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ON THE INTERPRETATION OF THE MORPHOLOGY-DENSITY RELATION FOR GALAXIES IN CLUSTERS

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ABSTRACT

A reexamination of Dressler's sample of nearly 6000 galaxies in 55 clusters shows that galactic morphology correlates as well with the projected distance from the center of the cluster, $R_{\rm clus}$, as it does with the projected local density of the 10 nearest galaxies. Most of the variation occurs within 0.5 Mpc of the cluster center. The effect is strongest in the 34 clusters with D galaxies, with the percentage of ellipticals rising from $18 \pm 3\%$ at $R_{\rm clus} = 0.6$ Mpc to $65 \pm 7\%$ at $R_{\rm clus} = 0.1$ Mpc. Various correlations suggest that the physical mechanisms which result in the population gradients for the spiral and S0 galaxies are different than the mechanism responsible for the preponderance of ellipticals near the cluster centers. Tentative evidence is also found that the fraction of S0 galaxies declines sharply within 0.2 Mpc of the cluster center, especially around central D galaxies.

Subject headings: galaxies: clustering — galaxies: structure

I. INTRODUCTION

The fact that nebulae in clusters are different than nebulae in the field was known even before it was understood that these nebulae were galaxies like our own Milky Way. For example, Curtis (1918) observed 304 small diffuse nebulae in the Coma cluster, but his belief that "all the many thousands of nebulae not definitely to be classed as diffuse or planetary are true spirals, and that the very minute spiral nebulae appear as textureless disks or ovals solely because of their small size," kept him from realizing the importance of his observations. However, by the early 1930s the difference between populations of galaxies in the field and in clusters was clearly understood (e.g., Hubble and Humason 1931). Oemler (1974) quantified this trend by defining three types of clusters with various ratios of elliptical, S0, and spiral galaxies. These are "spiral rich" (E/S0/S = 1/2/3), "spiral poor" (E/S0/S = 1/2/1), and "cD" clusters (E/S0/S = 3/4/2). Melnick and Sargent (1977) demonstrated the existence of population gradients as a function of distance from the center of the cluster, with elliptical galaxies occurring mainly near the centers and spirals predominating in the outer regions. This basic fact, that the inner regions of clusters contain a higher fraction of elliptical galaxies than the outer regions of clusters, or the field, should provide an important clue for understanding what determines one of the most fundamental characteristics of a galaxy, its Hubble type. However, recent interest has focused on the possible existence of substructure within clusters (e.g., Fitchett 1988), and the role it may play in determining the morphological types of galaxies within clusters.

The classic work in this field is Dressler's (1980) study of galaxies in 55 relatively nearby clusters. Dressler concludes that the fundamental correlation is between morphological type and *local* projected galaxy density (defined as the projected density enclosing the nearest 10 galaxies). This conclusion is based on a comparison of the morphology-density relation with the morphology-clustercentric distance relation for 6 irregular clusters (see Fig. 5 from Dressler 1980). As Dressler states: "The gradients are much more striking when the density is employed as the independent parameter, which indicates that the local projected density enhancements represent real physical associations and that populations are largely a function of local rather than global conditions." The purpose of the current paper is to reexamine Dressler's (1980) data to determine whether the morphology-density relation is really better than the morphology-clustercentric distance relation.

Several groups have extended Dressler's morphology-density relation to less dense environments (Postman and Geller 1984; Giovanelli, Haynes, and Chincarini 1986; Tully 1988). They find that the fractions of elliptical, S0, and spiral galaxies within lower density regions in the field, and in loose groups, join smoothly onto the low-density regions in the outer parts of Dressler's clusters. Sodré *et al.* (1989) have recently shown that the velocity dispersions for the system of spiral galaxies in clusters are generally larger than the velocity dispersions for the system of ellipticals. They interpret this as evidence that late-type galaxies are still in the process of falling into the virialized core of the clusters. This would explain the continuity of the population fractions from the field to the outer regions of clusters and suggests that galaxies within the cores of clusters have undergone an episode of violent relaxation and virialization while the outer galaxies in clusters have not. Perhaps this bimodality is also related to the preponderance of elliptical galaxies near the centers of clusters and spirals in the outer regions.

This paper compares the morphology-density relation with the morphology-clustercentric distance relation, and concludes that using the clustercentric distance as the independent parameter results in correlations which are comparable, or slightly better, than when local density is used. This suggests that global conditions may actually be the prime determinant of the morphological type of a galaxy rather than local conditions.

II. THE MORPHOLOGY-CLUSTERCENTRIC DISTANCE RELATION

The determination of the "dynamical center" of a cluster is problematic, especially for very irregular clusters. This led Dressler (1980) to try using a locally derived parameter (the projected galaxy density within an area encompassing the

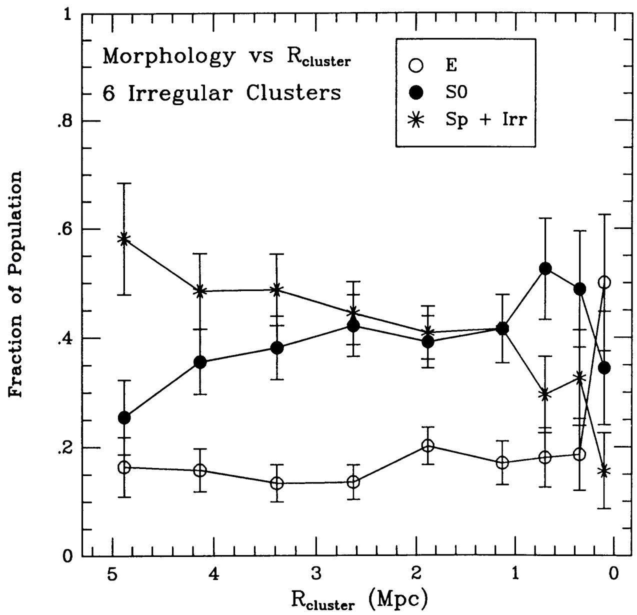

FIG. 1*a*

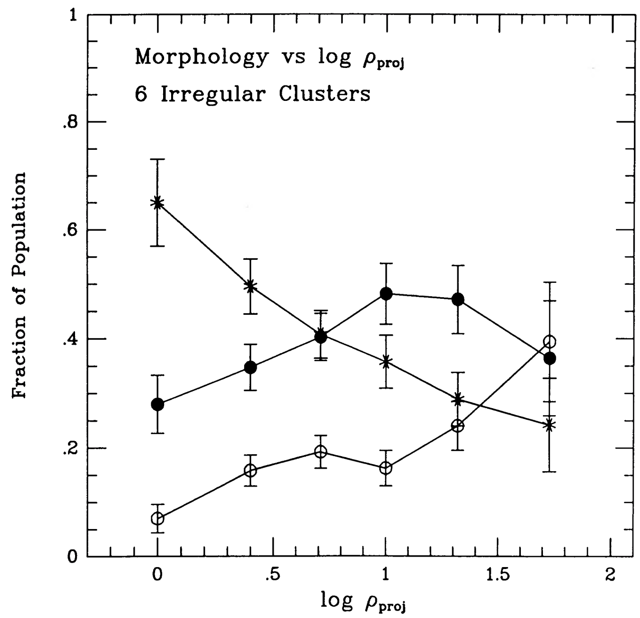

FIG. 1*b*

FIG. 1.—(*a*) The fraction of E, S0, and S + I galaxies as a function of the clustercentric distance, R_{clus}, for the six irregular clusters used by Dressler (1980; Fig. 5). The galaxy with the highest local density is used as the center. Note the sharp rise in the fraction of ellipticals very near the cluster centers. (*b*) Same as (*a*) but using local projected galaxy density as the independent parameter.

nearest 10 galaxies) as his independent parameter when examining how the morphology of galaxies varied within a cluster. Since this gave fairly good correlations, the obvious question became whether the fundamental parameter was the clustercentric distance, as Melnick and Sargent (1977) had suggested, or the projected local galaxy density. One difficulty in making this comparison is that the local galaxy density is a rather smooth function of the radius in regular clusters, making it difficult to determine which is the fundamental correlation. Dressler therefore used a subsample of six moderately irregular clusters to make the comparison (see his Fig. 5) and concluded that local density was the better discriminant.

Figure 1 shows the same data as Dressler used, but with two differences. The first is the use of the galaxy with the highest local galaxy density as the center of the cluster when calculating the clustercentric distance, R_{clus}. Dressler used the centroid of the cluster, which can often be in a relatively low density location if the cluster is not very regular. The second difference is that Dressler's inner bin extended from 0 to 1.0 Mpc, while we have divided this region into three separate bins. We find that unlike the earlier result, using the clustercentric distance as the independent parameter results in similar variations in the populations of galaxies (e.g., for the elliptical fraction; a range of 35% [from 15%–50%] results when clustercentric distance is used and 33% [from 7%–40%] results when local density is used). Most of the variation in the ellipticals occurs very near the cluster centers. Dressler's use of a large central bin diluted this effect.

The small number of galaxies in the inner bin of Figure 1*a* (16 ellipticals, 11 S0s, and 5 spirals) and Figure 1*b* (13 ellipticals, 12 S0s, and 8 spirals) introduces the largest uncertainty in the comparison. In Figure 2 we show the same correlations for all 55 clusters. We find that the fraction of ellipticals increases dramatically inside 0.5 Mpc to a peak of 44% at 0.1 Mpc, and the fraction of spirals plummets over the same range. Using the local density as the independent parameter tends to obscure the fact that most of the variation is actually very near the cluster center.

The fact that the binning can have such a strong effect when comparing the central morphological fractions led us to divide the sample into 20 equal bins, arranged first by clustercentric

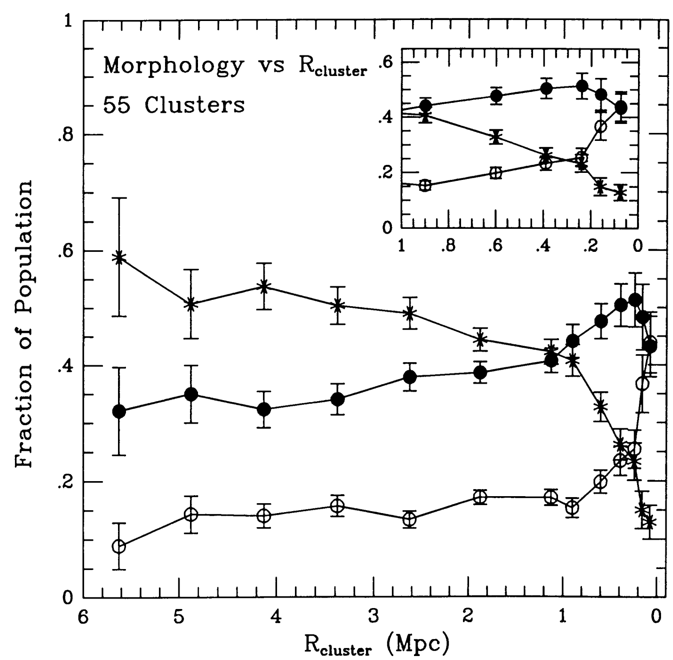

FIG. 2.—The fraction of E, S0, and S + I galaxies as a function of the clustercentric distance for all 55 clusters in the sample. The galaxy with the highest local density is used as the center. The symbols are the same as in Fig. 1. The insert in the upper right shows the same data at higher spatial resolution.

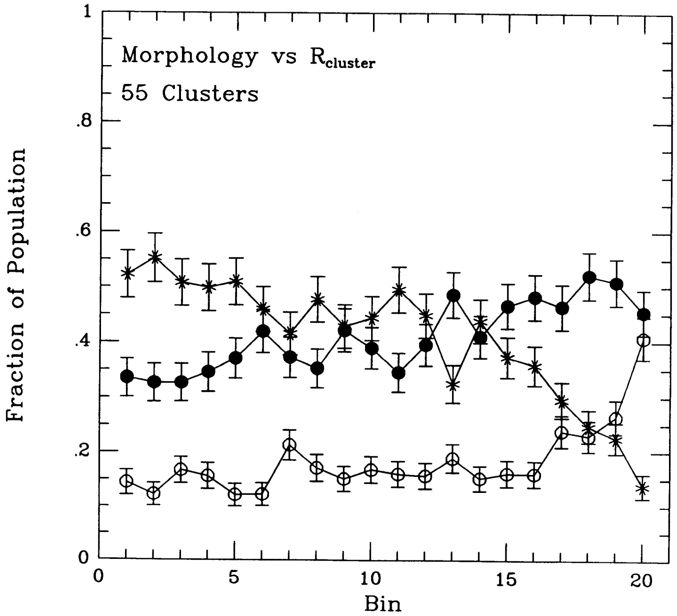

FIG. 3a,

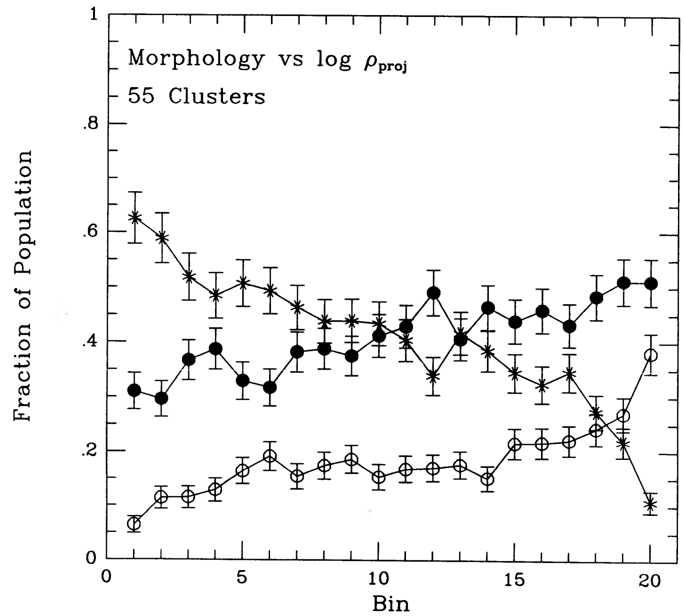

FIG. 3b

FIG. 3.—(a) The fraction of E, S0, and S+I galaxies as a function of the clustercentric distance for all 55 clusters in the sample. The galaxy with the highest local density is used as the center. Twenty equal bins are used to facilitate the comparison. The symbols are the same as in Fig. 1. (b) Same as (a) but using local projected galaxy density as the independent parameter.

distance and then by local density. This allows us to make a direct comparison between the two correlations. The results are shown in Figures 3a and 3b. In both cases the maximum elliptical fraction reaches ~40%, making it impossible from this test to determine which parameter is more fundamental. However, it is clear that the morphology-clustercentric distance relation is comparable to the morphology-density relation.

One possible explanation for the similarity between Figure 3a and 3b would be that the local projected galaxy density and the clustercentric distance are very tightly correlated. This is not the case, however, as shown by Figure 4. For example, at a given value of R_{clus}, the spread in log ρ_{proj} is roughly a third of

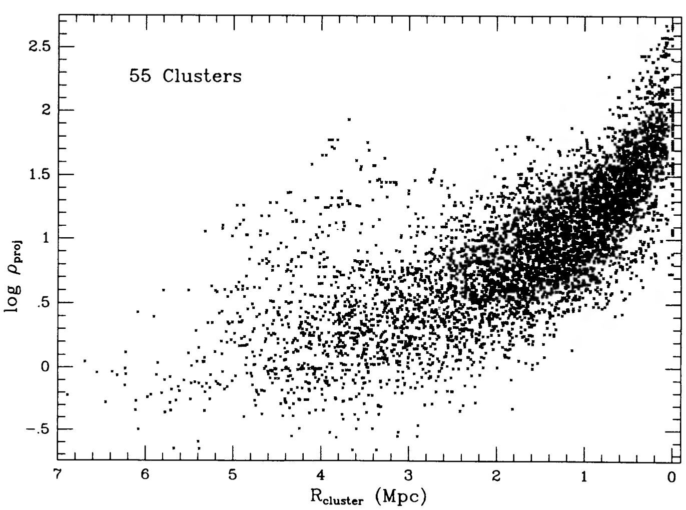

FIG. 4.—The local projected galaxy density vs. the clustercentric distance for the galaxies in all 55 clusters. The large scatter shows that the two parameters are not well correlated.

the full range in log ρ_{proj}. The "bump" of high-density galaxies at about $R_{clus} = 3.8$ Mpc is caused by the double cluster Abell 548. Removing this cluster from the sample makes a negligible change to Figure 3.

It is interesting to note that the elliptical fraction in Figure 3a is essentially flat for roughly three-fourths of the sample (i.e., bins 1–16), and is also flat in Figure 3b for one half of the sample (i.e., bins 5–14). Only in the very low density regions of Figure 3b is a possible downturn present. Perhaps these are actually field galaxies rather than cluster members.

Beers and Tonry (1986) have shown that the true dynamical center of a cluster is better defined by the location of a D or cD galaxy in the cluster, or the location of the peak of the X-ray emission, rather than by the centroid of the galaxy distribution. If we restrict ourselves to the 34 clusters in Dressler's sample with D galaxies, and use the D galaxy as the center of the cluster, the fraction of ellipticals goes up to an impressive 64% in the inner bin (Fig. 5). Part of this increase may be due to the fact that we have chosen the central point to be an elliptical galaxy, by definition. However, even if we exclude all the D galaxies from the calculation, the elliptical fraction in the inner bin is still 51%. Since the position of the D galaxy is generally a good indication of where the dynamical center of a cluster is, the higher value of 64% is probably the more appropriate number.

Figures 6a and 6b show the sample of clusters with D galaxies using the equal bins technique. The elliptical fraction for the central point is higher when using the clustercentric distance as the independent parameter ($56 \pm 6\%$) than when using local density ($40 \pm 5\%$). Excluding all the D galaxies would reduce the central elliptical percentage to 45% for the inner bin of Figure 6a. However, as explained above, the higher value of 56% is probably the more appropriate percentage to compare with.

Another interesting result is the apparent decrease in the fraction of S0 galaxies very near the centers of clusters. This

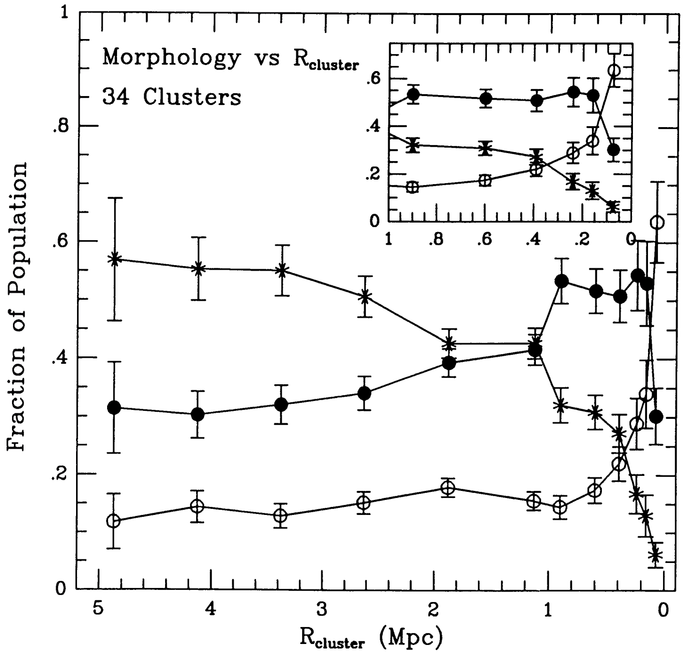

FIG. 5.—The fraction of E, S0, and S + I galaxies as a function of the clustercentric distance for the 34 clusters with D galaxies. The position of the D galaxy is used as the center. The symbols are the same as in Fig. 1. The insert in the upper right shows the same data at higher spatial resolution. Note the sharp rise in the fraction of elliptical galaxies very near the cluster centers, and the rapid decline in the S0 fraction.

can be seen very weakly in Figures 2 and 3 for the full sample of 55 clusters, but is much stronger when only the clusters with D galaxies are included (i.e., the S0 fraction falls from 54 ± 7% at 0.25 Mpc to 30 ± 5% at 0.075 Mpc in Fig. 5). Perhaps this indicates that the process that makes elliptical galaxies results in the destruction of S0 galaxies, or never allows them to form. If we exclude all the D galaxies from the sample, the fraction of S0 galaxies rises to only 41%.

It is also possible that the lack of S0 galaxies near the cluster centers is caused by some systematic classification problem. For example, the extended envelope of the central galaxy may make it difficult to distinguish between elliptical and S0 galaxies that are within the envelope. This does not appear to be a serious problem, however. We have manually examined PSS-O or SRC-J plates of all the clusters with D galaxies. Only 15 galaxies are deep enough within the envelope of the D galaxy to make the determination of Hubble type questionable. Twelve of these are ellipticals while three are S0 galaxies. If all 15 galaxies are excluded from the central bin, the percentage of S0s only increases from 30% to 32%. It therefore appears probable that the deficit of S0 galaxies near the centers of clusters is real.

The clustercentric distance may not be the optimal choice for the independent parameter when examining what controls the morphological fractions within clusters. For example, the center of the Coma cluster is treated the same as the center of a very poor cluster when using R_{clus}, even though the environmental effects are likely to be very different. With this in mind, we tried using a variety of other parameters to see if any of them could improve the correlations (e.g., an estimate of the local projected binding energy at the position of each galaxy in the cluster). None of these attempts resulted in better correlations than those shown in Figure 3. Other more physically meaningful parameters such as the cluster velocity dispersions or X-ray luminosities might be more useful, but unfortunately, only a small fraction of the 55 clusters have reliable estimates of these parameters at present.

III. DISCUSSION

a) Population Gradients for Spiral and S0 Galaxies

Dressler (1980) also examines the morphology-density relation for samples of low-concentration, high-concentration, and

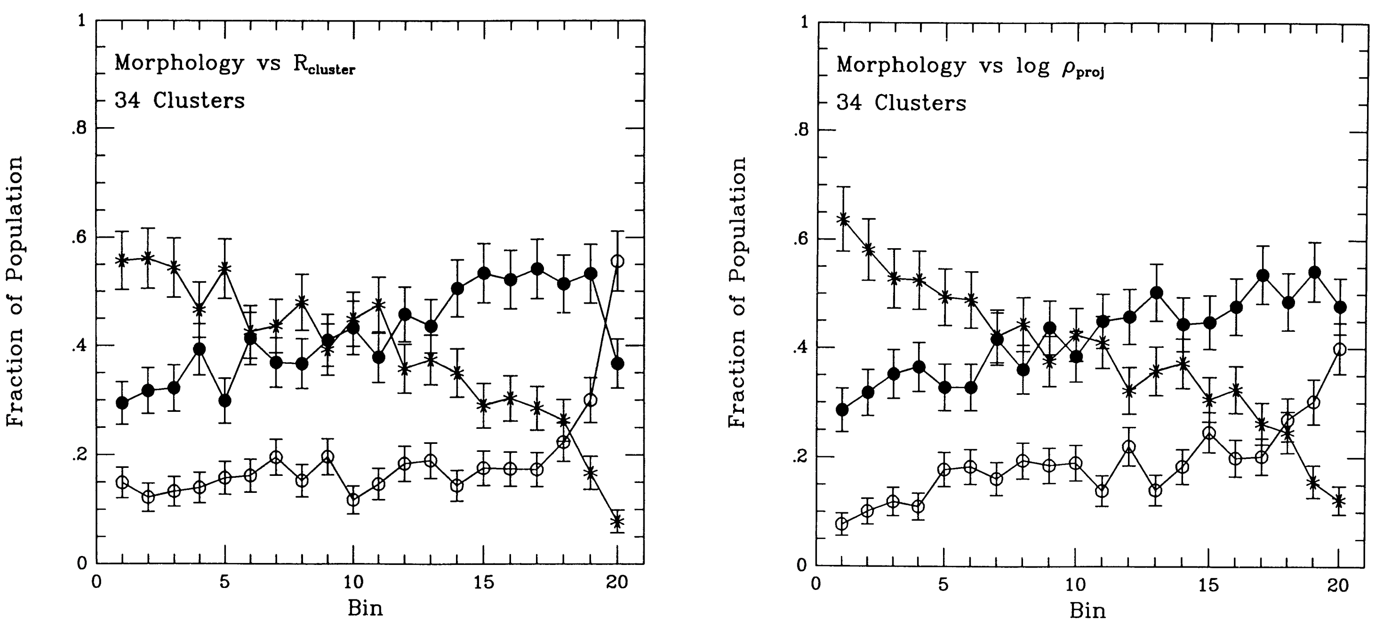

FIG. 6*a* FIG. 6*b*

FIG. 6.—(*a*) The fraction of E, S0, and S + I galaxies as a function of the clustercentric distance for the 34 clusters with D galaxies. The position of the D galaxy is used as the center. The symbols are the same as in Figure 1. Twenty equal bins are used to facilitate the comparison. (*b*) Same as (*a*) but using local projected galaxy density as the independent parameter.

X-ray emitting clusters and concludes that the relations for the three samples are very similar (Dressler's Figs. 8, 9, and 10). Although the elliptical fractions do look the same in all three samples, there is a clear trend for the fractions of spirals to be lower (at the same local projected galaxy density) in high-concentration and X-ray emitting clusters than in low-concentration clusters. The S0 galaxies show the reverse trend. This suggests that the mechanisms that cause the gradients in the spiral and S0 fractions may be different than the mechanism that causes the gradient in the elliptical fraction.

Another indication that the spiral and S0 fractions might be controlled by a different mechanism than the ellipticals is the flatness of the gradient in the elliptical fraction (vs. either $R_{\rm clus}$ or local density) in the outer, low-density region, as compared to the steep spiral and S0 gradients in the same region. Postman and Geller (1984) used this fact to suggest that the spiral and S0 fractions might be controlled by stripping mechanisms, while the ellipticals are produced near the cluster center because the collapse time of the cluster is shorter than the settling time of the disks.

b) Related Studies

The strategy employed in this paper has been to determine which parameters result in better correlations with the morphological fractions. Sanromà and Salvador-Solé (1990) have used a completely different approach to determine whether subclustering is responsible for the morphology-density relation, as Dressler (1980) and Dressler and Schechtman (1988) suggest, or whether some global effect is responsible. Using Dressler's data, they produced artificial clusters by taking each galaxy and randomly repositioning it in angular coordinates around the center of the cluster. In this way they destroy any subclusters that might be present, but keep the global properties (such as richness, central concentration, $R_{\rm clus}$) the same. They then construct the normal morphology-density relation for the scrambled clusters and compare it to the relation for the real clusters. The two diagrams are essentially identical, suggesting that the morphology-density relation may be controlled by global conditions rather than subclustering. Sanromà and Salvador-Solé are careful to point out that this does not imply that there is no substructure, but only that the substructure does not appear to play an important role in determining the morphological type of the galaxies. One possible problem with this study is that the majority of clusters may not have sufficient subclustering to show a difference using this technique. It would be useful to repeat the study including only the clusters with the strongest apparent subclustering.

Salvador-Solé, Sanromà, and Jordana (1989) have also shown that the observed morphology-density relation in two dimensions can be understood in terms of an intrinsic correlation in three dimensions that is dependent on cluster concentration.

c) The Morphology-Density Relation in Compact Groups

In compact groups of galaxies, the space densities are as high or higher than in even the densest regions of clusters, so we might expect the compact groups to consist of essentially all elliptical galaxies, based on the morphology-density relation. This is not the case, however (see Mamon 1986, Fig. 2, and Hickson, Kindl, and Huchra 1988, hereafter HKH). The fraction of ellipticals is only $\sim 20\%$ in the Hickson (1982) compact groups (HKH; Rood and Williams 1989), only slightly above the fraction found in the outer regions of a cluster ($\approx 12\%$; Dressler 1980), or the loose groups surrounding the compact groups ($\approx 7\%$; Rood and Williams 1989). Perhaps the lack of a high percentage of ellipticals is caused by the small number of galaxies in the compact groups, generally only four or five. Although the space density is similar to the densest regions in clusters, the small number of galaxies cannot produce the deep potential well found in clusters. Whitmore (1990) reviews the situation for compact groups in more detail.

IV. SUMMARY

Dressler's (1980) data on nearly 6000 galaxies in 55 clusters has been reexamined with the goal of determining whether the morphology-density relation is better than the morphology-clustercentric distance relation. The primary results are as follows.

1. Using the clustercentric distance as the independent parameter results in as wide a range in the morphological fractions as projected local density, contrary to earlier results. *The success of the morphology-density relation may therefore simply reflect the fact that the local galaxy density is generally correlated with position in the cluster.*
2. Only within 0.5 Mpc of the cluster center does the fraction of ellipticals rise dramatically. This effect is masked when using the local density as the independent parameter.
3. There is tentative evidence that the fraction of S0 galaxies falls within 0.2 Mpc of the cluster center, especially around D galaxies.
4. The physical mechanisms resulting in the gradients in the spiral and S0 fractions in the outer low-density regions of clusters are probably different than the mechanism resulting in the dramatic rise in the fraction of ellipticals near the cluster centers.

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