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SURFACE BRIGHTNESS AND MASS DISTRIBUTION OF THE LATE TYPE SPIRAL GALAXY NGC 2403

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ABSTRACT

Luminosity profile of the late type spiral galaxy NGC 2403 was obtained using the PDS scan of the plate. Some physical parameters (scale length, total magnitude, central brightness, disk to bulge ratio and concentric indices) were calculated from the brightness distribution. Total mass and the mass to luminosity ratio were estimated from the fitting of various mass models.

I. INTRODUCTION

NGC 2403 located far west side of M81 group and has only marginal bulge which is the typical character of the late type spiral galaxy. Elmegreen (1980) found a spur with 200 pc depth, 0.8 kpc length and 2 kpc radial distance from center. Elmegreen and Elmegreen (1984) regard this galaxy as the flocculent galaxy whose arm class is 4.

Beyond the Local group NGC 2403 is the first extragalaxy where the cepheid variable was found, and this has been a parameter to define the extragalactic distance scale. Until 1960, 27 variables have been found in this galaxy and among them 10 cepheids have the period of 18 to 54 days. From the study of cepheids Tammann and Sandage (1968) determined the apparent distance modulus as 27.8, while de Vaucouleurs (1978) found this as 27.1. Later Sandage (1984) calculated the apparent distance modulus as 27.9 from the cepheid. After the reddening and extinction corrections of cepheids, Tosi and Diaz (1985) adopted 2.62 Mpc as the distance to NGC 2403 and we used this value as the distance.

NGC 2403 is a relatively large ($29' \times 15'$) galaxy and the distribution of H I shows wider range than the optical object (Burns and Roberts 1971). Total mass of the neutral hydrogen was calculated as $3.5 \pm 0.7 \times 10^9 M_\odot$ (Shostak 1973), $3.7 \times 10^9 M_\odot$ (Guelin and Weliachew 1969) and $4.8 \times 10^9 M_\odot$ by Roberts (1969). The total blue luminosity was taken as $6.1 \times 10^9 L_\odot$ by Rogstad and Shostak (1972), and one year later Shostak (1973) adopted this as $6.7 \times 10^9 L_\odot$.

Estimation of the total mass shows some difference among scholars. Most of the mass estimation comes from the rotation curve fitting to the Brandt and Belton's model. Deharveng and Pellet (1970) got the total mass as $5.6\times10^{10}M_{\odot}$ using the rotation curve observed from the H II regions. From the 21cm observation Burns and Roberts estimated this as $1.0\times10^{11}M_{\odot}$ and Shostak (1973) calculated the total mass as $1.1\times10^{11}M_{\odot}$ from the neutral hydrogen aperture synthesis. Table 1 listed some characters of NGC 2403.

Table 1. Some Characters of NGC 2403

Coordinate	R.A.	$7^h32^m.05$
(1950)	DEC.	65°42′.7
	L	150°.58
	B	29°.19
	SGL	30°.8
	SGB	−8°.3
Morphological Type	Hubble	SABcd (T=6)
Luminosity Class	Ⅲ	L=5
Isophotal Diameter	Log D_{25}	2.25±0.023
Corrected Diameter	Log D_o	2.23
Axes Ratio	Log R_{25}	0.21±0.16
Effective Aperture	Log A_e	1.80±0.05
Corrected B Magnitude	B_T°	$8.^m30$
Absolute Magnitude		$-19.^m2$[1]
Luminosity		$6.7\times10^9L_{\odot}$
Inclination		60°
Position Angle		125°.5±1°
Systematic Velocity		128±3km/s
Distance Modulus		28.1
Holmberg Radius		14.′5
Total H I Mass		$4.6\times10^9M_{\odot}$[2]
Total Mass		$1\times10^{11}M_{\odot}$

1) Shostak (1973)

2) Burns and Roberts (1971)

II. SURFACE BRIGHTNESS DISTRIBUTION

1. Observation

PAL 0+66 sky survey plate was scanned to get the surface brightness distribution of NGC

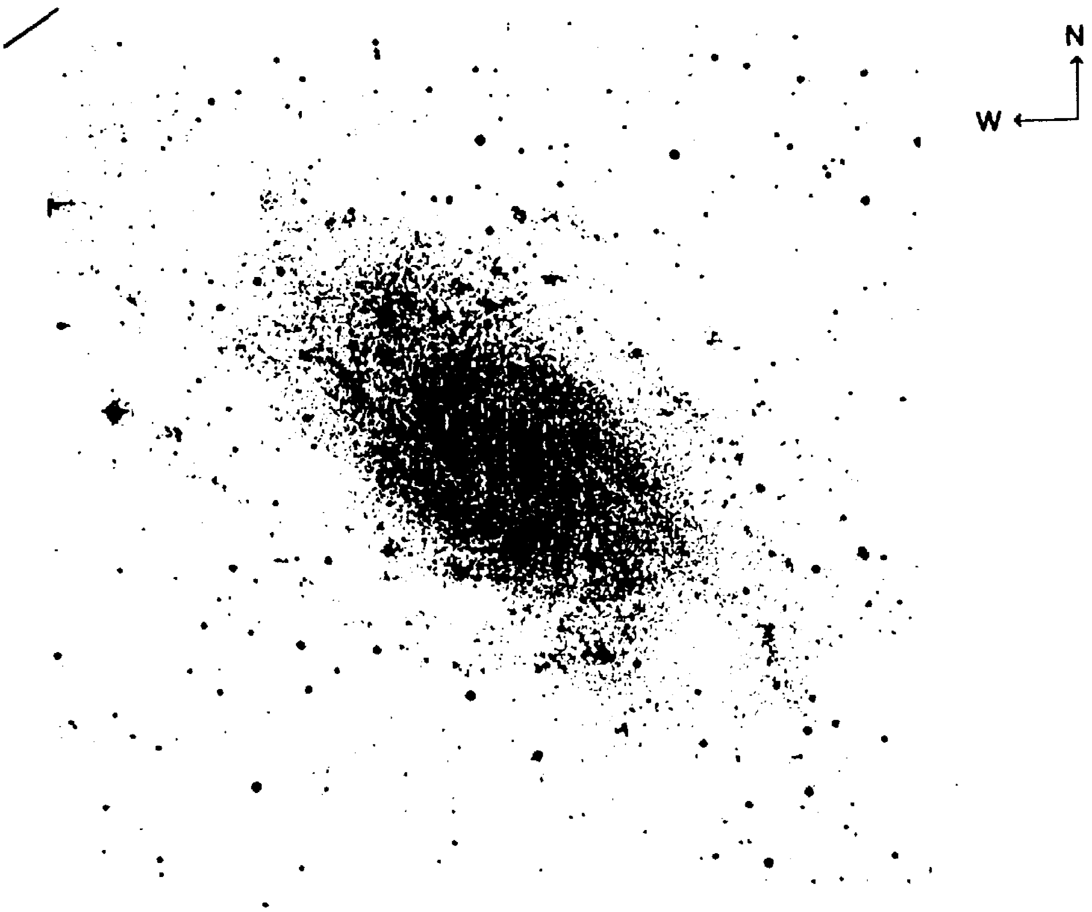


Fig. 1. Density Gray map of NGC 2403

2403. PDS microdensitometer was used for this scanning. The scanning aperture was 17 μm (1″.15) and the space between each scanning point was 10 μm (0″.68). The total scanning area was 14′.1×14′.1 and this area was divided as 1250×1250 scanning points. The scanning speed was 40 PDS unit.

2. Contour Map

The density gray map from the reading of the PDS microdensitometer is in Figure 1, and which shows the typical character of the late type spiral galaxy as the small nuclei and the loosely winding spiral pattern. From this gray map we can estimate the axial ratio $q=0.53$ until $r=0'.47$ and $q=0.49$ to $r=2'.77$, and the inclinations for these are 59° and 62°. The position angle of the major axis is 122°.

3. Surface Luminosity Distribution Curve

Surface luminosity distribution curve was obtained through the integration of the luminosity of

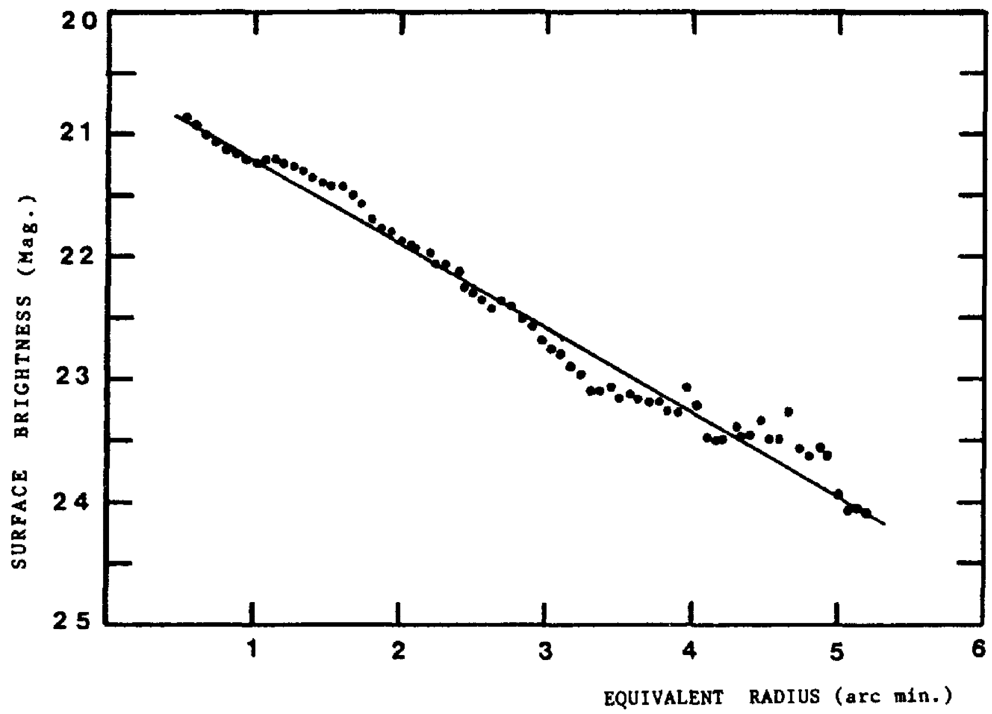
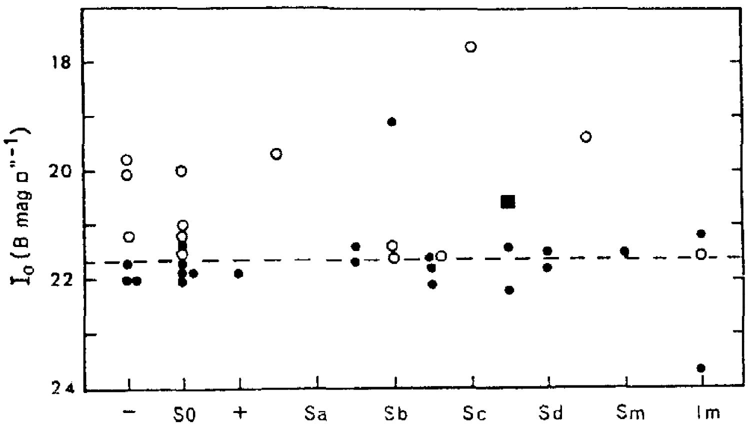


Fig. 2. Surface Brightness distribution with the exponential law fitting.



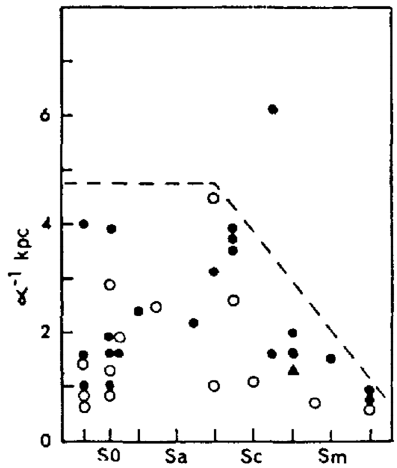


Fig. 3. Central brightness and morphological type of galaxies. Filled circle denotes the Freeman's type I, while open circle represents the Freeman's type II. NGC 2403 was plotted as the filled square.

Fig. 4. The correlation between the morphological type and the scale length of galaxies

the contour map. In Figure 2 we presented luminosity distribution curve of NGC 2403, which shows that NGC 2403 is a typical disk galaxy and the luminosity distribution is very close to Freeman's Type I system.

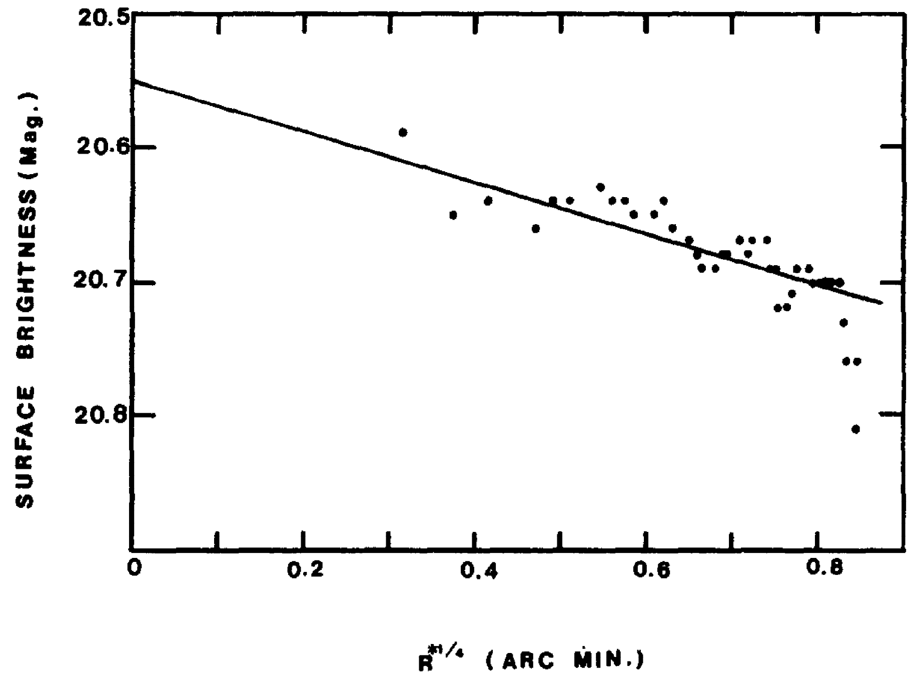


Fig. 5. Fitting the central surface brightness distribution to the $R^{1/4}$ law

Exponential law fitting to the observed surface brightness distribution was made in Figure 2 as a straight line. We used the fitting equation proposed by de Vaucouleurs as

$$U(R^*)_{CD}=U(0)_{CD}+1.0857\times R^*$$

From this fitting we can get the central brightness which comes from the extrapolation of the disk component as $20^m.51$, and the scale length α^{-1} as 1.57 kpc. We compared these data with the galaxy morphological type in Figures 3 and 4. Here the filled circle denotes the Freeman's type I galaxy, while the open circle represents the type II. NGC 2403 was plotted as the filled triangle except Figure 3 (In this Figure we make this galaxy as a filled square). From Figures 3 and 4 it was assumed that NGC 2403 belongs to type I, which fact already comes from the surface brightness distribution in Figure 2.

The radius of the nuclear bulge can be estimated through the fitting of the surface brightness distribution to the $R^{1/4}$ law. In Figure 5 we fitted the central region of the surface distribution (dotted points) to $R^{1/4}$ law (solid line) and can get the radius of the nuclear bulge as $0'.47$.

4. Physical Parameters

From the extrapolation of the observed surface brightness distribution, the apparent total blue magnitude was estimated as $8^m.68$ and the corrected apparent total face on blue magnitude B_T°

was calculated as $8^m.12$. If we adopted the distance to NGC 2403 as 2.62 Mpc, then the corrected absoluted magnitude was $-18^m.97$ and the corresponding total luminosity was estimated as $6.0 \times 10^9 L_\odot$. These values with the others are listed in Table 2 for comparison.

Table 2. Total Magnitudes of NGC 2403

	this paper	others
total apparent magnitude	$B_T = 8^m.68$	$B_T = 8^m.85$ (de Vaucouleurs 1976) $m_{pg} = 8^m.8$ (Epstein 1964)
corrected total apparent magnitude	$B_T^\circ = 8^m.12$	$B_T^\circ = 8^m.30$ (de Vaucouleurs 1976)
corrected absoluted magnitude	$M_T^\circ = -18^m.97$	$M_T^\circ = -19^m.2$ (Shostak 1973)
total luminosity	$L_T^B = 6.0 \times 10^9 L_\odot$	$L_T = 6.0 \times 10^9 L_\odot$ (Rogstad and Shostak 1972)

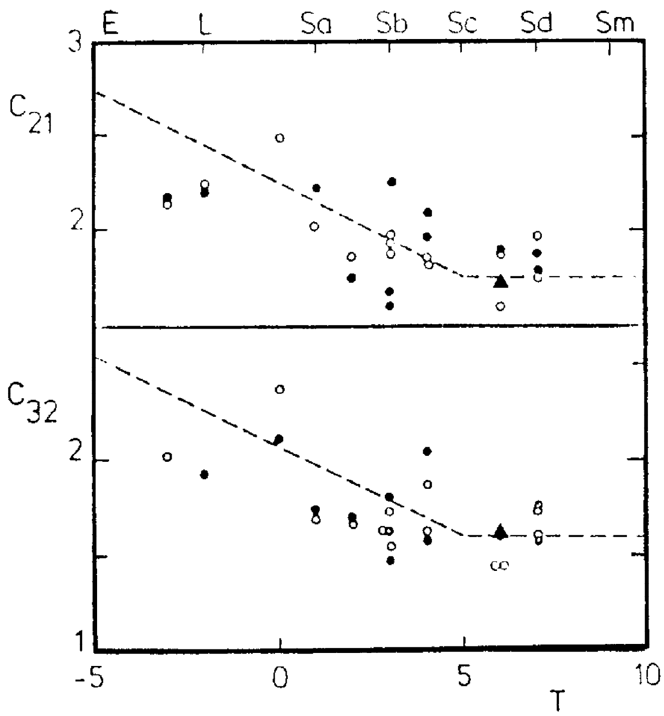


Fig. 6. Correlation between the morphology and the concentric indices. NGC 2403 was plotted as a filled triangle.

The luminosity ratio of the nuclear bulge to the disk (D/B) of NGC 2403 was calculated as 6.75, and the fractional light of the disk to the total luminosity was 0.83. From these ratios we can get the disk radius as 5′.16.

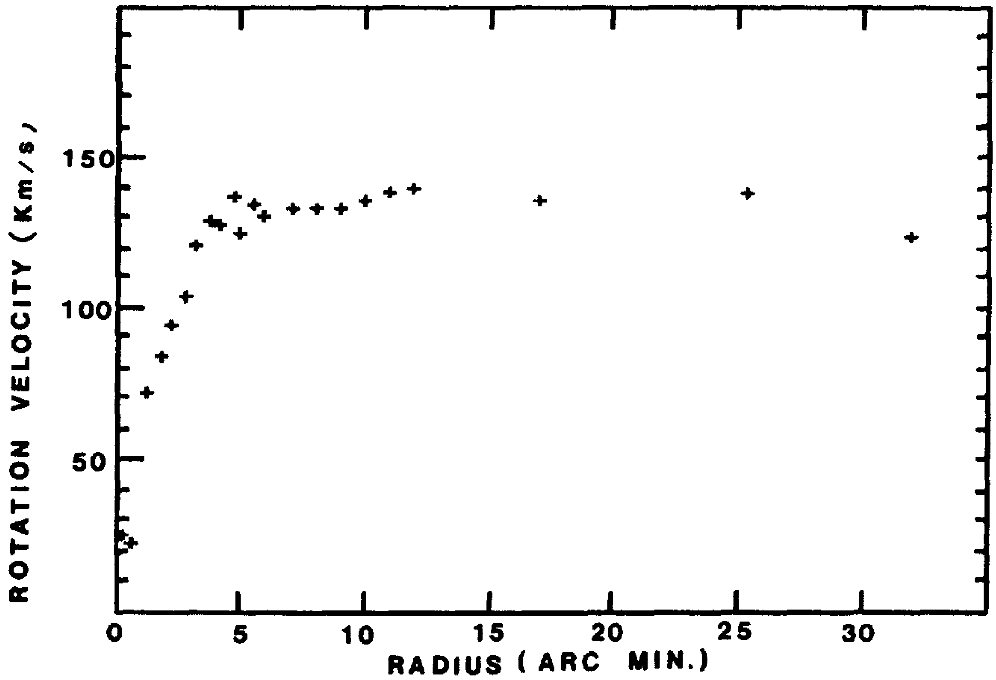


Fig. 7. Observed rotation velocity curve of NGC 2403

The concentration indices C_{21}, C_{32}, and C_{31}, are 1.71, 1.61 and 2.71 each. We plotted C_{21} and C_{32} to the morphological type T in Figure 6. Filled circle represents type I and open circle denotes type II, and NGC 2403 is denoted as the filled triangle. The dotted line indicates the exponential distribution in Figure 6, and NGC 2403's concentration indices are well fitted to this line.

III. MASS

1. Rotation Curve

Rotational velocities of NGC 2403 were made by Deharveng and Pellet (1970 ; using the Fabry–Perot interferometer until $R=6'$), Shostak (1973 ; using H I aperture synthesis until $R=12'.8$) and Huchtmeier (1975 ; using high sensitive single dish until $R=30'$).To make the homogeneity of these data we corrected the Deharveng and Pellet (1970) data to match with the Shostak's parameter (1973), and then we added the Huchtmeier's data (1975). However the dispersion of the rotation velocity data was large until $R=5'$, we divided the radius every $0'.5$ and get a mean value in each ring. Figure 7 shows the rotation velocity curve which comes from the above description.

2. Mass Model Fitting

2.1. Fitting to the Brandt and Belton's mass model

The observed rotation velocity curve in Figure 7 was fitted to the Brandt and Belton's mass

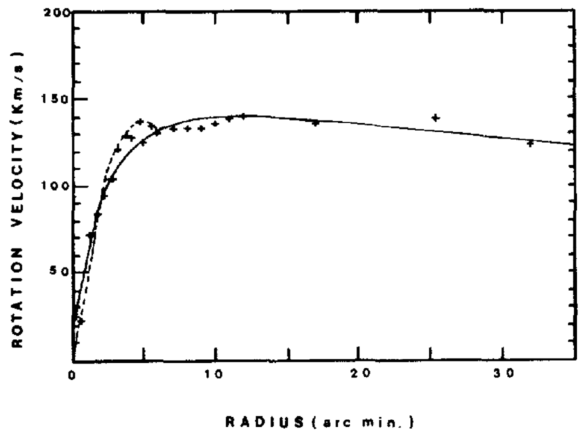


Fig. 8. Fitting the rotation curve to the Brandt and Belton's model. Straight line was fitted in case 1 and case 2 which was plotted as the dotted line.

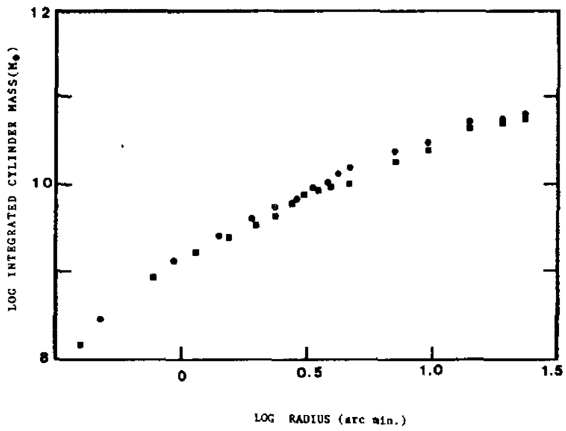


Fig. 9. Integrated cylinder mass distribution to the radial distance. Filled circles come from case 1 while filled squares represent case 2.

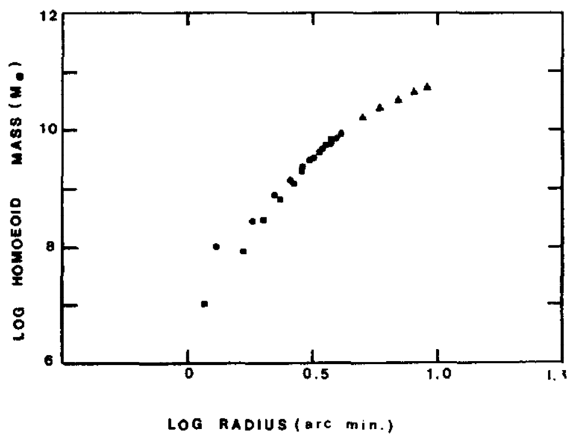


Fig. 10. The homoeoid mass distribution to the radius. Filled triangle represents the common part of case 1 and case 2.

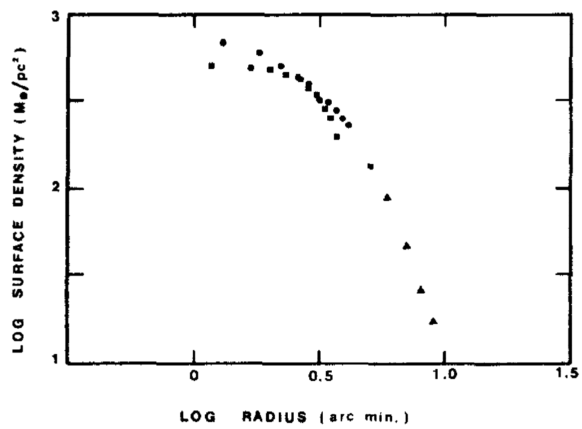


Fig. 11. Surface density distribution to the radial distance in NGC 2403

model in 2 cases. In the case 1 we assumed that the rotation curve is quite linear and fitted the single curve with $n=0.75$, $Rm=12.'0$ and $Vm=140$ km/s. In the case 2 we consider a hump in the rotation curve at $R=4'.5$. From center to $R=4'.8$ the fitting was made with the parameters $n=3.5$, $Rm=4'.8$ and $Vm=136$ km/s, and after $R=4'.8$ the fitting parameters $n=0.75$, $Rm=12'.0$ and $Vm=140$ km/s were applied. Figure 8 shows the fitting for case 1 (solid line) and case 2 (dotted line).

From the fitting we can estimated various dynamical parameters. Figure 9 shows the integrated cylinder mass distribution to the radial distance. Here the filled circle represents case 1 and the filled square comes from case 2. The radial integrated homoeoid mass distribution is

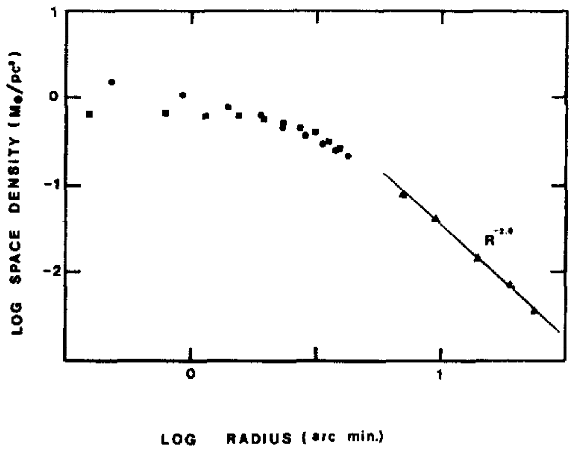


Fig. 12. Space density distribution to the radius.

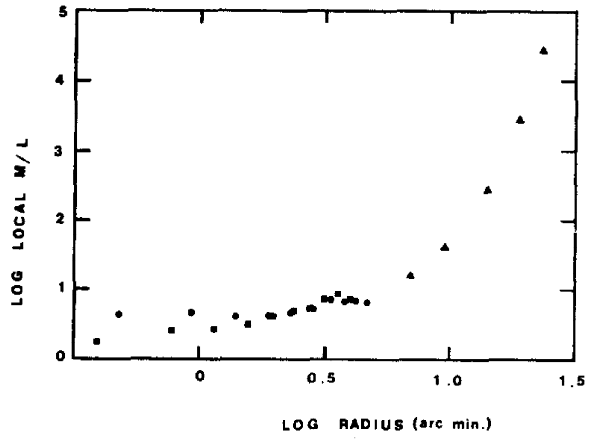


Fig. 13. Local mass to luminosity ratio to the radial distance.

in Figure 10. Triangle represents the common part in cases 1 and 2. Figure 11 shows the surface density distribution, where the central densities are 761 $M_\odot/pc^2$ and 508 $M_\odot/pc^2$ for case 1 and case 2. Space density distribution is in Figure 12. Local mass to luminosity ratio is displayed in Figure 13. From this diagram we found that there is a middle dip near at $R=4'.7$ which was suggested by Blackman (1979 a,b,c). In table 3 we listed masses and mass to luminosity ratio of each region of NGC 2403.

Table 3. Mass to Luminosity Ratios for each Region Using the Brandt & Belton's Model.

	Mass ($10^9 M_\odot$)	Luminosity	M/L
Nuclear region	case 1: 0.27	0.23	1.2
($0<R<0.36$ kpc)	case 2: 0.28		1.2
disk	case 1: 15.8	5.02	3.2
($0.36<R<0.36$ kpc)	case 2: 10.6		2.1
halo	case 1: 193.9	0.78	249
($R>3.93$ kpc)	case 1: 193.9		249

2.2. Fitting to the Toomre's model.

Toomre's model is the similar one to that of the Brandt's model except Toomre used Bessel transform to get the solution. Before reaching the maximum velocity Toomre's curves are alike each other. However after the maximum velocity his curves declines rapidly according to the increasing model parameter.

As the rotation curve of NGC 2403 is rather flat in the outer part, it is reasonable to use the

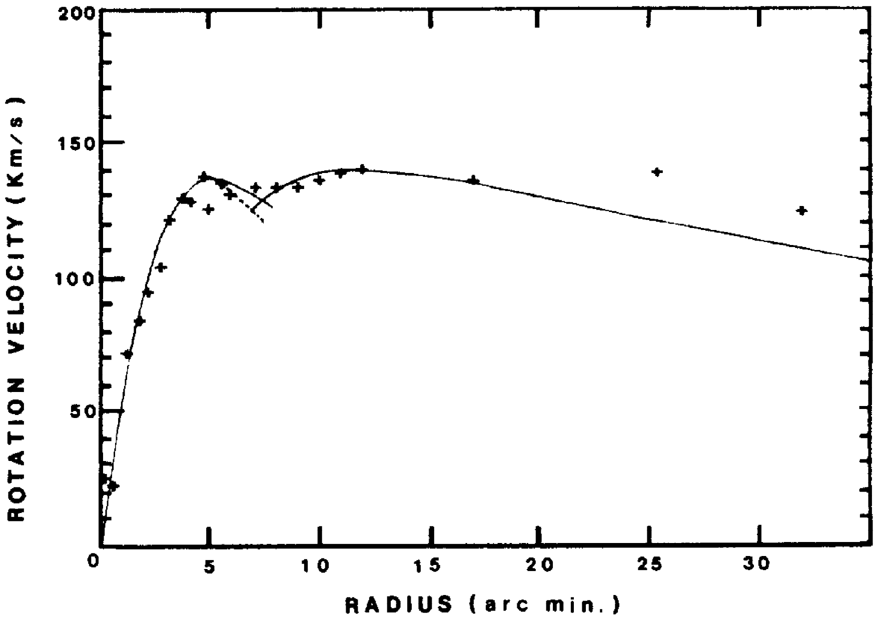


Fig. 14. Fitting the rotation velocity curve of NGC 2403 to the Toomre's model. Straight line represents the case 1, and case 2 is in dotted line.

smaller model parameter as like $n=1$ and 2. Fitting the rotation curve of NGC 2403 to the Toomre's model is made in Figure 14. Until R=7'.5 we fitted with parameters like $n=1$, $Rm=4'.8$ and $Vm=136$ km/s and after this radius we applied new parameters ($n=1$, $Rm=12'.0$ and $Vm=140$ km/s) to the rotation curve (we refer this as Case 1.). In the other hand, the fitting was made with parameters ($n=2$, $Rm=4'.8$ and $Vm=136$ km/s) until $R=7'.0$ and after that we used the same parameters as in case 1 (we call it as case 2.). The straight line comes from case 1 and the dotted line is for case 2. The total mass is 7.4×10^{10} $M_{\odot}$ which comes from both cases 1 and 2, and the mass to luminosity ratio is 12.3. We listed masses and luminosities for each region of NGC 2403 in Table 4.

Table 4. Mass to Luminosity ratio (Toomre Model)

	Mass (10^9 $M_{\odot}$)	Luminosity	M/L
Nuclear region	case 1: 0.28	0.23	1.2
($0<R<0.36$ kpc)	case 2: 0.25		1.1
disk	case 1: 12.8	5.02	2.5
($0.36<R<3.93$ kpc)	case 2: 12.1		2.4
halo	case 1: 61.4	0.78	79
($R>3.93$ kpc)	case 2: 61.8		79

IV. DISCUSSION

Surface density distribution and the contour map were used to get the physical parameters of

NGC 2403. Surface brightness distribution indicates that NGC 2403 belongs to the Freeman's type I, and the scale length and concentric indices of this galaxy are typical values of SABcd galaxy. The absolute magnitude is $-18^{m}.97$ and the total luminosity is $6.0 \times 10^{9} L_{\odot}$.To get the mass we fitted the rotation curve of NGC 2403 to the Brandt and Belton's model(1962). The total mass was calculated as $2.1 \times 10^{11} M_{\odot}$ and the mass to light ratio M/L is 35. Fitting the Toomre's model, we can estimated the rotation velocity by Huchtmeier – which comes from the single dish observation – is quite accurate, then the rotation curve of NGC 2403 is well fitted to the Brandt and Belton's model. In this case the mass of the halo of NGC 2403 is 12 times more than the disk mass, which value is more than Turner's one(1976). If we accepts this value for halo, then NGC 2403 is the typical galaxy which has a massive halo suggested by Ostriker and Peebles (1973).

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