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PHOTOMETRIC PROPERTIES OF THE BRIGHT LENTICULAR GALAXY NGC 5102

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ABSTRACT

Using the photographic imagery of the SO galaxy NGC 5102, the equivalent luminosity profile and the fractional integrated luminosity curve have been derived. Several photometric parameters of the galaxy, such as a total magnitude (B_T), equivalent radius (r_e^*), effective surface brightness (μ_e^*), and concentration indices (C_{21}, C_{32}) were derived from the luminosity profiles. According to the decomposition method from the nonlinear least squares fitting, photometric parameters of the bulge (μ_e, r_e) and the exponential disk ($\mu(0)$, α^{-1}), and the bulge to total luminosity ratio (B/T) were obtained. The derived central disk surface brightness ($\mu(0)$ $= 22.06 \pm 0.18$ mag/□″) and the evaluated B/T ratio ($= 0.52$) of the NGC 5102 are close to the mean values ($\mu(0) = 21.65 \pm 0.3$ mag/□″, $B/T = 0.63$) of the SO galaxies. Analysis showed that a lens-like hump is embedded in the equivalent luminosity profile of the NGC 5102.

I. INTRODUCTION

The bright southern lenticular galaxy NGC 5102 ($B_T^0 = 9.86$ in Second Reference Catalogue of the Bright Galaxies (de Vaucouleurs, de Vaucouleurs and Corwin 1976: RC2)) has been classified as SAO$^-$ (de Vaucouleurs *et al.* 1976), SO_1 by Sandage and Tammann (1981), and SO by Lauberts (1982). Van den Bergh (1976) reported NGC 5102 as a classical example of SO galaxies, which consist of a bright nuclear bulge that is imbedded in a faint disk which does not show evidence for spiral structure. NGC 5102 differs, however, from old gas-free typical SO galaxies as follows.

There is a strong radial color gradient in that the nucleus is much bluer than the surrounding bulge and disk of the NGC 5102 (Freeman 1971; Alcaino 1976; van den Bergh 1976) and the integrated colors ($(B - V)_T^0 = 0.58$ and $(U - B)_T^0 = 0.19$ in RC2) are bluer than those of typical lenticular galaxies. Gallagher *et al.* (1975) have shown that the nucleus of this galaxy has an A

type spectrum, which was interpreted as the young stellar component in the nucleus. From the study of the colors in the nucleus of the NGC 5102, van den Bergh (1976) suggested that a burst of star formation, strongly concentrated toward the center of this galaxy, took place about 4×10^8 years ago. Danks *et al.* (1979) found that there are two dust lanes in the nuclear region and several patches in the disk of the NGC 5102, and they suggested that star formation apparently has been widespread in the disk over the last 10^7 years. Pritchet (1979) has obtained two color (broad band B and R) imageries of the nucleus and bulge of the NGC 5102 using a CCD as a detector, and found an isophotal twist near the nucleus of the galaxy. He suggested that this may be caused by obscuring dust, or triaxial bulge, indicating peculiar circumstances in the center of the galaxy (Williams and Schwarzschild 1979).

The aims of this paper are to provide the luminosity profile of the NGC 5102 from the central to the outer disk, and to derive the photometric parameters of the bulge and disk from the luminosity profile following the decomposition method from the nonlinear least squares fitting. The collected basic parameters of the NGC 5102 are shown in Table 1.

Table 1. Characteristics of the NGC 5102

R. A. (1950)[1]	$13^h19^m.12$	Axial ratio[2]	1.71
Dec. (1950)[1]	$-36°22'.1$	$B_T^{0\ 2}$	9.86 mag
l^1	$309°.74$	$(B-V)_T^{0\ 2}$	0.58 mag
b^1	$25°.84$	$(U-B)_T^{0\ 2}$	0.19 mag
Morphological class[1]	SAO $(T=-3)$	Distance[1]	4 Mpc
Central brightness $\mu_B(0)^2$	22.2 mag/□″	$M_{HI}/L_B{}^1$	0.12
D/B ratio[2]	4.5	$L_{IR}/L_b{}^1$	0.01
Inclination[1]	71°	L_X/L_B (0.5 − 4.5 KeV)[2]	$< 3.0 \times 10^{-5}$
P. A. of major axis[2]	48°		

[1]RC2, [2]van Driel (1987)

II. OBSERVATION AND DATA REDUCTION

The photographic plate of the NGC 5102 was taken in B (IIa-O) + GG385) at the Mt. Stromlo Observatory (MSO) with the 1 m telescope, which gives the plate scale as 25 arcsec/mm, in May 7, 1970 (Freeman 1990). The total exposure time of the plate is 3 hours and the total development time of the plate is 5 minutes in D19.

We used the Perkin–Elmer PDS microdensitometer at MSO, in density mode, to digitize the image of the NGC 5102. The plate was scanned with a 25 μm^2 aperture at the scanning speed of 5 mm/sec, stepping by 25 μm (0.625 arcsec/pixel). The resulting 1600 × 1600 array covered nearly 16′.6 × 16′.6 (40 × 40 mm^2). We reduced the array to 800 × 800 array to use it on the reduction procedures. Then each pixel of the final image array has the mean value of the four pixels around it. Figure 1 is the contour map of the NGC 5102, which includes the region brighter than 23 mag/□″. The interval of each contour is 0.5 magnitude.

To obtain the luminosity profile of the NGC 5102, we used the bright galaxy surface photo-

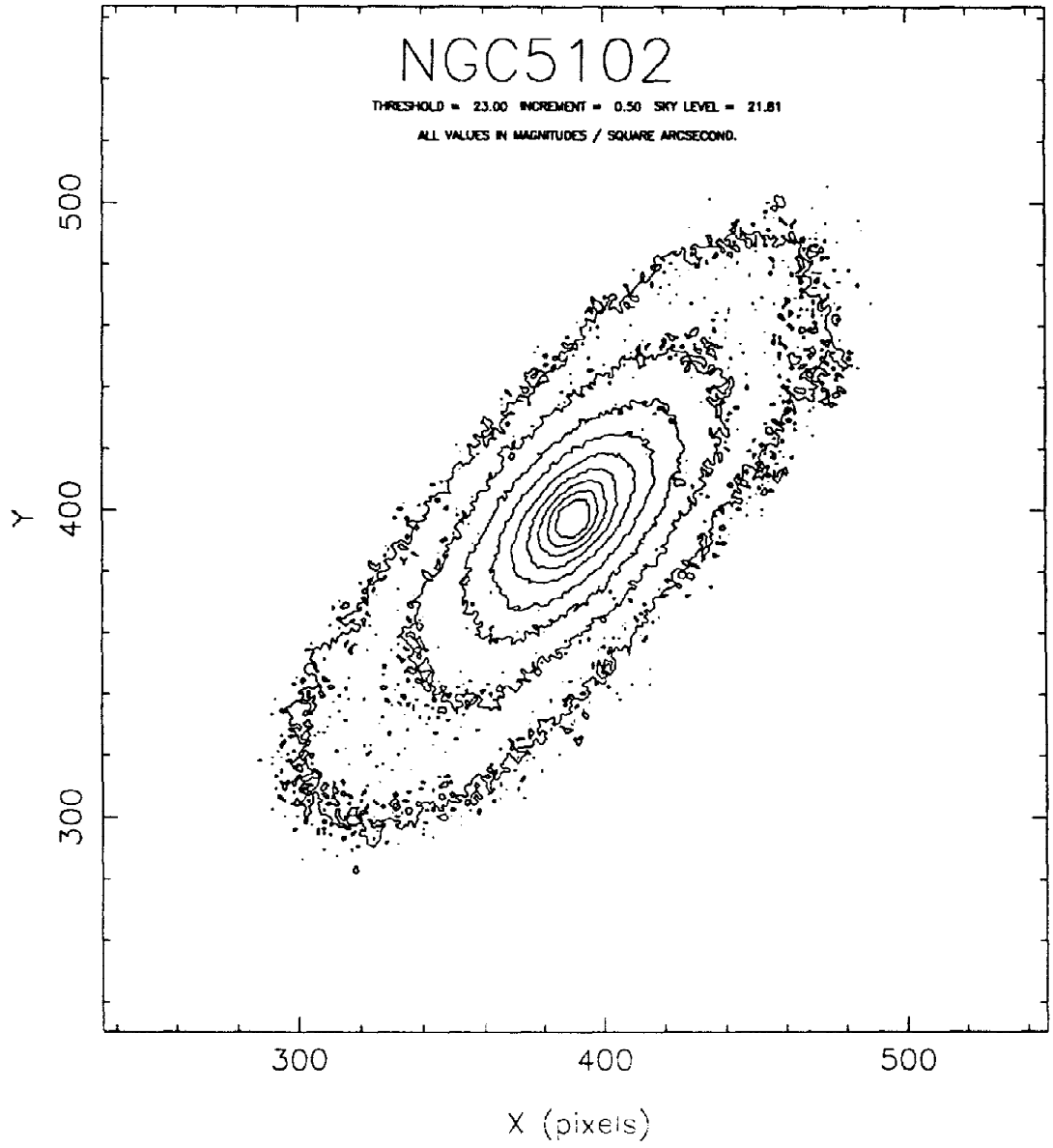

Figure 1. The contour map of the NGC 5102. The threshold value of the contour is 23 mag/□″ and the interval of each contour is 0.5 magnitude. The determined sky value is 21.81 mag/□″. The center of the image $(x_c, y_c) = (391, 398)$.

metry software package GALPHOT within Starlink. The first step in the photographic plate data reduction on this procedure was the PDS density–to–intensity calibration using the spots available for the plate. The characteristic curve (Fig. 2) was then fitted in the relative intensity to PDS density value plane with a third order polynomial. The PDS array was then converted into I_{G+S} (Galaxy + Sky) array. For a galaxy image would might be contaminated with foreground stars and the plate blemish, we removed these defects with a circular patch, which is fitted on the selected object and replace it by the mean intensity around the patch. In order to remove and

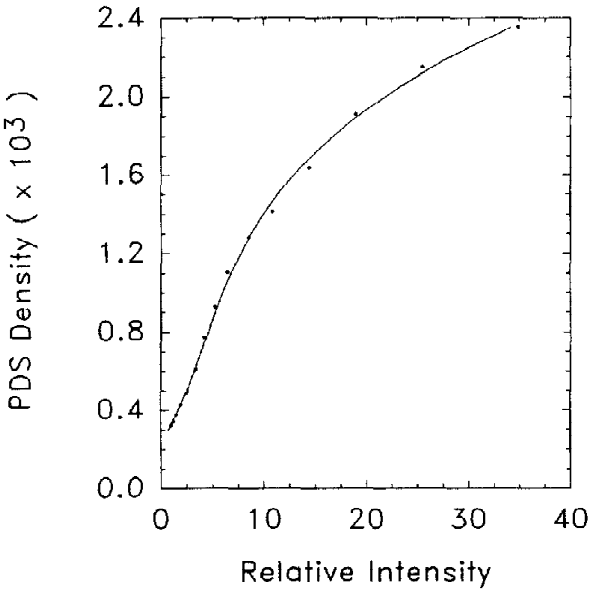

Figure 2. Characteristic curve of the plate. Relative intensities of the spots are fitted to the PDS density by a third order polynomial. Fitting coefficients $a0$, $a1$, $a2$, and $a3$ are -2.794, 1.457×10^{-2}, -1.037×10^{-5}, and 4.618×10^{-9} respectively.

1/16	1/18	1/16
1/8	1/4	1/8
1/16	1/18	1/16

(a)

1/256	1/64	3/128	1/64	1/256
1/64	1/16	3/32	1/16	1/64
3/128	3/32	9/64	3/32	3/128
1/64	1/16	3/32	1/16	1/64
1/256	1/64	3/128	1/64	1/256

(b)

Figure 3. The weighted pattern of the smoothing grid. (a) is for the 3×3 points smoothing and (b) is for the 5×5 points smoothing.

correct the background intensity variation, which show significant variations over distance of a few cm of the plate, the polynomial orders of 3 and 4 for x and y axis of the array is fitted to the background sky intensity. After these procedure, we obtained an image normalized to the intensity of the background sky as 1.0. The intensity of the sky I_s (x, y) at each point in the array was then calculated and the final intensity of the galaxy alone was given by I_G $(x, y) = \{I_{G+S}$ $(x, y) - I_S$ $(x, y)\}/I_S$ (x, y). In order to reduce the noise in the observed image, it is necessary to smooth the observed array. To do this, weighted smoothing with a Gaussian grid was used. Bright pixels close to the nucleus of the galaxy were unsmoothed, indeed smoothing here would degrade the quality of the image (Jones *et al.* 1967). The 3×3 points smoothing was applied on the moderate brightness pixels (between 20% and 5% of the night sky intensity), and the 5×5 smoothing on the faint pixels (below 5% of the night sky intensity). The weighted patterns of the smoothing grid are shown in Figure 3. To transform the relative intensity array of the image into the absolute surface brightness in mag/□″, the sky brightness was determined using the multi-aperture photoelectric data of NGC 5102 which can be found in various literatures (Table 2). The determined background sky brightness is 21.81 mag/□″.

Table 2. Photoelectric multi-aperture photometry data of the NGC 5102. The aperture diameters (A in arc min.) are listed in column 1, The B magnitude and $(B - V)$ color are listed in column 2 and 3.

$A(')$	B	$(B-V)$	$A(')$	B	$(B-V)$	$A(')$	B	$(B-V)$
0.083^{1}	13.22	0.44	0.350^{3}	11.94	0.51	0.923^{6}	11.51	0.70
0.092^{2}	13.48	0.51	0.400^{3}	11.82	0.53	0.923^{6}	11.50	0.68
0.167^{1}	12.72	0.53	0.427^{6}	12.03	0.64	0.992^{5}	11.51	0.74
0.183^{2}	12.70	0.54	0.433^{8}	12.02	0.63	1.000^{3}	11.23	0.55
0.200^{3}	12.28	0.43	0.497^{5}	11.93	0.66	1.017^{8}	11.48	0.70
0.237^{4}	12.47	0.59	0.550^{7}	11.80	0.63	1.322^{6}	11.28	0.70
0.247^{5}	12.59	0.60	0.563^{4}	11.76	0.64	1.395^{5}	11.33	0.77
0.250^{1}	12.38	0.57	0.653^{6}	11.74	0.67	1.467^{2}	11.31	0.70
0.267^{6}	12.35	0.60	0.653^{6}	11.72	0.66	1.865^{6}	11.11	0.73
0.275^{7}	12.35	0.59	0.733^{2}	11.70	0.58	1.983^{8}	11.07	0.73
0.333^{1}	12.16	0.60	0.733^{3}	11.48	0.55	1.993^{5}	11.19	0.78
0.350^{2}	12.05	0.61	0.813^{7}	11.55	0.65	2.754^{7}	10.89	0.71

1. van den Bergh (1976), 2. Alcaino (1976), 3. Dottori (1979), 4. Wegner (1979), 5. Sandage and Visvanathan (1978), 6. Griersmith *et al.* (1982), 7. de Vaucouleurs *et al.* (1978), 8. Persson *et al.* (1979).

Table 3. Equivalent luminosity profile of the NGC 5102

$r^*(")$	μ	$r^*(")$	μ	$r^*(")$	μ	$r^*(")$	μ
7.7	18.5	23.4	20.5	89.4	22.5	180.2	24.5
8.9	18.7	26.1	20.7	99.9	22.7	195.4	24.7
9.8	18.9	29.1	20.9	110.1	22.9	213.7	24.9
11.1	19.1	32.7	21.1	120.1	23.1	231.7	25.1
12.3	19.3	36.5	21.3	126.9	23.3	251.1	25.3
13.7	19.5	40.9	21.5	134.8	23.5	270.3	25.5
15.3	19.7	46.5	21.7	142.3	23.7	289.0	25.7
17.0	19.9	53.5	21.9	150.0	23.9	306.4	25.9
18.8	20.1	64.0	22.1	158.4	24.1	322.5	26.1
21.1	20.3	77.1	22.3	168.2	24.3	337.0	26.3

III. LUMINOSITY PROFILE AND PHOTOMETRIC PARAMETERS

Using the observed image, we derived the equivalent profile (de Vaucouleurs 1962) of the NGC 5102. Table 3 gives the values of the equivalent luminosity profile with the equivalent radius $r^* = (A/\pi)^{1/2}$, where A being the total area of a given isophot. If we let $\mu(r^*)$ be the surface brightness (in mag/□″) along a given isophot of the total area A, the integrated luminosity out to r^* would be expressed as

$$L(r^*) = 2\pi \int_0^{r^*} \mu(r^*) r \, dr$$

and the total luminosity of the galaxy as

$$L_T = 2\pi \int_0^\infty \mu(r^*) r \, dr.$$

Then the fractional integrated luminosity can be defined by

$$K(r^*) = L(r^*)/L_T$$

as a function of r^*.

The equivalent luminosity profile of NGC 5102 is shown in Figure 4 and the fractional integrated luminosity curve $K(r^*)$ in Figure 5. From these profiles, we obtained several photometric parameters of the NGC 5102. The total magnitude B_T was then found to be $10^m.28 \pm 0.40$. This can be compared with $B_T = 10^m.35 \pm 0.2$ given in RC2. The effective equivalent radius (r_e^*), within which the fractional integrated luminosity to the total luminosity is equal to 1/2, is 1'.38. The effective surface brightness at r_e^* is $\mu_e^* = 22.89$ mag/□". The quantities $K(r_1^*) = 1/4$ and $K(r_3^*) = 3/4$ may be used to define concentration indices $C_{21} = r_e^*/r_1^*$ and $C_{32} = r_3^*/r_e^*$ which are known to be varying systematically with morphology type (de Vaucouleurs and Agüero 1973). The concentration indices C_{21} and C_{32} for the NGC 5102 were derived as 2.42 and 1.81, respectively. These values are slightly smaller than the mean values of the lenticular galaxies (de Vaucouleurs and Agüero 1973).

Using the method of decomposition with the nonlinear least squares fitting (Kormendy 1977;

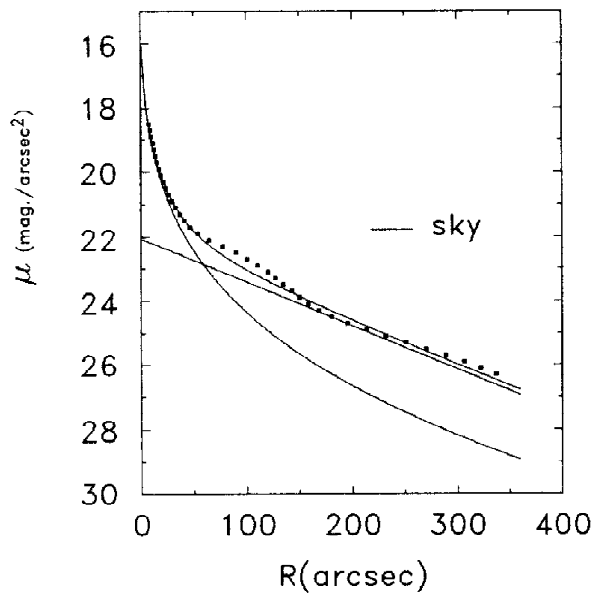

Figure 4. Equivalent luminosity profile of the NGC 5102.
Observed luminosity profile (filled squares) is decomposed into bulge and disk components, which follow a de Vaucouleurs $r^{1/4}$ and an exponential disk laws.

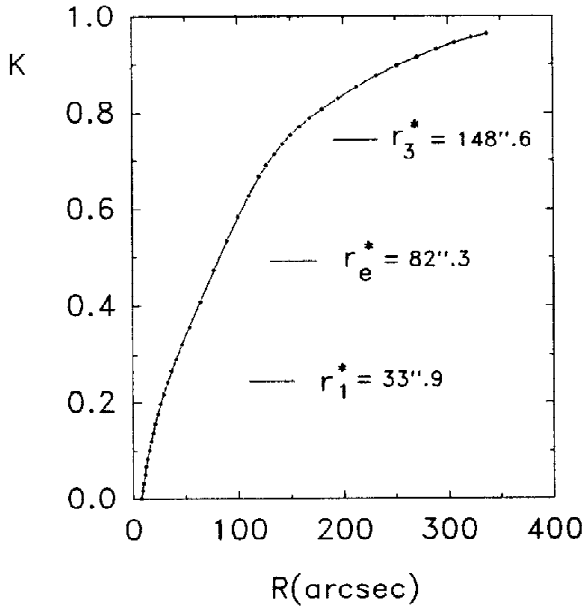

Figure 5. Fractional integrated luminosity profile of the NGC 5102.
r_1^*, r_e^*, and r_3^* are the radii, where the fractional integrated luminosity (K) to the total luminosity is equal to 1/4, 1/2, and 3/4, respectively.

Burstein 1979; Kent 1985; Schombert and Bothun 1987), we have derived photometric parameters of the bulge and disk components, assuming that they follow a de Vaucouleurs $r^{1/4}$ law and an exponential disk, respectively.

$$\mu_{\text{bulge}} = \mu_e + 8.325\ [(r/r_e)^{1/4} - 1]$$

$$\mu_{\text{disk}} = \mu(0) + 1.082\ (r/\alpha)$$

In these equations, μ_{bulge}, and μ_{disk} are the surface brightness in mag/□″ at a radius r, μ_e and $\mu(0)$ are characteristic surface brightness, r_e is the effective radius within which contain one half the total light of the bulge component, and α^{-1} is the scale length of the disk component. The observed surface brightness of each component (μ_{obs}) has been converted to a face–on surface brightness ($\mu_{\text{face–on}}$) by the equation,

$$\mu_{\text{face–on}} = \mu_{\text{obs}} - 2.5 \log (1 - \varepsilon)$$

where $\varepsilon = 1 - b/a$. In this way the contributions of the disk and the bulge components to the overall galaxy brightness distribution have been isolated. Then we can evaluate the ratio D/B of the luminosities of these two components, using the equation (Mihalas and Binney 1981).

$$D/B = 0.28\ (\alpha/r_e)^2(\Sigma_0/\Sigma_e)$$

where Σ_e is the surface luminosity at the effective radius (r_e) of the bulge and Σ_0 is the central surface luminosity of the exponential disk. We adopt the distance of the NGC 5102 as $\Delta \sim 4$ Mpc given by van Driel (1987). For the bulge component of the NGC 5102, an effective bulge radius was then obtained to be $r_e = 0.44$ kpc, and a surface brightness (μ_e) at r_e as 20.61 ± 0.36 mag/□″. For the disk component of the galaxy, a disk scale length (α^{-1}) was obtained as 1.55 kpc, and a central disk surface brightness $\mu(0)$, corrected for galactic absorption and inclination, as 22.06 ± 0.18 mag/□″, which is very close to the mean value of SOs ($\mu(0)$ = 21.65 ± 0.3 mag/□″) found by Freeman (1970). We derive a disk to bulge luminosity ratio D/B = 0.92 and a bulge to total luminosity ratio B/T = 0.52, which is comparable to the mean value (B/T = 0.63) of SO galaxies (Kent 1985). Photometric parameters of the bulge and disk of the NGC 5102 have been obtained by Yoshizawa and Wakamatsu (1974), Simien and de Vaucouleurs (1986) from Sérsic (1968) profile, and by van Driel (1987) using the Lauberts and Valentijn (1985) profile. The derived photometric parameters in this paper are listed in Table 4 with the values of others.

According to the Hubble Atlas of galaxies (Sandage 1961), the characteristic features of the SO galaxies are a bright nucleus and a central lens surrounded by a faint and sometimes extensive envelope. Kormendy (1977) has defined the lens by the following characteristics; (1) clear differentiation from the spheroid and the exponential disk, if visible; (2) a shallow brightness gra-

Table 4. Photometric parameters of NGC 5102

parameters	ref.	parameters	ref.
μ_e (mag/□″)	20.61[1]	α^{-1} (kpc)	1.55[1]
	18.83[2]		1.1 [2]
r_e (kpc)	0.44[1]		1.8 [3]
	0.28[2]	B/T	0.52[1]
	0.26[3]		0.33[2]
$\mu_B(0)$ (mag/□″)	22.06[1]		0.18[3]
	20.68[2]		
	22.2 [3]		

1. This paper
2. Yoshizawa and Wakamatus (1975)
3. van Driel (1987)

dient, possibly exponential, but only over < 1 scale length, so other fucntions may work as well; and (3) a sharp and steep outer cut off. Kormendy (1977) also suggested that lenses are distinct components in brightness distribution and seem to be morphologically intermediate between spheroids and disks. The derived luminosity profile of the NGC 5102 in this paper also shows the presence of a lens–like hump between about 60″ and 100″ of the equivalent radius, as well as the presence of a bulge and an exponential disk.

IV. CONCLUSION

With a photographic image, we derived the luminosity profiles of the NGC 5102 from the nuclear region to the outer disk. From the equivalent luminosity profile and the fractional integrated luminosity curve, we have obtained several photometric parameters, such as B_T, r_e^*, μ_e^*, and concentration indices C_{21}, C_{32}. Using the method of decomposition with the nonlinear least squares fitting, photometric parameters of bulge (μ_e, r_e) and disk ($\mu(0)$, α^{-1}), and the bulge to total luminosity ratio (B/T) were obtained. A derived central disk surface brightness ($\mu(0) = 22.06 \pm 0.18$ mag/□″) of the NGC 5102 is close to the mean value of SO galaxies ($\mu(0) = 21.65 \pm 0.3$ mag/□″) found by Freeman (1970), and the evaluated B/T ratio can be compared with the mean value ($B/T = 0.63$) of SOs (Kent 1985).

A lens–like feature in the luminosity profile of the NGC 5102 was detected between about 60″ and 100″ of equivalent radius.

REFERENCES

Alcaino, G. 1976, *Astr. Ap. Suppl.*, **26**, 261.
Burstein, D. 1979, *Ap. J.*, **234**, 435.
Danks, A. C., Laustsen, S., and van Woerden, H. 1979, *Astr. Ap.*, **73**, 247.

de Vaucouleurs, G. 1962, *in IAU Symposium 15, Problems of Extragalactic Research* (Newyork: Macmillan), p3.

de Vaucouleurs, G., and Agüero, E. 1973, *Pub.A.S.P.*, **85**, 150.

de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. 1976, *Second Reference Catalog of Bright Galaxies* (RC2).

de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. 1978, *A. J.*, **83**, 1331.

Dottori, H. A. 1979, *Astr. Ap. Suppl.*, **37**, 519.

Freeman, K. C. 1970, *Ap. J.*, **160**, 811.

Freeman, K. C., 1991, private communication.

Freeman, K. C., quoted by Eggen, O. J. 1971, *Quart. J. Roy. Astro. Soc.*, **12**, 305.

Gallagher, J. S., Faber, S. H., and Balick, B. 1975, *Ap. J.*, **202**, 7.

Griersmith, D., Hyland, A. R., and Jones, T. J. 1982, *A. J.*, **87**, 1106.

Jones, W. B., Obitts, D. L., Gallet, R. M., and de Vaucouleurs, G. 1967, *Pub. Dept. Astr. Univ. Texas, Ser II, 1, No. 8.*

Kent, S. M. 1985, *Ap. J. Suppl.*, **59**, 115.

Kormendy, J. 1977, *Ap. J.*, **217**, 406.

Lauberts, A. 1982, *The ESO/Uppsala Survey of the ESO (B) Atlas.*

Lauberts, A., and Valentijn, E. A. 1985, *New Aspects of the Galaxy Photometry*, Proc. of the Specialized meeting of the eight IAU European Regional Astronomical Meeting.

Mihalas, D., and Binney, J. 1981, *Galactic Astronomy* (San Francisco: W. H. Freeman and Company).

Persson, S. E., Frogel, J. A., and Aaronson, M. 1979, *Ap. J. Suppl.*, **39**, 61.

Pritchet, C. 1979, *Ap. J.*, **227**, 56.

Sandage, A. 1961, *The Hubble Atlas of Galaxies.*

Sandage, A., and Tammann, G. 1981, *A Revised Sharpley–Ames Catalog of Bright Galaxies.*

Sandage, A., and Visvanathan, N. 1978, *Ap. J.*, **223**, 707.

Schombert, J. M., and Bothun, G. D. 1987, *A. J.*, **92**, 60.

Sérsic, J. L. 1968, *Atlas de Galaxies Australes, Cordoba Univ. Obs.*

Simien, F., and de Vaucouleurs, G. 1986, *Ap. J.*, **302**, 564.

van den Bergh, S. 1976, *A. J.*, **81**, 795.

van Driel, W. 1987, *Ph.D. Thesis* (Univ. of Groningen).

Wegner, G. 1979, *Ap. Space Sci.*, **60**, 15.

Williams, T. B., and Schwarzschild, M. 1979, *Ap. J.*, **227**, 56.

Yoshizawa, M., and Wakamatsu, K. 1975, *Astr. Ap.*, **44**, 363.