THE ASTRONOMICAL JOURNAL, 120:741–751, 2000 August
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FACE-ON GALAXIES NGC 524 AND NGC 6340: CHEMICALLY DECOUPLED NUCLEI AND INCLINED CIRCUMNUCLEAR DISKS

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Received 1999 September 1; accepted 2000 May 2

ABSTRACT

The central regions of the early-type disk galaxies NGC 524 and NGC 6340 have been investigated with the Multipupil Field Spectrograph at the 6 m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences. We confirm the existence of chemically distinct stellar nuclei in these galaxies, which had been claimed earlier. The metallicity differences that we have found between the nuclei and the bulges, 0.5–1.0 kpc from the centers, reach 0.5–0.6 dex. Both nuclei are magnesium overabundant, but the bulges have different magnesium-to-iron ratios: it is solar in NGC 6340 and the same as the nuclear one in NGC 524. Kinematical and morphological analyses reveal the existence of inclined central disks in these galaxies. In NGC 524 the central disk consists of stars, dust, and ionized gas; its extension may be as large as up to $R \approx 3$ kpc, and it is inclined by some 20° to the global galactic plane. In NGC 6340 only a gaseous polar disk is detected, the extension of which does not exceed $R \approx 500$ pc.

Key words: galaxies: evolution — galaxies: individual (NGC 524, NGC 6340) — galaxies: nuclei — galaxies: structure

1. INTRODUCTION

Early-type disk galaxies differ from late-type disk (spiral) galaxies by the smooth appearance of their disks. In general, they lack a massive gaseous component and noticeable star formation regions. However, often some gas is present in the circumnuclear regions; it is widely accepted that this gas has an external origin. Bertola and coworkers have reported a large body of statistics of decoupled distributions and kinematics of gaseous and stellar components in nearby lenticulars. Particularly, Bertola et al. (1992a) have reported three cases of gas counterrotation in a sample of 15 objects, and they concluded, drawing on data in the literature, that at least 40% of gas-possessing S0 have to accrete this gas during their late evolution. Kuijken et al. (1996) also noted that a significant fraction of gas disks in lenticulars ($24\% \pm 8\%$ in their sample) demonstrate counterrotation with respect to stars. Among the known decoupled distributions of gas and stars, a class of polar rings is the most spectacular one. Besides the extreme case of NGC 2685, where the radius of the gaseous polar ring is comparable to the radius of the global stellar disk, there exist more "minor-axis dust-lane" galaxies, such as NGC 1947 (Bertola et al. 1992b) or NGC 7280 (Carollo et al. 1997b; Afanasiev & Sil'chenko 2000) where compact circumnuclear gaseous disks are shown to rotate orthogonally with respect to the global stellar rotation.

In 1992 we published our first paper (Sil'chenko et al. 1992) on chemically distinct nuclei in early-type disk galaxies. In three lenticulars and in three Sa–Sb's we have found a sharp drop in magnesium absorption-line strength when passing from the nuclei to the surrounding bulges. The difference in Mg absorption strength indicates an order of magnitude change in metallicity on scales of a few arcseconds, whereas smooth metallicity gradients in galactic spheroids are usually only 0.3 dex per decade in radius in ellipticals (Carollo et al. 1993) or somewhat larger, with a mean of -0.5 and an extreme of -1.0 per dex, in bulges of early-type disk galaxies (Balcells & Peletier 1994; Fisher et al. 1996). The origin of chemically decoupled nuclei in disk galaxies may be related to a gas accretion event and a subsequent star formation burst in the nucleus where the accreted gas is accumulated. With this hypothesis we try to find a connection between the chemical distinctness of the nuclear stellar population and the presence of gas subsystems of obviously external origin. We (Sil'chenko et al. 1992; Sil'chenko 1999a) have already noted chemically distinct nuclei in the lenticulars NGC 1023, where an inclined extended H I disk is present, and NGC 7332 where circumnuclear gas counterrotates with respect to the stars. The lenticular galaxy with the chemically decoupled nucleus NGC 7280 represents a remarkable example. The circumnuclear gas coupling with tiny dust lanes is extended, and it rotates orthogonally to the circumnuclear stellar disk, which is, on its own, inclined with respect to the main galactic disk (Afanasiev & Sil'chenko 2000).

In this paper we present the results of a complex study of the central parts of two nearby face-on, early-type disk galaxies, NGC 524 and NGC 6340. Some time ago we found chemically decoupled nuclei in these galaxies. NGC 524 (Sil'chenko et al. 1992) and NGC 6340 (Sil'chenko 1995) were observed at the 6 m telescope with the Multipupil Field Spectrograph (MPFS) equipped by IPCS, and the drops of the magnesium absorption-line equivalent width along the radius were detected. Recently we reobserved the galaxies because the MPFS is now equipped with a CCD, making the data become more accurate. Besides the investigation of the radial variations of absorption-line indices, we also present results of kinematical and morphological analyses for the central parts of NGC 524 and NGC 6340. Due to the face-on orientation of their main planes, any inclined disks, both stellar and gaseous, can be easily detected if systematic visible velocity gradients are observed that can be attributed to rotation velocity projection onto the line of sight. The paper is organized as follows. Section 2 describes the observations and their reduction, as well as the data from open archives which we use. In § 3 we reconsider radial variations of metal absorption-line indices and

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confirm that the stellar nuclei of NGC 524 and NGC 6340 are chemically decoupled. In § 4 we study the morphology of distributions of gas and stars in the galaxies, and in § 5 we present two-dimensional velocity fields both for ionized gas and stars in the central regions. Section 6 contains the main conclusions. In Table 1 we give the basic parameters for the galaxies under consideration.

2. OBSERVATIONS AND DATA REDUCTION

The observations of NGC 524 and NGC 6340 presented in this paper were performed in 1996–1997 with the MPFS of the 6 m telescope at the Special Astrophysical Observatory (SAO), Nizhnij Arkhyz, Russia (Afanasiev et al. 1990, 1996). The detailed log of the observations is given in Table 2. The detector used was 520×580 CCD ISD015A (Electron, St. Petersburg), with a pixel size of 18 μm $\times$ 24 μm and read-out noise of 13 e^{-1}. The gain was 3.4 e^{-1} in 1996 and 7 e^{-1} in 1997.

The MPFS, which resembles the French integral-field spectrograph TIGER (Bacon et al. 1995) in the principles of its design, makes it possible to obtain simultaneously a set of spectra from an extended area (8×12 square elements in the present work); each spatial element is $1''.3 \times 1''.3$, so the full field of view which we center on the nuclei of the galaxies is $10'' \times 16''$. Two spectral ranges were exposed, blue and red, with a (reciprocal) dispersion of 1.6 Å pixel^{-1} (with the spectral resolution of 4–6 Å slightly varying over the field of view). The blue spectral range under consideration contains several strong absorption lines, such as the Mgb feature. We have used it to derive stellar velocity fields by cross-correlating spectra of the galaxies with the spectra of K giant stars observed during the same nights with the same spectrograph. Also we have calculated absorption-line indices Hβ, Mgb, and Fe5270 in the popular Lick system (Worthey et al. 1994) to study radial variations of the mean metallicity of the stellar populations. The sky background in the blue was exposed separately after each galaxy exposure. Properly normalized and smoothed, it was then subtracted from the spectra of the galaxies. The exposure times for the galaxies were long enough to achieve a signal-to-noise ratio (S/N) not less than 50–70 Å^{-1} in the nuclei—this level of S/N provides an accuracy of the absorption-line indices of better than 0.2 Å (Cardiel et al. 1998). However, the accuracy drops to 0.5–0.6 Å for the outermost elements observed, and, to keep a constant level of signal-to-noise ratio up to $R \approx 8''$, we added the element spectra in concentric circular rings with a width of $1''.3$ and the center in the nuclei. After azimuthal averaging, the accuracy of all indices measured along the radius is about 0.1 Å. To check consistency of our index system with the standard Lick one, we have observed nine G8–K3 stars, both giants and dwarfs, from the list of Worthey et al. (1994) and calculated their indices in the same manner as those for the galaxies. The agreement between stellar indices measured by us and those tabulated in Worthey et al. (1994) is excellent within the errors cited by them; the mean deviations of our measurements from those of Worthey et al. (1994) for all the indices are less than 0.05 Å, so we need not degenerate our spectral resolution to come into agreement with the standard Lick index system. The indices Mgb and Fe5270 measured in the galaxies have been corrected for the stellar velocity dispersion broadening; the correction values are determined by artificial Gauss broadening the stellar spectra with varying σs. For NGC 6340 this correction is small (only 0.1 Å) because the stellar velocity dispersion in the center of this galaxy is 100–140 km s^{-1} (Bottema 1989). For NGC 524 this correction is 0.5 Å in the nucleus and 0.4 Å beyond it, because the nuclear stellar velocity dispersion is 246 km s^{-1} (LEDA) or 236 ± 19 km s^{-1} (Schechter 1983), and it decreases only slightly in the nearest vicinity of the nucleus (our impression from the visual inspection of the spectra). The red spectral range under consideration contains the

TABLE 1

GLOBAL PARAMETERS OF THE GALAXIES

Parmeter	NGC 524	NGC 6340
Type (NED)	SA(rs)0$^+$	SA (s)0/a
R_{25} (kpc) (RC3+LEDA)	13.2	9.3
B_T^0 (RC3)	11.17	11.67
M_B (LEDA)	-21.39	-19.94
$(B-V)_T^0$ (RC3)	1.00	0.79
$(U-B)_T^0$ (RC3)	0.58	
V_r (RC3)	(opt) 2421 km s^{-1}	(radio) 1198 km s^{-1}
Distance (Mpc) (LEDA, $H_0 = 75$ km s^{-1} Mpc^{-1})	33	19.8
Inclination (deg) (LEDA)	8.7	25.6
P.A.$_0$ (deg) (LEDA)		120
σ_0 (km s^{-1}) (LEDA)	246	146
v_m (km s^{-1}) (LEDA)		245

TABLE 2

TWO-DIMENSIONAL SPECTROSCOPY OF NGC 524 AND NGC 6340

Date	Galaxy	Exposure (min)	Spectral Range (Å)	P.A.(top) (deg)	Seeing (arcsec)
1996 Aug 14–15	NGC 6340	90	4800–5400	209	1.7
1996 Aug 14–15	NGC 6340	90	6250–6900	180	1.7
1996 Oct 14–15	NGC 524	60	6250–6900	67	1.6
1997 Oct 31–Nov 1	NGC 6340	81	4800–5400	164	2.2
1997 Oct 31–Nov 1	NGC 524	94	4800–5400	149	2.2

emission line [N II] λ6583, which is strong in the centers of NGC 524 and NGC 6340. It is used to obtain the two-dimensional velocity fields of the ionized gas. The wavelength calibration for both spectral ranges was made by using separate exposures of the hollow-cathode lamp filled with helium, neon, and argon. The accuracy and absence of systematic shifts of the velocity scale was checked by measuring the night-sky emission lines. The accuracy of the individual velocity measurements both for stars and ionized gas is about 25 km s^{-1}. The primary data reduction—bias subtraction, flat fielding, cosmic-ray removal, extraction of one-dimensional spectra, wavelength calibration, construction of surface brightness maps—have been performed with software developed in the Special Astrophysical Observatory (Vlasyuk 1993). The absorption-line indices were calculated with our own FORTRAN programs.

We have also retrieved a long-slit spectrum of NGC 524 from the La Palma Archive. The galaxy was observed on 1995 December 24 at the ISIS William Herschel Telescope (WHT) with a dispersion of 0.4 Å $pixel^{-1}$ in the spectral range 5000–5400 Å (blue arm of the spectrograph); the slit (width equal to 0.″62) was aligned almost along the minor axis of the galaxy, P.A. = 135°. We have used this spectrum to calculate Mgb and Fe5270 indices along the slit with the same techniques as the indices from our MPFS data (the sky for subtracting was taken from the edges of the slit), though we cannot reduce these indices into the standard Lick system because of the lack of standard Lick star observations.

The photometric data involved in our analysis are taken from the La Palma and *Hubble Space Telescope* (*HST*) Archives. The details of the observations are given in Table 3. The programs in the frame of which the central parts of the galaxies have been observed by the *HST* are Core Properties of Bulges of Spiral Galaxies (PI: M. Stiavelli, program ID 6359) and Nuclear Structure of S0 Galaxies (PI: A. Phillips, program ID 5999). We derived morphological characteristics of the surface brightness distribution in the galaxies by analyzing these images; the FITELL program of V. V. Vlasyuk has been used for this purpose.

3. CHEMICALLY DECOUPLED NUCLEI IN NGC 524 AND NGC 6340

As noted in the introduction, the galaxies under consideration exhibit stellar nuclei with enhanced magnesium absorption lines (for NGC 524, see Sil'chenko et al. 1992; for NGC 6340, see Sil'chenko 1995). Now we present more precise radial profiles of Mgb together with those of Fe5270 and Hβ. The azimuthally averaged index measurements are presented in Table 4. The accuracy of the azimuthally averaged measurements is improved by a factor of 3 with respect to our earlier results. However, the qualitative conclusions remain the same.

NGC 524 (Fig. 1) shows radial profiles of the magnesium and iron indices of very similar shapes. The maximum equivalent widths of the metal lines are observed in the nucleus and decrease radially up to $R \approx 4''$ (600 pc). Between $R = 4''$ and $R = 8''$ the MPFS profiles flatten off. Their extensions by the long-slit data confirm the flat behavior of the metal-index profiles in the radius range 5″–20″ (the bulge-dominated region), though the long-slit measurements are not reduced into the Lick system. By calculating index gradients in the bulge in a traditional manner (versus $d\log R$ in the radial range 3″–8″), we have obtained $d\mathrm{Mgb}/d\log R = -0.85 \pm 0.18$ Å dex^{-1} and $d\mathrm{Fe5270}/d\log R = -0.59 \pm 0.02$ Å dex^{-1}, both gradients corresponding to $d[m/\mathrm{H}]/\log R = -0.4$—a value quite typical for early-type galaxies (Balcells & Peletier 1994; Fisher et al. 1996). The zero points of the linear regressions corresponding to the extrapolated bulge indices at $R = 1''$,

TABLE 3

PHOTOMETRIC OBSERVATIONS OF NGC 524 AND 6340

Date	Galaxy	Telescope	Filter	Exposure (seconds)	Seeing (arcsec)	Scale (arcsec)
1988 May 9–10	NGC 6340	JKT	*V*	600	1.6	0.30
1988 May 9–10	NGC 6340	JKT	*R*	600	1.7	0.30
1988 May 9–10	NGC 6340	JKT	*I*	720	1.6	0.30
1998 May 17–18.....	NGC 6340	JKT	*R*	900	1.1	0.33
1996 Nov 6–7.....	NGC 524	JKT	*I*	360	2.6	0.31
1995 Sep 24	NGC 524	*HST* + WFPC2	F555W	160	0.13	0.045
1995 Sep 24	NGC 524	*HST* + WFPC2	F814W	320	0.13	0.045
1996 Jun 2	NGC 6340	*HST* + WFPC2	F606W	400	0.15	0.045

TABLE 4

AZIMUTHALLY AVERAGED LICK INDICES IN NGC 524 AND NGC 6340

	NGC 524			NGC 6340 (1996 Aug)			NGC 6340 (1997 Oct)		
R (arcsec)	Hβ	Mgb	Fe5270	Hβ	Mgb	Fe5270	Hβ	Mgb	Fe5270
0.....	1.33	4.87	3.06	1.05	4.65	2.68	1.56	4.49	2.93
1.3.....	1.42	4.65	2.97	1.24	4.20	2.88	1.35	4.38	2.83
2.6.....	1.23	4.20	2.75	1.30	3.60	2.43	1.00	3.83	2.48
3.9.....	1.16	3.88	2.34	0.91	2.97	2.34	1.23	3.18	2.34
5.2.....	0.94	3.70	2.27	0.80	3.16	2.14	1.24	3.17	2.30
6.5.....	1.22	3.68	2.21	0.92	2.26	1.64	1.39	3.10	2.00
7.8.....	0.98	3.61	...	0.78	2.24	2.03	1.59	2.49	0.99

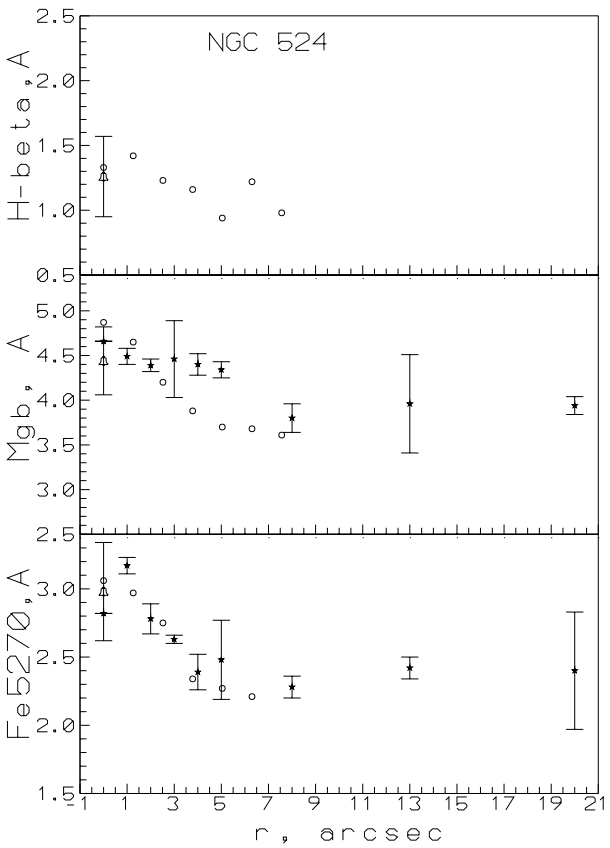

FIG. 1.—NGC 524: Radial profiles of the absorption-line indices Hβ, Mgb, and Fe5270. Open circles present our MPFS data; the bell with the error bar is the data of Trager et al. (1998). Asterisks show the long-slit data from the ISIS WHT (La Palma Archive) not corrected for stellar velocity dispersion and not reduced to the standard Lick system.

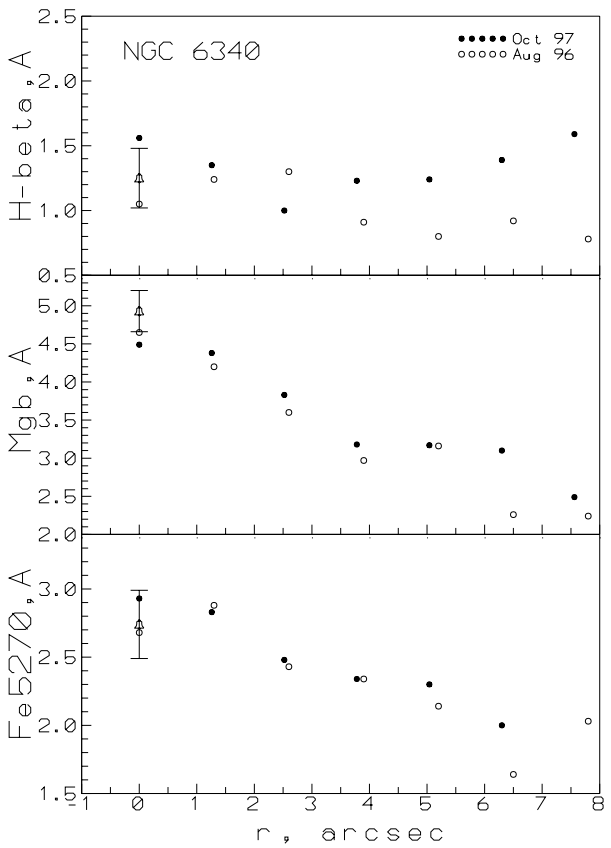

FIG. 2.—NGC 6340: Radial profiles of the absorption-line indices Hβ, Mgb, and Fe5270. Filled and open circles present our MPFS data; the bell with the error bar is the data of Trager et al. (1998).

Mgb = 4.34 ± 0.14 Å and Fe5270 = 2.68 ± 0.01 Å, are noticeably smaller than the nuclear indices, Mgb(nuc) = 4.87 ± 0.16 Å and Fe5270(nuc) = 3.16 ± 0.19 Å. We have taken the mean bulge characteristics by averaging the MPFS data in the radial range 4″–8″, resulting in ⟨Mgb(bul)⟩ = 3.75 ± 0.06 Å and ⟨Fe5270(bul)⟩ = 2.27 ± 0.04 Å. If we now apply the models of Worthey (1994) for old stellar populations to the differences ΔMgb and ΔFe5270 between the nucleus and the mean bulge, under the assumption of equal mean stellar population ages, we obtain Δ[Fe/H] = 0.50 ± 0.10 dex from ΔMgb and Δ[Fe/H] = 0.56 ± 0.15 dex from ΔFe5270, the nucleus being more metal-rich. Unfortunately, we cannot determine the mean age of the stellar population in the center of NGC 524 by using the absorption-line index Hβ, because it is notably affected by the emission line. However, chemically decoupled nuclei in lenticular galaxies usually appear to be younger than the bulges (Sil'chenko 1999a; Afanasiev & Sil'chenko 2000), so the derived metallicity difference must be considered to be a low limit. The coincidence within the errors of the Δ[Fe/H] values derived from ΔMgb and ΔFe5270 gives some evidence for equal magnesium-to-iron ratios in the nucleus and in the bulge of NGC 524.

NGC 6340 (Fig. 2) has been observed twice in the green spectral range with the MPFS+CCD, so we can independently estimate the accuracy of our measurements by comparing the two data sets. One can see in Figure 2 that the claimed accuracy of 0.1 Å for the azimuthally averaged points is kept quite well up to $R \approx 6''$. The shape of the radial profiles of the metal-line indices demonstrates again the presence of a chemically decoupled nucleus, though the contrast of the Fe5270 drop is obviously smaller than that of Mgb. As we have in this galaxy more measurements than in NGC 524, the mean indices for the nucleus and the bulge of NGC 6340 are estimated more precisely. For the nucleus, Mgb(nuc) = 4.57 ± 0.08 Å and Fe5270(nuc) = 2.80 ± 0.13 Å, and for the bulge, $R = 4''$–$6''$, Mgb(bul) = 3.22 ± 0.04 Å and Fe5270(bul) = 2.32 ± 0.07 Å. After applying the models of Worthey (1994) to the nucleus-bulge differences, ΔMgb and ΔFe5270, we obtain Δ[Fe/H] = 0.61 ± 0.05 dex from ΔMgb and Δ[Fe/H] = 0.30 ± 0.13 dex from ΔFe5270. Again, these metallicity differences represent only low limits, owing to age uncertainty: a narrow Hβ emission line is seen inside the broader absorption, and so the absorption-line index, Hβ, is invalid for the age diagnostics. Unlike NGC 524, NGC 6340 demonstrates different Δ[Fe/H] from the magnesium and iron index differences; it may be a signature of different magnesium-to-iron ratios in the bulge and in the nucleus of this galaxy.

The question of the magnesium-to-iron ratio can be addressed directly with a diagram (Fe5270-Mgb). The first fruitful attempt to use this diagram to diagnose the Mg/Fe ratio was made by Worthey et al. (1992), and they found immediately that a lot of luminous ellipticals are magnesium overabundant. I noted that Mgb and Fe5270 in the centers of disk galaxies, including lenticulars, satisfy the models with solar magnesium-to-iron ratio (Sil'chenko

1993), though later Fisher et al. (1996) reported several nuclei (but not the bulges!) in luminous lenticulars that were magnesium overabundant. Figure 3 presents these diagrams for NGC 524 and NGC 6340; the model sequences with varying metallicity and ages calculated by Worthey (1994) for [Mg/Fe] = 0 border the narrow locus of the solar Mg/Fe ratio. The comparison of the observations with the models reveals that both chemically decoupled nuclei are magnesium overabundant; though less accurate, the measurements of Trager et al. (1998) confirm this conclusion. The magnesium overabundance of the chemically decoupled nuclei in lenticular galaxies is not unique—we have found it, for example, in NGC 1023 (Sil'chenko 1999a). But it is not a rule—NGC 7332 and NGC 7280, being of the same total luminosity as NGC 6340, demonstrate the solar Mg/Fe in their chemically decoupled nuclei as well as in their bulges (Sil'chenko 1999a; Afanasiev & Sil'chenko 2000). NGC 6340 shows a solar magnesium-to-iron ratio in its bulge; the [Mg/Fe] difference between the nucleus and the bulge is about 0.3 dex. NGC 524 demonstrates a quite different Mg/Fe behavior. The data taken along the radius lie parallel to the model sequence but shifted to the right. This is interpreted as [Mg/Fe] $\approx +0.3$, constant up to $R \approx 8''$ (1 kpc) in this galaxy. Such behavior of Mg/Fe resembles that in ellipticals (Worthey et al. 1992) and in some bulges of supergiant spirals, such as M31 (Sil'chenko et al. 1998) or NGC 488 (Sil'chenko 1999b).

4. MORPHOLOGY OF STELLAR AND GAS DISTRIBUTIONS IN THE CENTER OF NGC 524 AND NGC 6340

To understand the structure of the central regions in NGC 524 and NGC 6340, we have analyzed digital images obtained from the La Palma and *HST* archives. The radial dependencies of the major-axis position angle and ellipticity of the isophotes approximated by ellipses are presented in Figure 4 for NGC 524 and in Figure 5 for NGC 6340.

The galaxies have been studied photometrically earlier, especially NGC 524. For NGC 6340 only one-dimensional brightness profiles can be found in the literature (Boroson 1981; Whitmore & Kirshner 1982); they give evidence that the global disk begins to dominate at $R \geq 15''$. For NGC 524 the information is rich and somewhat controversial. According to Kent (1985) and Bothun & Gregg (1990), who have performed the brightness profile decomposition in the *r* band and *B* band, respectively, the bulge dominates over the disk at all radii; so in some respects NGC 524 may be reclassified as an elliptical with embedded disk. However, the profiles presented by Hodge & Steidl (1976) and Magrelli et al. (1992) reveal an extended exponential disk dominating over the bulge at $R \geq 30''$. The ellipticity estimates for the outer isophotes range from 0.03 ± 0.01 (Hodge & Steidl 1976) to 0.06 (Kent 1984); our estimate from the La Palma data is 0.06; in any case, the galaxy inclination cannot be larger than 20°. The line-of-nodes orientation lies somewhere between P.A.$_0 = 5° \pm 23°$ (Hodge & Steidl 1976) and 41° (Kent 1984; Magrelli et al. 1992). More exact determination is prevented by the low ellipticity of the isophotes; LEDA and RC3, in particular, omit the estimate of the major-axis position angle (see our Table 1).

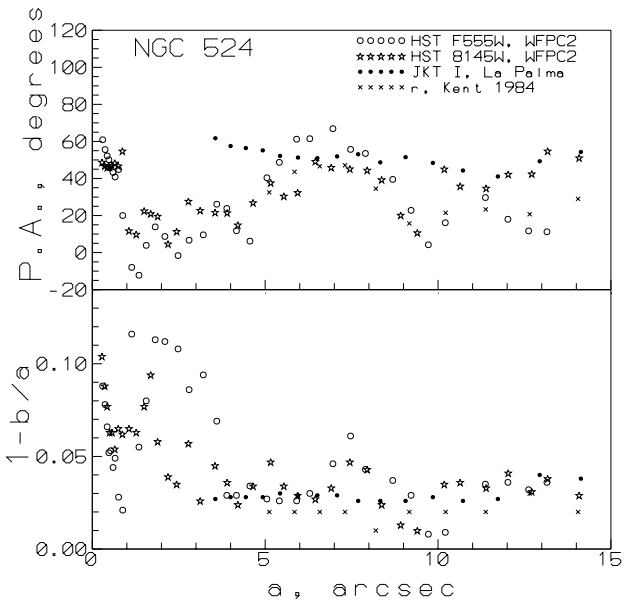

FIG. 4.—Radial variations of the isophote morphological characteristics in the center of NGC 524 according to *HST* data and La Palma data.

The combination of the photometric data of different spatial resolution allows us to study the structure of the inner regions of NGC 524 and NGC 6340 in more detail.

Figure 4 shows the radial variations of the major-axis position angle and ellipticity in the center of NGC 524. At $R > 5''$ they look rather constant, with P.A.$_0$ at the level of

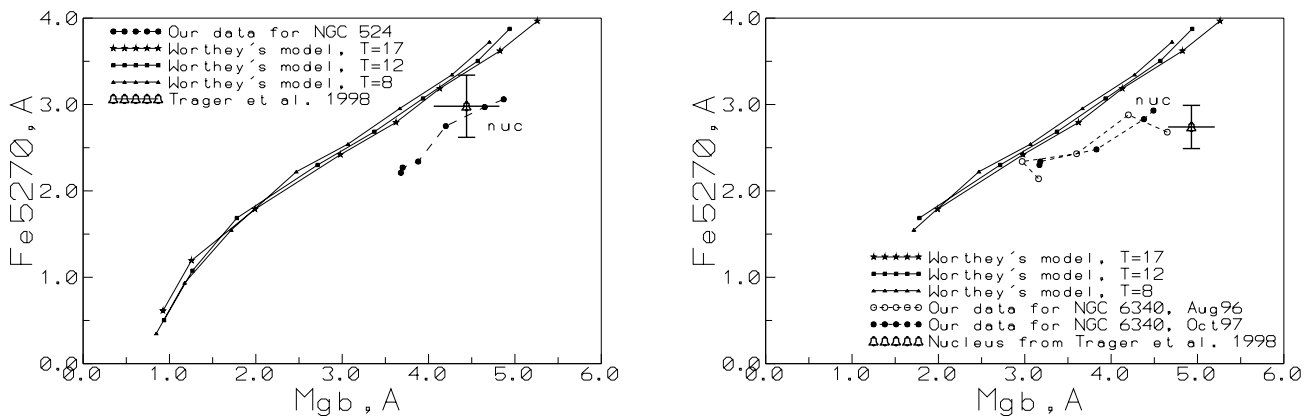

FIG. 3.—Diagrams (Fe5270-Mgb). (*left*), NGC 524; (*right*) NGC 6340. The measurements are azimuthally averaged and taken along the radius with the step of 1.″3. The nuclear measurements from Trager et al. (1998) are plotted for comparison with their error bars. The ages of Worthey's (1994) models for [Mg/Fe] = 0 are given in billion years.

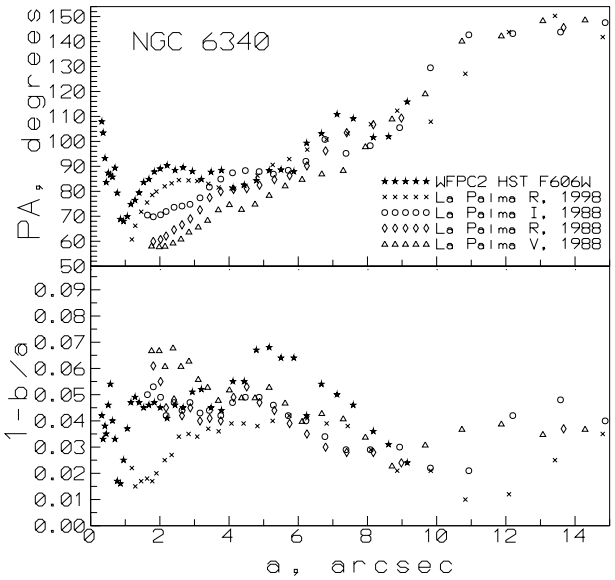

FIG. 5.—Radial variations of the isophote morphological characteristics in the center of NGC 6340 according to *HST* data and La Palma data.

about 40° and $1 - b/a$ at the level of 0.03. This behavior does not contradict the data for the outer regions according to, e.g., Magrelli et al. (1992). However, at $R \leq 4''$ the major axis seems to be turned by some 20° and, more importantly, the ellipticity seems to increase up to about 0.10—a value that is not reached even in the outermost part of the galaxy. Though the accuracy of the morphological parameter estimates is low for such roundish isophotes and though some dust is present inside $R \approx 1''$ (Byun et al. 1996), which causes a discrepancy of two *HST* measurements of the ellipticity through the different filters, it seems quite probable that a visibly elongated stellar structure is present in the center of NGC 524.

The variations of the morphological parameters in the center of NGC 6340 are even more prominent than in the center of NGC 524. In the disk-dominated region, at $R = 30''$–$35''$, the position angle of the isophote major axis, that is, the orientation of the line of nodes, is $\mathrm{P.A.}_0 = 131°$. The asymptotic ellipticity is 0.08, so the inclination of the galactic plane may be as large as 23°. However, at $R < 5''$ (Fig. 5) the major axis is surely turned and its P.A. $\approx 85°$ differs from the orientation of the line of nodes at least by 45°. The ellipticity demonstrates a local maximum at $R \approx 5''$, the most prominent in the high-resolution *HST* data. Though some discrepancy of the data inside $R \approx 3''$ (caused by the different spatial resolutions of the observations) can be seen, the elongated stellar structure in the center of NGC 6340 is also rather probable.

Our spectral observations have detected the emission line [N II] λ6583, and thus the presence of ionized gas, in the centers of both galaxies. We wonder whether the distributions of diffuse matter, gas, and dust resemble those of the stellar components. First, we can examine the dust. Figure 6 presents direct WFPC2 (namely, PC) images of both galaxies. One can see a rather extended roundish dust disk in the center of NGC 524 consisting of tightly wrapped thin dark spirals. Lower resolution observations made by Veron-Cetty & Veron (1988) also revealed a red nucleus and an "almost face-on dust ring" $16'' \times 12''$ in size. Let us note, however, that such an axis ratio, 0.75, favors a dust disk inclination rather close to 40°, not exactly face-on. In the center of NGC 6340 (left panel of Fig. 6) Carollo et al. (1997b) noticed "a tiny dust lane." We can add that the very compact (with a radius of less than 0.″5) dust disk is seen almost edge-on ($i_{\mathrm{dust}} \geq 70°$), and therefore we deal with a circumnuclear polar ring. Its line of nodes is close to $\mathrm{P.A.}_0 \approx 90°$.

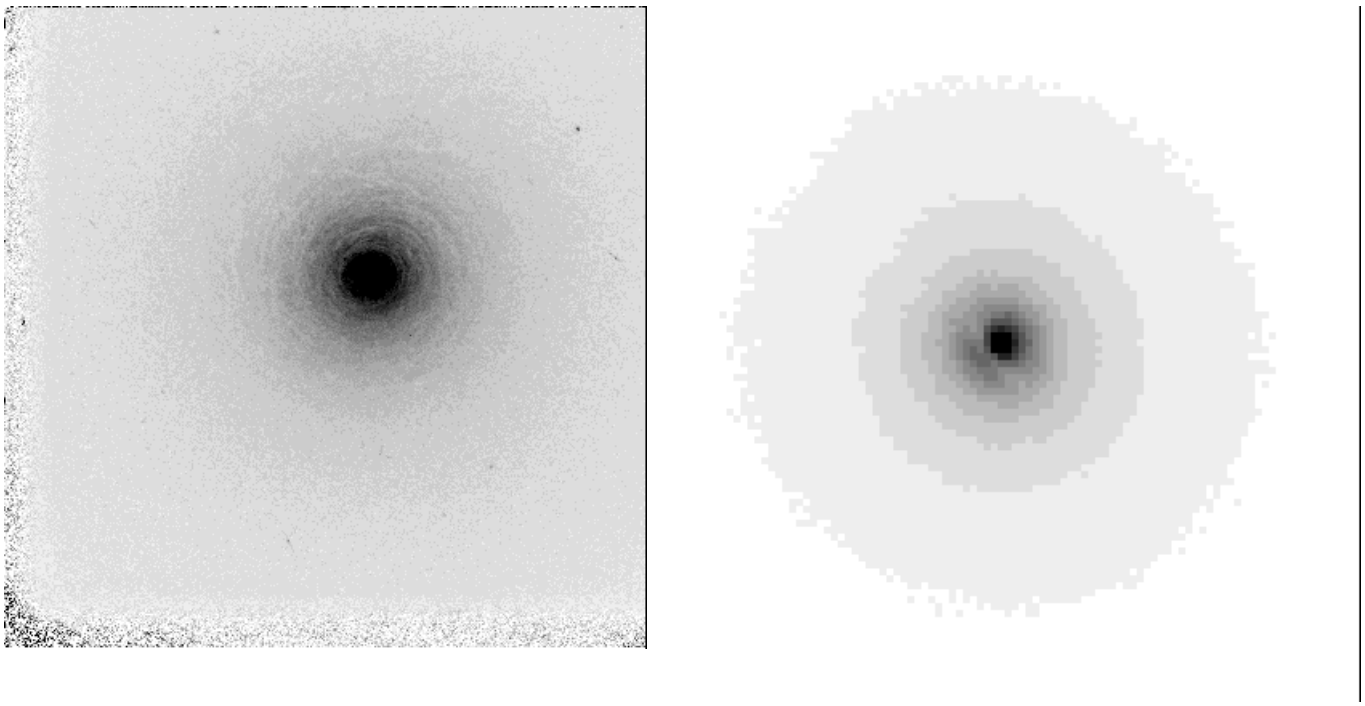

FIG. 6.—Direct views of the images of NGC 524 (*left*) and NGC 6340 (*right*), obtained by the *HST* WFPC2 in the visual passbands. The sizes of the maps shown are $36'' \times 36''$ and $4.''5 \times 4.''5$, respectively. The orientations are P.A.(top) $= -68°$ and P.A.(top) $= -129°$.

Our MPFS observations allow us to refer directly to emission-line brightness maps. Figure 7 presents surface distributions of the [N II] emission intensity in arbitrary units. In NGC 6340 the nitrogen emission-line isophotes are elongated in P.A. $\approx 130°$, so they imply the existence of a rather extended gaseous disk, which in the line of nodes, but not the inclination, coincides with that of the global disk. In NGC 524 the emission distribution is strongly asymmetric. It is confined to the western part of the circumnuclear region, and its geometry is not quite evident. However, if we recall the work of Macchetto et al. (1996), who observed lenticular galaxies through the narrowband H_α+[N II] filter, we find that the emission distribution in the center of NGC 524 matches perfectly that of the dust: there is the same roundish patchy disk with a radius of some 20″. A bright emission knot in the western vicinity of the nucleus is also seen in the map presented by Macchetto et al. (1996), so our left panel of Figure 7 probably represents a high-level slice of the overall emission distribution.

5. KINEMATICS OF GAS AND STARS IN THE CENTRAL REGIONS OF NGC 524 AND NGC 6340

When we look at a rotating disk from its pole, it is projected "face-on" (on the sky plane), and the projection of its rotation velocity onto the line of sight is zero. Generally, face-on galaxies should lack any line-of-sight velocity gradients (over their images). It is just what we would expect from NGC 524 and NGC 6340. However, the line-of-sight velocity fields obtained by us for these galaxies look quite different.

Figure 8 presents velocity fields for the ionized gas in the centers of the galaxies. Both maps demonstrate obvious signs of regular rotation: the measured line-of-sight velocities gradually changes from one map corner to another. In the case of axisymmetrical (circular, cylindric) rotation, the direction of the highest velocity gradient (which we call the "dynamical major axis") should coincide with the line of nodes. In NGC 524 (left panel of Fig. 8) this direction is P.A.$_0 \approx 23°$; in NGC 6340 (right panel of Fig. 8), P.A.$_0 \approx 115°$. Both directions are indeed close to the major axes of the inner isophotes as reported in the previous section, though it is not quite true for NGC 6340. P.A.$_0$(phot) changes along the radius in the center of this galaxy, and it is not quite clear what orientation must be chosen as a reference one. But as the first approximation, one can conclude that we see circumnuclear rotating thin (cold) gaseous disks; and these disks, unlike the main stellar disks, are obviously not face-on: their visible rotation is very fast.

As for stellar rotation, we have not found clear signs of it in the center of NGC 6340. The systematic velocity variation over the full line-of-sight velocity field of this galaxy, the spatial base of which is some 10″, if it exists, does not exceed the random error of one velocity measurement, namely, 25 km s^{-1}. On the contrary, stars in the center of NGC 524 demonstrate quite noticeable rotation (Fig. 9). This is somewhat unexpected. LEDA (see Table 1) gives for NGC 524 $i = 8\overset{\circ}{.}7$ and for NGC 6340 $i = 25\overset{\circ}{.}6$, so the latter galaxy would have a projection factor 3 times less than the former. Besides, the stellar velocity dispersion in the center of NGC 524 is rather high. The galaxy is thought by many photometrists to be bulge dominated, so this galaxy is closer to ellipticals than NGC 6340, and, as a luminous

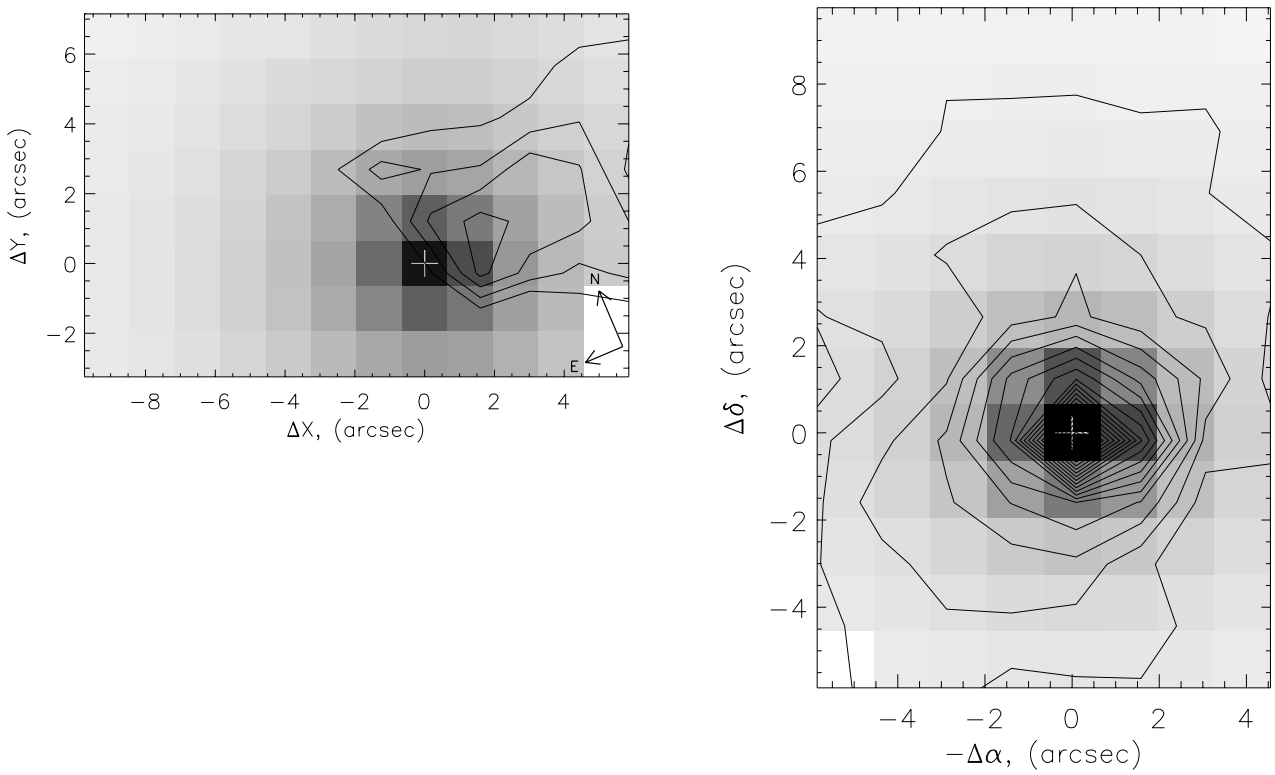

FIG. 7.—Surface brightness distributions for the emission line [N II] λ6583 (isolines) superposed on the gray-scaled red continuum map for NGC 524 (*left*) and NGC 6340 (*right*). The maps are direct. The orientations are P.A.(top) = −23° for NGC 524 and P.A.(top) = 0° for NGC 6340. The brightness units are arbitrary.

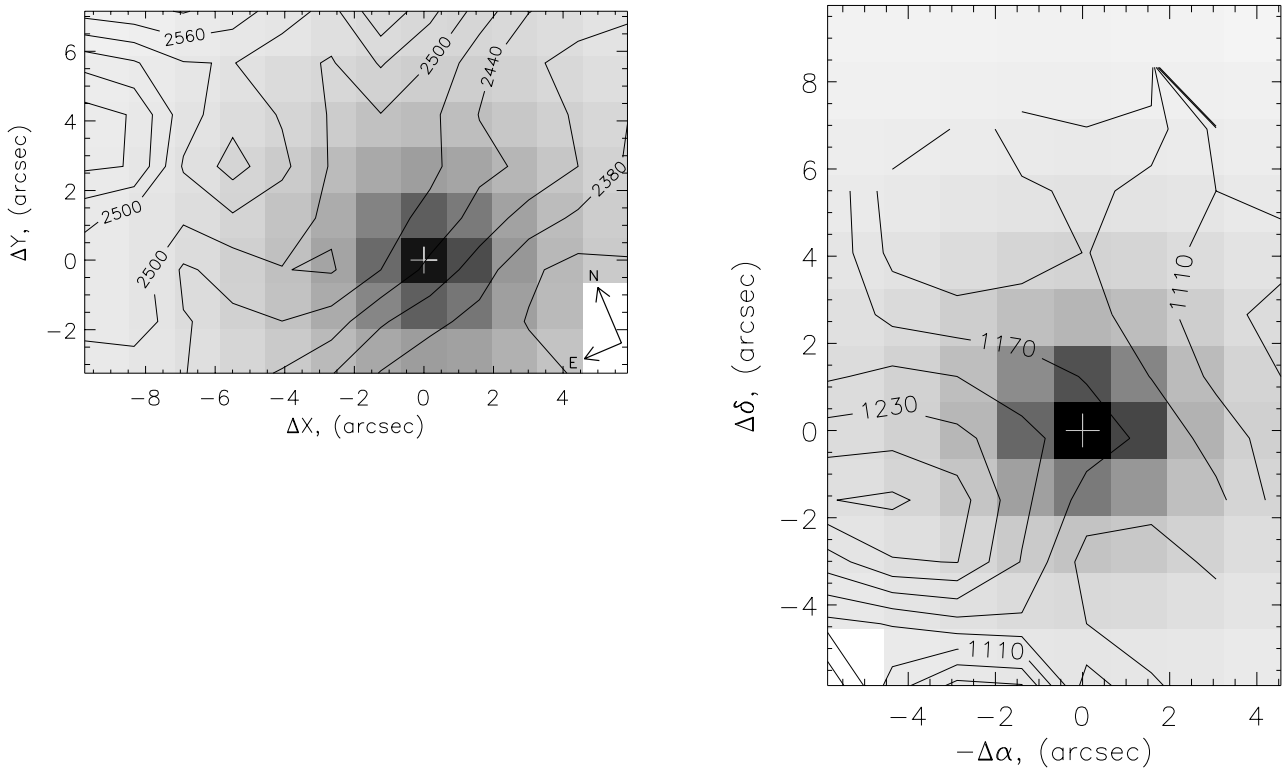

FIG. 8.—Isovelocities for the ionized gas in the centers of NGC 524 (*left*) and NGC 6340 (*right*). The maps are direct. The orientations are P.A.(top) = −23° for NGC 524 and P.A.(top) = 0° for NGC 6340. The positions of photometric centers are shown by the white plus signs

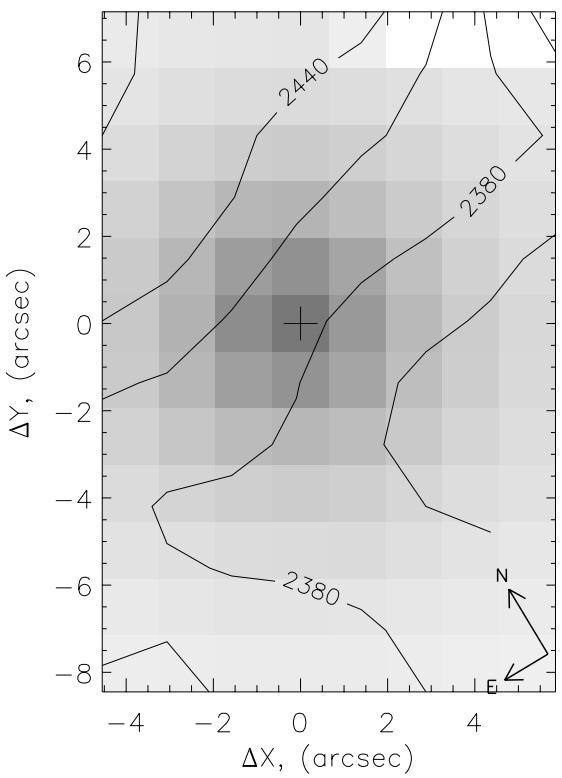

FIG. 9.—Stellar isovelocities in the centers of NGC 524. The map is direct. P.A.(top) = −31°, the position of the photometric center is shown by the plus sign.

early-type galaxy, it should rotate slowly. However, the line-of-sight velocity gradient is quite visible in Figure 9; the direction of the maximum velocity gradient, P.A.$_0 \approx 19°$, agrees well with the dynamical major axis of the gaseous component. As the photometric major axis in the radius range of 1″–4″ is also aligned in P.A.$_0$(phot) $\approx 20°$ (Fig. 4), we conclude that the separate stellar disk, with the radius of 4″–5″ (0.6–0.8 kpc) and a gaseous extension up to $R \approx 20''$ (3 kpc), exists in the center of NGC 524. Its line of nodes is aligned in P.A. $\approx 20°$, whereas the global line of nodes is close to P.A.$_0 \approx 40°$ (Fig. 4; see also Magrelli et al. 1992), so the circumnuclear disk is inclined with respect to the main galactic plane.

To compare more thoroughly stellar and gaseous rotations in the centers of NGC 524 and NGC 6340, we have simulated one-dimensional velocity profiles along the dynamical major axes overlapping a narrow "slit" on the two-dimensional velocity fields for the gas and stars. The resulting profiles are plotted in Figure 10. In NGC 524 (left panel of Fig. 10) there is no significant discrepancy between the stellar and gaseous rotation; however, both velocity variation amplitudes are too high to be attributed to the rotation plane inclined by $i \leq 20°$, unless we accept $V_{\rm rot} \geq 360$ km s^{-1} at $R < 1$ kpc. We would rather ascribe $i \approx 40°$ implied by the morphology of the dust ring (Veron-Cetty & Veron 1988) to this fast rotating circumnuclear disk. This is one more sign of its decoupling. In NGC 6340 we had a problem with determining a position angle for our cross-section. The ionized gas shows P.A.$_0 \approx 115°$, the dynamical major axis of the circumnuclear stellar component is unknown, and the global line of nodes is close to P.A.$_0 \approx$

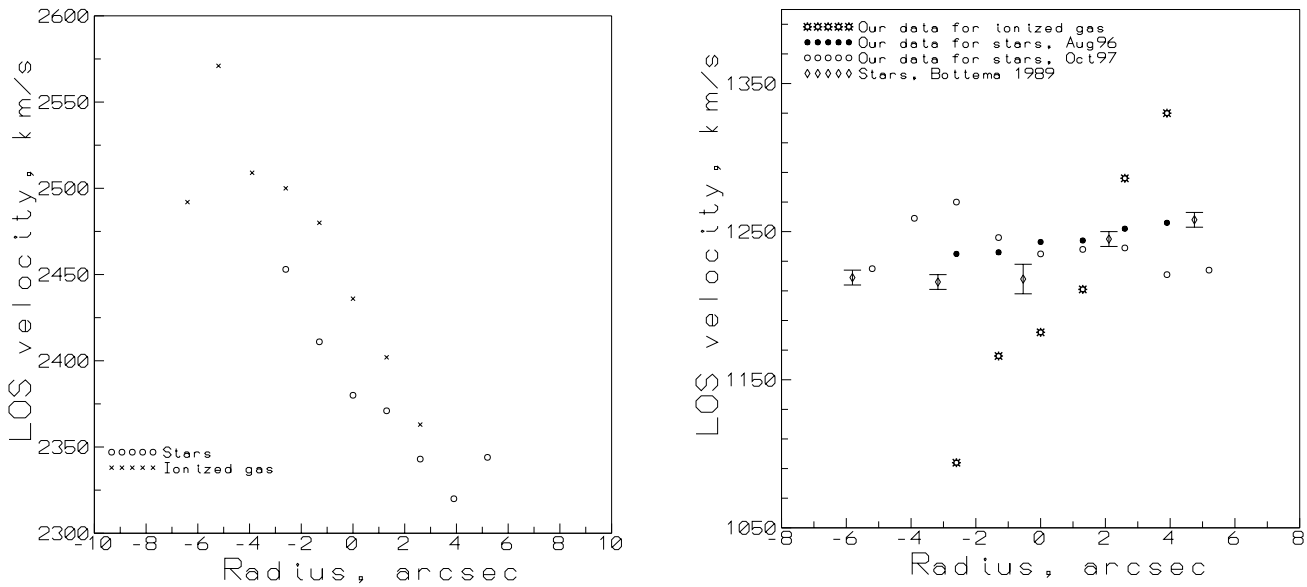

FIG. 10.—Major-axis line-of-sight velocity profiles for the stellar and gaseous components in the centers of NGC 524 (*left*), P.A.(cut) = 20°, and NGC 6340 (*right*), P.A.(cut) = 130°.

140° (Fig. 5). Bottema (1989) has chosen P.A. = 130° for his long-slit observations, and, to make comparison with his data as well, we cut the velocity fields along P.A. = 130°. The gas and stellar velocity profiles in the center of NGC 6340 look quite different (right panel of Fig. 10). The slope of the gas velocity profile, though it is not taken exactly along the dynamical major axis, is at least 5 times steeper than that for the stellar component. The central stellar velocity dispersion is low; galactic bulges with such σ_* usually rotate rapidly (Kormendy & Illingworth 1982). An explanation that can reconcile the visible kinematics of both components is that the gas and stars in the center of NGC 6340 rotate in different planes. While Bottema (1989) decided that the visible stellar rotation of NGC 6340 is quite normal for the inclination of 20°, the rotation of the ionized gas must be more related to the edge-on circumnuclear dust ring visible on the image provided by the *HST* (Fig. 6*b*). The highly elongated isophotes of the [N II] emission surface brightness distribution (right panel of Fig. 7) support this suggestion.

6. CONCLUSIONS AND DISCUSSION

Two early-type, face-on disk galaxies, NGC 524 and NGC 6340, where we previously suspected the presence of chemically decoupled nuclei, have been reinvestigated with the Multipupil Field Spectrograph of the 6 m telescope equipped with CCDs. We confirm a drop of the magnesium-line index between the nuclei and the bulges 4″–8″ from the centers in these galaxies; the ΔMgb's measured now imply metallicity differences of 0.5–0.6 dex. In NGC 524 the iron-line index Fe5270 also demonstrates a drop between the nucleus and the bulge; the magnesium overabundance, [Mg/Fe] $\approx +0.3$, is almost constant over the full radius range under consideration. In NGC 6340 the nucleus is magnesium overabundant too, but the ratio [Mg/Fe] falls to zero toward $R \approx 4''$.

The presence of chemically decoupled nuclei in the galaxies is accompanied by indications of inclined disks detected in the circumnuclear regions, though our investigation is completely confined to the bulge-dominated regions. In NGC 524 the central velocity fields of the ionized gas and stars are similar; the orientation of the dynamical major axis, P.A.$_0 \approx 20°$, coincides with the photometric major axis orientation in the radius range of 1″–5″. Though both deviate from the line of nodes (which has P.A.$_0 = 32°$–$42°$), the coincidence of the photometric and dynamical major axes proves the axisymmetric character of rotation. In a triaxial potential the photometric and dynamical major axes turn in opposite directions with respect to the line of nodes (Monnet et al. 1992). As the gaseous and stellar rotation velocities are comparable, we are probably dealing with a stellar and gaseous disk inclined with respect to the main plane of the galaxy. The rather high visible velocity variation amplitude favors larger inclination of the circumnuclear disk than is that of the global disk of the galaxy. From the geometry of the dust distribution (Veron-Cetty & Veron 1988) we would guess about $i \approx 40°$ in the center versus $i \leq 20°$ for the whole galaxy. The central disk may be extended up to $R \approx 20''$ (3 kpc), as evidenced by the dust spirals and emission-line distribution in Macchetto et al. (1996) (in the bluer passbands we also trace P.A.$_0 \approx 20°$ up to $R \approx 13''$, Fig. 4). But we see the fast, solid-body rotation only up to $R \approx 5''$, and under the assumption of $i = 40°$ the mass contained within this radius can be estimated as (7–10)10^9 $M_\odot$—a rather high value corresponding to the fast circumnuclear rotation, $\omega \approx 280$ km s^{-1} kpc^{-1}.

In the center of NGC 6340 the stellar and gaseous velocity fields differ dramatically. The lack of visible stellar rotation must be confronted with the isophote major-axis turn and the local ellipticity maximum in the radius range 1″–5″. Such a combination of morphological and kinematical properties in the center of the face-on disk galaxy may be explained by a slight bulge triaxiality, with its largest axis aligned in P.A. $\approx 85°$, whereas the line of nodes of the galaxy is close to P.A.$_0 \approx 130°$–$140°$. Interestingly, the tiny dust lane noticed by Carollo et al. (1997*b*) in their *HST* observations of NGC 6340 goes through the nucleus just in this direction. Obviously, the diffuse matter is going to settle

into one of the principal planes of the triaxial bulge; in this particular case we see a quasi-polar circumnuclear gaseous disk. The alignment of the [N II] emission isophotes (right panel of Fig. 7) and of the dynamical major axis of the gas velocity field (right panel of Fig. 8) in $P.A._0 \approx 115°$–$120°$ proves a planar character of the gas rotation, but not exactly in the principal plane of the triaxial bulge. Perhaps the circumnuclear gaseous disk is not completely stabilized yet. However the high line-of-sight velocity gradient is evidence for a rather edge-on orientation of the rotation plane.

Circumnuclear polar gaseous disks in galaxies with triaxial bulges or bars represent a rather new phenomenon, which is not yet widely known. However, several examples are found in nearby noninteracting disk galaxies. We (Sil'chenko et al. 1997) have reported on the existence of a fast rotating gaseous polar disk with a radius of ~ 200 pc in the regular Sb galaxy NGC 2841; later we proved that its bulge is triaxial (Afanasiev & Sil'chenko 1999). The orthogonal planar rotations of ionized gas and stars have also been detected by us in the center of the lenticular galaxy NGC 7280 (Afanasiev & Sil'chenko 2000); this galaxy also possesses an intermediate-scale bar. Another example of the circumnuclear polar gaseous disk is known in NGC 253 (Anantharamaiah & Goss 1996). Qualitative arguments (Sofue & Wakamatsu 1994) suggest that the existence of circumnuclear polar gaseous disks well inside triaxial stellar structures may be a result of intrinsic dynamical evolution; an accretion of external gas is not quite necessary in such a case. However, an extended stellar-and-gaseous disk with a randomly inclined rotation axis in the axisymmetric galaxy such as NGC 524 seems to require external accretion of gas (and stars?).

Another important question that we have tried to answer for some time is whether a chemically distinct nucleus (core) and a circumnuclear stellar disk are the same thing, or whether they are different substructures, though perhaps evolutionarily related? In elliptical galaxies the former variant has been discussed for several years (Surma & Bender 1995; Carollo et al. 1997a). But in some spiral galaxies we clearly resolve the circumnuclear stellar disks and simultaneously cannot resolve their chemically distinct nuclei. Perhaps, the brightest example is M31. The size of its chemically distinct entity is restricted by $R \leq 4''$, whereas the circumnuclear stellar disk extends up to $R \approx 30''$ (Sil'chenko et al. 1998). Though less convincing, because of worse spatial resolution, a similar situation appears to be present in NGC 524. The kinematically traced inclined stellar disk is seen at $R = 4''$, but the effect of the chemically distinct nucleus is already negligible at this radius. So we would prefer to separate the chemically distinct nucleus and the circumnuclear stellar disk in this galaxy. Rather, we would associate the chemically distinct nucleus in NGC 524 with its "core," which has been found from WFPC *HST* observations of the central luminosity profile (Byun et al. 1996). The radius of the photometrically distinct core in NGC 524 is $0''.3$, which cannot be resolved in our observations; but as it is detectable from photometry, it may affect the spectral characteristics of the galactic nucleus, if the stellar population of the core is different from the stellar population of the bulge. As for NGC 6340, we do not know if this galaxy has a separate circumnuclear stellar disk—not identified by its kinematics, it may be only face-on. But a photometric core detected from the *HST* data is also present in NGC 6340; its radius is $0''.5$ (Carollo & Stiavelli 1998), so we would see it as an unresolved issue.

I thank the astronomers of the Special Astrophysical Observatory, V. L. Afanasiev, S. N. Dodonov, V. V. Vlasyuk, and S. V. Drabek for supporting the observations at the 6 m telescope. I am also grateful to the postgraduate student of the Special Astrophysical Observatory A. V. Moiseev for help in preparing the manuscript. The 6 m telescope is operated under the financial support of Science Ministry of Russia (registration number 01-43). During the data analysis I have used the Lyon-Meudon Extragalactic Database (LEDA) supplied by the LEDA team at the CRAL-Observatoire de Lyon (France) and the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has made use of the La Palma Archive. The telescope JKT is operated on the island of La Palma by the Royal Greenwich Observatory in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. The work is partly based on observations made with the NASA/ESA *Hubble Space Telescope*, obtained from the data archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. The work was supported by the grant of the Russian Foundation for Basic Researches 98-02-16196, by the grant of the President of Russian Federation for young Russian doctors of sciences 98-15-96029 and by the Russian State Scientific-Technical Program Astronomy Basic Space Researches (the section Astronomy).

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