A PRELIMINARY EXAMINATION OF THE EFFECT OF CLUSTER GAS ON TAILED RADIO GALAXIES

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ABSTRACT

From a comparison of X-ray and radio data for 20 clusters which contain tailed radio galaxies, we find evidence for the effects of buoyant forces on the low brightness parts of radio tails. In several cases, the width of the tail increases markedly in low gas density regions, strengthening the case for thermal gas confinement of radio tails. Three examples of enhanced X-ray emission around radio galaxies which are further than 2 Mpc from their cluster centers are found.

1. INTRODUCTION

The basic features of cluster radio sources have been worked out over the last ten years predominantly from the radio observations and supporting optical data. Now, however, we are able to study the gas distribution from Einstein Observatory (EO) images of clusters. These new data will allow us to evaluate many of the hypotheses involved in models of tailed radio galaxies (TRG). The present paper is a preliminary comparison of published radio maps of TRGs with EO observations obtained with the imaging proportional counter (one degree field with 1.5 arcmin resolution, Gorenstein et al. 1981). The X-ray observations are non-uniform in sensitivity because of different exposure times. Furthermore, there is a positional uncertainty of up to one arcmin for features on most of the IPC images which were processed prior to February 1981.

For convenience we divided the radio sources into 3 groups according to the length of the tail: short (< 100 kpc), medium (100 to 400 kpc) and long ($\gtrsim$ 400 kpc). These groups are rather coarse because the available radio data do not have a uniform sensitivity, resolution, or frequency coverage.

The present sample consists of 20 clusters (Table 1). These were chosen purely on the basis of available data and for this reason, the results noted below should be considered as "exploratory".

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Table 1. A Selection of Tailed Radio Galaxies for Which IPC X-ray Observations are Available

Cluster	Radio Type	Consistent with Buoyancy? H	L	Observer	Notes
A84	S	–		R	
A401	L	–	–	CAL	
A478	S	–		CFA	
3C129	S,L		+	CAL	
A629	M	–		CFA	
A754	L		+	HCDE	1,2
A1314	L,S(WAT)	–	+	HCDE	
A1367	M			CFA	
A1775	M	–	+	CFA	
A1940	M(WAT)	–		CFA	
A2022	L			CFA	
Zw 1615	L	–	+	HCDE	
A2199	S(WAT)			CFA	
A2220	M(WAT)		+	B	1
A2250	L	–	+	HCDWM	2
A2255	M	–	+	CFA	1
A2256	M			CFA	
A2306	M(WAT)	+	+	HCDE	
A2319	S			CFA	
4C47.51	L(WAT)		+	B	2

Notes: The radio types are L, long, M, medium; and S, short. "WAT" means "wide angle tail".

The columns "H" and "L" contain entries which indicate if the source morphology is (+) or is not (–) consistent with buoyancy effects. "H" is for the higher surface brightness parts of the radio tail and "L" is for the lower brightness parts.

Abbreviations for the observer are:
- CFA: Center for Astrophysics
- CAL: Columbia Astrophysics Laboratory
- R: J.G. Robertson
- B: J.O. Burns
- HCDE: Harris, Costain, Dewdney, and Ekers
- HCDWM: Harris, Costain, Dewdney, Willis, and Miley

1. This entry is, or contains, a radio galaxy which is associated with an X-ray source which is separate from the general cluster emission.
2. Apparent expansion of the radio source coincides with a region of lower gas density.

2. BUOYANCY

The effects of buoyancy on extended radio lobes have been suggested by many authors. To determine if the radio morphology could be caused by buoyant forces, we have assumed that higher surface brightness regions on the X-ray map correspond to spatial regions of higher gas density. This assumption is reasonable because the X-ray emissivity is proportional to the square of the electron density. However, moderate densities with long path lengths will also increase the surface brightness as will local heating of a cool gas where the emissivity is dropping exponentially in the EO energy band.

Examination of the present sample leads us to suggest that the high brightness parts of radio tails often bend toward high density regions but that the low brightness parts usually bend towards regions of lower density. Figure 1 is an X-ray map of Abell 2255 with a sketch of the radio sources superimposed. The bright part of the TRG, 4C64.20.1A, extends into the central, high density region. At 610 MHz (not shown), the tail is weak and bends to the north, a region

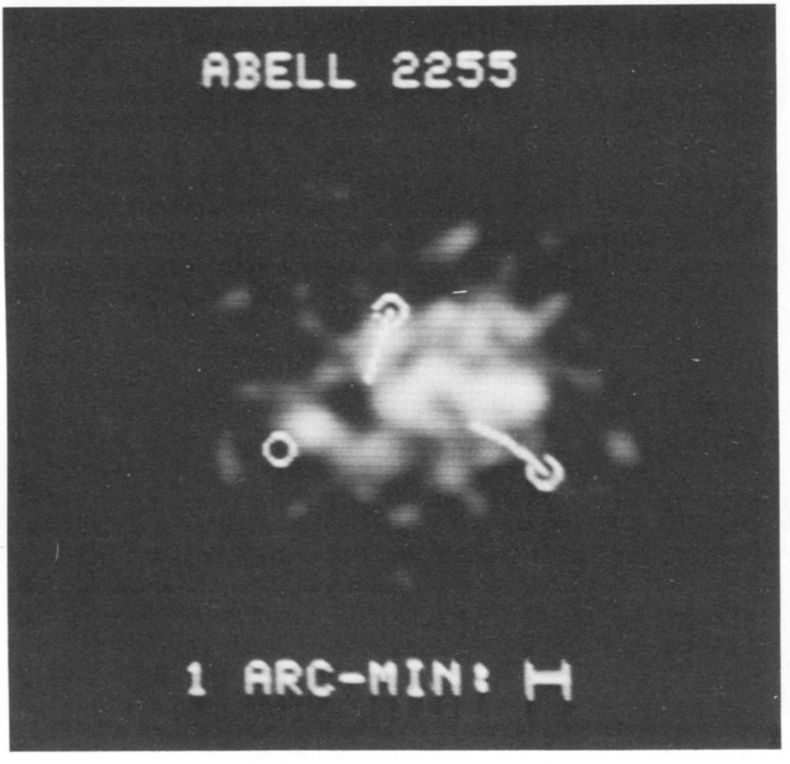

Figure 1. A2255. The X-ray map is shown by the grey scale, the radio galaxies by small circles, and the radio tails by white lines. For H_o=50 km s^{-1} Mpc^{-1}, one arcmin=138 kpc. The X-ray image has been smoothed with a Gaussian of 48".

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of lower gas density. The details of the radio structure may be found in Harris et al. (1980a).

Abell 2250 is shown in Figure 2. Here, the bright part of the tail cuts across the central high density region, but the faint ends of both tails bend into low density regions (unpublished observation at 610 MHz).

An example of a wide angle tail (WAT) is shown in Figure 3 (Abell 2306). In this case, the whole structure is consistent with the effects of buoyancy.

In Table 1, we have indicated by a "+" or "-" whether or not the radio structure bends towards regions of low density. If our analysis is correct, the simplest explanation would be that the primary curvature of TRGs comes from curved trajectories of the parent galaxy, but that the older, lower surface brightness parts of the tails have had sufficient time to respond to buoyant forces.

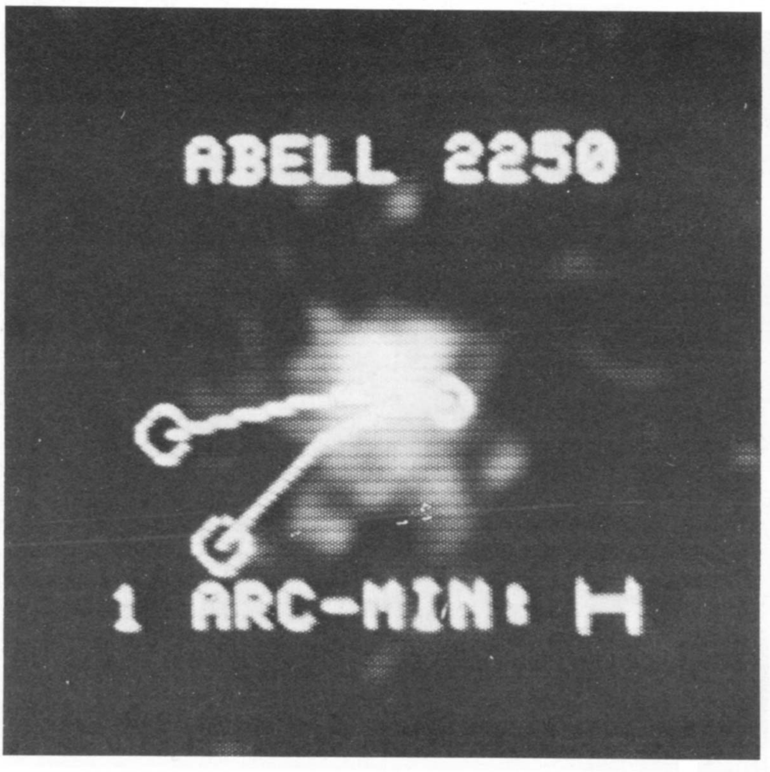

Figure 2. Abell 2250. The scale is 114 kpc for one arcmin. The two circles at the East ends of the tail indicate the positions of the expanded radio components mentioned in the text.

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3. THERMAL CONFINEMENT

An approximate parity between the external gas pressure and the internal pressure in radio lobes has been found for many TRGs. The external pressure is estimated from the gas density and temperature, both derived from the X-ray observations, and the minimum internal pressure is calculated from the minimum energy density of the magnetic field and relativistic particles. Since the non-thermal pressure is often close to the external gas pressure, it follows that the internal gas pressure is probably substantially less than the external gas pressure. This is consistent with the conjecture that radio tails are less dense than the surrounding medium and are thus subjected to buoyant forces.

For three clusters in the present sample, A2250 (Fig. 2), A754, and 4C47.51, we find radio structure which shows evidence of thermal confinement. In all three cases, we see a relatively narrow tail which becomes wide and puffy in regions of low gas density.

Figure 3. A2306. The head of this wide angle tail lies close to the brightest part of the X-ray image. An extended radio source just to the north is identified with a double galaxy. For an estimated redshift of z=0.1, the scale would be 175 kpc/arcmin.

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4. LOCAL GAS AROUND ISOLATED RADIO GALAXIES

The incidence of hot gas around radio galaxies is presently being studied by many authors. Here we note three cases of radio galaxies which lie at a projected distance of 2 to 4 Mpc from their respective cluster centers and which appear to be X-ray sources. The associated X-ray emission is quite distinct from the general cluster emission. The TRG in A2255 called "the Beaver" by Harris et al. (1980a) lies 2.6 Mpc to the south of the cluster center and is coincident with an unresolved X-ray source. The TRG in A754 (26W20, Harris et al. 1980b) is associated with an extended IPC source, and a galaxy which may be a member of A2220 (14W79, Harris et al. 1980a) also coincides with an IPC source.

While it is natural to hypothesize a higher density gas filling a local potential well, two other explanations should be investigated. For unresolved sources, the X-ray emission may arise from the nucleus of the galaxy rather than from a halo around the galaxy. Another possibility is local heating. If the outer regions of most clusters contain large amounts of gas at temperatures $\lesssim 10^6$K, then local heating from radio galaxies could result in raising the temperature of this gas such that the 0.1 to 4 keV X-ray emission would be greatly enhanced. Evidence for gas at large distances from the center of A2255 is given by Hintzen and Scott (1980). A statistical study of normal and radio galaxies within 2 to 5 Mpc of cluster centers should help in differentiating between density enhancements and local heating.

5. THE LOCATION OF SMALL TRGs

There are a number of TRGs which are, in projection at least, physically small; on the order of 100 kpc or less. From the present sample, it appears that these "stubby" TRGs occur predominantly in regions of high gas density: 3C129.1, A478, A2199, A84, and two in A2319. Four of these six examples lie in the central regions of hot, smooth clusters and the other two are in the brighter parts of their respective clusters. The 3C129 cluster is a particularly striking example of this effect: 3C129.1 is in the center of the high brightness X-ray distribution while the long TRG, 3C129, skirts the edge of the visible gas.

Normally one assumes that short TRGs are just those that have a low velocity with respect to the surrounding gas. However, other possibilities should be considered. Is there any process which might suppress the creation of a long, well defined tail? Could high gas density and/or high temperature lead to excessive turbulence and rapid dispersion? If so, a dispersive loss of relativistic electrons might generate an extended radio halo of the type found in the Coma Cluster and in A2319.

6. SUMMARY

From a comparison of radio and X-ray observations of 20 clusters which contain tailed radio galaxies, we find:

(a) evidence for the effects of buoyancy on the old, faint parts of tails,
(b) evidence for thermal confinement of tails,
(c) the occurrence of enhanced X-ray emission from radio galaxies in the outer regions of clusters, and
(d) an indication that the formation of long, well defined tails may be suppressed in regions of high density and/or temperature.

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