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THE EFFECT OF THE GALAXY DENSITY ON THE FLATTENING DISTRIBUTION OF GALAXIES

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RESUMEN

La distribución del achatamiento de algunos tipos morfológicos se comparan en dos regiones con diferente densidad superficial. Primero se comparan dos distintas muestras (UGC y RC2) con cocientes axiales medidos aproximadamente en la misma banda espectral pero en diferentes niveles de isofotas. Después se analizan dos muestras UGC con diámetros medidos en dos diferentes bandas espectrales. Los resultados no muestran diferencias significativas en la distribución de cocientes axiales entre el azul y el rojo. Tampoco se han observado diferencias significativas en el achatamiento de galaxias con relación a la densidad del entorno. Por otro lado, los datos sugieren una leve tendencia a diferentes distribuciones de achatamientos según el nivel de las isofotas del mismo.

ABSTRACT

The flattening distribution of some morphological types of galaxies is compared in two regions with different surface densities. First, two different samples (UGC and RC2) with axial ratios measured roughly in the same spectral band but at different isophotal levels are compared. Then, two UGC samples with diameters measured at two different spectral bands are analysed. The results show no significant differences between the blue and red axial ratio distributions; furthermore no significant differences are observed in the galaxy flattening in relation to the environment density. On the other hand, a slight trend of different flattening distribution according to the isophotal level is suggested by the data.

Key words: **CLUSTERS-GALAXIES – GALAXIES-STRUCTURE**

I. INTRODUCTION

To date no theory describes in a consistent way the evolution of galaxies according to their morphological types. Studies on this subject are still being performed and some authors believe that the morphological type of a galaxy may vary during its dynamical evolution (Spitzer and Baade 1951; Gunn and Gott 1972; Oemler 1974; Cowie and Songaila 1977; Gregg 1989), while others believe that the morphological type is only due to the conditions prevailing during protogalaxy formation (Burstein 1979; Gisler 1980; Dressler 1980; Dressler and Sandage 1983).

Some studies have tried to investigate whether lenticulars may be created from spirals by comparing the axial ratios of these galaxies (Sandage, Freeman, and Stokes 1970; de Vaucouleurs 1974; van den Bergh 1977; Okamura *et al.* 1981; Pacheco, de Souza, and Arakaki 1983; de Souza, Vettolani and Chincarini 1985). The results are very contradictory according to the samples analysed. For example, Okamura *et al.* (1981) obtain different results according to the isophote level at which the axial ratios are measured: the distribution of intrinsic flattenings of S0 objects shows different characteristics depending upon the surface-brightness level; a distribution with one component is obtained from the data at RC1 catalogue level, $\mu_B = 23.5$ mag/arcsec^2, (de Vaucouleurs and de Vaucouleurs 1964), and that with two components at the RC2 catalogue level, $\mu_B = 25$ mag/arcsec^2 (de Vaucouleurs, de Vaucouleurs, and Corwin 1976). Also, Okamura *et al.* (1981) show that the intrinsic flattenings of spirals and lenticulars derived from the data of both catalogues, RC1 and RC2, indicate a significant difference from one another. A different result was obtained by Sandage *et al.* (1970) and van den Bergh (1977) who find a similar flattening for spirals and S0 galaxies, based on studies on the intrinsic and apparent flattening of galaxies, respectively, from an RC1 sample.

The purpose of this paper is to study the

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influence of the surface density on the apparent flattening of galaxies as well as to verify the influence of the isophote on which the axial ratios are based. Two different samples with axial ratios measured in the blue band will be compared: one using the Uppsala catalogue (UGC), μ_B = 23.5 mag/arcsec^2 (Nilson 1973), and another one using the RC2 catalogue, μ_B = 25 mag/arcsec^2. Also, the flattening distribution measured in two different bands, blue (B) and red (R), at the same isophote will be compared; none of the studies mentioned above have carried out this type of an analysis. The axial ratio measured in the B band reflects the contribution mainly of Population I stars (disk population) while in the red, the diameters reflect the spatial distribution of population II stars (halo objects). In this way, at the same time, I verify both the effect of the galaxy density on the flattening distribution of galaxies and the effect of the spectral band on this distribution. The samples and analyses of this work are presented in §II, and a discussion of the results is presented in §III.

II. THE SAMPLES AND METHODS

For every selected galaxy in the sample, I have calculated the number n of neighbours in an area of 2° × 2° centered in the object. I have followed the procedure by Pacheco *et al.* (1983) selecting objects inside two different regions: a low density medium ($n \leq 5$) and a high density one ($n \geq 10$), respectively. For the UGC galaxies the apparent magnitude was calculated using a calibration – magnitude versus angular diameter– adopted by Junqueira (1987). Objects with $m_B > 14.5$ and galactic latitude $|b| > 27.6°$ (equivalent to $|b| > 38°$ at B spectral band) were excluded in order to maintain the completeness of the sample. In addition, a culled sample was prepared excluding objects without morphological classification or with dubious morphological types. Barred and non-barred spirals were grouped together and the label Sp indicates the sum of types Sa, Sb, Sc and S. For every object, the observed axial ratio (minor diameter to major diameter), p, was estimated; for the UGC galaxies I used the R diameters and for the RC2 the B ones. A similar procedure was adopted for the RC2 objects; in this case objects with galactic latitude $|b| > 38°$ were excluded. The axial ratio interval $0 \leq p \leq 1$ was then divided into ten bins and the galaxies were counted in each bin. The frequency distribution of the different samples are given in Tables 1 and 2, which constitute the main data used in this analysis.

The projected density ratio (E + S0)/Sp for the UGC galaxies is 0.22 for objects located in a low galaxy density medium and increases up to 0.55 in the high density environment. These numbers

TABLE 1

OBSERVED FREQUENCY DISTRIBUTION OF FLATTENING FOR UGC SAMPLE[a]

P	E	S0	Sa	Sb	Sc	Sp
$n \leq 5$						
0.00–0.10	00	00	00	01	09	10
0.10–0.20	00	02	03	21	53	94
0.20–0.30	00	09	13	34	51	142
0.30–0.40	00	15	21	39	50	157
0.40–0.50	01	22	09	38	57	157
0.50–0.60	12	39	38	66	78	247
0.60–0.70	15	44	19	54	80	207
0.70–0.80	28	49	21	58	78	208
0.80–0.90	27	48	25	67	101	251
0.90–1.00	38	50	31	68	135	294
Total	121	278	180	446	692	1767
$n \geq 10$						
0.00–0.10	00	00	00	00	01	01
0.10–0.20	00	02	01	06	20	33
0.20–0.30	00	10	08	20	13	60
0.30–0.40	00	14	13	15	12	68
0.40–0.50	02	25	10	21	14	65
0.50–0.60	11	39	09	16	27	74
0.60–0.70	15	25	08	14	24	58
0.70–0.80	21	20	13	11	18	58
0.80–0.90	35	32	15	15	22	66
0.90–1.00	40	33	15	24	43	107
Total	124	200	92	142	194	590

a. The diameters are measured in R spectral band.

TABLE 2

OBSERVED FREQUENCY DISTRIBUTION OF FLATTENING FOR RC2 SAMPLE[a]

P	E	S0	Sp	P	E	S0	Sp
$n \leq 5$				$n \geq 10$			
0.00–0.10	00	00	00	0.00–0.10	00	00	00
0.10–0.20	00	01	33	0.10–0.20	00	01	02
0.20–0.30	00	11	73	0.20–0.30	00	03	17
0.30–0.40	02	21	93	0.30–0.40	00	19	12
0.40–0.50	05	19	80	0.40–0.50	02	12	11
0.50–0.60	09	25	119	0.50–0.60	02	16	16
0.60–0.70	16	29	116	0.60–0.70	08	15	08
0.70–0.80	29	42	139	0.70–0.80	05	15	10
0.80–0.90	20	46	118	0.80–0.90	15	17	14
0.90–1.00	34	37	119	0.90–1.00	24	19	06
Total	115	231	890	Total	56	117	96

a. The diameters are measured in the B spectral band.

indicate a clear morphological segregation related to the galaxy density environment, in agreement with previous findings (Oemler 1974; Dressler 1980; de Souza 1983). It is worth mentioning that some of the 2° × 2° cells with the highest number of objects coincide with positions of known clusters of galaxies as, for example, the Virgo and the Perseus clusters. A morphological segregation also occurs for RC2 galaxies.

Tables 3 and 4 give the mean axial ratio and the corresponding mean square deviation for both UGC and RC2 samples in the two adopted galaxy regions. I have applied the χ^2 test to both samples, the distribution being independent of the density considering the null hypothesis.

The analysis of the UGC sample of ellipticals does not indicate any influence of the environment on the flattening distribution. Application of the Kolmogorov-Smirnov test (KS) to this sample indicates that the null hypothesis (both distributions coming from the same parent population) cannot be discarded at a significant level of 5%. There is a slight suggestion that the S0 galaxies in the UGC sample are flatter in higher density regions; but this has a weak statistical significance since the density-independent hypothesis is rejected at the 20% level by the χ^2 test. The KS test states that the null hypothesis cannot be rejected at the 5% level. A similar conclusion was obtained for the spiral galaxies; in this case the KS test indicates that the null hypothesis cannot be discarded even at the 10% level. However, for the Sb types the UGC sample suggests a more flattened distribution in higher density region which cannot be discarded at 5% level by the KS test.

TABLE 3

MEDIAN VALUES FOR THE FLATTENING DISTRIBUTION AND VALUES FOR χ^2 TEST FROM THE UGC SAMPLE

Type	Density	$\bar{p}$	σ	χ^2	Prob.[a]
E	$n \leq 5$	0.80	0.135	2.42	< 99%
	$n \geq 10$	0.81	0.136		
S0	$n \leq 5$	0.69	0.198	13.81	< 20%
	$n \geq 10$	0.65	0.214		
Sa	$n \leq 5$	0.64	0.229	8.9	< 50%
	$n \geq 10$	0.63	0.239		
Sb	$n \leq 5$	0.63	0.241	15.54	< 10%
	$n \geq 10$	0.58	0.255		
Sc	$n \leq 5$	0.62	0.265	5.85	< 80%
	$n \geq 10$	0.62	0.270		
Sp	$n \leq 5$	0.62	0.249	18.35	< 05%
	$n \geq 10$	0.60	0.257		

a. Is the probability that the differences are due to statistical fluctuations.

TABLE 4

MEDIAN VALUES FOR THE FLATTENING DISTRIBUTION AND VALUES FOR χ^2 TEST FROM THE RC2 SAMPLE

Type	Density	$\bar{p}$	σ	χ^2	Prob.[a]
E	$n \leq 5$	0.78	0.16	10.68	< 30%
	$n \geq 10$	0.83	0.14		
S0	$n \leq 5$	0.68	0.21	8.12	< 70%
	$n \geq 10$	0.64	0.22		
Sp	$n \leq 5$	0.62	0.23	17.48	< 05%
	$n \geq 10$	0.55	0.23		

a. Is the probability that the differences are due to statistical fluctuations.

The ellipticals of the RC2 sample show a rounder distribution in higher density region; however, the KS test states that the null hypothesis cannot be discarded at the 5% level. The S0 objects belonging to this sample are more flattened in the densest region; however, the statistical significance of this result is very feeble; the KS test is rejected even at the 10% level. The spirals are also more flattened in the densest region and the KS test indicates a significance of 5%.

The possible influence of the spectral band in which the diameters are measured was studied using UGC galaxies, since diameter values in the visual and in the red band are available. A culled sample was prepared including only objects with diameters measured in both bands. These data are given respectively in Tables 5 and 6. No significant differences were found, although rounder galaxies would be expected on the red band sample, since we would expect a predominance of halo and bulge objects. In fact, the similarity of both distributions suggests that even in the red band the light of spirals is dominated by a disk population. Gregg (1989) argues that bulge-dominated S0 galaxies would have redder disks on average than the smaller systems with low values of bulge/disk, and that this effect does not occur; he claims that the value of bulge-to-disk ratio (B/D) does not seem to play a role in the determination of the content of the disks.

III. DISCUSSION

The RC2 sample is not suitable for any definite conclusion since the number of objects is not large

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TABLE 5

OBSERVED FREQUENCY DISTRIBUTION FOR GALAXIES[a]

	V			R		
P	E	S0	Sp	Sb	S0	Sp
			n ≤ 5			
0.00–0.10	00	00	11	00	00	10
0.10–0.20	00	00	86	00	01	86
0.20–0.30	00	06	107	00	04	103
0.30–0.40	00	19	120	00	15	137
0.40–0.50	04	23	157	02	24	153
0.50–0.60	04	19	133	06	17	119
0.60–0.70	16	35	183	11	40	184
0.70–0.80	16	32	132	21	34	127
0.80–0.90	25	40	205	25	42	214
0.90–1.00	26	35	188	26	32	189
Total	91	209	1322	91	209	1322
			n ≥ 10			
0.00–0.10	00	00	03	00	00	01
0.10–0.20	00	02	30	00	02	33
0.20–0.30	00	08	44	00	08	42
0.30–0.40	00	17	51	01	16	61
0.40–0.50	03	25	76	03	29	68
0.50–0.60	05	23	47	07	21	43
0.60–0.70	15	26	47	13	21	54
0.70–0.80	16	11	42	18	16	38
0.80–0.90	30	25	55	31	26	57
0.90–1.00	31	28	73	27	26	71
Total	100	165	468	100	165	468

a. The diameters are measured in *V* and *R* spectral band from the UGC subsample.

TABLE 6

MEDIAN VALUES FOR THE FLATTENING DISTRIBUTION FROM THE UGC SUBSAMPLE

		V		R	
Type	Density	$\bar{p}$	σ	$\bar{p}$	σ
E	n ≤ 5	0.80	0.141	0.80	0.132
	n ≥ 10	0.81	0.136	0.80	0.143
S0	n ≤ 5	0.68	0.203	0.69	0.195
	n ≥ 10	0.64	0.223	0.64	0.222
Sp	n ≤ 5	0.60	0.253	0.60	0.254
	n ≥ 10	0.58	0.256	0.58	0.256

enough and they are dominated by Virgo cluster galaxies. Keeping this fact in mind, if the results from Pacheco *et al.* (1983) for the spirals are compared with those from my RC2 sample, there are differences that may be related to the isophotal level in which the diameters are measured: Pacheco *et al.* do not find significant differences for these galaxies within the two density regions studied by them. Okamura *et al.* (1981) also find differences in the flattening distribution according to the isophotal level in which diameters are measured, although their conclusions are based on the intrinsic distribution of S0 galaxies using other samples (RC1 and RC2).

Are the differences among the flattening distribution of galaxies related to the time of galaxy formation or are due to the galactic evolution inside their environment? Only the ellipticals from the RC2 sample show variations that can be attributed to environmental effects. However, due to the reduced number of galaxies and the incompleteness of this sample as regards to the apparent magnitude, this result is not conclusive. In any case, the existence of a mechanism acting to make ellipticals rounder in the densest region cannot be discarded.

Concerning the S0 galaxies the situation is inverse: when the axial ratio distribution in a high density region and a low density region are compared it is found that lenticulars seem to be flatter in the densest region; although this result is not statistically significant. The same result was found by Pacheco *et al.* (1983) and de Souza *et al.* (1985); Pacheco *et al.* propose a mechanism where only the S0 galaxies located in regions of higher density have originated from spirals, most likely from Sa galaxies;de Souza *et al.* (1985) point out that their results for S0 galaxies are due to differences at the formation time of these galaxies and suggest that angular momentum and/or protogalaxy density may depend on environment at the time of formation.

The UGC sample shows a resemblance in the flattening distribution of Sb and S0 galaxies in the densest region. Bothun and Dressler (1986) suggest that the only remaining gas-rich galaxies in a cluster at the present epoch are those with small B/D ratio; as these galaxies infall into a dense intracluster medium (ICM) they are violently stripped and undergo a period of enhanced star formation. They suggest that their remnants probably increase the S0/elliptical population that dominates the core of clusters. Dressler and Gunn (1983) conjecture that Sc galaxies falling into a dense ICM would experience a sudden increase in their star formation rate (SFR). These authors give little credibility to this process due to the lack of small B/D S0 galaxies in clusters, the probable descendents of the infalling Sc objects. However, Bothun, Schommer, and Sullivan (1984) find a significant population of small B/D S0 galaxies in the Coma cluster.

Unfortunately, the results for the spirals are only marginal; moreover, the UGC and RC2 samples show different results. If the spirals are truly more flattened in denser regions, the hypothesis that S0 and spiral galaxies have a common ancestral protogalaxy (Larson, Tinsley, and Caldwell 1980) and that they evolve later differently, may be confirmed. In this case, the critical parameters of disk galaxies may depend on environment at the time of formation. On the other hand, if the flattening of spirals is insensitive to environmental density two other possibilities can be surmised:

1. S0 galaxies located in a higher density region may have originated from spirals (Pacheco *et al.* 1983; Bothun and Dressler 1986).
2. S0 and Sp galaxies have different origin. If this is the case, how did the parameters governing Hubble types at formation established a difference among S0 objects? (de Souza *et al.* 1985).

In any case, considering the results obtained here, we may conclude that there is a tendency of lenticulars with large B/D ratio, with large bulges (Dressler 1980; de Souza *et al.* 1985), or small disks (de Carvalho, da Costa, and Pellegrini 1985) to be located preferentially in rarefied regions.

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