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OBSERVATIONS OF NGC 6764, A BARRED SEYFERT GALAXY

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ABSTRACT

Spectra of NGC 6764, a previously unstudied barred spiral galaxy, reveal strong asymmetrical emission lines from the semistellar nucleus. Permitted and forbidden lines are about 750 km s^{-1} wide, which identify the galaxy as a Seyfert galaxy. Spectra in several position angles suggest that discrete gas clouds just outside the nucleus have both tangential and radial components of motion.

Subject headings: galaxies, individual — galaxies, motions in — Seyfert galaxies

I. INTRODUCTION

The purpose of this paper is to call attention to a previously unstudied barred spiral galaxy, with a Seyfert-like spectrum. The galaxy, NGC 6764, is located near the galactic plane, with $l = 81°$, $b = +18°$ ($\alpha_{1950} = 19^{h}07^{m}.0$, $\delta_{1950} = +50°50'$), and $m_{pg} = 13.2$ (Zwicky and Herzog 1966). On the Palomar Sky Survey print (Fig. 1*a*), the galaxy appears S-shaped, with a strong bar and weak outer arms. Numerous extensive dust lanes cross the bar. The alignment of some of these dust lanes with the weak emission from the outer regions of the galaxy suggests that the SW outer arm may rise out of the plane of the galaxy and pass in front of the bar NE of the nucleus. With $H = 75$ km s^{-1} Mpc^{-1}, the length of the bar is $18f$ kpc, where f is a factor greater than unity which takes into account the viewing angle. The nucleus is embedded in the bar, with no extended bulge. At the telescope the nucleus appears stellar, and on spectra taken at a large scale perpendicular to the dispersion, the continuum from the nucleus is only 1".6 wide. NGC 6764 resembles the brighter SBb I galaxy NGC 7479, although NGC 6764 is viewed at a larger angle of inclination.

II. OBSERVATIONS

Spectra were taken 1974 September with the Kitt Peak National Observatory 4-m and 2.1-m telescopes and the Cassegrain spectrographs, using an RCA C33063 image tube. Spectra of NGC 6764 reveal strong, very broad, asymmetrical emission lines of H, [N II], [S II], [O I], [O II], [O III], and He, and absorption lines of Na I and Ca II. A record of observations is listed in Table 1, and representative spectra are shown in Figures 1*b*–1*d*. In the nucleus, the lines of H and [N II] are each about 750 km s^{-1} wide, and appear to be composed of at least three distinct clouds. Except for exposure effects, all lines appear about equally broad and of similar shape. This may be seen on the high-dispersion plate in Figure 1*d*, by comparing the shapes of the strong Hα and [N II] lines with the weak [O I] and [S II] lines. Class 2 Seyfert galaxies are galaxies with semistellar nuclei, whose spectra show permitted and forbidden lines equally broad and in the 500–1000 km s^{-1} range (Khachikian and Weedman 1974). Hence NGC 6764 clearly falls in this category.

With the spectrograph slit aligned along the bar in P.A. = 73°, at least three clouds can be identified in

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TABLE 1
SPECTROSCOPIC OBSERVATIONS OF NGC 6764

Plate*	Date (1974)	Exposure (min)	Position Angle	Dispersion (Å mm^{-1})	Plate Scale (arcsec mm^{-1})	Region
M355........	Sept. 8	104	73	27	27	Nucleus centered, red
C2916a	Sept. 10	10	73	92	75	Nucleus centered, red
C2916b	Sept. 10	4	73	92	75	Nucleus centered, red
C2917a	Sept. 10	31.5	73	92	75	Nucleus centered, red
C2917b	Sept. 10	25	163	92	75	Nucleus centered, red
C2918a	Sept. 10	25	90	92	75	Slit just S of nucleus, red
C2924c	Sept. 11	10	90	122	75	Nucleus centered, blue
C2924d	Sept. 11	5	90	122	75	Nucleus centered, blue
C2925a	Sept. 11	2	90	122	75	Nucleus centered, blue

* M Series: Mayall 4-m telescope; C Series: 84-inch (2.1 m) telescope.

the nucleus: one displaced shortward and located about 1″ NE, one displaced longward and located about 1″ SW, and a weaker one displaced longward and centered 3″ or 4″ SW, which is strongest in the lines of [N II] and [S II]. In P.A. = 90°, the lines are also asymmetrical, again similar in shape to each other. We infer that the nucleus of NGC 6764 consists of discrete clouds which are in rapid rotation about the center, much like those studied by Ulrich (1973) and Anderson (1974) in the classical Seyfert NGC 4151. Evidence is presented below that the excited gas just outside the nucleus also has noncircular velocity components which can be interpreted as motions toward and away from the nucleus.

In the nucleus, Hα and [N II] are of approximately equal strength, as are also the two members of the [S II] doublet. Hβ is stronger than [O III] λ5007, which is not typical of Seyfert galaxies. However, [O III] is usually absent in typical barred spirals (Rubin, Ford, and Peterson 1975). The [O I] λ6300 line which is observed in NGC 6764 is seldom seen in galaxies, although Seyfert (1943) identified it in several Seyfert galaxies. More recently, it has been observed in strong emission-line galaxies such as M82 (Burbidge, Burbidge, and Rubin 1964), NGC 4038–39 (Rubin, Ford, and D'Odorico 1970), and the Seyfert galaxy NGC 3227 (Rubin and Ford 1968). In all of these galaxies, He λ5876 is also observed, as it is in NGC 6764. In the atlas of Seyfert galaxies published by Khachikian and Weedman (1974), none of the Seyferts of class 1 have either [O I] λ6300 or He λ5876, while four or five (~25%) of those of class 2 have [O I] in their spectra. These same galaxies also show He λ5876. Hence, even among all Seyfert galaxies, NGC 6764 ranks as a strong emission-line object, with a wide range of ionization present. Although several Seyfert galaxies are classified as barred or mixed spirals, we are unaware of any other S-barred Seyfert galaxy like NGC 6764.

At large distances from the nucleus, Hα and [N II] are observed from a few H II regions, with Hα much stronger than [N II]. On the deepest exposures, weak emission is detected also just off the nucleus.

III. THE VELOCITY FIELD

Emission-line velocities have been measured (using a Mann two-coordinate measuring engine) from Hα and [N II] in the nucleus; for points near the nucleus and near the ends of the bar (P.A. = 73°); and close to the nucleus in P.A. 90° and 163°, perpendicular to the bar. They are tabulated in Table 2. Those along the bar are plotted in Figure 2. The uncertainty of a single point is generally less than 15 km s^{-1}. The broad

TABLE 2

OBSERVED HELIOCENTRIC VELOCITIES IN NGC 6764

		Y (arcsec)	V (km s^{-1})
	Plate M 355		PA 73°
[N II] λ 6548		0	2339
Hα	SW	- 47	2527
		- 39	2486
		0	2356
		+ 12	2333
		+ 37	2336
		+ 46	2311
		+ 50	2266
	NE	+ 52	2263
[N II] λ 6583		0	2332
		+ 37	2344
		+ 46	2307
		+ 51	2277
	NE	+ 53	2271
	Plate K 2916b		PA 73°
Hα		0	2366
[N II] λ 6583		0	2348
	Plate K 2916a		PA 73°
Hα		0	2368
		+ 36	2316
		+ 43	2287
	NE	+ 48	2256
[N II] λ 6583		0	2374
	NE	+ 5	2397
	Plate K 2917a		PA 73°
Hα		+ 14	2329
		+ 35	2352
		+ 43	2326
	NE	+ 48	2270
[N II] λ 6583		+ 35	2327
		+ 44	2301
	NE	+ 50	2283
	Plate K 2918a		PA 90° (below nucleus)
Hα	W	- 8	2370
		0*	2368
	E	+ 9	2367
[N II] λ 6583	W	- 7	2385
		0	2371
	Plate K 2924c		PA 90°
Hβ		0	2377
		+ 4	2430
	E	+ 8	2458
[O III] λ 5007	E	+ 5	2467
	Plate K 2917b		PA 163°
Hα	NW	- 10	2443
		0	2396
[N II] λ 6583	NW	- 11	2436
		- 6	2395
		0	2372
	SE	+ 5	2328

* Corresponds to most intense emission, not nucleus.

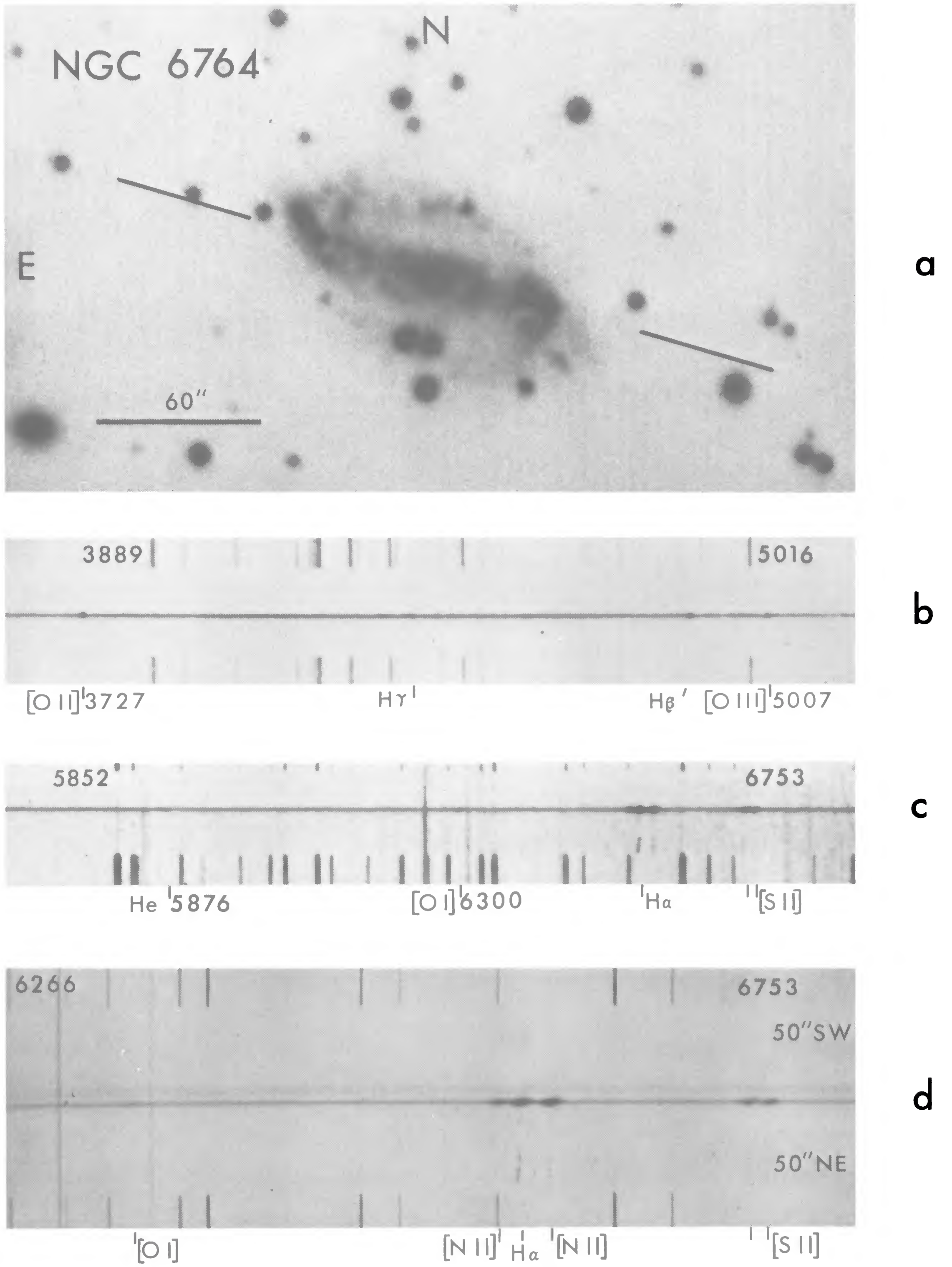

FIG. 1.—(*a*) Enlargement of NGC 6764 from the blue plate of the Palomar Sky Survey (© National Geographic Society–Palomar Observatory). Indicated slit position angle is 73°. (*b*) Plate C2924d, P.A. = 90°, original dispersion = 122 Å mm^{-1}, exp. = 5 min, 2.1-m telescope. (*c*) Plate C2917a, P.A. = 73°, original dispersion = 92 Å mm^{-1}, exp. = 31.5 min, 2.1-m telescope. (*d*) Plate M355, P.A. = 73°, original dispersion = 27 Å mm^{-1}, scale perpendicular to dispersion is three times that of previous spectra, exp. = 104 min, 4-m telescope. Note the breadth of the emission lines in the nucleus as compared with lines in the outer arms. All spectra taken with an image tube on N_2 baked IIIa-J plates; principal emission lines indicated below the spectra.

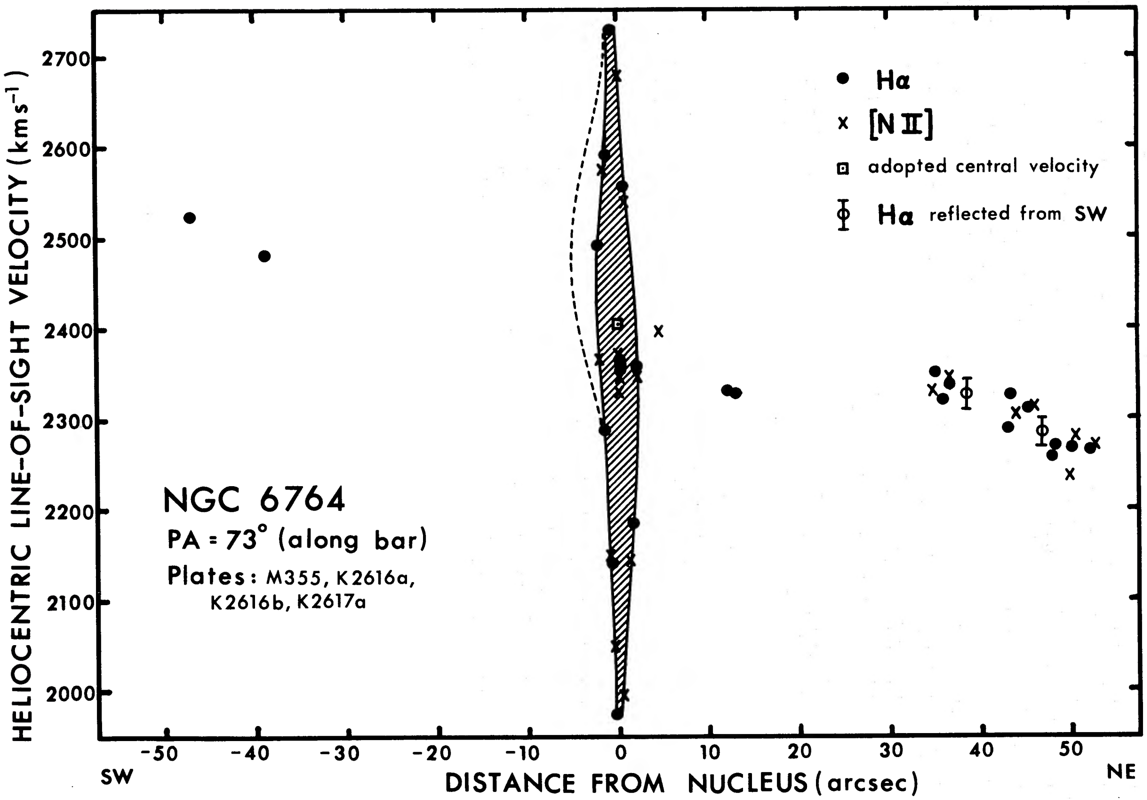

FIG. 2.—Line-of-sight velocities in P.A. = 73° (along bar) for NGC 6764 as a function of distance from the nucleus. The broad Hα and [N II] emission lines in the nucleus are indicated by the hatched area. Outline of the cloud seen in [N II] to the SW of the nucleus is indicated by the dotted line.

nuclear emission in Hα and [N II] has been mapped, and is indicated with the hatched region in the figure. The profiles of Hα and [N II] are identical, except that the SW longward cloud, indicated by the dotted line, is barely present in Hα, and has been measured in [N II] only. At large distances from the nucleus, velocities are available along the bar only. These come from three plates, and are in excellent agreement. All listed velocities are heliocentric.

The central velocity, an eye estimate of the midpoint of the broad emission, is $V_c = 2363 \pm 6$ km s^{-1} from five plates. However, if we reflect the SW velocities near $s = 45''$ to superpose on the NE, the center of symmetry is $V_c = 2405 \pm 8$ km s^{-1}; s is the angular distance from the nucleus. The reflected velocities are shown as open circles in Figure 2; the error bars indicate the uncertainty arising from the ± 8 km s^{-1}. We conclude that there are systematic motions within the nucleus which cause the systemic velocity not to coincide with the center of the emission, and we adopt $V_c = 2405$ km s^{-1} as the central velocity for NGC 6764. Correcting to the local standard of rest and to the center of the galaxy ($V_G = 250$ km s^{-1}) gives $V_c = 2655$ km s^{-1}. With $H = 75$ km s^{-1} Mpc^{-1}, this corresponds to a distance of 35 Mpc; $1'' = 172$ pc.

As is generally the case with barred spiral galaxies, it is not possible to determine the position angle of the line of nodes, ϕ, and the inclination i of the galaxy from its appearance. This is especially so for S-shaped barred galaxies, where there is little evidence that the outer contours are circles in the plane of the galaxy. Instead we have adopted a graphical procedure to indicate the range of ϕ and i which produces reasonable values for the rotational velocity in the plane of the galaxy, $V_{\rm rot}$. We assume that the motions near the ends of the bar arise from rotational velocities only; observations show that the NE side of the galaxy is approaching. The observed line-of-sight velocity, $\Delta V = V_{\rm obs} - V_c = 155$ km s^{-1}, is related to the rotational velocity by

$$V_{\rm rot} = \frac{V_{\rm obs} - V_c}{\cos(73° - \phi)\sin i} \times [\sec^2 i - \tan^2 i \cos^2(73° - \phi)]^{1/2} .$$

In Figure 3a we have plotted $V_{\rm rot}$ versus ϕ for various values of i. Any point within the outer envelope of the curves defines a (ϕ, i) pair such that $V_{\rm obs} - V_c = 155$ km s^{-1}; the corresponding value of $V_{\rm rot}$ is given by the abscissa of the point. If the observed velocities near $s = 52''$ come from the peak of the rotation curve, then we expect $V_{\rm rot}$ in the range $225 \leq V_{\rm rot} \leq 275$ km s^{-1}. This limit to the maximum $V_{\rm rot}$ defines a restricted set of (ϕ, i) pairs which are plotted in Figure 3b. For all (ϕ, i) pairs within the hatched region, a

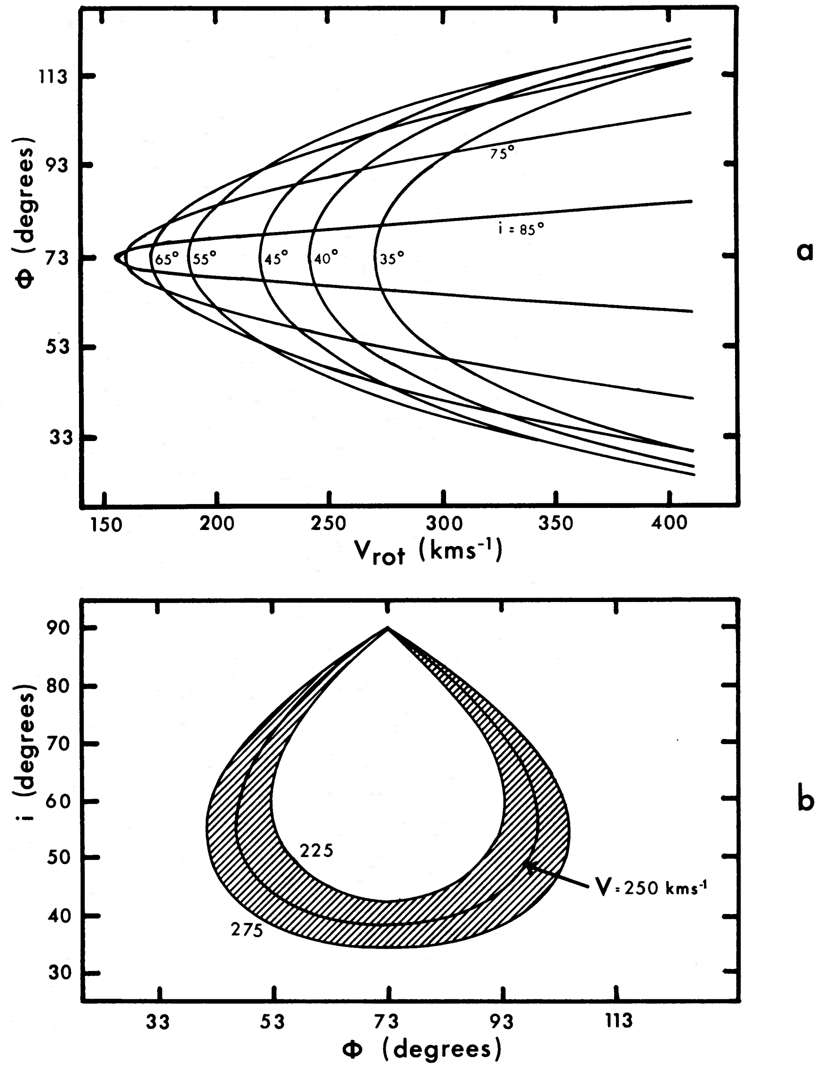

FIG. 3.—(*a*) Values of position angle of line of nodes ϕ, inclination of the galaxy i, and circular velocity in the plane of the sky V_{rot}, which will project to a line-of-sight velocity of 155 km s^{-1}. (*b*) Hatched region marks the range of values of ϕ and i for which a rotational velocity between 225 and 275 km s^{-1} will project to the observed line-of-sight velocity of 155 km s^{-1}.

value $225 \leq V_{rot} \leq 275$ km s^{-1} will project to a line-of-sight velocity of 155 km s^{-1}. If the rotation curve has not yet reached its peak at $s = 52''$, then V_{rot} will be less than 225 km s^{-1}, and permissible (ϕ, i) pairs will be even more restricted and will lie inside of the hatched region.

We conclude from Figure 3*b* that the line of nodes lies within 30° of the bar, and that the angle of inclination lies in the range 40°–70°. If the velocities we observe far out on the bar have a significant noncircular component, then these values might be enlarged. However, we have restricted our analysis to the simpler case of circular motion. The appearance of the galaxy in its principal plane has been plotted for six pairs of (ϕ, i) values with the above limits. These are sketched in Figure 4. It is obvious that none of these forms can be eliminated on the basis of physical implausibility.

Close to the nucleus, near $s = 5''$ ($R \sim 1$ kpc), a few velocities are available for P.A. = 73°, 90°, 163°, and 343°. Detailed model calculations show the following:

1) If the total range of values of (ϕ, i) inferred for the outer galaxy applies also to the nucleus, then radial motions toward and away from the nucleus must exist in the plane of the galaxy. Specifically, in P.A. 163° and 343° (perpendicular to the bar), motions away from the nucleus ($V \sim 40$ km s^{-1} at $R \sim 8''$), and in P.A. 90°, motions toward the nucleus ($V \sim 100$ km s^{-1} at $R \sim 6''$), are necessary to account for the observed velocities. These radial motions are in addition to the normal circular velocity at each R.

2) If instead we assume that only *circular* motions are present near the nucleus, then the velocity gradients observed in P.A. 90° and 163° imply that $\phi = 49°$. However, the sense of the rotation is such that the NE side of the nucleus is receding. This is opposite that

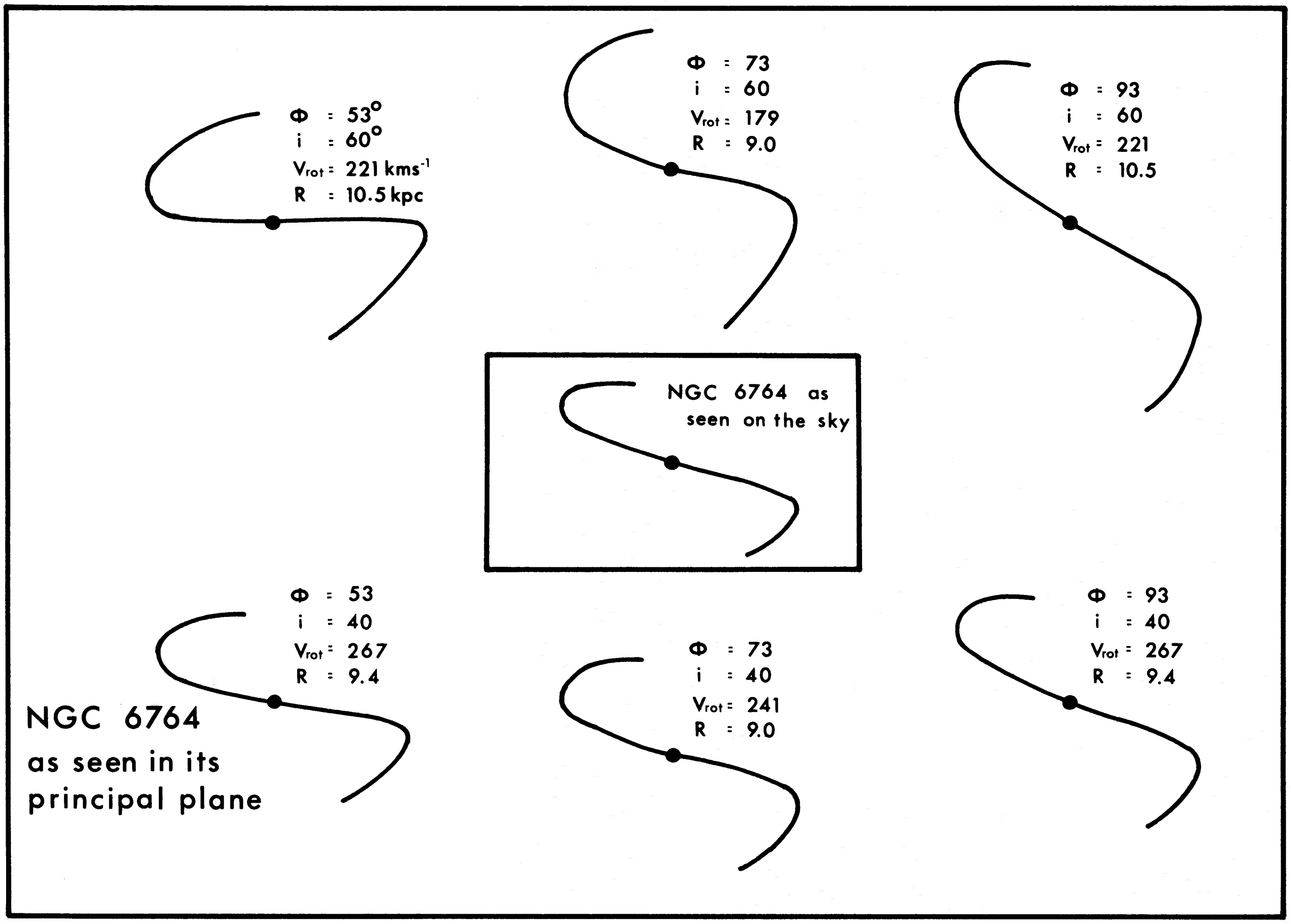

FIG. 4.—Sketches of the form of NGC 6764 in its principal plane, calculated from its appearance on the sky and the indicated choice of ϕ and i. For each case the value of V_{rot} in km s^{-1} which projects to a line-of-sight velocity of 155 km s^{-1}, and the value of R in kpc which projects to $s = 52\farcs5$ on the sky are also indicated.

observed for the outer bar, where the NE part is approaching. This is such an unlikely circumstance that we conclude that the assumption of only circular motions is invalid, and that radial motions exist in the gas near the nucleus.

IV. CONCLUSIONS

We summarize these considerations as follows:

1) NGC 6764 is an S-barred spiral galaxy with a semistellar nucleus. Its spectrum exhibits permitted and forbidden asymmetrical emission lines which are 750 km s^{-1} wide. NGC 6764 is among the nearest of the Seyfert galaxies.

2) The nucleus consists of discrete clouds in rapid rotation about the center. From the maximum line-of-sight velocity at $s = 52''$ ($R > 9$ kpc) plus the expectation that $V_{rot} < 275$ km s^{-1} in the plane of the galaxy, we can restrict the viewing geometry to a limited range of angles ϕ and i. Within this range, there is evidence that both expansion and contraction motions exist in the excited gas just outside the nucleus near $R \sim 1$ kpc. Velocities of the radial component are 50–100 km s^{-1}.

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