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Redshifts of galaxies in the cluster Abell 262, and in the region of the Pisces group (centred on NGC 383)

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Summary. Redshifts have been determined for 34 galaxies in the cluster Abell 262, and for 15 galaxies within 2° on the sky of the Pisces group (centred on NGC 383). The mean redshift with respect to the Local Group, and corrected line-of-sight velocity dispersion for Abell 262 are 0.0167 ± 0.0003 and 411 km/s respectively based on a total of 33 redshifts. Corresponding values for galaxies in the region of the Pisces group are 0.0177 ± 0.0003 and 380 km/s based on a total of 24 redshifts. Comparison of the velocity dispersions for spiral, $\sigma_V(S)$, and for elliptical and S0 galaxies, $\sigma_V(E, S0)$, for five clusters (Virgo cluster, Abell 1367, Abell 262, Abell 194, and the Centaurus cluster) shows that $\sigma_V(S) > \sigma_V(E, S0)$ for four of these clusters. A higher velocity dispersion for spiral, as compared to elliptical and S0 galaxies, is expected if the spirals are distributed in a collapsing shell about the cluster centre.

1 Introduction

Of the very rich clusters of galaxies Abell 1656 (the Coma cluster) has been studied in most detail. This cluster consists predominantly, or even entirely, of elliptical and S0 galaxies. However other clusters, in general less rich and less compact, have a significant proportion, or majority of bright galaxies which are spirals. Of these clusters the one for which most data are available is the Virgo cluster. The projected distribution of spiral galaxies differs from that of elliptical and S0 galaxies and there has been some debate as to how the kinematical properties of the two groups differ (Tammann 1972; de Vaucouleurs & de Vaucouleurs 1973), and further as to whether the spiral galaxies form a separate dynamical system as has been suggested by de Vaucouleurs (1961). The study of similar clusters at low redshift may be expected to help resolve these questions. Redshifts are here presented and discussed for galaxies in the cluster Abell 262, and for galaxies within approximately 2° on the sky of the Pisces group, otherwise known as the chain of galaxies centred on NGC 383 (Markarian 1963; Arp 1968). The majority of bright galaxies in Abell 262 are spirals, whilst a significant fraction of the bright galaxies in the region of the Pisces group are also spirals.

Abell 262 is a cluster of richness class 0, distance class 1, which lies at the low galactic latitude $b^{II} = -25°$. The X-ray source, 3U 0151 +36, which is associated with the cluster is one of six resolved cluster sources. The cluster centre ($\alpha = 01^h\ 49^m.8$, $\delta = 36°\ 09'$, epoch 1950.0; Bahcall 1974) lies on the edge of the 90 per cent confidence error box which has an area 0.94 square degrees. Kellogg & Murray (1974) give an angular size for the cluster X-ray source of 45 arcmin corresponding to a linear diameter of 1.3 Mpc (+1.2, −0.6) assuming the Hubble constant, $H_0 = 50$ km/(s Mpc).* The measured size of the X-ray source gives added confidence in the identification of the source with the cluster as a whole. The luminosity function for galaxies in the cluster based on photographic photometry to a limiting magnitude $18^m.0$ has been determined by Kalloglyan (1969), who also gives the distribution of cluster galaxies with diameters $\geqslant 0.2$ mm on PSS prints. Kalloglyan (1972) has classified galaxies according to morphological type to a limiting photographic magnitude of $16^m.8$ within $\sim 1°.3$ of the cluster centre. Of the 95 galaxies classified 75 per cent are spirals, 20 per cent are elliptical or S0. Kalloglyan estimates four to five foreground/background galaxies per square degree to this limiting magnitude. By comparison, of the 61 galaxies classified in the cluster Abell 2151 (the Hercules cluster) by Burbidge & Burbidge (1959) 69 per cent are spirals and 31 per cent elliptical or S0. It is difficult to compare exact percentages of galaxies of a given type between different clusters due to the dependence of these figures on the cluster area surveyed, the limiting magnitude, and an uncertain correction for foreground/background galaxies. However the above comparison suggests that Abell 262 is at least as spiral rich as Abell 2151, which, of the rich clusters, is the most spiral rich known at present. No strong radio source is associated with any of the bright cluster galaxies. A map at 610 MHz with a resolution 52 × 90 arcsec of all sources within approximately 1°.3 of the cluster centre to a limiting flux (at the field centre) = $6.75 \times 10^{-29}\,\mathrm{W\,m^{-2}\,Hz^{-1}}$ has been produced by Wilson *et al.* (1976). The cluster has been classified as irregular (I) by Rood & Sastry (1971).

The concentration of galaxies centred on NGC 383 consists of a tight 'knot' of elliptical and S0 galaxies surrounded by a more extended distribution of elliptical, S0 and spiral galaxies. The central 'knot' of 25 elliptical and S0 galaxies was described by Hubble & Humason (1931) as a group superimposed on an approximately uniform background of field galaxies. Zwicky (1937) described the same concentration of galaxies as one of four concentrations in a much larger elliptical cluster with a major axis ~ 10°. In relation to the Pisces group the nearest of these other concentrations, which is also richer, is approximately 3° to the east. The redshifts of nine members of the group are given by Humason, Mayall & Sandage (1956). The group is one of a number of similar chains of galaxies (Arp 1966, 1968).

An inspection of the distribution of galaxies as given by Zwicky *et al.* (1961–1968) shows that a 'bridge' of bright galaxies extends over ~ 9° between Abell 262 and the two concentrations of the extended Pisces cluster.

2 Observations and results

Spectra were obtained during the period 1972–75 using various telescopes and equipment, details of which are listed in Table 1.

The observation technique and reduction procedure have been described previously (Dickens & Moss 1976). All measurements were made by one of us (CM). A change in the observing procedure was frequent spectrum/broadening by varying the magnetic field of the image tube, which is equivalent to use of a 'moonlight eliminator'. A test for line curvature showed this to be negligible, as had previously been found for unbroadened spectra.

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* This value for the Hubble constant will be assumed throughout what follows.

Table 1. List of instrumentation.

Telescope	Herstmonceux 0.9 m	Herstmonceux 2.5 m	Herstmonceux 2.5 m
Image tube	EMI 3-stage	Spectracon	EMI 3-stage
Emulsion	IIa-O (baked)	G5	IIa-O (baked)
Dispersion, Å/mm	210	210	210
Wavelength region, Å	3500–8000	3500–8000	3500–8000
Projected slit on sky (arcsec)	4.5	1.8	1.8
Projected slit on plate (Å)	6.3	6.3	6.3
Exposure time, min	20–30	90	20–30
Comparison lamp	Cu/Ar	Cu/Ar	Cu/Ar
Plate designation	hy	hs	h

Note:

In the corresponding table (Table 1) of a previous paper (Dickens & Moss 1976) the plate designations h, and hy were inadvertently interchanged. The correct notation is given above.

Similarly a test for zero-point velocity shift based on spectra of radial-velocity standard stars, and on wavelength determination of night sky lines on spectra not used in the final analysis showed no systematic effect.

Tables 2 and 3 give velocities with respect to the Sun determined for galaxies in Abell 262, and in the region of the Pisces group respectively. Positions and magnitudes have been taken from Zwicky *et al.* In both tables galaxy morphological types are given in column six. For Abell 262 types have been taken from Kalloglyan (1972), from Nilson (1973) or have been estimated by one of us (CM) from the PSS 'O' print. For galaxies in the region of the Pisces group galaxy types were taken from de Vaucouleurs & de Vaucouleurs (1964), or from Nilson (1973). In columns nine and ten are given the total number of emission (n_e) and absorption lines (n_a) upon which the velocity measurements are based.

Depending whether galaxy no. 68 is accepted or rejected as a cluster member it has a velocity 2.9σ or 3.4σ respectively less than the cluster mean velocity for Abell 262. In what follows it will be taken as a field galaxy. The mean redshift of the cluster Abell 262 with respect to the Local Group is 0.0167 ± 0.0003 based on 33 redshifts. The corresponding value for the corrected velocity dispersion in the line of sight, assuming a dispersion in the velocity measurement errors of 150 km/s, is 411 km/s. For the region of the Pisces group galaxy no. 31 is taken as a background galaxy. The mean redshift of galaxies in this region with respect to the Local Group is 0.0177 ± 0.0003 based on 24 redshifts, and the corrected velocity dispersion in the line of sight is 380 km/s.

The distribution of bright galaxies in Abell 262 exhibits a flattened structure. A test for solid body rotation about the axis perpendicular to the direction of cluster flattening showed no significant rotation at the 10 per cent level.

3 Discussion

3.1 FOREGROUND/BACKGROUND GALAXIES

The difficult problem of distinguishing cluster and non-cluster members assumes a particular importance for those clusters with a high proportion of spiral galaxies which in general are less rich and less compact. In the present case Kalloglyan estimates four to five foreground/background★ galaxies per square degree to a limiting photographic magnitude $16^{\mathrm{m}}.8$ in the

★ The term field galaxies will subsequently be taken to include both foreground and background galaxies.

Table 2. Radial velocities of galaxies in the cluster Abell 262.

Galaxy no.	NGC/IC*	Position (1950) α	δ	m_p	Type	$V_\odot$ km/s	Av. dev. km/s	Lines measured n_e	n_a	Plates	Notes
		h m	° ′	m							
1	708	1 49.9	35 55	14.8	E	5047	47		4	h, h	(i)
2	703	1 49.8	35 56	14.5	S	5175	59		2	h	
3	705	1 49.8	35 54	14.5	S0	4645	217		5	hs, h	
4	704	1 49.7	35 52	14.1	E	4618	42		3	h	(ii)
6	714	1 50.6	35 58	13.9	S0	4534	63		3	h	
7	717	1 51.0	35 59	14.7	S	4968	142		4	h	
8		1 50.9	36 06	15.3	S	4114	172		2	h	
10		1 49.7	36 15	14.0	S	4428	78		4	h, h	
11		1 49.8	36 22	13.9	S	4996	122		2	h	
12	687	1 47.6	36 07	13.3	E	5094	191		5	hs, h	
13		1 47.9	36 01	14.5	E	5034	155		5	h, h	
15	679	1 47.8	35 32	13.1	E	4853	80		2	hy	
22	712	1 50.2	36 34	13.9	S	5303	147		4	h	
23	668	1 43.4	36 12	13.5	S	5151	32		2	hy	
25	669	1 44.3	35 18	12.9	S	4756	22		2	hy	
26		1 46.5	35 12	14.5	S	4238	14		2	h	
27	688	1 47.8	35 02	13.3	S	4096	149	2	5	h, h	
28	171*	1 52.3	35 02	13.8	S	5362	228		4	h, hy	
30		1 53.8	36 08	14.5	S	4796	58		2	h	
32		1 52.0	36 41	14.2	S	5458	69	5		h	(iii)
33	753	1 54.8	35 40	12.6	S	4902	75	2	3	h, h	(iv)
34	759	1 54.9	36 05	13.7	E	4714	232		4	h, h	
37		1 56.4	36 35	15.0	S0	4817	24		2	h	
39	179*	1 57.2	37 47	13.4	E	4062	50		3	h, h	
40		1 57.9	37 58	14.0	S	4249	43	2	—	h	
42	801	2 00.7	38 01	13.5	S	5716	174		4	h	
45	732	1 53.5	36 34	14.9	S	5813	173	2	2	h	
46		1 50.4	36 43	14.4	E	5055	173		5	h	
47		1 46.3	34 50	14.3	S0	4864	172		3	h	
63		1 49.2	35 10	15.1	S0	4877	—		1	h	
64		1 50.4	35 46	15.6	S0	5113	28		2	h	
65	700	1 49.2	35 50	15.6	S0	4364	42		2	h	
68	709	1 49.9	35 59	15.2	E	3338	78		3	h	
92		1 55.1	37 20	15.3	E	4669	84		4	h	

Notes:

(i) Previous measured velocity, $V_\odot = 4830$ km/s (Peterson 1970).

(ii) Double system.

(iii) Markarian 2. Redshift estimated by Weedman & Khachikyan (1968) 'judging by the emission lines $z = 0.018$'.

(iv) Previous measured velocity, $V_\odot = 4766$ km/s (Zwicky *et al.* 1961–68).

region of Abell 262. Bahcall (1973) has estimated the number of field galaxies in regions 5°–6° from the centre of the Coma cluster to the limiting magnitudes $V_{26} = 15.0$ and 16.5 to be 1 and 11 per square degree respectively. All above estimates are based on galaxy counts. An independent estimate may be derived from redshift data. Tifft & Gregory (1976) give the redshifts for samples of galaxies complete to the limiting magnitudes $m_p = 14.9$ and 15.7 within 6° and 3° of the centre of the Coma cluster respectively. In the former sample there are 22 galaxies with $V_0 < 4400$ km/s or $V_0 > 9400$ km/s, which we assume are not members of the Coma cluster, but isolated galaxies or galaxies in small groups. On the other

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Table 3. Radial velocities of galaxies in the region of the Pisces group (centred on NGC 383).

Galaxy no.	NGC/IC★	Position (1950) α	δ	m_p	Type	$V_\odot$	Av. dev.	Lines measured n_e	n_a	Plates
		h m	° ′	m		km/s	km/s			
1	410	1 08.2	32 53	12.6	E:	5238			1	h
2	392	1 05.6	32 52	13.9	E–S0	4672			1	h
6	403	1 06.5	32 29	13.3	S:	4977	212		3	h
7		1 07.2	32 05	14.0	S	5414			1	h
8	420	1 09.3	31 52	13.4	S0:	5199			1	h
9	431	1 11.3	33 27	14.0	S0	5786			1	h
15	407	1 07.8	32 51	14.3	S	5610			1	h
16		1 05.3	33 11	14.7	S	4719	68	3	1	h
19	374	1 04.3	32 32	14.3	S0/a	5067	161		2	h
23	399	1 06.2	32 22	14.5	S	5167	121		2	h
27		1 08.5	31 37	14.8	S	5229			1	h
28		1 00.7	31 58	15.0	S	5418	66		2	h
31		1 06.0	33 12	15.6	S	12624	73	2	1	h
44	1618★	1 03.2	32 09	15.6	S0	4706	6		2	h
60	1652★	1 12.2	31 42	14.3	S0/a	5317			1	h

Previous radial velocity measurements.

NGC/IC★	Position (1950) α	δ	m_p	Type	$V_\odot$	Notes
	h m	° ′	m		km/s	
375	1 04.3	32 05	(15.9)	E	6011	(i)
379	1 04.5	32 15	14.0	S0	5374	
380	1 04.5	32 13	13.9	E	4341	
382	1 04.7	32 08	14.2	E	5156	
383	1 04.7	32 09	13.6	S0	4888	
384	1 04.7	32 01	14.3	S0	4401	
385	1 04.7	32 03	14.3	E	4845	
386	1 04.8	32 05	15.4	E	5555	
388	1 05.0	32 02	15.5	E	5114	
449≡1656★	1 12.8	32 48	14.0	S0/a	4800	(ii)

Notes:

(i) Radial velocities for this galaxy, and for the subsequent eight galaxies are taken from Humason, Mayall & Sandage (1956).

(ii) Markarian 1.

hand the luminosity function determined for galaxies not members of rich clusters by Christensen (1975) predicts 48 galaxies within these velocity limits for the given sample, although Christensen notes the uncertainty in assuming the luminosity function representative of a general space volume. However if the shape of the Christensen luminosity function is accepted, with a normalization based on the complete sample of Tifft & Gregory we obtain 0.31 field galaxies per square degree. This value has a strong dependence on the value of the slope of the faint end of the luminosity function. A value of ~ 0.20 for the slope given by Holmberg (1969) as compared to the value 0.36 given by Christensen leads to approximately a 50 per cent increase in the field galaxy surface density.

In the subsequent discussion a value for the field galaxy surface density to the limiting magnitude $m_p = 14.9$ of 0.31 galaxies per square degree will be adopted, although this is probably better regarded as a lower limit. Field galaxies will be assumed 75 per cent spiral, 25 per cent elliptical or S0. Despite considerable uncertainty, all above estimates of the surface density of field galaxies agree within a factor of approximately 2. Uniform space density of field galaxies will be assumed. This assumption allows a simple extrapolation of the surface density to other limiting magnitudes.

3.2 SEGREGATION OF GALAXIES OF DIFFERING MORPHOLOGICAL TYPES

Oemler (1974) has divided clusters into three classes, spiral rich, spiral poor, and cD clusters according to the relative numbers of elliptical, S0 and spiral galaxies and, in the case of cD clusters, whether there is a single unique and dominant member, or pair of such members. For spiral poor and cD clusters he demonstrated that the fraction of spiral galaxies in the projected density distribution decreases towards the cluster centre. Although no such segregation effect is detected by Oemler within the gravitational radius for the combined galaxy distributions of spiral-rich clusters he studied, a segregation effect similar to the above is well known for the Virgo cluster (de Vaucouleurs 1961) which has proportions of galaxy types similar to a spiral-rich cluster. The distribution of spiral galaxies is uniform, without the central concentration which is apparent for the combined distribution of elliptical and S0 galaxies. For the spiral rich but compact cluster Abell 1367 the distributions of spiral, and of elliptical and S0 galaxies also show a similar segregation effect (Dickens & Moss 1976). In the present case more extensive data are available for Abell 262 than for galaxies in the region of the Pisces group. For a complete sample of galaxies to a limiting photographic magnitude $16^{m}.8$ within $1^{\circ}.3$ of the cluster centre of Abell 262 Kalloglyan (1972) has demonstrated a segregation by galaxy type similar to that above. The distributions of the elliptical and S0 galaxies, and of the spiral galaxies in the Kalloglyan sample are shown in Figs 1 and 2. The more centrally concentrated distribution of the elliptical and S0 galaxies as compared to the spirals is striking. It is evident that some segregation by galaxy type can occur in even the most spiral-rich of the rich clusters.

The differing distributions for the various galaxy types can be compared quantitatively by calculating the corresponding gravitational radii, R_G. Values of R_G(E), R_G(S0), R_G(E, S0)

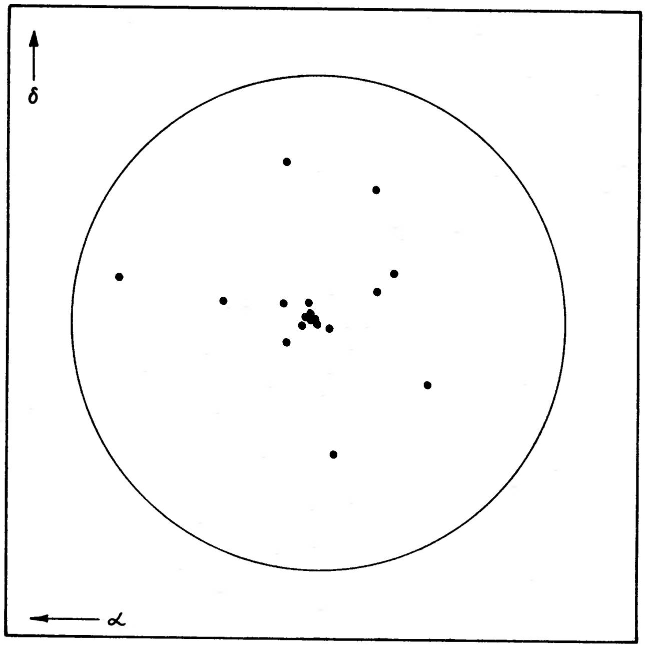

Figure 1. Distribution of elliptical and S0 galaxies in Abell 262 within $1^{\circ}.3$ (the circle indicated) of the cluster centre ($\alpha = 01^{h}\,49^{m}.8$, $\delta = 36^{\circ}\,09'$ (1950.0)), from Kalloglyan (1969, 1972).

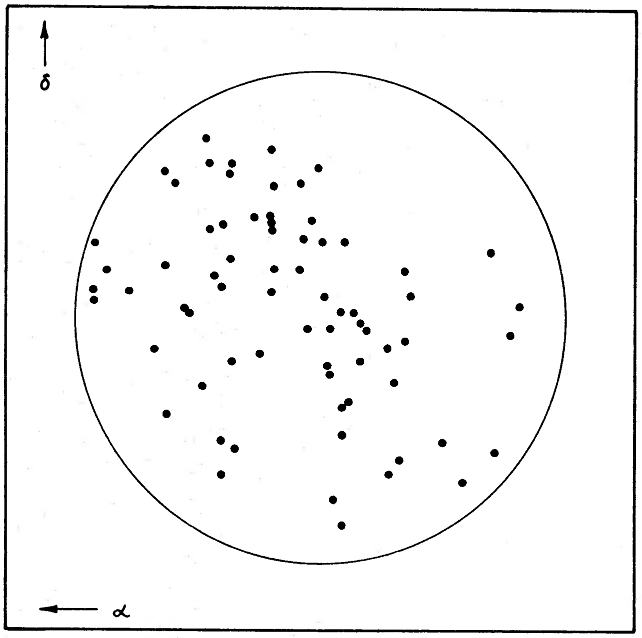

Figure 2. Distribution of spiral galaxies in Abell 262 within 1°.3 of the cluster centre, from Kalloglyan (1969, 1972). Indicated circle and centre as in Fig. 1.

and R_G(S) for the three clusters Virgo, Abell 1367, and Abell 262 are given in Table 6. Apart from the Virgo cluster the distribution of S0 galaxies is closely similar to that of the ellipticals. However in all cases the value for the combined distribution R_G(E, S0) < R_G(S). In calculating the above values of R_G no account has been taken of the contamination of the various samples by included field galaxies. The sample for which the effect is most serious is that of spiral galaxies in Abell 1367. With the adopted field galaxy surface density above, we expect a total of 12 field galaxies included within this sample. A lower limit to R_G(S) estimated by omitting the 12 galaxies furthest from the cluster centre is given in Table 6. However even the value of this lower limit considerably exceeds the corresponding value of R_G(E, S0).

3.3 CLUSTER KINEMATICS

Whereas the shift in mean velocity in the Virgo cluster between the two morphological groups, of spiral galaxies, and of elliptical and S0 galaxies, suggested by de Vaucouleurs (1961) has been subject to some debate, a higher velocity dispersion for the spiral galaxies has generally been accepted (Tammann 1972). Even though the data are still very limited it is of interest to compare mean velocities and velocity dispersions for the two morphological groups for other clusters with a significant fraction of spiral galaxies. Values of mean velocity and dispersion about the mean for the two groups are given for Abell 262 and for galaxies within 2° of NGC 383 in Table 4. No significant difference in mean velocity between the two groups is shown in either case. However, as for the Virgo cluster, the value of the line-of-sight velocity dispersion for spiral galaxies, σ_V(S), for Abell 262 is significantly greater than for elliptical and S0 galaxies. This result is the more surprising given the less centrally concentrated projected distribution of spiral galaxies in both clusters. We might expect σ_V to decrease with increasing radial distance due, for example, to the increasing predominance of radially elongated orbits at distances further from the cluster centre. Such a decrease in the value of σ_V with increasing radial distance is observed for the Coma cluster

Table 4. Mean velocities and velocity dispersions of groups of galaxies divided according to morphological type.

Cluster	$\bar{V}_E$ km/s	$\bar{V}_{E,S0}$ km/s	$\bar{V}_S$ km/s	$\frac{\bar{V}_S - \bar{V}_{E,S0}}{\sigma}$	$\sigma_V(E)$ km/s	$\sigma_V(E, S0)$ km/s	$\sigma_V(S)$ km/s	F test	n_E	E, S0	n_S	References
Virgo*	898	1012	1296	+ 1.57	569	517	828	$\Theta<0.5\%$	18	42	26	de Vaucouleurs & de Vaucouleurs (1973)
Abell 1367	6303	6432	6631	0.77	551	586	845	$10\%>\Theta>5\%$	9	18	15	Dickens & Moss (1976)
Abell 262	4972	4951	5091	+ 0.93	330	289	543	$\Theta\leqslant1\%$	9	16	17	
	(5064)†	(4998)‡		(+ 0.65)‡	(196)†	(226)‡		$(\Theta<0.5\%)$‡	(8)†	(15)‡		
Abell 194	5416	5414	5419	+ 0.03	437	408	513	$\Theta>10\%$	19	22	19	Zwicky & Humason (1964)
	(5347) §	(5354)**		(+ 0.48)**	(325) §	(304)**		$(2.5\%>\Theta$ $>1\%)$**	(18) §	(21)**		
Pisces	5378	5290	5417	+ 0.73	525	490	301	$\Theta>10\%$	7	14	7	
		(5284)††	(5370)††			(452)††	(284)††			(17)††	(10)††	
Centaurus	3400	3240	3330	0.40	1000	920	780	$\Theta>10\%$	12	41	20	Dawe & Dickens (1977)

Notes:

Mean velocities are measured with respect to the Local Group.

* See Table 6, note (i).

† Omission of galaxy no. 39 with a velocity 2.2σ from the mean. This galaxy is ~2°.5 from the cluster centre.

‡ Omission of galaxy no. 39 with a velocity 2.46σ from mean.

§ Omission of galaxy no. 7 (Zwicky & Humason 1964) with a velocity 2.85σ from mean.

** Omission of galaxy no. 7 with a velocity 3.06σ from mean.

†† Inclusion of galaxies type S0/a.

(Rood *et al.* 1972). Although the number of elliptical and S0 galaxies with measured velocities in the region of Abell 262 is small (17 in total) the sample is selected from all galaxies listed in Zwicky *et al.* within the cluster boundary specified by these authors, with the addition of the bright galaxy NGC 668. Of this list only 19 are elliptical or S0 galaxies (with one galaxy of unknown type). The sample of elliptical and S0 galaxies with measured velocity is therefore nearly complete.

In Table 4 are also listed mean velocities and velocity dispersions for the above two morphological groups for clusters either spiral rich or spiral poor with the number of galaxies with measured redshift in each morphological group, $n > 10$. The proportions of galaxies of the various types in the Centaurus cluster (de Vaucouleurs 1956) are between those of a spiral-rich and a spiral-poor cluster (Dawe, Dickens & Peterson 1977). Apart from the Virgo cluster no significant systematic velocity shift is detected between the mean velocities of spiral, and of elliptical and S0 galaxies in any of the clusters. In comparing the velocity dispersions of the two morphological groups in rich clusters it is incorrect to include the Pisces group, since, as mentioned above, it is a compact chain of galaxies superposed on an otherwise approximately uniform background. For four of the five remaining clusters $\sigma_V(\mathrm{S}) > \sigma_V(\mathrm{E, S0})$ while in two cases (the Virgo cluster and Abell 262) a single-tailed F test indicates the probability of the two dispersions being equal as less than 1 per cent. For the Centaurus cluster with a large sample of measured redshifts no significant difference exists between the measured values of $\sigma_V(\mathrm{S})$ and $\sigma_V(\mathrm{E, S0})$. This cluster also has an unusual distribution of spiral galaxies. Distributions of galaxies of differing morphological types for the cluster have been given by Dawe, Dickens & Peterson (1977). Whereas the elliptical and S0 galaxies form a symmetric, moderately compact system, the spiral galaxies have an irregular distribution with a pronounced line of galaxies extending from the cluster centre to the west. The cause of this irregular distribution, and whether it might account for the difference in the kinematic properties between this cluster and the other clusters considered above, is at present unknown. It was shown above that the distributions of bright elliptical and S0 galaxies in Abell 1367 and Abell 262 are similar. From the data given in Table 4 it is also seen that for the five clusters considered, the values of σ_V for these two groups are equal. This similarity in the properties of elliptical and S0 galaxies provides a reason for considering the S0 galaxies with the ellipticals rather than with the spirals. Moreover it can be given a straightforward explanation in terms of cluster collapse (*cf.* below).

For the above clusters there is in general a greater variation in velocity dispersion between samples of galaxies selected according to galaxy type, than between such samples selected according to either radial distance from the cluster centre, or magnitude. F values for each cluster for the three cases are listed in Table 5. In all cases apart from the Centaurus cluster the variation of σ_V with galaxy type is more significant. For the Centaurus cluster the variation in σ_V is not significant either between galaxies of different type, or between the samples of galaxies chosen according to radial distance from the cluster centre.

The combined distributions of velocities for all five clusters are shown for each of the two morphological groups separately in Figs 3 and 4. The peaked distribution of the velocities of the elliptical and S0 galaxies is quite dissimilar to the more extended velocity distribution for the spirals. The above data indicate that a higher velocity dispersion for spiral galaxies appears to be a general property of those clusters containing a significant fraction of these galaxies. Further work would be desirable to strengthen this conclusion. In particular there is an uncertain contribution to the velocity dispersion from field galaxies inadvertently included in the cluster sample. For the adopted field galaxy surface density above we expect two field galaxies in the sample of 15 spirals with measured redshift in Abell 1367. The corresponding percentage of field galaxies in the spiral sample for Abell 262 is expected to be less. Estimates of possible field galaxy contamination for Abell 194 and for the

Table 5. Statistical tests and comparisons of velocity dispersions of various galaxy groupings.

Cluster	F_t	F_r	F_m	Total sample	Spiral galaxies				
					σ_1 $(r<r')$ km/s	σ_2 $(r>r')$ km/s	r' degree	n_1	n_2
Virgo	2.54	1.89	1.35	68	913	712	3.05	13	13
Abell 1367	2.08	1.90	1.34	33	1042	620	0.35	7	8
Abell 262	3.53	1.79	1.54	33	450	642	0.81	8	9
Abell 194	1.58	1.39	1.04	41	405	599	0.43	9	10
Centaurus	1.39	1.12	—	61	—	—	—	—	—

Notes:

F values computed by division of sample according to morphological type (E, S0 galaxies, and S galaxies), F_t, and into approximately equal groups according to radial distance from the cluster centre, F_r, and magnitude, F_m. Data as in Table 4.

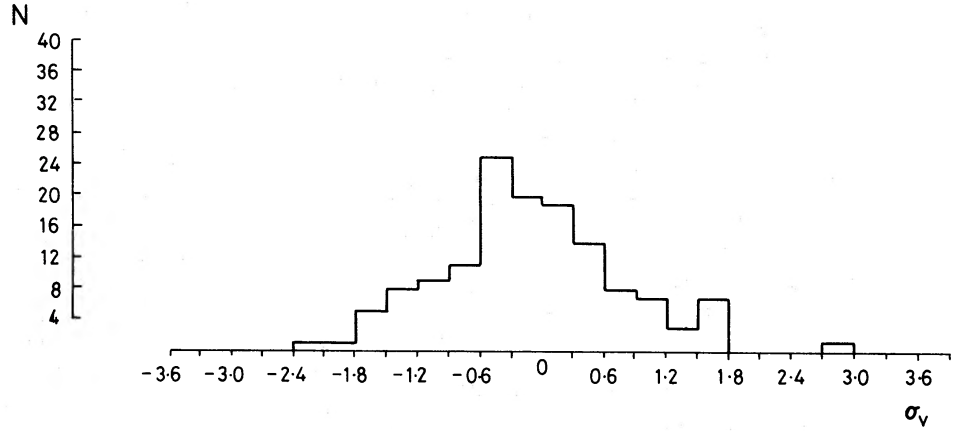

Figure 3. Combined velocity distribution for elliptical and S0 galaxies in Virgo, Abell 1367, Abell 262, Abell 194 and the Centaurus cluster. Total sample, $N = 139$.

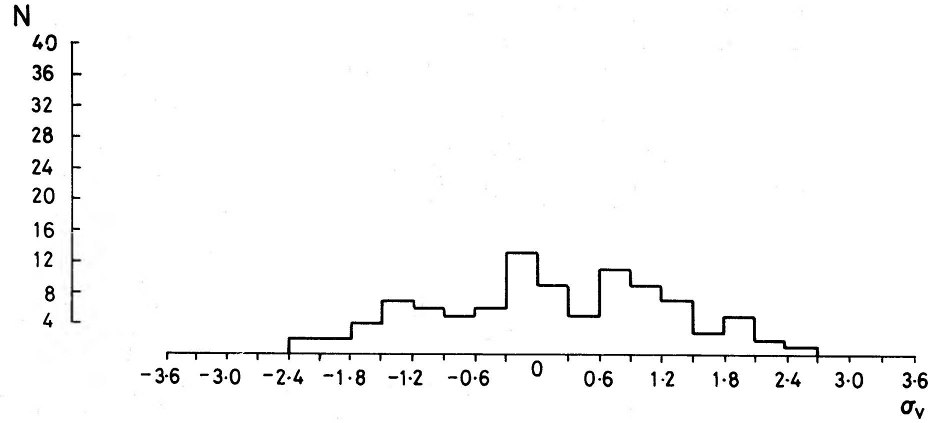

Figure 4. Combined velocity distribution for spiral galaxies in Virgo, Abell 1367, Abell 262, Abell 194 and the Centaurus cluster. Total sample, $N = 97$.

Centaurus cluster are less certain, but are again expected to be a smaller percentage than for Abell 1367. However an increase in the adopted field galaxy surface density will increase the contamination of the sample of galaxies with measured redshift accordingly.★

★ Other selection effects may be important. For example a significant fraction of the spirals selected for redshift measurement in Abell 1367 were chosen on account of emission lines in the spectra (Dickens & Moss 1976).

3.4 CLUSTER COLLAPSE

As a basis for understanding the above results we propose to adopt the model of cluster formation suggested by Gunn & Gott (1972). The cluster as an initial bound perturbation at the recombination epoch ($z \sim 1000$) subsequently expands with the Universe whilst galaxy formation takes place, eventually to collapse and form a rich regular cluster, a typical example of which is the Coma cluster. Upon collapse and violent relaxation any residual gas from the galaxy formation process is thermalized. This hot gas ($\sim 10^8$K) cools by bremsstrahlung X-ray emission which is observed in the bright cluster X-ray sources. Gunn & Gott demonstrated that the density of hot gas required to produce the observed X-ray emission for the Coma cluster is more than adequate to strip spiral galaxies moving through the central cluster region of gas by ram pressure. On this model a similar gas-stripping process can be expected for other rich clusters which are X-ray sources. Any spiral galaxies falling into the cluster are transmuted into S0 galaxies by the gas-stripping process. Gunn & Gott distinguished between regular and irregular, open clusters (Abell 1965). They suggested that the latter, rich in spiral galaxies, had not undergone collapse. As was shown above, the spiral-rich clusters, Virgo, Abell 1367, and Abell 262 – the last having the highest percentage of spiral galaxies known at present among rich clusters – show segregation by morphological type, which on this model is a feature of a collapsed cluster. The X-ray source associated with Abell 262 is extended, which is at least consistent with thermal bremsstrahlung emission from a hot intra-cluster gas. Further, the luminosity of the X-ray source ($\sim 10^{43}$ erg/s) is too great to be explained simply as the combined X-ray emission from normal spiral galaxies in the cluster, assuming an X-ray luminosity for these latter sources 10^{38}–10^{39} erg/s (Giacconi & Gursky 1974). A simple extension of the above model of Gunn & Gott is that while the central regions of rich clusters with a significant fraction of spiral galaxies have undergone collapse, they are surrounded by an infalling shell of spiral galaxies. On this picture a higher observed velocity dispersion for spiral galaxies is the combination of two effects, an infall velocity greater than the virial equilibrium value, and a projected distribution of spiral galaxies with measured redshift weighted towards the cluster centre. Although the collapse time of a particular shell (~ 1–4×10^9 yr) is rather short compared to the age of the Universe, two effects may combine to increase the probability of observing a collapse event. One is a selection effect. (Rich, spiral-rich clusters are precisely those having an infalling shell of galaxies.) The other arises from the postulated initial density distribution. For simplicity Gunn & Gott assumed a spherically symmetric initial perturbation of uniform density. An equally, if not more plausible assumption, is an initial density perturbation which has a radially decreasing density. This would give rise to a sequence of infalling shells, with different collapse times. Two observational consequences may be expected to follow on the above model. One is a predicted decrease, with increasing radial distance, in the observed line-of-sight velocity dispersion of spiral galaxies. Values of $\sigma_V(S)$ for approximately equal samples of spiral galaxies according to radial distance are given for the various clusters in Table 5. The evidence is inconclusive with $\sigma_2 > \sigma_1$ for Abell 262 and Abell 194. However, apart from Abell 1367, the variation in σ_V between the two samples does not approach significance even at the 10 per cent level. The other observational consequence is that we expect the distribution of the elliptical and S0 galaxies in the central cluster region to exhibit the relaxed structure typical of the rich regular clusters.[★]

[★] It is noted that if the above models holds for the Virgo cluster, any magnitude limited sample of the brightest spiral galaxies with measured redshift will include a higher fraction of those spirals which are receding from the observer with respect to the cluster centre. This will produce a systematic velocity shift of the same sign as given by de Vaucouleurs (1961).

3.5 OTHER CLUSTER MODELS

The above model of cluster collapse provides one explanation of the observed segregation and higher velocity dispersion of spiral galaxies in spiral-rich and spiral-poor clusters. It is evident that the higher observed value of $\sigma_V(S)$ in these clusters cannot be due to the Hubble flow, whilst deviations from the Hubble flow are generally considered small (Sandage & Tammann 1975). However if the mass-to-light ratio of spiral galaxies is taken as an order of magnitude less than that of elliptical and S0 galaxies, then dynamical relaxation may also be expected to lead to a higher value for $\sigma_V(S)$ within a given cluster volume. Values of the 'standard crossing time' (Aarseth & Lecar 1975) for the various clusters are given in Table 6.

Table 6. Gravitational radii and other data for various galaxy groupings in several clusters.

Cluster	R_G(E) Mpc	R_G(S0) Mpc	R_G(E, S0) Mpc	R_G(S) Mpc	E, S0 galaxies			Notes
					t_{cr} 10^9 yr	(M_{VT}/M_L)	L $10^{12} L_\odot$	
Virgo	2.44	3.30	2.64	3.27	3.01	5.7 (3.5)	1.42	(i)
Abell 1367	4.81	4.93	4.71	7.60 (5.55)	4.68	3.5	5.01	(ii)
Abell 262	4.20	3.08	3.33	5.51	7.60	3.1 (0.51)	1.10	(iii)
Abell 194	—	—	—	—	3.86:	—	—	(iv)
Centaurus	—	—	—	—	1.68:	—	—	(v)

Notes:

Values for R_G were calculated assuming $(M/L)_{E,S0} = 50\,(M_\odot/L_\odot)$ and $(M/L)_S = 7\,(M_\odot/L_\odot)$.

(i) The Virgo cluster is here taken as comprising the E cloud, and galaxies of Sa–Scd in the S, S′ clouds (de Vaucouleurs 1961; de Vaucouleurs & de Vaucouleurs 1973). The value of (M_{VT}/M_L) in parentheses is obtained by omitting NGC 4406 which has a velocity 2.66σ less than the mean.

(ii) Data comprise all galaxies listed in the CGCG (Zwicky *et al.* 1961–68) within the cluster boundary given by this catalogue. Galaxy types and velocities are from Dickens & Moss (1976). The value of R_G(S) in parentheses is obtained by omitting the 12 galaxies furthest from the cluster centre.

(iii) Data comprise all galaxies within the cluster boundary listed in CGCG, with the addition of NGC 668. The value of (M_{VT}/M_L) in parentheses is obtained by omitting galaxy no. 39. A value, $(M_{VT}/M_L) = 3.6$ is obtained for the combined distribution of galaxies of all morphological types in the cluster.

(iv) Velocity data from Zwicky & Humason (1964). A value of $R_G = 2.6$ Mpc is assumed (Oemler 1974).

(v) Data from Dawe, Dickens & Peterson (1977).

Since the number of crossing times over the age of the Universe is small it is doubtful whether the required relaxations could have taken place. On the cluster collapse model of Gunn & Gott (1972) the constraints are even more severe. The cluster collapse time is ~3 times the crossing time which for most of the clusters considered is about the age of the Universe, and hence the time available for cluster relaxation is correspondingly shortened. If the clusters have relaxed, it is unlikely that the spiral galaxies observed have passed through the cluster central regions, or the source of X-ray emission must be other than a hot intracluster gas. The irregular distributions of spiral galaxies in these clusters have generally been taken as indicating that the clusters could not have undergone collapse (Oemler 1974). The above model of infalling shells of spiral galaxies thus appears a more attractive explanation for the morphological and kinematic properties of these clusters, than does dynamical relaxation.

Abell (1974) has suggested that in general, a rich cluster could be a bound condensation in a much larger supercluster and that some galaxies meeting the usual criteria for cluster membership may, in fact, be bound to the supercluster rather than to the condensation. If these are predominantly the spiral galaxies in the above clusters, this could account both for the more uniform distribution, and for the increased velocity dispersion of spiral as compared to elliptical and S0 galaxies. With the limited data presently available it is not possible to decide between this model, and the model of infalling shells of spiral galaxies discussed above. It is even possible that the observed properties of spiral galaxies in clusters result from some combination of the two effects. However both explanations result in a similar estimate of the virial mass, which is now considered.

3.6 VIRIAL MASS

The assumption of virial equilibrium made in deriving the mass of rich regular clusters becomes the more uncertain for less rich, irregular clusters such as Abell 262. Acceptance of the above model of cluster collapse implies the existence in the central cluster region of a separate, violently relaxed system of elliptical and S0 galaxies. In fact, as has already been noted for the Virgo cluster (de Vaucouleurs 1961) the assumption of a separate elliptical, S0 system does little to relieve the 'missing mass' problem. Values of the ratio, virial-to-luminous mass ($M_{\mathrm{VT}}/M_{\mathrm{L}}$) for elliptical and S0 galaxies for the various clusters are given in Table 6. Magnitudes of cluster galaxies have been taken from de Vaucouleurs (1961), or Zwicky *et al.* Magnitude corrections ($m_{\mathrm{p}} - m_{\mathrm{B}}$) were taken from Kron & Shane (1976). m_{B} is the B magnitude observed photoelectrically with an aperture radius r, where $r = 150$ arcsec for a 12.0 mag galaxy. An aperture correction ($\Delta m = -0.25$) to a radius $r' = 391$ arcsec was made. The total galaxy luminosity is thus a lower limit based on existing photometric measurements. Extrapolation to the total cluster luminosity was made by the expression,

$$L = L_0 \exp(L_c/L^*)$$

derived from the Schechter luminosity function, with $\alpha = -1$ (Turner & Gott 1976). L is the total cluster luminosity, while L_0 is the observed cluster luminosity to a limiting luminosity L_c. The constant $L^* = 3.4 \times 10^{10} L_\odot$. For the Virgo cluster, Abell 1367, and Abell 262 the median value of $(M_{\mathrm{VT}}/M_{\mathrm{L}}) = 3.5$, which agrees well with the corresponding value for the Comacluster, $(M_{\mathrm{VT}}/M_{\mathrm{L}}) = 3.3$ (Rood *et al.* 1972). This indicates that on the basis of present data the mass discrepancy factor for elliptical and S0 galaxies is similar for all cluster types. Omitting galaxy no. 39 in Abell 262 removes the mass discrepancy for this cluster, with a value $(M/L)_{\mathrm{E,\,S0}} = 26(M_\odot/L_\odot)$. However the exact value obtained for the mass-to-light ratio depends upon the estimated errors in the velocity measurements, although there is an upper limit $M/L = 75(M_\odot/L_\odot)$. For comparison the value of $(M_{\mathrm{VT}}/M_{\mathrm{L}})$ for Abell 262 for galaxies of all morphological types has also been given in Table 6.

Apart from M87 in the Virgo cluster the above estimates of cluster luminosity neglect additional luminosity from either the coronas of massive galaxies, or from intergalactic matter. Arp & Bertola (1971) have shown that galaxies in the NGC 383 chain have a common luminosity halo extending to an outer isophote of dimensions, 0.54 x 0.26 Mpc. This corresponds to a diameter of 0.26 Mpc for NGC 383, far beyond usual photometric limits. Similarly for Abell 194 these authors show the double galaxy system NGC 545–547, with NGC 541 to have a common luminosity halo with outer isophote of dimensions 0.39 x 0.23 Mpc. De Vaucouleurs & de Vaucouleurs (1970) using photoelectric scans estimated at 40 per cent increase in the total luminosity of the Coma cluster within 100 arcmin of the cluster centre due mainly to the overlapping coronas of NGC 4874 and NGC 4889, and a few other galaxies. De Vaucouleurs (1969, 1972) has estimated an increase in the magnitude of M87 of 1.35 mag due to additional luminosity from a very extended corona. Estimates of this additional luminosity in massive galaxies are important since, besides reducing the overall mass to light ratio of the cluster, the mean gravitational potential may be increased due to the slight central concentration of these galaxies, thus reducing the virial mass (Tarter & Silk 1974). Clearly, on the above model of cluster collapse, a smaller fraction of the total cluster luminosity in intracluster light in spiral-rich clusters, than in the Coma cluster, could have an equal dynamical significance.

Present data available for Abell 262 only permit a rough estimate of the density and mass of the X-ray emitting gas. Assuming a thermal energy per unit mass of the gas equal to the corresponding kinetic energy of elliptical and S0 galaxies, and adopting an isothermal model (Lea *et al.* 1973) we obtain for the density and mass of the X-ray emitting gas, $\sim 10^{-3}$ atom cm^{-3} and $\sim 2 \times 10^{14} M_{\odot}$ respectively. The mass of gas thus obtained is very high, but these estimates clearly remain very uncertain until better data are available.

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