RADIO PROPERTIES OF ABELL CLUSTERS

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Since the early 60's the association of some radio sources with rich clusters of galaxies was noted (Mills, 1960; van den Bergh, 1961) and subsequent investigations concentrated mostly on the radio properties of clusters in the Abell catalogue. This paper is confined to this subject, although one should bear in mind the importance of associations with other scales of clustering which do not appear as entries of that catalogue. In this paper we shall use $H_o = 100$ km sec^{-1} and the radio power P in WHz^{-1} at 408 MHz.

1. RADIO LUMINOSITY FUNCTION OF GALAXIES IN ABELL CLUSTERS

The first item that attracted general attention is whether galaxies inside Abell clusters have a probability of being radio sources different from that of the galaxies outside. This item is best studied by constructing a radio luminosity function (RLF). Recent determinations based on large samples have been obtained by Owen(1975), Riley(1975), Mills and Hoskins(1977). The first two are in the form of spatial density or fraction of clusters with radioemission, the third, based on an attempt to identify each source specifically with a cluster member, can be more directly compared with the bivariate RLF of the general population of galaxies, which expresses quantitatively the dependence of the probability of radioemission on the optical absolute magnitude M of the galaxies. A recent study at 1415 MHz with the WSRT (WC105 project, D.Harris, C.Lari, J.Vallée, A.Wilson) of B2 sources located within one Abell radius, R_A, of Abell clusters with D≤5, combines a good positional accuracy with a reasonably good resolution even for D=5 clusters, and therefore improves over Mills and Hoskins (MH) in the identification process. We shall refer extensively to the preliminary results we have extracted from it. WC105 contains all Abell clusters, surveyed in the B2.1-5 catalogues, with D≤5 (21°<Dec<42°, tot. of 279). MH studied all clusters south of +18° with D≤4, plus a random selection of D=5 and 6 (tot. of 247). The two samples are completely independent, while there is a large overlap between WC105 and the samples used by Owen and by Riley.

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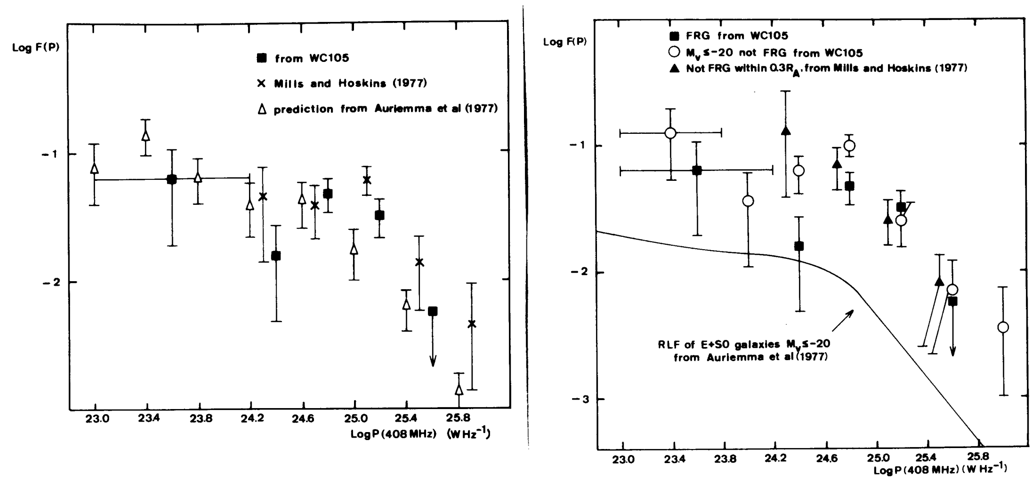

Figg. 1 and 2. Radio luminosity function of the first ranked galaxies and of the other member galaxies in Abell clusters.

In WC105 we find 76 sources which can be associated with 63 clusters. About 90% of the "good" associations can be unambiguously identified with a single galaxy. All the identifications are with E type galaxies, except that a few objects are too faint to classify on the PSSP. This allows a comparison to be made with the local ($z \leq 0.1$) bivariate RLF constructed by Auriemma et al(1977) for the E+S0 type galaxies. These authors find that, at logP>24.5 and up to at least 26, the probability of radioemission depends on M as $10^{-0.6M}$, irrespective of P. This dependence weakens as logP decreases below 24.5.

1.i. RLF of the first ranked galaxies (FRG).

Fig.1 gives the fractional RLF of the FRG's from MH and from WC105, along with an expectation based on the bivariate RLF in Auriemma et al, and on the distribution in M_V of the 82 FRG's in Sandage(1972). The MH points (from which we have subtracted the D=6 clusters to avoid an evolutionary bias relative to WC105) are in excess over our estimate at logP greater than 25. This may be due to a statistical fluctuation, but also to the stricter criteria adopted by us in the identification process. It is very important to solve this dilemma, because WC105 gives only a slight excess (1.5σ) over the expectation at logP>25, while the excess becomes 3.5σ if the two samples are combined. The latter result, if confirmed by a study of the MH clusters technically homogeneous to WC105, would be difficult to evaluate as a real excess, because of the uncertainty on the $10^{-0.6M}$ dependence and the probable presence of systematic biases in the RLF used for comparison. One of these is the incidence of the S0 galaxies in the normalization adopted by Auriemma et al: their exclusion as galaxies with radio properties different from those of the typical morphologies of the FRG's would reduce the discrepancy. Moreover evolutionary effects cannot be excluded at logP>25, although a recent study (Ulrich et al, in prep.) shows that in a range of redshifts compa-

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rable to that of D=4,5 clusters, the general RLF is still the same as the "local" one up to logP=26. A possibility is a difference of the evolutionary rate in the clusters. A real excess would imply in any case that the cumulative lifetime of FRG's as strong radio sources is longer than for equal magnitude galaxies outside of clusters.

1.ii. RLF of the other cluster members.

In Fig.2 we give from WC105 the number of sources per cluster identified with galaxies other than the FRG, which, if members, would be brighter than M_V=-20 (to avoid background contamination). The same function, but for sources within $0.3R_A$, derived from MH is also given. The agreement is good, even if 30% of the associations in WC105 lie outside $0.3R_A$. It appears that: a)the forms of the RLF for the FRG's and for the other galaxies are rather similar, but the proportion of FRG's fainter than logP=24.8 is significantly smaller than that of the other members.
b) The form of the RLF for the members other than the FRG's is fairly similar to that of the general RLF for galaxies brighter than M_V=-20. Comparison in absolute value (that is, per galaxy) with the latter requires knowledge of the average number of members brighter than -20 in the clusters surveyed. From counts available for a restricted number of nearby clusters we estimate the normalization factor to be between 10 and 15; with such a value, the agreement with the expectation would be reasonably good. We note that WC105 does not confirm the presence of a turn down in the cluster RLF found by Owen (1975) below logP=24.8, but agrees with the finding by Auriemma et al, based on 5 nearby clusters, that from logP=22 to logP=24 the RLF in clusters does not differ significantly from the general one.

1.iii. Correlation with Bautz-Morgan type.

Guthrie(1974), McHardy(1974), Tovmasyan and Shirbakyan(1974) found that powerful sources occur more frequently in BM class I clusters than in any other class. The results from WC105 are given in Table 1.

Table 1. Distribution of sources per Bautz-Morgan class

B-M class	I	I-II	II	II-III	III
(a)	7(.28)	5(.20)	2(.08)	3(.12)	8(.32)
(b)	2(.06)	3(.08)	7(.18)	10(.26)	15(.42)
(c)	10(.13)	7(.09)	10(.13)	16(.21)	33(.44)
(d)	.22	.11	.13	.21	.33

The key of the table is: (a) number (and fraction) of clusters with the FRG detected (we find no correlation between radio power and BM class); (b) clusters with a galaxy detected other than the FRG. It is clear that BMI are more frequent in (a) than in (b). (c) is the distribution among

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76 nearby clusters (McHardy,1974). Although there can be doubts that (c) is an adequate representation of clusters in D=4,5 it is noteworthy that (b) and (c) are consistent with each other, so that the effect found by the previous authors has to be attributed to the FRG's. The last line (d) is the distribution predicted from (c) using the $10^{-0.6M}$ dependence in the RLF and the estimate by Sandage and Hardy(1973) of the deviation of $<M_V>$ of the FRG's from the overall mean, per BM class. Comparison of (d) with (a) suggests that the excess of FRG's in BMI with radioemission can be attributed to a fair extent to the magnitude effect in the RLF.

We have seen however in 1.i that this effect may be insufficient to account for the fraction of radioemitting FRG's. The absolute magnitude is conceivably not the only "good" parameter on which the probability of radioemission may depend. Other parameters, like the colours and the morphological properties, can be important. Tovmasyan and Shirbakyan (1974) have made an analysis on the PSSP of 355 clusters in D=5 surveyed by them and by Owen. They find that outstandingly bright D galaxies, dumbells and peculiar ellipticals appear to have a higher probability of radioemission than the ordinary giant ellipticals. For the WC105 sample a similar study is in progress, but we mention that, out of 25 FRG's detected, 11 and 5 are of D and dB type respectively.

1.iv. Correlation with richness class R.

Several authors (van den Bergh,1961; Rogstad and Ekers,1969; Tovmasyan and Shirbakyan,1974; Owen,1975; Riley,1975) found that the percentage of radioemitting clusters is at best only weakly correlated with R. This is not surprising because the probability of radioemission in a cluster depends basically on the bright end of the optical luminosity function, and, for instance, Sandage(1972) found no correlation between R and the average M_V of the FRG's. From WC105 we have constructed the RLF for clusters with different R, and we find (above logP=24.2, a range of P where all richness classes in our sample are surveyed at best): a)the fraction of FRG with radioemission is independent of R, except that an excess of low statistical significance is found for R=2+3 relative to R=0+1. b)The fraction of sources per cluster <u>not</u> associated with the FRG is 0.13 (R=0), 0.15 (R=1), 0.45 (R=2+3), that is about three times as many sources per cluster are found in R=2+3 than in R=0+1. Moreover the percentage of clusters with more than one source increases with R, confirming a finding by MH. These results indicate that the number of sources found in clusters is proportional to the number of <u>individual</u> candidate galaxies.

1.v. RLF of Spiral and Irregular galaxies.

These galaxies are weak radioemitters and cluster spirals have been detected only in deep radio surveys of nearby clusters. A systematic study of their properties is in progress (see Jaffe and Perola,1976). Slight differences are found between cluster and field galaxies, and between cluster and cluster. The latter appears to correlate with the presence of optical emission lines (Jaffe, Perola and Valentijn, 1976).

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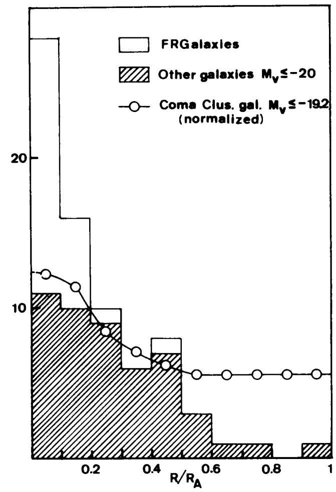

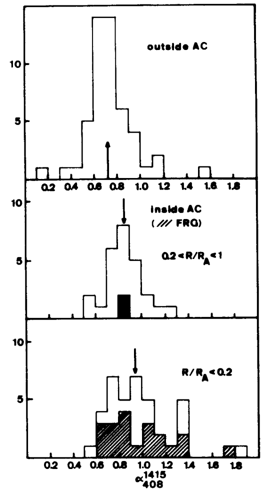

Fig.3. Radial distribution of radiogalaxies in Abell clusters.

Fig.4. Distribution of spectral index between 408 and 1415 MHz.

2. RADIAL DISTRIBUTION OF RADIOGALAXIES IN ABELL CLUSTERS

The radiogalaxies brighter than M_V=-20 in WC105 have the radial distribution (with respect to the centres in the Abell catalogue) shown in Fig.3. For comparison is given also the fit to the distribution of galaxies brighter than M_V=-19.2 in the Coma cluster (Bahcall,1973), normalized to the same number of objects. Clearly the "composite radio cluster" is more centrally condensed than the optical cluster. The excess peak within 0.2R_A is due to the FRG's and follows from the combination of two effects, the first that the FRG's have a more centrally peaked distribution than the other galaxies, the second that, from the $10^{-0.6M}$ dependence, the brightest galaxy has the largest probability in a cluster to be a strong source. Since the FRG in the first two BM classes tend to be more centrally located than in the others, on the basis of the results in 1.iii, we expect the radioemitting FRG's to have a narrower distribution than the general one. This effect has been noted already (Leir,1976). After subtracting the FRG's, the radiogalaxies follow remarkably well the optical distribution out to 0.5R_A, but are proportionally far less numerous than the galaxies beyond that point. Radiogalaxies brighter than -20.5 have an even narrower distribution. These results we tentatively explain as due to a progressive decrease with increasing radial distance of the fraction of very bright galaxies in the "average" cluster. This segregation in magnitude would be strongly enhanced by the M dependence in the radioemission probability. This explanation need however to be supported by specific counts on a representative number of clusters. For the moment we cannot exclude that Fig.3 is evidence that a galaxy is more likely to be a radio source the closer it is to the cluster centre.

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3. SPECTRAL INDEXES OF RADIO SOURCES IN ABELL CLUSTERS

Several authors (e.g. Baldwin and Scott,1973; Slingo,1974; Colla et al,1975; Roland et al,1976) have shown that steep spectrum sources are found more frequently in clusters than outside. This result has been interpreted as evidence of enhanced efficiency in the radio source confinement by the intergalactic gas inside clusters, which allows the effects of radiative losses to show up as a spectral steepening. In Fig.4 we give the distribution of the spectral index between 408 and 1415 MHz for sources with $\log P>24.2$ in the WC105 and in a complete sample of galaxies outside Abell clusters (from Colla et al,1975, and Fanti et al,1977b). Sources between 0.2 and one R_A have a distribution similar in form to that of the outside sources, although the median, indicated by an arrow, is larger by about 0.15. Sources within $0.2R_A$ have a definitely broader distribution, and the median is larger by about 0.2. So the above results are confirmed and it is found that the spectral index distribution in clusters correlates with the distance from the centre, the one of the sources in the innermost regions being the more dissimilar from that of the outside sources. This strengthens the validity of the interpretation mentioned. Roland et al(1976) find that the distribution is broader for sources in BMI to II than in the other classes. This reflects the fact that radiogalaxies other than the FRG are more centrally located in the BMI to II classes than in the others: we find 60% against 32% within $.2R_A$.

4. RADIO SOURCE STRUCTURES IN ABELL CLUSTERS

In the last 9 years it has become progressively more clear that the content of sources per morphological type is different inside and outside clusters, and a great deal of observational and theoretical work has been devoted to the "peculiar" radio structures found in clusters. We shall not review this work here, but limit ourselves to statistical properties. A careful comparison in/out need to be based on samples chosen from complete radio surveys and having a similar distribution in P, because radio morphology and size are to some extent a function of P (see Fanaroff and Riley,1974; Gavazzi and Perola,1977).

4.i. Distribution of largest physical size.

The great majority of the WC105 sources are within 24.2 and 25.2 in logP. For comparison we therefore use sources in the same power interval from two samples of B2 sources identified with galaxies outside Abell clusters brighter than $m_p=15.7$ (Fanti et al,1977a) and with $14<m_v<17$ (Fanti et al,1977b). These sources have also been mapped at 1415 MHz with the WSRT. The distribution of the largest physical size (LPS) for 58 inside and 41 outside Abell clusters is given in Fig.5. The two distributions are practically identical, with the median value of the LPS (indicated by an arrow) within 15 kpc, and a maximum value in both cases of 300-400 kpc.

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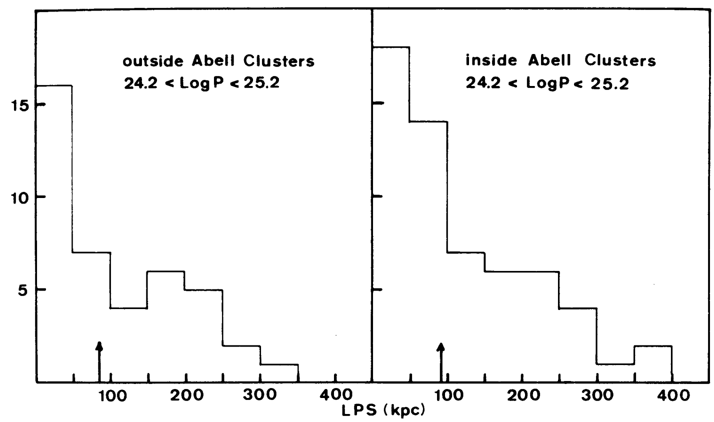

Fig.5. Distribution of the largest physical size.

4.ii. Morphological types.

The percentage distribution of morphological types in the two samples is given in Table 2. Symbols: D=aligned double; V=V-shape or highly misaligned double; T=tail or head-tail; CX=complex structure; H=halo; PW=source extended on opposite sides of peak (this category probably contains some unresolved doubles); NC=slightly resolved not classified; NR=not resolved.

Table 2. Distribution of morphological types

	D	V	T	CX	H	PW	NC	NR
outside (%)	54	2	5	2	-	7	15	15
inside (%)	17	12	16	7	3	16	17	12
FRG's (%)	24	12	4	12	12	8	12	16

Note two striking differences: a) outside clusters more than half of the sources have a D structure, while inside less than 20% show such a structure. On the other hand the size distribution of the D's in the two samples appear rather similar, except that, if the PW sources are all considered unresolved doubles, there would be proportionally more doubles with LPS less than 100 kpc inside the clusters. We recall that previous analyses of the size of D sources in the 3CR catalogue (which are generally brighter than those in our samples) also found no statistically significant differences between in and out (Hooley,1974; Burns and Owen,1977).

b)The V+T+CX type sources amount to at most 10% outside, but make up 35% inside. It is remarkable that the percentage of these types toge-

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ther with the D sources inside (52%) and outside (63%) are rather close values. This result supports the opinion that the D "missing" from the cluster sample are sources of the type V, T and CX, whose morphology is dramatically affected by the physical conditions prevailing in the intra-cluster medium, in particular the dynamical action of a denser than average intergalactic gas. Its effects can be of various kinds, like (1) drag on radiocomponents associated with galaxies moving through the medium (Miley et al,1972); (2) buoyancy of radiocomponents (Gull and Northover, 1973); (3) asymmetric ram pressure on moving components (W.Christiansen in Rudnick and Owen,1977); (4) bulk motions of the gas. In view of these effects, it would be of considerable interest to study the radial distribution of the various types. Unfortunately the statistics in the WC105 sample is too poor for telling significant radial dependences. It seems however that the FRG's (see Tab.3) differ from the rest. In particular the H type sources in the sample are associated with an FRG, while only one T source is. On the other hand, the percentage of V sources is the same for the FRG's and the other galaxies. This result, along with the finding by Owen and Rudnick(1976), and confirmed in WC105, that T sources are on average associated with less bright galaxies than the V's, supports their view that while effect (1) is mostly responsible for the tail structure, effects (2,3) are likely to be more important in determining the V shapes, being these sources associated with galaxies which can be suspected to move at a relatively lower speed with respect to the medium.

Thanks to a higher resolution, the work by Rudnick and Owen(1977) on several sources in cluster reveals the structure of small sources. In their statistical sample of 37 sources, 11% are small doubles (<30kpc) and 16% are V sources with size less than 50kpc. It is remarkable that a high percentage of doubles be distorted into a V when their size is less or comparable to the main body of the optical galaxy. Moreover, Rudnick and Owen note the curious effect that these V sources tend to point away from the cluster centres, and interpret it as due to pressure gradients or buoyancy in the general cluster field.

On the contrary, T type sources appears randomly directed (e.g. Harris,1977).This supports the idea that their elongation is generally in the direction of the galaxy velocity. The rather sharp bendings in some of the longest tails can be due to buoyancy (Cowie and McKee,1975), but there is no clear evidence that the tails are affected by bulk motions in the gas, like a general outflow or inflow (Lea,1976). It has been suggested that galaxies with radio tails may be endowed with peculiarly high velocities. An analysis for 12 well known tails (Baggio,Perola and Tarenghi, in prep.) shows the contrary, that is the quantity $x= \Delta v/\sigma$ (ratio of radial velocity difference with respect to cluster average, to cluster velocity dispersion) appears normally distributed.

5. CORRELATION BETWEEN RADIO AND X-RAY EMISSION IN CLUSTERS

To check the existence of a correlation, we have used the 15 Abell clusters with $D\leq3$ in the Ariel catalogue, all of which have been surveyed

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in radio. We find that 10/15 (67%) contain at least a radio source with logP>24.2. The fraction of clusters in general with a radiogalaxy more powerful than logP=24.2 is instead 25%. However, the 15 X-ray clusters have a peculiar richness distribution: 1 with R=3, 7 with R=2, 6 with R=1 and 1 with R=0. If the prediction is corrected accordingly, the expectation becomes 45% that is 7 out of 15. It seems to us that, on the statistically limited basis of the sample used, there is little evidence for the existence of such a correlation.

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DISCUSSION

Abell: Is there a single known case of a tail source that is not in some kind of cluster or group that can be recognized, say, on the sky surveys? What about V-shaped sources?

Perola: I know of no examples of head-tail radio sources which are outside clusters or groups of galaxies. There is an example of a V-shape source (B2 source 0034+25), which is associated with a fairly isolated galaxy, which, however, (from its redshift) may just be in an underpopulated area of the Perseus supercluster.

Longair: In Cambridge, Ian McHardy has completed a survey of a statistical sample of 60 Abell clusters which are 4C radio sources. His conclusions agree substantially with those described by Drs Perola and Ekers. One correlation which McHardy finds is that the radio trail sources are almost exclusively associated with Bautz-Morgan class III clusters. Few of them are associated with Bautz-Morgan class I. This provides a neat picture in which in the BM III clusters, all the brightest galaxies have roughly the same absolute magnitudes and hence they must all be in motion with respect to the dynamical centre of the clusters.

Ostriker: At a given optical luminosity, is there a significant difference between the probability that a first ranked galaxy or any other galaxy will be a radio source? That is, is there a correlation between rank and radio properties independent of the correlation between optical luminosity and radio properties?

Tinsley: Further to Dr Ostriker's question, Dr Perola has found that the probability of a first-ranked galaxy being a radio source increases with its optical luminosity. Gunn has shown that this leads to an important bias in the Hubble diagram for q_o, if the galaxies are selected by their radio emission because the optically brightest galaxies are thereby selected and the value of q_o obtained in such a sample is too large if the selection effect increases with redshift. Perola's result suggests that samples of galaxies used in the Hubble diagram should not be obtained from radio catalogues, as it has been done in some studies.

Perola: It seems to me that the correct statement is as follows: the addition to the Hubble diagram for first ranked cluster galaxies of objects in very distant clusters detected in radio surveys may lead to a bias, much in the same way as the Bautz-Morgan class effect, which in principle at least can be corrected for. A similar statement, however, is not correct when the Hubble diagram is constructed only with galaxies selected entirely from radio samples, irrespective of their being members or not of rich clusters, provided that only objects with P(408 MHz) $> 10^{25}\mathrm{WHz}^{-1}$ are used, or that the radio limit of the sample is properly taken into account. The latter statement is explained in Auriemma et al. (1977) and also, but rather telegraphically, in Fanti and Perola (1976) at the Cambridge Symposium on radio sources.

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Longair: In response to Dr Tinsley's remarks and to amplify Dr Perola's answer, it should be noted that the correlations between radio and optical luminosity refer only to low luminosity radio sources. The Abell cluster radio sources from the B2 Catalogue are at the very low end of what one normally calls a radio galaxy. If one restricts attention to the radio sources, which are classical doubles, there is little or no correlation between radio and optical luminosity for these cD galaxies.

Komberg: Is there a correlation between the properties of elongated radio structures of radio galaxies in clusters of galaxies and the values of velocities of these galaxies, relative to the centre of the cluster?

Perola: At present we do not have sufficient data on the redshifts of galaxies in the clusters.

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