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A Chemically Decoupled Nucleus and Inner Polar Ring of the SBb Galaxy NGC 4548

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Abstract—Our investigation of the central region in NGC 4548, a bright Sb galaxy with a large-scale bar, using the Multipupil Field Spectrograph of the 6-m telescope revealed a chemically decoupled compact stellar nucleus with [Fe/H] = +0.6 and [Mg/Fe] = +0.1 . . . + 0.2 and with a mean stellar-population age of 5 Gyr. This nucleus, a probable circumnuclear disk coplanar with the global galactic disk, is embedded in the bulge whose stars are generally also young, $T \approx 4$ Gyr, although they are a factor of 2.5 more metal-poor. The bulge of NGC 4548 is triaxial and has a de Vaucouleurs surface-brightness profile; the unusual characteristics of its stellar population suggest the bulge formation or completion in the course of secular evolution in the triaxial potential of the global bar. The ionized gas within 3″ of the NGC 4548 nucleus rotates in a plane inclined to the principal symmetry plane of the galaxy, possibly, even in its polar plane, which may also result from the action of the large-scale bar. © *2002 MAIK "Nauka/Interperiodica"*.

Key words: *galaxies, groups and clusters of galaxies, intergalactic gas*

INTRODUCTION

We began our searches for chemically decoupled nuclei in disk galaxies with the Multipupil Field Spectrograph of the 6-m telescope in 1989 (Sil'chenko *et al.* 1992). The detectors were changed several times in the course of our work, each time marking a qualitative leap in the informativeness of our data; the spectrograph itself was changed twice. We have discovered a total of almost thirty galaxies with chemically decoupled nuclei. Having come across this phenomenon, we also analyzed other galaxy properties—the kinematics of gas and stars in the central region, its structure, and peculiarities of the global galactic structure, etc.—in an attempt to guess which of them could be related to the origin of the chemically decoupled nuclei. In particular, these efforts led to the discovery of circumnuclear polar gaseous disks. It has long been known that there is a rare type of peculiar galaxies, galaxies with global polar rings [see the catalog of such galaxies by Whitmore *et al.* (1990)]. Occasionally, but rarely, the polar rings are smaller in size than the galaxy itself, as, for example, in the case of IC 1689 (Hagen-Thorn and Reshetnikov 1997; Sil'chenko 1998). We also know cases where the rotation axes of the circumnuclear ionized gas and circumnuclear stars in early-type galaxies devoid of gas outside the central region are misaligned (see, e.g., Bertola *et al.* 1992, 1995). In both cases, a universally accepted explanation of the phenomenon was the capture by the galaxy of a foreign gas whose angular momentum does not necessarily coincide with the angular momentum of the capturing galaxy. However, for the first time, we have discovered circumnuclear polar disks in spiral galaxies with a large amount of normally rotating gas in the global disks outside the central region: in the Sb galaxy NGC 2841 (Sil'chenko *et al.* 1997) and the Sa galaxies NGC 6340 (Sil'chenko 2000) and NGC 7217 (Zasov and Sil'chenko 1997; Sil'chenko and Afanasiev 2000). In these cases, it is hard to suggest that the captured gas with an orthogonal angular momentum immediately reached the center of the capturing galaxy by avoiding collisions with clouds of its own gas; besides, the galaxies turned out to be isolated. It would be more natural to search for an intrinsic mechanism of transferring the galactic circumnuclear gas to a polar orbit. This mechanism has already been hinted at in the literature devoted to three-dimensional gas dynamics in a triaxial potential. By numerically simulating the secular evolution of a flat cold stellar–gaseous disk, Friedli and Benz (1993) obtained stable orbits for gaseous clouds with the opposite sense of rotation in a plane inclined to the global galactic plane after the stellar-bar formation. A qualitative reasoning of Sofue and Wakamatsu (1994) led them to conclude that the dissipative component of the galactic disk (gas) during its interaction with a bar must lose the tangential velocity component, increase the radial velocity of the motion toward the center, and keep

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Spectroscopic observations of NGC 4548

Date	T(exp), min	PA(top)	Range, Å	FWHM$_*$
May 8–9, 1997	60	75°	4600–5600	2.5″
May 8–9, 1997	40	75	6000–7000	2.5

the vertical velocity component constant; collectively, all these factors must give rise to circumnuclear polar gaseous disks in barred galaxies. Observations seem to confirm the relationship of the circumnuclear polar rings to the presence of a triaxial potential in the galaxy: although all three galaxies in which we detected this phenomenon are formally not classified as barred, our morphological analysis of their isophotes suggests the existence of triaxial bulges in NGC 2841 and NGC 6340 and an oval dense inner disk (a lens?) in NGC 7217.

The galaxy NGC 4548, which is dealt with here, possesses an indubitable large-scale bar and has always been classified as SBb. In contrast to the slightly triaxial structures in NGC 2841, NGC 6340, and NGC 7217, NGC 4548 has a thin, high-contrast bar. A morphological analysis of this galaxy is also facilitated by the fact that it is seen almost, but not exactly face-on (all structural features can be closely examined), which also allows the kinematics of its gas and stars to be analyzed in the galactic disk plane. The basic parameters of NGC 4548 are:

Morphological type	SBb
R_{25}	13 kpc
B_T^0	10.60
M_B	−20.98
V_r(radio)	485 km s^{-1}
Distance	17 Mpc (Virgo)
Line-of-sight inclination	37°
$PA_{\rm phot}$	150°
v_m, km s^{-1}	180
σ_*, km s^{-1}	155

It is all the more interesting to search for a circumnuclear polar ring in such a classical triaxial potential. NGC 4548 was also included in our list of candidates with chemically decoupled nuclei (Sil'chenko 1994) and, as such, was observed with the Mutipupil Field Spectrograph of the 6-m telescope as part of our program of searching for chemically decoupled nuclei in disk galaxies. Here, we present the results of these observations.

OBSERVATIONS AND DATA REDUCTION

The central part of NGC 4548 was observed with the Multipupil Field Spectrograph (MPFS) at the prime focus of the 6-m Special Astrophysical Observatory (SAO) telescope [see Afanasiev *et al.* (1990) for a description of the instrument] near the Mg Ib λ 5175 Å absorption line and Hα with a reciprocal dispersion of 1.6 Å per pixel (a spectral resolution of ~ 4 Å). A log of our spectroscopic observations for NGC 4548 is given in the table.

The detector for the MPFS was a Russian-made 1040×1160-pixel CCD array produced by the Elektron research-and-production association. During the MPFS observations, a 8×16 array of microlenses formed a pupil matrix, which was fed to the entrance of a grating spectrograph. This configuration allows up to 128 spectra to be simultaneously taken, each corresponding to a $1.3'' \times 1.3''$ spatial element of the galaxy image. We separately took a comparison spectrum of a helium–neon–argon lamp for wavelength calibration and a dawn-sky spectrum to make corrections for vignetting and for different microlens transmission. We also separately exposed the sky background near the galaxy in the green spectral range where the absorption-line equivalent widths were to be calculated; its spectra were then smoothed and subtracted from the object spectra. The main data reduction steps included the following: bias subtraction, cosmic-ray particle hit removal, the extraction of one-dimensional spectra from the matrix format, the linearization of extracted spectra, and the construction of two-dimensional surface-brightness distributions and velocity fields. These were performed with a software package developed at the SAO (Vlasyuk 1993).

We used the MPFS observations in the spectral range 4600–5600 Å, first, to investigate the radial dependences of the absorption-line equivalent widths and, second, to construct the two-dimensional line-of-sight velocity field of stars at the galactic center. The first goal was achieved by adding up the spectra in concentric rings centered on the galactic nucleus with a width and radial step of 1.3″, i.e., equal to the spatial element size (in this way, we managed to maintain an approximately constant signal-to-noise ratio along the radius, which is unattainable, say, in long-slit observations). Subsequently, we calculated the Hβ, Mgb, Fe5270, and Fe5335 indices in the standard Lick system (Worthey *et al.* 1994). Detailed model calculations in terms of old stellar population synthesis models are available for the above strong absorption lines (Worthey 1994; Vazdekis *et al.* 1996; Tantalo *et al.* 1998). To achieve the second goal, the spectrum of each spatial element after the continuum subtraction and conversion to the velocity scale was

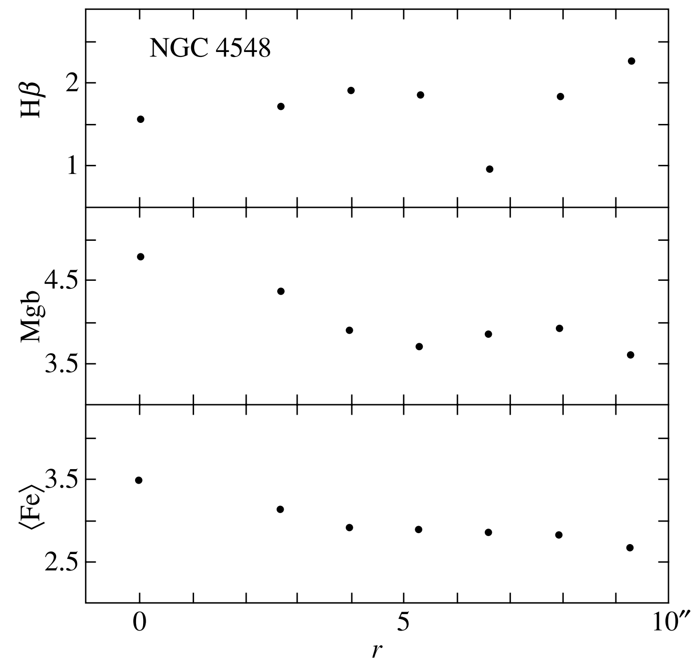

Fig. 1. Radial variations in the azimuthally averaged absorption-line indices Hβ, Mgb, and $\langle\mathrm{Fe}\rangle \equiv (\mathrm{Fe}5270 + \mathrm{Fe}5335)/2$, as inferred from our MPFS data for NGC 4548.

cross-correlated with the spectra of the K0–K2 III giant stars observed during our set with the same instrumentation as for the galaxy. The observations in the red spectral range were used to construct the two-dimensional line-of-sight velocity field of ionized gas. To this end, we accurately measured the centroid positions of the [N II] λ 6583 Å emission line; since NGC 4548 is a LINER, the Hα emission is weak in its circumnuclear region. The night-sky λ 5577, 6300, and 6864 Å lines were used to check the accuracy of the wavelength scale and the measured velocity zero point. We estimated the accuracy of individual line-of-sight velocity measurements for stars and gas to be 20 and 30 km s^{-1}, respectively, and the accuracy of determining the absorption-line equivalent widths in the azimuthally averaged spectra to be 0.15 Å.

We made use of data from the Hubble Space Telescope (HST) archive and from the Digital Atlas of Nearby Galaxies by Frei *et al.* (1996) to morphologically investigate the central part of NGC 4548. The galaxy was imaged with the STIS/HST instrument on April 26, 1999, as part of the program "The Nature of Nuclear Activity in Nearby Galaxies" by H.-W. Rix. A very broadband (1000 Å) filter centered at 7150 Å was used; the exposure time was 60 s. The scale with which the central part of the galaxy $5'' \times 5''$ in size was exposed was $0.05''$ per pixel. The image morphology was analyzed with the FITELL code written by V.V. Vlasyuk.

A CHEMICALLY DECOUPLED NUCLEUS IN NGC 4548

Figure 1 shows the radial dependences of the azimuthally averaged Lick indices Hβ, Mgb, and $\langle\mathrm{Fe}\rangle \equiv (\mathrm{Fe}5270 + \mathrm{Fe}5335)/2$. Note that the dependences are flat at radii larger than $3''$ (if the Hβ spike at $R = 6.6''$ is assumed to be fortuitous). The indices, particularly the metal indices, are virtually constant outside the zone of influence of the unresolved nucleus, FWHM $\approx 2.5''$. We can calculate the following means from five points in the range $R = 4''$–$9''$: $\langle\mathrm{Mgb}\rangle_{\mathrm{bul}} = 3.82 \pm 0.06$ Å and $\langle\mathrm{Fe}\rangle_{\mathrm{bul}} = 2.85 \pm 0.04$ Å. The estimates of the rms scatter from point to point are 0.14 Å and 0.09 Å, respectively, which is completely within the limits of our observational (statistical) error, 0.15 Å. If we now compare the above calculated mean circumnuclear values of Mgb and $\langle\mathrm{Fe}\rangle$ with the indices measured in the unresolved nucleus, $\mathrm{Mgb}_{\mathrm{nuc}} = 4.82$ Å and $\langle\mathrm{Fe}\rangle_{\mathrm{nuc}} = 3.50$ Å, then we will immediately see that NGC 4548 possesses a chemically decoupled nucleus. Having been calibrated in terms of the metallicity difference (assuming the stellar populations to be of the same age), the differences in the nuclear and circumnuclear metal indices, $\Delta\mathrm{Mgb} = 1.00$ Å and $\Delta\langle\mathrm{Fe}\rangle = 0.65$ Å, correspond, according to the models by Worthey (1994), to $\Delta[\mathrm{Fe/H}] \approx 0.4$; i.e., the mean metallicity of nuclear stars in NGC 4548 is a factor of 2.5 higher

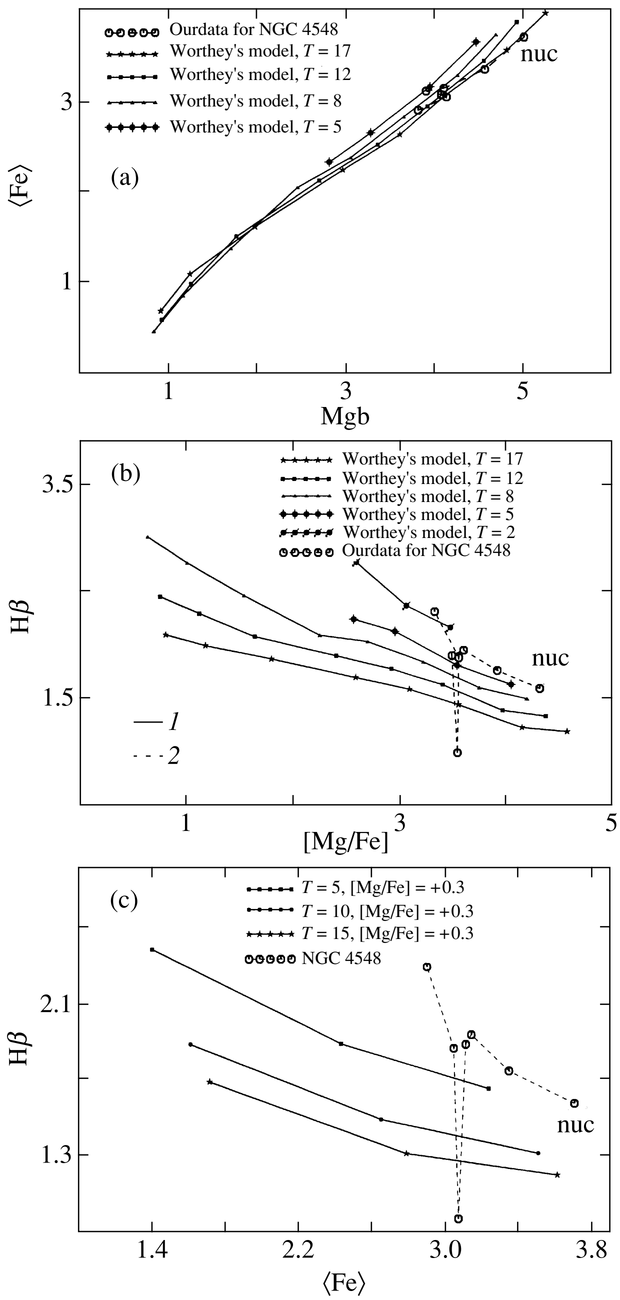

Fig. 2. Diagnostic index–index diagrams: a comparison of models with the azimuthally averaged observational data for NGC 4548. The large symbols connected by lines *2* represent the observational data for NGC 4548 taken along the radius at 1.3″ steps; the nucleus position is marked by "nuc." (a) The (⟨Fe⟩, Mgb) diagram with the models by Worthey (1994) for [Mg/Fe] = 0, (b) the (Hβ, [MgFe] $\equiv$ (Mgb⟨Fe⟩)$^{1/2}$) diagram with the models by Worthey (1994) for [Mg/Fe] = 0, and (c) the (Hβ, ⟨Fe⟩) diagram with the models by Tantalo *et al.* (1998) for [Mg/Fe]= +0.3. Lines *1* connect the models of the same age; the small symbols mark the positions of the models with the following metallicities (from right to left): +0.50, +0.25, 0.00, −0.22, −0.50, −1.00, −1.50, −2.00 for the models by Worthey (1994) and +0.4, 0.0, −0.7 for the models by Tantalo *et al.* (1998).

than the mean metallicity of stars in the immediate vicinity of its nucleus.

Meanwhile, not only metallicity but also the mean age of the stellar population affects the metal-line depth in the integrated stellar-population spectrum: the younger it is, the shallower the metal lines are. Note that the hydrogen absorption lines exhibit an exactly opposite behavior and a comparison of the metal and hydrogen-line indices allows one to remove degeneracy and to simultaneously determine both parameters of the stellar population (Sil'chenko 1993; Worthey 1994). It should only be made sure that the magnesium-to-iron abundance ratio in the models used to determine the stellar-population parameters correspond to the actual Mg/Fe ratio in the galaxy under study. Otherwise, an ambiguity in the choice of the metal index to be compared with Hβ arises.

The (⟨Fe⟩, Mgb) diagram (Fig. 2a) compares the observed, azimuthally averaged indices at various distances from the NGC 4548 center with the models for old stellar populations calculated by Worthey (1994) at a solar magnesium-to-iron abundance ratio, [Mg/Fe] = 0. In the (⟨Fe⟩, Mgb) diagram, the models for [Mg/Fe] = 0 occupy a narrow band containing stellar systems of all metallicities, ages, and star-formation histories; the deviations of the observed points from this band can be unequivocally interpreted as a nonsolar magnesium-to-iron abundance ratio. At first glance, the observed indices for NGC 4548 satisfy the solar Mg/Fe ratio at all radii; however, a slight radial drift of the points across the [Mg/Fe] = 0 band may still be noticed. Since, in addition, as we will see below, the mean age of the nuclear stellar population does not exceed 5 Gyr, we must admit a small magnesium overabundance for the NGC 4548 nucleus, [Mg/Fe] = +0.1 . . . + 0.2. By contrast, [Mg/Fe] = 0 in the circumnuclear region.

Keeping this result in mind, we turn to the diagrams that diagnose the stellar-population age by comparing the Hβ index with one of the metal indices or their combination. Figure 2b shows a comparison of the observations with the models by Worthey (1994) for [Mg/Fe] = 0. It must be used to determine primarily the parameters of the circumnuclear region. We see that the circumnuclear stellar population, if we discard the outlier, is fairly young, $T \approx 4$ Gyr, and metal-rich, [Fe/H] $\approx +0.2$. If this circumnuclear region is a bulge, then such unusual parameters of its stellar population suggest the bulge formation or, to be more precise, completion over the entire galaxy lifetime; i.e., there is clear evidence of the so-called secular evolution. To determine the age of the nuclear stellar population in NGC 4548, we take into account its magnesium overabundance and, in addition to Fig. 2b, invoke the diagram in Fig. 2c, where the models by Tantalo *et al.* (1998) are shown for [Mg/Fe] $= +0.3$. The two diagrams suggest that the mean age of the nuclear stellar population in NGC 4548 is about 5 Gyr and the mean metallicity is monstrously high: [Fe/H] $\approx +0.6$! Thus, in contrast to our previously studied central regions of galaxies with chemically decoupled nuclei, the sharp radial decrease in metallicity in NGC 4548 is not accompanied by a significant age gradient. This implies that in the case under consideration, the chemical "decoupleness" of the nucleus did not result from an isolated compact star-formation burst in it but simply suggests that the secondary star formation proceeded in the nucleus faster and more effectively than in the circumnuclear region.

THE KINEMATICS OF GAS AND STARS IN THE CENTRAL REGION OF NGC 4548

In kinematic studies, the use of two-dimensional spectroscopy is of fundamental importance: only when analyzing the two-dimensional line-of-sight velocity field of gas or stars can the pattern of rotation be established without assuming *a priori* that it is circular. Indeed, if the stars are distributed and rotate in a thin circular disk (or, in a more general sense, if the geometry and rotation are axisymmetric), then by looking at it at some angle, we will see, in projection onto the sky, an ellipse and a maximum line-of-sight velocity, the projected rotation velocity, on the major axis of this ellipse, which will coincide with the line of nodes of the galactic plane. Simple geometric considerations allow us to write out the following formula for the azimuthal variation in the apparent line-of-sight velocity gradient within the region of rigid rotation:

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

where ω is the angular velocity of the galactic center, i is the inclination of the galactic-disk rotation axis to the line of sight, and PA_0 is the position angle of the line of nodes. Thus, for a circular (axisymmetric) distribution and rotation of stars, the isophotal major axis coincides with the line of nodes, while the central velocity-field isoline, the line of a zero relative line-of-sight velocity, is perpendicular to this direction. In a triaxial potential, for example, in a bar, the velocity-field isolines turn along the bar. Thus, if the direction of the maximum line-of-sight velocity gradient is called a kinematic major axis, then the kinematic and photometric major axes in a triaxial potential must turn in opposite directions from the line of nodes of the disk [see Monnet *et al.* (1992) and Moiseev and Mustsevoi (2000) for more details].

Figure 3 shows the two-dimensional line-of-sight velocity fields for stars and ionized gas at the center of NGC 4548 that we obtained from our MPFS observations. The stars (Fig. 3a) exhibit a regular quasi-rigid rotation over the entire segment under study. A cosine-wave fit to the azimuthal variations in dv_r/dr indicates that within $3''$ of the center, the kinematic major axis is oriented at $PA = 145°$; i.e., it virtually coincides with the line of nodes of the global galactic disk (see an isophotal analysis below and conclusions in the Introduction). Further out, at $R = 3''–5''$, $PA_{0,\mathrm{kin}} = 134.5°$. This may imply a turn of the kinematic major axis from the nodal line, but it is not very significant. The cosine-wave amplitude in the two radial ranges is 11 km s^{-1} arcsec^{-1} ($\pm 5\ldots 6$ km s^{-1} arcsec^{-1}), which confirms the rigid rotation of the stars within $5''$ of the center; given the projection effect, the angular velocity at the center is 18 km s^{-1} arcsec^{-1} or about 220 km s^{-1} kpc^{-1}. The appearance of the ionized-gas velocity field is completely different (Fig. 3b). Near the galactic nucleus, within $3''–4''$ of the center, we see the lines of equal velocities to turn through 90°. At the very center, the cosine-wave fit to the azimuthal dependence of the line-of-sight velocity gradients clearly yields an angular velocity of 19 ± 9 km s^{-1} arcsec^{-1} and the orientation of the kinematic major axis $PA_{0,\mathrm{kyn}} = 236°$. That the gas rotates slightly faster than the stars is, in principle, normal, considering an appreciable stellar velocity dispersion in the NGC 4548 bulge (see conclusions in the Introduction). However, the position angle of the kinematic major axis for ionized gas within $3''$ of the NGC 4548 center differs by 91° from that of the kinematic major axis for stars; i.e., we may observe an exactly polar circumnuclear gaseous disk. In this case, the difference between the apparent cosine-wave amplitudes constructed from the line-of-sight velocity gradients of gas and stars can most likely be attributed to the difference between the inclinations of the rotation planes to the line of sight: we must see the polar disk almost edge-on, and the correction to the gas rotation velocity for the projection effect must be small. A blue image of the central part of NGC 4548 with a high spatial resolution would help in determining the exact orientation of its circumnuclear gaseous disk: since the galaxy is seen nearly face-on, the polar gaseous disk could manifest itself as a thin dust lane passing through the bright central part of the bulge. It is by this configuration that we first suspected a circumnuclear polar gaseous disk in NGC 6340, which was subsequently confirmed by kinematic data (Sil'chenko 2000). Unfortunately, however, only a red image of NGC 4548 was obtained with the STIS/HST instrument; al-

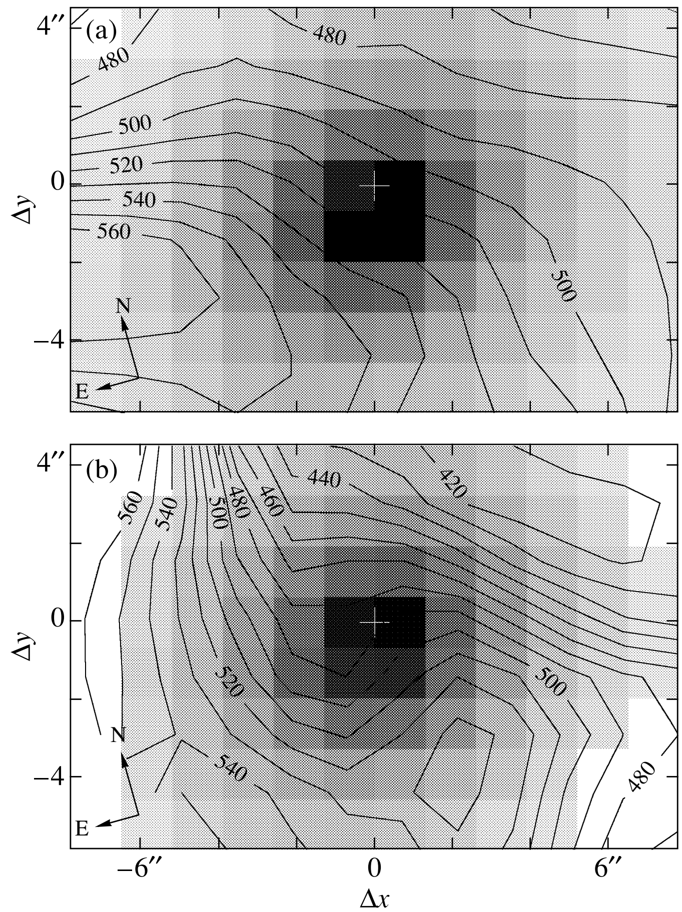

Fig. 3. Two-dimensional line-of-sight velocity fields for (a) stars and (b) ionized gas at the center of NGC 4548, as derived from our MPFS data (isolines). The gray-scaled background indicates the continuum intensity map; the cross marks the photometric center of the galaxy.

though it reveals a rich morphology (see below), there is no clear evidence for the presence of dust.

Nevertheless, let us turn to the morphological characteristics of the isophotes in the central region of NGC 4548, which are of considerable interest. Figure 4 shows the data obtained with various spatial resolutions. Whereas the seeing during the observations by Frei *et al.* (1996) was $2.3''-2.6''$, the seeing during the observations by Rauscher (1995) was $0.75''$ and the HST spatial resolution was $0.1''-0.2''$. Still, there is general agreement between the data even near the very center. At the galactic center, at $R < 2''$, according to Rauscher (1995), and at $R < 0.5''$ if we use the HST/STIS data, the isophotal orientation comes to $PA = 140°-150°$, i.e., to the line of nodes. Since, as we now know, the kinematic major axis of the circumnuclear stars is also oriented at $PA_{0,\mathrm{kin}} = 145°$, this coincidence proves that the rotation (and distribution) of stars at the very center of NGC 4548 is axisymmetric, despite the existence of a global bar in the galaxy. This is all the more surprising, because there is ample evidence that the global bar is not the only triaxial structure in NGC 4548. According to Fig. 4, the orientation of the isophotal major axis in the range of distances from the center $2''-14''$ is kept near $PA \sim 100°-120°$; this is neither the line of nodes (148°) nor the global-bar direction (60°). The ellipticity in this radial range exhibits a local maximum, $1 - b/a = 0.13$, at $R \approx 6''$. Since 0.13 is less than 0.2, the ellipticity of the outer isophotes that corresponds to a global-disk inclination of 38°, this structure cannot be a flat secondary bar in the thin disk. It most closely resembles a triaxial bulge.

Let us now look at the same morphological characteristics of the isophotes on the scale of the entire galaxy (Fig. 5). The quiet, undisturbed global disk of NGC 4548 shows up only at $R > 120''$, or 10 kpc: the spiral arms are a hindrance closer to the center, while at $R \approx 30''-60''$, the thin high-contrast bar elongated virtually perpendicular to the line of nodes dominates. When analyzing the azimuthally

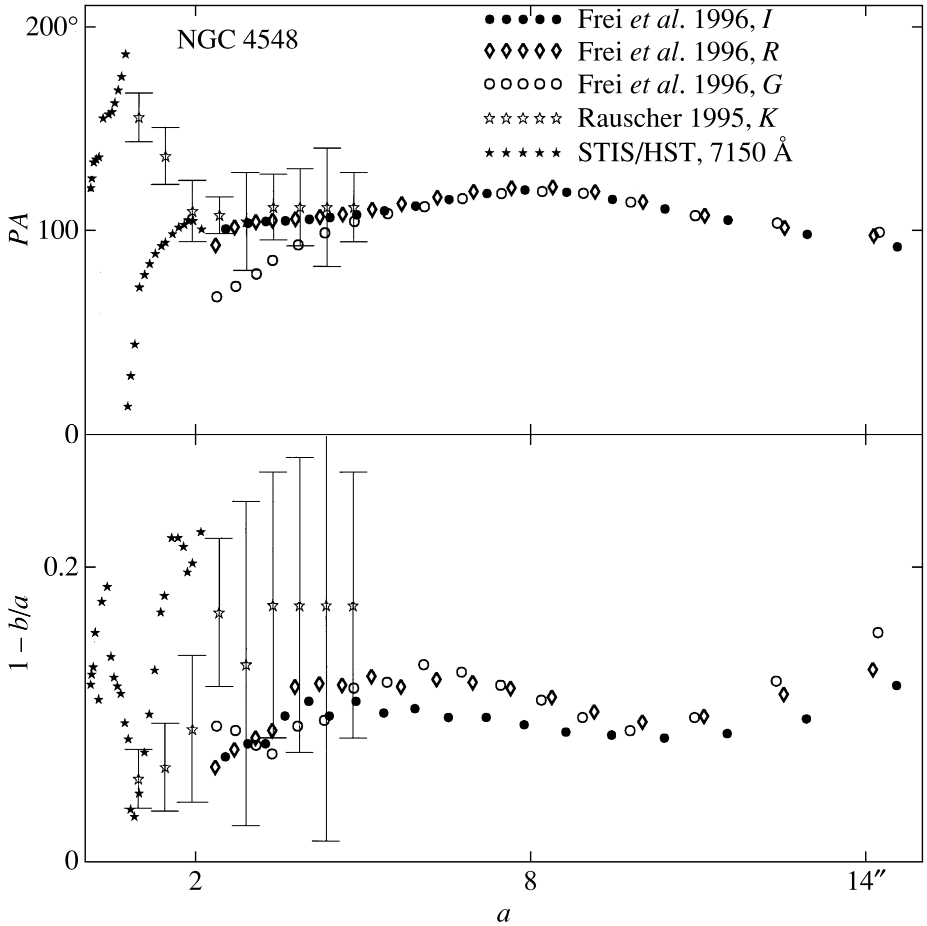

Fig. 4. The morphological characteristics of isophotes, the major-axis position angle and ellipticity, at the center of NGC 4548, as derived from various photometric data.

averaged brightness profile in the outer parts, we obtained an exponential global-disk scale length of 62.8″, which significantly exceeds the value of 28.7″ in Baggett *et al.* (1998). When we subtracted the model of an exponential disk with the line of nodes at $PA = 148°$, an inclination of 38°, and our derived parameters of the radial brightness profile from the actual digital images of NGC 4548 taken from the Atlas by Frei *et al.* (1996), the residual brightnesses in the radial range 2.4″–20″ excellently fitted into a de Vaucouleurs law with $r_e = 24''$ [Baggett *et al.* (1998) give $r_e = 36.7''$]. The K (2 mkm) band brightness profile of NGC 4548 within $R \approx 6''$ obtained by Rauscher (1995) also obeys the de Vaucouleurs law. Finally, in their photometric survey, where the galaxy images were decomposed into a disk and a bulge with an arbitrary brightness profile, Gavazzi *et al.* (2000) also pointed out that a bulge with a de Vaucouleurs brightness profile was found in NGC 4548 in the H (1.6 mkm) band. Thus, although the bulge of NGC 4548 is triaxial, it has a young stellar population and is, probably, a product of the secular evolution of the galaxy with a global bar; nevertheless, it exhibits a classical de Vaucouleurs brightness profile. This is an unexpected result that is in conflict with some theoretical predictions.

DISCUSSION

Having measured the indices (equivalent widths) of magnesium and iron absorption lines in the nucleus and circumnuclear region of NGC 4548, we found an unresolved chemically decoupled nucleus in this galaxy. However, it proved to bear no resemblance to all the previously studied chemically decoupled nuclei and most likely stems from the fact that we investigate a galaxy with a thin, high-contrast large-scale bar for the first time.

First of all, the nuclear stellar population in NGC 4548 shows a record high metallicity: it is a factor of 4 higher than the solar one. The structure of the decoupled nucleus itself is, probably, conventional: according to the HST data, a compact stellar disk whose plane coincides with the principal

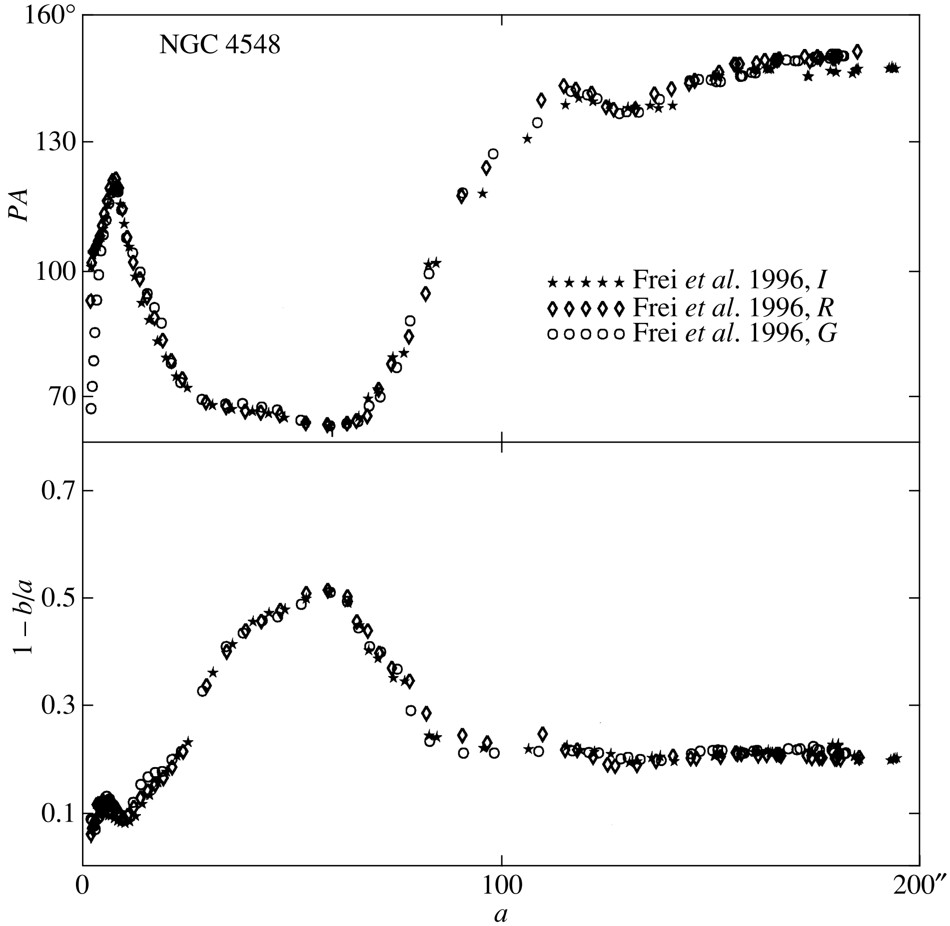

Fig. 5. The morphological characteristics of isophotes, the major-axis position angle and ellipticity, in NGC 4548 on large scales, as derived from the photometric data by Frei *et al.* (1996).

galactic symmetry plane can be seen within 0.4″ (∼33 pc). The stars in this disk rotate in circular orbits. However, the conventional circumnuclear stellar disk is embedded in quite an unusual bulge: although its stars are, on average, a factor of 2.5 less metal-rich than those in the nucleus (which still implies a mean metallicity higher than the solar one), the mean age of the stellar population is the same or younger than that in the nucleus, less than 5 Gyr. This implies that the central star-formation burst that occurred several Gyr ago encompassed an extended circumnuclear territory; the fact that the nucleus turned out to be chemically decoupled and to have an enhanced Mg/Fe ratio suggests a shorter time scale and a higher star-formation efficiency in the circumnuclear disk that those in the bulge region distended in all directions. This behavior of the circumnuclear star-formation burst may stem from the fact that the large-scale bar intensively supplied the nucleus with fuel for the burst, providing an inflow of gas with a large angular momentum from the outer global disk. Interestingly, the rejuvenated bulge is slightly triaxial and has a classical de Vaucouleurs brightness profile, whereas the calculations of models for the secular evolution, a gradual bulge formation over a period of several Gyr through radial gas inflow, generally yield quasi-exponential profiles (Courteau *et al.* 1996). It may well be that this is evidence of the bursting rather than a monotonic event that determined the bulge structure.

Finally, note the unusual kinematics of the ionized gas within 200–250 pc of the galactic center. The kinematic major axis of its velocity field, the direction of the maximum line-of-sight velocity gradient, is perpendicular to the kinematic major axis of the stellar velocity field and to the line of nodes of the global galactic disk. Theoretically, this is possible in two cases: either the gas lies in the galactic symmetry plane but has only purely radial motions or it regularly rotates in a plane that does not coincide with the global-disk plane. The former situation seems unlikely. Radial gas motions are usually produced either by the bar or (much weaker) by the spiral arms. There is no minibar at the center of NGC 4548: we

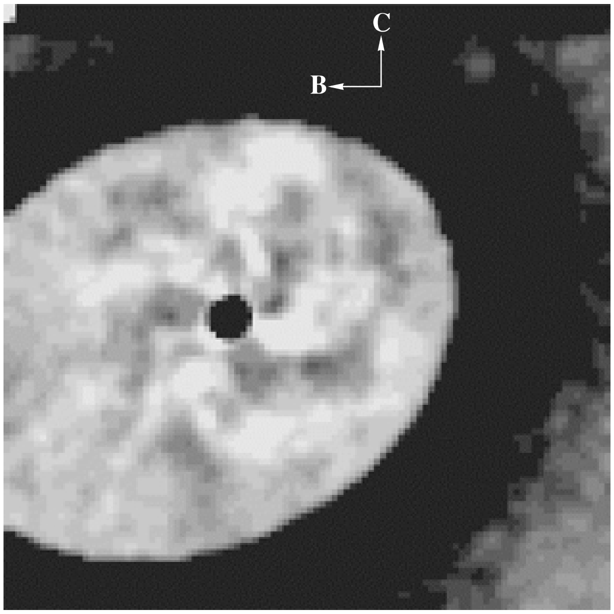

Fig. 6. The residual-brightness map for NGC 4548 in a λ 7150 Å (STIS HST) filter after the subtraction of a model with purely elliptical isophotes: the position angle of the vertical line is 17°, and the total region size is $5'' \times 5''$. We did not subtract the model at the very center (painted black); the light ellipse encloses the region in which the model was subtracted.

made sure in the preceding section that the stars within $R \approx 3''$ are distributed and rotate axisymmetrically. There are spiral arms, though: Fig. 6 shows the residual-brightness map for NGC 4548 obtained with the STIS/HST instrument after the subtraction of a model distribution with purely elliptical isophotes; a four-arm spiral pattern is clearly seen on this map within 1.5″ of the center. However, the perturbed velocities introduced by the spiral pattern generally do not exceed 20–30 km s^{-1}; in contrast, being a dynamically cold subsystem, the gas must rotate, judging by the stellar rotation, with a velocity no less than 50 km s^{-1} at 2″–3″. If the amplitudes of the radial and tangential gas velocities are comparable, then the kinematic major axis will turn through a mere 45°; in order that this axis turn through an apparent angle of 90°, the radial gas velocities at the center of NGC 4548 must exceed the rotational component at least by an order of magnitude. Bearing in mind the regular morphology and the absence of any nuclear activity in NGC 4548, such radial motions seem implausible. It remains to assume that the gas at the center of NGC 4548 rotates in an inclined plane. We cannot prove that this plane is exactly polar, as long as we have no confirmation in the form of morphological evidence based on a blue map with a high spatial resolution. However, given the reasoning concerning bars and presented in the Introduction, the fact that the circumnuclear gaseous disk in NGC 4548 is polar seems highly likely.

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