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DISCORDANT ARGUMENTS ON COMPACT GROUPS

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ABSTRACT

Much print has been dedicated to explaining discordant redshifts in compact groups as unrelated background galaxies. But no one has analyzed the accordant galaxies. It is shown here that when there is a brightest galaxy in the group, the remainder with differences of less than 1000 km s^{-1} are systematically redshifted. This is the same result as obtained in all other well-defined groups and demonstrates again an increasing intrinsic redshift with fainter luminosity.

Defining discordant redshifts as 1000 km s^{-1} or greater than the brightest galaxy, it is shown that 76 out of 345, or 22% are discordant, reaching excesses of up to 23,000 km s^{-1}. This large percentage cannot be explained by background contamination because the number of discordances would be expected to increase rapidly with larger excesses, exactly opposite to what is observed in compact groups.

Hickson's logarithmic intensity image of the NGC 1199 group confirms earlier direct evidence from Arp that a peculiar, compact object of 13,300 km s^{-1} redshift is silhouetted *in front* of the 2705 km s^{-1} central galaxy.

Subject headings: galaxies: clusters: general — galaxies: distances and redshifts

1. INTRODUCTION

When redshifts began to be measured in the nearest, densest groups of galaxies, it quickly became evident that they contained too many redshifts, far in excess of escape velocities (Burbidge & Burbidge 1961; Arp 1973, 1976; Sulentic 1984). Arguments were then made that many fainter groups existed that might not contain discordant redshifts (Rose 1977). The number of these fainter groups, however, turned out to be vastly overestimated, and in any case they would have had to contain no discordant redshifts in order to change the conclusion from the complete sample of the brightest groups with known redshifts (Sulentic 1983, 1993). In subsequent years, redshifts of galaxies in fainter groups have been measured, and recently Hickson (1994) has published an Atlas of Compact Groups of Galaxies that contains nearly complete redshift measures in 100 groups. The analysis in the present paper shows that 76 out of 345 galaxies fainter than brightest have discordant redshifts, thus validating the previous evidence from the brightest groups and reinforcing the problem with which the conventional assumption concerning the nature of redshifts is faced.

On the other hand, the galaxies with accordant redshifts, taken arbitrarily here as less than 1000 km s^{-1} different from the brightest in the group, have never been tested for redshift distribution. This is surprising, since it has been long known that companion (fainter) galaxies in the best-known, nearest groups show very significant systematic redshifts (Arp 1970; Collin-Souffrin, Pecker, & Tovmassian 1974; Arp 1976, 1987a, 1987b; Girardi et al. 1992; Arp 1994). It would be unlikely that the fainter galaxies in the compact groups behaved differently, and that important prediction is tested here in the first section.

Finally, the intrinsic redshifts exhibited by galaxies in these groups, their tendency to occur near very large, very low redshift galaxies, and their X-ray properties are considered. These empirical data suggest a working model to account for their origin and age.

2. THE ACCORDANT GROUP MEMBERS

Accordant members are here defined as galaxies with $\Delta cz < 1000$ km s^{-1} difference from the redshift of the brightest galaxy in the group. This definition springs from the fact that this is about 4 times the escape velocity from a large Sb galaxy like M31, and this would encompass safely most of the galaxies that were bound dynamically to the group. Perhaps more important, surveys of numbers of groups empirically show total redshift ranges of 800–900 km s^{-1} (Jaakkola & Moles 1976; Arp 1982; Huchra & Geller 1982; Sulentic 1984; Arp & Sulentic 1985; Arp 1986).

Again, $\Delta cz < 1000$ km s^{-1} is a generous limit beyond which a galaxy would not be a conventional member of a group. Although this value cannot be assigned precisely, it is not at all critical to the testing of the distribution of accordant redshifts because, as we will show, the excess of relative redshifts over blueshifts holds up all the way to small redshift differences, and moreover, the higher redshift differences become rapidly less numerous.

Table 1 here is derived from the values given in the Atlas of Compact Groups of Galaxies (Hickson 1994). The first column is the Hickson group number, and the second column is the difference in apparent magnitude between the brightest galaxy in the group and the second brightest (Δmag). The third column is the morphological type of the brightest galaxy. Two broad columns follow: the first lists the positive redshift differences between the companions and the brightest galaxy, and the second lists the negative differences. In both cases the accordant differences are on the left, and the discordant differences are on the right.

Figure 1 plots Δmag versus Δcz for the 269 accordant redshift values in Table 1. The figure demonstrates that as Δmag becomes greater, the distribution of Δcz becomes progressively imbalanced toward positive values of Δcz. This means that as the brightest galaxy in the group becomes more dominant in luminosity (and hence, by inference in mass), a higher percentage of the companions are relatively redshifted with respect to that dominant galaxy. This effect is illustrated by Table 2.

TABLE 1

HICKSON GROUPS

GROUP NUMBER	Δmag	TYPE	POSITIVE REDSHIFT DIFFERENCES (Δcz)[a]		NEGATIVE REDSHIFT DIFFERENCES (Δcz)[a]	
			Accordant	Discordant	Accordant	Discordant
1......	0.60	Sc	+29	...	−181, −117	...
2......	0.80	SBd	+40	+17014	−91	...
3......	0.56	Sc	+558, 502	+4243	...	...
4......	1.47	Sc	+766, 118	+10383	...	−1032
5......	0.97	Sab	+74, 342	...	...	−3932
6......	0.10	S0a	...	...	−292, 702, 235	...
7......	0.38	SBc	...	...	−156, 128, 250	...
8......	0.83	E5	+327	+1073	−48	...
9......	0.61	E2	...	...	...	−2429, 10749, 9855
10......	0.08	SBb	...	...	−286, 488, 528	...
11......	2.33	SBbc	...	+7791, 7400, 4182	...	...
12......	1.47	S0	+549, 162, 62	...	−166	...
13......	0.64	SBab	+124	...	−369, 229, 260	...
14......	0.60	E5	+564	+3051	−220	...
15......	0.08	Sa	+255, 150, 230	...	−723, −725	...
16......	0.34	SBab	...	...	−175, 301, 305	...
17......	0.07	E0	...	...	−384, 64, 164, 312	...
18......	0.11	Im	Missing redshifts	...	Missing redshifts	...
19......	0.46	E2	Missing redshifts	...	Missing redshifts	...
20......	0.06	E1	...	...	−55, 608, 720, 752	−4471
21......	0.25	Sab	+46	+1267, 1275	−212	...
22......	1.66	E2	+23	+6637, 6801	−80	...
23......	0.10	Sab	+123, 218	+5352	−236	...
24......	0.34	SBa	+111, 146, 186	...	−358	...
25......	0.59	SBc	+123, 116	+5894, 4680, 4579	−6	...
26......	0.2	E0	+346, 286, 291, 294	...	−199, 39	...
27......	0.35	SBc	...	+7570, 7514, 7726, 7822	−190	...
28......	0.02	E5	...	+18716	−48, 199	...
29......	2.51	CI	...	+18386, 18341, 17496	...	...
30......	0.78	SBa	...	...	−72, 189, 31	...
31......	1.81	Im	+103	+22832	−26	...
32......	1.48	E2	...	...	−422, 563, 234	...
33......	0.06	E1	+436, 253, 197	...	...	...
34......	2.08	E2	+623, 395	...	−180	...
35......	0.43	E1	+19, 435	...	−419, 540, 8	...
36......	1.48	Sb	...	+2525, 4827, 11860	...	...
37......	1.53	E7	+612	...	−4, 538, 382	...
38......	0.49	SBd	+21, 31	+15, 543	...	...
39......	0.36	Sb	+57	...	−452, 71	...
40......	1.09	E3	+214, 262	...	−136, 3	...
41......	0.57	Sab	+680	+5966, 3490	...	...
42......	2.23	E3	+573, 380, 451	...	...	...
43......	0.05	Sb	...	+9342	−76, 247, 533, 527	...
44......	0.10	Sa	+85, 286	...	−75	...
45......	2.04	Sa	+384	...	−12	−1076
46......	0.02	SB0	+498, 868, 203	...	...	...
47......	1.06	SBb	...	...	−94, 52, 110	...
48......	1.42	E2	+31	+1189	−629	...
49......	0.43	Scd	+71	...	−9, 13	...
50......	0.10	E0	+676	...	−700, 472, 220	...
51......	0.28	El	+487, 4	+1206	−167, 164	...
52......	0.76	SBab	+61	...	−349	−6686
53......	1.82	SBbc	...	+2809	−95, 201	...
54......	2.22	Sdm	+15, 23, 273	...	...	...
55......	0.63	E0	+250	+21060	−340, 130	...
56......	0.74	SB0	+326, 191, 427, 5	...	...	...
57......	0.33	Sb	+295, 354, 250, 265, 867, 689	...	...	...
58......	0.10	Sb	+365, 132	...	−35, 86	...
59......	(0.12)	Sa	+238	+19591	−201, 243	...
60......	(0.96)	E2	+270	...	−689, 707	...
61......	0.23	Im	...	+2853, 2829, 2657	...	...
62......	0.40	E3	+4 } No plot	...	−704, 232 } No plot	...
	2.01	E3+S0	+356, 120 }		... }	...
63......	0.70	SBc	+114	...	−205	−4118
64......	0.00	Sd	...	+4953, 4576, 4449	...	...
65......	0.83	E3	+595, 138, 300	...	−372	...
66......	1.12	El	+784, 113, 162	...	...	...
67......	1.15	E1	+382, 168	...	−191	...
68......	0.09	S0	+473, 151, 246, 239	...	...	...
69......	0.00	Sc-S0	...	No plot	...	...
70......	0.25	S0a	...	+10772, 11005, 10879, 10608	−40, 159	...
71......	1.15	SBc	+15	+11270	−870	...

TABLE 1—*Continued*

Group Number	Δmag	Type	Positive Redshift Differences (Δcz)[a]		Negative Redshift Differences (Δcz)[a]	
			Accordant	Discordant	Accordant	Discordant
72......	1.62	Sa	+556, 52	+1444, 11544	−150	...
73......	2.92	Scd	...	+7872, 7518, 7752, 22772	...	...
74......	1.01	E1	+11	...	−145, 574, 766	...
75......	0.30	Sb	+310, 64, 106, 72, 852	...	...	...
76......	0.29	E2	+52, 661, 148, 326, 214	...	−159	...
77......	0.24	S0	+182 } No plot	+8490, 8308	...	...
	1.39	Im	+50 } No plot	...	...	...
78......	0.26	SBb	+945	+1401, +9601	...	...
79......	0.57	S0	+57	+15363	−152, 300	...
80......	1.07	Am	+621, 587, 145	...	...	...
81......	0.26	Sc	+474, 374, 278	...	...	...
82......	0.48	E3	+508	...	−730	−1082
83......	0.05	E0	+882, 960, 0	...	−60	...
84......	1.01	E2	+146, 296	+15846	−100, 301	...
85......	0.50	E1	+967, 757, 745	...	...	...
86......	0.50	E2	+22	...	−645, 258	...
87......	1.13	Sbc	+278, 226	+1506	...	...
88......	0.06	Sb	+50	...	−23, 1	...
89......	0.78	Sc	+135, 22, 7	...	...	...
90......	0.21	Sa	+121, 203	...	−50	...
91......	1.85	SBc	+364, 487, 363	...	...	...
92......	0.65	Sd	...	+5813, 5844, 5978, 4998	...	...
93......	0.57	E1	+33	+3741	−468, 8	...
94......	0.62	E1	+80, 969, 210, 888	+1160	−66	...
95......	0.92	E3	+462	...	−251, 326	...
96......	0.96	Sc	+55, 277	...	−82	...
97......	0.29	E5	+30	...	−915, 671, 331	...
98......	2.02	SB0	+104, 290	+7095	...	...
99......	0.06	Sa	+141, 302	...	−489, 62	...
100......	1.24	Sb	+161	...	−47	...

Notes.—Group number 7: If the Sb is taken as central galaxy, Δcz = +28, +156, −94.

Number 22: The bright galaxy is NGC 1199. A very peculiar, compact object of cz = 13,300 km s^{-1} was found in its southwest edge, *silhouetted in front of the low-redshift, E galaxy*. The log intensity image shown by Hickson confirms this crucial example! (See Arp 1978 for original paper.) In some photographs, evidence for an absorption connection leading from the high-redshift object back to the center of NGC 1199 is seen. It would be a key object for which to obtain further high-resolution, high–signal-to-noise observations.

Number 27: If the Sb is taken as central galaxy, Δcz = +190, +8012, +7916, +7704, +7760.

Number 28: If the Sb is taken as central galaxy, Δcz = +48, −151, +18,764.

Number 29: Galaxy a better classified Am.

Number 38: Galaxy a better classified SBbpec.

Number 47: Galaxy a better classified SBb.

Number 53: Galaxy a better classified Sbcpec.

Number 54: Galaxy a better classified Spec (not Sdm).

Number 56: Not noted by Hickson, this chain is VV/50, Arp 322, and it is in the edge of the large SB galaxy NGC 3718. Galaxy b, the brightest, is a Seyfert (Arp 1973).

Number 59: Galaxy c magnitude presumably fainter than listed; 15.40?

Number 60: Galaxy b obscured; it might be the brightest in the group.

Number 61: If galaxy a is taken as the brightest in the group of three, Δcz = +172, +196.

Number 62: If galaxies a and b are taken as a single galaxy, Δcz = +356, +120.

Number 64: If galaxy a (better classified Spec) is taken as the brightest, Δcz = +127, +504.

Number 68: If galaxy c (Sbbc) is overbright, Δmag ≈ 0.4.

Number 69: If S0 is taken as the central galaxy, Δcz = +310, 161, 603.

Number 71: Galaxy a better classified as SBcpec.

Number 74: Galaxy a is a radio source.

Number 77: Galaxy d is a knot in extreme dwarf c (no plot), although Δcz = +182, +8490, +8308.

Number 80: Galaxy a is definitely an Am (starburst galaxy).

Number 91: Galaxy a better classified as SBpec.

[a] Differences between companions and the brightest galaxy, in units of km s^{-1}.

TABLE 2

Percentage of Companions That Are Redshifted as Brightest Galaxy Becomes More Dominant in Luminosity

Δmag	+Δz	Percentage
≥0.2......	124/205	60.5
≥1.1......	37/54	69
≥1.7......	15/20	75

Previous observations have shown that as the difference in magnitude between the brightest and next brightest galaxy diminishes, there is a greater chance that the wrong galaxy is picked as the dominant one. For example, a less massive galaxy can experience a burst of star formation and become temporarily brighter. The notes to Table 1 indicate a number of cases in which, if the earlier morphological type of the two brightest galaxies is chosen, the companions switch to generally positive residuals. (Earlier galaxy types

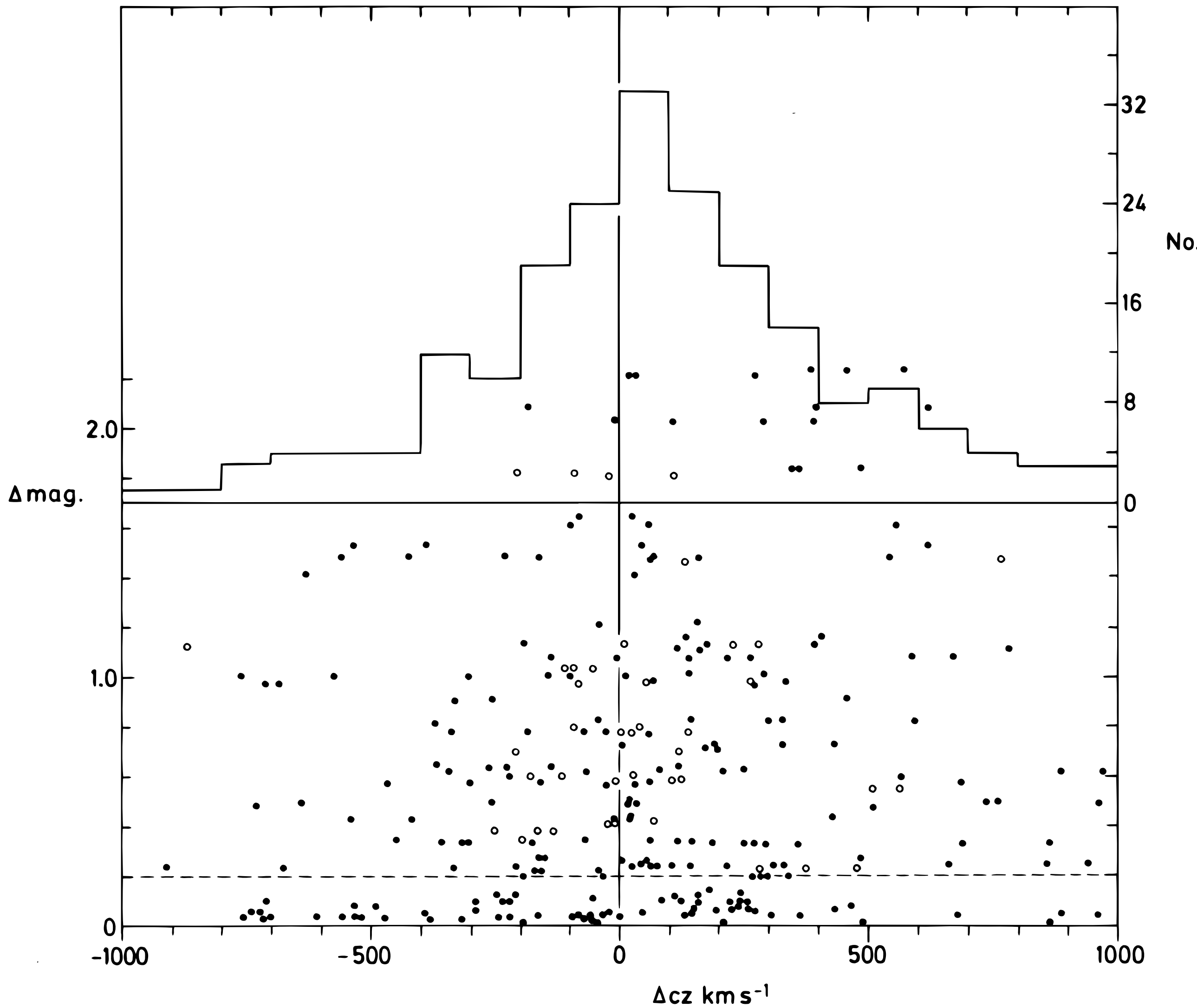

FIG. 1.—In each compact group, the amount by which the brightest galaxy is brighter than the second brightest is Δmag. The redshift of each galaxy in the group minus the redshift of the brightest galaxy is Δcz. The points show that as the brightest galaxy becomes more dominant, the companions become more systematically redshifted on average. The histogram shows the data in Table 1 for Δmag > 0.2 mag. Open circles denote groups dominated by late-type galaxies (Sc or later).

contain relatively more older stars and have higher M/L ratios and hence will be more massive at approximately equal magnitudes—particularly blue magnitudes.)

For Δmag ≥ 1.7, the 15/20 translate via the binomial theorem into $p = 0.014$ for the hypothesis of random orbits. If we take only those Δmag ≥ 1.7 groups dominated by early-type galaxies, we obtain 14/16 or $p = 0.002$. Therefore, the groups in which we are the most certain which are the dominant galaxies, the significance of the redshift excess of the companions ranges between 99% and 99.8%.

But let us also test the compact group sample with no discrimination as to type of brightest galaxy and a small Δmag cutoff that will give the largest number of companions. The histogram at the top of Figure 1 shows the distribution of Δz values for all fainter galaxies in groups in which Δmag ≥ 0.2 mag. It is a remarkable fact that in all 10 of the 100 km s^{-1} bins from $0 < |c\,\Delta z| < 1000$ km s^{-1}, the number of positive Δz values is greater than the number of negative Δz values. The possibility that this could happen by accident is $(0.5)^{10}$, or one chance in 1000. The large number in the sample gives a significant result even though the dominant galaxy is increasingly prone to misidentification as the Δmag becomes smaller.

If companions moved in groups such as might be hypothesized in mergers or encounters, then each galaxy would not represent an independent trial. However, the excess of intrinsic redshift is strong enough to manifest itself over reduced sample numbers. For example, for groups with the clearest dominant galaxy, $\Delta z \geq 1.1$ mag, there are 11 with more positive redshift companions and only three with more negative. For $\Delta z \geq 1.7$ mag, the numbers are six and one.

This, the first major result of the paper, presents evidence that the fainter galaxies in compact groups, as in all other well-investigated groups, have a component of intrinsic redshift. (see Arp 1994, 1995 for summary of results on less compact groups.) To look at a sample of the compact groups in which there is no doubt about the dominant galaxy, we show the distribution for Δmag ≥ 1.7 mag. Figure 2 (*top*) shows the result for the five groups in which the dominant galaxy is of early type. (Including the two groups in which the brightest galaxy is of late type makes

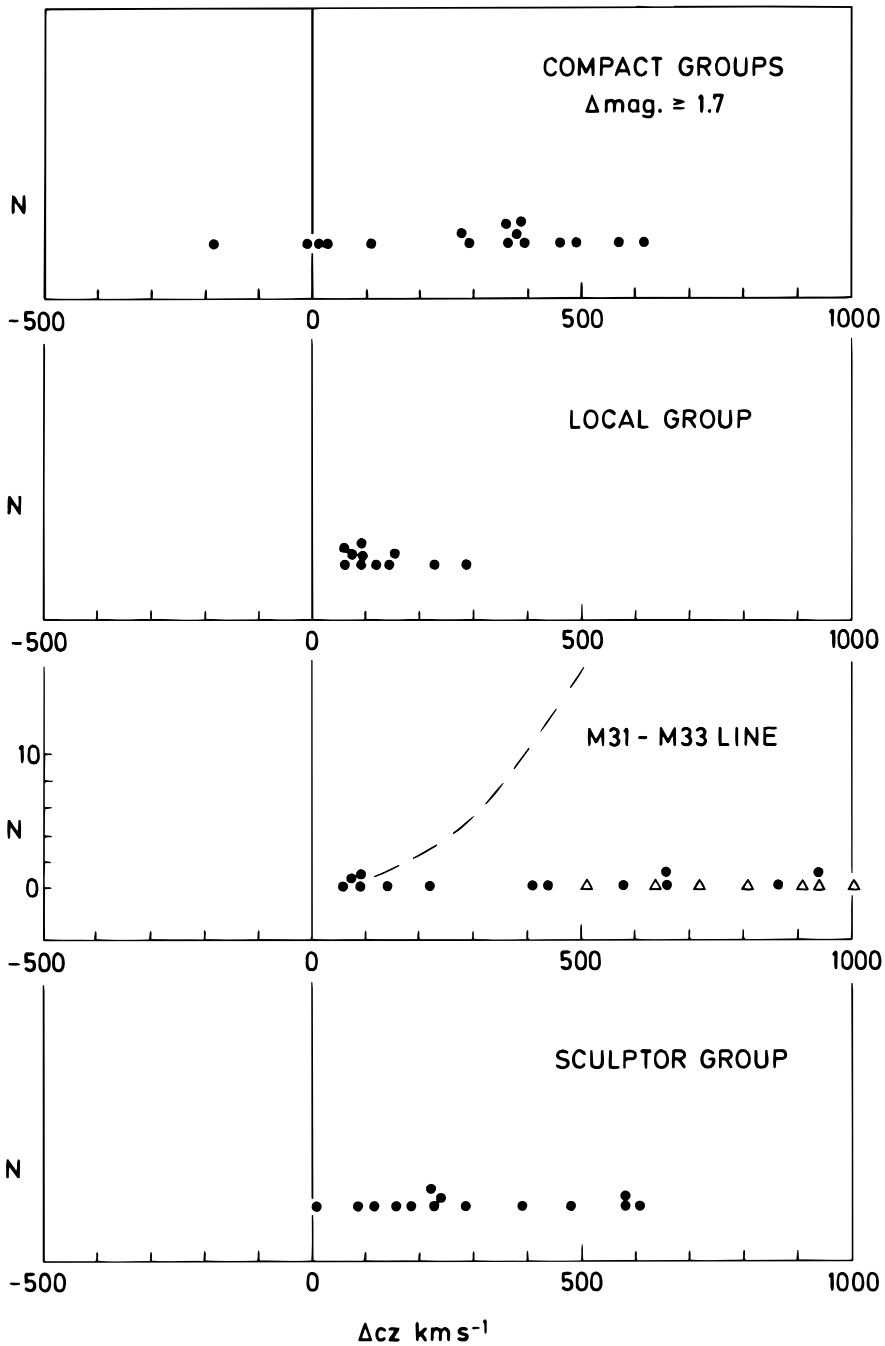

FIG. 2.—For Δmag > 1.7 (two late-type–dominated groups omitted), the first panel shows that companion redshifts in compact groups fall from −200 to +600 km s^{-1}. Accepted members of the Local Group have excess redshifts from +50 to +300 km s^{-1} (*second panel from top*). However, fainter, predominantly low-luminosity galaxies concentrated on the M31–M33 area show excess redshifts of +50–+1000 km s^{-1} (*third panel from top*). Open triangles denote faintest companions from 14th to 18th magnitude. Finally the second nearest group, the Sculptor group, shows, in the bottom panel, excess companion redshifts of 0–+600 km s^{-1}.

no essential difference in the result.) For comparison to the compact group case, we show (second from top in Fig. 2) that the classically accepted companions in the Local Group are essentially all redshifted by from ∼50 to 300 km s^{-1}. (The M31 and M81 groups combined have 22 out 22 major companions relatively redshifted relative to the dominant Sb, giving a chance of accidental occurrence of 2.5×10^{-7}, as shown in Arp 1994.)

There is a conspicuous aspect of the Local Group and M81 group, however, that is consistently ignored. That is that the total range of the accepted companions is less than 300 km s^{-1}. As previous references attest, for groups of galaxies seen at greater distances, the obvious members characteristically have total ranges of 800–900 km s^{-1}. The missing members of the Local Group are shown in the third panel from the top in Figure 2. They are identified from galaxies in the south Galactic hemisphere (SGH) (direction of the Local Group) as listed in the Revised Shapley Ames (Sandage & Tammann 1981) and the Rood Catalog (H. J. Rood, private communication). Within the SGH, and toward the direction of the center of the Local Group, there is a concentration of galaxies along a line extending from M31 through M33 and the southeast (see Arp 1987b, Fig. 1). Obviously these are members of the Local Group, and their redshifts are plotted in the third panel from the top in Figure 2. The dashed line in that panel indicates how numbers of background galaxies would increase if redshift were assumed equal to distance (as the cube of the distance, or as $N \propto z^2$ in the present differential plot). *But these galaxies are clearly not distant because they are close enough to be morphologically typed, and they are predominantly dwarf or low-luminosity class galaxies.* The open triangles in this panel represent those of faintest apparent magnitudes, between 14 and 18 mag. In more distant groups, these would be too faint to be seen or readily distinguishable from the background.

It is evident that these higher redshift members have not been included in the Local Group because the systematic nature of the redshift of the companions would then be unavoidable. But they are unmistakably concentrated toward the center of the Local Group, and their inclusion brings the total range of redshifts into agreement with the range characteristic of more distant groups.

One further comparison is interesting, and that is with the Sculptor group of galaxies, which is closer than the M81 group and thus completes the analysis of the three nearest groups to us. The final panel in Figure 2 shows the distribution of companion redshifts relative to the brightest galaxies in the Sculptor group. Again, the higher redshift companions are dwarfs or low-luminosity classes (see Arp 1987b for details), so that they are certainly members of the group, and again the group has a total range of redshift of about 600 km s^{-1}. More important, of course, is the repeated confirmation that the fainter companions are increasingly systematically redshifted.

3. COMPACT GROUPS COMPARED TO NEAREST GROUPS

There are two aspects of the local groups that we could compare to the compact groups:

1. *The degree of dominance of the central galaxy.*—Since we are situated within the Milky Way, the second brightest galaxy in our Local Group, it is difficult to estimate our own apparent magnitude. But from the Fisher-Tully relation, it would be 1.2 mag less bright if it had the same M/L ratio (see Arp 1986). But, of course, later type spirals usually have smaller M/L ratios, or rather the old population bulge in the earlier types has a higher M/L. Add to this the propensity for later type spirals to be dominated by young stars that have periods of increased star formation, and the presence of a bright, late-type spiral in a group makes the identification of the dominant mass galaxy in the system from relative apparent magnitude somewhat uncertain. The clearest situation is when an Sb or earlier type is the brightest in the system. This is true of both M31 and M81, although it should be noted that the next brightest galaxy in the latter system is M82, a starburst galaxy (type Am) that is 1.4 mag fainter but which for most of its history, would be even fainter relative to M81 than it is now.

A particular case in point is the Sculptor group, in which NGC 253 is nearly the brightest but is a starburst Sc. The other two galaxies are late type also, but clearly they are normally the dominant galaxies in brightest, and both have similar low redshifts. As mentioned, in the compact groups the clearest cases are those in which an Sb or earlier type galaxy is considerably brighter than the remainder of the group. There are, however, enough cases now measured in the compact groups for the effect to be significant, on average, when measured without regard to morphological type of the brightest galaxy, as shown in Figure 1.

2. *The compactness of the nearby groups.*—The compact groups are defined as four or more galaxies within the order of their optical diameters and within a 3 mag range in brightness. How comparable are they to the nearby groups? The two nearest companions to M31 are M32 and NGC 205 and are within a diameter, but they are 5 mag fainter. The Milky Way and M33 are within the 3 mag brightness criterion but are a number of diameters away. Viewed from certain orientations, however, the Local Group would come close to meeting the requirements for a compact group. The same could be said of M81 interacting with M82 and NGC 3077 with NGC 2403 a number of diameters away. In the Sculptor group, we have three bright spirals clearly grouped with a number of fainter members in the same area. The point is that there is nothing radically different about the parameters of the three nearest groups and the compact groups. One would not expect radically different physical behavior and, in fact, one finds in Figures 1 and 2 essentially the same distribution of galaxy types and redshifts and particularly the systematically excess redshift of the fainter members.

4. DISCORDANT REDSHIFT MEMBERS OF THE COMPACT GROUPS

In Table 1 there are 76 galaxies that differ by >1000 km s^{-1} from the redshift of the brightest group member. Their distribution in redshift is shown in Figure 3. The outstanding feature of this distribution is the rapid decline in numbers as the discordant redshifts become larger, clearly implying that they are a continuous tail to the distribution of accordant redshifts with $\Delta cz < 1000$ km s^{-1}.

It is usually argued that these discordant redshifts are contamination by background galaxies from the general field. The increase of the numbers of such galaxies with increasing redshift, however, should be very great, as indicated by the two lines of small plus signs in Figure 3. One cannot argue that the discordant group members are rare high-luminosity background galaxies (a kind of extreme Malmquist bias) because they generally do not appear to be of such morphology. But the decisive argument is that if they were of rare high-luminosity type, then the previous estimates of background density adjacent to the compact groups would have to consider only such types, and the predicted background contamination would then be even more negligible.

There are several further comments that can be made:

1. The previous analyses that have claimed that the discordant redshifts were background contamination generally assumed too large a diameter for the compact group (Sulentic 1993). The area of comparison background is naturally very sensitive to assumed group radius, varying as the square. But in addition to this, W. Napier (private communication) pointed out that there was something wrong with the extant claims because changing the position of the discordant galaxies within the group had no effect on the calculated probability. This comment turned out to be prophetic when about a year later Mendes de Oliveira (1995) reported that discordant redshift galaxies preferentially fell closer to the center of the groups. She attributed this to gravitational lensing, which has many adjustable parameters and which requires enormous quantities of

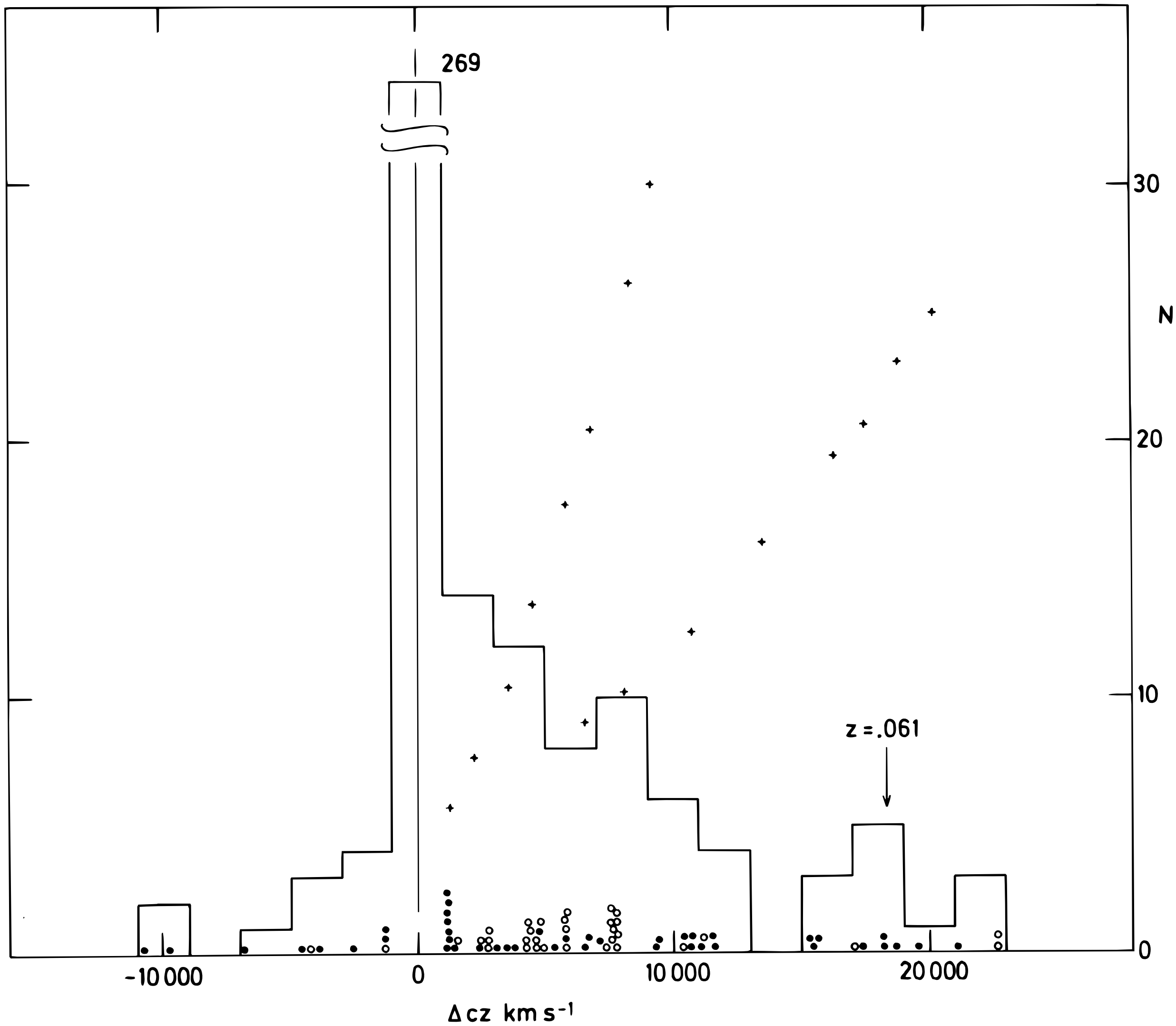

FIG. 3.—Numbers of discordant redshifts as a function of Δcz for compact groups. Number of accordant redshifts ($\Delta cz < 1000$ km s^{-1}) from Fig. 1 is 269. Lines of plus signs show expected increase of field galaxies ($N \propto z^2$) from groups with low ($\sim$4000 km s^{-1}) and high ($\sim$13,000 km s^{-1}) redshifts. Arrow points to preferred redshift peak of $z = 0.061$ found in all sky measures of quasar and quasar-like objects.

undetected mass. But even cursory inspection of the galaxy images reveals no lensing distortions.

2. Examining only the largest discordant redshifts, $17{,}000 < \Delta cz < 22{,}800$ km s^{-1}, it turns out that they come from groups in which the brightest galaxies have two distinct values of redshift. One mean redshift is 4591 km s^{-1} (four cases), and the other is 13,546 km s^{-1} (three cases). In the latter case, the expected increase of field galaxies is less steep because the starting redshift is already large. This is the reason for showing in Figure 3 two expected rates of increase for field galaxies. In either case, however, there is no way the distribution of discordant redshifts could be mistaken for that of normal field galaxies.

3. The highest discordant redshifts in Figure 3 form a distinct concentration at $\Delta cz \approx 18{,}500$ km s^{-1}. This is a significant value of redshift; since Burbidge (1968) pointed out a conspicuous peak in emission objects at $z = 0.061$, Karlsson (1971) showed that this was one of the values that fitted the recursion formula for favored quasar redshifts, and Arp et al. (1990) confirmed the presence of this peak in both bright and faint quasar-like objects. In Figure 3 the position of the predicted $z = 0.061$ peak is marked by an arrow.

This result could be interpreted in either of two ways. One is that these brightest discordant redshifts were created in this favored ratio to the redshift of the dominant galaxy in the group. The other interpretation is that the brightest members of the group themselves had intrinsic redshifts, and all the group members took part in the pattern of quantized redshifts that are observed over the whole sky. We will favor the latter alternative, as we go on to show that many of the compact groups are assignable as companions of large, very low redshift galaxies.

5. THE ISOLATION OF GROUPS AND CONVENTIONAL INTERPRETATIONS

The conventional assumption that redshifts are identically equal to velocity has produced so many observational contradictions in connection with groups that it would be impractical to discuss them all in detail. But it would be useful to make some specific comments with reference to a

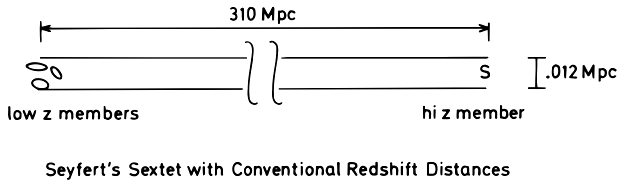

FIG. 5.—If Seyfert's Sextet were a tube viewed end on, the length-to-diameter ratio would be 25,800:1.

specific example. The example we choose is Seyfert's Sextet, pictured in Figure 4 (Plate 1).

The photograph is limiting on IIIa-J plates with the KPNO 4 m telescope. This means that galaxies are detectable to $m_J \approx 24$ mag over the $\sim 1°$ diameter of the field. The compactness, isolation, and lack of background galaxies over the field is striking. Attempts have been made to argue that there exists a contaminating background of field galaxies of which the $B_{TC} = 15.87$ mag discordant spiral ($\Delta cz = +15{,}363$ km s^{-1}) is a representative (Hickson, Kindl, & Huchra 1988). The photograph in Figure 4 is so deep and detailed, however, that it permits a simple visual judgement of the extreme improbability of an accidental interloper in the group (see also Sulentic 1993).

Another claim that has been made is that the compact groups represent elongated filaments of galaxies pointed toward the observer (Ostriker, Lubin, & Hernquist 1995). As an example, we compute here for Seyfert's Sextet that the discordant galaxy lies about 0.'24 from the center of the group. At the low-redshift distance for the group, that corresponds to a diameter for the four inner galaxies of ~ 0.012 Mpc. But if the group members were at their redshift distances, the nearby members would be at 86 Mpc distance (for $H_0 = 50$ km s^{-1} Mpc^{-1}) and the discordant member at 396 Mpc. Therefore, as Figure 5 illustrated, we would have a tube of galaxies with a length-to-diameter ratio of 25,800 to 1! And pointing directly at the observer!

Other compact groups with discordant redshift members are not quite so extreme, but the principle is the same, and all have to be pointing quite accurately at the observer. As further evidence against this hypothesis, one can comment that these "filaments" would be characteristically empty along their length and only occupied at the ends.

A related point about Seyfert's Sextet in particular is that the discordant spiral is probably nearest to a classification of ScI, which most astronomers believe to be high luminosity. But that is a result that springs almost entirely from their high redshifts. Detailed analysis of the observations instead indicate that ScI galaxies are the least luminous of spirals (Arp 1990b). Finally, it is to be noted that the 14.2 mag Sb, UGC 10127, is seen 17.'5 ENE of Seyfert's sextet, while 92′ ENE (out of the frame of Fig. 4) is the peculiar double NGC 6052 (Mark 297) at 13.3 mag. It is possible that these galaxies all form a physical chain (Arp 1990a).

6. MULTIPLE INTERACTING GALAXIES

Actually the brightest apparent magnitude, multiple interacting galaxies were investigated more than 20 years ago (Arp 1973). These systems were defined as "three or more galaxies falling within a few diameters of each other, at least two of which are strongly interacting." Of these six, four have subsequently been cataloged as "compact groups." The six multiple interacting groups investigated at that time, however, represented the essence of compact groups, and the major result of the investigation was unequivocal: "[These groups] preferentially occur in the immediate vicinity of galaxies with much larger apparent diameters and much lower redshifts. The chance for these associations to be accidental is computed to be between 10^{-4} and 10^{-6}."

As an illustrative example, Figure 6 (Plate 2) shows a photograph of VV150 (Hickson 56). It is clear that not only is this group located within the disk of the large, nearby Seyfert NGC 3718, but its physical proximity is actually demonstrated by the bending of the nearest spiral arms of the low-redshift galaxy backward in an obvious perturbation. This and a number of other examples of interaction of discordant redshift companions with nearby, low-redshift galaxies are presented in detail in Arp (1987a, 1990b). Turning the correlation around, it was shown by Arp, Sulentic, & di Tullio (1978) that in the environs of large Sb and Sbc type spirals, close and often interacting groups were characteristically found associated. This establishes the point that the compact groups are generally in the nature of companions to larger galaxies and have small to moderate redshift excesses. But, of course, within these close groups of companions are often found objects of much higher redshift excess.

One of the best examples of this is Stephan's Quintet (Stephan 1877). As Figure 7 shows, the large, low-redshift Sb galaxy NGC 7331 at $z = 800$ km s^{-1} has a typical dwarf companion 30′ to the southeast (NGC 7320). This Sd companion has a slightly larger redshift than NGC 7331 (i.e., a typical accordant companion) but is itself interacting with the remaining high-redshift members of the compact quintet, which have redshifts between 5700 and 6700 km s^{-1} (Arp 1987a, p. 97). On the other side of NGC 7331, however, is a group of similar companions with similar high

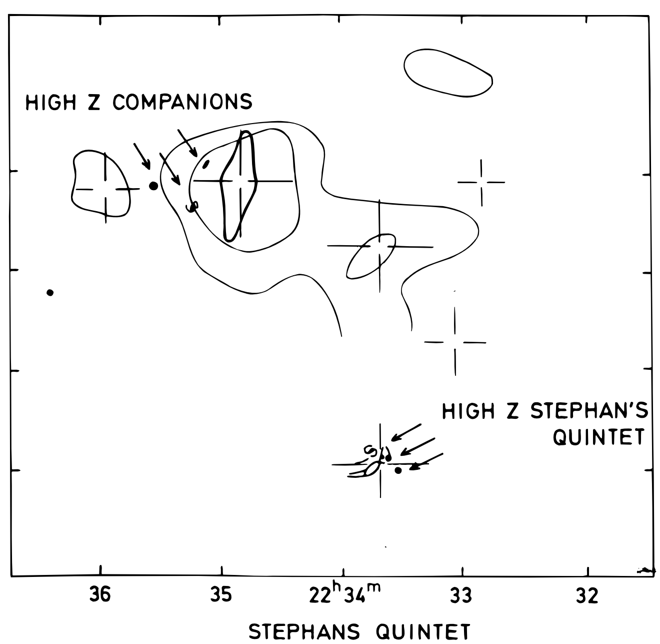

FIG. 7.—Isophotes show radio emission and plus marks show strong radio sources in the region of NGC 7331 and Stephan's Quintet. The high-z members of Stephan's Quintet are similar in all respects, including redshifts of 6000–8000 km s^{-1}, to the companion galaxies on the other side of NGC 7331.

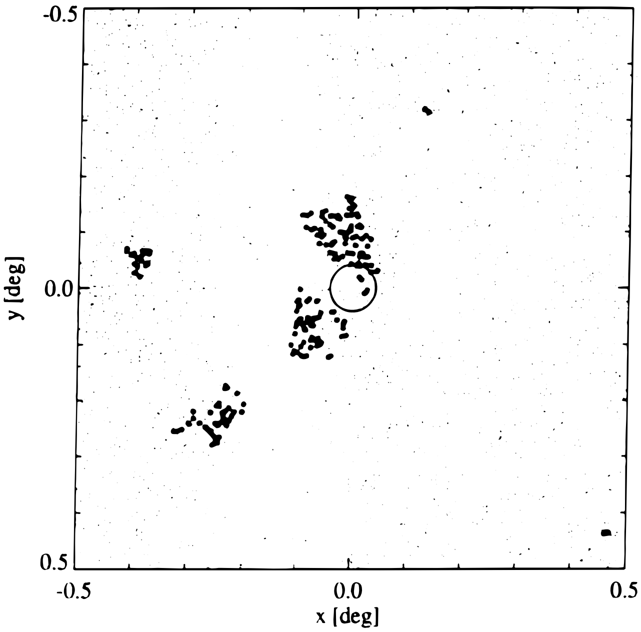

FIG. 8.—HCG 71 as observed in the *ROSAT* X-ray survey (from Ebeling et al. 1994).

redshifts that are obviously associated with that large Sb galaxy. There could hardly be a clearer illustration of the association of high- and low-redshift companions in compact groups with large, low-redshift central galaxies.

A case of a smaller, compact companion that actually shows evidence for being in front of a much lower redshift central galaxy is NGC 1199 (Hickson 22). Photography and electronic imaging (Arp 1978) indicated silhouetting of the absorption around this highly discordant object against the halo of NGC 1199. Now the log intensity image shown by Hickson (1994) appears to confirm this evidence. Further high-contrast, high–signal-to-noise ratio images seem to be the only actions capable of establishing this key example.

7. A UNIFIED HYPOTHESIS FOR COMPANIONS AND COMPACT GROUPS

The empirical evidence furnished by the first photographic sky surveys and atlases of active galaxies led Ambartsumian (1958) and Arp (1968a, 1968b, 1978) to postulate that material was ejected from galaxies that formed new galaxies. It subsequently became increasingly evident that not only radio sources were ejected from active galaxy nuclei, but that the sources were often associated with compact objects of varying degrees of higher redshift.

The intrinsic redshifts required by the observations were explained theoretically by a variable particle mass hypothesis (Narlikar & Arp 1993). The essential contribution of this theory was to show that for matter not "created" all at the same instant in a big bang, the intrinsic redshift of objects increased as the age of the objects decreased. Therefore, for ejected material that evolved into companion objects, the younger objects had the higher intrinsic redshifts.

The usefulness of this working model for explaining the observations on compact groups is the following: As younger material is ejected, it can entrain material through which it passes that is of the same age and same redshift as the parent galaxy. This is why higher redshift groups such as Stephan's Quintet and the "box" (HCG 61) contain low surface brightness dwarfs of very low redshift and also why dwarfs are found along ejection paths such as in NGC 4651 (Arp 1996). The ejected material itself can be of varying younger ages and hence varying higher redshifts. This encompasses ejected quasars, high-redshift galaxies, and multiple companions only slightly higher in redshift than the parent galaxies. This sequence represents decreasing amounts of intrinsic redshift and presumably an evolutionary sequence.

It is noticeable that companions tend to be multiple, and the objects in groups tend to be nonequilibrium spirals or compact (high surface brightness) ellipticals or irregulars. This reinforces the correlation between recent activity and high redshift. It suggests also that these are sites of recent secondary ejection activity. Observations that quasars tend to be associated with companion galaxies (Arp 1987a) almost require such cascading, hierarchical generation.

Viewing the compact groups as younger, more recently formed objects solves the otherwise impossible conventional results that the crossing times are so small compared to the cosmic timescale that the individual objects would have long ago merged into a single object (see Sulentic 1993 for discussion). The final consequence of having young, active objects as companions and in groups is that we should see evidence of the activity in shorter, more energetic wavelengths such as X-rays.

8. COMPACT GROUPS DETECTED IN X-RAYS

The *ROSAT* whole-sky survey was recently analyzed by Ebeling, Voges, & Böhringer (1994). They reported the X-ray detection of 11 Hickson compact groups. In eight of these, they felt that the observations required a hot intergalactic medium (IGM) in the group. This IGM, however, cannot represent a hot gas in equilibrium because it is generally elongated and asymmetrical about the location of the compact group. The observations of HCG 51 and 68 are particularly striking in this regard.

There are other cases in which X-ray emission streams away from the group center in filaments and pairs. One example, HCG 71, is reproduced here from their work as Figure 8. A number of other examples from their Figure 4 appear very similar to radio emissions emanating from active centers. The point here is that the observed X-ray emission does not look at all like gas that has been smoothed into an equilibrium distribution for 15×10^9 yr: it has much more the aspect of energetic ejections that have occurred recently.

9. SUMMARY AND CONCLUSIONS

The brightest galaxies in compact groups have the lowest redshifts. In this respect, they agree completely with the nearest, best-known groups, large galaxy clusters and large galaxies with companions. In short, all the physical associations of galaxies that can be tested show the fainter galaxies to have increasing amounts of intrinsic redshift.

Discordant redshifts ($\Delta cz > 1000$ km s^{-1}) represent a continuation of compact group membership to objects that are generally even smaller and more peculiar and that have an even larger component of intrinsic redshift. These fainter group members are often compact and active and approach the characteristics of Seyfert-like galaxies and quasars that are associated with large, nearby galaxies.

The working hypothesis that unifies these observations is that more recently created material in the centers of large galaxies is ejected outward as in radio ejections and forms associated objects that evolve from high to lower redshift companions as they age. Recent X-ray observations support the energetic nature of the processes taking place in the compact groups and emphasize the physical continuity between compact groups, groups, and clusters and their evolutionary origin from larger entities.

A final comment on compact groups, groups, and companion galaxies can be made by referring to Stephan's Quintet (Fig. 7). It was already clear in 1961 when the redshift measurements in the group were completed that these redshifts could not be velocities. The argument is a simple one: Two of the central galaxies, NGC 7318a and b, were so entangled and distorted that there could be no question that they occupied the same small region of space. But they had systematic "velocities" about 1000 km s^{-1} different. There were only two possibilities: (1) One of them was an interloper from outside the group. But field galaxies have peculiar velocities much less than 1000 km s^{-1}, and in any case it would require a precise hit from a random object to be occurring at just this instant in the vastness of cosmic time. (2) The second possibility was that one of the galaxies was escaping the system. But again it would be gone so fast that there would be negligible chance of our seeing it at this place at this precise moment. The result is that one of these galaxies must have a nonvelocity redshift. Because there are no conspicuous redshift gradients, it is unlikely that it could involve gravitational redshifts.

The next step is to notice the large Sb galaxy NGC 7331 only 30′ away from Stephan's Quintet. It has a close enough redshift to the dwarfish, low-redshift member of the quintet, NGC 7320, to ensure that the latter is a companion to the Sb galaxy. (It has always been accepted as such.) But then one notices that closely around NGC 7331 are companions that are just like the high-redshift companions around NGC 7320 in Stephan's Quintet (again Fig. 7). The companions are the same in number, apparent magnitude, surface brightness, and excess redshift, ~6000–8000 km s^{-1}. So it is clear that both the high- and low-redshift companions belong to the only major concentration of matter in this whole large area of the sky, namely, the low-redshift NGC 7331.

If one does not accept the thesis of big bang cosmology that something can be created out of nothing, then these companions, both high and low redshift, must have been created in connection with the large, central Sb galaxy. Moreover, the nonequilibrium configuration of Stephan's Quintet would have pointed to a recent origin for the high-redshift members. So already in 1961 we should have been able to argue that redshifts were not a reliable measure of distance, luminosities, or masses in the universe. In hindsight, the important lesson seems to be that even the initial observations often invalidate our starting assumptions.

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