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NATURE OF NUCLEAR RINGS IN UNBARRED GALAXIES: NGC 7742 AND NGC 7217

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ABSTRACT

We have studied an unbarred Sb galaxy with a nuclear star-forming ring, NGC 7742, by means of two-dimensional spectroscopy, long-slit spectroscopy, and imaging and have compared the results with the properties of another galaxy of this type, NGC 7217, which was studied by us earlier. Both galaxies have many peculiar features in common: each has two global exponential stellar disks with different scale lengths, each possesses a circumnuclear inclined gaseous disk with a radius of 300 pc, and each has a global counterrotating subsystem, a gaseous one in NGC 7742 and a stellar one in NGC 7217. We suggest that a past minor merger is the probable cause of all these peculiarities, including the appearance of nuclear star-forming rings without global bars; the rings might be produced as resonance features by tidally induced oval distortions of the global stellar disks.

Key words: galaxies: evolution — galaxies: individual (NGC 7217, NGC 7742) — galaxies: kinematics and dynamics — galaxies: structure

1. INTRODUCTION

Nuclear rings look like prominent features due to their intense star formation and are mostly found in barred galaxies, so they are commonly treated as being linked to inner Lindblad resonances, where all radial gas inflows are slowed down and where gas is accumulated (Buta & Crocker 1993; Heller & Shlosman 1996). However, there are several cases of spectacular nuclear rings in unbarred galaxies, such as those in NGC 278, NGC 7217, NGC 7702, and NGC 7742. Most of these galaxies are seen face-on, so the conclusion about the bar absence is quite safe in them. Suggestions about the origin of nuclear rings in unbarred galaxies include resonance effects produced by a weakly triaxial potential (Jungwiert & Palous 1996; Buta et al. 1995); resonance effects produced by a past bar that is now dissolved (Athanassoula 1996); viscous gas accretion produced by rotation velocity shear in the global disk and its accumulation at a stagnation point at the turnover radius of the rotation curve (Sil'chenko & Lipunov 1987); and finally, a minor merger (Knapen et al. 2004). Among these hypotheses, the last provides more opportunities to explain various combinations of observational facts. Indeed, Athanassoula et al. (1997) have shown that the vertical central impact of a small satellite whose mass is about 10% of the host mass should produce a nuclear stellar ring that is morphologically indistinguishable from a resonance ring. On the other hand, if the merged satellite orbit was close to the main galaxy disk plane, their gravitational interaction might produce an oval disk distortion that could in its turn create a resonance nuclear ring. However, certain combinations of predictions are provided by each theoretical model, and by collecting more various observational data, both morphological and kinematical, for every galaxy in question, we should be able at last to restrict the possible mechanisms of nuclear ring generation in any particular case.

In this paper we consider NGC 7742 and NGC 7217; both galaxies have prominent nuclear star formation rings with radii of some 10″. We attempt to find any general features that may be connected to the nuclear ring origin. As for the latter galaxy, we are now undertaking our third approach to its study. Earlier we found a circumnuclear gas polar ring and two exponential stellar disks with different scale lengths (Zasov & Sil'chenko 1997; Sil'chenko & Afanasiev 2000). Also, NGC 7217 is known to possess two counterrotating stellar subsystems (Merrifield & Kuijken 1994; Sil'chenko & Afanasiev 2000). Recently, the SAURON team has also found a gas-stars counterrotation in the center of NGC 7742 (de Zeeuw et al. 2002), so this fact may lead to interesting speculations. Both galaxies are moderate-luminosity unbarred spirals of Sb type.

2. OBSERVATIONS AND DATA USED

The new observational data that we intend to analyze in this work mainly concern NGC 7742: panoramic spectral data for NGC 7742 have been obtained with the scanning Fabry-Pérot Interferometer (IFP) of the 6 m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) and with two integral-field spectrographs: the fiber-lens Multi-Pupil Fiber Spectrograph (MPFS) at the 6 m telescope of the SAO RAS and the international Tigre-mode SAURON at the 4.2 m William Herschel Telescope (WHT) at La Palma (see Table 1). Our two-dimensional spectroscopic data for NGC 7217 have been described in detail earlier: the Fabry-Pérot data by Zasov & Sil'chenko (1997) and the MPFS data by Sil'chenko & Afanasiev (2000).

2.1. *Two-dimensional Spectroscopy with the MPFS*

The present modification of the MPFS of the 6 m telescope has been at the prime focus since the summer of 1998 (Afanasiev et al. 2001).[2] NGC 7742 was observed with the MPFS several times during 2001–2003. MPFS is a fiber-lens system; densely packed square microlenses placed in the focal plane of the

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[2] See also http://www.sao.ru/hq/lsfvo/devices/mpfs/mpfs_main.html.

TABLE 1
Integral-Field Spectroscopy of the Galaxies Studied

Date	Galaxy	Exposure (minutes)	Configuration	Field (arcsec)	Spectral Range (Å)	Seeing (arcsec)
1999 Oct 14	NGC 7217, Pos. 1	120	WHT SAURON + CCD 2k × 4k	33 × 41	4800–5400	1.4
1999 Oct 14	NGC 7217, Pos. 2	120	WHT SAURON + CCD 2k × 4k	33 × 41	4800–5400	1.4
1999 Oct 13	NGC 7742	120	WHT SAURON + CCD 2k × 4k	33 × 41	4800–5400	1.1
2001 Sep 22	NGC 7742	45	6 m MPFS + CCD 1024 × 1024	16 × 15	4200–5600	2.1
2003 Oct 2	NGC 7742	20	6 m MPFS + CCD 2048 × 2048	16 × 16	5800–7200	2.0

telescope create a set of 16 × 15 micropupils, or 16 × 16 in 2003, and the fibers after them transmit the light from the square elements of the galaxy image to the slit of the spectrograph, together with 16 (17) additional fibers that transmit the sky background light taken at a distance of 4′ from the galaxy, so the sky spectra are obtained together with those of the target. The size of one spatial element is approximately 1″ × 1″; a CCD TK 1024 × 1024 and, during the latest run of 2003 October, a CCD EEV 42-40 2048 × 2048 were used. The spectral resolution was about 4 Å, varying by about 20% over the field of view. The wavelength calibration was done with a He-Ne-Ar lamp before and after the galaxy exposures; the internal accuracy of linearization was typically 0.25 Å in the green and 0.1 Å in the red. We also checked the accuracy of the wavelength calibration and for the absence of a systematic velocity shift by measuring strong emission lines of the night sky, [O i] λ5577 and [O i] λ6300. We obtained the MPFS data in two spectral ranges, green (4300–5600 Å) and red (5900–7200 Å). The green spectra were used to obtain the line-of-sight velocity field for the stellar component and a map of the stellar velocity dispersion by their cross-correlation with spectra of some template stars, usually of G8 III–K1 III spectral type. The red spectral range, which contains strong emission lines in Hα and [N ii] λ6583, is appropriate for deriving line-of-sight velocity fields of the ionized gas.

2.2. *Two-dimensional Spectroscopy with SAURON*

The other two-dimensional spectrograph whose data we use is a rather new instrument, SAURON, installed at the 4.2 m WHT on La Palma; for its detailed description see Bacon et al. (2001), and for some preliminary scientific results see de Zeeuw et al. (2002). We have taken the data for both our galaxies, NGC 7217 and NGC 7742 observed in 1999 October, from the open ING Archive of the UK Astronomy Data Centre. To give a brief description, the field of view of this instrument is 41″ × 33″ with a spatial element size of 0.″94 × 0.″94. The sky background is taken less than 2′ from the center of the galaxy and is exposed simultaneously with the target. The spectral range is fixed at 4800–5400 Å, and the spectral resolution is about 4 Å, also varying over the field of view. The comparison spectrum is that of pure neon, and to make the linearization we fitted a polynomial of second order with an accuracy of 0.07 Å.

2.3. *Two-dimensional Spectroscopy with the IFP*

In 2003 November NGC 7742 was observed with the scanning IFP of the 6 m telescope installed at the prime focus within the focal reducer SCORPIO (Afanasiev & Moiseev 2005).[3] The total number of 32 spectral channels were exposed, each for 3 minutes, providing a spectral resolution of 2.5 Å. The seeing was 1.″7–2.″1, the spatial binning used was 0.″7 pixel^{-1}, and the full field of view obtained was 6′ × 6′. The narrow filter centered on the spectral region around redshifted Hα and [N ii] λ6583 emission lines was used. The velocity field of the ionized gas obtained by measuring the Hα is more precise and extended, whereas the measurements of [N ii] allow us to probe the very center of the galaxy, where the Hα emission is strongly contaminated by the absorption line.

As we discuss below, both velocity fields consistently give the orientation parameters of the gas disk: the kinematical major axis, or the line of nodes, at a position angle P.A. = 128° and an inclination $i = 9°$.

2.4. *Long-Slit Spectroscopy of NGC 7742*

To supplement our two-dimensional spectroscopy with additional data, we have retrieved some long-slit data for NGC 7742 from the ING Archive: the galaxy was observed in 1997 November with the two-armed ISIS spectrograph of the 4.2 m WHT. However, the quality of these data seems to be insufficient: evidently, the spectral focus was not checked properly, and the spectral resolution was bad. So we have only the measured barycenters of the most prominent emission lines in the long-slit cross section of P.A. = 160° to determine the line-of-sight velocities of the ionized gas near the center of the galaxy; neither gas velocity dispersion nor stellar kinematics are probed. The direction of the slit, P.A. = 160°, is not very close to the kinematical major axis of the gas. So to obtain more conclusive data, in 2004 November we observed NGC 7742 at the 6 m telescope with the focal reducer SCORPIO in the long-slit mode with a large spectral range of 5700–7200 Å and a spectral resolution of about 5 Å. The seeing was about 1.″5. The slit of 1″ width was aligned with the kinematical major axis at P.A. = 128°. Here we analyzed both the emission lines and the absorption line of Na i D to probe the kinematics of the stellar component. The K giants HD 4744 and 20893 were observed in the same night at the same mode; their spectra were used for cross-correlation with the spectra of the galaxy.

2.5. *Imaging Data*

The same night, on 2004 November 5, we obtained a rather deep *V*-filter image of NGC 7742 over 240 s with the focal reducer SCORPIO in the imaging mode (the pixel scale was 0.″36, and the seeing was 1.″7). In addition, we have retrieved large-scale *B*- and *I*-filter images for this galaxy from the ING Archive (the images were obtained with the 1 m Jacobus Kapteyn Telescope, the scale was 0.″33 pixel^{-1}, and the seeing was 1″), as well as small-scale *Hubble Space Telescope* (*HST*) NICMOS2 images (with a scale of 0.″075 and a spatial resolution of 0.″2) and *HST* WFPC2 images (with a scale of 0.″1 and a spatial resolution of 0.″2) from the *HST* archive. To check the large-scale structure of the galaxies in the near-IR, we have used Two Micron All Sky Survey images taken from the NASA/IPAC Extragalactic Database.

The data have been mostly analyzed using the software produced by V. V. Vlasyuk of the SAO (Vlasyuk 1993); only primary reduction of the data obtained with the MPFS and SCORPIO

[3] See also http://www.sao.ru/hq/moisav/scorpio/scorpio.html.

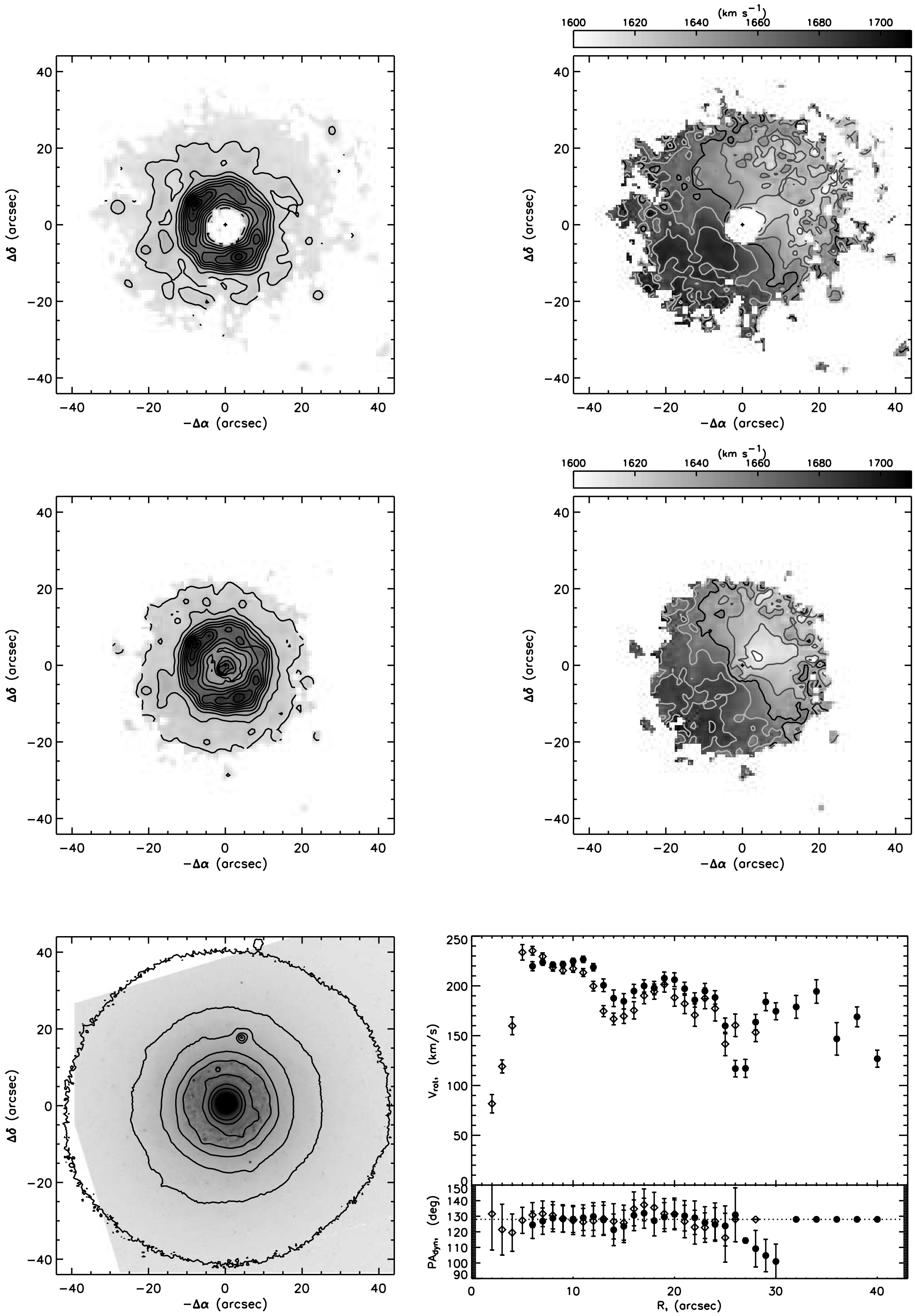

FIG. 1.—Large-scale emission-line intensity distributions and ionized-gas velocity fields for NGC 7742 according to our IFP data for Hα (*top panels*) and [N II] λ6583 (*middle panels*). The bottom panels contain the continuum image, gray-scale *HST* F675W map with the broadband SCORPIO *V* isophotes superposed (*left*) and the results of the tilted-ring analysis of the Hα (*filled circles*) and [N II] (*open diamonds*) velocity fields (*right*; see the text).

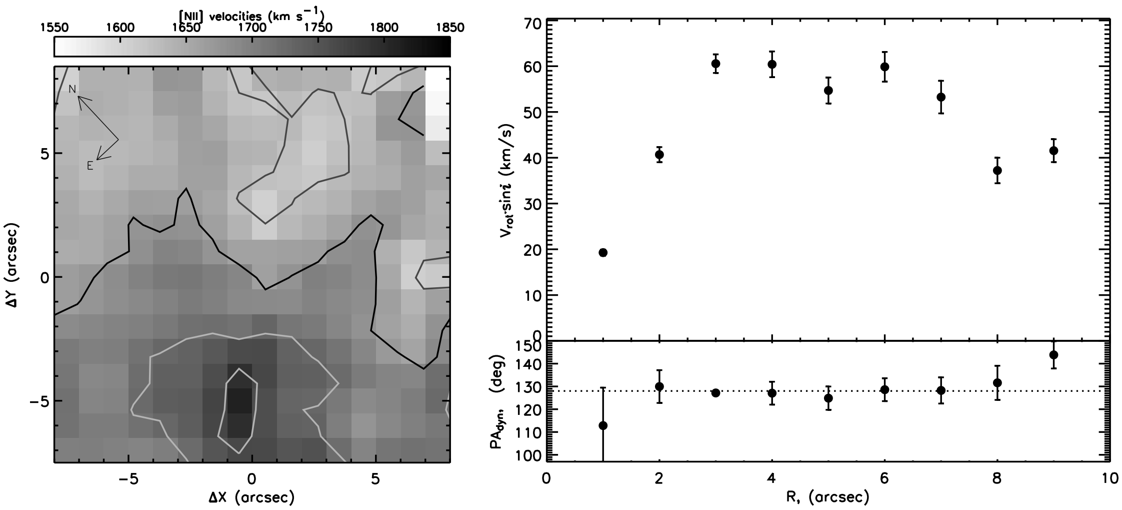

FIG. 2.—Small-scale [N II] λ6583 velocity field of NGC 7742 according to our MPFS data (*left*) and the results of its analysis (*right*). The inclination for the innermost part of the gaseous disk cannot be determined properly.

(images and long-slit) was done in IDL with various pieces of software created by one of us (A. V. M.) and by V. L. Afanasiev. The *V*-filter image of NGC 7742 obtained with the reducer SCORPIO has been calibrated into the standard Johnson system by using the single photoelectric aperture measurement by Keel & Weedman (1978). The data observed with the IFP were reduced with the IDL-based software described by Moiseev (2002). Also, the ADHOC package[4] was used to smooth the "data cubes." The monochromatic images and velocity fields of the emission lines Hα and [N II] λ6583 were constructed by means of fitting the IFP spectra with Gaussians. We analyzed two kinds of data: one with the original spatial resolution (2.″2) and the other smoothed by a Gaussian filter with an FWHM of 2×2 elements (the spatial resolution of 2.″7). The results are mainly the same, but the last data are better for the low-brightness regions.

3. STELLAR AND GASEOUS KINEMATICS OF NGC 7742

De Zeeuw et al. (2002), having presented the SAURON two-dimensional velocity fields both for stars and for the ionized gas in NGC 7742, the latter obtained from their sophisticated measurement of the weak [O III] λ5007 emission line, have claimed an appearance of strict counterrotation of the stars versus the gas. However, they have shown only the very central parts of the velocity fields within the nuclear ring ($R \approx 10''$), so it has remained unclear whether we deal with a global counterrotation or with a compact circumnuclear counterrotating gaseous disk. Figure 1 presents our large-scale Fabry-Pérot observations of NGC 7742 in the Hα and [N II] emission lines. In the upper two rows we give the distributions of the emission-line intensities (*left panels*) and the velocity fields (*right panels*), and the bottom right plot presents the results of the velocity field analysis made by a tilted-ring method (Begeman 1989). One can see that despite the face-on view of the galactic disk, the line-of-sight velocity field of the ionized gas demonstrates a quite regular rotation up to the border of the noticeable Hα emission at $R = 30''-40''$, with a visible amplitude of line-of-sight velocity variations of about 40 km s^{-1}. By fixing the kinematic center position to coincide reasonably well with the photometric center, and also the systemic velocity, and by assuming the same orientation angles, line of nodes position angle P.A.$_0$, and inclination i for the whole gaseous disk, we obtain rather sure estimates of the disk orientation parameters:

[4] The ADHOC software is written by J. Boulesteix (Observatoire de Marseille). See http://www-obs.cnrs-mrs.fr/ADHOC/adhoc.html.

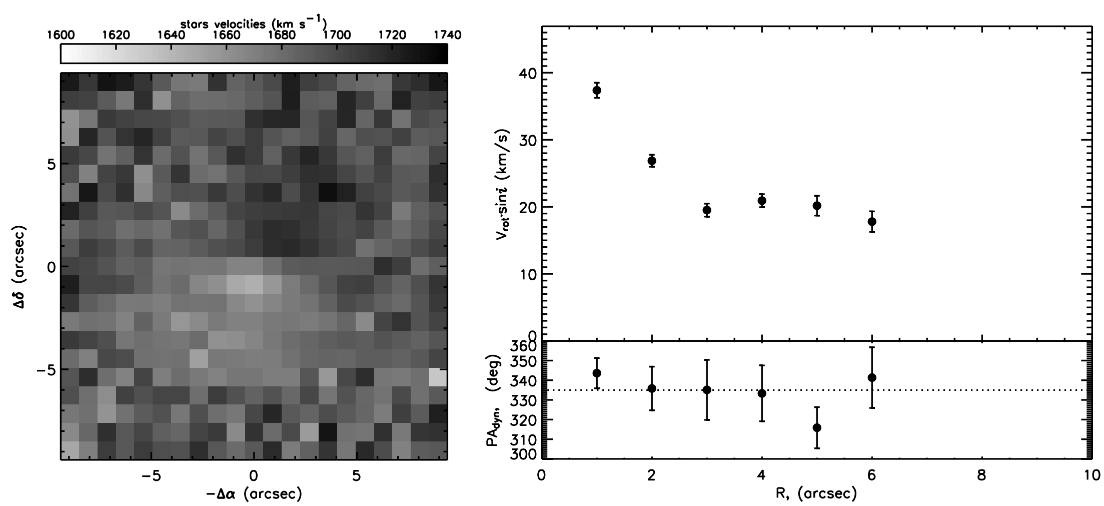

FIG. 3.—Small-scale stellar velocity field of NGC 7742 according to the SAURON data (*left*) and the results of its analysis as concerning the azimuthally averaged projected rotation and the kinematical major axis orientation (*right*). The inclination has not been determined for the stellar rotation plane.

$i = 9° \pm 4°$ and $\mathrm{P.A.}_{0,\mathrm{kin,gas}} = 128° \pm 1°$. With these parameters of the disk orientation, the azimuthally averaged circular rotation velocity can be estimated as 220–230 km s^{-1} within the nuclear ring radius, $R \leq 10''$; outside it decreases smoothly to ~150 km s^{-1} at $R \approx 40''$. At the outer edge of the nuclear disk we note a drop of the rotation velocity by ~30 km s^{-1}; another drop, more prominent in the Hα velocity field than in the [N II] velocity field, can be detected at radii of $25''$–$28''$. As we show below, the latter radius is also distinguished photometrically. So we can conclude that the sense of the gas rotation (which is opposite to the star rotation in the center) remains unchanged up to large radii. We can even expand the spatial range over which the conclusion is valid beyond the borders of the Hα emission. Knapp et al. (1978) measured an emission line of neutral hydrogen at 21 cm in several positions near NGC 7742. Although their spacing and half-beam resolution was rather rough, about $2'$, they detected a noticeable rotation "in an east-west direction," with the eastern side of the H I disk receding. So we conclude that NGC 7742 possesses a large gaseous disk that rotates regularly so that its eastern side is receding; the line of nodes of this disk is at P.A. = 128°, and the inclination can be determined kinematically as $i \approx 9°$.

Figure 2 presents the circumnuclear velocity field of the ionized gas that we have obtained with the MPFS by measuring the strongest emission line of this region, [N II] λ6583. These data complement the large-scale gas velocity field obtained with the IFP. Over this velocity field as well, we see a regular rotation, with a visible amplitude of the line-of-sight velocity variations of ±60 km s^{-1}, and its kinematical major axis at radii larger than $2''$ can be determined quite certainly as $\mathrm{P.A.}_0 = 128°$, being completely consistent with the line of nodes of the global gaseous disk. However, if we apply the inclination of 9° found for the global gas disk to the circumnuclear velocity field, we obtain a formal value of the circular rotation velocity of 400 km s^{-1} at $R \approx 3''$. This seems improbable for a galaxy of such moderate luminosity, inconsistent with the Tully-Fisher relation; moreover, the central stellar velocity dispersion in NGC 7742 estimated by us with both the MPFS and the SAURON data is less than 80 km s^{-1}, so there are no signs of a huge mass concentration in the nucleus of this galaxy. We should rather conclude that an inclination of 9° is not valid for the very central part of the gaseous disk, $R < 4''$, and that the disk begins to warp when approaching the nucleus. The SAURON data were obtained under better seeing conditions than ours, and in the recently delivered doctoral thesis of Fathi (2004), the gas velocity field of NGC 7742 reveals a turn of its kinematical major axis by 90° at $R < 2''$. The comment of Fathi is that we see radial gas motions. But if the gaseous disk were nearly face-on around the nucleus, we would not see any noticeable projection of radial velocities confined within the disk onto the line of sight. Indeed, if we accept the inclination of 9° obtained for the whole gaseous disk for the very center of NGC 7742, Fathi's results would imply an amplitude of the possible radial motions exceeding twice the rotation velocities, namely, of ±~400 km s^{-1}. We do not see any reason to suspect such supersonic radial gas flows in a morphologically regular galaxy with the nuclear activity of a rather weak LINER/transition type. More likely, we see here an inclined circumnuclear disk similar to those found in some spiral galaxies, and in particular in NGC 7217 (Zasov & Sil'chenko 1997; Sil'chenko & Afanasiev 2000).

As for the stellar rotation, it does not seem to be as fast as that of the gas and is mostly confined to the very inner, $R < 3''$, region of the galaxy. Since the seeing conditions during our MPFS observations of NGC 7742 were not good enough to resolve this small region properly, the measured amplitude of the stellar line-of-sight velocity variations is dropped due to spatial smoothing, and the orientation of the kinematical major axis cannot be determined properly from our data. In Figure 3 we show our analysis of the SAURON velocity field for the stars in the center of NGC 7742. We have obtained $\mathrm{P.A.}_{0,\mathrm{kin},*} = 335°$ for the stellar component within $R = 6''$, in some disagreement with the $\mathrm{P.A.}_{0,*} = 320°$ found by Fathi; however, the possible error may be as large as 10°. If again we formally fix the inclination of the rotation plane of the stars at the value obtained for the outer gaseous disk, $i = 9°$, the peak rotation velocity achieved at $R = 1''$ would be $v_{\mathrm{rot}} \approx 250$ km s^{-1}. Farther from the nucleus it drops to zero at the radius of the ring, and beyond the ring it rises marginally. Due to low signal-to-noise ratio, we are not sure of our results at $R > 10''$, and to check whether the stars continue to counterrotate with the gas outside the ring radius, we appeal to the long-slit data.

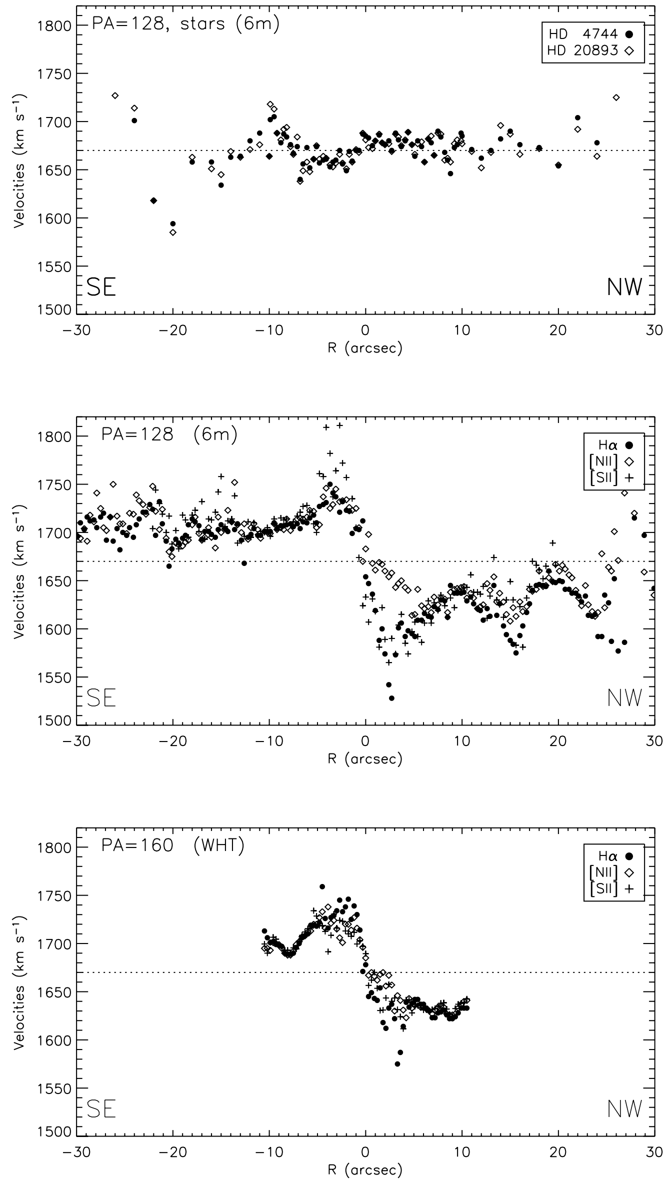

Fig. 4.—Long-slit velocity measurements for NGC 7742. *Top*: Stellar line-of-sight velocities according to the SCORPIO data, with two giant stars of different spectral types used as templates for cross-correlation. *Middle*: Ionized-gas line-of-sight velocities from the measurements of the various emission lines according to the SCORPIO data. *Bottom*: Ionized-gas line-of-sight velocities according to the WHT ISIS data.

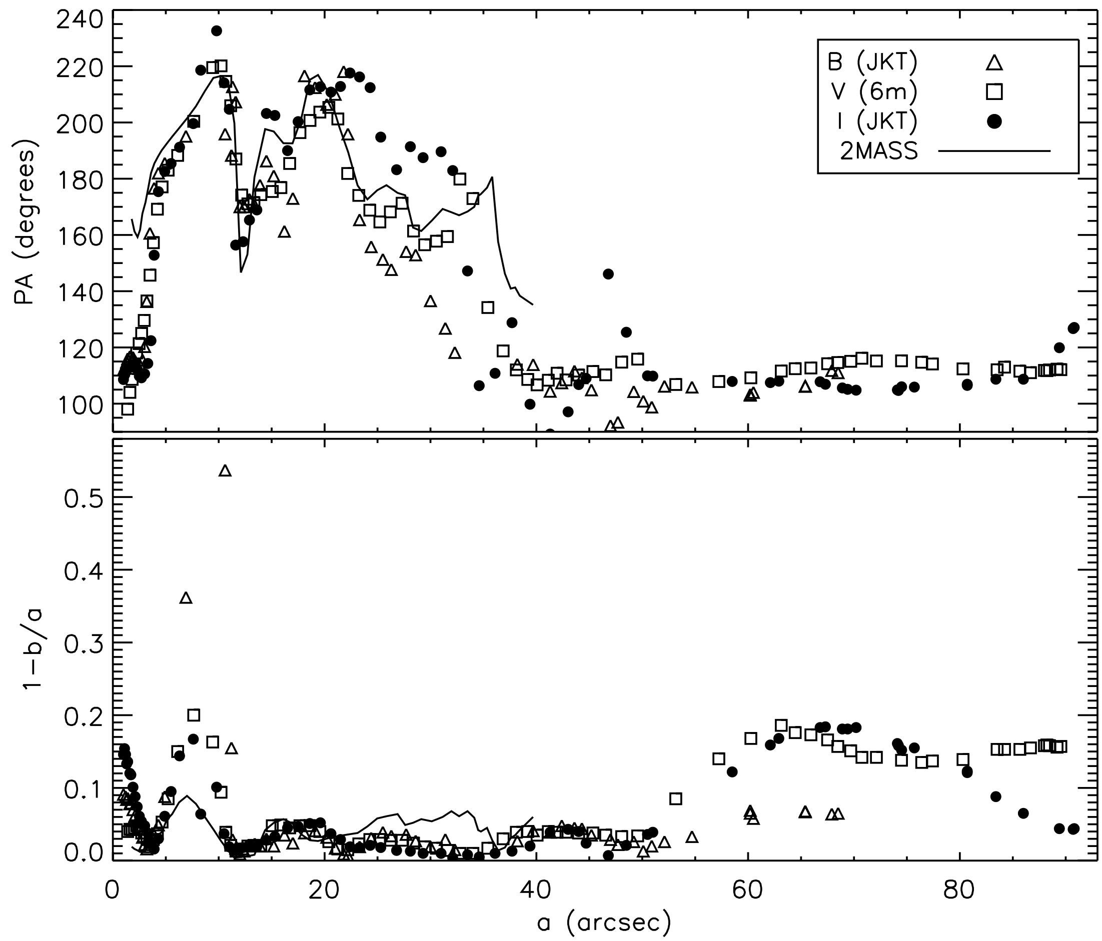

Fig. 5.—Results of the isophote analysis of the various broadband images of NGC 7742.

Figure 4 presents long-slit velocity profiles for the stars and ionized gas: SCORPIO data along the kinematical major axis P.A. $= 128°$ and WHT ISIS data at P.A. $= 160°$. Because of the low surface brightness of NGC 7742 at $R > 10''$, the measurements of the stellar velocities (Fig. 4, *top*) are not very extended and are not very precise; however, some qualitative conclusions can be made. The sense of rotation of the stellar component observed in the center persists up to $R \approx 25''$ at least; but at $R \approx 10''$—the radius of the ring—we see strong stellar velocity variations, such that the line-of-sight velocities of the stars at this radius coincide exactly with those of the ionized gas. We suggest that violent star formation in the ring has already produced a substantial stellar population, including stars of F-G-K type, so that their rotation coupled with their parent gas contributes significantly to the integrated line-of-sight velocity distribution of the stars at this radius.

The long-slit gas velocity profiles (Fig. 4, *middle, bottom*) demonstrate different characters with respect to the rather smooth rotation curve obtained by azimuthal averaging of the two-dimensional IFP gas velocity field (Fig. 1). They "oscillate" by 70–80 km s^{-1}, with a characteristic radial period of $\sim 10''$, and the locations of the velocity maxima and minima differ at P.A. $=$ 128° and 160°. We think that these velocity variations do not relate to regular rotation; they resemble the vertical small-scale oscillations of a tidally perturbed gaseous disk.

However, another peculiarity of the long-slit gas velocity profiles that we have expected based on our two-dimensional MPFS data is the very steep central velocity gradient and the decoupled fast gas rotation within $R = 3''$; it is confirmed by both the SCORPIO and ISIS data. Moreover, the [N II] emission-line measurements at the approaching branch of the velocity profile even give underestimated values of the rotation velocity; they deviate toward the systemic velocity not only with respect to the Hα measurements, which may be affected by underlying absorption lines, but also with respect to the [S II] emission-line measurements. Similar differences between velocity estimates made with different emission lines had been detected more than once in the centers of other spiral galaxies (Afanasiev & Shapovalova 1981; Afanasiev et al. 1988) and might be explained if the Hα and [S II] emission lines relate to regularly rotating gas ionized by OB stars and the [N II] emission lines are formed mostly in shock-wave sites where the ionized gas decelerates. Enormous visible rotation of the ionized gas within $R = 3''$ revealed by the long-slit data gives strong evidence for the highly inclined orientation of the gas rotation plane in the very center of NGC 7742 ($i_{\rm gas} > 35°$), as opposed to the nearly face-on orientation of the global gaseous disk.

4. GLOBAL STRUCTURE OF NGC 7742

The morphological type of NGC 7742 is SA(r)b, and taking into account the face-on orientation of the global disk, the galaxy looks indeed quite round and axisymmetric, except for the very central part (Fig. 1). However, the rather early morphological type Sb, perhaps deduced from the appearance of tightly wound, faint, spiral arms, is not supported by the very low stellar velocity dispersion in the center, ≤ 80 km s^{-1}, implying the absence of a large bulge, which is obliged to be a dynamically hot stellar subsystem by definition.

The *V*-band image obtained with SCORPIO appears to be very deep: our surface brightness measurements reach a radius almost twice that of the 25th *B* magnitude. Figure 5 presents the results of an isophotal analysis of this image, together with the measurements of the *I*-band image taken from the ING Archive, which is almost similarly deep. The ellipticity behavior reveals a central rise and a peak near the position of the nuclear ring; the isophotes in the radius range of $12''$–$50''$ (please note that $R_{25} = 52''$) are indeed round. However, the most interesting things are seen at $R > R_{25}$: the ellipticity rises to a mean value of 0.15, and the major axis position angle can be measured quite certainly at $\langle \mathrm{P.A.}_0 \rangle = 112°$. We cannot be sure that we see a round outer stellar disk inclined by $\sim 30°$ to the line of sight because the kinematical parameters of the orientation of the more inner *gaseous* disk, $\mathrm{P.A.}_0 = 128°$ and $i = 9°$, do not coincide with the photometric parameters found for the outermost part of the broadband image; a hypothesis that may be more plausible is that the outer disk is intrinsically oval. Unfortunately, we have no detailed kinematical measurements at such large radii.

We have tried to decompose the whole *V*-filter image into separate photometric subcomponents, such as an outer exponential disk and some more inner components. Two methods were applied: the software GIDRA (Ciroi et al. 2005), which uses two-dimensional surface brightness modeling under constant orientation parameters over all the image, and iterative one-dimensional brightness profile fitting starting from the outermost component with subsequent subtraction of the two-dimensional model components from the original image. The latter method allows us to vary orientation parameters from one component to another according to isophote analysis results when calculating the azimuthally averaged brightness profile at every step of decomposition. The GIDRA analysis of the *V*-filter image under the fixed kinematical parameters of the orientation, P.A. (line of nodes) $= 128°$ and $i = 9°$, with an approximation of the seeing FWHM by $1\farcs7$, gives *two* exponential disks superposed, with scale lengths of $17\farcs6$ and $7\farcs2$ and central surface brightnesses, $\mu_{0,V}$, of 20.6 and 18.2 mag arcsec^{-2}, respectively. The third photometric component, seen only in the very center, may be a de Vaucouleurs bulge with $r_e = 4\farcs2$. One-dimensional brightness profile fitting made with $\mathrm{P.A.}_0 = 112°$ and with an isophote axis ratio of $b/a = 0.85$ for the outer component and with $\mathrm{P.A.}_0 = 13°$ and $b/a = 0.93$ for the inner components also gives two exponential disks: the outermost one approximately in the radius range of $50''$–$93''$ has $\mu_{0,V} = 21.04$ and $r_0 = 20''$, and the inner one, seen in the radius range of $15''$–$42''$ after subtracting the outer disk, has $\mu_{0,V} = 18.45$ and $r_0 = 7\farcs2$ (see Fig. 6). The most central component left after subtraction of two exponential disks gives a noticeable contribution only inside $R \approx 5''$, and since it is affected by spatial resolution effects we cannot definitely determine the shape of its profile: it may be exponential, as well as something else. However, both our fitting methods certainly indicate the presence of two exponential disks with different scale lengths. We would like to stress that it is the outer disk that is "normal": its $\mu_{0,V}$, 21 *V* mag arcsec^{-2}, is very close to the canonical Freeman's value (Freeman 1970), and the relation between its central surface brightness and its scale length in kiloparsecs is typical for an Sb galaxy (de Jong 1996). The inner disk is more compact and has higher surface brightness than spiral galaxies usually have, although not as compact and bright as circumnuclear disks of early-type galaxies; in the μ_0-h diagram published by Reshetnikov (2000), it settles among the large disks of lenticular galaxies. However, the spiral arms and noticeable star formation (Hα emission) in NGC 7742 are confined just to this inner disk.

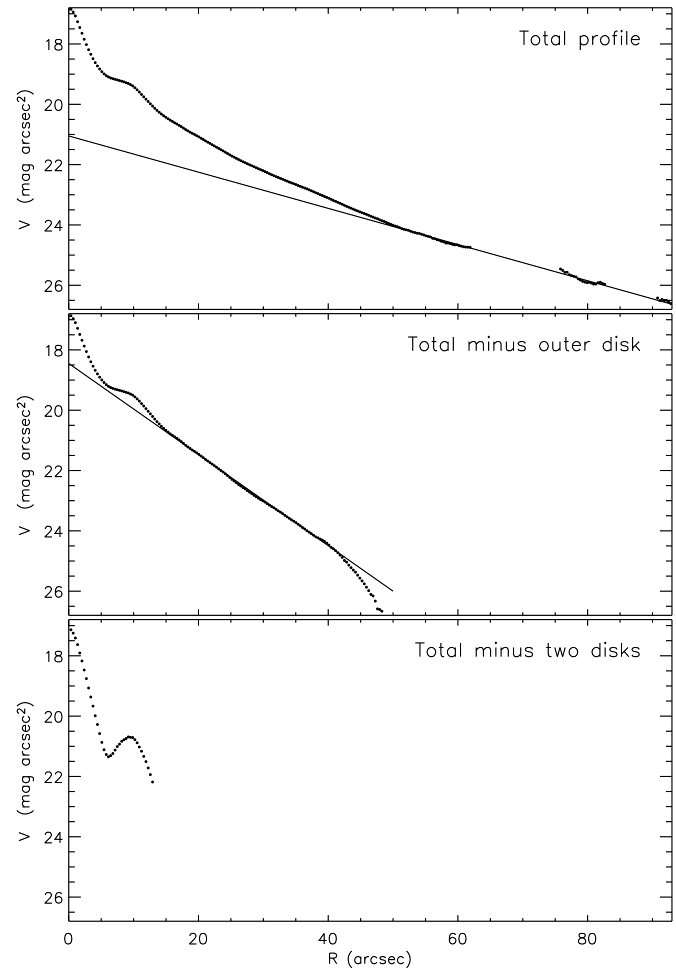

FIG. 6.—Results of decomposition of the azimuthally averaged surface brightness profile calculated from the deep *V*-band image (SCORPIO) of NGC 7742 into two exponential disks and one central bulge.

Interestingly, NGC 7217—another galaxy with rings and without a bar—has very similar structure. We have decomposed its brightness profile in our work (Sil'chenko & Afanasiev 2000) and have found two exponential disks, the outermost disk being the "normal" one, together with a compact exponential bulge. We compare the structural characteristics of the components for both galaxies in Table 2. The scale lengths are very close: 2–3 kpc for the outer disks and $\sim$1 kpc for the inner disks. The visible shapes of the outer and inner disks are different in both galaxies. However, in comparing the derived photometric characteristics of the disks with the orientation parameters estimated from the global gas kinematics, we conclude that in NGC 7217 the outer disk is round and the inner disk is inclined or is oval (a destroyed bar?), whereas in NGC 7742 the configuration is opposite: the inner disk is round and the outer one is oval, which perhaps is due to an external tidal perturbation.

Recently, Knapen et al. (2004) have studied another unbarred ringed galaxy, NGC 278, which has a morphological type close to that of NGC 7217 and NGC 7742, SAB(rs)b. Their graphic presentation of the surface brightness profile of NGC 278 allows us to suggest the same multitiered structure of the global stellar disk as we found in NGC 7217 and NGC 7742. All the present star formation in NGC 278 is confined to the inner disk, within a radius of 1.1 kpc, as well as in NGC 7742.

Some words about the central component of NGC 7742 must be added. Its rather high visible ellipticity was noted earlier, e.g.,

TABLE 2
Exponential Parameters of the Brightness Profiles Fitting

Disk	Radius Range of Fitting (arcsec)	Radius Range of Fitting (kpc)	P.A.$_0$ (deg)	b/a	r_0 (arcsec)	r_0 (kpc)
		NGC 7217				
Outer	60–110	5–9	90	0.82	35.8	2.9
Inner	20–50	1.6–4	...	0.92	12.5	1.0
Central bulge	5–20	0.4–1.6	82	0.88	3.9	0.3
		NGC 7742				
Outer	50–93	6–11	112	0.85	20	2.34
Inner	15–42	1.8–4.9	...	0.93	7.2	0.8
Central (bulge?)	1–5	0.1–0.6	...	0.93	1.3	0.15

by Wakamatsu et al. (1996) and by Wozniak et al. (1995); the former authors mentioned the turn of the isophote major axis from $110^\circ \pm 10^\circ$ to $10^\circ \pm 10^\circ$ between $r = 1\farcs5$ and $5\farcs1$. We confirm this result and point out that the rather high ellipticity of the isophotes at some distinct radii, namely, at $r \approx 1''$ and $7''$ (Fig. 5), makes the estimate of the major axis turn quite good. Might any one of these elongated structures be a bar or a compact triaxial bulge? If such triaxiality exists in the center of NGC 7742, it would cause a Z-shaped disturbance of the gas velocity field; as we have seen in § 3, the orientation of the kinematical major axis of the gas rotation, $\mathrm{P.A.}_{\mathrm{kin,gas}} = 128^\circ$, stays firmly between $r = 2''$ and $40''$. So we do not see any signatures of a triaxial potential in the center of NGC 7742. Instead, we suggest a strong warp of the rotation and symmetry planes in the center of the galaxy: immediately inside $R \approx 5''$ the gas rotation plane conserves the line of nodes of the outer gaseous disk but probably increases its inclination, which can be deduced from the visible fast rotation, and closer to the center, at $R < 1\farcs5$, the kinematical major axis of the gas "switches" to the "orthogonal" orientation (Fathi 2004).

5. THE STELLAR KINEMATICS AND STRUCTURE OF NGC 7217

As we have noted above, two galaxies with rings and without bars, NGC 7217 and NGC 7742, have very similar global structures. As for the fine features in their centers, in this work we suggest a strong warp of the rotation plane both for the stars and for the ionized gas in the center of NGC 7742. In NGC 7217, which is slightly less face-on, we have found a circumnuclear polar gaseous ring with a radius of $3''$–$4''$ (Sil'chenko & Afanasiev 2000). As for the stellar kinematics in the center of NGC 7217, from our MPFS observations, with our spatial resolution of $\sim 2''$ we have not found any deviations from an axisymmetric rotation around the main symmetry axis of the galaxy at $R \geq 2''$. However, the surface distribution of the stellar velocity dispersion in the center of NGC 7217 looks very strange, with an off-center minimum, and we (Sil'chenko & Afanasiev 2000) were not able to give a reasonable explanation for it.

Now we have in hand the two-dimensional spectral data for NGC 7217 obtained with SAURON; these data provide a larger field of view and a slightly better spatial resolution than the MPFS data, so now we can expand our previous analysis of the kinematics of the central part in this galaxy. By applying a tilted-ring method to the whole stellar velocity field (Fig. 7, *right*) representing a combination of two different pointings of the telescope, outside $R = 3''$ we obtain the mean parameters of the rotation plane orientation, $\mathrm{P.A.}_{0,\mathrm{kin},*} = 268^\circ \pm 2^\circ$ and $i = 30^\circ \pm 4^\circ$, very stable along the radius and consistent with axisymmetric rotation in the main galactic plane. The velocity field of the ionized gas

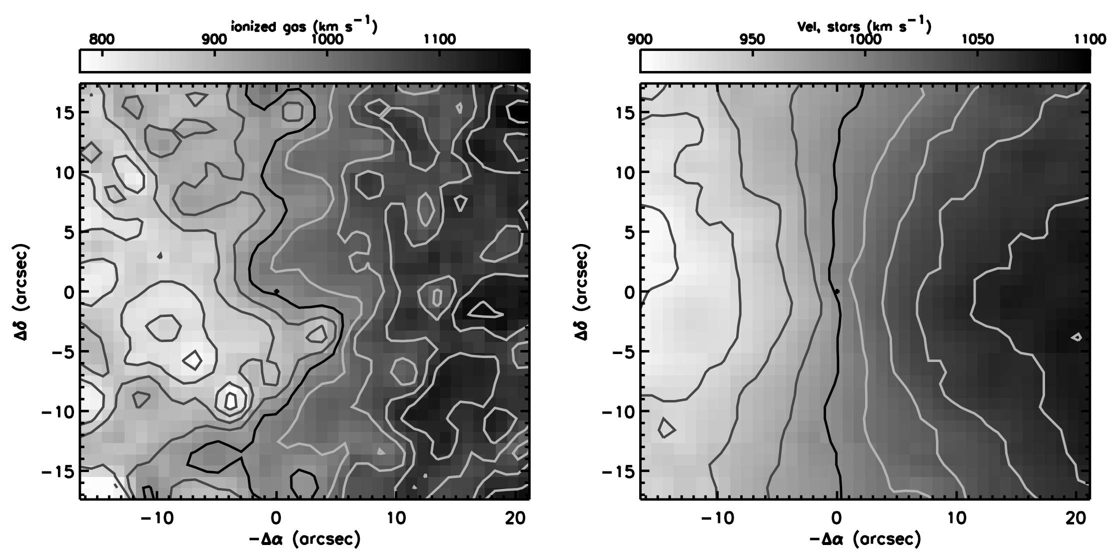

Fig. 7.—NGC 7217 line-of-sight velocity fields for the ionized gas (*left*) and for the stars (*right*) according to the SAURON data. The maps represent a combination of two different pointings of the WHT. The isovelocities at the systemic velocity value are enhanced by black color.

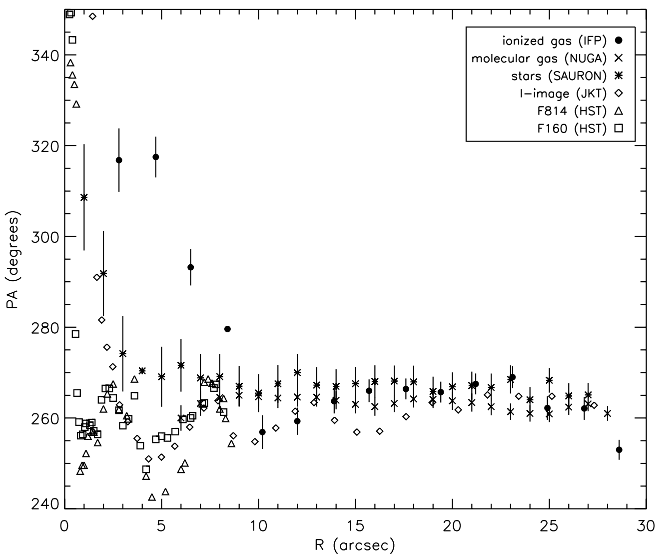

FIG. 8.— Comparison of the photometric (*HST* and Jacobus Kapteyn Telescope) and kinematical major axis orientations in NGC 7217.

(Fig. 7, *left*) obtained by measuring the emission line [O III] λ5007, strong in the center of NGC 7217, confirms the orientation of the kinematical major axis for the ionized gas found by us earlier (Sil'chenko & Afanasiev 2000): $\mathrm{P.A.}_{0,\mathrm{kin,gas}} = 329° \pm 4°$ at $R = 1''–4''$. The angular rotation velocity is rather high, $\omega \sin i_{\mathrm{gas}} \approx 29$ km s^{-1} arcsec^{-1}, compared to the stellar rotation velocity at the same radius, $\omega \sin i_* \approx 14.5$ km s^{-1} arcsec^{-1}, and taking into account that $\sin i_* = 0.5$, it implies the presence of a circumnuclear edge-on gaseous disk. The higher spatial resolution of the SAURON data with respect to the previous MPFS data allows us to observe a turn of the stellar kinematical major axis inside $R \leq 2''$, which is quite a new finding. Inside this radius the stellar kinematical major axis turns and reaches $\mathrm{P.A.}_{0,\mathrm{kin},*} = 309° \pm 12°$ at $R = 1''$; compare this to $\mathrm{P.A.}_{0,\mathrm{kin,gas}} = 329° \pm 4°$ for the ionized gas inside $R = 3''$. There is a clear impression that a *stellar* inclined disk exists too, but it is much more compact than the gaseous one. We have collected all the available velocity fields for the central part of NGC 7217 by adding to the data analyzed in this work the Fabry-Pérot ionized-gas velocity field presented by us earlier (Zasov & Sil'chenko 1997) and the CO velocity field presented recently by Combes et al. (2004) in the Nuclei of Galaxies project. We have applied the tilted-ring analysis to all of them and have traced the kinematical major axis orientation from the very center to $R \approx 30''$. In Figure 8 we compare these results to the photometric major axis orientation. Outside the nuclear ring, at $R > 10''$, both the gas—warm and cold—and stars rotate quite axisymmetrically, with their kinematical major axes agreeing perfectly with the photometric major axis. It is somewhat strange, because earlier (Sil'chenko & Afanasiev 2000) we supposed the inner disk seen at $R > 20''$ to be oval because its photometric major axis, after subtracting the other structural components, deviated by some 30° from the line of nodes of the outer disk. The only tentative signature of possible noncircular motions of the gas within the inner disk of NGC 7217 may be small radial velocities of 5–7 km s^{-1}, detected by us in the CO velocity field; but this presence of radial gas motions is not confirmed by the results of our analysis of the IFP ionized-gas velocity field. We must note here that the IFP velocity measurements for the ionized gas of NGC 7217 were made with the weak emission line [N II] λ6583 and are rather noisy and patchy, so perhaps we were not able to detect radial motions of less than 10 km s^{-1}. As for the stars, the inner stellar disk of NGC 7217 is not very cold (Sil'chenko & Afanasiev 2000), so the stars may be more stable against a weak triaxial perturbation. Inside the inner ring, at $R \leq 8''$, the kinematical major axis of the ionized gas starts to turn, implying an inclined disk. At $R = 4''$, $\mathrm{P.A.}_{0,\mathrm{kin,gas}} \approx 320°$, which differs by 80° from the direction of the photometric major axis, which here is at $\mathrm{P.A.}_{\mathrm{phot}} \approx 240°$. The kinematical major axis of stars starts to turn much closer to the center, at $R < 3''$, and at $R = 1''$ it reaches almost the same orientation as that of the ionized gas. So in NGC 7217 we have two circumnuclear inclined disks, gaseous and stellar, fairly coplanar to each other, but the latter is much more compact than the former.

Figure 9 (*left*) presents the map of the stellar velocity dispersion in the center of NGC 7217 obtained from the SAURON data. Now, with the larger field of view, we can unambiguously recognize the central structure seen in this map: although the

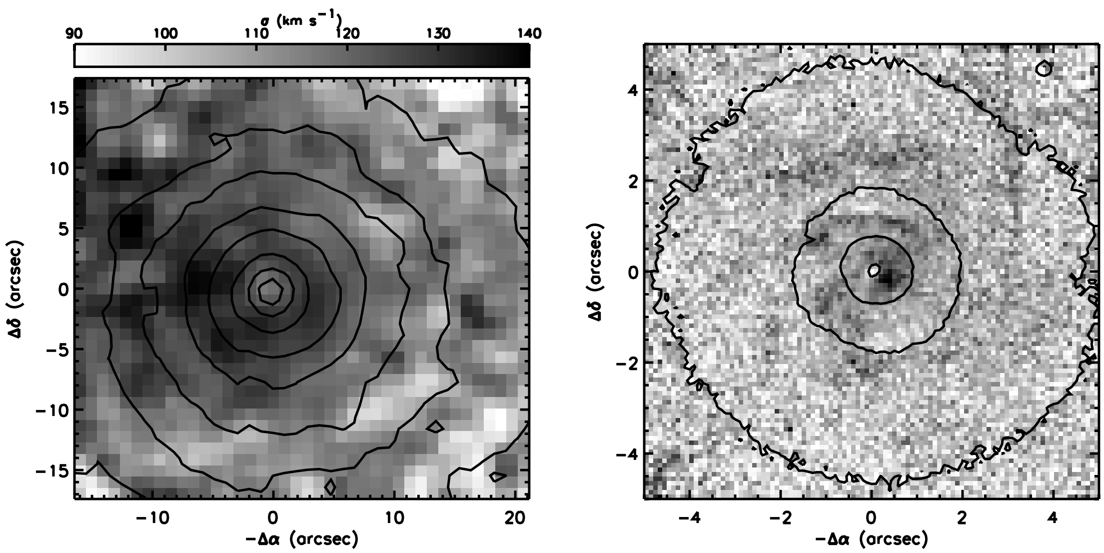

FIG. 9.—*Left*: Stellar velocity dispersion map for NGC 7217 according to the SAURON data. The continuum isophotes are overlaid. *Right*: Color map calculated from two *HST* WFPC2 images, F814W and F606W, to show the central asymmetry of the dust distribution.

whole distribution is slightly asymmetric, in the very center there is a certain σ_* minimum, perhaps shifted by $1''$–$2''$ to the north. Since the color distribution derived by us from the *HST* WFPC2 data is also asymmetric, with the color maximum being shifted in the opposite direction with respect to the stellar velocity dispersion minimum, we suggest that this asymmetry may be caused by the dust in the inclined circumnuclear disk. We conclude that the stellar velocity dispersion distribution is another signature of a compact circumnuclear stellar disk in this galaxy, which must be a relatively "cold" dynamical component.

6. CONCLUSIONS AND DISCUSSION

By using a variety of two-dimensional kinematical data, as well as deep images of NGC 7742, we analyze stellar and gaseous kinematics in this unbarred Sb galaxy possessing a nuclear star-forming ring; we compare it to NGC 7217, another unbarred spiral galaxy with rings that were studied by us earlier. We have found some common features in NGC 7217 and NGC 7742.

1. Both galaxies demonstrate global structure consisting of two exponential stellar disks with different scale lengths; the outer disks look quite normal, whereas the inner disks are compact, with $r_0 \approx 1$ kpc, and have unusually high surface brightness.

We would like to propose the following qualitative scenario to form such a "multitiered" stellar disk. A few gigayears ago there may have been a sudden global gas redistribution in the disk, perhaps due to external tidal perturbation or a minor merger. Before that event, stars should have formed in the disk with a large, normal scale length, and after that, when all the gas had been dropped closer to the center, the star formation should have continued in the disk with a smaller scale length and higher surface density.

2. Both galaxies, NGC 7742 and NGC 7217, have circumnuclear gaseous disks with radii of some 300 pc, highly inclined to the global disk planes; the outer gas disks are, on the contrary, close to the main galactic symmetry planes. Both galaxies also possess some counterrotating subsystems. NGC 7742 has all its gas in counterrotation with respect to all its stars, with the exception of some newly born stellar population in the ring, while in NGC 7217 the gas outside $R = 300$ pc corotates with the bulk of stars, but there are some 30% of all stars in the inner disk that counterrotate (Merrifield & Kuijken 1994).

Three-dimensional dynamical simulations of the self-consistent evolution of a stellar-gaseous galactic disk unstable with respect to barlike perturbations presented by Friedli & Benz (1993) proposed a scenario for the origin of circumnuclear inclined gas rings. If initially the gas of the global disk counterrotates with the stars, then drifting to the center in a triaxial potential of a transient bar, this gas must leave the disk plane and accumulate in orbits strongly inclined to this plane; only these inclined orbits remain stable for the initially counterrotating gas near the inner Lindblad resonances. We suggest that the gas that is now observed as the circumnuclear strongly inclined disks in NGC 7217 and NGC 7742 has come from the outer parts of the galaxies, and when it was there, it counterrotated with the stars.

As for the problem of the origin of the initially counterrotating gas, it may be solved together with the problem of the origin of the nuclear star-forming rings. If we suggest a past minor merger of a gas-rich dwarf galaxy from a retrograde orbit, this event had to have supplied some amount of counterrotating gas, and at the same time it might have caused an oval distortion of the stellar disk of the host galaxy that in its turn had to produce rapid radial gas redistribution and the appearance of the nuclear star-forming ring: all the peculiar features observed in NGC 7217 and NGC 7742. NGC 7742 demonstrates strong vertical gas oscillations in its counterrotating gaseous disk, implying rather recent gas accretion; NGC 7217 might have possessed counterrotating gas in the past, but now it has been fully reprocessed into counterrotating stars. Knapen et al. (2004) have detected strongly peculiar kinematics of neutral and ionized hydrogen beyond the optical stellar disk in the unbarred galaxy with rings NGC 278, although the galaxy is morphologically regular and quite isolated; they conclude that the galaxy has recently experienced a minor merger. In the absence of detailed neutral-hydrogen observations well outside the optical borders of the galaxy, one would treat NGC 278 as a twin for NGC 7217 and NGC 7742. In our opinion, NGC 278 may represent an early stage of the evolution following a minor merger, with respect to the two galaxies considered in our work, and its nearest future is perhaps to become like NGC 7742. The presence of numerous minor merger signatures in the three unbarred galaxies with nuclear star-forming rings makes the hypothesis of *tidally induced oval distortion of the global stellar disks* the most attractive scenario for the ring origin in unbarred galaxies.

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