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Clusters of galaxies and the statistics of emission-line galaxies

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Summary. A sample of optical spectra of 1316 galaxies collected from the literature is used to study the relative frequencies of emission-line galaxies inside and outside dense clusters.

It is concluded that emission-line galaxies are indeed much less common in dense clusters than in less prominent associations or in the field and that this effect applies to spiral nuclei as well as to E and SO galaxies. A number of possible selection effects are investigated, but it is found that none of them contribute substantially to the observed effect.

Markarian galaxies apparently avoid dense clusters also and a similar, though very tentative, conclusion is reached for Seyfert galaxies.

1 Introduction

In the past few years, astronomers have discussed several alternative or complementary mechanisms for keeping the gas content of early-type galaxies down to the observed low levels despite continued mass loss from stars. Interest now centres mainly on the removal of gas by galactic winds (Mathews & Baker 1971; Faber & Gallagher 1976), by ram-pressure ablation (Gunn & Gott 1972; Gisler 1976; Lea & De Young 1976) and by thermal evaporation (Cowie & Songaila 1977). It is not inconceivable that all three processes operate to some extent in most galaxies at some stage in their evolution.

The last two mechanisms depend for their success on the existence of a substantial intergalactic medium surrounding the galaxy in question, and are therefore expected to be more effective for galaxies in clusters. Osterbrock (1960) presented evidence that the frequency of detection of the $\lambda 3727$ emission line of [O II] is much smaller for elliptical galaxies in dense clusters than for galaxies in the Virgo cluster and in less conspicuous aggregates and this evidence has been taken as support for the idea that cluster galaxies are gas deficient with respect to their field counterparts (Davies & Lewis 1973).

The data used in Osterbrock's study were those published by Humason, Mayall & Sandage (1956, HMS), and it is possible that effects of observational selection influence the result.

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For instance, galaxies in dense clusters are on average more distant and fainter than field galaxies. In the HMS catalogue, these galaxies were often observed with lower spectral dispersions, which would make it harder to detect a narrow emission line. This effect could contribute to the result obtained by Osterbrock.

In view of the renewed interest in the possible difference between the gas content of field and cluster galaxies, it seemed worthwhile to examine the large body of data in the astronomical literature since 1956 on the optical spectra of galaxies, to see whether Osterbrock's results are confirmed in the more recent data. Since the mass of gas indicated by the presence of line emission is a very small fraction of the mass of the galaxy, usually $\sim 10^{-6}$, an emission-line test would seem to be a very sensitive indicator of the physical conditions in the galaxy and its immediate surroundings.

2 The index of galaxy spectra

With this aim in view, I have collected data on galaxy spectra in a comprehensive literature search and have placed these data in an Index of Galaxy Spectra on punched cards (Gisler 1977, unpublished). The criteria for inclusion of a galaxy in the Index are:

(a) The galaxy must be included in the *Uppsala General Catalogue of Galaxies* (*UGC*, Nilson 1973), from which are taken data on positions, magnitudes, Hubble types and group or cluster membership.
(b) The galaxy must have a published (up to the end of 1976) radial velocity less than or about 15 000 km/s.

Up to six independent spectral observations are included for each galaxy and for each spectrum the Index entry contains the galactocentric velocity, an indication as to the nature of the spectrum (emission lines present – emission lines absent – no information), the spectral dispersion used and the reference. A few radial velocities obtained from observations of the 21-cm line of neutral hydrogen are also included for galaxies which have no published optical spectra, in order to make the information on clustering as complete as possible.

The cluster membership datum for each galaxy is the cluster number assigned by the *UGC*, or zero, implying 'field'. The *UGC* assigns a galaxy to a cluster if that galaxy lies within the contour boundary of a 'near' ($cz < 15\,000$ km/s) distance class cluster in the *Catalogue of Galaxies and Clusters of Galaxies* (*CGCG*, Zwicky, Herzog & Wild 1960; Zwicky & Herzog 1963, 1966, 1968; Zwicky, Karpowitz & Kowal 1965; Zwicky & Kowal 1968). Since the Virgo cluster has too great an angular size to be recognized in the *CGCG*, a special number indicating Virgo cluster membership was assigned to a galaxy if at least one of the references which reported a spectrum for the galaxy associated it with the Virgo cluster. The Zwicky characters ('compact', 'medium compact', 'open') of the clusters were taken from the *CGCG*, but for the case of Virgo, where Zwicky's (1959) description of it as 'medium compact' was used (though some recent observers prefer to think of it as an 'open' cluster).

With cluster membership assigned in this way, there is a certain risk of contamination by foreground and background galaxies. While it would be possible to utilize velocity data to eliminate cluster non-members and (in certain instances) to include outlying probable members, I have not done so because undesirable effects may be introduced by the arbitrary procedure which must be used because of the scarcity of velocity data over most parts of the sky. In any case, the contamination does not affect the results seriously. As will be pointed out later, four of the 59 galaxies which are given as compact-cluster members are in fact foreground galaxies.

The Index of Galaxy Spectra so produced contains data for 1638 galaxies, of which 1316 have $m_p \leqslant 15.7$, $v_R \leqslant 15\,000$ km/s, spectral dispersions better than 500 Å/mm and information as to the presence or absence of emission lines.

3 Method of data preparation and analysis

I have analysed the sample of 1316 galaxies to test whether the frequency of detection of emission lines is less for galaxies in Zwicky clusters of increasing compactness. With a sample as large as the present one, it has been possible to investigate directly the effects which observational selection and inhomogeneity of the data have upon the final result. The data analysed include spectra obtained over the last 30 years by scores of different observers, for a variety of purposes. Many, of course, are far from ideal for emission-line detection, while a few have been obtained at very high dispersions for the detailed study of line profiles. Subsamples of the data can be defined from which these inhomogeneities have been eliminated; in most cases these subsamples are still large enough to give a statistically meaningful result.

In cases where the Index entry refers to multiple spectroscopic observations of a single galaxy, I have called a galaxy an emission-line galaxy if *any* of the spectra show emission lines. The dispersion quoted with the spectrum is, however, always the highest dispersion used on the galaxy, regardless of whether the associated spectrum shows emission lines or not. In most cases, but not all, the highest dispersion observation is the one which shows emission lines if any of the observations do. Using a package of statistical programs on the Leiden University computer, I divided the 1316 galaxies into a large number of different two- and three-dimensional sets of subsamples, according to the values of selected variables. From these subsamples, I constructed Tables 1–5, in which various properties of the galaxies and their spectra are tabulated against cluster character.

Tables 1–4 concern the emission-line properties of the 1316 galaxies in the full sample. Table 5 concerns Markarian and Seyfert frequencies, discussed later. In each cell of Tables 1–4 are two numbers. The upper number is N, the total number of galaxies having the properties corresponding to that cell and the lower number, expressed as a percentage, is f, the fraction of the galaxies in the cell which show emission. The number of galaxies which occupy a given cell and show emission is thus fN. The right-hand margin of each table, under the word 'Totals', gives the total N and f for each row of the rable and the bottom margin gives N and f for each column.

The column variable, cluster character, is the same in all tables, referring, from left to right, to 'field' galaxies (galaxies which do not lie within the contour boundary of any 'near' cluster of galaxies as drawn in the *CGCG*) and galaxies in 'open', 'medium compact' and 'compact' clusters respectively, where all of these terms are defined in the *CGCG*. Galaxies which are here called 'field' may well belong to nearby groups, to clusters not recognized by the *CGCG* (excepting Virgo, as mentioned above), or even to clusters in Zwicky's 'medium distant' class (estimated $cz > 15\,000$ km/s).

The rows of Tables 1–4 divide the full sample into subsamples defined by Hubble type, radial velocity, apparent magnitude and spectral dispersion used. Effects of observational selection operating upon a row variable can be diminished by restricting attention to the subsamples defined by the individual rows of a table.

The selection or distributional effects operating upon the whole sample can be estimated, for each table, by calculating the f values which would result in the bottom margin under the null hypothesis that emission-line frequency is independent of cluster character within each of the subsamples defined by the rows of the table. To do this, the f values in one column of the table must be selected as standard, and the f values of other cells in the table replaced by the standard f value for the row, in accordance with the null hypothesis. The distributional bottom marginals are then calculated for each column by taking the averages of the standard f values, weighted by the numbers of galaxies in each cell of the respective column. The distributional f value for the column which has been chosen as standard will thus be identical with the true total f value for that column. For the other columns, the degree to which the true total f values differ from the distributional f values provides an estimate of the extent to which the true effect is *not* an effect of distribution over the variable concerned. Any of the four columns may be chosen as standard, but I have always used the 'field' column for the purpose because it is the most populated and it is therefore the most reliable indicator of trends with respect to the row variable.

The test just described has been carried out for all tables, and the null hypothesis distributional f values so calculated are given in the next section, together with the table descriptions. For Tables 2–4, the test was performed on tables of three times higher resolution in the row variable than those presented here.

4 Results

4.1 SELECTION BY HUBBLE TYPE

The rows of Table 1 divide the sample into groups of Hubble types as given in the *UGC*, except that barred and unbarred spirals are grouped together. The classifications 'S...' and '...' arise in cases where there is too little information on the Sky Survey print to permit more precise classification.

Table 1. Numbers of galaxies and emission-line frequencies as functions of Hubble type and cluster character.

Hubble type		Cluster character: Field galaxies	Galaxies in open clusters	Galaxies in medium compact clusters	Galaxies in compact clusters	Totals
E, E–SO	N	42	30	103	19	194
	f	26.2%	23.3%	11.7%	0.0%	15.5%
SO	N	71	25	82	9	187
	f	47.9%	40.0%	22.0%	0.0%	33.2%
SO–a, Sa, Sa–b	N	66	24	64	8	162
	f	65.2%	58.3%	40.6%	12.5%	51.9%
Sb, S...	N	157	34	91	14	296
	f	82.2%	70.6%	70.3%	21.4%	74.3%
Sb–c, Sc	N	164	45	56	5	270
	f	85.4%	77.8%	80.4%	60.0%	82.6%
Sc–I, irr, pec, compact, multiple, and ... (unclassified)	N	137	32	34	4	207
	f	88.3%	84.4%	85.3%	75.0%	87.0%
Totals	N	637	190	430	59	1316
	f	75.0%	61.6%	45.1%	16.9%	60.7%

N = number of galaxies.
f = percentage of those galaxies which show emission lines in their spectra.

It is immediately apparent from this table that there is a strong tendency for galaxies in *less* compact associations to be reported *more* frequently in emission and that this tendency is strongest for early-type galaxies and weakens substantially toward later types. The total fraction of galaxies observed in emission increases toward later galactic types for all cluster characters, consistent with the conclusion derived from 21-cm data that the mass fraction in gas is greater in galaxies of later Hubble types (Roberts 1969).

The bottom marginals shows that the tendency for compact clusters to have fewer emission-line galaxies is very strong and highly significant for the sample as a whole. Contributing to the effect for the whole sample are the effects within each of the slices through the sample defined by the rows of the table, plus a systematic effect which is an effect of distribution: the fraction of the total number of galaxies in each slide which are in the field is greater for later Hubble types; since the later types have higher overall frequencies of detection, this distributional effect contributes to the sample-wide trend in the same sense as the trends within each slice do. That is to say, because the slices for late Hubble types are weighted towards field galaxies, there is bound to be a deficit of emission-line galaxies in clusters and thus the trend for the whole sample is slightly steepened.

The extent of this steepening may be estimated by calculating the distributional f values for this table, on the basis of the null hypothesis that emission-line frequency is independent of cluster character within each line, in the manner described above. The results are 75.0, 68.5, 60.6 and 57.3 per cent for field, open, medium compact and compact clusters respectively. The slight steepening due to the distributional effect is thus small compared to the strength of the overall trend. These distributional f values for Hubble type should be compared with the f values for the individual rows of Tables 2–4, in which all Hubble types are lumped together.

It is appropriate here to comment on the detection of emission lines in spirals. In looking at the spectra of distant spirals, it is often difficult to say whether an emission lines comes from the nucleus or from a H II region in the spiral arms. The orientation of the slit with respect to the distribution of H II regions within the galaxy is therefore critical in determining whether a given spiral will be detected in emission. If emission is not detected at all, however, one can be fairly certain that (to a level set by the observational equipment used and the effects of internal obscuration for galaxies observed nearly edge-on) there are no emission lines present *in the nucleus* of the galaxy, since observers nearly always pass their slits across galactic nuclei when trying to obtain systemic velocities. Thus the statistics presented here, in so far as they apply to spirals, refer to the nuclei and provide evidence that ionized gas in the nuclei of spiral galaxies occurs less frequently in dense clusters.

4.2 SELECTION BY RADIAL VELOCITY

The rows of Table 2 divide the sample into radial-velocity intervals, in order to identify any systematic effects with distance. It should be noted that there are no compact clusters with radial velocities less than 5000 km/s, so that the four galaxies in the compact-cluster column with velocities less than 3000 km/s are most probably foreground objects.

There is apparently no overall systematic effect with distance. Field galaxies between 1000 and 4000 km/s are slightly less likely to be seen in emission than field galaxies which are nearer or more distant. Beyond 4000 km/s, the detection frequency does not change much. The distribution of galaxies in the Index with respect to clustering and radial velocity is such that this dip in detection frequency does not make a systematic contribution toward the deficit of emission-line galaxies in dense clusters. In fact the distributional f values calculated from the null hypothesis for this table are 75.0, 74.3, 76.6 and 83.0 per cent for

Table 2. Numbers of galaxies and emission-line frequencies as functions of radial velocity and cluster character.

Radial velocity (km/s)	Cluster character: Field galaxies	Galaxies in open clusters	Galaxies in medium compact clusters	Galaxies in compact clusters	Totals
⩽2000	239 74.9%	59 66.1%	140 49.3%	2 100%	440 65.7%
2001–4000	136 63.2%	44 52.3%	61 55.7%	2 100%	243 59.3%
4001–7000	175 77.7%	55 58.2%	165 39.4%	25 4.0%	420 55.7%
7001–15 000	87 88.5%	32 75.0%	64 40.6%	30 16.7%	213 62.0%
Totals	637 75.0%	190 61.6%	430 45.1%	59 16.9%	1316 60.7%

the respective columns, so that clustered galaxies ought to be observed in emission slightly more often than field galaxies, if this effect were acting alone.

4.3 SELECTION BY APPARENT MAGNITUDE

In Table 3 the sample is divided into slices according to the magnitude of the galaxy in the *CGCG* and there is likewise no overall systematic effect. The null hypothesis then yields 75.0, 75.2, 74.3 and 80.8 per cent for the distributional *f* values, giving a further weak bias *towards* the detection of emission lines in compact-cluster galaxies. The lack of a systematic effect with magnitude is explained by the fact that an emission line, in order to be seen against the background of the stellar continuum, must be fractionally (say 15–25 per cent) brighter than the continuum and this threshold of detectability is independent of the total brightness.

4.4 SELECTION BY QUALITY AND NUMBER OF SPECTRAL OBSERVATIONS

In Table 4, the sample is divided according to the best spectral dispersion with which the galaxy has been observed and in two further tables not shown here the row variables were

Table 3. Numbers of galaxies and emission-line frequencies as functions of Zwicky magnitude and cluster characters.

Zwicky magnitude	Cluster character: Field galaxies	Galaxies in open clusters	Galaxies in medium compact clusters	Galaxies in compact clusters	Totals
⩽13.0	253 67.6%	62 50.0%	154 48.1%	3 66.7%	472 58.9%
13.1–15.7	384 79.9%	128 67.2%	276 43.5%	56 14.3%	844 61.7%
Totals	637 75.0%	190 61.6%	430 45.1%	59 16.9%	1316 60.7%

Table 4. Numbers of galaxies and emission-line frequencies as functions of spectral dispersion used and cluster character.

Dispersion class	Cluster character: Field galaxies	Galaxies in open clusters	Galaxies in medium compact clusters	Galaxies in compact clusters	Totals
<300 Å/mm	315 87.9%	99 75.8%	256 48.0%	56 17.9%	726 66.8%
>300 Å/mm	322 62.4%	91 46.2%	174 40.8%	3 0.0%	590 53.2%
Totals	637 75.0%	190 61.6%	430 45.1%	59 16.9%	1316 60.7%

the publication date of that best spectrum and the number of spectral observations published. As expected, the use of a higher inverse dispersion increases the level of detection substantially. The modal dispersion interval used for galaxies in compact and medium compact clusters is 201–300 Å/mm, compared to 401–500 Å/mm for field galaxies, however, so that this effect does not bias against emission-line detection in cluster galaxies (null hypothesis f values: 75.0, 74.6, 75.8 and 83.7 per cent).

Also, as expected, detection frequencies are much higher in recent studies than in HMS, due to the dramatic improvement in observational techniques in the last 20 years. However, since relatively recent work has contributed almost all the data in compact clusters, this effect *favours* detections in compact-cluster galaxies (null hypothesis f values: 75.0, 73.3, 72.4 and 81.2 per cent).

Finally, galaxies which have been observed more than once show emission lines more frequently than those observed only once, but since relatively more cluster galaxies than field galaxies have been multiply observed this effect weakly favours detections in compact clusters (null hypothesis f values: 75.0, 75.2, 74.5 and 77.3 per cent).

The fact that the emission-line detection frequency increases with better observational equipment and multiple observations suggests that almost all galaxies will show emission lines if examined closely enough. It is therefore desirable to frame the question I have been asking in a more quantitative way and investigate the amount of gas actually present in the H II region in the nucleus and its physical parameters – temperature, density, ionization level, chemical composition, etc. – to see whether these quantities differ systematically between galaxies in different environments. It should be possible to make such a quantitative study in the not too distant future, for a limited number of galaxies.

4.5 MARKARIAN AND SEYFERT GALAXIES

A recent review paper by Komberg (1976) points out a possible deficiency in the numbers of Seyfert galaxies and galaxies with ultraviolet continua (Markarian 1967, 1969a, b); Markarian & Lipovetsky 1971, 1972, 1973, 1974) in clusters of galaxies. A notable exception is of course the peculiar Seyfert NGC 1275, the brightest galaxy in the Perseus cluster (a medium compact cluster).

Because the Seyfert galaxies are phenomenologically rather extreme examples of emission-line galaxies and Markarian galaxies (heterogeneous as they may be) are very frequently found to be emission-line objects, Komberg's conclusion may be just a reflection of the deficiency of emission-line galaxies, in general, from clusters. Because of the intrinsic

Table 5. Markarian and Seyfert frequencies as functions of Hubble type and cluster characters.

Hubble type		Cluster character: Field galaxies	Galaxies in open clusters	Galaxies in medium compact clusters	Galaxies in compact clusters	Totals
E, E–SO	N	42	30	103	19	194
	f_1	2.4%	0.0%	0.0%	0.0%	0.5%
	f_2	0.0%	0.0%	0.0%	0.0%	0.0%
SO	N	71	25	82	9	187
	f_1	18.3%	8.0%	2.4%	0.0%	9.1%
	f_2	7.0%	4.0%	1.2%	0.0%	3.7%
SO–a, Sa, Sa–b	N	66	24	64	8	162
	f_1	16.7%	12.5%	4.7%	0.0%	10.5%
	f_2	4.5%	12.5%	3.1%	0.0%	4.9%
Sb, S . . .	N	157	34	91	14	296
	f_1	15.3%	14.7%	11.0%	0.0%	13.2%
	f_2	1.3%	5.9%	3.3%	0.0%	2.4%
Sb–c, Sc	N	164	45	56	5	270
	f_1	3.7%	0.0%	1.8%	0.0%	2.6%
	f_2	0.6%	0.0%	0.0%	0.0%	0.4%
Sc–I, irr, pec, compact,	N	137	32	34	4	207
multiple and . . .	f_1	34.3%	31.3%	20.6%	25.0%	31.4%
(unclassified)	f_2	2.2%	3.1%	2.9%	0.0%	2.4%
Totals	N	637	190	430	59	1316
	f_1	16.0%	10.5%	5.3%	1.7%	11.1%
	f_2	2.2%	3.7%	1.6%	0.0%	2.1%

N = number of galaxies in cell.
f_1 = percentage of galaxies of Markarian type.
f_2 = percentage of galaxies of Seyfert type.

interest his conclusion has, I have, however, constructed Table 5 to look for the effect within the present sample of 1316 galaxies.

In format this table is exactly similar to Table 1 for the case of emission lines in general, with N as before representing the total number of galaxies occupying each cell. In this table there are two f's per cell: f_1, the middle number, is the fraction of galaxies in the cell contained in Markarian's lists (referenced above), but *excluding* all Markarian galaxies which were later found to be Seyferts. f_2, the bottom number, is the fraction which are Seyferts. Since the total numbers of Seyfert and Markarian galaxies in the sample are much smaller than the numbers of emission-line objects, the statistics for this table are much weaker and the null-hypothesis values of the f's are not very meaningful.

As in Table 1, the sample is divided by Hubble type. Markarian galaxies are much more common among the later types, while the modal type for Seyferts is Sa. Medium compact and compact clusters are indeed deficient in both Seyfert and Markarian galaxies of most Hubble types, but *open* clusters have proportionately more Seyferts than the field. The Markarian galaxy which appears in the compact-cluster column is a nearby dwarf, Markarian 178, which is superimposed on the cluster Abell 1314 (Vallée & Wilson 1976). There are therefore *no* Markarian or Seyfert galaxies in the Index which are true members of compact clusters.

Similar results are obtained in tables where the sample is segregated into subsamples by radial velocity and apparent magnitude. In particular, removing nearby dwarfs does not diminish the trend that Markarian galaxies are less frequent in dense clusters.

5 Discussion

The inhomogeneity of the present sample of galaxy spectra presents problems for the interpretation of the results of the previous section, in that it is impossible to make a full accounting of the effects of observational selection. The criteria by which a particular galaxy is selected for observation by a particular observer with a particular set of instruments are very complex, perhaps idiosyncratic and often involving random or pseudo-random considerations (e.g. the weather, lunations and the decisions of programme committees). It is hardly conceivable, however, that these manifold factors could devilishly conspire to discriminate against the observation of emission-line galaxies in dense clusters. Those selection criteria which are expected to have some bearing on the problem and which are amenable to test – yield, as we have shown – weak biases *in the direction opposite* to the observed tendency. Only the differing distributions of galaxies with respect to Hubble types in the four cluster categories produces a systematic effect in the observed direction for samples in which all Hubble types are lumped together. That this systematic effect does not dominate the observed tendency is proved by the fact that the same tendency is present in each of the subsamples of Table 1 and in most of them, to a *greater* degree than in the null hypothesis distributional f values *for the whole table*. The null-hypothesis *for individual rows* of the table (emission-line fraction independent of degree of clustering) is ruled out at levels of 10^{-3}, 10^{-5}, 3×10^{-4}, 10^{-4}, 0.07 and 0.20 respectively, using a statistical test based on the rank-order correlation coefficient Kendall's τ; Kendall (1955). Note that the significance of the result is low for late Hubble types.

The result of Osterbrock (1960) is therefore confirmed and greatly strengthened by the present investigations: *H II regions in the nuclei of galaxies (spirals as well as ellipticals) are less commonly found among galaxies inside dense clusters than among galaxies in general.*

For the Markarian and Seyfert galaxies, the numbers are much smaller and the statistics less impressive. Moreover, it is even more difficult to account for effects of selection; Markarian's surveys have been neither as complete or as homogeneous as could be desired and the only galaxies from his surveys which appear in the Index are of course those for which measurable spectra have been obtained (with but a few exceptions, they are all emission-line objects whose spectra have been obtained at Byurakan, Alma-Ata and the Crimea). Nevertheless, on the basis of the available data, Markarian galaxies seem to avoid dense clusters as suspected by Komberg (1976). In the case of the Seyferts, the conclusion must be even more tentative since the numbers are still smaller, but even here a case can be made for a similar effect. Since Seyfert galaxies may be relatively mild examples of more violent forms of nuclear activity, leading up to quasi-stellar objects, this tentative conclusion may be relevant to the theoretical case for the inhibition of violent activity in cluster galaxies presented in Gisler (1976) using fuelling-rate arguments.

6 Implications

The ionized gas content of galactic nuclei in dense clusters is thus considerably smaller than that of their counterparts in less conspicuous aggregates. The theoretical implication of this conclusion is that the presence of a substantial intergalactic medium does indeed hinder the formation of a H II region in the nucleus of a galaxy and the conclusion seems therefore to be consistent with the idea of thermal evaporation of intragalactic gas by electron conduction in the intergalactic medium, or the idea of ablation of the intragalactic gas by the dynamical pressure of the galaxy's rapid motion through the medium.

It may not yet be possible to distinguish between these two possibilities on the basis of presently available data. Both of them should be more effective in more compact clusters because of the (presumed) higher temperatures and higher densities of the intracluster gas and the higher velocities of the galaxies relative to the gas. However, both of them have problems, *alone*, in explaining all the data presented here: on the one hand the nucleus of a galaxy has a higher gas replenishment rate per unit volume than any other part of the galaxy and it is perhaps surprising that a purely dynamical interaction can be effective there in removing the gas as rapidly as it is produced by the stars in the neighbourhood (Gisler 1976). On the other hand, thermal evaporation mass-loss rates are a good deal larger (Cowie & Songaila 1977); if evaporation is not inhibited by the galaxy's motion or by magnetic fields then it is surprising that *any* cluster galaxies – and particularly the spirals – can retain their gas. Because of their large surface areas, spirals would be particularly susceptible to evaporative mechanisms while they would be largely immune to ablative influences because of their rapid gas replenishment rates.

Because of the distinct differences in the way in which these two mechanisms depend upon the physical characteristics of the galaxies and their surroundings, it should be relatively easy to distinguish between them with data which will become available in the next few years. In particular, the high resolution X-ray data on clusters of galaxies which will be provided by *HEAO-B* will give information on the temperature and density distributions of the gas in clusters. This, together with information on the distribution of gas-rich and gas-poor galaxies in the same clusters, will serve to establish the extent to which each of these gas-removal mechanisms is operating.

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