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The Stellar Population and Evolution of Galaxies of the NGC 80 Group

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Abstract—Seven early-type galaxies that are members of the massive X-ray group containing NGC 80 have been studied using two-dimensional spectroscopy with the 6-m telescope of the Special Astrophysical Observatory. We searched for evidence for the synchronous secular evolution of the galaxies in the group. The bulges of five of the seven galaxies appear to be old, with the average age of the bulge stars being 10–15 billion years. Signs of a relatively recent star-formation burst are observed in the small S0 galaxy IC 1548, whose average bulge age is 3 billion years and average core age is 1.5 billion years. A circumnuclear polar gas ring was also detected in this galaxy; in its outer regions, it makes a smooth transition to a gas disk that counter-rotates relative to the stars. IC 1548 probably underwent a close interaction, which resulted in its transformation from a spiral to a lenticular galaxy; the same interaction may also have induced the central burst of star formation. In the giant E0 galaxy NGC 83, a compact massive stellar–gas disk with a radius of about 2 kpc and very rapid rotation is observed, with ongoing star formation; the so-called "minor merger" is likely to have occurred there. We conclude that the NGC 80 group is in a state of formation, with the small NGC 83 subgroup "falling into" the large, old NGC 80 subgroup.

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1. INTRODUCTION

The evolution of galaxies is affected by various factors, which may be divided into external and internal. Internal factors are specified by the intrinsic properties of the galaxy, primarily its mass and rotational angular momentum, and include various dynamical instabilities. External factors are related to the surroundings of the galaxy, such as other galaxies and the intergalactic medium, and can be both gravitational and hydrodynamical. Groups of galaxies present the best conditions for the manifestation of external evolution mechanisms. In many, hot, gaseous X-ray haloes are detected, suggesting the presence of an intergalactic medium that is common to the entire group, which can "strip" the gas reservoirs of spiral galaxies and transform them into lenticular galaxies. In the case of gravitational interactions, there must be neighbors, and the object with which a galaxy interacts can often be unambiguously identified. In addition, the velocity dispersions of galaxies in groups are small, comparable to the intrinsic internal motions of stars in the centers of the galaxies, facilitating the development of tidal effects. Simulations of galaxy interactions show that an external tidal effect will stimulate the development of non-axisymmetric structures at the center of a galaxy, disrupt the circular rotation of gas and stars, and result in a radial redistribution of matter in the disk. It is currently thought that a broad range of galactic bulges, namely those with exponential brightness profiles, may have been formed relatively recently in the course of the "secular evolution" of their galaxies (see the review [1]), for example, due to an inflow of gas to the galactic center under the action of a non-axisymmetric potential, with subsequent star formation in the central kiloparsec.

If several interacting galaxies experience similar conditions at the center of a group, it is likely that the global restructuring and formation of central stellar components in them will be synchronized; i.e., the stellar populations in the galactic centers will have the same average ages and similar geometrical distributions. The detection of synchronization of the evolution of the central regions of galaxies in groups could provide substantial support for the domination of external effects, while the absence of such synchronization would suggest differences in the internal conditions for the evolution of the galaxies. Previously, we used observations with the 6-m telescope of the Special Astrophysical Observatory (SAO) equipped with the MPFS multi-pupil spectrograph to study two to three central galaxies in each of five close groups. In Leo I [2] and the groups NGC 5576 [3] and NGC 3169 [4], the parameters of the stellar populations in the circumnuclear disks of the galaxies proved to be the same: in spite of the early types of their parent galaxies, the disks were formed relatively recently, 1–3 billion years ago; in addition, in the Leo I group, they display the same spatial orientation. In contrast, the ages of the stellar populations and kinematic parameters of the gas in the centers of NGC 3623 and NGC 3627 in the Leo triplet are substantially different [5], suggesting that the galaxies of the triplet "met" recently, no earlier than 1 billion years ago.

In the Leo II group, which was the only one of the five groups studied by us with an X-ray halo, the circumnuclear, kinematically distinguished stellar structures in the two central galaxies proved to be old, and to display different ages, 6 and 10 billion years [6]. Here, we present the results of our study of the stellar populations in galaxies of another massive group with X-ray-emitting gas, NGC 80.

The group of galaxies surrounding the giant lenticular galaxy NGC 80 is rich and massive. In the catalog of groups of galaxies [7], 13 galaxies belonging to the group have magnitudes within 2^m of the brightest galaxy; in [8], the group is considered to include 21 galaxies, while 45 are included in the group in [9]. The estimated X-ray luminosity of the group is $\log L_x = 42.56 \pm 0.09$ [10], where L_x is given in erg/s, which is a very high X-ray luminosity for a group. The center of the X-ray surface brightness distribution essentially coincides with NGC 80, which is the brightest member in the group, and probably also the group's dynamical center. According to [9], the velocity dispersion of the galaxies in the group is 336 km/s, and the group systemic velocity is 5771 ± 48 km/s. After several false members of the group (field galaxies) are rejected, these parameters become 246 and 5663 ± 51 km/s, respectively. The central galaxy, NGC 80, is lenticular; as expected, its systemic velocity (5698 km/s) is close to that of the group. The giant elliptical galaxy NGC 83 is very close to NGC 80, and has exactly the same luminosity as NGC 80; however, its systemic velocity exceeds that of NGC 80 (and the other galaxies in the group) by more than 500 km/s. Another substantial member of the group is the brightest spiral galaxy, NGC 93. Based on 21 cm neutral-hydrogen line data, it was concluded in [11] that this galaxy is massive (the rotational velocity is 317 km/s) and "anemic;" i.e., very red and with decreased a $M(\mathrm{HI})/L_B$ ratio (exactly like massive spiral galaxies in the Virgo cluster). It is thought that the "anemia" of spiral galaxies in clusters results from the effect of the hot intergalactic medium, most likely due to the sweeping out of the intrinsic neutral hydrogen in these galaxies by the frontal pressure of the surrounding hot gas. Since the NGC 80 group is rich in X-ray gas, NGC 93 may have been subject to this effect.

We have used panoramic spectroscopy to study the stellar populations and kinematics of the central regions of the brightest galaxies of the group: NGC 80, NGC 83, NGC 93, and the elliptical galaxy NGC 79 and lenticular galaxies NGC 86, IC 1541, and IC 1548. Figure 1 presents a map of the group indicating the studied galaxies, and Table 1 presents their global parameters, taken from the NED and HYPERLEDA databases.

2. OBSERVATIONS AND DATA PROCESSING

The central regions of all the galaxies ($16'' \times 16''$) were observed with the multi-pupil fiber spectrograph (MPFS) at the prime focus of the 6-m telescope of the SAO at blue–green wavelengths, 4150–5650 Å with an inverse dispersion of 0.75 Å/pix (a spectral resolution of about 3 Å; see the description of this instrument in [12]). The detector was a 2048×2048 CCD. In the MPFS, a 16×16 set of microlenses forms an array of micro-pupils into the diffraction spectrograph, making it possible to simultaneously record 256 spectra, each of corresponding to a $1'' \times 1''$ spatial element of the galaxy image. The wavelength scale was calibrated using a comparison spectrum from a HeNe lamp. Corrections for vignetting and the different transparencies of the microlenses were derived using the continuum spectrum of a lamp and observations of the morning and evening twilight sky. The initial processing of the data, including the subtraction of the electrical zero level, removal of cosmic-ray traces, extraction of the one-dimensional spectra from the array format, and linearization of the extracted spectra, was carried out using code developed in the IDL software environment by one of the authors (V.L.A.).

We used our blue-green observations with the MPFS, first, to study the distribution of the equivalent widths of absorption lines expressed in Lick indices [13] across the galaxy (equivalent-width mapping) and, second, to construct the two-dimensional field of the stellar radial velocities and derive the corresponding velocity dispersions. To calculate the variations of the Lick indices with distance from the centers of the galaxies, we summed spectra in concentric rings centered on the nucleus of the galaxy,

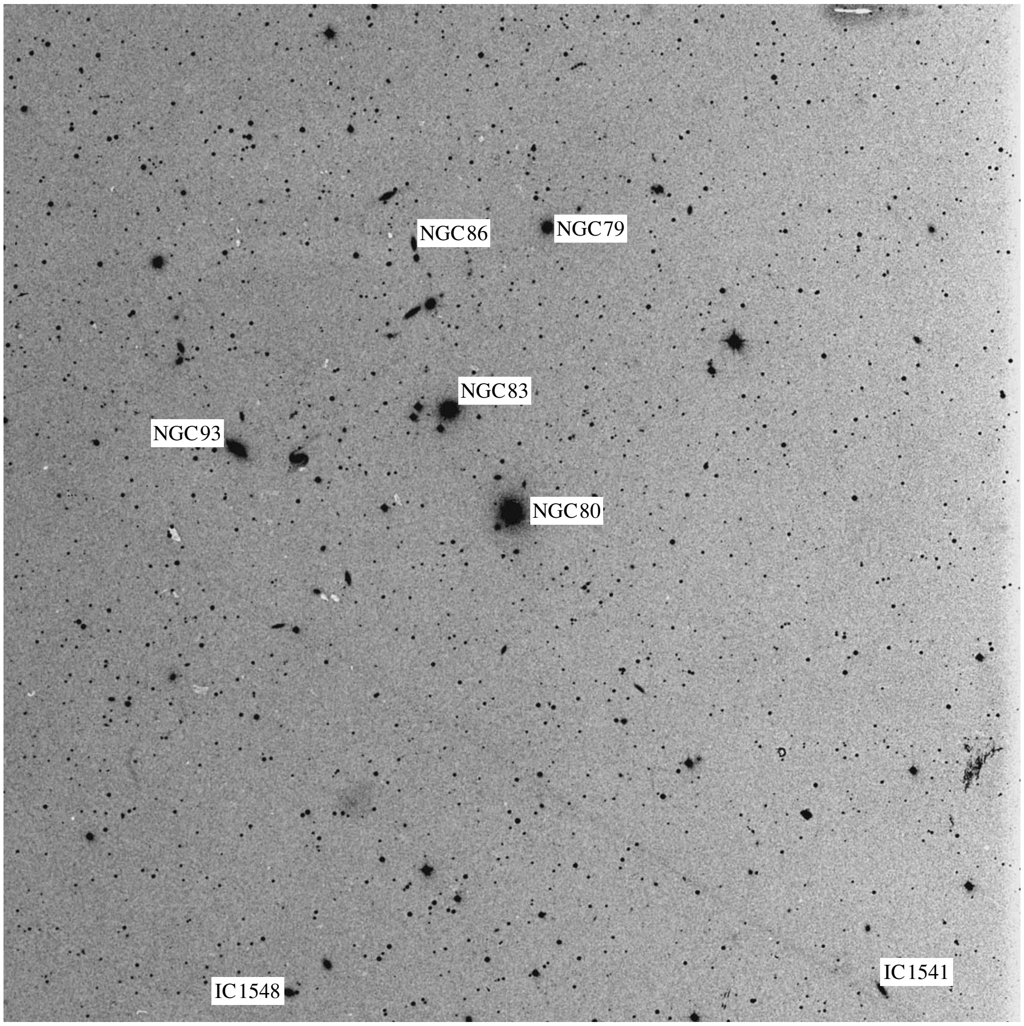


Fig. 1. A 45′ field containing NGC 80; the studied galaxies are labeled.

with widths of 1″ and also separated in radius by 1″ (i.e., since the separation was equal to the size of the spatial element, an approximately constant signal-to-noise ratio was maintained with radius, which is not possible in long-slit observations). Later, we calculated the indices for the Hβ, Mgb, Fe5270, and Fe5335 absorption lines from the spectra summed in the rings. Detailed calculations for models of the evolutionary synthesis of old stellar populations are available for these strong lines [14, 15]. To calculate the stellar radial velocities, after subtracting the continuum and transforming to the velocity scale, the spectrum of each spatial element was cross-correlated with the spectra of G8–K3 giants observed on the same night and with the same equipment. The accuracy of the linearization of the wavelength scale and the zero-point of the measured velocities were checked using the night-sky λ5577 Å line. We estimate the accuracy of our individual stellar radial-velocity measurements to be 10 km/s, and the accuracy of the equivalent widths of absorption lines in the azimuth-averaged spectra to be 0.15 Å.

To analyze the kinematics of the ionized gas, we also observed NGC 83 at red wavelengths, 5800–7200 Å, where the central region of the galaxy displays appreciable Hα and [NII] λ6583 Å emission. The accuracy of the radial-velocity estimates for the ionized gas calculated from the positions of the barycenters of the emission lines is about 20 km/s.

Table 2 presents a detailed log of the MPFS observations of the NGC 80 group.

To analyze the stellar kinematics at distances from the center of NGC 80 exceeding 10″, this galaxy was also observed with the SCORPIO reducer [16] in its long-slit mode. These observations were carried out on December 18, 2004, with seeing of 2.8″ and a total exposure time of 75 min. We used the VPHG 2300 grating at 4790–5560 Å with a spectral resolution 2.3 Å. The spectrograph slit was oriented along the

Table 1. Global parameters of the studied galaxies

Parameter	NGC 80	NGC 83	NGC 79	NGC 93	NGC 86	IC 1541	IC 1548
Morphological type (LEDA)	SA0-	E	E	Sab	Sa	S0	S0
D_{25}, arcmin (LEDA)	1.82	1.29	0.81	1.35	0.76	0.76	0.69
B_T^0 (LEDA)	12.98	13.22	14.66	13.66	14.35	15.15	15.20
M_B (LEDA)	−21.6	−21.6	−19.8	−20.8	−20.2	−19.5	−19.4
$(B-V)_e$ (LEDA)	1.07	1.12	–	1.16	–	–	–
$(U-B)_e$ (LEDA)	0.66	0.60	–	0.61	–	–	–
V_r, km/s (NED)	5698	6227	5485	5380	5591	5926	5746
Distance, Mpc	77 [9]						
PA$_{phot}$, deg (LEDA)	4.5	112	163	49	8	36	78
σ_*, km/s (LEDA)	260	262	201	–	–	–	154
Distance to the center of the group, kpc	0	119	284	280	282	599	524

Note: LEDA denotes the Lyon–Meudon Extragalactic Database and NED the NASA/IPAC Extragalactic Database.

minor axis of the galaxy at position angle 270°. Apart from the galaxy, we also observed two giant stars as radial-velocity standards: HD 20893 (K3III) and HD 27371 (K0III).

3. STELLAR POPULATION IN THE CENTRAL REGIONS

We had already studied the stellar population at the center of NGC 80 using the previous version of the multi-pupil spectrograph [17]. We reported the detection of a chemically distinguished nucleus and ring of intermediate-age stars with a radius of 5″–7″; the bulge in which these "secondary" stellar structures were submerged appeared to be old, with the average age of the stars being about 10 billion years.

Table 2. MPFS observations

NGC/IC	Date	Exposure time, min	Wavelengths, Å	FWHM$_*$, arcsec
NGC 80	30.09.2003	90	4150–5650	1.7
NGC 83	8.10.2004	120	4150–5650	1.2
NGC 83	30.09.2005	80	5800–7300	3
NGC 93	19.09.2006	80	4150–5650	1.5
NGC 79	19.09.2006	120	4150–5650	1.5
NGC 86	17.08.2007	90	4150–5650	1.4
IC 1541	18.08.2007	90	4150–5650	1.4
IC 1548	18.08.2007	120	4150–5650	1.4

Our new spectral data have a higher spectral resolution and cover a larger region. However, the radial variations of the Lick indices at the center of NGC 80 calculated using these new data are fully consistent with the previously published values (Fig. 2). This demonstrates the high accuracy of our measurements and the reliable calibration of the indices to the standard Lick system (the Lick system was constructed with a spectral resolution 8 Å, whereas our spectral resolutions were 5 Å for the earlier observations and 3 Å for our new MPFS observations).

Tables 3 and 4 contain the parameters of the stellar populations (calculated by us from the Lick indices) for all the observed galaxies of the group, separately for the point-like unresolved nuclei and for integrated rings with inner and outer radii of 4″ and 6″; we attribute the latter parameters as "bulges," i.e., global stellar spheroids in the studied early-type (E–S0–Sa) galaxies. At the redshift of NGC 80, the linear distance from the nucleus of the galaxy where we "probe" the bulge is approximately 2 kpc. The accuracies of the Lick indices for the nuclei and bulges are about 0.15 Å, while the accuracies of the other calculated parameters of the stellar population are 1 billion years for ages below 8 billion years, 2 billion years for the older stellar populations, 0.1 dex for the total metallicities, and 0.05 dex for the ratio of the Mg and Fe abundances. The presented Hβ indices are corrected for the effect of emission when emission was noted (NGC 83, NGC 93, and IC 1548). The correction for NGC 83 was made using the equivalent width of the Hα emission line, adopting the average ratio of the intensities of the Balmer

Table 3. Lick indices and parameters of the stellar population in the nuclei

NGC/IC	Hβ	Mgb	⟨Fe⟩	T, billion years	[Z/H]	[Mg/Fe]
NGC 80	1.66	5.00	2.94	6	+0.5	+0.29
NGC 83	1.87	5.20	2.94	4	+0.6	+0.34
NGC 93	1.90	4.36	3.08	4	+0.4	+0.12
NGC 79	1.15	5.22	3.16	15	+0.3	+0.22
NGC 86	1.77	4.10	2.78	8	+0.2	+0.17
IC 1541	1.48	4.76	2.94	12	+0.2	+0.22
IC 1548	3.28	3.40	2.68	1.5	+0.7	+0.06

Table 4. Lick indices and parameters of the stellar population in the bulges

NGC/IC	Hβ	Mgb	⟨Fe⟩	T, billion years	[Z/H]	[Mg/Fe]
NGC 80	1.76	4.50	2.81	7–8	+0.3	+0.23
NGC 83	2.02	5.69	2.84	3	+0.7	+0.47
NGC 93	1.63	3.98	2.62	12	0.0	+0.20
NGC 79	1.52	5.04	2.97	10	+0.4	+0.25
NGC 86	1.61	3.72	2.95	12	+0.0	+0.01
IC 1541	1.20	3.79	2.32	15	0.0	+0.28
IC 1548	2.42	2.81	2.18	3	0.0	+0.17

emission lines $\mathrm{EW(H\beta)} = 0.25\mathrm{EW(H\alpha)}$ [18]. For the other galaxies, we used the mean statistical (for the early-type galaxies) relation $\mathrm{EW(H\beta)} = 0.6\mathrm{EW([OIII\lambda5007)}$ [19].

We calculated the parameters of the stellar populations as follows by comparing our observations with the evolutionary stellar-population models of [15]. We first determined the average metallicity and age of the stellar population by comparing the index for the Hβ absorption line and the combined metal index [MgFe] ($\mathrm{[MgFe]} \equiv (\mathrm{Mgb}\langle\mathrm{Fe}\rangle)^{1/2}$) (where $\langle\mathrm{Fe}\rangle \equiv (\mathrm{Fe5270} + \mathrm{Fe5335})/2$ is the iron index): the effects of age and metallicity are separated in the Hβ–[MgFe] diagram, enabling us to unambiguously determine both parameters. We used the combined metal index, since the resulting ages of the stellar populations are relatively insensitive to the Mg-to-Fe abundance ratios, which, as we can see from the tables, are very different in the nuclei and bulges of the studied galaxies. After determining the age of a stellar population, we calculated the [Mg/Fe] abundance ratio by comparing the Mg and Fe indices; this can be done using the models of [15], for which the [Mg/Fe] ratio varies between −0.3 and +0.5. It is currently thought that the [Mg/Fe] ratio indicates the duration of a star-formation burst; the solar ratio provides evidence for a long (several billion years) event, and a magnesium overabundance by a factor of two to three is possible only if the star formation had totally finished over a time of less than 1 billion years.

Figures 3 and 4 present diagnostic diagrams indicating the nuclei and bulges of five “peripheral” galaxies of the group: the elliptical galaxy NGC 79, early-type spiral galaxies NGC 86 and NGC 93, and lenticular galaxies IC 1541 and IC 1548. In four of these, the central stellar populations are old: the average age of stars in the nucleus is 5–15 billion years, and the bulges are even older, 10–15 billion years. One lenticular galaxy (IC 1548) is distinguished by the intense [OIII] λ5007 line emission in both its nucleus and bulge, and its stellar population is, on average, young: 1.5 billion years in the nucleus and 3 billion years in the bulge. It seems tempting to treat this as evidence of the recent addition of IC 1548 to the group and its transformation from a spiral to a lenticular galaxy under the action of the pressure of the hot intergalactic medium. However, IC 1548 is not the most distant lenticular galaxy from the center of the group: IC 1541 is even farther, but its spectrum is totally free of emission lines and does not show any signs for recent star formation. Some type of binary

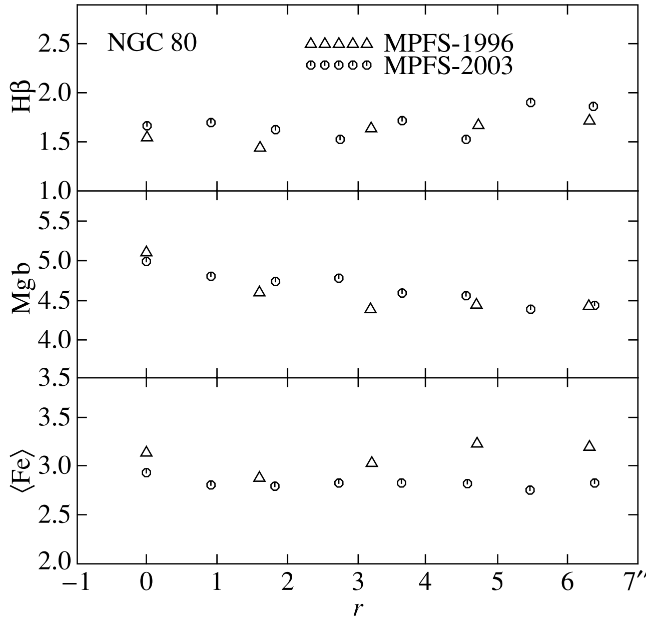


Fig. 2. Radial variations of the azimuth-averaged measurements for the indices of the Hβ, Mgb, and ⟨Fe⟩ absorption lines in NGC 80 according to our MPFS data obtained in 1996 (triangles) and 2003 (circles).

interaction with mass transfer is more likely: there is a blue spiral galaxy very close to IC 1548, 130″ (50 kpc) to the northwest, which may have donated gas to IC 1548 and whose gravitation may have stimulated the recent star-formation burst in this lenticular galaxy. Judging from the increased [Mg/Fe] ratio and the older ages of the stars in the bulge, the star-formation burst at the center of IC 1548 initially covered an extended region, but was prolonged only in the nucleus itself, thus raising the metallicity of the stars there to a very high level for a galaxy with such a moderate luminosity ([Z/H]) $= +0.7$. Note that, despite the old ages of the nuclear stars, the nuclei of NGC 93 and IC 1541 are chemically distinguished; i.e., secondary star-formation bursts did occur in these nuclei, but very long ago. We conclude that, as an "aggregate," the NGC 80 group is probably old: most of the galaxies were assembled together long ago, at $z \geq 0.5$.

Let us now discuss two central galaxies of the group. They have the same luminosity and, at first sight, are also morphologically similar, both being large and spherical. However, NGC 80 is classified as a lenticular galaxy, while NGC 83 is an elliptical. Figure 5 presents the radial variations of their Lick indices, plotted in the diagnostic diagrams in order to compare them with the models of [15]. The age of 7–8 billion years for the bulge of NGC 80 (Table 4) resulted from some non-physical averaging: along with the old (∼10 billion years) bulge, we integrated a ring of relatively young (∼5 billion years) stars. As was noted in [17], the nature of the ring of young stars with a radius of 2.5 kpc in this lenticular galaxy remains unknown: surface photometry of NGC 80 shows neither a bar, nor any other deviations from axial symmetry, which are usually related to the origin of ring structures in galaxies. However, the center of NGC 83, the giant elliptical galaxy, is even more spectacular: the stars in both the nucleus and the entire circumnuclear region within 8″ of the center have an average age that does not exceed 3–4 billion years, and, within 5″ of the nucleus, intense Hα emission provides evidence for star formation occurring right before our eyes.

4. GAS DISKS IN NGC 83 AND IC 1548

Table 5 presents the results of studies of the kinematics of the stellar and gaseous components for all seven observed galaxies of the group. The stellar-velocity dispersions (σ_*) were determined separately for the nuclei and the bulges, as the Lick indices were previously. In most cases, the orientations of the kinematic major axes varied with radius from $R = 2''$ to $R = 5''$ (possibly, due to the impact of the bar); therefore, Table 5 presents the intervals for particular values. The presented angular-rotation velocities ($\omega_0 \sin i$) refer to the innermost rigidly rotating regions of the galaxies ($R < 2''$).

In two early-type galaxies, we were able to detect the presence of central gas disks and to estimate their orientation and rotation.

The giant elliptical galaxy NGC 83 is peculiar because of its IR excess, first detected by IRAS;

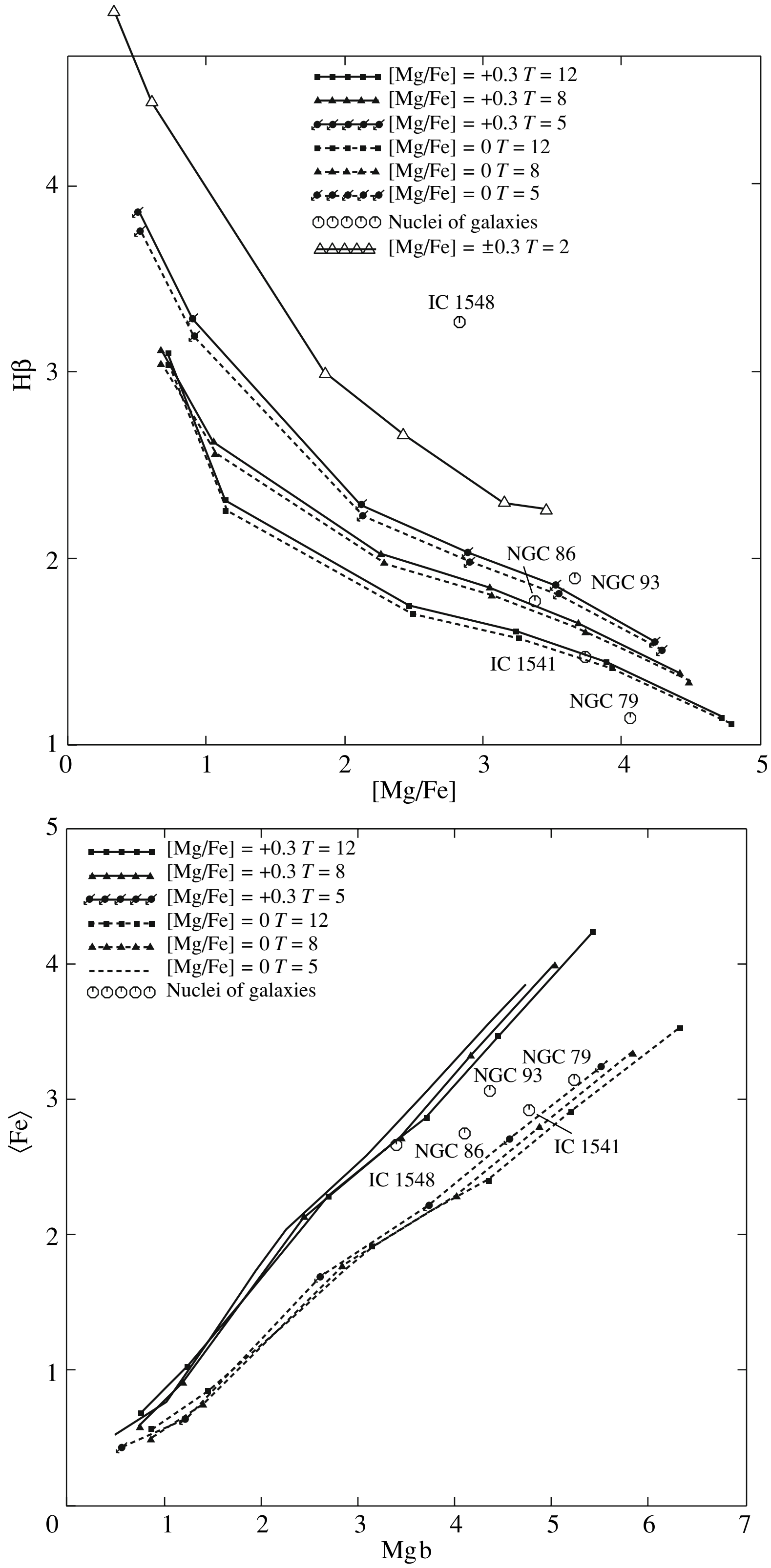
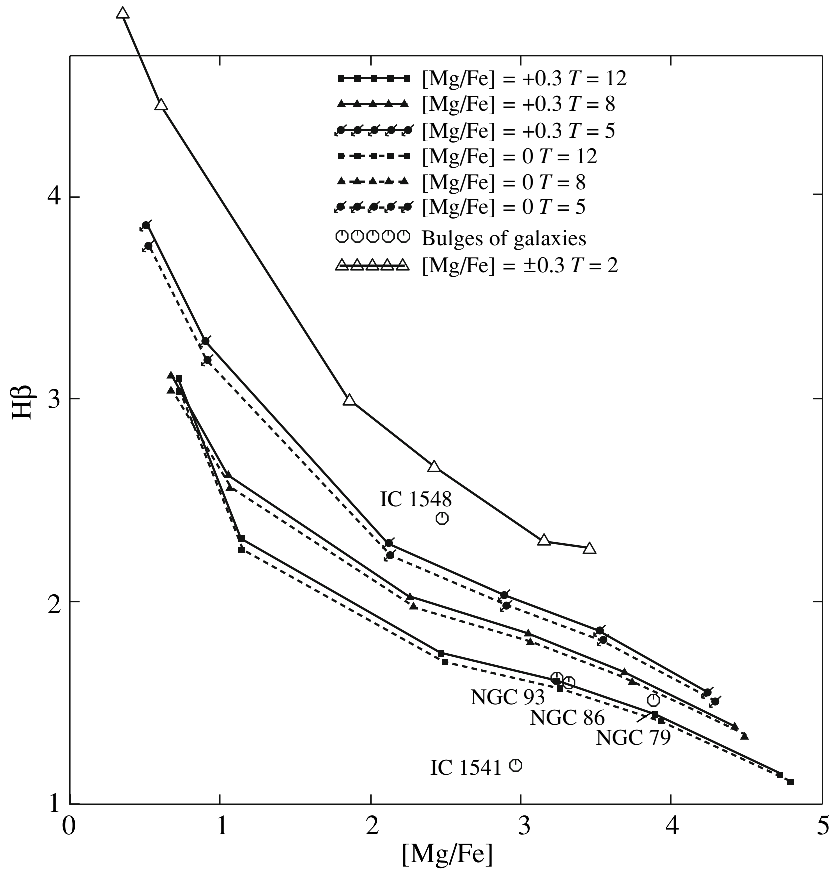


Fig. 3. Diagnostic "index–index" diagrams for the measurements in the nuclei of five "non-central" galaxies of the group (large circles). The small symbols attached to the solid and dashed lines correspond to models from [15] for stellar populations with the same age and various [Mg/Fe] values. The model age T is given in billions of years. The model metallicities for the points along the curves (small symbols) are +0.67, +0.35, 0.00, −0.33, −1.35, and −2.25, from right to left.



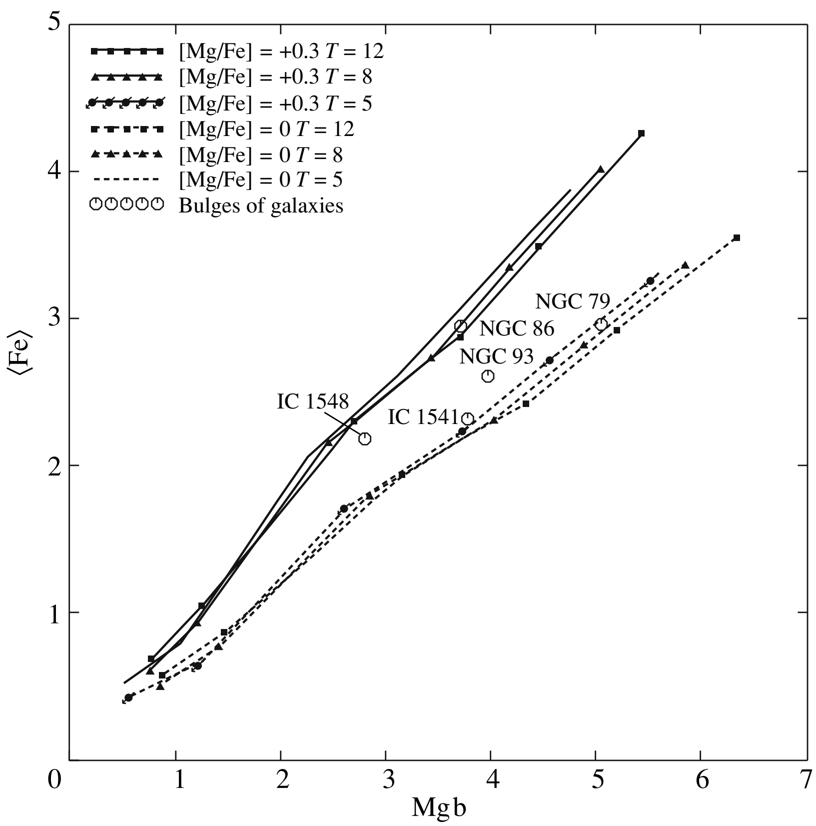


Fig. 4. Same as Fig. 3 for the bulges of the galaxies.

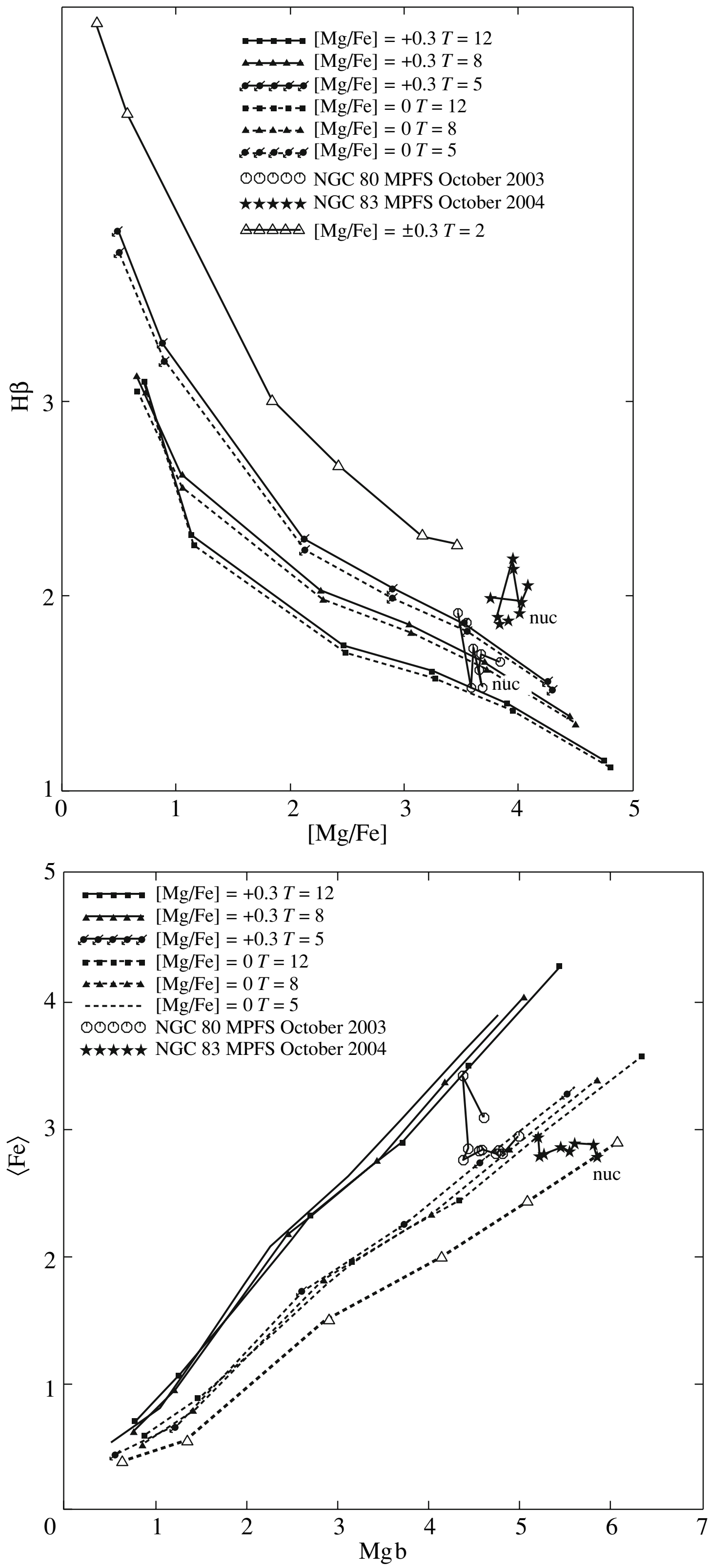


Fig. 5. Diagnostic "index–index" diagrams for azimuthally averaged measurements in NGC 80 (large circles) and NGC 83 (large asterisks). The data for the galaxies are taken with steps of $1''$ in radius and connected by the solid curve in ascending order in R (the nucleus of the galaxy is indicated). The small symbols connected by the solid and dashed curves represent models for stellar populations from [15] with the same ages and various [Mg/Fe] values. The model age T is given in billions of years. The model metallicities are +0.67, +0.35, 0.00, −0.33, −1.35, and −2.25 for the points along the curves (small symbols), from right to left.

Table 5. Kinematic parameters

NGC/IC	V_{sys}, km/s	σ_*(nucleus), km/s	σ_*(bulge), km/s	PA_{kin}, deg	$\omega_0 \sin i$, km/s arcsec
NGC 80 (stars)	5746	192	140	–	6 ± 8
NGC 83 (stars)	6218	170	113	114	62
NGC 83 (gas)	6218	–	–	116 ± 4	90
NGC 93 (stars)	5539	166	124	50–60	57
NGC 79 (stars)	5408	156	120	–	6 ± 6
NGC 86 (stars)	5611	130	92	$11 \ldots -3$	47
IC 1541 (stars)	5961	155	86	223–213	27
IC 1548 (stars)	5661	140	110	76–56	37
IC 1548 (gas)	5661	–	–	349–276	43

it also displays an appreciable amount of molecular gas [20, 21]. A characteristic two-peaked shape of the integrated CO line profile, with the maxima separated by 417 km/s, and the presence of a compact massive gaseous disk are indicated in [21]; however, the question of possible current star formation in the disk remains unanswered. Our observations of NGC 83 with the MPFS at red wavelengths revealed strong Hα and [NII] λ6583 line emission within 5″ of the center; the ratio of the line intensities increases with the radius, although it does not reach a factor of two—the value characteristic of "pure" excitation in an HII region. It is likely that, in the nucleus itself, the excitation of the warm gas is due to the LINER mechanism, with this excitation being accompanied by star formation in the circumnuclear gaseous disk (radiative ionization by young massive stars).

Figure 6 presents the two-dimensional line-of-sight velosity field for the stars and ionized gas in the center of NGC 83 derived from the MPFS data. We can see the regular, correlated rotation of the gas and stars in the same plane with approximately the same velocity. This velocity is also consistent with the width of CO emission-line profile [21]. This velocity is very high, around 200 km/s projected onto the line of sight, taking into account the fact that we are viewing the rotating disk close to face-on. Since the isophotes do not show any "disk-like" signs, the inclination of the disk to the line of sight must be lower than 40°. The study [19] reports the inclination of the plane of the gas–dust disk to be 26°–37°, based on the apparent ellipticity of the dust disk. In this case, the rotational velocity of the gas in the circumnuclear disk of NGC 83 exceeds 350 km/s.

The velocity field of the ionized gas in the lenticular galaxy IC 1548 is even more interesting (Fig. 7). Since we do not have any data at red wavelengths for this galaxy, we constructed the gas velocity field using measurements of the weak [OIII] λ5007 emission line, which can be traced approximately to a distance of 4″ from the center. At the outer edge of the gas disk, at distances of 2″–4″ from the center, the ionized gas counter-rotates relative to the stars ($\mathrm{PA}_0 \approx 260°$ as opposed to $\mathrm{PA}_0 \approx 70°$), while the gas shifts to polar orbits at the very center, within 1.5″ of the nucleus. This is already the fourth case that we know when outer counter-rotating gas shifts to polar orbits as it approaches the nucleus [22, 23]. Theoretically, this can happen if the gas rotates within a triaxial potential, for example, in the gravitation field of a bar [24].

5. NATURE OF THE INNER EXPONENTIAL COMPONENT OF NGC 80

In our surface photometry of the central galaxy of the NGC 80 group and analysis of the radial profile of its surface brightness [17], we found that two large-scale stellar components of the galaxy display exponential brightness profiles. The outer component, which dominates at distances from the center exceeding 30″ (11 kpc), is apparently a global stellar disk: although its radial scale (11 kpc) appreciably exceeds the mean statistical value for lenticular galaxies, the central surface brightness is entirely typical. The inner exponential component, at radii of 10″–30″, has a high surface brightness and compact scale of only 2.2 kpc. This could essentially be either an inner stellar disk (in which case it should be geometrically thin and dynamically cool) or a so-called "pseudobulge" (the term introduced by Kormendy [25] for bulges formed from disk material in the course of the "secular" evolution of the galaxy). Since bulges are

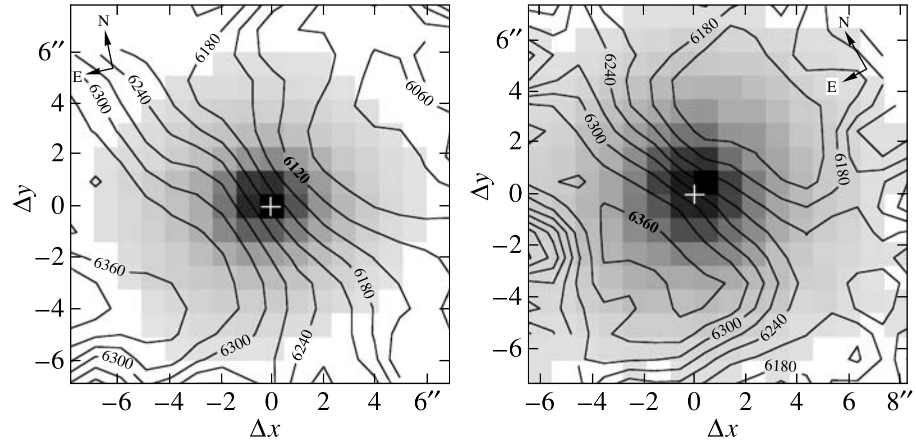


Fig. 6. Two-dimensional line-of-sight velosity field (contours) in NGC 83 for the stellar component (left), and ionized gas (right). The continuum map is shown in gray scale.

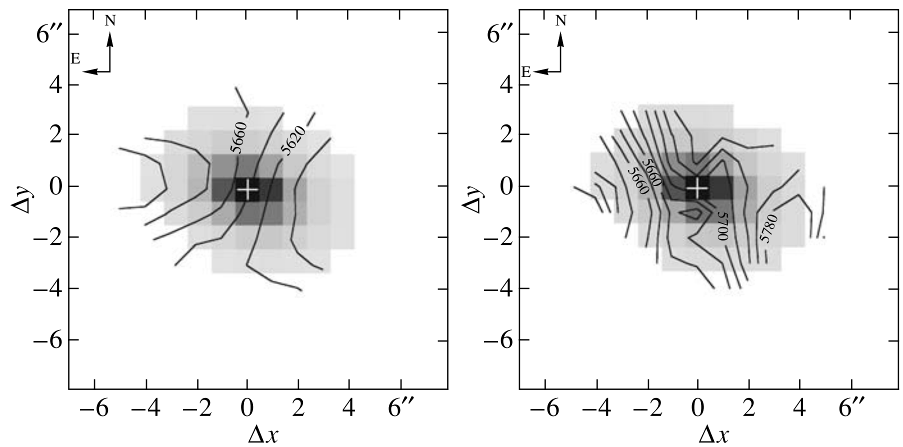


Fig. 7. Same as Fig. 6 for IC 1548.

spheroids with substantial vertical extent (the direction of the axis of rotation), they should be dynamically hot; i.e., their stars should display an appreciable velocity dispersion in the vertical direction.

To clarify the nature of the inner exponential component in NGC 80, we used long-slit spectral observations of the galaxy with the multi-purpose SCORPIO reductor mounted on the 6-m telescope. The slit was aligned with the minor axis of the galaxy (which is almost spherical, however); the variations of the stellar-velocity dispersion along the slit were measured by cross-correlating the spectrum of the galaxy with the spectra of two late-type giant stars. By using two stars, we were able to estimate the systematic error due to the so-called "calibration error effect" (or template mismatch), which can reach values of the order of 10 km/s. We were able to follow the variations of the stellar-velocity dispersion to roughly 25″ from the center; i.e., right to the region of the inner exponential component. Figure 8 presents this profile. It is obvious that the stellar-velocity dispersion in the region of the inner exponential component is large, exceeding 160 km/s. Such dispersions do not occur in disks, leading us to suggest that the NGC 80 bulge is a pseudo-bulge. Generally speaking, pseudo-bulges are usually considered to belong to late-type spiral galaxies, and the presence of such a large one in NGC 80 presents a problem for theories of secular evolution.

6. DISCUSSION OF THE RESULTS

We have studied seven early-type galaxies (from elliptical to Sab) that are members of the NGC 80 massive X-ray group of galaxies using two-dimensional spectroscopy obtained with the 6-m telescope

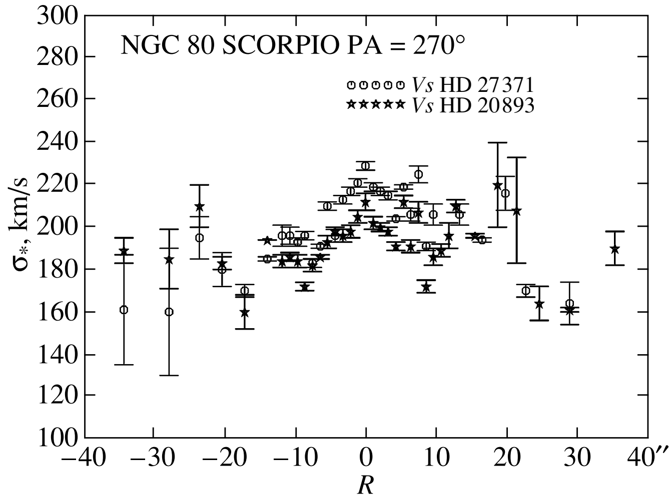


Fig. 8. Stellar-velocity dispersion σ_* derived from long-slit observations, with the slit along the minor axis, for the galaxy NGC 80. The spectra of two giants with different spectral types were used for the cross-correlation with the galaxy spectra.

of the SAO, in particular, searched for signs of synchronous secular evolution of the galaxies in the group. We also obtained long-slit spectra for the central galaxy of the group. In five of the seven studied galaxies, the bulges are old, with average ages for their stars of 10–15 billion years. As we found previously [17], intermediate-age, circumnuclear stellar structures (the ring and nucleus) are seen in the central galaxy NGC 80 itself, but are no younger than 5 billion years. The inner exponential stellar component of NGC 80, which we detected previously [17], but could not diagnose without kinematic data, appears to be a dynamically hot pseudobulge. Despite the fact that previously suggested mechanisms for the secular evolution of disk galaxies (intrinsic instabilities in the stellar–gas disks, the radial redistribution of the gas under the action of the potential of the bar, etc.) are not able to explain the formation of such massive bulges, it is clear that the galaxy NGC 80 underwent an epoch of restructuring accompanied by a circumnuclear star-formation burst approximately 5 billion years ago. In the anaemic giant spiral galaxy NGC 93, whose neutral gas was probably partially removed by the pressure of the hot intergalactic medium when the galaxy entered the group, the average age of the stellar population in the chemically distinguished nucleus is about 4 billion years. If the nuclear star-formation burst that gave birth to the nucleus is associated with the time when the galaxy was added to the group, then it becomes likely that this occurred 4 billion years ago. It is clear that the basic composition of the group was formed around 4–5 billion years ago.

However, the group also contains early-type galaxies, with younger stellar populations. Signs of a relatively recent star-formation burst are observed at the center of the S0 galaxy IC 1548: the average ages of the bulge and nucleus are 3 billion years and 1.5 billion years, respectively. In the same galaxy, we detected a circumnuclear polar gaseous ring, which is smoothly transformed in more outer regions into a gaseous disk that counter-rotates relative to the stars. IC 1548 probably underwent a close interaction with an adjacent late-type spiral galaxy, resulting in mass transfer from the spiral to the lenticular galaxy; this same interaction may have induced the recent central star-formation burst. A compact, massive, very rapidly rotating stellar–gas disk with a radius of about 2 kpc is observed in the giant E0 galaxy NGC 83, in which star formation is ongoing. It is likely that a merger of a gas-abundant spiral or irregular galaxy—a so-called "minor merger"—occurred there. The radial velocity of NGC 83—a giant galaxy whose luminosity is equal to that of the central galaxy of the group and which is located near the center of the group—is appreciably different from the systemic velocity of the group, exceeding it by twice the velocity dispersion of the group. Only a few central galaxies (NGC 81, NGC 85, and PGC 1327) display radial velocities close to that of NGC 83, while the radial velocities of the other dozens of group members are all ±(200–300) km/s, close to that of NGC 80. It may be that the galaxy NGC 83 with a few satellites "fell into" the NGC 80 group very recently. Was this galaxy also elliptical before it joined the group? Did the gas presently concentrated in its central two kiloparsecs originally belong to the galaxy, or is it the result of its merger with another galaxy? Here, various interpretation remain possible.

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