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ANALYZING THE DRESSLER CATALOG USING THE POINTWISE DIMENSION

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ABSTRACT

In this paper I explore the application of the pointwise dimension as a large-scale structure descriptor to the Dressler catalog. This technique has been particularly illuminating in the study of correlations between morphology and environment, and its application to the familiar problem of morphology-environment relationships offers new insights. An examination of the 55 clusters in the Dressler catalog (each cluster containing between ~ 40 and ~ 250 galaxies with morphology information) finds that for the combined Dressler data, Komolgorov-Smirnov tests show that the environments of the early-type galaxies are statistically different to the 99% level from the environments of the late-type galaxies. This result is in agreement with the general concept of a morphology-density relationship. Furthermore, 14 individual clusters were examined; these clusters had velocities determined for many of the individual galaxies. These velocities were used solely to determine cluster membership. Each of these 14 clusters showed very few of the statistical differences between morphological environments that characterized the combined Dressler catalog. This contradiction found between the combined sample (for which foreground members were not removed) and these individual clusters (for which contamination was seriously reduced) suggests that the morphology-density relationship is not applicable to at least one-quarter of the clusters from which the result was credited in the first place (and in which the relationship should therefore be most evident), and it is therefore not as fundamental a relationship as has been previously assumed.

Subject headings: galaxies: clusters: general — galaxies: structure — methods: statistical

1. INTRODUCTION

For some time it has been known that the morphological fractions of elliptical, lenticular, and spiral galaxies are related to the density of the environment (Hubble & Humason 1931). The fraction of elliptical galaxies ranges from less than 10% in the lowest density environments to more than 50% in the centers of galaxy clusters (Dressler 1980a). It is still not apparent whether this is a result of conditions conducive to formation of a particular morphological type (nature) or to an evolutionary process (nurture). Of course, implicit in this relationship is that the environments of different morphologies are significantly different.

One general type of nature scenario (Zurek, Quinn, & Salmon 1988) requires that the star formation rate depends on the level of the density fluctuation that forms a galaxy. An elliptical galaxy results from a large fluctuation in which stars deplete the gas before it can form a disk. Nurture scenarios have been devised to account for galaxy evolution from spiral-type to elliptical-type, as well as in the opposite direction. For instance, a spiral or lenticular galaxy could be stripped of its disk by tidal or pressure forces in the center of a galaxy cluster, thus losing its gas and becoming an elliptical galaxy (Gunn & Gott 1972). Alternatively, since elliptical galaxies are traditionally thought to be old galaxies, it may be that they form first and somehow acquire disks at a later stage. Finally, scenarios for the origin of elliptical and lenticular galaxies from mergers have been quite successful (Toomre 1977; Hernquist 1980). Since mergers are known to occur, as evidenced by systems such as the Antennae and "Atoms for Peace" systems (Barnes & Hernquist 1992), this interactive nurture mechanism surely plays some role in the development of morphology.

It is very difficult to determine which of the various nature and nurture mechanisms dominate. It would appear that the clustering properties of different morphological types should be diagnostic of the formation mechanism, but in practice the distinctions are very subtle. If nature is the motivating factor, then whatever local properties are needed to make ellipticals could tend to exist over a large region. If a nurture mechanism involving mergers is the dominant mechanism, then initial correlations in the positions of spirals could lead to numerous mergers in one region. Postman & Geller (1984) argue that the morphology-density relationship holds over 6 orders of magnitude in galaxy space density, even though clusters showing significant substructure should have some clumps merge, wiping out such a relation. The authors state that the collapse time is vital to the understanding of the existence of morphological segregation even within groups of galaxies. If the dynamical timescale is roughly the Hubble time, population fractions are independent of density. In situations where elliptical galaxies outnumber spiral galaxies, the collapse time of $\sim 10^8$ yr is shorter than the $\sim 10^9$ necessary for disk formation.

The presence of substructure may or may not play an active role in the determination of the morphology-density relationship. Dressler (1980b), among others, argues that subclustering is due to clumps that are true physical structures, and that these physical structures are connected to morphological segregation. On the other hand, Sanromà & Salvador-Solé (1990) argue that even if the substructuring is real, it has little to no effect on the observed morphological relationships.

Substructure as an observational artifact can also have a significant impact upon any observed relationships of the type we seek. For instance, Beers et al. (1992) perform a detailed spatial, kinematical, and dynamical analysis of Abell 400. That paper finds not a single cluster, but an

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[2] Expected organizational implementation in Fall 1999.

entity composed of four distinct subclusters. Two elliptically rich subclusters are separated by just under 700 km s^{-1}, while a spiral rich component is separated from the farthest elliptical component by over 800 km s^{-1}. All of these components taken as a single cluster would lead one to believe that the spiral fraction of the cluster is higher than it truly is. This spiral component would in turn bias any relationship based on morphology.

Sanromà & Salvador-Solé (1990) argue that even if clumpiness in clusters exists, this subclustering plays no significant role in the observed morphology-density relationship.

The purpose of this paper is to use a statistic known as the pointwise dimension (PD) to analyze the environments of galaxies of different morphologies within the Dressler catalog. This paper does not address the issue of substructure as defined by Bird & Beers (1993), i.e., " … correlations between the velocities and locations of the individual galaxies, which may imply the existence of internally bound groups within the overall cluster potential." This issue has been addressed by other authors (Dressler & Shectman 1988b; Sanromà & Salvador-Solé 1990; Bode et al. 1994; Kriessler & Beers 1997). Rather, I am addressing the claim that the morphology-density relationship can be taken at face value, i.e., that local conditions are the prime determinant of a galaxy's morphological type.

In the next section, I shall describe the PD and its applicability to astronomical situations, § 3 details the analyses of the Dressler catalog, and § 4 presents a discussion of those results.

2. FRACTALS AND THE POINTWISE DIMENSION

The two-point correlation function of galaxies has a nearly constant slope over more than 2 orders of magnitude in distance. This behavior for object clustering suggests that the concept of fractal geometry may apply (Mandelbrot 1983). The modern interest in fractals as descriptors of chaotic systems[3] found as one of its applications the study of large-scale structure, giving a quantitative descriptive scheme to ideas that had been expressed qualitatively as early as Charlier's map of extragalactic nebulae in the 1920s (Charlier 1922). Several types of fractal analyses have been applied to large-scale structure description, such as wavelet transforms (Martinez et al. 1993) and percolation statistics (Klypin & Shandarin 1993). The PD has been shown by Best, Charlton, & Mayer-Kress (1996) to be particularly useful for analyses of correlations between morphology and environment. It also has the distinction of being conceptually simple and easy to apply to two- and three-dimensional object catalogs.

Following the discussion of Mayer-Kress (1994), I can consider a function $N_{x_m}(r)$, which is the count of the number of data points within a distance r from a reference point x_m. In a log-log representation of $N_{x_m}(r)$ versus r, there is a scaling region over which a slope can be defined; within that scaling region, which is bounded by $r_{\min}$ and $r_{\max}$, this slope d_{x_m} is interpreted as the PD and is defined as

$$d_{x_m} = \frac{\log\,[N_{x_m}(r_{\max})] - \log\,[N_{x_m}(r_{\min})]}{\log r_{\max} - \log r_{\min}}\,. \qquad (1)$$

While the motivation of the Mayer-Kress paper is to accurately reconstruct the dimensions of attractors from time series, the PD can also be applied to a diverse range of problems in other fields (Elgar & Mayer-Kress 1989; Zbilut, Mayer-Kress, & Sobotka 1989). Further discussion of the method can be found in Farmer, Ott, & Yorke (1983).

The PD technique can easily be applied to a catalog of galaxies. Consider a two-dimensional catalog in which an angular position in the sky is specified for each object. For each object (known as the primary) I can plot a curve that gives the number of objects within angle θ of that object (these objects are called secondaries with respect to the primary).

For each object, a dimension can be calculated by applying a least-squares fit to each curve, following the prescription of Holzfuss & Mayer-Kress (1986, hereafter HMK). The term "pointwise" is used because a slope is calculated separately for each curve, i.e., around each point in the distribution. Figure 1, from Best et al. (1996), shows what a set of typical curves looks like (in this case, 20 elliptical galaxies in the RC3 catalog). A sample or subsample of galaxies can then be described by the distribution of slopes, and such distributions can be compared between subsamples (e.g., for a given morphology, absolute luminosity, or region of space). A large slope of $N_{x_m}(r)$ versus r indicates a large number of galaxies within the distance range of r from the primary [since the rise, $N_{x_m}(r)$, would be increasing greatly with respect to the run (r)]; similarly, a smaller slope indicates fewer galaxies in the vicinity of the primary. Peebles (1993) and Pietronero, Sylos Labini, & Montouri (1998) discuss expected values for various astrophysical situations (e.g., a homogeneous distribution having a dimension of 3). HMK, Martinez et al. (1993), and Pietronero et al. (1998) demonstrate and discuss applications to model data. The reader is referred to these papers for more details.

As a further examination of the ability to differentiate real signals from spurious signals with the PD, a study has been conducted using three representative Dressler clusters. The criteria for selection were the number of galaxies in the individual clusters and prior evidence of subclustering for these clusters. A cluster with under 100 members (Abell 2657, 84 members), one with between 100 and 200 members

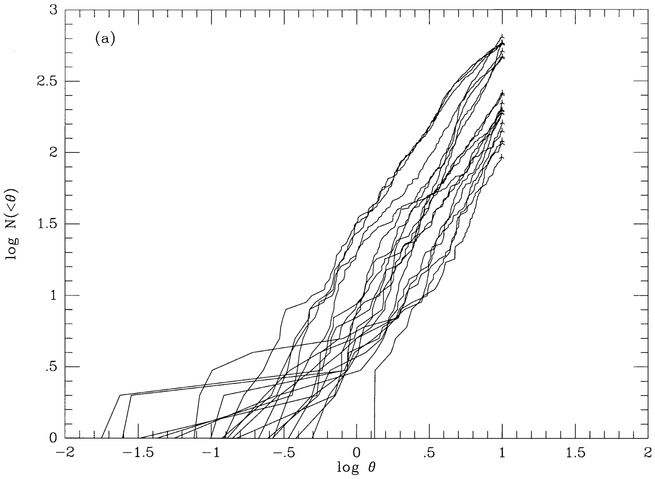

FIG. 1.—Set of typical curves generated by the PD analyses. The data are the generated curves from 20 elliptical galaxies in the RC3 catalog and were originally presented in Best et al. (1996).

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[3] See J. D. Meiss 1996, Nonlinear Science FAQ, http://amath.colorado.edu/appm/faculty/jdm/faq.html.

(DC 0608−33, 125 members), and one with greater than 200 members (Abell 1656, 247 members) were selected. I have studied the results for each real cluster being compared with a three-dimensional random cluster projected into two dimensions with the same number of members and size. No morphologies were assigned to the galaxies in the random clusters or were used in the real clusters for these comparisons. If the PD was unable to differentiate real signals from those that would arise from a random cluster, then the majority of environments of the galaxies should not show statistically significant differences between the real and generated clusters. However, all three real clusters have a majority of environments that differ to the 95% level (using Komolgorov-Smirnov [KS] tests) from those of their random cluster counterparts. Since these real clusters are known to have subclustering, the conclusion drawn from this test is that the PD can differentiate between real signals and those arising from chance alignment and is therefore applicable for such use.

Of course, a single-slope fit to a curve is not a complete description of the distribution of galaxies around the object represented by the curve. Although the single slope is indicative of the type of environment in which the object resides, two differently shaped curves can certainly lead to the same least-squares fit. However, I can adapt the PD description to address structure separately on various scales simply by limiting the distance range over which the slope is determined. In essence, I can analyze radial subregions of the chosen scaling region. For example, to address the question of whether the distribution of galaxies becomes homogeneous on the largest scales, I can determine a slope for each object by just fitting over a range of large distances.

There are several reasons why the PD analysis is advantageous: (1) Other correlation descriptors such as the Grassberger-Procaccia dimension (Grassberger & Procaccia 1983) were criticized by HMK because they effectively average together curves with different amplitudes. This is the case with the two-point correlation function as well, and this is reflected in its inability to distinguish how many galaxies contribute to large correlations observed on small scales. (2) The PD is very simple to compute and understand, partly because it is not normalized by a random catalog. Even for distant galaxies in a magnitude-limited catalog, the slope will not be biased by selection effects since, unless there is a correlation between luminosity and separation for galaxy pairs (which has not to this point been shown to exist), galaxies will be missing roughly equally at all separations. (3) Morphology-environment studies are facilitated by use of the PD. The two-point correlation function has often been used to explore clustering within a morphological type (using only early- or late-type galaxies). For some purposes, however, I would like to analyze all galaxies in the neighborhood of a particular object, regardless of morphology. All of the mass in the vicinity of an object may be influential in determining the properties with which it forms. (4) The PD has much smaller errors than other dimension determinators (see comparison in HMK). (5) There is no assumption that the galaxy distribution becomes spatially homogeneous on a length scale that is smaller than that of the catalog being analyzed. Pietronero (1987) describes how, if this assumption is invalid, the amplitude of the correlation function and the length scale where the function becomes small are sample-dependent.

I also note that, since these analyses focus on the local environment of each galaxy regardless of its location in the cluster, the difficulties in locating the center of each cluster are not relevant to this particular analysis. This also follows the Dressler (1980a) procedure, which finds advantage in "the use of density instead of radius as the independent parameter."

3. THE POINTWISE DIMENSION APPLIED TO DRESSLER'S CATALOG

PD analyses were conducted on Dressler's 1980 catalog of morphological types in 55 rich clusters of galaxies (Dressler 1980b), which contains information on the positions, morphologies, apparent visual magnitudes, estimated bulge sizes, and ellipticities of ∼6000 galaxies. If redshifts are available, the angular separations of galaxies can be converted to a projected separation in units of megaparsecs. For conversions I use a Hubble constant of 80 km s^{-1} Mpc^{-1} throughout (Jacoby et al. 1992; Gonzalez & Faber 1997).

The analyses performed on the Dressler clusters proceeded as follows: For each cluster, the PD was calculated for every galaxy on scales from 0 to 1 Mpc in 0.1 Mpc increments. In other words, a PD slope was determined around a galaxy from 0 to 0.1 Mpc, from 0 to 0.2 Mpc, and so on. Furthermore, the PD for each galaxy was computed from 0 to 10 Mpc in 1 Mpc increments. In the cases where the maximum extent of the clusters is less than 10 Mpc, the calculation is carried out to that maximum extent. The majority of analyses have been done using morphology as a selection criterion. The data presented are for elliptical, lenticular, and spiral galaxies, although calculations have been made for all five of Dressler's morphological classes. In dealing with morphological transitional cases, Dressler's primary classification is selected; i.e., a galaxy classified by Dressler as E/S0 is taken to be an E galaxy, while an S0/E galaxy is taken as a lenticular galaxy.

3.1. *PD Analysis Done for Separate Morphological Types: KS Tests*

In order to discuss the significance of the differences between any two environments, a KS test is best suited and has been used. Table 1 contains the results of such a test on the combined data samples. The samples are divided in the following way: every galaxy in each cluster will have PD fits in a "fitting range" from 0 to 0.1 Mpc, from 0 to 0.2 Mpc, and so on, out to the maximum distance for which a PD fit can be applied. The maximum fitting range is rarely, if ever, greater than 7 Mpc. This would give us a maximum of 16 fitting ranges: 0–0.1, 0–0.2, 0–0.3, 0–0.4, 0–0.5, 0–0.6, 0–0.7, 0–0.8, 0–0.9, 0–1, 0–2, 0–3, 0–4, 0–5, 0–6, and 0–7 Mpc. For every paired set of data being compared, we count the total number of fitting ranges for which the difference between the two sets of data is significant. In this and in all other KS tests in this paper, the data are presented in fractional format: the denominator represents the total possible number of fitting ranges with data present (this number would be 16 if all fitting ranges above had data present), and the numerator represents the number of the fitting ranges for which the data sets do not conform to the null hypothesis that the sets were drawn from the same distribution. Note that what is being addressed is not the significance of any particular fitting range's KS value but only the sum total of the behaviors of the fitting ranges. Also, it is true

TABLE 1

DRESSLER CATALOG PD KS TESTS

PS Sample 1[a] (1)	PS Sample 2 (2)	Combined Catalog (3)	Combined with Velocity[b] (4)	A1644[c] (5)	DC 0003 − 50[c] (6)
EE	EL	$\frac{11}{15}$	$\frac{5}{14}$	$\frac{0}{10}$	$\frac{0}{5}$
EE	ES	$\frac{11}{15}$	$\frac{8}{14}$	$\frac{1}{9}$	$\frac{0}{5}$
EL	ES	$\frac{5}{15}$	$\frac{1}{14}$	$\frac{4}{10}$	$\frac{0}{7}$
LE	LL	$\frac{13}{15}$	$\frac{7}{14}$	$\frac{0}{10}$	$\frac{0}{7}$
LE	LS	$\frac{12}{15}$	$\frac{5}{14}$	$\frac{0}{10}$	$\frac{0}{6}$
LL	LS	$\frac{4}{15}$	$\frac{2}{14}$	$\frac{3}{9}$	$\frac{0}{7}$
SE	SL	$\frac{13}{15}$	$\frac{9}{14}$	$\frac{0}{9}$	$\frac{1}{7}$
SE	SS	$\frac{13}{15}$	$\frac{11}{15}$	$\frac{0}{9}$	$\frac{0}{6}$
SL	SS	$\frac{4}{16}$	$\frac{4}{14}$	$\frac{0}{9}$	$\frac{0}{6}$
EA	LA	$\frac{12}{15}$	$\frac{7}{14}$	$\frac{0}{12}$	$\frac{0}{10}$
EA	SA	$\frac{12}{15}$	$\frac{11}{15}$	$\frac{0}{12}$	$\frac{0}{9}$
LA	SA	$\frac{10}{16}$	$\frac{2}{14}$	$\frac{0}{12}$	$\frac{0}{10}$

[a] PS gives the primary type–secondary type comparison: elliptical (E), lenticular (L), spiral (S), all galaxies regardless of morphology (A).

[b] Combined 14 clusters with velocity information for galaxies within.

[c] Representative cluster for which velocity information exists (see Dressler & Shectman 1988a).

that the fitting ranges as defined are not completely independent in the sense that, for instance, the 0–2 Mpc fitting range contains within it by definition the 0–1 Mpc fitting range. This has led to the conjecture that the 0–0.1 Mpc range will dominate the behavior of any larger fits. However, one cannot assume that the smallest fitting ranges (0–0.2 Mpc and below) are dominating any results. This is because there are many instances in which there are no fits in these smallest ranges. Therefore, the smallest ranges cannot dominate, because they do not always exist.

The KS tests have been applied to the data sets in the following manner: I compare how a particular galaxy type as a primary is clustered with respect to two different secondaries, the secondaries being selected on the basis of morphology. Of the nine possible combinations of this type listed in Table 1 (hereafter the "cross-morphological case comparisons"), we see in two-thirds of these cases that the majority of environments differ to the 99% level.

When we consider the entire environment, i.e., a single morphology clustering with respect to all other galaxies regardless of morphology versus a second morphology clustering with respect to all other galaxies regardless of morphology, we see that in the three possible combinations of this type listed in Table 1 (hereafter the "total environment case comparisons"), the majority of the environments are significantly different in all three cases to the 99% level. Figure 2 graphically illustrates a typical KS test result.

In general, the combined sample shows a significant statistical difference in environments due to morphology, even when the entire environment (no morphological criterion on secondaries) is considered. This is consistent with the notion of a morphology-density relationship.

Dressler (1980a) holds that "analyses of individual clusters indicate that the relation between population and density holds within individual clusters as well." In Dressler & Shectman (1988a), radial velocity information is presented for 1268 galaxies in 14 clusters (one-quarter) of the catalog. The particular clusters were chosen regardless of structure and tended to be the richer clusters. Any object with a bulge magnitude $V \leq 16$ was automatically included for redshift determination. The rms accuracy of a single measurement is ~ 45 km s^{-1}. For each cluster, Dressler & Shectman determine a velocity range that defines the cluster; this determination is presented in histogram form in Dressler & Shectman (1988a) and numerically in Dressler & Shectman (1988b). The 1988b paper claims a radial velocity determination of 50%–70% for a 2 deg^2 sampled area of each cluster, which corresponds to 100–200 galaxies per typical cluster. In the following analyses, the velocity information in these clusters (as determined by Dressler & Shectman 1988b) is used only to constrain cluster membership. I note that early-type galaxies are the highest by percentage in 13 of the 14 clusters. Table 2 and Figures 3, 4, and 5 demonstrate various effects of the imposition of this membership criterion.

3.2. *Analyses of the Velocity-selected Clusters Individually*

Each of the 14 clusters with velocity information for at least some of the galaxies was studied individually. Dressler clusters Abell 1644 and DC 0003 − 50 (listed in Table 1 alongside the combined Dressler cluster data) are two representative examples of the 14 individual clusters. I discuss the general results of a consideration of all 14 individual clusters here, to show how individual clusters conform to or

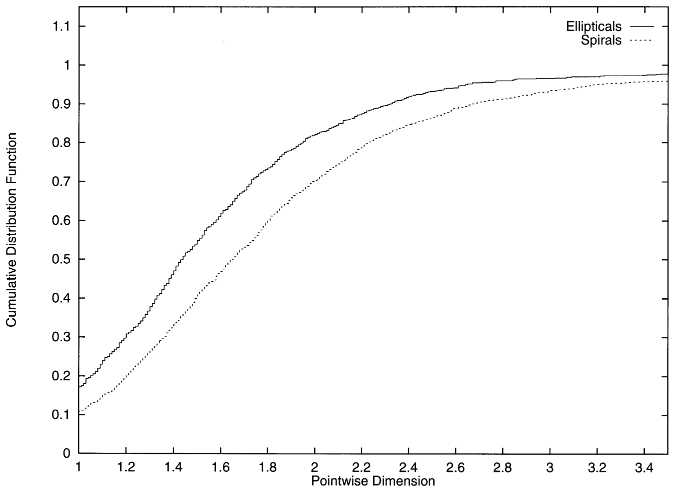

FIG. 2.—Graphical representation of a typical KS test for a comparison of PD values with respect to morphology. The comparison sets are elliptical galaxies with respect to all other galaxies and spiral galaxies with respect to all other galaxies. The fitting range around each galaxy is 0.7 Mpc.

TABLE 2

Dressler Catalog Membership by Velocity

Cluster	Morphology[a]	Total	With Velocity[b]	In Cluster[b]	With Velocity/Total	In Cluster/Total
Abell 548	E	44	34	34	0.77	0.77
	L	93	59	58	0.63	0.62
	S	94	41	41	0.44	0.44
	O	4	0	0	0.00	0.00
Abell 754	E	25	24	21	0.96	0.84
	L	70	42	40	0.60	0.57
	S	51	22	20	0.43	0.39
	O	4	1	1	0.25	0.25
Abell 1631	E	18	16	13	0.89	0.72
	L	59	46	40	0.78	0.68
	S	57	27	17	0.47	0.30
	O	5	1	1	0.20	0.20
Abell 1644	E	21	21	20	1.00	0.95
	L	68	49	47	0.72	0.69
	S	49	32	25	0.65	0.51
	O	7	1	0	0.14	0.00
Abell 1656	E	70	39	38	0.56	0.54
	L	124	48	46	0.39	0.37
	S	46	14	14	0.30	0.30
	O	7	1	1	0.14	0.14
Abell 1736	E	22	20	19	0.91	0.86
	L	55	42	40	0.76	0.73
	S	85	38	36	0.45	0.42
	O	8	4	2	0.50	0.25
Abell 1983	E	20	20	16	1.00	0.80
	L	42	38	32	0.90	0.76
	S	62	42	26	0.68	0.42
	O	0	0	0	...	...
Abell 2151	E	25	21	20	0.84	0.80
	L	44	34	32	0.77	0.73
	S	86	49	46	0.57	0.53
	O	2	1	1	0.50	0.50
DC 0003−50......	E	20	20	9	1.00	0.45
	L	29	21	15	0.72	0.52
	S	28	14	10	0.50	0.36
	O	3	0	0	0.00	0.00
DC 0247−31......	E	9	7	6	0.78	0.67
	L	19	11	10	0.58	0.53
	S	17	12	10	0.71	0.59
	O	3	0	0	0.00	0.00
DC 0428−53......	E	38	36	30	0.95	0.79
	L	50	43	38	0.86	0.76
	S	37	19	15	0.51	0.41
	O	6	2	2	0.33	0.33
DC 0559−40......	E	19	18	18	0.95	0.95
	L	46	35	32	0.76	0.70
	S	44	29	26	0.66	0.59
	O	7	2	1	0.29	0.14
DC 0608−33......	E	15	11	8	0.73	0.53
	L	32	21	13	0.66	0.41
	S	67	29	8	0.43	0.12
	O	11	3	2	0.27	0.18
DC 2048−52......	E	49	38	30	0.78	0.61
	L	90	47	44	0.52	0.49
	S	87	21	18	0.24	0.21
	O	7	0	0	0.00	0.00

[a] Morphology Classification: elliptical (E), lenticular (L), spiral (S), all other galaxies (O).

[b] Velocity information and membership in cluster based on Dressler & Shectman 1988a.

diverge from the results of a combination of the clusters (the data for the combined clusters for which velocity information is available are in col. [4] of Table 1). For comparision's sake, I calculate that the mean redshift and standard deviation are as follows: for the combined complete Dressler catalog, 0.0413 ± 0.0141; for the combined clusters for which velocity information exists, 0.0403 ± 0.0094; and for all clusters combined except those with velocity information, 0.0417 ± 0.0155. This similarity in the values suggests strongly that any differences detected

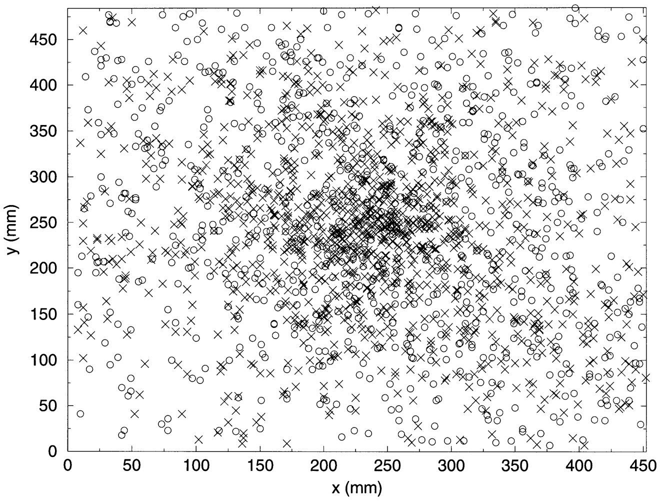

FIG. 3.—Distribution of galaxies in the combined data sets of all clusters with velocity information for at least some of the galaxies. The figure shows all galaxies in the combined data sets, with an "average" center location of $x = 225.64$ and $y = 242.07$. Crosses denote galaxies with determined velocity, and circles show galaxies without determined velocity.

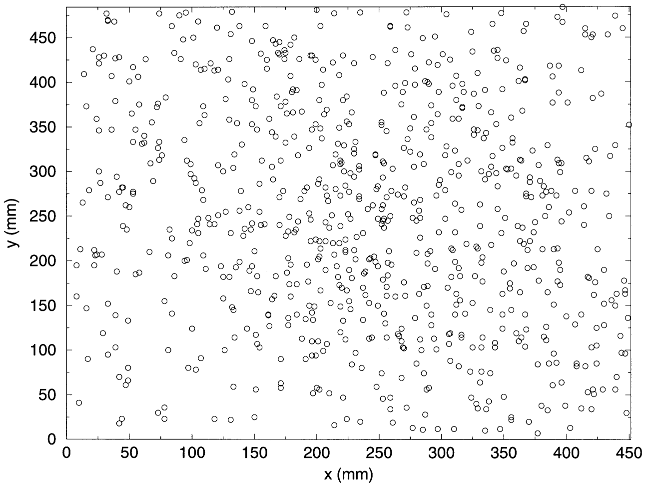

FIG. 4.—Same as Fig. 3, but for galaxies in the combined data sets without determined velocities only

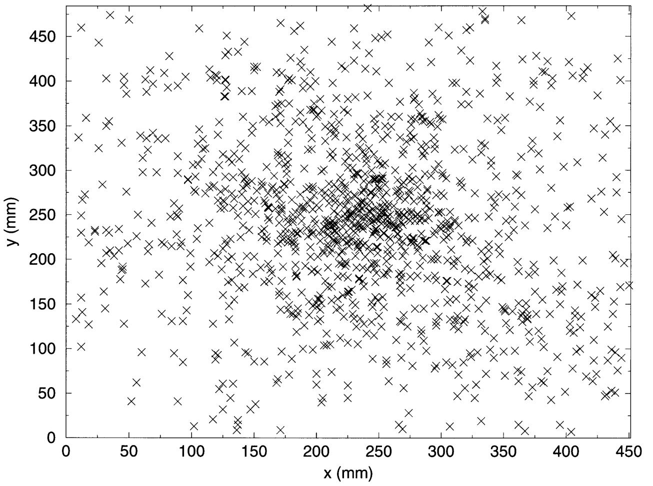

FIG. 5.—Same as Fig. 3, but for galaxies in the combined data sets with determined velocities only

between the sets cannot be ascribed simply to differences in relative distance between the clusters with and those without individual galaxy velocity information.

In the majority of the 14 clusters, none of the samples have even one fitting range for which there is a statistically significant difference between the two samples. In some cases, none of the samples have even one fitting range for which the two samples are statistically different to the 99% level (e.g., DC 2048 − 52), while in others, no more than one or two of the cross-morphological samples have a single fitting range for which there is a difference (e.g., Abell 754). In fact, only in the case of Abell 1656 can one find at least one fitting range in which a majority of the environments shows a significant difference to the 99% level: LL versus LS (see Table 1 for abbreviations).

If we now consider samples where the primary galaxy is morphologically constrained while the secondary is not (total environment scenarios), we find that 10 of the 14 clusters have no fitting ranges for which the environments of the comparison samples are significantly different to the 99% level. Of the remaining clusters (Abell 1983, Abell 2151, DC 0559 − 40, and DC 0608 − 33), only Abell 2151 has even one sample in which a majority of the environments are significantly different, EA versus LA (see Table 1 for abbreviations).

Physically, this means that for the 14 clusters for which foreground and background contamination were seriously reduced, there is not one of the clusters for which a morphology-density relationship is prominent. If the relationship is real, one would expect the removal of contamination to enhance, not remove, the relationship.

4. DISCUSSION AND CONCLUSIONS

This paper discussed the use of the PD on various scales to examine the relationships between galaxies of differing morphological types in cluster environments. This has been done as a function of the morphologies of the galaxies.

When the 55 clusters are combined and analyzed, we see that for the vast majority of morphological cross-comparisons, the environments are significantly different to a 99% level. Even when the complete local and global environment is considered with respect to each morphology, this result does not change. In fact, all three sets of comparisons (EA vs. LA, EA vs. SA, and LA vs. SA) show that a majority of the environments are significantly different (see Table 1).

I undertook the detailed analysis of each cluster in the velocity-limited sample. The individual clusters proved most interesting, because the overall trend found is that within each cluster, the vast majority of environments are not significantly different. This holds true if both the primaries and the secondaries are constrained by morphology or if only the primaries are morphologically selected (see individual cluster entries in Table 1). The fact that all three galaxy types exist in each of these clusters, yet so very few of the environments are different when a cross-morphological study is done, leads to the belief that if it were only the environment that were the determining factor in a galaxy's morphological development, such a wide range of galaxies should not be prevalent in all of these clusters. This is not to say that environment can never be a factor: these analyses provide evidence that environment need not be the sole factor. It must also be noted that these clusters have a wide range of spiral fractions: from Abell 1656's 18.6% spiral fraction to Abell 2151's 54.7%, these 14 clusters span the range of spiral fraction. Clearly, the fact that so few of the fitting ranges are significantly different cannot be attributed to a relative lack of or excess of spiral galaxies as compared with the whole. How then, can we have a majority of the environments different when morphology is considered for the combined Dressler samples and in the combined clusters with velocity information, but so few of the fitting ranges significantly different for these 14 clusters (the only difference in these clusters from the rest of the catalog being that some of the velocities of the cluster members are determined)?

The discovery of this disparity, using the PD of the combined data showing significant differences in environments but the individual clusters showing far less, is bolstered by Andreon (1996). Andreon studied an absolute magnitude complete sample of the Coma cluster in order to quantify the difference in galaxy properties along the Hubble sequence. The 187 galaxies included were all galaxies brighter than B magnitude 16.5 within 1° of the Coma cluster (1° equaling 2.7 Mpc if $H_0 = 50$ km s^{-1} Mpc^{-1}). Andreon assigns two types of morphological classifications: "coarse" (equivalent to Dressler's) and "fine." Andreon's most relevant result in regards to this work is that he finds that "… even if there is a general tendency for galaxies to obey morphology-density (or radius), evidenced by averaging them over many clusters, as done by all previous studies … there is a large scatter in the individual clusters which can affect the morphology-density (or radius) shapes or normalizations … ." This result was found using both morphological classification schemes. While Andreon's further claim that "… if you have enough statistics and you look for a dependence on one of these two parameters [those parameters being clustercentric distance and galaxy density] you find the segregation that you are looking for … " might be extreme, it is worth noting that the fundamental thrust of his result is that relationships other than morphology-density should be examined. The results garnered by the PD further extend this result.

If morphology-density is not fundamental, we are forced to look for alternatives. The work of Whitmore, Gilmore, & Jones (1993) is an attractive alternative. Whitmore et al. (1993) argue for a hybrid model of origin of morphology in which the same fractions of spiral, lenticular, and elliptical galaxies are set by nature to form everywhere in the universe. In this model, clustercentric distance, not density, is the most important factor in the determination of morphology. Formation of a particular type is equally likely in any environment. However, in this model the process of spiral formation is not as likely to reach completion in the centers of galaxy clusters, and additional evolutionary processes (such as tidal stripping) also alter the populations. These affect the spirals selectively, since the disks of protospirals in the center of a cluster would tend to be more sensitive to external effects than would protoellipticals. It follows from these ideas that the population of elliptical galaxies outside of galaxy clusters should not have particularly different distributions of galaxies around them than other morphological types that are also not in clusters. The Whitmore argument can, of course, be reversed. For instance, assume that within low-velocity dispersion environments many mergers occur. These low-velocity clumps would coalesce into the main cluster, leaving the cluster spiral-poor. Other considerations of the precluster environment and its importance in such a relationship include Andreon (1996), who claims that the fundamental parameter to consider when examining morphological segregation is neither local density nor clustercentric distance, but the direction of the supercluster into which the galaxies are embedded. While physical subclustering is a viable explanation of the morphology-density relationship (as a function of collapse time vs. disk formation time), this mechanism would not be sufficient to explain why the relationship seems to hold within the most prominent void of the original CfA "slice of the universe" (Thorstensen et al. 1995). Santiago & Strauss (1992) argue that on large scales, galaxies of all morphology are not drawn from common density fields. They put this in the context of biasing models, opting against a uniform bias factor. Of course, the Beers et al. (1992) analysis shows how great a factor observational contamination can truly be.

I conclude by making reference again to the Dressler (1980a) claim that "analyses of individual clusters indicate that the relation between population and density holds within individual clusters as well." The PD analyses, which have in essence looked at the familiar problem of morphology-density relationships in the catalog used to determine such relationship, show that models in which density is not considered as the determining factor for morphology must be carefully considered.

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REFERENCES

Andreon, S. 1996, A&A, 314, 763
Barnes, J., & Hernquist, L. 1992, ARA&A, 30, 705
Beers, T. C., et al. 1992, ApJ, 400, 410
Best, J., Charlton, J., & Mayer-Kress, G. 1996, ApJ, 456, 55
Bird, C. M., & Beers, T. C. 1993, AJ, 105, 1596
Bode, P. W., et al. 1994, ApJ, 433, 479
Charlier, C. 1922, Ark. Mat. Astron. Fys., 16, 1
Dressler, A. 1980a, ApJ, 236, 351
———. 1980b, ApJS, 42, 565
Dressler, A., & Shectman, S. A. 1988a, AJ, 95, 284
———. 1988b, AJ, 95, 985
Elgar, S., & Mayer-Kress, G. 1989, Physica D, 37, 104
Farmer, J. D., Ott, E., & Yorke, J. A. 1983, Physica D, 7, 153
Gonzalez, A. H., & Faber, S. 1997, ApJ, 485, 80
Grassberger, P., & Procaccia, I. 1983, Phys. Rev. Lett., 50, 346
Gunn, J., & Gott, J. 1972, ApJ, 176, 1
Hernquist, L. 1980, in The Environment and Evolution of Galaxies, ed. J. M. Shull & H. A. Thronson, Jr. (Dordrecht: Kluwer), 327
Holzfuss, J., & Mayer-Kress, G. 1986, in Dimensions and Entropies in Chaotic Systems, ed. G. Mayer-Kress (Berlin: Springer), 114
Hubble, E., & Humason, M. 1931, ApJ, 74, 43
Jacoby, G., et al. 1992, PASP, 104, 599
Klypin, A., & Shandarin, S. F. 1993, ApJ, 413, 48
Kriessler, J. R., & Beers, T. C. 1997, AJ, 113, 80
Mandelbrot, B. 1983, The Fractal Geometry of Nature (New York: Freeman)
Martinez, V. J., et al. 1993, MNRAS, 260, 365
Mayer-Kress, G. 1994, Integrative Physiological Behavioral Sci., 29, 203
Peebles, P. J. E. 1993, Principles of Physical Cosmology (Princeton: Princeton Univ. Press)
Pietronero, L. 1987, Physica, 114a, 257
Pietronero, L., Sylos Labini, F., & Montouri, M. 1998, in Fourth Paris Cosmology Colloquium: Phase Transitions in Cosmology, ed. N. Sanchez & H. de Vega (Singapore: World Scientific), 223
Postman, M., & Geller, M. 1984, ApJ, 281, 95
Sanromà, M., & Salvador-Solé, E. 1990, ApJ, 360, 16
Santiago, B. X., & Strauss, M. A. 1992, ApJ, 387, 9
Thorstensen, J. R., et al. 1995, AJ, 109, 2368
Toomre, A. 1977, The Evolution of Galaxies and Stellar Populations, ed. B. Tinsley & R. Larson (New Haven: Yale Univ. Obs.), 401
Whitmore, B., Gilmore, D., & Jones, C. 1993, ApJ, 407, 487
Zbilut, J., Mayer-Kress, G., & Sobotka, P. 1989, Biological Cybernetics, 61, 371
Zurek, W., Quinn, P., & Salmon, J. 1988, ApJ, 330, 519