

A SURVEY OF COMPACT GROUPS OF GALAXIES

JAMES A. ROSE*

Yale University Observatory

Received 1976 May 14

ABSTRACT

The distribution of compact groups of galaxies has been studied on a number of the Palomar Observatory Sky Survey plates and the Yale-Columbia southern proper motion plates. It is found that the number of compact groups is large enough to explain the occasional anomalous-redshift galaxies observed in these systems as superposed field galaxies. Also, compact chains of galaxies are found to be chance alignments of the galaxies in groups. Therefore, new physics is not needed to explain either of these phenomena. Nearly every group studied has at least one galaxy closer to it than would be expected for randomly distributed field galaxies; it is concluded that in general compact groups are small subsystems of larger groups of galaxies. As a result, application of the virial theorem to the compact groups alone could lead to invalid estimates of galaxy mass-to-light ratios. The dispersion in magnitude of the galaxies in compact groups is also discussed.

Subject headings: galaxies: clusters of — galaxies: redshifts

I. INTRODUCTION

The dynamics and morphology of compact groups of galaxies has been a subject of considerable interest ever since the original dynamical study of Stefan's Quintet by Burbidge and Burbidge (1961) revealed the existence of both a substantial virial mass discrepancy and an anomalous-redshift galaxy in this group. Roughly speaking, a compact group is an aggregate of several galaxies whose projected separations are typically on the order of the diameters of the galaxies themselves. Owing to the compact nature of these systems, the incidence of a superposed field galaxy should be extremely rare; thus compact galaxy groups appear to be dynamically pure systems which are ideally suited for virial theorem studies of galaxy mass-to-light ratios. In an extensive review of the subject, Burbidge and Sargent (1971) describe the results of applying the virial theorem to a number of compact groups. In almost every case the virial mass-to-light ratio of the group as a whole is significantly larger than the mass-to-light ratios that have been determined for individual galaxies on the basis of galaxy rotation curves and internal velocity dispersions. This virial mass discrepancy has most often been interpreted as evidence that the groups are gravitationally unstable and rapidly expanding (Ambartsumian 1958), that there is hidden mass spread throughout the groups, or that galaxies have extended massive halos (e.g., Ostriker, Peebles, and Yahil 1974). In addition, in three of the compact groups studied, one of the galaxies has a wildly discrepant redshift. It has been suggested that these anomalous-redshift galaxies have been ejected from their associated groups through some unknown physical process or that a component of their redshifts

is noncosmological in origin. On the other hand, the galaxies may simply be field galaxies superposed on the groups, although the ex post facto probability of such a chance superposition is typically only 1 in 300 in these three cases.

This paper reports the results of a systematic search for compact groups of galaxies on the Palomar Observatory Sky Survey plates and on the Yale-Columbia southern proper motion plates. The results of this plate search are presented in § II. The primary objective was to obtain a well-defined sample of galaxy groups with which to conduct a study of galaxy mass-to-light ratios. However, detailed knowledge of the distribution and morphology of compact groups also contributes relevant information to the question of whether new physics must be introduced in order to explain the anomalous redshifts and galaxy chains which have been found in these systems. The issue of anomalous redshifts is examined in § III, whereas the nature of galaxy chains is discussed in § IV. In addition, in § V we study the distribution of the nearest neighboring galaxies around compact groups in order to determine whether or not these groups are dynamically isolated systems. Finally, in § VI the average dispersion in magnitude of the galaxies in compact groups is compared with that in loose groups.

II. THE DISTRIBUTION OF COMPACT GALAXY GROUPS

a) Plate Material

A systematic search for compact groups of galaxies has been carried out on 69 of the Kitt Peak National Observatory glass copies of the Palomar Observatory Sky Survey plates (henceforth POSS). A list of plate centers searched is given in Table 1 along with the field numbers of the plates as given in *The Catalogue of Galaxies and Clusters of Galaxies* (Zwicky et al. 1961-1968, henceforth CGCG). All of the fields have

* Visiting Student, Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1
COORDINATES OF PLATE CENTERS

Field	R.A. (1950.0)	Decl. (1950.0)
11.....	11 ^h 16 ^m	0°
13.....	12 00	0
14.....	12 24	0
15.....	12 48	0
16.....	13 12	0
17.....	13 36	0
39.....	11 12	+6
40.....	11 36	6
41.....	12 00	6
42.....	12 24	6
43.....	12 48	6
44.....	13 12	6
45.....	13 36	6
46.....	14 00	6
47.....	14 24	6
66.....	10 48	12
67.....	11 12	12
68.....	11 36	12
69.....	12 00	12
71.....	12 48	12
72.....	13 12	12
73.....	13 36	12
74.....	14 00	12
75.....	14 24	12
76.....	14 48	12
94.....	10 24	18
95.....	10 48	18
96.....	11 12	18
97.....	11 36	18
98.....	12 00	18
99.....	12 24	18
100.....	12 48	18
101.....	13 12	18
102.....	13 36	18
103.....	14 00	18
104.....	14 24	18
105.....	14 48	18
124.....	10 24	24
125.....	10 50	24
126.....	11 16	24
127.....	11 42	24
128.....	12 08	24
129.....	12 34	24
130.....	13 00	24
131.....	13 26	24
132.....	13 52	24
133.....	14 18	24
134.....	14 44	24
135.....	15 10	24
154.....	10 24	30
156.....	11 16	30
158.....	12 08	30
159.....	12 34	30
161.....	13 26	30
162.....	13 52	30
163.....	14 18	30
164.....	14 44	30
165.....	15 10	30
183.....	10 16	36
184.....	10 44	36
185.....	11 12	36
186.....	11 40	36
187.....	12 08	36
188.....	12 36	36
189.....	13 04	36
190.....	13 32	36
191.....	14 00	36
192.....	14 28	36
193.....	14 56	36

galactic latitude $|b^{\text{II}}| \geq 55^\circ$ in order to avoid absorption within the Galaxy and to minimize the number of stellar images on the plates; declinations of the plate centers range between $+36^\circ$ and 0° . Each blue plate has been carefully scanned with a $7\times$ magnifier, and all compact groups brighter than a limiting magnitude of 17.5 have been recorded. The corresponding red plate has been frequently used, particularly in cases where the number of galaxies in a group is difficult to determine. Also, the noninteracting galaxies generally show up better on the red plates. Each POSS plate covers an area of $6^\circ \times 6^\circ$ when overlap between the edges of adjoining plates is accounted for.

An identical program has been carried out on 23 of the blue plates of the Yale-Columbia southern proper motion survey. The limiting magnitude in galaxies on these plates is approximately 18, so that magnitude 17 galaxies appear only as faint smudges and are virtually indistinguishable from faint stars. For this reason, any statistics as to the *distribution* of galaxy groups has been based solely on the more reliable POSS material. The Yale-Columbia plates cover an area of $5^\circ \times 5^\circ$ when overlap is accounted for, and the plate scale 55.1 mm^{-1} . A description of this sky survey has been given by Wesselink (1974). In addition, direct photographs of four of the most probable compact galaxy groups found on the Yale-Columbia plates have been obtained with the Yale-CTIO 1 meter f/10.3 reflector during August–September of 1975. These photographs were taken through a GG385 filter on 103a-O emulsion baked 12 hours in nitrogen; exposure times ranged from 2 to 3 hours with a limiting blue magnitude on the plates of approximately 20–21.

b) Definition of Compact Groups and Determination of the Field Galaxy Density

A compact group of galaxies is defined in the following way: Suppose that an aggregate of three or more galaxies subtends an area of $A \text{ arcmin}^2$. Let σ be the average number of field galaxies per arcmin^2 with blue magnitude equal to or brighter than the faintest galaxy enclosed in the area. Then the aggregate of galaxies is defined to be a compact group if $A\sigma \leq 0.0035$ and if the faintest galaxy in the group has a blue magnitude equal to or brighter than 17.5. Thus a compact group of n galaxies represents a surface density contrast of at least $n/0.0035$ times the average density of the field. Groups obviously located in a dense cluster of galaxies are not counted. The cutoff value of $A\sigma$ is the average value for the three known cases of compact galaxy groups with discrepant redshifts (Stefan's Quintet, Seyfert's Sextet, and VV 172); the limiting magnitude of 17.5 is chosen because the faintest galaxies in VV 172, which is the faintest of the discrepant-redshift groups, are 17.5. Thus the definition for compact galaxy groups is chosen to include only those groups which are at least as compact as and as bright as the known cases of groups with discordant redshifts.

The number density of field galaxies brighter than a blue magnitude of 17.5 has been determined in the

following manner: A point is randomly selected on one of the POSS plates at high galactic latitude and the distances in arcminutes of the three nearest neighboring galaxies from this point are measured. This procedure is repeated 5 times per POSS plate on 10 different plates. Average distances of 7.2, 10.4, and 13.2 have been derived for the first, second, and third nearest neighboring galaxies, respectively, using this method. Assuming the field galaxies to be randomly distributed, it then follows that $\langle r_n \rangle$, the average distance of the n th nearest galaxy to a given point, is given by (see Appendix):

$$\langle r_n \rangle = \frac{1}{(n-1)!} \Gamma(n + \frac{1}{2}) \frac{1}{(\pi\sigma)^{1/2}} \quad (1)$$

The above equation has been solved for σ for the first three nearest neighboring galaxies, yielding a density of 0.005 galaxies per square arcminute, or 18 galaxies per square degree with a limiting magnitude of 17.5. This figure is in fairly good agreement with that of 24 galaxies per square degree derived by Hubble (1934). In addition, it implies average distances to the first three nearest galaxies of 7.1, 10.5, and 13.3. As the agreement with the observed values is so close, for the purposes of this paper the "field" galaxies are considered to be randomly distributed.

The above method of determining the average galaxy density is essentially equivalent to the tradi-

tional galaxy count approach. The advantage of this method is that we have also directly determined the average distances of nearest neighboring field galaxies. In § V we will make use of these data in order to examine the question of whether or not compact groups of galaxies are dynamically isolated systems.

c) Group Data

On the 69 POSS fields which have been examined approximately 170 compact trios of galaxies have been located. In addition, 26 definite and seven probable compact quartets have been found as well as two compact quintets. One of the compact quintets is the well-known group VV 165, and the other is located on the same POSS field at $\alpha = 14^h49^m0$ and $\delta = +18^\circ53'$. In some cases it is impossible to decide how many galaxies there are in a given group on the basis of the blue and red POSS plates alone. The main uncertainties are: (1) confusion of stars with compact galaxies in cases where two or more of the objects in a group overlap and are blended together; (2) uncertainty in the number of discrete galaxies present in a strongly interacting group.

A list of the 33 definite and probable compact quartets is provided in Table 2 along with their physical characteristics. The last seven entries in the table are the *probable* quartets; no physical characteristics are given for these groups. The 1950.0 coordinates for each group accurate to 1' are given in

TABLE 2
NORTHERN COMPACT GROUPS

Group	R.A. (1950.0)	Decl. (1950.0)	Magnitudes	Dimensions	Field
1.....	10 ^h 45 ^m 4	+24°14'	16.5 16.5 17.0 17.5	1.35 × 0.22	125
2.....	10 51.9	+12 46	17.5 17.5 17.5 17.5	0.40 × 0.20	66
3.....	11 00.0	+17 22	17.5 17.5 17.5 17.5	1.20 × 0.40	95
4.....	11 15.4	+30 41	15.2 15.5 16.5 17.0	1.80 × 0.35	156
5.....	11 45.4	+37 43	16.0 16.5 17.5 17.5	0.90 × 0.22	186
6.....	11 45.8	+26 02	16.5 17.0 17.0 17.0	0.50 × 0.22	127
7.....	11 45.9	+12 59	14.7 15.3 15.3 15.3	3.10 × 1.45	68
8.....	12 02.2	+31 27	14.0 15.2 16.5 16.5	1.95 × 0.40	158
9.....	12 05.5	+10 02	16.0 16.0 16.5 16.5	1.90 × 0.80	69
10.....	12 09.8	+29 26	12.9 13.7 14.2 14.3	3.80 × 2.45	158
11.....	12 10.4	+22 52	17.0 17.0 17.5 17.5	0.45 × 0.30	128
12.....	13 22.6	+32 47	15.3 16.0 16.5 17.0	3.00 × 0.35	190
13.....	13 26.0	+16 06	17.0 17.0 17.5 17.5	0.22 × 0.11	101
14.....	13 38.5	+02 03	16.0 17.0 17.0 17.5	0.50 × 0.11	17
15.....	13 45.6	+07 38	15.0 15.0 16.0 17.0	1.90 × 0.30	45
16.....	13 54.2	+28 46	15.4 15.5 15.6 15.7	6.70 × 0.90	162
17.....	14 09.7	+25 10	16.0 16.5 17.5 17.5	1.85 × 0.35	133
18.....	14 10.7	+08 52	15.5 16.0 16.0 17.0	1.10 × 0.40	74
19.....	14 11.3	+08 27	16.0 16.0 17.0 17.5	1.10 × 0.15	74
20.....	14 15.2	+08 25	16.0 17.0 17.0 17.5	0.65 × 0.50	46
21.....	14 32.8	+26 46	17.0 17.0 17.0 17.5	1.00 × 0.60	163
22.....	14 47.5	+11 13	16.5 16.5 17.0 17.5	2.70 × 0.11	76
23.....	14 48.4	+10 19	16.5 17.0 17.0 17.0	1.35 × 0.55	76
24.....	15 03.1	+29 00	17.0 17.0 17.5 17.5	1.35 × 0.22	165
25.....	15 06.1	+34 35	17.0 17.0 17.5 17.5	0.45 × 0.11	193
26.....	15 10.2	+28 01	16.5 17.0 17.0 17.5	1.80 × 0.80	165
27.....	11 26.5	+20 51	...	...	126
28.....	12 04.3	+24 54	...	...	128
29.....	12 16.1	+12 01	...	...	69
30.....	13 14.4	+12 49	...	...	72
31.....	13 14.9	-02 55	...	...	16
32.....	13 42.0	+20 40	...	...	131
33.....	14 08.5	+15 27	...	...	103

columns (2) and (3). Magnitudes of the individual group members are listed in column (4), and the physical dimensions of the groups are given in column (5). Finally, the field number of the plate on which the group was discovered is given in column (6). Magnitudes of galaxies brighter than 15.7 are taken directly from the *CGCG*. For galaxies fainter than 15.7, rough magnitudes based on eye estimates are given; the three brightest and two faintest galaxies in VV 172 have been used as "standard" 17 and 17.5 magnitude galaxies, respectively.

Additional photographic material has been obtained for group numbers 13, 19, and 23. Group number 23 appears to be a system containing six objects, but a two hour exposure with the Yale-CTIO 1 m telescope clearly shows that the two southernmost objects are foreground stars. Photographs of groups 13 and 19 were kindly supplied to me by Dr. R. D. McClure; these are 10 minute exposures on IIa-O emulsion taken with the KPNO 4 m telescope on 1975 May 16-17. Group number 13 is listed as a quintuple system in the *CGCG*, but the northernmost object in the group is unquestionably stellar on the 4 m plate. The 10 minute exposure of group number 19 definitely establishes that there are four objects in this system.

Data for five southern compact quartets are given in Table 3. The first four groups in the Table (numbers 34-37) were found on the Yale-Columbia plates and photographed with the Yale-CTIO 1 m telescope. The fifth group (number 38) is the Klemola 30 system which contains NGC 6845 (Graham and Rubin 1973). Coordinates for the groups accurate to one arcminute are given in columns (2) and (3). Individual magnitudes for the group members are listed in column (4), and the group dimensions are given in column (5). The magnitudes given for group numbers 34 and 38 have been derived from a combination of photoelectric and photographic data obtained with the Yale-CTIO 1 m and the CTIO 90 cm reflectors during the previously mentioned 1975 August-September observing run. Details of this procedure will be published elsewhere. Magnitudes of the galaxies in group number 35 have been derived from very rough eye estimates on the Yale-Columbia plates using the galaxies in groups 34 and 38 as standards.

The overall number of compact trios, quartets, and quintets of galaxies can now be derived from the data obtained from the POSS plates. As mentioned earlier, the data obtained from the Yale-Columbia plates is too uncertain to be of use for this purpose. Let n_i

be the number of groups with i members found in the plate search and N_i be the corresponding number of groups extrapolated to the whole sky. Taking $n_3 = 170$, $n_4 = 26-33$, and $n_5 = 2$, we find that $N_3 = 2800$, $N_4 = 430-550$, and $N_5 = 33$. Our value for N_5 is, of course, highly uncertain. The relative number of trios to quartets is approximately 5.5 to 1. The relative number of quartets to quintets is approximately 15 to 1, but is obviously a poorly determined number.

III. DISCREPANT REDSHIFTS IN COMPACT GROUPS

Now that the distribution of compact galaxy groups is known, we can make a simple statistical test in order to determine whether or not the observed cases of anomalous redshift galaxies can be attributed to the chance superposition of field galaxies. Burbidge and Sargent (1971) have described the three known examples of discordant redshifts in compact groups. All three of these groups are quintets brighter than magnitude 17.5 (the sixth "galaxy" in Seyfert's Sextet is believed to be material tidally stripped from NGC 6027), and each contains a *single* discrepant-redshift galaxy. By looking at the number of compact quartets brighter than magnitude 17.5, we can predict how many discrepant redshift quintets that there are likely to be due to chance superposition. If N_4 is the number of compact quartets with $A\sigma = 0.0035$ and N_d is the *expected* number of discrepant redshift quintets, then

$$N_d = N_4 \sigma A. \quad (2)$$

As N_4 is between 433 and 550, we would most likely expect to see 1.5-2.0 compact quintets with a single discrepant-redshift galaxy. This figure agrees remarkably well with the fact that three discrepant-redshift quintets have been found in a presumably thorough survey of the area covered by the POSS (about 67% of the sky).

Similarly, the expected number of compact quintets containing two superposed field galaxies is

$$N_d = \frac{1}{2} N_3 (\sigma A)^2, \quad (3)$$

where N_3 , the number of compact trios, is approximately equal to 2800. Thus it is clear why no quintets with two discrepant redshifts have been found. Finally, there is also a natural explanation for the fact that the discrepant redshifts have been found in compact quintets only. Since the ratio of the number of quartets to quintets is much higher than that of trios to quartets,

TABLE 3
SOUTHERN COMPACT GROUPS

Group	R.A. (1975.0)	Decl. (1975.0)	Magnitudes	Dimensions
34.....	00 ^h 20 ^m 1	-48°48'	14.2 14.4 15.2 15.6	2.90 × 2.40
35.....	03 02.4	-50 35	16.0 16.5 17.0 17.5	2.40 × 0.28
36.....	03 05.4	-42 46		2.20 × 0.80
37.....	03 29.9	-50 16		2.60 × 0.95
38.....	19 59.5	-47 09	13.7 14.8 15.2 16.4	8.55 × 1.65

a much larger percentage of quintets should have superposed field galaxies than quartets. As an approximately equal number of quartets and quintets have been studied spectroscopically, it is not surprising that all of the discrepant redshift galaxies have been found in compact quintets.

IV. THE NATURE OF GALAXY CHAINS

Another characteristic of some compact galaxy groups which has caused speculation as to the need for new physics is the chaining phenomenon. The compact group VV 172 is perhaps the most striking example of a chain of galaxies (Sargent 1968). Sargent and Turner (1972) have noted that the observed velocity dispersions of the galaxies in chains imply that the chains must be a transient phenomenon with typical lifetimes on the order of 10^8 years. They have advanced the explanation that galaxy chains are simply the chance alignment of the galaxies in groups as seen projected onto the sky. In order to test this interpretation they have performed computer simulations of groups of six galaxies and find that 8% of the time the galaxies line up in chains purely through chance alignment as seen projected into two dimensions.

In order to further test the interpretation of Sargent and Turner, a similar program has been carried out with numerical simulations of groups of four galaxies. Each group was generated by randomly selecting four points within a unit sphere and then projecting these positions into two dimensions; the assumption was made that a dynamical simulation of groups was unnecessary. The percentage of chains found in the numerical simulations can then be compared with the percentage of chains found among the compact quartets of galaxies listed in Tables 2 and 3. However, rather than use a subjective criterion in order to pick out chains among the computer simulated groups and the POSS groups, the following "chaining parameter" has been used:

Let l be the line joining the two members in a group which have the maximum projected separation. Let W be the width and L the length of the narrowest possible rectangle that encloses all of the galaxies in the group and that has its long sides parallel to and equal in length to the line l . Then the ratio (W/L) of the width to the length of the rectangle is a parameter which is a good indicator of how closely the galaxies are aligned in a chain.

The quantities W and L have been measured for each of the definite northern and southern compact quartets and are listed in column (5) of Tables 2 and 3. The distribution of W/L for both the observed and the computer generated groups are compared in Figure 1. $N(\leq W/L)$ is the percentage of groups for which the chaining parameter is less than or equal to W/L . The circles represent data generated from 300 computer simulated groups. The solid lines represent the corresponding data derived from the five southern quartets (Table 3) and all of the definite northern quartets (Table 2) excepting group numbers 12, 16, and 22. Inclusions of groups 12, 16, and 22 would introduce a

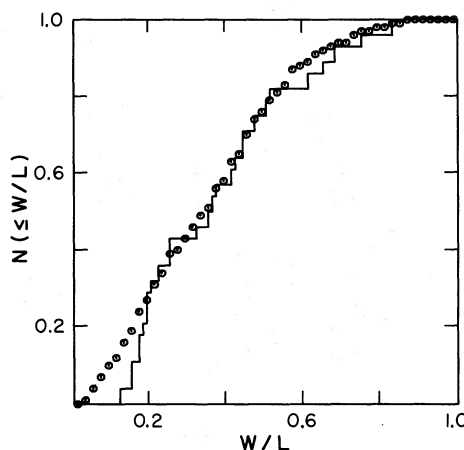


FIG. 1.— W and L are the width and length of the narrowest possible rectangle that can be drawn around a group which includes all members of the group and has its long sides parallel to and equal in length to the line connecting the two galaxies in the group with the maximum projected separation. The circles represent data generated from 300 computer-simulated groups. The solid lines are data obtained from groups found on the POSS plates.

bias in Figure 1 toward those groups with low values of W/L ; the diameters of these three groups are so large that only groups with very small W/L and having this diameter would satisfy the compactness criterion of $A \leq 0.0035/\sigma$ and be included in the sample. Figure 1 shows good agreement between the observed and simulated groups, so that considerable support is given to the conclusions of Sargent and Turner.

V. THE DISTRIBUTION OF NEAREST NEIGHBORING GALAXIES TO COMPACT GROUPS

Compact galaxy groups appear to be dynamical systems which are ideally suited to the derivation of galaxy mass-to-light ratios. Owing to their small angular size, mass-to-light ratios derived from the application of the virial theorem to compact groups will not be biased by the contamination of groups with superposed field galaxies. However, in applying the virial theorem to compact galaxy groups, two assumptions are always made:

1. The groups are dynamically isolated systems; i.e., they are not compact subsystems of looser groups.
2. In determining the true separations of the galaxies in groups from the observed projected separations, it is assumed that the projection angles are randomly distributed. The same assumption is made in deriving the space velocities of the galaxies from the observed line-of-sight velocities.

Unfortunately, these assumptions have been made not on the basis of supporting evidence, but rather from the point of view of simplicity. Recently, Turner (1976) has shown that for a sample of binary galaxies selected on the basis of their small projected separations, the projection angles are decidedly nonrandom in the sense that the average intrinsic pair separation is vastly underestimated if the projection angles are

assumed to be randomly oriented. As compact groups of galaxies are selected in essentially the same manner as Turner's sample of galaxy pairs (i.e., on the basis of small projected separations of the group members), the validity of assumption (2) is somewhat questionable.

The validity of assumption (1) can be tested rather easily by looking at the distribution of nearest neighboring galaxies around compact groups. As noted previously and in the Appendix, if the nearest neighboring galaxies to compact groups are simply randomly distributed field galaxies, then the first three nearest galaxies should lie at average distances of $\frac{1}{2}\sigma^{1/2}$, $\frac{3}{4}\sigma^{1/2}$, and $\frac{1}{6}\sigma^{1/2}$ arcminutes, respectively. As found in § II, σ is equal to 0.005 galaxies per square arcminute brighter than magnitude 17.5, implying an average distance to the first three nearest galaxies of 7.1, 10.5, and 13.3, respectively. Also, the standard deviation in the distance of the nearest galaxy should be

$$[(1/\pi - \frac{1}{4})\sigma]^{1/2},$$

or 3.7. This value agrees well with the observed value of 4.1. We then obtain the following expressions for the average distances of the first three nearest neighboring galaxies as a function of limiting magnitude m :

$$\langle r_1 \rangle = 7.1 \times 10^{0.3(17.5-m)}, \quad (4a)$$

$$\langle r_2 \rangle = 10.5 \times 10^{0.3(17.5-m)}, \quad (4b)$$

$$\langle r_3 \rangle = 13.3 \times 10^{0.3(17.5-m)}. \quad (4c)$$

The above data for randomly distributed field galaxies can now be compared with the distribution of galaxies around compact groups. Let a_i be the observed number of galaxies within a radius $(\langle r_i \rangle - 1.0)$ arcminutes of the center of a given compact group ($\langle r_i \rangle$ has been computed with m equal to the average magnitude of the galaxies in the group). As the expected number of galaxies within a radius r of the group is $\pi\sigma r^2$, then the quantity $a_i - \pi\sigma(\langle r_i \rangle - 1.0)^2$ is a measure of the *probable* number of galaxies which are physically associated with the compact group out to the radius $(\langle r_i \rangle - 1.0)$.

Data for a_1 , a_2 , and a_3 are presented in Table 4. The last five entries in the table (groups a , b , c , d , and e) represent Stefan's Quintet, Seyfert's Sextet, VV 172, VV 116, and VV 165, respectively. The values of a_1 , a_2 , and a_3 for each group are given in columns (2), (3), and (4), respectively. The average values of the a_i 's and the expected values for a random distribution are given at the bottom of the table. In nearly every case there appears to be at least one galaxy physically associated with the compact group. Only group numbers 6, 21, 25, and 38 appear to be completely isolated. Also, the data in Table 4 suggest that the radii of the "halos" of galaxies around compact groups are generally of the order of $\langle r_2 \rangle$, since in most cases there is no increase in the excess number of galaxies between $\langle r_2 \rangle$ and $\langle r_3 \rangle$. In most cases, then, compact groups are surrounded by a "halo" of one or more galaxies with a typical radius that is 5–10 times the radius of the compact group itself.

TABLE 4
ADDITIONAL MEMBERS OF COMPACT GALAXY GROUPS

Group	a_1	a_2	a_3
1.....	2	5	6
2.....	3	4	5
3.....	0	3	4
4.....	1	2	3
5.....	3	5	6
6.....	0	1	1
7.....	1	2	3
8.....	3	5	8
9.....	1	2	3
10.....	3	8	9
11.....	1	2	3
12.....	3	5	6
14.....	1	2	4
15.....	3	4	5
16.....	4	9	10
18.....	3	4	7
20.....	2	4	7
21.....	0	0	0
22.....	2	5	6
23.....	3	4	5
24.....	1	2	3
25.....	0	1	2
26.....	2	3	4
34.....	1	1	2
38.....	0	0	1
<i>a</i>	1	6	7
<i>b</i>	1	2	3
<i>c</i>	4	5	6
<i>d</i>	4	6	7
<i>e</i>	0	1	4
Average....	1.8	3.5	4.8
Expected....	0.6	1.4	2.4

The most plausible explanations for the dynamical relationship between compact groups and their surrounding "halos" of galaxies are:

1. The "halo" may consist of galaxies which have been thrown into highly eccentric orbits due to previous close encounters with galaxies in the compact core of the group.

2. Compact groups could be loose groups of galaxies in which several of the galaxies happen to be projected close to each other while the remaining members appear to form the looser halo. It is unlikely that this explanation is strictly true for all compact groups since in many of these systems there are strong signs of tidal interaction indicating the proximity of at least some of the members.

3. The compact group might be a loose group in which several of the members happen to reach the center of the group at the same time and thus appear to form a dynamical subsystem.

4. The true explanation may lie in a combination of (2) and (3).

In the past, galaxy mass-to-light ratios have been derived from the application of the virial theorem to compact groups under the assumption that the galaxy separation vectors are randomly projected onto the sky. However, it is evident that unless explanation (1) is correct for all compact groups, application of the virial theorem under the assumption of randomly oriented projection angles would lead to invalid conclusions about the mass-to-light ratios of galaxies. For

explanation (2), M/L would be substantially underestimated. On the other hand, if (3) is correct, M/L would be overestimated by up to a factor of 2 since, for galaxies at "perigalacticon," $T \approx -U \gg E$ (where T , U , and E are the kinetic, potential, and total energies of the system, respectively). In the case of (4) one cannot predict whether an overestimate or underestimate of M/L would result as there are two competing effects here.

It is possible in principle to test the validity of (1) by measuring the amount and spatial extent of diffuse light in compact groups. The diffuse light would arise from matter tidally stripped from the group members in the numerous close encounters which would occur in an *intrinsically* compact system, such as in (1). Furthermore, if (1) were to be ruled out by this method, then one can choose between (2), (3), and (4) by making numerical simulations of loose groups of galaxies and examining the transient "compact" subsystems which occasionally form in the loose groups. An investigation of both of these subjects is planned.

VI. GROUP LUMINOSITY FUNCTION

An analysis of the luminosity function of galaxies in compact groups provides a potential means of investigating the relationship between compact groups and their surrounding "halos." According to the explanations (2), (3), and (4) mentioned in the last section, the luminosity function for compact galaxy groups should be identical to that for loose groups, as in each of these cases the compact group is explained as a transient configuration occurring in a loose group. On the other hand, if possibility (1) were correct, the dispersion in luminosity for the galaxies in compact groups might well be lower than that in loose groups because the low-luminosity (low mass) galaxies would most likely be preferentially ejected into the surrounding "halo" or tidally disrupted by the more massive members. Thus by comparing the dispersion in magnitude between the galaxies in compact groups with that in loose groups we might be able to determine whether compact groups are *intrinsically* compact.

A comparison of the average magnitude dispersion (σ_m) for the definite compact quartets in Tables 2 and 3 with that for four loose quartets shows no evidence for a difference in σ_m between compact and loose groups. The loose groups have been taken from a list of galaxy groups compiled by Turner and Gott (1976) and have an average magnitude dispersion of 0.48 mag, whereas σ_m for the compact quartets is 0.45 mag. It must be noted, however, that the average dispersion in magnitude for the groups calculated above do not represent the *true* dispersion in magnitude for these groups. As both the Turner and Gott loose groups and the compact groups consist of magnitude-limited surveys ($m_b \leq 14.0$ for Turner and Gott; $m_b \leq 17.5$ for the compact groups), then near the limiting mag-

nitude of the survey there exists a bias in favor of groups with a small magnitude dispersion. Accordingly, the average magnitude dispersion has been calculated for only those groups whose brightest galaxy is at least 2 mag above the survey limit. For the 10 compact groups fulfilling this criterion, σ_m is equal to 0.62 mag, whereas the one loose quartet (group number 32 in the Turner and Gott list) has a σ_m of 0.72 mag.

It is evident that accurate magnitude determinations for a large number of compact and loose groups will be required if any conclusions are to be reached about the dynamical relationship between a compact group and its associated loose group. Moreover, detailed dynamical simulations of compact galaxy groups are required in order to determine whether observable mass segregation would occur in intrinsically compact groups.

VII. SUMMARY

The main conclusions of this paper are:

1. The approximate number of compact trios, quartets, and quintets of galaxies down to a limiting blue magnitude of 17.5 are 2800, 430–550, and 33, respectively. However, the number of quintets is very uncertain.

2. The anomalous-redshift galaxies found in three compact quintets can be consistently explained as field galaxies superposed on the groups.

3. Galaxy chains in compact groups are chance configurations of the galaxies as seen projected onto the sky.

4. Nearly every compact group has at least one galaxy closer to it than would be expected for randomly distributed field galaxies. The most logical interpretation is that compact groups are a small subsystem of a looser group of galaxies. Therefore, application of the virial theorem to the compact group alone may well lead to incorrect conclusions about galaxy masses.

It is of primary importance, then, to understand the dynamical relationship between the compact group and its associated looser group. If this question can be satisfactorily answered, so that we can confidently apply the virial theorem in the proper manner to the compact group alone, then we can obtain useful information about galaxy masses. Further research is planned which will help to clarify the dynamical structure of compact groups.

I am deeply grateful to R. B. Larson and J. A. Graham for many valuable discussions. Thanks are due to R. B. Hanson for important advice on the statistics of nearest neighboring galaxies and to E. L. Turner for a stimulating conversation and for sending me preprints in advance of publication. I am also grateful to R. D. McClure for obtaining additional photographic data for me and to C. P. Wilson and an anonymous referee for their comments.

APPENDIX

DERIVATION OF THE DISTANCES OF RANDOMLY DISTRIBUTED NEAREST NEIGHBORING FIELD GALAXIES

Assume that field galaxies are randomly distributed. Let $P_n(r)dr$ be the normalized probability that the n th nearest neighboring galaxy lies at a distance r from the point. Then

$$P_n(r)dr = P'_{n-1}(r) \cdot 2\pi\sigma r dr \quad (\text{A1})$$

where $P'_{n-1}(r)$ is the probability that $n-1$ galaxies lie within a radius r from the point and $2\pi\sigma \cdot r dr$ is the relative probability that the n th galaxy lies in a shell of radius r and thickness dr and σ is the average surface density of galaxies per square arcminute. Since the galaxies are randomly located, their distribution is described by Poisson statistics, so that

$$P'_n(r) = \frac{e^{-m} \cdot m^n}{n!} \quad (\text{A2})$$

is the probability that n galaxies lie within a radius r of a given point and $m = \pi\sigma r^2$ is the average number of galaxies within the radius r .

Therefore,

$$P_n(r) = \frac{e^{-\pi\sigma r^2} (\pi\sigma r^2)^{n-1} (2\pi\sigma r)}{(n-1)!} \quad (\text{A3})$$

Now let r_n be the mean distance of the n th nearest neighbor. Then

$$\langle r_n \rangle = \int_0^\infty r P_n(r) dr \quad (\text{A4})$$

so that

$$\langle r_n \rangle = \frac{1}{(n-1)!} \Gamma(n + \frac{1}{2}) \frac{1}{(\pi\sigma)^{1/2}}. \quad (\text{A5})$$

The function $\Gamma(n)$ is defined by $\Gamma(n+1) = n \cdot \Gamma(n)$ and $\Gamma(\frac{1}{2}) = \pi^{1/2}$.

REFERENCES

- | | |
|---|---|
| <p>Ambartsumian, V. A. 1958, <i>Izv. Akad. Nauk. Arm. SSR, Fiz.-Mat.</i>, 11, 9.</p> <p>Burbidge, E. M., and Burbidge, G. R. 1961, <i>Ap. J.</i>, 134, 244.</p> <p>Burbidge, E. M., and Sargent, W. L. W. 1971, in <i>Nuclei of Galaxies</i>, ed. D. J. K. O'Connell (Amsterdam: North-Holland).</p> <p>Graham, J. A., and Rubin, Vera C. 1973, <i>Ap. J.</i>, 183, 19.</p> <p>Hubble, E. 1934, <i>Ap. J.</i>, 79, 8.</p> <p>Ostriker, J. P., Peebles, P. J. E., and Yahil, A. 1974, <i>Ap. J. (Letters)</i>, 193, L1.</p> <p>Sargent, W. L. W. 1968, <i>Ap. J. (Letters)</i>, 153, L135.</p> | <p>Sargent, W. L. W., and Turner, E. L. 1972, in <i>Ann. Rept. Director Hale Observatories 1972-1973</i>, p. 123.</p> <p>Turner, Edwin L. 1976, <i>Ap. J.</i>, 208, 20.</p> <p>Turner, Edwin L., and Gott, J. Richard, III. 1976, preprint.</p> <p>Wesselink, A. J. 1974, in <i>New Problems in Astrometry, IAU Symposium No. 61</i>, ed. W. Gliese, C. A. Murray, and R. H. Tucker (Dordrecht: Reidel), p. 201.</p> <p>Zwicky, F., Herzog, E., Wild, P., Karpowicz, M., and Kowal, C. T. 1961-1968, <i>Catalog of Galaxies and Clusters of Galaxies</i>, in 6 vols. (Pasadena: California Institute of Technology).</p> |
|---|---|

JAMES A. ROSE: Yale University Observatory, Department of Astronomy, Box 2023 Yale Station, New Haven, CT 06520