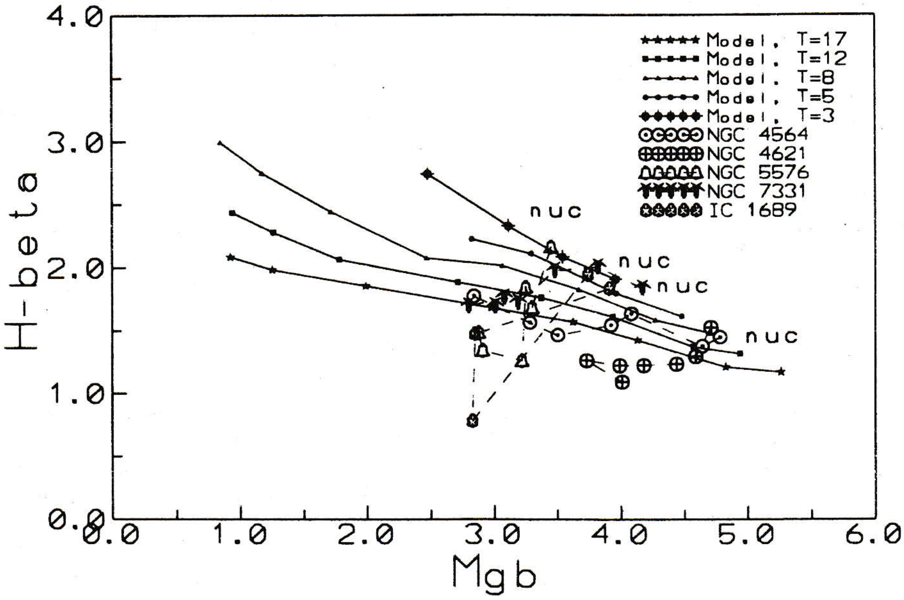

Figure 3: *The (H_β, Mgb) diagram for the central parts of five galaxies with chemically decoupled nuclei. The observational points taken along radii with the step of 1.3″ are connected by dashed lines. The nuclei are marked by "nuc". The model metallicity sequences from Worthey (1994) (solid lines) are marked at the values [m/H]=+0.5, +0.25, 0.0, -0.25, -0.5, -1.0, -1.5, -2.0 by black asterisks (T=17 billion years), squares (T=12 billion years), triangles (T=8 billion years), dots (T=5 billion years), and dots with pluses (T=3 billion years). The last two sequences are ended at [m/H]=-0.22*

The spirals are all isolated. So we see that the galaxies possessing chemically distinct nuclei are quite different: they have different morphological types, different environments and different luminosity classes (e. g. NGC 4826 is a dwarf spiral, and NGC 5533 is a supergiant). But we can point out two common features which may be related to the origin of chemically decoupled nuclei.

Firstly, almost all the galaxies are known to have dynamically decoupled stellar and/or gaseous subsystems. NGC 4826 has two counterrotating gaseous disks. NGC 2841, 2685, 1052, and IC 1689 have polar gaseous disks of different sizes. NGC 7331 and 2841 have "counterrotating" (dynamically decoupled) bulge components. NGC 4621 has a fast-rotating nuclear stellar disk (Bender, 1990, Scorza & Bender, 1995). In some cases the multi-component structure is clearly seen from the photometric data: NGC 5533 and 7331 have two exponential disks, inner and outer, with different scales, and the elliptical galaxy NGC 4564 has a weak large-scale disk embedded into a spheroid.

Secondly, often an age difference between stellar populations of a chemically decoupled nucleus and of its outskirts can be detected: stars of chemically decoupled nuclei are on the average younger. Among 10 galaxies under consideration, six demonstrate nuclear spectra relatively free of Balmer emissions, so that we can use their H_β absorption for age diagnostics. Only NGC 2685 has a rather old nuclear stellar population; the others are plotted in Fig. 3. We see that the mean age of the stellar populations of chemically decoupled nuclei in five galaxies under consideration ranges from 3 to 8 billion years; outside the chemically decoupled nuclei the mean age of the stellar populations sharply increases, as a rule. (In IC 1689 a return to 5 billion years takes place at $R = 5''$, namely, in the blue polar ring; among other things, the polar ring demonstrates a strong Balmer emission, so 5 billion years is an upper limit to the age of its stellar population).

This set of observational properties allows us to suggest what may result in chemical distinctness of nuclei. The multiple gaseous subsystems imply some gas accretion events. The multiple stellar subsystems imply several discrete star formation epochs. The younger ages of stars in decoupled nuclei suggest one of the latest star formation events to be localized in the nuclei. So we suppose that a galaxy which possesses now a chemically decoupled nucleus has once met another gas-rich galaxy or accreted a large gaseous cloud. If it was originally a spiral galaxy with its own large-scale gaseous disk, this disk must be strongly turbulized, and the galaxy's own gas must fall partly into the centre having made a start to a secondary star formation burst within a very small radius which produced a new high-metallicity star generation looking now as a chemically decoupled nucleus. Accreted gas was initially distributed beyond the global disk of the galaxy, so its drift to the centre was not so effective due to smaller viscosity and dynamical friction. It is more probable that the final distribution of the accreted gas may be extended enough; it could be transformed into stars (NGC 2841 and 7331) or remain in the form of gas (NGC 4826). It is interesting, in three of four elliptical galaxies under consideration the chemically decoupled nuclei are resolved, with radii of several hundred parsecs while all chemically decoupled nuclei in disk galaxies are unresolved. Perhaps, it may be related to probable absense of own (primordial) gas in elliptical galaxies.

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