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HEAD-TAIL RADIO SOURCES IN CLUSTERS OF GALAXIES

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ABSTRACT

New observations are presented of six head-tail radio galaxies, five of which are previously unreported in the literature. Total intensity maps at 2695 MHz and optical identifications are presented. Some physical parameters of these sources are derived, and are found to be similar to those of the other known head-tail sources. For the 14 head-tail sources mapped to date, we find no pattern in the orientation of the tails with respect to the optical cluster centers. However, some tendency exists for the tails to be pointing away from nearby galaxies. We suggest a classification scheme for radio galaxies based on their optical dominance which illustrates the correlation between head-tail sources and galaxies of lower optical luminosity. Based on the observations available at present, we find that head-tail sources may be consistently described as resulting from relative motion of a galaxy through a hot, relatively dense, intracluster medium.

Subject headings: galaxies: clusters of — galaxies: intergalactic medium — radio sources: general

I. INTRODUCTION

Studies of head-tail ratio galaxies are among the most promising sources of information about radio source evolution and the intergalactic medium in clusters of galaxies. High-quality radio data on the few well-studied examples (e.g., NGC 1265, 3C 129) suggest that the "tail" parts of these sources are the trails left behind by radio galaxies plowing through a hot, relatively dense medium (Miley *et al.* 1972). The highly aligned polarization angles of NGC 1265 and 3C 129 also suggest at least semipermanent magnetic fields oriented parallel to the tails (Miley 1973). Jaffe and Perola (1973, 1974, hereafter JP) have proposed a magnetospheric model which explains the general features of the few well-observed cases. Although these sources may be explained by other mechanisms, the JP model is the only one published with sufficient detail to compare with observations. More examples of head-tail sources are needed to test the validity of the JP model, as well as to extend our knowledge about the intergalactic medium (IGM) in clusters of galaxies. During a survey of radio sources in the directions of Abell clusters of galaxies with the NRAO interferometer, we have found several new examples of head-tail sources. In this *Letter*, we present total intensity maps and optical identifications for six of these sources. We also discuss some derived physical parameters of these sources. For the 14 head-tail sources mapped to date, we examine their relationships to the corresponding optical fields.

II. OBSERVATIONS

Observations were made with the three 26 m telescopes of the NRAO interferometer at 2695 MHz, using 11 of the 16 possible baselines. Maps of the total intensities at 2695 MHz are presented here. More detailed data from the NRAO interferometer, including linear polarization, 8085 MHz maps, and observations on the 35 km baseline are under analysis and will be reported later. For each source, 100–200 well-distributed points were sampled in the (u, v)-plane. After calibration, these data were Fourier transformed, and the resulting maps cleaned (see, e.g., Hogböm 1974). The rms noise on the maps is 1–2 mJy per beam area.

The optical identifications were made from the Palomar Sky Survey E prints, using a technique similar to that described in Owen and Rudnick (1976). All objects within a region comparable in size to the radio extent were measured to an accuracy of $1''$–$2''$. For each of the six radio sources presented in this *Letter*, a single galaxy was coincident with the head of the source. In the case of 1712+640, a second galaxy was found approximately $15''$ down the tail.

III. RESULTS

Clean maps of the six head-tail sources at 2695 MHz are presented in Figure 1. The source 1712+640 has previously been reported to be a head-tail source (Slingo 1974*b*), which extends to the northeast to a distance of $90''$ from the galaxy. Our observations of this source show only the head and the first part of the tail. The source 1706+786 lies near the center of the X-ray cluster Abell 2256, and is another example of the association of head-tail radio galaxies and cluster X-ray sources.

The cross on each map marks the position of the optical identification. Slingo (1974*a*, *b*) has previously identified 0810+665, 1706+786, and 1712+640; however, we disagree with 1706+786. We agree with the identification for 0039+211 proposed by Riley (1975). Reproductions of the Palomar Sky Survey E prints are shown in Figure 2 (Plate L8), indicating the optical identifications.

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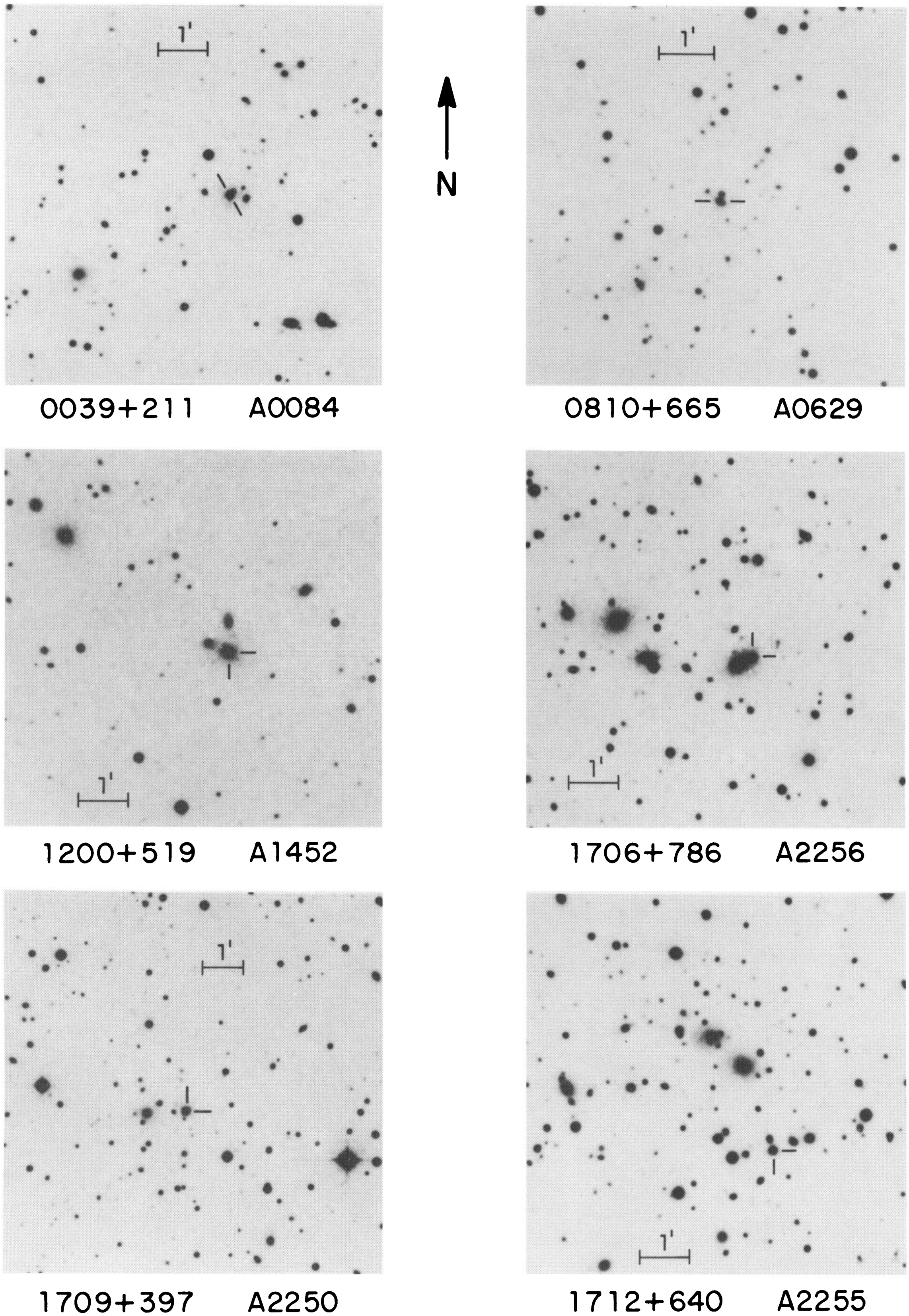

FIG. 2.—Finding charts for head-tail sources. © National Geographic Society–Palomar Sky Survey. Reproduced by permission from the Hale Observatories.

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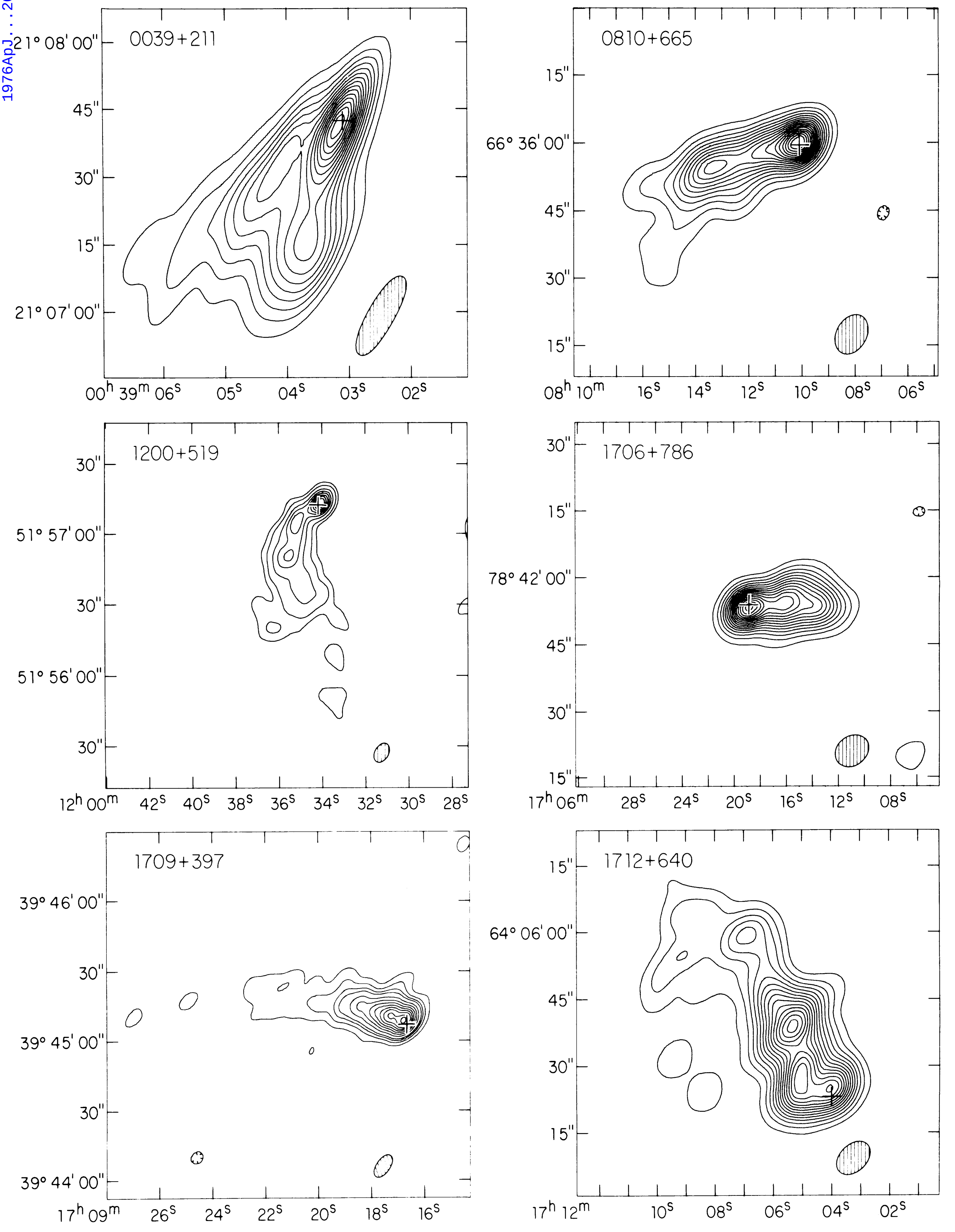
0039+211
21° 08' 00"
45"
30"
15"
21° 07' 00"
00h 39m 06s
05s
04s
03s
02s
0810+665
15"
66° 36' 00"
45"
30"
15"
08h 10m
16s
14s
12s
10s
08s
06s
1200+519
30"
51° 57' 00"
30"
51° 56' 00"
30"
12h 00m
42s
40s
38s
36s
34s
32s
30s
28s
1706+786
30"
15"
78° 42' 00"
45"
30"
15"
17h 06m
28s
24s
20s
16s
12s
08s
1709+397
39° 46' 00"
30"
39° 45' 00"
30"
39° 44' 00"
17h 09m
26s
24s
22s
20s
18s
16s
1712+640
15"
64° 06' 00"
45"
30"
15"
17h 12m
10s
08s
06s
04s
02s

IV. PHYSICAL PARAMETERS

Characteristic physical parameters for each source were derived from the radio observations, and are given in Table 1. The redshifts given in Table 2 and a Hubble constant of 50 km s^{-1} Mpc^{-1} were used. Cutoff frequencies of 10^7 and 10^{10} Hz, equal electron and proton energies, and cylindrical symmetry of the radio structure were assumed for these calculations. The most serious uncertainty is probably in our lack of knowledge of the true emitting volumes V. If the emitting region were confined to a plane or to narrow tubes, for example, this would result in an underestimate of the equipartition field proportional to $V^{-2/7}$.

All of these derived parameters are similar to those found for other head-tail sources in rich clusters. A somewhat smaller field has been found by Schilizzi and Ekers (1975) for the head-tail source in the poor cluster Zw 2247+11. In the JP model, the magnetic field energy must be larger than the relativistic particle energy to maintain the field alignment along the tail. Thus, the equipartition fields and corresponding thermal pressures quoted ($p = nkT$) are lower limits. On the other hand, the additional ram pressure from the galaxy motion through the external medium will reduce the required thermal pressure. Despite these unknown factors, the calculated values are consistent with estimates of nT ($\approx 10^5$ K cm^{-3}) resulting from X-ray observations of rich clusters (e.g., Lea *et al.* 1973; Kellogg, Baldwin, and Koch 1975). Therefore, no difficulties arise in confining the head-tail sources, at least from these observations.

Crude estimates of the velocities of the relativistic particles in the tails with respect to the associated galaxies can also be made. We assume that all "blobs" originally have the same luminosity, and that the change in brightness down the tail is dominated by synchrotron and inverse Compton losses. Assuming a constant magnetic field (equal to the equipartition value) we derive typical values of a thousand to a few thousand kilometers per second. These values are also consistent with typical velocity dispersions measured for rich clusters of galaxies. However, higher resolution observations are required to make more reliable estimates.

V. OPTICAL FIELDS

Two relevant clues to the nature of head-tail sources can be obtained from the relation of the head-tail galaxy to the rest of the cluster. First, there should be a pattern to the orientation of the tails with respect to the cluster centers if there are any radially symmetric flows in the IGM, with velocities comparable to those of the galaxies. Second, if the motion of the galaxy through the external medium is important in determining the head-tail structure, we might expect head-tail sources in clusters to be associated with fainter, less massive galaxies. The most massive, dominant galaxy in the cluster might be expected to have a smaller random velocity with respect to the IGM, if some equipartition of energy has occurred.

Table 2 summarizes the data on the optical fields for the 14 available examples of head-tail sources. We find no tendency for the tails in this sample to be pointing toward or away from their respective cluster centers. This may not be surprising since many of these clusters

TABLE 1

PHYSICAL PARAMETERS

Source	Luminosity $h^{-2}\times10^{42}$ ergs s^{-1}	Spectral Index	z^2S_{2695}(mJy)	Width h^{-1} kpc	Equipartition field $h^{2/7}\times10^{-6}$ gauss	Density × Temperature $h^{4/7}\times10^4$ K cm^{-3}
0039+211	3.0	0.8	5.6	28	6	1
0810+665	1.8	0.9	2.7	$\lesssim$24	$\gtrsim$8	$\gtrsim$2
1200+519	1.0	0.7	1.8	17	8	2
1706+786	0.15	0.7	0.3	$\lesssim$11	$\gtrsim$8	$\gtrsim$2
1709+397	1.2	1.1	1.1	$\lesssim$13	$\gtrsim$10	$\gtrsim$3
1712+640	0.8	1.1	0.8	17	8	2

NOTES TO TABLE 1

Column (1) gives the source name. Column (2) is the total luminosity of the source, using the spectral index given in column (3), defined by $S \propto \nu^{-\alpha}$. Column (4) gives the monochromatic luminosity at 2695 MHz.

Column (5) is the half-power width of the source used to calculate the equipartition field. Column (6) is an estimate of the equipartition magnetic field just behind the head of the source, assuming $\alpha = 0.7$ at this point. Column (7) gives the density-temperature product outside the tail, required to statically balance the equipartition field pressure. The explicit dependence of each parameter on the Hubble constant is shown, where $H_0 \equiv 50h$ km s^{-1} Mpc^{-1}, and h was assumed equal to 1.

The following references were used to derive approximate overall spectra: Williams *et al.* (1966); Pilkington and Scott (1965); Gower *et al.* (1967); Caswell *et al.* (1967); Colla *et al.* (1973); Slingo (1974*a*, *b*); Riley (1973), Owen (1975).

FIG. 1.—Total intensity maps at 2695 MHz. Contour levels are at equally spaced multiples (unless otherwise noted) of the following flux densities per clean beam area: 0039+211: 4.3 mJy/beam; clean beam = 19″.7 × 5″.7 at 150°. 0810+665: 2.1 mJy/beam; clean beam = 8″.9 × 6″.7 at 150°. 1200+519: Levels at (1,2,4,6,8,10,12,14) × 2.5 mJy/beam; clean beam = 9″.1 × 6″.3 at 153°. 1706+786: 0.98 mJy/beam; clean beam = 8″.1 × 6″.4 at 132°. 1709+397: Levels at (1,2,3,4,6,8,10,12,14,16,18,20) × 2.1 mJy/beam; clean beam = 11″.3 × 6″.2 at 145°. 1712+640: 0.81 mJy/beam; clean beam = 8″.7 × 6″.1 at 138°. The clean beams are shown as shaded ellipses on the maps.

TABLE 2

OPTICAL FIELD DATA

Source	Cluster	Richness	Redshift	Opt. Dom. Type	Tail Direction with Respect to Center	Tail Direction with Respect to Nearby Galaxies	Ref.
0039+211	A0084	1	0.118	2	Toward	Away from nearest galaxy	*
4C 13.17A	A0401	2	0.063	3	Away	Away from dominant cluster members	1
IC 310	A0426	2	0.018	3	Away	Away from dominant cluster members	2
0314+413	A0426	2	0.018	3	Toward	Toward dominant cluster members	3
3C 83.1B	A0426	2	0.018	3	Away	Away from dominant cluster members	2
3C 129	...	?	0.021	2(3?)	Away (?)	Away from 3C 129.1	4
3C 129.1	...	?	0.022	2(3?)	Away (?)	Away from 3C 129	5
0810+665	A0629	1	0.138	2	Toward	Away from nearest galaxy	*
1200+519	A1452	0	0.067	2	Away	Away from two nearby galaxies	*
5C 4.81	A1656	2	0.023	3	Away	Away from dominant cluster members	6
1706+786	A2256	2	0.054	3	?	Away from nearby galaxy	*
1709+397	A2250	1	0.061	2	Away	Toward nearest comparable galaxy	*
1712+640	A2255	2	0.078	3	Toward	Toward dominant cluster members	1
2247+11	Zw 2247+11	≤0	0.027	2	Toward	Away from nearest comparable galaxy	7

NOTES TO TABLE 2

The redshifts refer to the clusters (except as noted) and were derived from the following sources: 0039+211, 0810+665, 4C 13.17A: estimated from tenth brightest galaxy, Abell (1958). 1200+519, 1706+786, 1709+397: M.-H. Ulrich, private communication. 1712+640: Zwicky (1971). 3C 129, 3C 129.1: individual galaxy redshifts from Spinrad (1975).

The other redshifts may be found in the references to the maps, which are as follows: *This paper. (1) Slingo 1974*b*. (2) Ryle and Windram 1968. (3) Miley *et al.* 1972. (4) Hill and Longair 1971. (5) Miley 1973. (6) Willson 1970. (7) Schilizzi and Ekers 1975.

The cluster centers are from Abell (1958) and Zwicky *et al.* (1965), with improved values, where available, from Bahcall (1974).

do not have a well-defined concentration of galaxies at their optical center. On the other hand, there may be some tendency for the tails to be pointing away from the nearest large galaxy or concentration of galaxies in the cluster (i.e., the tail is farther away from these neighbors than is the head). However, 1709+397 and 1712+640 are counterexamples to this pattern, at least in projection. Thus, we find no evidence for radially symmetric velocity fields in the IGM, although more localized patterns may exist.

To examine the correlation of head-tail galaxies in clusters with the degree of optical dominance, it is useful to introduce a classification scheme for cluster galaxies. The scheme is somewhat analogous to the Bautz-Morgan system for clusters as a whole (Bautz and Morgan 1970). Type 1 galaxies are defined as those which are clearly dominant optically over the rest of the cluster. Type 2 galaxies are those whose optical luminosity is comparable to the other brightest galaxies in the cluster. Type 3 galaxies are much less luminous than the brightest galaxy in the cluster. Examples of types 1, 2, and 3 are, respectively NGC 6166 (3C 338), NGC 4874 (5C 4.85), and NGC 4869 (5C 4.81).

Applying this classification to the 14 head-tail radio galaxies, we find that they are all either of type 2 or type 3 (see Table 2). Since other kinds of cluster radio sources are associated with type 1 galaxies, one explanation for this correlation is that head-tail radio galaxies move at high velocities through the intracluster medium.

VI. CONCLUSIONS

By examining the gross characteristics of head-tail sources, we find that they may be consistently described in terms of relative motions of radio galaxies through the local IGM in clusters of galaxies. Observations presented in this paper are consistent with the JP magnetospheric model. However, these observations are not sufficient to confirm the detailed predictions of that particular model. In addition, we have not dealt with such features as the spreading of the tails (0039+211, 1200+519) and the curvature of the tails (1200+519, 1709+397).

We also note that in the clusters containing 0039+211, 1200+519, and 1709+397 there are no other sources of comparable radio luminosity, contrary to earlier ideas about head-tail sources (e.g., Hill and Longair 1971).

We summarize the major characteristics of head-tail sources which have resulted from this analysis:

1. The equipartition magnetic fields and the thermal pressures required to confine them are consistent with the characteristic densities and temperatures implied by X-ray observations of rich clusters.
2. Rough estimates of the velocities of relativistic particles down the tail are consistent with typical dispersion velocities for rich clusters.
3. No tendency exists for radio tails to point toward or away from cluster centers; however, there appears to be a tendency for them to point away from nearby galaxies in the cluster.
4. Head-tail radio sources are not associated with the single dominant galaxy in a rich cluster. This is consistent with the hypothesis that motion through the IGM is responsible for the tails, and that single dominant galaxies are at rest with respect to the IGM.

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