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DYNAMICAL PROPERTIES OF COMPACT GROUPS OF GALAXIES

PAUL HICKSON[1] AND CLÁUDIA MENDES DE OLIVEIRA[1]
Department of Geophysics and Astronomy, University of British Columbia, 2219 Main Mall, Vancouver, British Columbia, Canada V6T 1Z4
JOHN P. HUCHRA
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
AND
GIORGIO G. C. PALUMBO[1]
Dipartimento di Astronomia, Università degli studi di Bologna, Via Zamboni 33, Bologna, Italy
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ABSTRACT

We present radial velocities for 457 galaxies in the 100 Hickson compact groups. More than 84% of the galaxies measured have velocities within 1000 km s^{-1} of the median velocity in the group. Here 92 groups have at least three accordant members, and 69 groups have at least four.

The radial velocities of these groups range from 1380 to 41,731 km s^{-1} with a median of 8889 km s^{-1}, corresponding to a median distance of 89 h^{-1} Mpc. The redshift distribution of the groups is consistent with their having a uniform space distribution, and a luminosity function characterized by a Schechter function with $M^* = -20.6$ and $\alpha = -0.2$. The apparent space density of these systems ranges from 300 to as much as 10^8 h^2 Mpc^{-2}, which exceeds the densities in the centers of rich clusters. The median projected separation between galaxies is only 39 h^{-1} kpc, comparable to the sizes of the galaxies themselves.

The median radial velocity dispersion is 200 km s^{-1}, comparable to values reported for loose groups. This corresponds to an intrinsic three-dimensional velocity dispersion of 331 km s^{-1}. The median galaxy crossing time ranges from $0.001H_0^{-1}$ to $8.7H_0^{-1}$ with a median of $0.016H_0^{-1}$.

A significant correlation is found between crossing time and the fraction of gas-rich galaxies in the groups, and a weak anticorrelation is found between crossing time and the luminosity contrast of the first-ranked galaxy.

Derived mass-to-light ratios M/L for the groups range up to 10^3, with a median of 50 h. This is about 7 times the median M/L reported for individual galaxies in the groups and strongly suggests that as much as ~85% of the mass of a group, in the region interior to the galaxy orbits, consists of dark matter.

Subject headings: galaxies: clustering — galaxies: distances and redshifts — galaxies: interstellar matter — galaxies: luminosity function, mass function

1. INTRODUCTION

Examples of dense groups of galaxies have been known for more than a century. Originally, they were of interest because of the close proximity and obvious distortion of many of their member galaxies. In addition, many of the classical groups (Stephan's quintet, Seyfert's sextet, and VV 172, for example) were found to contain a galaxy whose redshift differed significantly from the others. The indicated Doppler velocity difference can be as high as 20,000 km s^{-1}. Early observational studies (Zwicky 1933; Smith 1936; Zwicky 1937; Burbidge & Burbidge 1961; Burbidge & Sargent 1971) indicated that virial masses of many groups exceeded the mass expected due to the galaxies alone. This lent support to Ambartsumyan's (1958) conclusion that the groups were unbound, expanding systems. However, the subsequent discovery of virial mass discrepancies in clusters (Burbidge & Burbidge 1959; Rood 1965; Karachentsev 1966) and evidence for massive galactic halos (Rubin, Ford, & Thonnard 1980; Ostriker, Peebles, & Yahil 1974; Persic & Salucci 1988) led to the general acceptance of the alternative explanation, that the groups are bound by unseen "dark" matter.

More recently, it was realized that such systems should be dynamically unstable (Hickson, Richstone, & Turner 1977). Collisions and dynamical friction might cause these groups to be destroyed by galaxy mergers in times short compared to the age of the universe. However, too few groups were known to allow a convincing statistical analysis at the time, and even these were found by selection criteria that were not clearly defined.

The first systematic search for compact groups of galaxies was conducted by Rose (1977), who identified 170 galaxy trios, 33 quartets, and two quintets on 69 glass copies of the Palomar Observatory Sky Survey (POSS) with a surface number density contrast of 10^3 or more. Rose (1979) concluded that most groups are transient dense configurations in loose groups, but did not rule out the possibility that they are dense systems that have evolved from looser groups.

In order to obtain a larger, uniformly selected sample, one of us (P. H.) undertook a visual search of the entire set of POSS "E" (red) prints. Exactly 100 compact groups were found which satisfied three selection criteria of group membership, isolation, and mean surface brightness (Hickson 1982, hereafter Paper I). In order that this catalog form a data base for studies of such systems, a comprehensive program of imaging, spectroscopic, and radio observations was begun to obtain as much high-quality data as possible on these groups. A com-

[1] Guest Observer, Canada-France-Hawaii Telescope, operated by NRC of Canada, CNRS of France, and the University of Hawaii.

plete set of CCD images (Hickson 1992) was obtained with the Canada-France-Hawaii Telescope, from which photometry and Hubble classifications were derived for all galaxies (Hickson, Kindl, & Auman 1989a, hereafter HKA). Additional photometry and classifications have been published from photographic and CCD data (Tikhonov 1987a, b, 1989; Williams & Rood 1987). Infrared emission from the groups is discussed by Hickson et al. (1989d), and X-ray observations exist for a few groups (Bahcall, Harris, & Rood 1984). Radio frequency studies are described by Menon & Hickson (1985), Williams & Rood (1987), Williams & van Gorkom (1988), Menon (1991). Optical rotation curves have been obtained for many galaxies in these groups (Rubin, Hunter, & Ford 1991). In addition, there have been three independent studies of the environments of these compact groups (Sulentic 1987; Rood & Williams 1989; Kindl 1990). Results of these and other studies are briefly reviewed by Hickson (1989).

This paper presents results of two spectroscopic observing programs during which all galaxies in Hickson's compact group catalog (including the several additional members cataloged by HKA) were observed. From these observations, redshifts were determined for almost all the galaxies, which were then used to derive distances and physical properties of the groups. The observations are discussed in § 2, the membership and completeness of the groups is discussed in § 3, and dynamical properties of the groups are discussed in § 4.

2. OBSERVATIONS

Brighter galaxies in the sample were observed over the period 1984–1986, using the 1.5 m telescope of the F. L. Whipple Observatory on Mt. Hopkins, Arizona. The instrumentation consisted of a Cassegrain spectrograph with 600 groove mm^{-1} grating, and a 2 × 1024 Reticon diode array operating in a photon-counting mode (Davis & Latham 1979; Latham 1982). Twin slits were used, each 3″.2 wide by 6″.4 long giving 6 Å (FWHM) resolution and a spectral coverage from 4600 to 7100 Å. Equal integration times were obtained with the galaxy image on each slit. The reflecting slit assembly was viewed through an electrostatic intensifier.

Wavelength calibration was obtained by He-Ne-Ar comparison lamp exposures before and after each galaxy exposure. Total integration times on the galaxies ranged from 10 to 60 minutes, with a typical signal-to-noise ratio of 20 being obtained. Redshifts and error estimates were obtained by a cross-correlation technique (Tonry & Davis 1979). The resulting heliocentric velocities typically have estimated rms errors of 40 km s^{-1} or less. The total number of galaxies observed with this telescope was 315.

The remaining fainter galaxies were observed with the Canada-France-Hawaii Telescope on Mauna Kea using the Herzberg spectrograph with the f/2 camera and 600 groove mm^{-1} grating. Three different detectors were used, as the technology evolved. The earliest observations used the RCA-2, RCA-4, and SAIC-1 CCDs. Dates and details of the observations are given in Table 1. Fe-Ar comparison exposures were taken before and after each galaxy exposure. The data were preprocessed with Hickson's "GSI" software, and spectra were extracted and analyzed using the IRAF astronomical data reduction package. All velocities were converted to a heliocentric reference frame.

Velocity errors were estimated by adding in quadrature two error terms. The first, accounting for errors in the wavelength calibration, was determined from the wavelength solution for each calibration image. The second, accounting for the noise in the spectra, was generally determined from the dispersion in velocity estimates using several different galaxy and star templates (for more details see Mendes de Oliveira 1992). In the case of emission-line redshifts, the latter error was estimated from the dispersion in redshifts obtained using different emission lines. Each velocity was assigned a confidence code as follows: 0 = highest confidence—spectral features clearly visible; 1 = lower confidence—spectral features not clearly visible; 2 = lowest confidence—very noisy spectra with no obvious features. Only three galaxies have code 2.

TABLE 1

SPECTROSCOPIC OBSERVATIONS

UT	Detector	Spectral Range (Å)	Resolution (Å)
1985 Dec 13–15	UBC IPCS	4700–7100	13
1986 Jul 12–14	RCA-2 CCD	3600–6000	14
1989 Jun 8–10	RCA-4 CCD	3800–6200	17
1990 Dec 10–12	SAIC-1 CCD	4200–7200	16

Group 55 (VV 172) was not observed. Velocities for galaxies in this group were taken from Sargent (1968), with assumed errors of 100 km s^{-1}.

3. RESULTS

The velocities and their estimated uncertainties are listed in Table 2. The column headings are as follows: (1) galaxy designation as in Paper I; (2) galaxy right ascension (epoch 1950.0) in hours, minutes, and seconds of time; (3) galaxy declination in degrees, minutes, and arcseconds; (4) heliocentric velocity in km s^{-1}; (5) estimated rms velocity error in km s^{-1}; (6) velocity confidence code—described above.

3.1. *Membership*

Figure 1 shows the distribution of Δv, the difference between the velocity of a galaxy and the median velocity of all cataloged galaxies in the same group, for the range $|\Delta v| < 3000$ km s^{-1}. The great majority of measured galaxies have velocities within about 1000 km s^{-1} of the median and are presumably physically associated with the group. For relative velocities greater

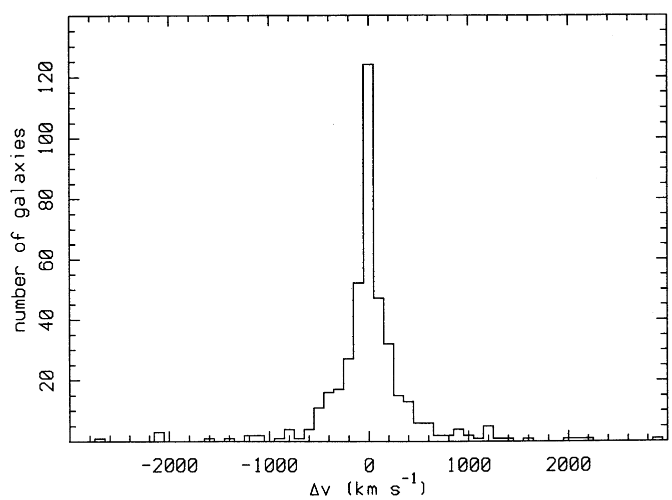

FIG. 1.—Distribution of galaxy velocities with respect to the median velocity of all cataloged galaxies in the same group.

TABLE 2

GALAXY DATA

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
01a	00^{h}23^{m}29^{s}92	+25°26′53″9	10237	39	0
01b	00 23 28.77	+25 26 31.9	10266	40	0
01c	00 23 17.29	+25 26 47.6	10056	34	0
01d	00 23 21.66	+25 26 53.4	10120	47	0
02a	00 28 48.85	+08 11 32.0	4326	30	0
02b	00 28 43.74	+08 11 57.0	4366	34	0
02c	00 28 54.32	+08 07 28.9	4235	34	0
02d	00 29 03.31	+08 06 53.1	21340	85	0
03a	00 31 40.70	−07 50 25.4	7302	51	0
03b	00 31 52.61	−07 52 30.9	7860	45	0
03c	00 31 47.55	−07 52 32.8	11545	68	1
03d	00 31 37.33	−07 52 39.9	7804	30	0
04a	00 31 43.69	−21 42 50.9	8097	36	0
04b	00 31 44.16	−21 44 44.8	7065	44	0
04c	00 31 45.62	−21 41 36.2	8863	74	1
04d	00 31 46.77	−21 45 11.5	8215	37	0
04e	00 31 38.37	−21 42 41.1	18480	180	1
05a	00 36 19.61	+06 47 16.6	12147	34	0
05b	00 36 19.62	+06 46 53.1	12221	29	0
05c	00 36 17.72	+06 47 52.8	12489	47	0
05d	00 36 19.90	+06 46 23.9	8215	37	1
06a	00 36 41.70	−08 40 07.7	11669	52	1
06b	00 36 38.10	−08 40 18.6	11377	61	0
06c	00 36 38.98	−08 40 29.1	10967	61	0
06d	00 36 35.50	−08 40 32.7	11434	62	0
07a	00 36 39.66	+00 35 20.5	4210	20	0
07b	00 36 44.13	+00 38 17.3	4238	25	0
07c	00 37 01.15	+00 35 06.3	4366	36	0
07d	00 36 45.08	+00 37 00.8	4116	38	0
08a	00 46 54.48	+23 18 20.0	16014	51	0
08b	00 46 55.51	+23 19 08.2	15966	38	0
08c	00 46 56.12	+23 18 41.9	17087	51	0
08d	00 46 56.99	+23 18 02.7	16341	39	0
09a	00 51 53.57	−23 49 25.2	20155	125	0
09b	00 51 49.15	−23 48 23.1	9406	150	1
09c	00 51 52.51	−23 50 21.5	10300	192	0
09d	00 51 50.06	−23 49 24.9	17726	193	0
10a	01 23 31.03	+34 26 33.3	5148	19	0
10b	01 22 50.05	+34 27 11.1	4862	22	0
10c	01 23 28.38	+34 29 40.1	4660	32	0
10d	01 23 40.43	+34 24 56.5	4620	40	0
11a	01 24 10.80	−23 29 07.6	5504	33	0
11b	01 24 10.67	−23 31 29.8	13295	86	0
11c	01 24 05.84	−23 27 11.0	12904	61	0
11d	01 24 22.47	−23 28 50.0	9686	61	0
12a	01 25 01.78	−04 56 30.2	14407	53	0
12b	01 25 02.73	−04 54 39.7	14956	38	0
12c	01 25 05.70	−04 55 12.6	14569	66	1
12d	01 25 05.46	−04 55 39.2	14241	62	0
12e	01 24 56.21	−04 56 11.0	14469	62	0
13a	01 29 50.52	−08 07 01.0	12469	42	0
13b	01 29 52.38	−08 07 50.9	12100	101	0
13c	01 29 53.26	−08 08 14.4	12240	105	0
13d	01 29 49.24	−08 09 13.6	12209	107	0
13e	01 29 56.06	−08 07 37.2	12593	61	0
14a	01 57 22.66	−07 19 42.5	5929	35	0
14b	01 57 20.23	−07 18 04.0	5365	28	0
14c	01 57 19.08	−07 16 22.1	5145	37	0
14d	01 57 13.95	−07 13 28.5	8416	58	0
15a	02 05 18.02	+01 55 50.1	6967	30	0
15b	02 04 59.15	+01 52 40.8	7117	36	0
15c	02 05 04.78	+01 54 45.3	7222	30	0
15d	02 05 02.51	+01 56 37.0	6244	36	0
15e	02 04 50.39	+01 52 43.8	7197	32	0
15f	02 05 02.85	+01 57 11.2	6242	102	0
16a	02 06 57.41	−10 22 20.0	4152	39	0
16b	02 06 53.32	−10 22 08.9	3977	25	0
16c	02 07 11.25	−10 22 56.0	3851	36	0
16d	02 07 15.60	−10 25 11.1	3847	44	0

TABLE 2—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
17a	02 11 22.80	+13 04 41.0	18228	44	0
17b	02 11 24.40	+13 04 48.7	17904	48	0
17c	02 11 22.77	+13 05 03.9	18224	105	0
17d	02 11 25.31	+13 04 24.8	18124	107	0
17e	02 11 21.88	+13 05 09.8	17976	142	1
18a	02 36 21.72	+18 09 08.5	10019	47	0
18b	02 36 18.47	+18 10 04.1	...	...	...
18c	02 36 18.20	+18 10 24.5	4143	37	0
18d	02 36 16.95	+18 10 43.9	4067	58	0
19a	02 40 14.26	−12 38 00.4	4279	25	0
19b	02 40 17.99	−12 38 23.6	4210	25	0
19c	02 40 22.67	−12 36 35.6	...	...	...
19d	02 40 18.66	−12 39 33.5	...	...	...
20a	02 41 17.08	+25 53 17.1	14477	45	0
20b	02 41 17.58	+25 53 54.7	14424	42	0
20c	02 41 18.64	+25 53 40.0	15032	45	0
20d	02 41 23.50	+25 53 49.0	10561	61	0
20e	02 41 21.90	+25 53 30.4	14312	49	0
20f	02 41 22.19	+25 54 00.6	14280	62	0
21a	02 42 58.42	−17 55 07.5	7614	29	0
21b	02 43 16.59	−17 53 56.5	7568	35	0
21c	02 42 34.04	−17 52 12.8	7356	31	0
21d	02 43 09.92	−17 45 09.5	8835	48	0
21e	02 43 02.86	−17 44 37.0	8843	61	0
22a	03 01 18.22	−15 48 30.4	2705	22	0
22b	03 01 05.95	−15 51 24.5	2625	38	0
22c	03 01 04.02	−15 49 05.8	2728	60	0
22d	03 01 10.73	−15 52 49.8	9342	45	0
22e	03 01 14.52	−15 52 25.3	9506	49	0
23a	03 04 30.36	−09 44 09.5	4798	37	0
23b	03 04 44.07	−09 47 06.1	4921	30	0
23c	03 04 53.01	−09 48 17.5	5016	97	0
23d	03 04 29.78	−09 49 17.2	4562	54	0
23e	03 04 44.94	−09 46 09.0	10150	60	0
24a	03 17 51.42	−11 02 35.0	9248	41	0
24b	03 17 58.94	−11 02 49.5	9137	44	0
24c	03 17 48.95	−11 02 35.4	9283	109	0
24d	03 17 56.24	−11 02 16.4	8779	61	0
24e	03 17 54.31	−11 02 49.1	9323	61	0
25a	03 18 10.47	−01 17 19.8	6285	30	0
25b	03 18 12.86	−01 13 27.5	6408	35	0
25c	03 18 10.57	−01 10 55.3	10864	61	0
25d	03 18 06.07	−01 12 53.8	6401	36	0
25e	03 18 10.04	−01 11 09.7	10965	38	0
25f	03 18 12.82	−01 14 01.3	6279	37	0
25g	03 18 19.60	−01 14 34.1	12179	26	0
26a	03 19 34.10	−13 49 44.9	9678	50	0
26b	03 19 35.95	−13 49 36.0	9332	39	0
26c	03 19 28.35	−13 49 26.1	9618	62	0
26d	03 19 35.34	−13 49 25.3	9133	62	0
26e	03 19 29.94	−13 50 35.1	9623	50	0
26f	03 19 36.40	−13 50 31.8	9626	46	0
26g	03 19 34.03	−13 49 37.3	9293	62	0
27a	04 17 05.85	−11 51 11.0	18340	62	0
27b	04 16 57.47	−11 49 17.7	18530	61	0
27c	04 17 02.75	−11 50 34.3	26352	62	0
27d	04 16 54.25	−11 48 40.6	26256	62	0
27e	04 17 00.39	−11 49 51.3	26044	115	0
27f	04 16 57.07	−11 48 48.7	26100	134	2
28a	04 24 56.04	−10 25 01.7	11441	26	0
28b	04 24 57.48	−10 26 13.5	11489	23	0
28c	04 24 55.67	−10 25 43.9	11290	26	0
28d	04 24 56.65	−10 26 11.7	30205	63	0
29a	04 32 46.53	−30 38 50.1	13328	46	0
29b	04 32 47.81	−30 38 45.0	30824	64	0
29c	04 32 48.70	−30 38 38.9	31669	64	0
29d	04 32 50.45	−30 38 45.0	31714	63	0
30a	04 33 47.98	−02 55 55.7	4697	20	0
30b	04 33 59.72	−02 58 01.9	4625	24	0
30c	04 33 52.64	−02 54 02.2	4508	38	1
30d	04 34 06.07	−02 56 36.7	4666	49	0

TABLE 2—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
31a	04 59 09.86	−04 19 51.8	4042	44	0
31b	04 59 06.53	−04 20 08.4	4171	43	0
31c	04 59 08.91	−04 19 45.5	4068	34	0
31d	04 59 06.54	−04 19 42.2	26900	65	0
32a	04 59 29.38	−15 31 12.8	12547	38	0
32b	04 59 24.22	−15 28 11.6	12125	57	0
32c	04 59 32.77	−15 30 07.0	11984	49	1
32d	04 59 29.58	−15 30 07.8	12313	52	1
33a	05 07 53.09	+17 57 27.5	7570	41	0
33b	05 07 52.73	+17 58 06.7	8006	21	0
33c	05 07 50.29	+17 57 30.5	7823	47	1
33d	05 07 58.66	+17 58 19.2	7767	37	0
34a	05 19 04.51	+06 38 27.5	8997	31	0
34b	05 19 08.49	+06 37 43.6	9620	40	0
34c	05 19 07.55	+06 38 02.7	9392	40	0
34d	05 19 06.33	+06 38 08.9	8817	66	1
35a	08 41 57.67	+44 42 10.5	15919	38	0
35b	08 41 57.08	+44 41 29.0	16338	32	0
35c	08 41 54.89	+44 42 35.7	16357	39	0
35d	08 41 57.11	+44 43 19.0	15798	40	0
35e	08 41 57.16	+44 41 08.4	16773	57	0
35f	08 41 57.31	+44 42 56.0	16330	62	0
36a	09 06 35.82	+15 59 58.0	3808	29	0
36b	09 06 39.75	+16 00 30.8	6333	41	0
36c	09 06 33.61	+16 00 33.6	8635	45	0
36d	09 06 35.57	+15 58 57.2	15668	62	0
37a	09 10 39.82	+30 11 57.9	6745	20	0
37b	09 10 32.96	+30 12 24.0	6741	34	0
37c	09 10 37.59	+30 12 23.4	7357	41	0
37d	09 10 34.19	+30 13 16.8	6207	50	1
37e	09 10 34.34	+30 14 48.0	6363	20	0
38a	09 24 51.80	+12 29 14.1	8760	75	0
38b	09 25 00.74	+12 30 19.2	8739	42	0
38c	09 25 01.64	+12 30 21.8	8770	89	0
38d	09 24 51.42	+12 31 09.4	24282	62	0
39a	09 29 54.92	−01 07 34.2	21119	52	0
39b	09 26 55.81	−01 07 47.8	21176	61	1
39c	09 26 56.74	−01 07 59.4	20667	35	0
39d	09 26 54.39	−01 07 12.4	21048	37	0
40a	09 36 23.02	−04 37 21.5	6628	27	0
40b	09 36 24.55	−04 38 22.8	6842	27	0
40c	09 36 22.70	−04 37 58.7	6890	21	0
40d	09 36 25.26	−04 36 39.4	6492	21	0
40e	09 36 24.95	−04 37 52.8	6625	49	0
41a	09 54 27.50	+45 28 05.3	3751	27	0
41b	09 54 32.68	+45 29 50.4	7241	24	0
41c	09 54 19.23	+45 28 36.9	9717	40	0
41d	09 54 42.49	+45 28 01.5	4431	67	0
42a	09 57 52.29	−19 23 45.5	3625	32	0
42b	09 58 11.38	−19 25 16.8	4198	28	0
42c	09 57 48.44	−19 22 54.3	4005	31	0
42d	09 57 51.10	−19 25 55.8	4076	48	0
43a	10 08 46.08	+00 13 25.6	10163	38	0
43b	10 08 33.79	+00 12 15.6	10087	35	0
43c	10 08 38.87	+00 10 44.7	9916	33	0
43d	10 08 39.23	+00 09 34.8	9630	37	0
43e	10 08 40.56	+00 11 43.0	9636	68	0
43f	10 08 44.85	+00 14 18.3	19505	64	0
44a	10 15 20.64	+22 04 54.9	1293	24	0
44b	10 15 39.55	+22 08 36.8	1378	19	0
44c	10 14 53.29	+21 56 18.8	1218	14	0
44d	10 15 02.47	+22 07 25.4	1579	91	0
45a	10 15 51.41	+59 22 54.4	21811	34	0
45b	10 15 43.07	+59 21 22.4	22195	29	0
45c	10 15 45.68	+59 20 06.5	21799	72	0
45d	10 15 53.97	+59 23 18.3	20735	43	0
46a	10 19 24.39	+18 05 26.8	8201	35	0
46b	10 19 30.12	+18 06 22.0	8571	36	0
46c	10 19 29.87	+18 06 44.7	7906	42	0
46d	10 19 34.36	+18 08 04.6	7703	33	0
47a	10 23 05.93	+13 58 17.0	9581	31	0

TABLE 2—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
47b	10 23 08.23	+13 58 56.9	9487	32	0
47c	10 23 08.66	+14 00 27.4	9529	50	0
47d	10 23 07.45	+14 00 11.5	9471	56	0
48a	10 35 25.58	−26 49 13.1	3014	48	0
48b	10 35 27.90	−26 51 41.5	2385	51	0
48c	10 35 18.89	−26 47 51.2	4203	36	0
48d	10 35 19.93	−26 47 02.1	3045	139	0
49a	10 53 13.11	+67 27 08.5	9939	36	0
49b	10 53 20.72	+67 26 50.9	9930	51	0
49c	10 53 18.20	+67 26 54.3	9926	60	0
49d	10 53 14.95	+67 26 42.9	10010	72	0
50a	11 14 14.37	+55 11 23.2	41870	118	0
50b	11 14 16.31	+55 11 25.0	41170	111	0
50c	11 14 12.11	+55 11 37.3	41398	62	0
50d	11 14 14.53	+55 11 46.8	42546	62	0
50e	11 14 16.93	+55 11 34.6	41650	62	0
51a	11 19 47.57	+24 34 23.1	7696	34	0
51b	11 19 35.51	+24 34 25.1	8183	62	0
51c	11 19 51.42	+24 33 12.2	8902	20	0
51d	11 19 51.90	+24 34 25.8	7529	35	0
51e	11 19 34.58	+24 35 27.4	7700	23	0
51f	11 19 47.72	+24 34 04.4	7532	30	0
51g	11 19 49.49	+24 34 09.6	...	...	...
52a	11 23 41.32	+21 22 16.2	12979	38	0
52b	11 23 38.86	+21 22 54.9	13040	73	0
52c	11 23 41.59	+21 19 47.4	12630	61	0
52d	11 23 38.68	+21 21 47.3	6293	65	0
53a	11 26 13.01	+21 04 15.3	6261	31	0
53b	11 26 22.67	+21 00 54.2	6166	81	0
53c	11 26 21.21	+21 01 32.3	6060	50	0
53d	11 26 37.44	+21 02 57.3	9070	174	2
54a	11 26 37.92	+20 51 33.2	1397	46	0
54b	11 26 36.80	+20 51 25.7	1412	33	0
54c	11 26 39.01	+20 51 43.6	1420	35	0
54d	11 26 39.25	+20 51 51.3	1670	50	0
55a	11 29 08.44	+71 05 29.4	15820	100	0
55b	11 29 06.99	+71 04 57.4	15690	100	0
55c	11 29 07.19	+71 05 13.4	15480	100	0
55d	11 29 08.38	+71 05 50.8	16070	100	0
55e	11 29 09.09	+71 05 41.5	36880	100	0
56a	11 30 01.85	+53 13 01.5	8245	35	0
56b	11 29 55.61	+53 13 36.0	7919	38	0
56c	11 29 51.83	+53 13 25.4	8110	28	0
56d	11 29 50.42	+53 13 24.2	8346	56	0
56e	11 29 47.85	+53 12 55.3	7924	63	0
57a	11 35 17.26	+22 15 27.9	8727	31	0
57b	11 35 07.13	+22 17 10.4	9022	20	0
57c	11 35 15.23	+22 15 02.7	9081	36	0
57d	11 35 18.60	+22 15 45.2	8977	41	0
57e	11 35 12.63	+22 18 09.6	8992	105	0
57f	11 35 17.57	+22 12 46.8	9594	105	0
57g	11 35 08.06	+22 17 51.8	9416	105	0
57h	11 35 14.16	+22 17 19.6	...	...	...
58a	11 39 36.31	+10 33 18.4	6138	20	0
58b	11 39 48.82	+10 32 29.9	6503	17	0
58c	11 39 18.38	+10 34 53.3	6103	19	0
58d	11 39 31.13	+10 37 41.8	6270	27	0
58e	11 39 30.06	+10 39 40.6	6052	33	0
59a	11 45 52.91	+13 00 19.0	4109	31	0
59b	11 45 45.55	+12 59 38.7	3908	58	0
59c	11 45 57.88	+12 58 59.5	4347	38	0
59d	11 45 56.12	+13 00 27.9	3866	36	0
59e	11 45 44.88	+13 02 07.1	23700	240	0
60a	12 00 34.23	+51 57 12.3	19007	46	0
60b	12 00 23.76	+51 58 24.5	18318	90	1
60c	12 00 34.00	+51 57 48.9	19277	180	0
60d	12 00 36.85	+51 57 22.8	18300	154	1
61a	12 09 46.60	+29 27 28.2	3784	18	0
61b	12 09 48.31	+29 29 23.4	1127	20	0
61c	12 09 59.03	+29 26 47.6	3956	20	0
61d	12 09 54.84	+29 25 37.7	3980	30	0

TABLE 2—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
62a	12 50 29.70	−08 55 59.7	4355	38	0
62b	12 50 28.32	−08 55 39.2	3651	41	0
62c	12 50 33.80	−08 55 36.4	4359	37	0
62d	12 50 30.62	−08 59 12.4	4123	76	0
63a	12 59 32.64	−32 29 37.3	5228	29	0
63b	12 59 22.33	−32 31 07.6	9346	29	0
63c	12 59 28.14	−32 29 55.0	9460	112	0
63d	12 59 19.57	−32 30 23.4	9141	133	0
64a	13 23 09.87	−03 36 15.2	10596	46	0
64b	13 23 07.61	−03 35 35.3	10723	32	0
64c	13 23 04.24	−03 33 17.4	6147	76	0
64d	13 23 06.78	−03 35 24.6	11100	89	0
65a	13 27 02.96	−29 15 24.4	14105	44	0
65b	13 27 06.93	−29 14 21.9	14700	55	1
65c	13 27 05.38	−29 14 02.5	14243	46	0
65d	13 27 04.19	−29 15 18.7	13733	27	0
65e	13 27 07.51	−29 14 01.1	14405	107	0
66a	13 36 48.38	+57 33 56.2	20688	36	0
66b	13 36 50.55	+57 33 56.6	21472	64	0
66c	13 36 45.16	+57 33 41.6	20801	74	0
66d	13 36 44.48	+57 33 27.7	20850	76	0
67a	13 46 33.78	−06 58 33.8	7262	26	0
67b	13 46 21.99	−06 56 50.7	7644	45	0
67c	13 46 34.98	−06 57 40.8	7430	45	0
67d	13 46 32.25	−06 59 01.0	7071	43	0
68a	13 51 19.59	+40 31 42.5	2162	27	0
68b	13 51 19.70	+40 32 52.8	2635	23	0
68c	13 51 14.81	+40 36 32.0	2313	38	0
68d	13 51 38.79	+40 35 00.5	2408	29	0
68e	13 51 52.87	+40 31 06.8	2401	27	0
69a	13 53 11.13	+25 19 05.8	8856	48	0
69b	13 53 15.68	+25 17 38.2	8707	36	0
69c	13 53 13.90	+25 19 07.2	8546	44	0
69d	13 53 09.62	+25 19 04.7	9149	55	0
70a	14 01 59.15	+33 34 34.3	8238	25	0
70b	14 01 59.88	+33 32 47.2	8198	47	0
70c	14 02 09.55	+33 33 36.2	8079	48	0
70d	14 01 59.00	+33 35 03.9	18846	49	0
70e	14 01 54.87	+33 33 33.7	19117	55	0
70f	14 01 53.34	+33 34 03.7	19243	130	0
70g	14 01 49.07	+33 34 13.4	19010	90	0
71a	14 08 40.48	+25 43 53.7	9320	17	0
71b	14 08 45.98	+25 45 16.1	9335	65	0
71c	14 08 48.59	+25 43 02.5	8450	76	1
71d	14 08 51.70	+25 41 32.9	20590	103	1
72a	14 45 35.17	+19 17 04.3	12506	36	0
72b	14 45 36.56	+19 16 04.7	12356	38	0
72c	14 45 38.57	+19 15 09.0	13062	40	0
72d	14 45 37.48	+19 15 52.3	12558	45	0
72e	14 45 36.96	+19 15 32.1	24050	288	1
72f	14 45 36.71	+19 15 19.0	13950	103	0
73a	15 00 29.05	+23 31 40.5	5728	43	0
73b	15 00 25.26	+23 32 39.7	13600	107	0
73c	15 00 36.95	+23 33 13.5	13300	75	0
73d	15 00 18.65	+23 33 50.1	13480	103	0
73e	15 00 18.29	+23 31 20.0	28500	109	1
74a	15 17 10.70	+21 04 34.1	12255	30	0
74b	15 17 10.16	+21 04 13.4	12110	43	0
74c	15 17 11.97	+21 04 46.3	12266	43	0
74d	15 17 17.80	+21 03 47.0	11681	42	0
74e	15 17 13.82	+21 05 18.5	11489	97	0
75a	15 19 16.68	+21 22 07.0	12538	42	0
75b	15 19 16.62	+21 22 15.6	12228	43	0
75c	15 19 25.03	+21 21 18.8	12292	56	0
75d	15 19 23.46	+21 21 35.1	12334	42	0
75e	15 19 20.32	+21 21 26.0	12300	300	0
75f	15 19 16.09	+21 21 49.5	13080	67	1
76a	15 29 20.80	+07 28 35.3	10054	34	0
76b	15 29 13.51	+07 30 27.0	10002	30	0
76c	15 29 10.12	+07 28 51.2	10663	29	0
76d	15 29 15.34	+07 27 19.5	10150	33	0

TABLE 2—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
76e	15 29 23.43	+07 28 46.9	10328	52	0
76f	15 29 12.53	+07 30 15.0	10216	90	0
76g	15 29 08.99	+07 31 05.5	9843	81	0
77a	15 47 05.96	+21 58 12.0	10508	56	0
77b	15 47 05.87	+21 58 27.4	10690	69	0
77c	15 47 05.56	+21 58 56.3	2200	76	0
77d	15 47 06.13	+21 58 45.8	2250	63	0
78a	15 48 04.69	+68 22 19.2	8599	31	0
78b	15 47 55.63	+68 21 29.6	9544	30	0
78c	15 48 29.43	+68 20 41.5	18200	281	1
78d	15 48 20.52	+68 23 15.8	10000	187	1
79a	15 56 59.59	+20 53 43.2	4292	35	0
79b	15 57 00.80	+20 54 15.4	4446	25	0
79c	15 56 59.14	+20 54 09.8	4146	50	0
79d	15 57 00.18	+20 53 15.5	4503	43	0
79e	15 57 01.31	+20 54 01.5	19809	50	0
80a	15 58 50.69	+65 22 21.7	8963	45	0
80b	15 58 53.14	+65 21 46.8	9584	39	0
80c	15 58 38.98	+65 22 25.8	9550	37	0
80d	15 58 43.66	+65 21 44.0	9108	54	0
81a	16 15 53.62	+12 55 25.4	14676	46	0
81b	16 15 53.99	+12 54 35.1	15150	94	0
81c	16 15 54.84	+12 54 50.5	15050	96	0
81d	16 15 54.54	+12 54 59.3	14954	91	0
82a	16 26 28.51	+32 57 31.0	11177	30	0
82b	16 26 34.10	+32 57 18.5	10447	37	0
82c	16 26 26.60	+32 55 13.0	10095	38	0
82d	16 26 22.92	+32 55 21.6	11685	46	0
83a	16 33 09.41	+06 22 01.0	15560	60	0
83b	16 33 13.35	+06 21 50.0	16442	69	0
83c	16 33 16.31	+06 22 49.7	16520	133	0
83d	16 33 14.19	+06 21 37.9	15500	133	1
83e	16 33 11.25	+06 22 29.4	15560	160	2
84a	16 46 43.95	+77 55 38.8	16654	61	0
84b	16 46 35.59	+77 56 50.7	16554	73	0
84c	16 46 51.36	+77 55 07.8	16353	71	0
84d	16 46 23.83	+77 56 44.4	16800	92	0
84e	16 46 48.57	+77 55 36.2	16950	81	0
84f	16 46 10.16	+77 56 16.3	32500	100	0
85a	18 51 21.97	+73 17 23.1	11155	38	0
85b	18 51 29.97	+73 17 00.7	12122	36	0
85c	18 51 33.22	+73 17 45.8	11912	47	0
85d	18 51 39.84	+73 17 14.6	11900	96	0
86a	19 48 59.87	−30 57 10.7	6174	39	0
86b	19 48 50.03	−30 56 42.8	6196	45	0
86c	19 48 48.25	−30 59 09.3	5529	42	0
86d	19 48 42.94	−30 56 15.3	5916	50	0
87a	20 45 23.03	−20 02 05.3	8694	35	0
87b	20 45 19.03	−20 02 29.8	8972	65	1
87c	20 45 20.15	−20 01 02.1	8920	133	1
87d	20 45 21.05	−20 01 53.9	10200	160	1
88a	20 49 56.55	−05 53 59.7	6033	25	0
88b	20 49 50.95	−05 56 08.5	6010	22	0
88c	20 49 47.18	−05 57 40.8	6083	26	0
88d	20 49 33.93	−05 59 12.7	6032	59	0
89a	21 17 24.26	−04 08 04.4	8850	61	0
89b	21 17 42.47	−04 06 31.8	8985	45	0
89c	21 17 31.59	−04 07 48.7	8872	40	0
89d	21 17 31.21	−04 07 14.6	8857	32	0
90a	21 59 07.58	−32 06 41.9	2575	28	0
90b	21 59 14.08	−32 13 56.1	2525	29	0
90c	21 59 08.78	−32 12 57.7	2696	24	0
90d	21 59 11.60	−32 14 08.8	2778	29	0
91a	22 06 17.17	−28 03 19.9	6832	40	0
91b	22 06 26.02	−27 58 37.6	7196	66	0
91c	22 06 23.70	−28 01 41.4	7319	49	0
91d	22 06 18.12	−28 02 47.6	7195	41	0
92a	22 33 45.95	+33 41 20.6	786	20	0
92b	22 33 41.05	+33 42 23.7	5774	24	0
92c	22 33 46.33	+33 42 57.4	6764	28	0
92d	22 33 39.40	+33 42 22.3	6630	23	0

TABLE 2—*Continued*

Name (1)	R.A. (1950) (2)	Decl. (3)	v (km s^{-1}) (4)	δv (km s^{-1}) (5)	Confidence (6)
92e	22 33 34.71	+33 41 07.0	6599	26	0
93a	23 12 46.80	+18 41 19.2	5140	31	0
93b	23 12 48.00	+18 46 07.6	4672	38	0
93c	23 12 34.43	+18 42 01.3	5132	33	0
93d	23 13 03.91	+18 46 30.1	5173	34	0
93e	23 13 09.07	+18 38 47.9	8881	39	0
94a	23 14 44.00	+18 26 04.4	12040	42	0
94b	23 14 42.50	+18 25 39.5	11974	37	0
94c	23 14 50.82	+18 27 39.7	12120	52	0
94d	23 14 45.75	+18 26 18.7	13009	42	0
94e	23 14 46.00	+18 27 12.1	12250	103	0
94f	23 14 49.10	+18 27 57.0	12920	108	0
94g	23 14 50.51	+18 28 32.6	13200	114	0
95a	23 16 58.17	+09 14 02.9	11888	45	0
95b	23 17 02.04	+09 13 16.0	11637	48	0
95c	23 16 59.31	+09 13 44.2	11562	40	0
95d	23 16 56.13	+09 13 14.0	12350	97	0
96a	23 25 24.61	+08 30 09.9	8698	25	0
96b	23 25 33.75	+08 29 34.5	8616	42	0
96c	23 25 26.52	+08 30 26.4	8753	35	0
96d	23 25 27.90	+08 29 30.7	8975	57	0
97a	23 44 49.08	−02 34 43.9	6910	25	0
97b	23 45 03.87	−02 35 42.3	6940	72	0
97c	23 44 49.78	−02 37 45.6	5995	35	0
97d	23 44 44.94	−02 35 28.3	6239	33	0
97e	23 44 45.87	−02 33 32.1	6579	45	0
98a	23 51 36.36	+00 06 16.3	7855	20	0
98b	23 51 38.49	+00 05 54.1	7959	26	0
98c	23 51 40.14	+00 04 43.4	8145	33	0
98d	23 51 36.98	+00 06 56.9	14950	67	0
99a	23 58 04.56	+28 06 23.9	8705	20	0
99b	23 58 13.50	+28 07 24.7	8846	30	0
99c	23 58 10.60	+28 07 23.0	8216	34	0
99d	23 58 11.69	+28 05 35.9	8643	82	0
99e	23 58 08.92	+28 05 27.2	9007	96	0
100a	23 58 46.33	+12 49 57.2	5300	27	0
100b	23 58 52.35	+12 50 03.8	5253	37	0
100c	23 58 39.75	+12 51 56.1	5461	38	0
100d	23 58 41.00	+12 50 03.3	...	...	...

than about 2000 km s^{-1} the distribution is roughly uniform. For the purpose of discussion of the dynamical properties of the groups we shall assume that galaxies which have $\Delta v < 1000$ km s^{-1} are physically associated with the group, and say that they have *accordant* velocities. Galaxies with Δv greater than this limit will be called *discordant* and assumed to be unrelated to the group. The exact value of this velocity limit is not critical to any of the conclusions that follow. Some galaxies will no doubt be incorrectly classified as accordant or discordant using this criteria, but this is unavoidable and is not likely to have a major impact. Only 71 (of 457) galaxies are classified as discordant by this criterion.

Eight groups were rejected because they had fewer than three galaxies with confirmed accordant velocities. These are groups 9, 11, 18, 19, 36, 41, 77, and 78. The remaining groups with three or more confirmed accordant velocities comprise the *accordant sample* that is used for the analysis that follows. This sample consists of 92 groups containing a total of 386 galaxies. Each group contains at least three galaxies, all of which have accordant velocities. Data for this sample are listed in Table 3. In all but the first three columns, the tabulated numbers are the common logarithms of the indicated quantities. The column headings for this table are (1) Group number as in Paper I; (2) group redshift derived from the median galaxy heliocentric velocity; (3) number of galaxies with accordant velocities; (4) radial velocity dispersion of the accordant galaxies; (5) estimated intrinsic three-dimensional velocity dispersion, corrected for measurement errors; (6) median projected separation; (7) crossing time; (8) virial mass; (9) projected mass; (10) average mass; (11) median mass; (12) adopted mass; (13) total blue luminosity of the accordant galaxies; (14) mass-to-light ratio; and (15) mass density. Throughout this paper we adopt a Hubble constant of 100 km s^{-1} Mpc^{-1}, h is defined as $H_0/100$ km s^{-1} Mpc^{-1}.

3.2. *Spatial Distribution and Completeness*

Figure 2 shows the distribution of group redshifts for the accordant sample. The solid line shows the distribution expected for a homogeneous population of groups with a luminosity function described by the Schechter (1976) formula with $M^* = -20.6$ and $\alpha = -0.2$. This curve was obtained by integrating the quantity $\phi(M, M^*, \alpha)P(m)$ over magnitude in each redshift shell. Here M and m are the absolute and apparent magnitudes of a group and $P(m)$ is the magnitude selection function for the HCG sample, $P(m) = [1 + \text{dex}(1.2[m - m_0])]^{-1}$ (HKA). These values of M^* and α are those derived from a study of the luminosity function of compact groups of galaxies (Mendes de Oliveira 1992; Hickson &

TABLE 3

GROUP DYNAMICAL PROPERTIES

Number	z	n	σ_v (km s^{-1})	V (km s^{-1})	R (Kpc)	$H_0 t_c$	M_v (g)	M_p (g)	M_a (g)	M_m (g)	M (g)	L (W)	M/L (solar units)	ρ (g cm^{-3})
1	0.0339	4	1.93	2.12	1.69	−1.32	44.61	45.20	45.33	45.30	45.25	37.37	1.17	−24.91
2	0.0144	3	1.74	1.88	1.72	−1.06	44.12	44.82	44.73	44.99	44.78	36.98	1.08	−25.47
3	0.0255	3	2.40	2.63	1.89	−1.64	45.95	46.34	46.19	46.58	46.27	37.00	2.56	−24.48
4	0.0280	3	2.53	2.76	1.76	−1.90	46.06	46.52	46.36	46.73	46.45	37.37	2.36	−23.91
5	0.0410	3	2.17	2.39	1.41	−1.88	44.96	45.48	45.37	45.88	45.43	37.41	1.30	−23.88
6	0.0379	4	2.40	2.63	1.40	−2.12	45.42	45.76	45.87	45.84	45.80	37.31	1.78	−23.49
7	0.0141	4	1.95	2.16	1.66	−1.40	44.71	45.20	45.28	45.23	45.21	37.34	1.15	−24.86
8	0.0545	4	2.65	2.89	1.46	−2.32	46.09	46.24	46.39	46.54	46.33	37.88	1.73	−23.14
10	0.0161	4	2.32	2.56	1.97	−1.48	45.79	46.05	46.13	46.42	46.09	37.49	1.89	−24.90
12	0.0485	5	2.38	2.62	1.77	−1.73	45.75	46.11	46.31	45.94	46.03	37.45	1.87	−24.37
13	0.0411	5	2.26	2.44	1.67	−1.66	45.30	45.64	45.88	45.90	45.78	37.47	1.59	−24.32
14	0.0183	3	2.52	2.76	1.43	−2.22	45.88	45.30	46.26	46.41	46.34	36.84	2.78	−23.04
15	0.0228	6	2.63	2.86	1.89	−1.87	46.29	46.64	47.01	47.03	46.86	37.36	2.79	−23.88
16	0.0132	4	2.09	2.31	1.65	−1.56	44.96	45.40	45.54	45.41	45.41	37.34	1.35	−24.63
17	0.0603	5	2.12	2.18	1.35	−1.73	44.58	44.75	45.10	44.59	44.59	37.22	0.65	−24.56
20	0.0484	5	2.44	2.67	1.50	−2.07	45.62	45.74	46.10	45.61	45.69	37.08	1.89	−23.89
21	0.0251	3	2.05	2.27	2.13	−1.03	45.52	46.00	45.89	46.42	45.95	37.43	1.80	−25.54
22	0.0090	3	1.64	1.25	1.43	−0.72	42.74	43.55	43.80	44.48	43.70	36.88	0.10	−25.67
23	0.0161	4	2.23	2.44	1.82	−1.52	45.51	45.90	45.99	46.02	45.95	36.82	2.41	−25.59
24	0.0305	5	2.30	2.51	1.47	−1.93	45.30	45.54	45.84	45.29	45.44	37.12	1.60	−24.07
25	0.0212	4	1.79	2.13	1.68	−1.16	44.22	44.74	44.85	44.94	44.80	37.11	0.97	−25.33
26	0.0316	7	2.30	2.52	1.50	−1.92	45.13	45.56	45.98	45.63	45.60	37.03	1.85	−23.99
27	0.0874	4	2.09	2.10	2.03	−0.97	44.99	45.59	45.60	45.75	45.60	37.42	1.46	−25.57
28	0.0380	3	1.93	...	1.34	−1.70	44.55	44.81	44.75	45.15	44.78	37.25	0.82	−24.34
29	0.1047	3	2.61	2.85	1.48	−2.26	45.96	46.46	46.29	46.55	46.38	37.48	2.19	−23.13
30	0.0154	4	1.86	2.04	1.71	−1.22	44.55	44.95	44.97	45.11	44.96	37.21	1.03	−25.26
31	0.0137	3	1.75	1.82	0.91	−1.80	43.23	43.93	43.90	44.27	43.91	37.12	0.08	−23.92
32	0.0408	4	2.32	2.55	1.79	−1.66	45.65	46.10	46.12	45.87	46.00	37.68	1.61	−24.45
33	0.0260	4	2.19	2.42	1.39	−1.92	45.03	45.13	45.35	45.50	45.26	36.88	1.66	−24.00
34	0.0307	4	2.50	2.74	1.19	−2.44	45.47	45.85	45.98	45.95	45.90	37.19	2.00	−22.77
35	0.0542	6	2.50	2.74	1.65	−1.98	45.88	46.39	46.64	46.20	46.31	37.68	1.91	−23.74
37	0.0223	5	2.60	2.84	1.46	−2.27	45.93	46.19	46.48	46.30	46.25	37.44	2.09	−23.21
38	0.0292	3	1.11	...	1.77	0.88	...	...	...	...	...	37.12	...	...
39	0.0701	4	2.30	2.52	1.44	−1.98	45.30	45.78	45.78	45.84	45.78	37.33	1.73	−23.61
40	0.0223	5	2.17	2.40	1.18	−2.12	44.84	45.29	45.48	45.23	45.26	37.39	1.16	−23.36
42	0.0133	4	2.33	2.56	1.65	−1.81	45.48	45.84	45.95	45.82	45.83	37.42	1.69	−24.20
43	0.0330	5	2.35	2.58	1.77	−170	45.75	46.15	46.35	46.06	46.11	37.21	2.19	−24.30
44	0.0046	4	2.13	2.34	1.58	−1.65	45.04	45.43	45.50	45.57	45.47	36.85	1.90	−24.37
45	0.0732	3	2.26	2.49	2.02	−1.36	45.85	46.10	46.04	46.52	46.07	37.60	1.75	−25.08
46	0.0270	4	2.51	2.75	1.60	−2.04	45.78	46.19	46.33	46.12	46.15	36.76	2.68	−23.74
47	0.0317	4	1.63	...	1.56	0.66	...	43.54	43.98	...	43.81	37.17	−0.07	−26.95
48	0.0094	3	2.48	2.70	1.31	−2.29	45.65	46.14	46.02	46.38	46.08	36.52	2.84	−22.93
49	0.0332	4	1.53	...	1.09	0.19	...	...	...	...	...	36.82	...	...
50	0.1392	5	2.67	2.91	1.59	−2.21	46.22	46.54	46.73	46.48	46.51	37.43	2.37	−23.33
51	0.0258	5	2.38	2.61	1.77	−1.73	45.51	46.14	46.33	45.81	46.01	37.43	1.86	−24.41
52	0.0430	3	2.26	2.47	1.94	−1.43	45.55	46.19	46.07	46.48	46.14	37.38	2.04	−24.76
53	0.0206	3	1.91	2.00	1.76	−1.14	44.30	44.99	44.99	44.50	44.81	37.35	0.74	−25.56
54	0.0049	4	2.05	2.26	0.20	−2.96	43.50	44.02	44.04	43.67	43.88	35.66	1.51	−21.80
55	0.0526	4	2.33	2.52	1.28	−2.13	45.13	45.58	45.69	45.42	45.51	37.44	1.35	−23.41
56	0.0270	5	2.23	2.45	1.33	−2.02	44.97	45.44	45.58	45.21	45.34	37.20	1.42	−23.74
57	0.0304	7	2.43	2.66	1.86	−1.69	45.80	46.37	46.68	46.10	46.26	37.71	1.84	−24.42
58	0.0207	5	2.21	2.44	1.95	−1.39	45.64	46.13	46.26	45.73	45.98	37.53	1.73	−24.97
59	0.0135	4	2.28	2.51	1.33	−2.07	45.15	45.61	45.62	45.46	45.54	36.67	2.15	−23.54
60	0.0625	4	2.63	2.85	1.75	−1.99	46.18	46.65	46.69	46.75	46.67	37.75	2.21	−24.67
61	0.0130	3	1.94	2.16	1.46	−1.60	44.56	45.05	44.92	45.43	44.99	37.11	1.16	−24.46
62	0.0137	4	2.46	2.69	1.43	−2.16	45.43	45.87	45.88	45.86	45.87	37.02	2.13	−23.51
63	0.0311	3	2.12	2.16	1.65	−1.41	44.73	45.20	45.23	45.23	45.22	37.53	0.97	−24.81
64	0.0360	3	2.33	2.55	1.41	−2.03	45.15	45.79	45.62	45.51	45.57	37.16	1.69	−23.76
65	0.0475	5	2.51	2.74	1.66	−1.97	45.74	46.19	46.44	46.11	46.15	38.08	1.36	−23.93
66	0.0699	4	2.48	2.72	1.51	−2.10	45.68	46.20	46.19	46.19	46.19	37.68	1.79	−23.44
67	0.0245	4	2.32	2.56	1.69	−1.76	45.42	46.06	46.11	46.00	46.03	37.65	1.67	−24.14
68	0.0080	5	2.19	2.42	1.52	−1.79	45.11	45.36	45.55	45.68	45.47	37.27	1.48	−24.18
69	0.0294	4	2.35	2.58	1.48	−1.99	45.31	45.77	45.84	45.53	45.67	37.20	1.76	−23.88
70	0.0636	4	2.16	2.31	1.86	−1.34	45.23	45.69	45.80	45.67	45.68	37.63	1.34	−24.99
71	0.0301	3	2.62	2.85	1.70	−2.04	46.27	46.69	46.55	47.05	46.62	37.40	2.51	−23.57
72	0.0421	4	2.42	2.66	1.55	−2.00	45.59	46.12	46.18	46.04	46.08	37.73	1.64	−23.66
73	0.0449	3	2.09	2.13	2.00	−1.02	45.10	45.55	45.60	45.87	45.57	36.89	1.97	−25.51
74	0.0399	5	2.50	2.73	1.59	−2.03	45.75	46.20	46.41	46.56	46.32	37.62	1.99	−23.55
75	0.0416	6	2.47	2.66	1.57	−1.98	45.52	46.14	46.35	45.13	45.93	37.55	1.67	−23.87
76	0.0340	7	2.39	2.62	1.86	−1.65	45.75	46.18	46.53	46.07	46.13	37.59	1.82	−24.54

TABLE 3—*Continued*

Number	z	n	σ_v (km s^{-1})	V (km s^{-1})	R (Kpc)	$H_0 t_c$	M_v (g)	M_p (g)	M_a (g)	M_m (g)	M (g)	L (W)	M/L (solar units)	ρ (g cm^{-3})
79	0.0145	4	2.14	2.36	0.83	−2.43	44.44	44.86	44.88	44.79	44.83	36.90	1.21	−22.74
80	0.0310	4	2.43	2.67	1.40	−2.16	45.58	45.95	45.94	46.17	45.94	37.13	2.10	−23.34
81	0.0499	4	2.25	2.43	1.26	−2.06	44.89	45.55	45.59	45.40	45.48	37.13	1.64	−23.39
82	0.0362	4	2.79	3.03	1.85	−2.07	46.61	47.06	47.02	47.06	47.04	37.62	2.70	−23.60
83	0.0531	5	2.66	2.89	1.70	−2.08	46.19	46.61	46.79	46.74	46.68	37.31	2.66	−23.50
84	0.0556	5	2.31	2.52	1.77	−1.64	45.42	45.96	46.04	45.73	45.86	37.75	1.39	−24.55
85	0.0393	4	2.56	2.80	1.39	−2.30	45.87	46.27	46.29	46.41	46.28	37.25	2.32	−22.98
86	0.0199	4	2.43	2.66	1.67	−1.89	45.80	46.16	46.24	46.24	46.20	37.24	2.25	−23.90
87	0.0296	3	2.08	2.16	1.49	−1.56	44.65	44.85	44.95	45.47	44.91	37.35	0.84	−24.64
88	0.0201	4	1.43	...	1.83	0.94	...	...	...	...	...	37.53	...	...
89	0.0297	4	1.74	1.72	1.77	−0.84	43.90	44.79	44.93	44.98	44.86	37.33	0.81	−25.54
90	0.0088	4	2.00	2.22	1.47	−1.65	44.39	45.10	45.06	44.94	45.00	37.19	1.09	−24.49
91	0.0238	4	2.26	2.48	1.72	−1.66	45.35	45.86	45.90	45.47	45.71	37.62	1.37	−24.55
92	0.0215	4	2.59	2.83	1.45	−2.27	45.78	46.01	46.21	45.95	45.98	37.62	1.64	−23.47
93	0.0168	4	2.32	2.55	1.85	−1.59	45.78	46.05	46.15	46.30	46.10	37.45	1.93	−24.55
94	0.0417	7	2.68	2.92	1.76	−2.05	46.28	46.78	47.10	46.66	46.72	37.80	2.20	−23.66
95	0.0396	4	2.49	2.72	1.48	−2.13	45.72	45.96	46.11	45.95	45.99	37.53	1.70	−23.59
96	0.0292	4	2.12	2.34	1.48	−1.76	44.97	45.33	45.43	45.44	45.38	37.49	1.17	−24.15
97	0.0218	5	2.57	2.80	1.80	−1.90	46.14	46.55	46.74	46.51	46.53	37.28	2.54	−23.95
98	0.0266	3	2.08	2.31	1.44	−1.76	44.83	45.42	45.27	45.43	45.35	37.26	1.37	−24.06
99	0.0290	5	2.42	2.65	1.63	−1.91	45.66	46.03	46.19	45.82	45.93	37.52	1.70	−24.05
100	0.0178	3	1.95	2.15	1.58	−1.46	44.69	45.25	45.12	45.44	45.19	36.97	1.50	−24.65

Mendes de Oliveira 1992). The observed and predicted redshift distributions are consistent; a Kolmogorov Smirnov (KS) test indicates that the deviations observed have a 46% probability of occurring by chance in a sample of this size. Therefore, we conclude that the space density of compact groups is essentially constant, at least to the redshift limit of our sample.

The median redshift of our sample is 0.0297 (8889 km s^{-1}) indicating that half the observed groups are more distant than 89 h^{-1} Mpc. The highest redshift observed is 0.1392 (41730 km s^{-1}). These groups thus extend well beyond the local supercluster; indeed, most are further away than the Coma cluster ($z = 0.0202$).

The redshift distribution of Figure 2 is not consistent with a luminosity function having $\alpha = -1$, representative of galaxies in loose groups and clusters, for any value of M^*. The best-fit curve with $\alpha = -1$ has a KS probability of only 0.002. This result is distinct from and complimentary to, that of Mendes de Oliveira & Hickson (1991), who find that the luminosity function of *galaxies* in compact groups is best fitted by the parameters $M^* = -19.6$ and $\alpha = -0.2$. It therefore appears that not only do compact groups contain relatively fewer low-luminosity galaxies than do clusters, loose groups, or field samples, but also that there are relatively fewer low-luminosity groups than would be expected if compact groups are simply random collections of field galaxies.

3.3. *Internal Dynamics and Masses*

The distribution of measured radial velocity dispersions σ_v for all groups in the accordant sample is shown in Figure 3. It can be seen that there is a wide range in σ_v (from 13 to 617 km s^{-1}) with a median of 200 km s^{-1}. This is comparable to typical values for loose groups for which values of 208 km s^{-1}

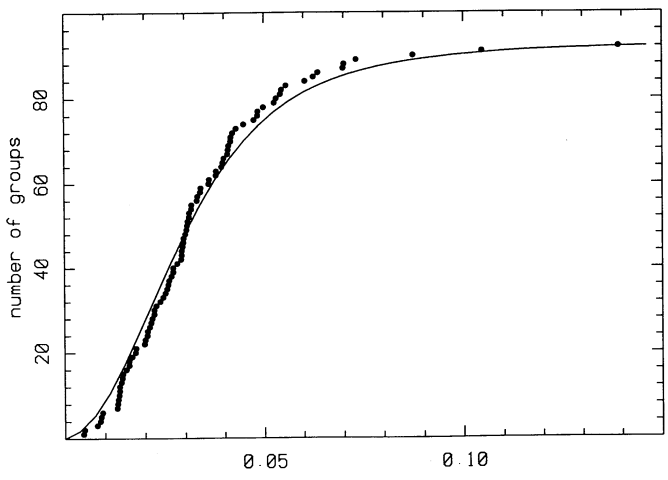

FIG. 2.—Cumulative distribution of group redshifts. The solid line is the distribution expected for a uniform space density of compact groups with luminosity function characterized by the Schechter form with $M^* = -20.6$ and $\alpha = -0.2$, which represents the best fit, and is statistically compatible with the data.

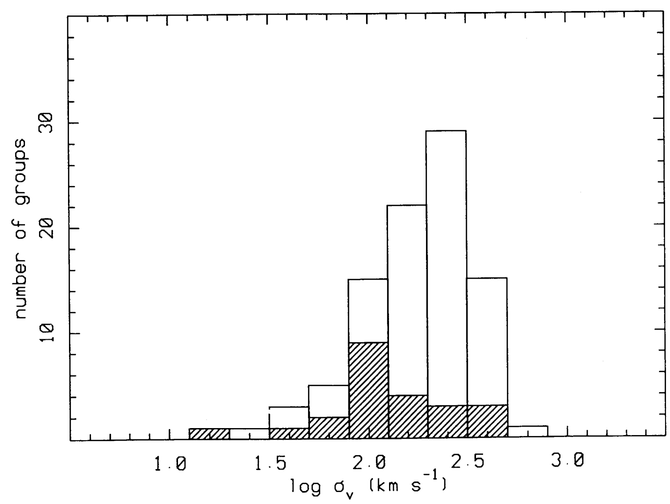

FIG. 3.—Distribution of observed velocity dispersions for all 92 groups having three or more accordant members. The hatched region indicates galaxy triplets.

(CfA survey, Geller & Huchra 1983) and 183 km s^{-1} (Southern groups of galaxies, Maia, da Costa, & Latham 1989) have been reported. However, it is much less than typical velocity dispersions in rich clusters (for example, the median σ_v found for 65 Abell clusters by Zabludoff, Huchra, & Geller 1990, is 744 km s^{-1}).

From the observed velocity dispersions we have estimated the intrinsic three-dimensional velocity dispersion V, statistically corrected for measurement errors, using the formula

$$V = [3(\langle v^2 \rangle - \langle v \rangle^2 - \langle \delta v^2 \rangle)]^{1/2} , \quad (1)$$

where v is the measured radial velocity of the galaxy, δv is the estimated velocity error, and $\langle\rangle$ denotes the average over all galaxies in the group. These intrinsic velocity dispersions are listed in column (5) of Table 3. Six groups have estimated errors larger than the observed velocity dispersions, and so the intrinsic velocity dispersion cannot be determined. The median intrinsic velocity dispersion is 331 km s^{-1}.

A convenient measure of the dynamical state of a group is the dimensionless "crossing" time $H_0 t_c$, which is the ratio of the crossing time to the approximate age of the universe. Its reciprocal is roughly the maximum number of times a galaxy could have traversed the group since its formation and is thus a measure of potential dynamical evolution. A robust estimator of the crossing time for compact groups is

$$t_c = \frac{4}{\pi} \frac{R}{V} , \quad (2)$$

where R is the median length of the two-dimensional galaxy-galaxy separation vector. The numerical factor accounts for geometrical projection of the three-dimensional separation vector. Note that $H_0 t_c$ is independent of the choice of Hubble constant. Crossing times for the groups in our sample are listed in column (7) of Table 3. As can be seen from Figure 4, $H_0 t_c$ ranges from 0.001 (Group 54) to 8.7 in our sample and is typically of order 0.02 for most groups. The median value of $H_0 t_c$ is 0.016.

One would expect effects of dynamical evolution to be most pronounced in groups with small t_c. It is therefore of interest to examine whether any independent physical properties of the groups correlate with t_c. In this paper we consider two such properties, the fraction f_s of late-type galaxies, and the magnitude difference Δm_{12} between the first- and second-ranked galaxies.

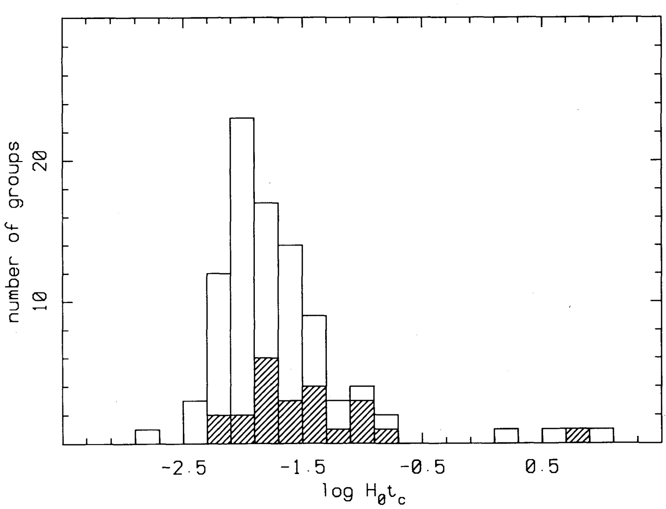

FIG. 4.—Distribution of dimensionless crossing times for the accordant sample. The shaded region indicates galaxy triplets. The median value of $H_0 t_c$ is 0.016.

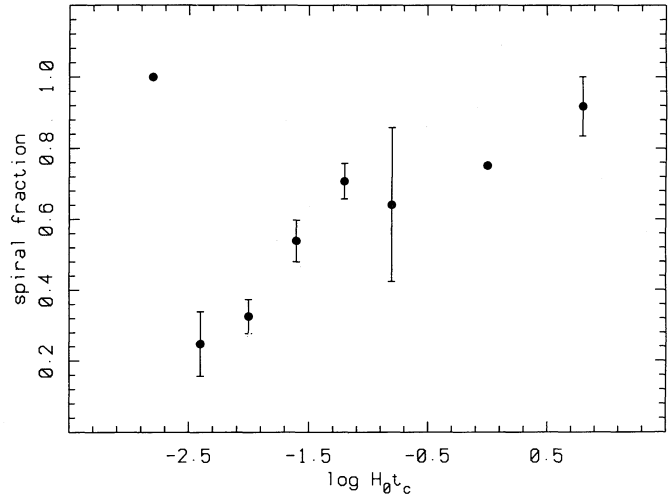

FIG. 5.—Fraction of late-type galaxies plotted vs. crossing time. The correlation is statistically significant. Groups with small crossing times typically contain fewer late-type galaxies.

If dynamical evolution converts spiral galaxies to elliptical galaxies by some process such as mergers, f_s should be smaller, on average, in groups with small t_c. The observed relationship between these quantities for our sample is shown in Figure 5. There is a clear trend for groups with crossing times less than about $0.03H_0^{-1}$ to be spiral-poor compared to groups whose crossing times are longer. The probability of this correlation appearing by chance is less than 10^{-4} according to the Spearman rank correlation test. The single point in the figure is group 54 which consists of a single spiral galaxy and three faint irregular galaxies and is an obvious exception to the trend.

Suppose then that mergers do play a role in modifying the structure of galaxies in compact groups. In what way does this proceed? In rich clusters, numerical simulations indicate that a dominant galaxy forms and grows by accreting smaller companions. If a similar process occurs in compact groups, one would expect to find an inverse relation between the magnitude difference Δm_{12} and $H_0 t_c$. The observational results are shown in Figure 6. While there does appear to be a trend toward larger Δm_{12} in groups with lower $H_0 t_c$, it is not highly significant. The Spearman rank correlation test gives a 6.2% probability of this correlation arising by chance.

The expected evolution of compact groups depends sensitively on the amount of mass and its distribution. We have estimated the masses of groups in the accordant sample using the virial theorem and three other mass estimators, "projected," "average," and "median" mass estimators discussed by Heisler, Tremaine, & Bahcall (1985; see also Perea, del Olmo, & Moles 1990). In all cases the masses were corrected for velocity errors. The individual mass estimates are listed in columns (8)–(11) of Table 3. The mass that we adopt for the group, which appears in column (12) of Table 3, is the median of the nonzero mass estimates in the previous four columns. Note that these mass estimators are sensitive only to mass interior to the region of space occupied by the galaxies and do not include any mass which may surround the group.

The derived group masses range up to $5.5 \times 10^{13}\ h^{-1}\ M_\odot$

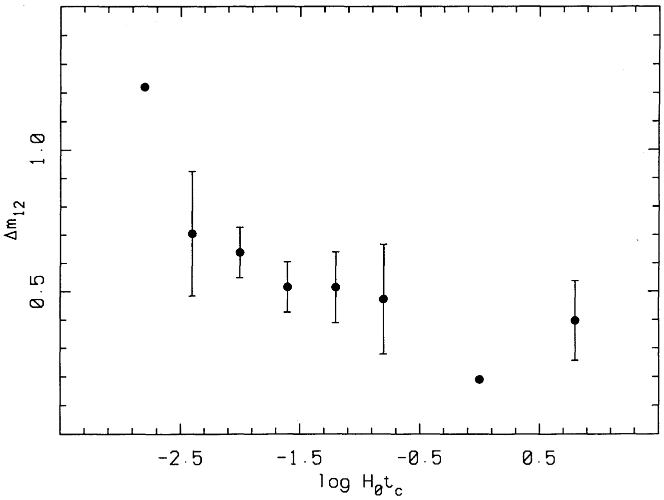

FIG. 6.—Magnitude difference between the first- and second-ranked galaxies plotted vs. crossing time. There is only a weak correlation of marginal significance.

(group 82). Several groups have velocity dispersions sufficiently small, compared to the errors, that no estimate of their mass can be made. These are groups 28, 38, 49, and 88. We emphasize that the mass derived for any individual group has a large uncertainty because of unknown projection factors which become important when the number of galaxies is small (see e.g., Anosova et al. 1991). Of the four mass estimators, the virial mass exhibits the largest fluctuations, particularly in the galaxy triplets. However, in all cases, the maximum difference between different mass estimators is less than an order of magnitude. According to Heisler et al. (1985) there is a 75% chance that the derived mass of any single group is within a factor of order 2 of the correct value. Since these groups form a reasonably large and homogeneous sample, average properties should be reasonably well determined. For example, if the groups have similar intrinsic values of M/L, the median value derived for our sample of 92 groups should be an order of magnitude more accurate than the estimated value for any individual group.

Mass-to-light ratios were obtained from the adopted mass and the total blue luminosity of the group, obtained from corrected B_T magnitudes of the accordant galaxies (col. [16] of Table 2 of HKA). The distribution of M/L, defined to be the mass-to-light ratio in units of $M_\odot/L_\odot$, is shown in Figure 7. There is a wide range of mass-to-light ratios in the groups, as expected. Several groups have estimated M/L of order unity, but only one of these contains more than three accordant galaxies. It is possible that these low values result from statistical fluctuations, due to the small number of galaxies in the groups. The cutoff at $M/L \sim 1000$ is in part a result of the velocity criterion used to select accordant groups. There is a trend of increasing M/L with group radius R, but because of the statistical fluctuations, the significance level of this correlation is low.

The median value of M/L in the sample is 50 h. This is rather smaller than values of M/L quoted for loose groups ($\sim$300 h, Geller & Peebles 1973; $\sim$280 h, Gott & Turner 1977; $\sim$254 h, Rood & Dickel 1978; $\sim$400 h, Geller 1984; Mezzetti et al. 1985; $\sim$180 h, Ramella, Geller, & Huchra 1989) but considerably higher than typical dynamical mass-to-light ratios of individual galaxies in the groups, derived from optical spectroscopy ($\sim$7 h, Rubin et al. 1991).

4. DISCUSSION

Let us first summarize the principal observational results:

1. More than 84% of the cataloged galaxies in Hickson's sample of compact groups have accordant velocities (within 1000 km s^{-1} of the group median). Of these, 92% have three or more accordant members, and 69% have four or more.

2. The redshift distribution of the groups is consistent with their having a uniform space distribution, and a luminosity function characterized by a Schechter function with $M^* = -20.6$ and $\alpha = -0.2$.

3. The median velocity dispersion of the accordant galaxies in the groups is 200 km s^{-1}, comparable to that of loose groups. The corresponding intrinsic three-dimensional velocity dispersion (corrected for measurement errors) is 331 km s^{-1}.

4. The median galaxy crossing time in these groups is only $0.016H_0^{-1}$.

5. There is a significant correlation between crossing time and the fraction of gas-rich galaxies in the groups. Groups with short crossing times typically contain fewer late-type galaxies. There is weak evidence for an anticorrelation between the luminosity contrast of the first-ranked galaxy and crossing time.

6. There is a considerable range in the derived mass-to-light ratios for the groups. The median value of M/L is 50 h, considerably higher than that found for the individual galaxies.

We conclude from these results that the selection criteria of Paper I, with the addition here of a velocity selection criterion, were successful in defining a relatively large sample of physically dense compact groups. The large majority of galaxies in these groups have accordant redshifts. The number of discordant galaxies is about what is expected due to the chance projection of field galaxies (Hickson, Kindl, & Huchra 1989b; Mendes de Oliveira & Hickson 1992). With the discordant galaxies removed, these groups span a range of physical parameters such as density and crossing time making them suitable for the investigation of dynamical effects in interacting systems.

The correlation of morphological type with crossing time supports the view that galaxy morphology is altered by dynamical effects. It is not yet clear, however, whether this occurs at the time of galaxy formation or during subsequent

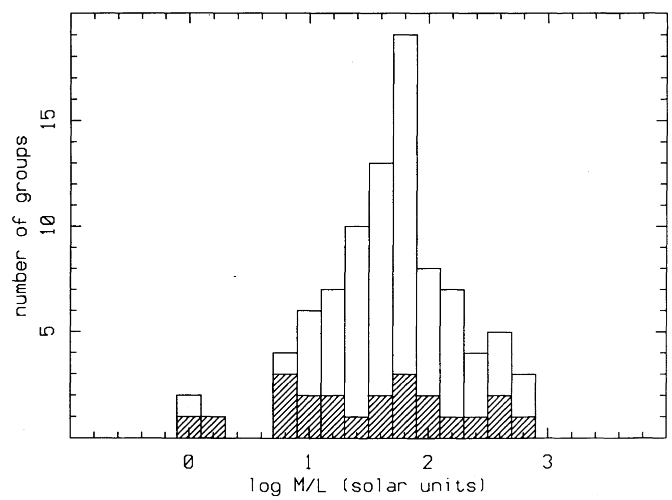

FIG. 7.—Distribution of mass-to-light ratios in the groups. Galaxy triplets are indicated by the shaded region. The median M/L is 50 h.

evolution. Numerical simulations (Carnevali, Cavaliere, & Santangelo 1981; Barnes 1985, 1989, 1990) confirm the earlier conclusion (Hickson et al. 1977) that such groups should be severely modified by merging on a time scale of the order of several crossing times. However, recent simulations by Governato, Bhatia, & Chincarini (1991) indicate that long-lived compact groups are possible. Also, one expects that if a large fraction of the mass of a group exists in a smooth halo, within which the galaxies move, the merging time scale may increase. This may be seen as follows: The time scale for loss of energy by dynamical friction for a galaxy of mass m moving uniformly with speed u through a smooth background of low-mass particles with density ρ and velocity dispersion V_b is given by (Chandrasekhar 1943)

$$t_f = \frac{u^3}{8\pi G^2 m\rho \ln \Lambda[\Phi(x) - x\Phi'(x)]}, \quad (3)$$

where $x = u/2^{1/2}V_b$, Λ is the ratio of maximum to minimum impact parameters, G is the Newtonian gravitational constant, and Φ and Φ' are the error function and its derivative. Suppose now that a fraction ϵ of the total mass of the group is contained in n individual galaxies of mass m. From the virial theorem, the total mass is

$$M \simeq \frac{\pi}{2G} V^2 R \simeq \frac{4\pi\rho}{3} R^3 + nm, \quad (4)$$

from which using equation (2) we obtain

$$t_f \simeq \frac{n}{6\pi\epsilon(1-\epsilon)\ln \Lambda[\Phi(x) - x\Phi'(x)]} t_c. \quad (5)$$

We expect $x \sim 1$ for which the quantity in brackets ~ 0.4, and Λ may be estimated as the ratio of the radius of the group to the radius of a galaxy, typically $\Lambda \sim 4$. Thus, for $n \sim 4$,

$$t_f \simeq 0.4 \frac{t_c}{\epsilon(1-\epsilon)}. \quad (6)$$

If, for example, $\sim 10\%$ of the mass is attached to galaxies, the dynamical friction time scale is about 4 times the crossing time. Even in this case, recalling that the median crossing time is $0.016H_0$, the typical dynamical friction time scale is an order of magnitude smaller than the age of the universe.

Can the short dynamical time scales be due to selection effects? The compactness criteria used to catalog the groups would preferentially select groups with geometrical alignment resulting in smaller apparent sizes than would otherwise be expected. This bias would cause us to underestimate the crossing time. However, this type of bias has been investigated by Hickson & Rood (1988) who conclude that it is unlikely to be large. The bias would cause us to underestimate the total number of compact groups, as misaligned groups would not be counted. Since the cataloged compact groups alone are estimated to contribute $\sim 1\%$ of the visible luminosity density of the universe (Mendes de Oliveira & Hickson 1991), we conclude that the bias cannot be large.

The relatively high values of M/L found in these groups are suggestive of a substantial amount of dark matter. Considering that the median values of M/L found by Rubin et al. (1991) for individual galaxies in these groups is 7.0 h, it is quite possible that more than $\sim 85\%$ of the mass of a typical group is unseen. The Rubin et al. estimates are based on optical rotation curves and may significantly underestimate the total mass of an individual galaxy. It may therefore be possible that most of the dark matter resides in individual galaxy halos. However, the intergalaxy separation in these groups is so small that it is unlikely that the galaxies can retain extended individual halos for much more than a crossing time.

Can the dark matter reside in low-luminosity galaxies? Persic & Salucci (1990) estimate that $M/L \propto L^{-0.7}$. If one integrates a "normal" Schechter luminosity function down to $L \simeq 0.01L^*$, this may account for of order half the needed dark matter (M. Persic 1991, private communication). However, the luminosity function that we find for compact groups drops much faster with decreasing luminosity than does a normal luminosity function. This drop is very pronounced, many groups simply have no visible faint members, and is unlikely to be caused by brightening of the large galaxies due to interactions. We conclude that little dark matter can be hidden in low-luminosity galaxies in these groups.

Whether this dark matter occurs in individual galaxy halos or a common envelope is a crucial question. If galaxies collide with their halos attached, merging should proceed rapidly. If, as seems more likely, halos are stripped from the galaxies relatively early to form a common envelope, the subsequent dynamical evolution should proceed rather more slowly. This latter picture receives support from the observation (Hickson, Kindl, & Huchra 1989c) that velocity dispersion does not correlate with group radius. If most of the mass of a group remains attached to galaxies, one would expect (from the virial theorem, for example) the velocity dispersion to increase as the radius of a group decreases. If, however, the galaxies are orbiting within a roughly isothermal common halo, comprising most of the mass of the group, the mass interior to the orbits is proportional to R so the velocity dispersion remains constant. Davis & Peebles (1983) reached a similar conclusion from their study of galaxy pairs in the CfA redshift survey.

Detailed modeling of the dynamical evolution of compact groups should determine at what stage individual galaxy halos merge and the effect on the subsequent evolution of the group. In addition, deep optical and radio observations might detect for emission from material in a common envelope. Such studies would greatly elucidate the nature of dynamical evolution in compact groups and the importance of compact groups in the overall evolutionary picture.

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