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GALAXY COLLISIONS IN DENSE GROUPS

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ABSTRACT

Examination of a sample of 18 dense groups of galaxies reveals that the size of the largest galaxy in each group is correlated with the mean intergalactic separation. This limitation of galaxy sizes and its dependence on the group's velocity dispersion can be roughly understood in terms of a simple theory of tidal stripping. The observed galaxy sizes are consistent with the Roche approximation for groups with low velocity dispersions and with computer simulations of fast collisions for groups with large velocity dispersions. There is a strong depletion of galaxies with H II regions and dust lanes in the groups in which collisions are expected to be most frequent. Although this trend suggests a Spitzer-Baade mechanism at work, some of the groups have more galaxies with an apparent interstellar medium than would be expected, given the collision rate. The data indicate that galaxy masses, luminosities, and morphology have been modified by collisions in these groups.

Subject headings: galaxies: clusters of — galaxies: structure

I. INTRODUCTION

The interaction of galaxies in close proximity is evident from the distortions of peculiar galaxies (Arp 1966). The gravitational nature of the effect is suggested by the work of Toomre and Toomre (1972) and Enev, Kozlov, and Sunyaev (1973) for pairs of galaxies. Peebles (1971) reviewed the dynamical problems posed by groups and clusters of galaxies. Recent theoretical (Gallagher and Ostriker 1972; Richstone 1975 and 1976 [hereafter R1 and R2]) estimates of the extent to which fast tidal encounters and interpenetrating collisions of galaxies in rich clusters remove stellar material from the galaxies suggest that similar processes might be important in small dense groups. However, with the exception of two groups noted by Sandage (1973), there has been no observational investigation of the extent to which the sizes, masses, or luminosities of galaxies in dense groups may have been modified by dynamical processes.

We therefore examine the available data on 18 dense groups of galaxies for systematic effects that might result from the tidal interaction of group members. A correlation between the size of the largest galaxy in the group and mean intergalactic separation is noted. The sample, analysis, and this correlation are discussed in § II. In § III, we discuss a simple extension of an earlier theory for fast collisions (R1) to slower ones and predict a maximum size for cluster members. Within the uncertainties the sizes of the largest galaxy in each group are consistent with this theory. Difficulties with this interpretation and an observational prediction are discussed in § IV.

II. THE DATA

The sample consists of the 10 densest groups from a new catalog by Turner and Gott (1976), four dense chains from unpublished work by Sargent, and the well-known compact groups VV 172, Seyfert's Sextet, Stephan's Quintet, and the NGC 70 group. Collected data for these groups are listed in Table 1. Column (1) gives the group designation, column (2) contains N, the number of galaxies in the group, and column (3) contains the number of galaxies exhibiting evidence of an interstellar medium. For the radius R of the group we adopt the median projected intergalactic separation given in column (4). Column (5) contains the diameter d (along the major axis) on either the red or blue Sky Survey prints of the largest galaxy in each group. Column (6) lists the velocity dispersion of each group, and column (7) the source of the data.

The galaxy diameters were obtained from their angular sizes using a Hubble constant of 55 km s^{-1} Mpc^{-1}. Ideally, one needs surface brightness profiles to determine tidal radii; however, these are difficult to obtain. We have compared photographic surface brightness profiles for a small number of galaxies to visual size estimates to satisfy ourselves of their reliability.

Figure 1 is a plot of d against the mean intergalactic separation $\langle s \rangle$ defined by

$$\langle s \rangle = \left(\frac{4\pi}{3}\right)^{1/3} R N^{-1/3} . \qquad (1)$$

There is a definite correlation roughly of the form $d \sim \langle s \rangle^{1/2}$. This empirical relation provides clear evidence

TABLE 1

DATA FOR 18 DENSE GROUPS

Group	N	N_s	R (kpc)	d (kpc)	V_{c1} (km s^{-1})	Reference
TG 6	3	2	105	74	110	1
10	3	2	233	65	115	1
16	5	3	56	19	127	1
20	3	2	144	34	42	1
28	6	4	208	39	44	1
38	6	5	261	49	110	1
61	4	3	158	83	65	1
67	3	3	227	62	61	1
91	5	5	398	53	20	1
98	3	3	184	41	20	1
VV 150	5	2	38	28	155	3, 4
165	7	1	67	34	141	3, 4
169	4	1	32	24	89	3, 4
172*	4	1	38	25	205	2
282	8	4	115	67	276	3, 4
NGC 70*	7	2	74	52	240	6
Stephan's Quartet*	4	3	50	18	440	5
Seyfert's Quintet*	5	2	15	16	162	3

* One group member with a discrepant redshift has been removed.

REFERENCES.—(1) Turner and Gott 1976. (2) Sargent 1968. (3) Burbidge and Sargent 1971. (4) Sargent 1976. (5) Burbidge and Burbidge 1961. (6) Kormendy and Sargent 1974.

that a galaxy's size can be influenced by its environment either at formation or during subsequent evolution. For clusters with a fixed velocity dispersion of 1000 km s^{-1} and a range of densities, the maximum size of a cluster galaxy consistent with estimates of tidal stripping efficiency is expected to vary as $r_{\max} \sim \rho^{-1/2} \sim \langle s \rangle^{3/2}$ (R1). Of course, this theory is not applicable here since the small groups studied have a range of group velocity dispersions, all of which are smaller than 1000 km s^{-1}. The observed correlation prompts further consideration of "intermediate" velocity galaxy collisions.

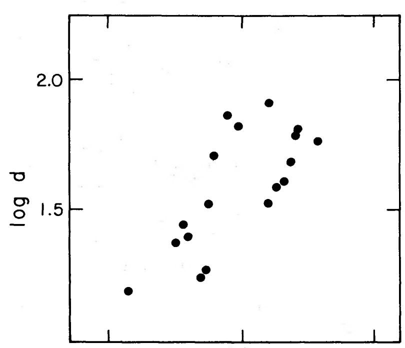

FIG. 1.—The relationship of log d, the size of the largest galaxy, to log $\langle s \rangle$, the mean intergalactic separation, for all groups in our sample in units of kpc. There is a clear correlation with $d \sim s^{1/2}$. This correlation suggests that the sizes of large galaxies in dense groups are influenced by their environment, either at formation or during their subsequent evolution.

III. THEORY

Suspecting that interactions of the galaxies have limited their sizes, we wish to determine the maximum possible size of a galaxy in a small group of specified density and velocity dispersion. Although we will not be able to do this, we will discuss a formalism which facilitates a discussion of this question, and will compare observations with theory in the low and high velocity limits.

We assume that each group is bound and has an age of order H_0^{-1}. It is also assumed that the orbits are distributed so that the collision rates are those of noninteracting gas particles confined at a specified density and temperature (velocity dispersion).

Earlier theoretical work (R1) shows that the cross section for removal of material from colliding galaxies varies as the geometrical cross section of the galaxies and suggests that it varies inversely as the collision velocity if that velocity is much larger than the internal velocity dispersions of the galaxies. (For very slow collisions, the Roche limit should apply at the distance of closest approach.)

Define η as the ratio of the collision cross section (corresponding to the impact parameter at which one collision does a great deal of damage) defined in R1, to the geometrical cross section of the galaxy. Then the collision rate and assumed age of the group give

$$2^{1/2} n \sigma V \eta = H_0 \,, \qquad (2)$$

n being the number density of galaxies in the group. The factor $2^{1/2}$ arises because a "typical" galaxy has a velocity distribution characterized by $2^{1/2}V$. Writing

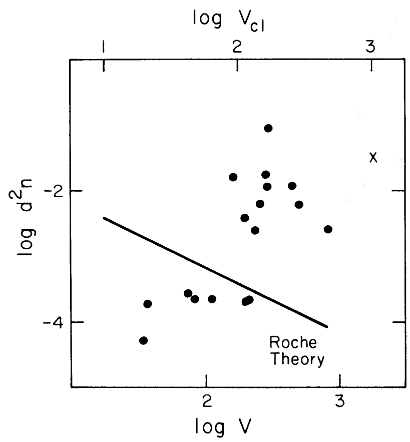

FIG. 2.—The relationship of d^2n (kpc^{-1}) to the group velocity dispersion (see eq. [7]). Also shown is the predicted upper limits on d^2n from the Roche theory and from the approximate intermediate velocity collision theory. The single point (×) is from numerical simulation (R1).

$\sigma = \pi/4d^2$ and collecting the velocity-dependent terms, we obtain

$$d^2n = 4\frac{H_0(V\eta)^{-1}}{2^{1/2}\pi}\,. \tag{3}$$

Figure 2 shows the observed variation of d^2n with V, the results of the R1 numerical simulation, and the relation expected if $\eta = 4$ (simple Roche theory).

This figure clearly shows that for the highest velocity dispersion groups, the sizes of the galaxies are consistent, or nearly so, with published tidal stripping efficiencies derived for high cluster velocity dispersions, while for the lowest velocity groups the galaxy sizes are consistent with the Roche limit applied at the distance of closest approach. The form of $\eta(v)$ for intermediate velocity collisions is unknown and difficult to calculate. Numerical simulations on at least the level of the restricted three-body approximation are probably necessary for a reliable estimate of this quantity. Nonetheless, the consistency of theory and observation in the low and high velocity limits supports the view that the small size of the galaxies in the densest groups is a result of encounters with the other galaxies in the group.

IV. DISCUSSION

From Figure 1 it is clear that the sizes of galaxies in these groups are correlated with the mean intergalactic separation. The sizes are, however, larger generally than would be expected from the simple Roche theory by an amount that correlates with the cluster velocity dispersion. Figure 2 shows that the sizes are consistent with assessments of tidal stripping efficiencies in the high and low velocity limits.

There are, however, two important problems for the tidal explanation. It is difficult to understand how many of these groups can contain several galaxies with an apparent interstellar medium; and dynamical-friction time scale estimates for the groups, while extremely uncertain, are disturbingly short.

It is well known that the spiral galaxies in the densest groups should have suffered many interpenetrating collisions (Peebles 1971). As Spitzer and Baade (1951) noted, spiral-spiral collisions would effectively destroy spiral structure by sweeping the gas out of the colliding galaxies. This process should be effective in clusters containing more than one spiral, and should increase rapidly with the number of spirals as $N_s(N_s - 1)$. As most collisions are grazing, we expect that several spiral-spiral collisions are necessary to destroy the spiral structure or remove the interstellar medium. In Figure 3 we have plotted the spiral fraction N_s/N against $N_{\rm col}$, the number of collisions expected for any group member in a Hubble time. The general anticorrelation of spiral content with the expected number of collisions is consistent with the Spitzer-Baade (1951) hypothesis of spiral destruction, but the presence of two or more spiral galaxies in the densest groups is hard to understand. The fact that the groups with the fewest spirals have N_s/N comparable to Oemler's (1974) spiral-poor or cD clusters may be a clue. It is likely that some spirals in these rich clusters survive because they start out in elongated orbits which only rarely (if ever) carry them through the cluster center. If the formation process for groups is comparable to that for clusters, a comparable fraction of the galaxies may acquire such orbits. In this way, a larger proportion of spirals would survive than expected from estimates which idealize a group as a uniform-density box.

The problem of short dynamical friction time scales is acute for many of these groups. The time scale for loss of orbital energy due to dynamical friction for a straight line orbit in a homogeneous background of low-mass stars is

$$T \equiv \left(\frac{1}{V}\frac{dV}{dt}\right)^{-1} = \frac{V^3}{4\pi G^2 M\rho \ln \Lambda}\,[\phi(jV) - jV\phi'(jV)] \tag{4}$$

(Chandrasekhar 1942; Spitzer 1962; Tremaine, Ostriker, and Spitzer 1975), where V is the galaxy velocity, j the inverse velocity dispersion of the background, ρ the background mass density, Λ the ratio of minimum to maximum impact parameters, and ϕ the usual error function. This formula may be easily applied to the groups under the assumption that the background of lighter objects (of mass $M_{\rm bk}$) and the galaxies have the same spatial distribution. Taking the average group density within the median radius R_h for ρ and the virial theorem in the form $v^2 = 0.4\,GM/R_h$ (Spitzer and Hart 1972) gives

$$T = 0.05\frac{R_h}{V}\frac{M_{\rm bk}}{M}\,, \tag{5}$$

neglecting the factor in brackets in equation (4) and taking $\ln \Lambda = 1$.

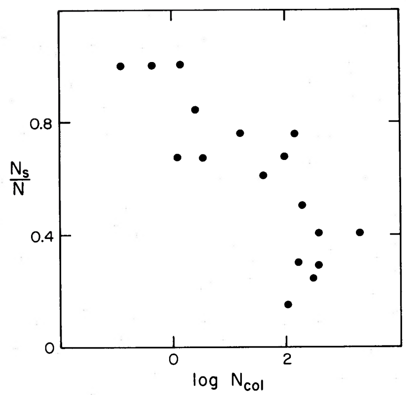

FIG. 3.—Ratio of the number of spiral galaxies to total number of galaxies in each group, as a function of the number of interpenetrating collisions (N_{col}) expected for a typical galaxy in the group. The trend in the number of spirals in the group with N_{col} is consistent with the Spitzer-Baade hypothesis of gas removal by interpenetrating collision, but there are too many spirals in the densest groups.

Since the groups discussed here have crossing times of order 10^{-1} to 10^{-2} H_0^{-1}, individual galaxies must comprise all or less than a few percent of the mass of the group, or the groups' dynamical friction times are much shorter than their assumed age (H_0^{-1}). If the galaxies in these groups have normal velocity dispersions of 100–200 km s^{-1}, then the sizes of the galaxies in the denser groups indicate that they contain (together) $\frac{1}{10}$ to $\frac{1}{2}$ of the groups' mass. Such masses lead to dynamical-friction time scales of the order of the crossing time.

This difficulty may result from a misapplication of the conventional dynamical friction theory, since the orbit of a galaxy in a small group is very different indeed from a linear path through a very large system of much lighter test particles. Kalnajs (1972) has shown that in the absence of resonances, massive particles in circular orbits in systems with light particles in epicyclic orbits do not experience dynamical friction. Therefore, the time scales estimated for these systems may be greatly in error.

If the smaller sizes of galaxies in dense clusters are a result of tidal damage, then their luminosities have been altered since formation. Group distances inferred from either the brightest member (as used by Sandage for the great clusters) or properties of the luminosity function (Bautz and Abell 1973; Schechter and Press 1976) may be systematically in error, although it is not clear that the effect is a large one.

Our interpretation of dense group data may be tested in three ways. Galaxies in small dense groups would be expected to be underluminous on average. This effect has been noted by Sandage in the NGC 70 and the NGC 6027 groups. There should be intracluster light in the dense groups, and the galaxy surface brightness profiles should be tidally truncated.

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