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THE LUMINOSITY-DIAMETER RELATION FOR DISK GALAXIES IN DIFFERENT ENVIRONMENTS

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ABSTRACT

We have collected several samples of disk galaxies, in order to study, in each of them, the relation between the blue total corrected absolute magnitude and the absolute corrected isophotal diameter. These luminosity-diameter relations have been compared to detect a possible dependence on the density of the galaxy environment. No significant differences have been found among the several relations, especially if selection criteria relative to the various samples are taken into account. This result is in disagreement with several previous claims.

Subject headings: galaxies: clustering — galaxies: photometry — galaxies: structure

I. INTRODUCTION

The formation and evolution of galaxies is still an open issue, and, in particular, the influence of the environment is still poorly understood (see, e.g., Dressler 1984; Kormendy 1982). In the last few years, considerable effort has been devoted to outlining the possible correlations of the galaxy properties with local density. The aim of this paper is to gain more insight into this question by using the relationship between luminosity and the absolute diameter of galaxies (hereafter referred to as L-D relation). The tightness of this relation suggests that possible environmental effects should be detectable from the analysis of its shape in different samples. Several authors have investigated the L-D relation, generally in its logarithmic form. As far back as 1958, Holmberg gave a relationship between the surface brightness and the magnitude of galaxies in the Virgo Cluster, and used it to derive a value of the Hubble constant; later, other authors explicitly used the L-D relation in the determination of extragalactic distances (e.g., Tully 1968; Brookes and Rood 1971; Heidmann, Heidmann, and de Vaucouleurs 1972; Paturel 1978). However, Tammann and Sandage (1983) claimed that this relation is not a very effective distance indicator.

Some theoretical works have suggested that tidal truncation can have a major effect on the galaxy halos (see, e.g., Richstone 1975, 1976; Larson 1972*a*, *b*), and on the visible diameters as well. Therefore, the L-D relation was investigated to find evidence of these evolutionary processes, particularly in the rich environments of clusters of galaxies. Nevertheless, Aguilar and White (1986) have recently predicted that the tidal truncation should have a hardly detectable effect on the galaxy isophotal diameter, as it is of the order of a few percent in a Hubble time.

Gudehus (1973) analyzed the observational L-D relation in four Abell clusters, the Virgo Cluster, and two samples of nearby elliptical and lenticular galaxies, finding an environmental dependence. He did not find, however, any correlation with the cluster classification scheme (connected with the average density; see, e.g., Bahcall 1977). Strom and Strom (1978*a*) showed that the mean effective radii (at a given luminosity) of ellipticals in the Coma Cluster are larger than those of ellipticals in the field and Virgo Cluster (taken from a sample of Kormendy 1977). The same authors (Strom and Strom 1978*b*, *c*, *d*) reported that elliptical galaxies in spiral-poor clusters have, on average, smaller diameters at a given luminosity than those of galaxies in spiral-rich clusters. Moreover, they also found that the diameters of ellipticals in the central regions of the spiral-poor and cD clusters are smaller compared to those in the outer regions (Strom and Strom 1978*a*, *b*, *c*, *d*). Peterson, Strom, and Strom (1979) examined the sizes of disk galaxies in the Virgo and Hercules Clusters. They found different intercepts in the L-D relations of the Virgo and Hercules clusters: the Virgo disk galaxies appeared to have smaller diameters, for a given luminosity, by a factor as large as $\simeq 30\%$. From a statistical analysis of the optical properties of galaxies in groups, Giuricin, Mardirossian, and Mezzetti (1985) found L-D relations with shallower slopes in samples of spirals located in higher compactness groups. Bosma (1985) found an environmental dependence of the relation between the 21 cm line width and the infrared surface brightness of spiral galaxies and suggested that this effect could be explained by differences in the diameters of cluster and field galaxies. Vader (1986) detected differences in the diameter of ellipticals in the Coma and the Virgo Clusters: at a given luminosity or mass, the Virgo ellipticals were found to be more compact than Coma ellipticals. Giuricin, Mardirossian, and Mezzetti (1988) examined the L-D relation for disk galaxies in seven clusters, finding some differences. Nevertheless, they did not find a clear dependence of the L-D relation on any cluster properties.

Recently, Giuricin *et al.* (1989) used the extensive and homogeneous survey of photometric data by Burstein *et al.* (1987) to investigate the environmental dependence of the L-D relation for elliptical galaxies. They examined six clusters, a sample of galaxy pairs and the groups identified by Geller and Huchra (1983), and did not find any significant differences in the L-D relations of these samples. This result induced us to reconsider the environmental dependence of the L-D relation for disk galaxies.

In § II we describe the data samples used; § III gives a full description of the analyses performed, in order to discover any significant differences in their L-D relations, along with the results of this work; § IV provides the relevant discussion and gives our conclusions.

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II. THE DATA SAMPLES

We collected several data samples from the literature. We looked for two basic parameters, the isophotal diameter D_{25}^{0} (at the surface brightness level $\mu_B = 25$ mag sec^{-2}) and the total blue magnitude B_T^0, both corrected for the galaxy's internal extinction and our own galaxy's extinction, and (the magnitudes) for K-dimming. When only the uncorrected data were available, we followed the *Second Reference Catalogue of Bright Galaxies* by de Vaucouleurs, de Vaucouleurs, and Corwin (1976; hereafter referred to as RC2), in the application of the necessary corrections. We discarded, from our samples, any galaxy whose magnitude and/or diameter was neither corrected in the literature, nor possible to correct, for lack of some of the necessary parameters (axial ratio and radial velocity). A morphological parameter was needed to select only disk galaxies, ranging from S0 lenticulars to irregulars. The cluster galaxies were assigned the mean Hubble distance of their own cluster (we adopted the membership assignments as given in the sources of the data). The mean heliocentric radial velocity of each cluster was taken from the literature and corrected for our peculiar motion as in Chapman, Geller, and Huchra (1988). If the galaxy was part of a "field" or "group" sample and its distance was not given among the other data, we estimated it via the Tully-Fisher distance estimator (Tully and Fisher 1977), with the knowledge of the galaxy's 21 cm line width.

Bothun *et al.* (1985) and Aaronson *et al.* (1986) provides a homogeneous data set for disk galaxies in 10 clusters; we retained only seven of them, since the cluster nature of Cancer and Z74-23 has been questioned (Bothun *et al.* 1983, 1985; Aaronson *et al.* 1986), and Abell 2634/66 had not enough data available. The remaining clusters are (1) Pisces, (2) Abell 400, (3) Abell 539, (4) Abell 1367, (5) Abell 1656 (Coma), (6) Abell 2151 (Hercules), and (7) Pegasus I. From Aaronson *et al.* (1986) we collected the "revised" diameters, while the total corrected blue magnitudes were taken from Bothun *et al.* (1985), as well as the membership assignment. The mean heliocentric radial velocity of each cluster was taken from Bothun *et al.* (1985), then corrected, and finally used to compute the absolute magnitudes M_B and diameters Δ_{25}, in kpc, via the Hubble law. Values of the Hubble constant $H_0 = 100$ km s^{-1} Mpc^{-1} and the deceleration parameter $q_0 = \frac{1}{2}$ are used throughout this paper. In the following we will refer to this sample as the "AC" sample (i.e., Clusters by Aaronson *et al.* 1986), followed by a number specifying a single cluster, i.e., AC-4 will denote the cluster Abell 1367.

A very large sample of galaxies is available for our neighboring cluster, Virgo: Binggeli, Sandage, and Tammann (1985) provided data on the total blue magnitudes and the isophotal diameters D_{25} for many of the Virgo galaxies. To correct these data via the RC2 relations, we used their axial ratios, R_{25}, their coordinates and radial velocities. Only real members (according to the authors) were chosen. The galaxies were located at the cluster distance, estimated via the Hubble law by adopting the mean heliocentric velocity as given by Huchra (1985). We will label this data sample as "VC" (Virgo Cluster).

Two other nearby clusters, Fornax and Hydra, were chosen from *The Surface Photometry Catalogue of the ESO-Uppsala Galaxies* by Lauberts and Valentijn (1989; hereafter referred to as ESO). The Centaurus Cluster is also present in this catalog, yet we preferred not to include it into our analysis, as it is a superposition of two galaxy groups (Lucey and Carter 1988). We corrected the total blue magnitudes and the D_{25} diameters as in RC2, by using the radial velocities, coordinates, and axial ratios $(a/b)^0$ as listed in ESO. Only the galaxies inside the ranges in right ascension, declination, and radial velocities given in ESO were selected as cluster members. We assigned them their cluster Hubble distance, derived from the mean heliocentric velocities taken from Aaronson *et al.* (1981) for Fornax and from Richter, Materne, and Huchtmeier (1982) for Hydra. The two data samples will be referred to as "FC," and "HC," respectively.

Two samples of "field" galaxies were chosen in the literature, having 21 cm line widths, and/or distance moduli available. The first field sample was taken from Bottinelli, Gouguenheim, and Teerikorpi (1988), from RC2 we took the blue total corrected magnitudes and isophotal diameters D_{25}^0 for these galaxies, and computed their absolute magnitudes and diameters using the distance moduli obtained by the authors via the application of the infrared Tully-Fisher relation. These distances were nevertheless rescaled to the value of the Hubble constant, adopted in this paper. The second field sample was taken from Davis and Seaquist (1983); their blue total corrected magnitudes and D_{25}^0 corrected isophotal diameters were converted to absolute magnitudes and diameters, via the blue Tully-Fisher relation, as given by Bottinelli *et al.* (1987). We applied the Tully-Fisher relation only to galaxies with an inclination angle larger than 30°, as suggested by the same authors. We computed the corrected line width parameter $V_{\max}$, suitable to the application of the adopted Tully-Fisher relation, from the 21 cm line width parameter V_{25}, given by Davis and Seaquist (1983). For this purpose, we had to interpolate between two values of the "k" parameter (see Bottinelli *et al.* 1983), i.e., $k(V_{20})$ and $k(V_{40})$ to obtain $k(V_{25})$. Once again, we had to rescale the distances by using our value of $H_0 = 100$ km s^{-1} Mpc^{-1}. The two field data samples will be labeled "BF," and "DF," i.e., "Field by Bottinelli, Gouguenheim, and Teerikorpi (1988)," and "Field by Davis and Seaquist (1983)," respectively.

The choice of these samples provided a large range of galaxy densities. In order to enlarge our set of data, we examined the *Nearby Galaxy Catalog* by Tully (1988; hereafter referred to as NBG). This catalog gives the membership of galaxies in all degrees of the hierarchy, including clusters, groups, and looser environments (the very existence of "isolated' galaxies is in doubt; see Tully 1987). Futhermore, NBG lists the local galaxy density, "ρ," that gave us the possibility of dividing the galaxy environments into finer ranges of galaxy density than those provided in the usual subdivisions of "field," "groups," and "clusters." NBG collects data for several sources in the literature and applies to them the same corrections. Moreover, the catalog estimates galaxy distances, based on velocities and the model of velocity perturbations in the vicinity of Virgo (see, for details, Tully and Shaya 1984). These distances are used to derive the absolute quantities M_B and Δ_{25}. All the data necessary to our analysis were taken directly from NBG; note, however, that the absolute quantities have been scaled using our choice for H_0 (instead of $H_0 = 75$ km s^{-1} Mpc^{-1}, used in NBG). The NBG data sample will be referred as the "T" sample (from the name of the author, Tully).

A detailed list of the references to the data is given in Table 1*a* and 1*b*, for the magnitudes and the diameters, respectively: column (1) lists the sample name and column (2) the references. It can be seen that our data samples share, in some cases, the same references. Moreover, some galaxies are present in more than one sample; whenever there is a large enough superposition, we compared the corrected apparent magnitudes and diameters of different samples to check the consistency of our data. In particular, we found that the "T" sample has 89 galaxies in common with the "VC" sample, 84 with the "BF" sample, and 56 with the "DF". These "double" samples were labeled "T-VC," "T-BF," "T-DF," when extracted from the NGB, and "O-VC," "O-BF," "O-DF," when extracted from the other data samples, with "T" denoting "Tully," and "O," others.

In Figures 1*a* 1*c*, and 1*e* we plotted the differences, ΔB_T^0, between the two values of the corrected apparent magnitudes, for each galaxy in common to the "T" and "O" samples versus the average, $\langle B_T^0 \rangle$, of the two values; similar plots are shown in Figures 1*b*, 1*d*, and 1*f* for the logarithm of the corrected apparent diameter $\log D_{25}^0$. The statistical analysis confirmed the visual impression that no significant correlation is present, neither between ΔB_T^0 and $\langle B_T^0 \rangle$, nor between $\Delta \log D_{25}^0$ and $\langle \log D_{25}^0 \rangle$, so there is no strong evidence for bias. The shift in the *y*-axes, evident from the figures, is due to the different corrections applied to the data (a major source of difference being the adopted values for the absorption of our galaxy in NBG and RC2). The different corrections applied to the data, and the possible differences in the distances used to derive absolute quantities, suggested us to consider the "T" samples separately from the others.

In order to fulfill the comparative analysis of the L-D relations of these samples, we needed to know the uncertainties to be assigned to both the quantities involved in the relation. The uncertainties in the data vary according to their source; we list them Tables 1A and 1B, for the magnitudes and the diameters respectively: column (3) contains the values of the uncertainties

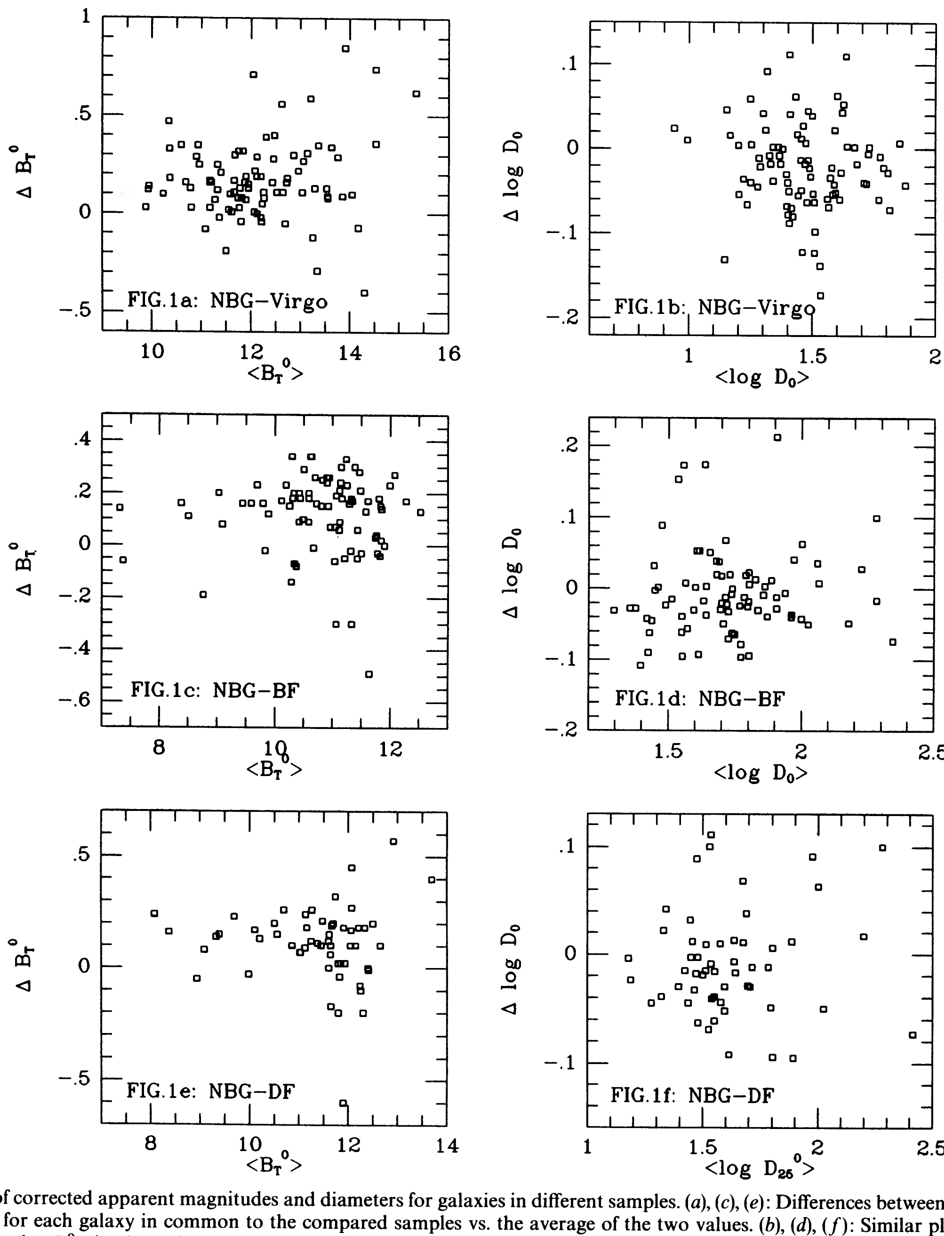

FIG. 1.—Comparison of corrected apparent magnitudes and diameters for galaxies in different samples. (*a*), (*c*), (*e*): Differences between the values of the corrected apparent magnitudes, B_T^0, for each galaxy in common to the compared samples vs. the average of the two values. (*b*), (*d*), (*f*): Similar plots of the logarithm of the corrected apparent diameter $\log D_{25}^0$, in place of the magnitude.

TABLE 1A

MAGNITUDE ERRORS

Sample (1)	Data Reference (2)	σ_{B_T} (3)	Error Reference (4)
AC	Bothun *et al.* 1985	0.2	Bothun *et al.* 1985
VC	1: de Vaucouleurs and Pence 1979	0.14	Binggeli, Sandage, and Tammann 1985
VC	2: de Vaucouleurs and Pence 1979	0.34	Binggeli, Sandage, and Tammann 1985
VC	3: Binggeli, Sandage, Tarenghi 1984	0.10	Binggeli, Sandage, and Tammann 1985
VC	4: Binggeli, Sandage, Tarenghi 1984	0.10	Binggeli, Sandage, and Tammann 1985
VC	5: Karachentsev and Karachentseva 1982	0.20	Binggeli, Sandage, and Tammann 1985
VC	6: Average from sources 1 and 4	0.26	Average error from sources 1 and 4
VC	7: Average from sources 2 and 4	0.30	Average error from sources 2 and 4
VC	8: Average from sources 5 and 4	0.27	Average error from sources 5 and 4
FC and HC	ESO	0.12	ESO
BF	RC2	0.09	RC2
DF	V: RC2	0.09	RC2
DF	H: Harvard magnitudes from RC2	0.35	RC2
DF	Z: Zwicky *et al.* 1961–1968	0.39	de Vaucouleurs and Pence 1979
T	1: Holmberg 1958	0.11	RC2
T	2: RC2	0.09	RC2
T	3: Zwicky *et al.* 1961–1968	0.39	de Vaucouleurs and Pence 1979
T	5: Harvard magnitudes from RC2	0.35	RC2
T	7: de Vaucouleurs, de Vaucouleurs, and Buta 1981	0.114	de Vaucouleurs, de Vaucouleurs, and Buta 1981

NOTES.—Col. (1): Sample identification label. col. (2): References to the magnitude data. col. (3): Error on the magnitude, σ_{B_T}. col. (4): References to the assumed error.

TABLE 1B

DIAMETER ERRORS

Sample (1)	Data Reference (2)	σ (3)	Error Reference (4)
AC	GASP: Aaronson *et al.* 1986	2".4	Cornell *et al.* 1987
AC	UGC: Aaronson *et al.* 1986	0.071	Cornell *et al.* 1987
VC	D_{25}: Binggeli, Sandage, and Tammann 1985	0.04	RC2
FC and HC	ESO	0.04	ESO
BF	RC2	0.04	RC2
DF	V: RC2	0.04	RC2
DF	U: Nilsson 1973	0.05	RC2
T	2: Nilsson 1973	0.05	RC2
T	4: Vorontsov-Velyaminov, Krasnogorskaya, and Arkipova 1962–74	0.06	RC2
T	5: de Vaucouleurs, de Vaucouleurs 1964	0.05	de Vaucouleurs and de Vaucouleurs 1964
T	6: Lauberts (1982)	0.04	ESO
T	9: Fouqué and Paturel 1983	0.027	Fouqué and Paturel 1983

NOTE.—Col. (1): Sample identification label. col. (2): References to the magnitude data. col. (3): Error on the logarithm of the diameter, $\sigma_{\log D_{25}}$, or error in arcsec on the diameter, $\sigma_{D_{25}}$, when the value has the superscript ", Col. (4): References to the assumed error.

on magnitudes (Table 1A) and the log D_{25} (Table 1B, except when the value has the superscript ", in which case the error is in seconds of arc on D_{25}; column (4) lists the reference to the paper from which we took the estimates of the uncertainties. The uncertainties listed do not include the errors in the distance estimates; these are negligible compared with the data uncertainties, when one is dealing with galaxies in the same cluster. As far as the field galaxies are concerned, we assumed distance errors = 20%, typical of good distance estimates from the Tully-Fisher relation (see, e.g., Bottinelli *et al.* 1983; Bertschinger *et al.* 1990; Biviano *et al.* 1990). No error was assigned to the distance estimates in NBG, because the various subsamples we compared would be equally affected by these errors, and we are not interested in the absolute values of the parameters of the L-D relation; moreover, an estimate of this error is not a trivial task. Table 2 lists the mean distances of the clusters considered in our analusis: column (1) lists the cluster name, column (2) its mean radial heliocentric velocity, $V_{\odot}$, column (3) the distance-modulus derived via the Hubble relation, using the velocity given in column (2) after the application of the corrections for the local motions. See Tully (1987) for the NBG clusters.

TABLE 2

CLUSTER PARAMETERS

Cluster Name (1)	$\langle V_{\odot} \rangle$ (2)	Distance Modulus (3)
Virgo	1150	30.54
Pisces	5271	33.64
Abell 400	7240	34.28
Abell 539	8535	34.64
Abell 1367	6426	34.09
Coma	6950	34.27
Abell 2151	10998	35.24
Pegasus	4168	33.10
Abell 2634/66	8936	34.78
Fornax	1340	30.17
Hydra	3707	32.78

II. COMPARATIVE ANALYSES: RESULTS

We investigated the L-D relation in its logarithmic form, M_B versus log Δ_{25}. To each data sample we fitted the straight regression line, obtained via the least-squares method applied to data affected by errors on both axes (see Guest 1961; for a recent astrophysical application, see, e.g., Biviano *et al.* 1990). In this way we appropriately weighted each datum, according to its internal accuracy. The comparison of different lines was given a statistical meaning via the use of two tests: the Welch test, that applies when only two lines are involved, and the homogeneity (or variance ratio) test, which applies in all other cases (see, e.g., Guest 1961; for recent astrophysical applications, see, e.g., Giuricin *et al.* 1989; Biviano *et al.* 1990). These tests yielded the probabilities "P(q)" and "P(p)" that the differences in the intercepts and slopes of the compared fitting lines are significant.

The results of the line fitting have been collected in Table 3: column (1) lists the sample identification label; column (2) lists the number of galaxies considered in the sample; column (3) lists the value of the intercept q of the regression line fitted to the data, M_B versus log Δ_{25}, followed by its associated error σ_q in parentheses; column (4) lists the value of the slope p of the same regression line, followed by its associated error σ_p, in parentheses; column (5) gives a few words of comment to allow an easier identification of the sample considered. The results of the comparison analyses have been listed in Table 4: column (1) lists the progressive number of the results obtained, column (2) lists the samples that have been compared, columns (3) and (4) list the values of $P(q)$ and $P(p)$ in percent obtained via the use of the homogeneity test or the Welch test; column (5) gives a few words of comment to allow an easier identification of the samples involved in the analysis performed.

a) *The Cluster Environments*

We started by comparing Aaronson's clusters. They span the whole range of galaxy densities typical of a cluster environment: from a loose cluster, like Pisces, to a rich one, like Coma. It is evident from result No. 1 in Table 4 that the homogeneity is quite large; nevertheless, the lines fitted to the data samples with very few galaxies have a low statistical significance (see

TABLE 3

RESULTS OF THE LINE-FITTING

Sample (1)	No. of Gal. (2)	$q(\sigma_q)$ (3)	$p(\sigma_p)$ (4)	Notes (5)
AC-1	18	−11.9(1.6)	−5.9(1.3)	Pisces cluster
AC-2	7	−15.3(1.6)	−3.4(1.2)	Abell 400 cluster
AC-3	5	−17.3(2.8)	−2.7(2.2)	Abell 539 cluster
AC-4	17	−14.3(0.8)	−4.2(0.7)	Abell 1367 cluster
AC-5	12	−13.7(4.2)	−4.6(3.1)	Coma cluster
AC-6	8	−15.7(1.9)	−3.2(1.4)	Abell 2151 cluster
AC-7	19	−12.8(1.2)	−5.0(1.1)	Pegasus I cluster
VC	177	−12.5(0.1)	−5.7(0.2)	Virgo cluster
VC-I	48	−12.5(0.2)	−5.8(0.2)	Virgo, inner shell
VC-M	29	−12.5(0.2)	−5.8(0.2)	Virgo, middle shell
VC-O	29	−12.5(0.3)	−5.7(0.4)	Virgo, outer shell
HC	83	−13.8(0.3)	−4.7(0.2)	Hydra cluster
HC-I	25	−13.2(0.4)	−5.2(0.4)	Hydra, inner shell
HC-M	29	−14.2(0.4)	−4.4(0.4)	Hydra, middle shell
HC-O	29	−14.1(0.5)	−4.4(0.4)	Hydra, outer shell
FC	58	−12.9(0.2)	−5.5(0.2)	Fornax cluster
FC-I	31	−12.7(0.2)	−5.8(0.3)	Fornax, inner shell
FC-MO	27	−13.1(0.2)	−5.3(0.3)	Fornax, middle/outer shell
BF	86	−13.1(0.3)	−5.4(0.3)	Bottinelli, Gouguenheim, and Teerikorpi (1988) field
DF	70	−13.7(0.4)	−4.7(0.3)	Davis and Seaquist (1983) field
DF-N	56	−13.2(0.5)	−5.1(0.4)	Davis and Seaquist (1983) field, Nearby sample
TC-1	100	−12.9(0.3)	−5.5(0.3)	NBG cluster Virgo
TC-2	54	−12.0(0.7)	−6.1(0.7)	NBG cluster Ursa Major
TC-3	19	−13.9(0.3)	−4.3(0.3)	NBG cluster Coma I
TC-4	13	−12.3(1.2)	−5.7(0.9)	NBG cluster NGC 5371
TF	520	−12.5(0.1)	−5.6(0.1)	NBG field galaxies
TG	758	−12.2(0.1)	−5.8(0.1)	NBG group galaxies
TC	238	−13.0(0.2)	−5.4(0.2)	NBG cluster galaxies
Tρ-8	396	−12.4(0.2)	−5.7(0.2)	NBG, log $\rho \leq -8$
Tρ-6	354	−12.6(0.2)	−5.6(0.2)	NBG, $-8 < \log \rho \leq -6$
Tρ-4	278	−12.1(0.2)	−5.9(0.2)	NBG, $-6 < \log \rho \leq -4$
Tρ-2	193	−12.4(0.2)	−5.7(0.2)	NBG, $-4 < \log \rho \leq -2$
Tρ0	122	−13.0(0.3)	−5.3(0.3)	NBG, $-2 < \log \rho \leq 0$
Tρ+	173	−12.6(0.3)	−5.7(0.3)	NBG, log $\rho > 0$
O-VC	89	−12.5(0.3)	−5.7(0.3)	Virgo double
O-BF	84	−13.4(0.4)	−5.0(0.4)	Davis and Seaquist (1983) field double
O-DF	56	−13.1(0.3)	−5.4(0.3)	Bottinelli, Gouguenheim, and Teerikorpi (1983) field double
T-VC	89	−12.7(0.4)	−5.6(0.4)	NBG Virgo double
T-BF	84	−13.2(0.3)	−5.2(0.3)	NBG Davies and Seaquist (1983) field double
T-DF	56	−12.3(0.5)	−5.9(0.4)	NBG Bottinelli, Gouguenheim, and Teerikorpi (1988) field double

NOTES.—Col. (1): Sample identification label. Col. (2): Number of galaxies in the sample. Col. (3): Intercept of the fitted line, q, and its associated error, σ_q, in parentheses. Col. (4): Slope of the fitted line, p, and its associated error, σ_p, in parentheses. Col. (5): Notes on the samples considered.

TABLE 4

RESULTS OF THE COMPARATIVE ANALYSES

Result no. (1)	Samples considered (2)	$P(q)$ (3)	$P(p)$ (4)	Notes (5)
1	AC-1, AC-2, AC-3, AC-4, AC-5, AC-6, AC-7	3.0	1.2	Aaronson *et al.* (1986) clusters
2	AC-1, AC-4, AC-5, AC-7	7.1	5.2	Well-sampled Aaronson *et al.* (1986) clusters
3	VC-I, VC-M, VC-O	0.3	0.6	Virgo Cluster galaxies in different shells
4	HC-I, HC-M, HC-O	51.4	51.3	Hydra Cluster galaxies in different shells
5	FC-I, FC-MO	88.2	89.4	Fornax Cluster galaxies in different shells
6	AC-1, AC-4, AC-5, AC-7, VC, HC, FC	73.0	60.8	All well-sampled clusters
7	BF, DF	88.6	95.8	Field samples
8	BF, GF-N	57.1	70.8	Bottinelli, Gouguenheim, and Teeikorpi (1988) field and nearby galaxies in Davis and Seaquist (1983) field
9	AC-1, AC-4, AC-5, AC-7, VC, HC, FC, BF, DF	84.9	75.9	All clusters and field samples
10	TC-1, TC-2, TC-3, TC-4	58.1	58.6	NBG clusters
11	TF, TG, TC	50.7	32.5	NBG galaxies in the field, groups and clusters
12	Tρ-8, Tρ-6, Tρ-4, Tσ-2, Tρ0, Tρ+	5.7	1.2	NBG galaxies at different local densities
13	O-VC, O-BF, O-DF	61.2	54.1	Double samples
14	T-VC, T-BF, T-DF	25.1	19.4	NBG double samples

NOTES.—Col. (1): Progressive numbers. col. (2): Samples compared. col. (3): Probability $P(q)$ in percent that the values of the intercepts of the compared fitting lines are not all estimates of the same intercept. col. (4): Probability $P(p)$ in percent that the values of the slopes of the compared fitting lines are not all estimates of the same slope. col. (5): Notes on the samples considered.

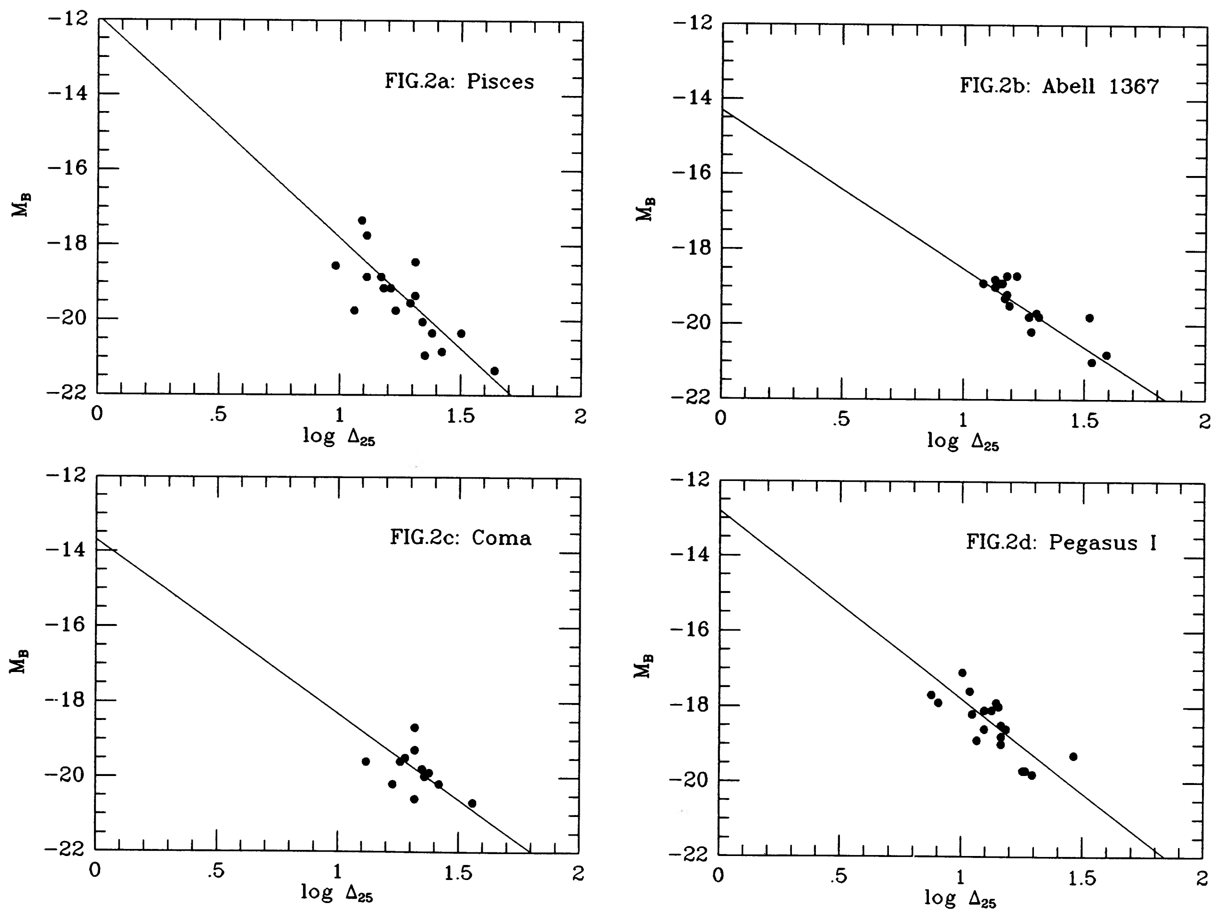

FIG. 2.—(*a*)–(*d*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): clusters by Aaronson *et al.* (1986); solid lines are the lines fitting the data.

Table 3), so, hereafter, in our analysis we will consider only samples containing at least 10 galaxies. Table shows that the homogeneity still holds for the four most populous samples only (see result No. 2). In Figures 2*a*–2*d* we plotted these data samples and their fitting lines.

We next considered the Virgo Cluster sample. The VC data sample being large enough, we subdivided it into three subsamples of galaxies located at different projected distances from the cluster center. In this way, we selected regions of different average galaxy densities. We labeled as "VC-I," "VC-M," "VC-O," the subsamples of galaxies in the inner, middle, and outer shells, respectively, defined by these limits:

1. inner shell, dist ≤ 0.5 Mpc;
2. middle shell, $0.5 <$ dist ≤ 1 Mpc;
3. outer shell, dist > 1 Mpc;

where "dist" is the distance from the cluster center, projected onto the plane of the sky. The three subsamples showed extremely similar L-D relations (see Table 3 and result No. 3 of Table 4). The subsamples are shown in Figure 3, plotted with different symbols; the fitting the whole data sample is also plotted.

The same partition was made for the samples HC and FC. Note, however, that since no more than four galaxies were present in the FC-O subsample, we linked it to FC-M: the combined sample was named FC-MO. Again, no significant differences are present (see Table 4, results Nos. 4 and 5; the subsamples are plotted in Figs. 4*a*, 4*b*).

Next we compared the well-sampled clusters all together: AC-1, AC-4, AC-5, AC-7, VC, HC, FC. The homogeneity was not found to be as large as for the AC samples alone (compare, in Table 4, results Nos. 2 and 6); this was to be expected, when comparing samples taken from different authors, who selected and corrected data in different ways. Nevertheless, the differences were not significant.

b) The Field Environments

The comparison of the two field samples showed a partially significant difference in the slopes (at the 96% confidence level; see Table 4, result No. 7). We noted that the DF sample had more galaxies of very large luminosities and diameters than the BF sample (see Figs. 5*a*, 5*b*, plotting the two data samples and their fitting lines). The difference is amenable to a selection bias in the sample compilation; in fact, the DF sample is partially made up of data from the *Uppsala General Catalogue of Galaxies* by Nilson (1973; hereafter referred to as UGC), a diameter-limited catalog. Hence, if the L-D relation for disk galaxies has an intrinsic scatter, the diameter selection by UGC will choose galaxies that are large for their magnitude. Since the observed diameter is a distance-dependent quantity, this bias is stronger for more distant galaxies. We then tried to overcome this problem by discarding the more distant galaxies of the DF sample, i.e., galaxies with $V_{\odot} > 2400$ km s^{-1}, the same upper limit on radial velocity as in the BF sample. This DF restricted sample was labeled "DF-N" (the suffix "-N" indicates the selection of "nearby" galaxies only in the sample). The result of the comparison of BF and DF-N can be seen in the relevant tables (see result No. 8): no significant difference was left (see also Figs. 5*a*, 5*b*: the dashed line in Fig. 5*b* is the line fitting the data sample DF-N).

The L-D relations of the field samples were found to be homogeneous also with those of the clusters: the homogeneity test yielded no significant values of $P(q)$ and $P(p)$ ($<90\%$; see result No. 9 in Table 4).

c) The NBG Sample

We considered the T sample separately, since it is a homogeneous sample (as explained in the previous section). We started by considering the clusters identified by Tully (1987) in NBG. Only 10 samples had sufficient data to allow us to perform our analysis, and, of these, four had more than 10 galaxies, i.e., clusters (1) Virgo, (2) Ursa Major, (3) Coma I, (4) NGC 5371. The cluster samples were found to be homogeneous in their L-D relations (see results No. 10 in Table 4; the cluster samples have been labelled "TC-j," with $j = 1, \ldots, 4$). Figures 6*a*–6*d* show the data samples and the corresponding fitting lines. Including the other six clusters with few data did not affect this result.

Since all the cluster samples were found to be homogeneous, we felt confident to combine their data in a single sample of cluster galaxies, labeled "TC," We compared it with a sample collecting all the galaxies located in groups, labeled "TG,"

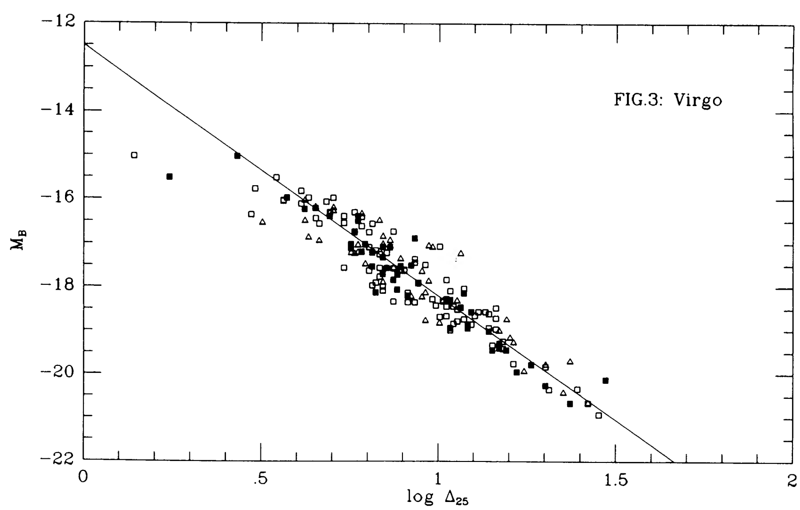

FIG. 3.—Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): Virgo Cluster; filled squares, open squares, open triangles represent galaxies in the inner, middle, and outer shells, respectively; solid line is the line fitting the whole sample.

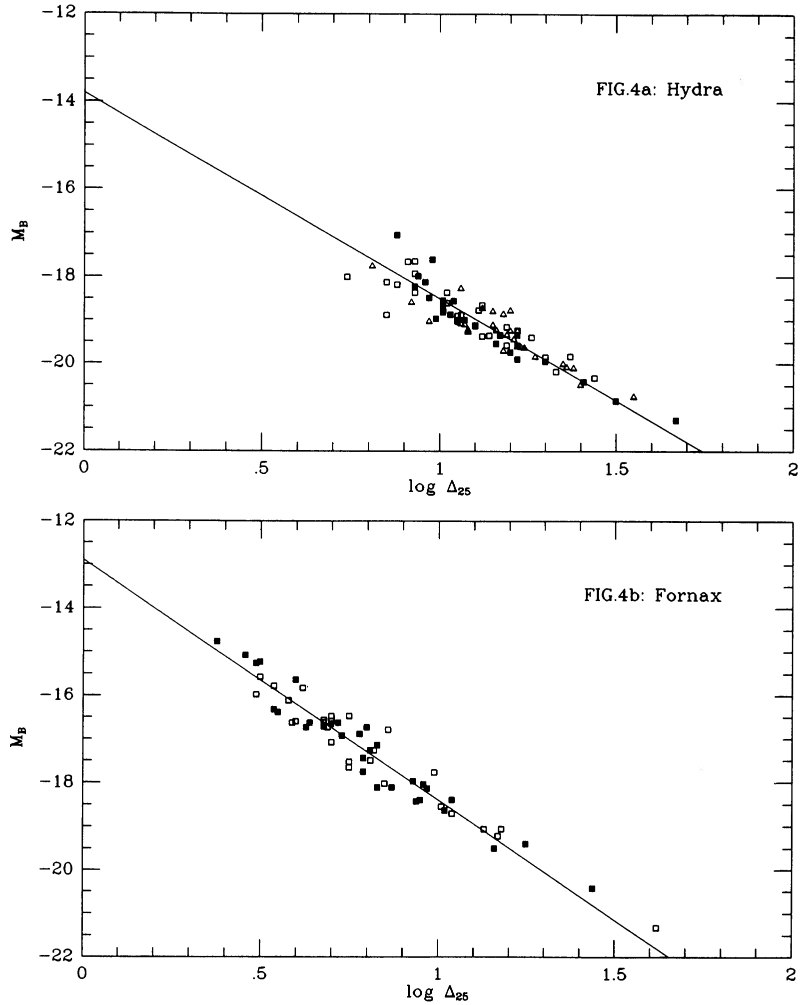

FIG. 4

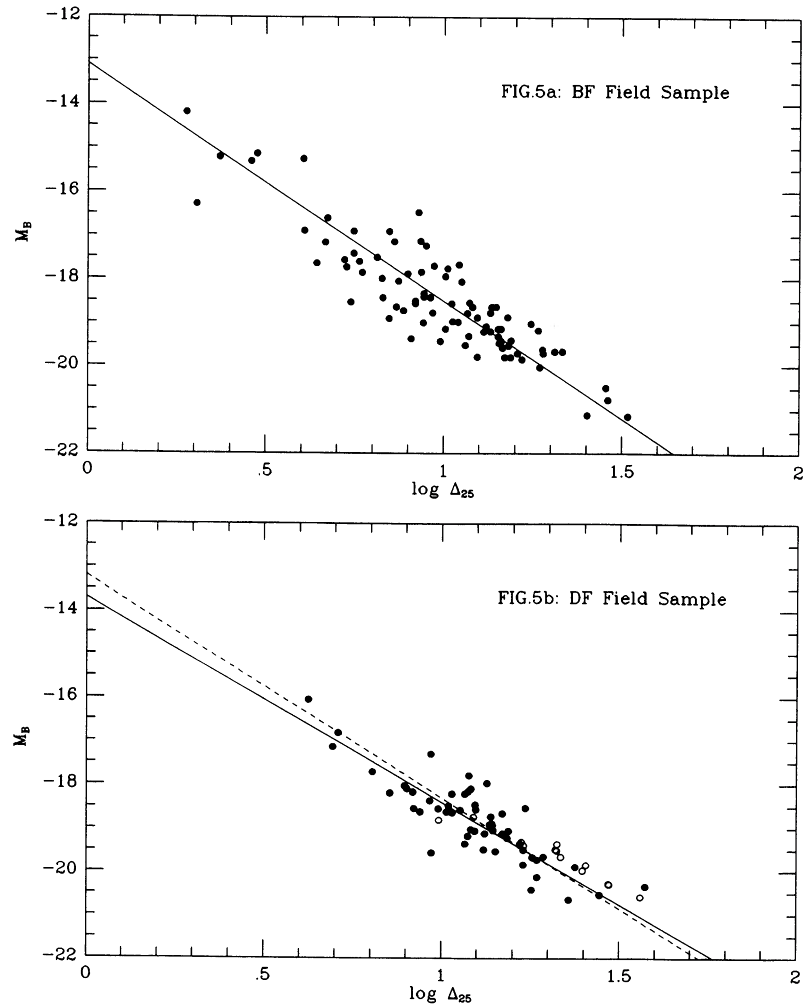

FIG. 5

FIG. 4.—(*a*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): Hydra Cluster; filled squares, open squares, open triangles represent galaxies in the inner, middle, and outer shells, respectively; solid line is the line fitting the whole sample. (*b*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): Fornax Cluster; filled squares and open squares represent galaxies in the inner and middle-outer shells, respectively; solid line is the line fitting the whole sample.

FIG. 5.—(*a*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): field sample of Bottinelli, Gouguenheim, and Teerikorpi (1988); solid line is the line fitting the data. (*b*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): field sample of Davis and Seaquist (1983); filled and open circles represent galaxies with radial velocities, respectively, lower and larger than 2400 km s^{-1}. The solid line is the line fitting the whole sample, the dashed line is the line fitting the sample of nearby galaxies only.

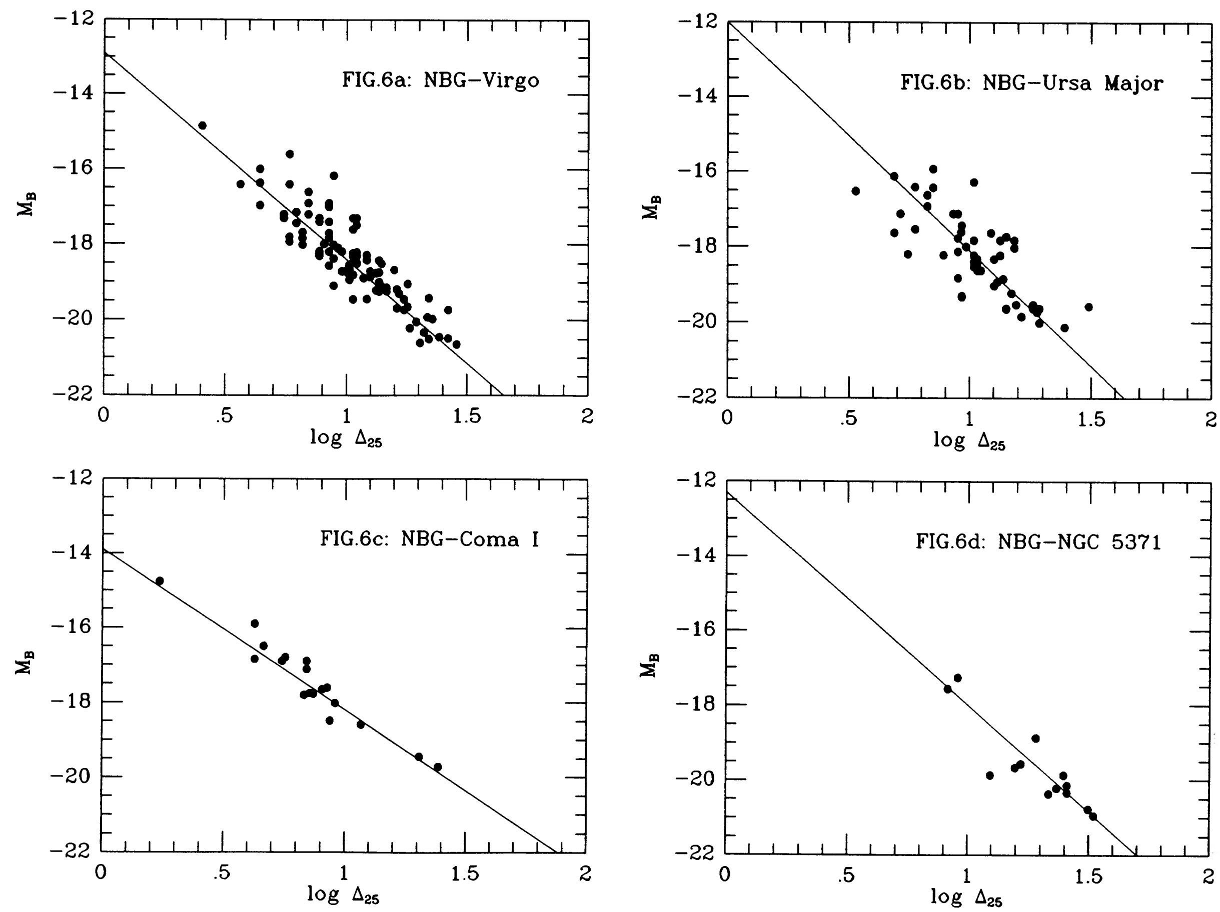

FIG. 6—(*a*)–(*d*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): NBG clusters; solid lines are the lines fitting the data

another sample of " field " galaxies, formed of all galaxies which are neither cluster nor group members; we labeled this sample "TF." These samples have significantly different mean densities $\langle\rho\rangle$

$$\langle\rho\rangle = \begin{cases} 1.74 \pm 0.07 & \cdots \text{ TC sample ,} \\ 0.32 \pm 0.01 & \cdots \text{ TG sample ,} \\ 0.21 \pm 0.01 & \cdots \text{ TF samples ,} \end{cases} \tag{1}$$

in units of galaxies Mpc^{-3} (see NBG). The values of the line parameters are listed in Table 3, and the result of the homogeneity test is given Table 4; the three subsamples are plotted in Figures 7*a*–7*c*, with the respective fitting lines.

Since NBG lists the local density of every galaxy, we examined a finer subdivision into ρ than the one considered previously. We divided the whole sample into intervals of values of log ρ, chosen in order to keep a (similar) large enough amount of data in each subsample. We have labeled these subsamples as follows:

1. "Tρ-8": galaxies with $\log\rho \leq -8$;
2. "Tρ-6": galaxies with $-8 < \log\rho \leq -6$;
3. "Tρ-4": galaxies with $-6 < \log\rho \leq -4$;
4. "Tρ-2': galaxies with $-4 < \log\rho \leq -2$;
5. "Tρ0": galaxies with $-2 < \log\rho \leq 0$;
6. " $T\rho$ + ": galaxies with $\log\rho > 0$.

The comparison of these subsamples showed a very high degree of homogeneity (see Table 3 for the values of the fitting line parameters, and Table 4 for the results of the homogeneity test); the probability that these lines are not sample estimates of the same "true" line is less than 10%. The similarity of the L-D relations can be appreciated by looking at Figures 8*a*–8*f*, where these data samples are plotted.

d) *Inhomogeneity Effects*

We thought it likely that part of the differences observed in the L-D relations of different samples could be ascribed to differences in the criteria used for selection and reduction of the data. In order to verify this, we compared the "double" samples "O-VC," "O-BF," "O-DF," with each other and, separately, the "double" samples "T-VC," "T-BF," "T-DF," with each other. These samples contain the same galaxies (see § II), yet the data in the "T" samples are taken from the same catalog (NBG), while this is not true for the data in the "O" samples. Hence, the absolute corrected magnitudes and diameters of the "T" samples have been obtained from the observed quantities in a more homogeneous way.

The comparisons showed that, although the values of the line parameters did not change very much from the "O" to the "T" samples (see Table 3), the homogeneity was larger in the "T" samples (compare, in Table 4, result Nos. 13 and 14). Thus, it is possible that part of the differences in the L-D relations arose because of the inhomogeneity of the data samples.

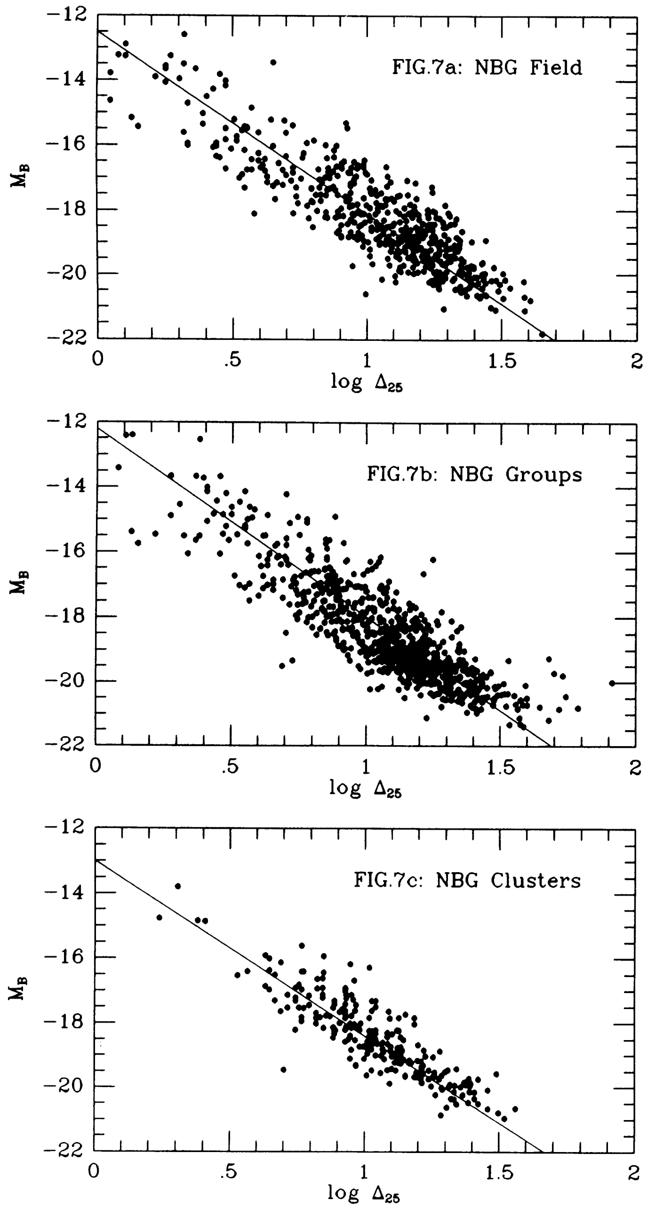

FIG. 7.—(*a*)–(*c*) Absolute total blue magnitude vs. logarithm of the isophotal absolute diameter in (kpc): NBG galaxy samples in the field, groups, and clusters; solid lines are the lines fitting the data.

IV. DISCUSSION

We analyzed the L-D relation for samples of galaxies located in environments of different densities. The differences among the different relations were not found to be statistically significant. This result applies both to the cluster environments alone and to the field, group, and cluster environments taken together. In the same cluster different regions can have different mean densities, so we also compared the L-D relation for galaxies located at different distance from their cluster center; again, a large homogeneity was found. When we used the local density parameter to discriminate among different environments, the L-D relations showed no differences either. These results showed that any possible environmental effect is not strong enough to affect significantly the L-D relation for disk galaxies in the samples used in the present paper.

A short discussion is needed regarding the previous findings concerning the L-D relation for disk galaxies. In particular, we note that our conclusion disagrees with the results obtained by Peterson, Strom, and Strom (1979) and Giuricin, Mardirossian, and Mezzetti (1985, 1988). The poor sample statistics can be thought to affect the significance of the result obtained by Peterson, Strom, and Strom (1978), their sample being composed of ≈ 30 galaxies at most for each of the two clusters considered. Moreover, they did not take into account the data errors in fitting the L-D relations to their samples, thus underestimating the errors associated with the parameters of the fitted lines. As a consequence, they probably amplified the significance of any existing difference.

On the other hand, Giuricin, Mardirossian, and Mezzetti (1988) dealt with a considerable amount of data, yet their samples were taken from a large variety of references, and thus are likely to be quite inhomogeneous. A large inhomogeneity can be responsible for the differences observed; in fact, the results of the previous section made it clear that the inhomogeneity in the L-D relations decreased when samples taken from the same authors were considered. In particular, we noted that the "double' samples taken from different authors yielded a lower degree of homogeneity than the "double" samples taken from NBG only; i.e., the comparison of inhomogeneous data samples is likely to increase the inhomogeneity in the L-D relations as well. Moreover, the test used by Giuricin, Mardirossian, and Mezzetti (1988), the Welch test, is not well suited for the comparison of more than two samples; the homogeneity test is certainly more appropriate, since it does compare the whole distribution of different values, and not only its tails.

A similar argument can be used to discuss the results obtained by Giuricin, Mardirossian, and Mezzetti (1985). They used a single galaxy catalog (i.e., the group catalog by Geller and Huchra 1983), so that inhomogeneities in the data should be reduced (although the basic parameters, magnitudes and diameters have been selected from several sources). Nevertheless, their results (regarding the L-D relations for samples of groups with different compactness) lose significance when the more appropriate homogeneity test is used, instead of the Welch test.

Our results are based on a large amount of data for galaxies spanning a wide range of galaxy densities; the statistical tools we used are well suited to the task of comparing many L-D relations. Our data samples are not highly homogeneous; nevertheless, the analyses limited to the more homogeneous samples (e.g., different shells in the same cluster) are in accordance with the overall conclusion. Moreover, any possible inhomogeneity is likely to induce, not to reduce, differences in the L-D relations, whereas we have not found any significant differences in our samples, so we are led to say that any difference in the L-D relations can be ascribed to differences in the sample selection criteria, and/or to a incorrect choice of the statistical tool used in the comparison analyses.

Our result can be restated by saying that the environment has a negligible effect on the L-D relations, either because these are physically unaffected by the local density, or because the scatter in the relations is too large and the accuracy in the data is too low, to allow us to detect any significant deviation from sample to sample. Lastly, we may remark that our conclusion on disk galaxies is in line with the recent finding by Giuricin *et al.* (1989) on elliptical galaxies and the theoretical work by Aguilar and White (1986); these results, taken together, seem to

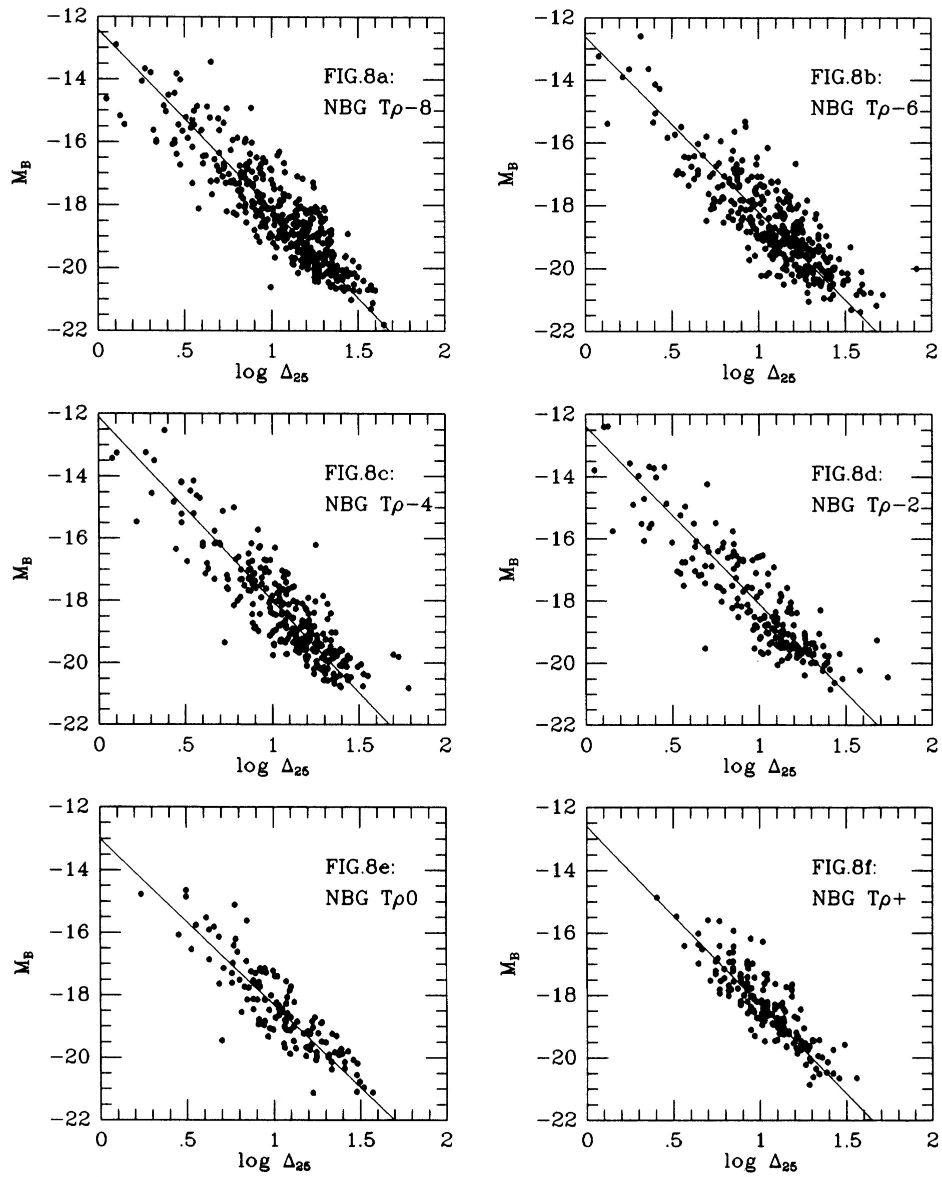

FIG. 8.—(*a*)–(*f*) Absloute total blue magnitude vs. logarithm of the isophotal absolute diameter (in kpc): NBG galaxy samples at different mean local densities, with density increasing from Fig. 7*a* to Fig. 7*f* (see text for further details). Solid lines are the lines fitting the data.

constrain previous claims for environmental effects to a lower level of significance.

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