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RADIO SOURCES WITH WIDE-ANGLE TAILS IN ABELL CLUSTERS OF GALAXIES

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ABSTRACT

Observations are presented of six previously unreported radio sources in rich clusters of galaxies. These sources were discovered during a survey of radio sources in Abell clusters of galaxies, using the NRAO interferometer. Total intensity maps at 2695 MHz and optical identifications are reported. Physical parameters are also derived for these radio galaxies, and their optical properties are summarized. It is argued that the sources presented here are a simple extension of the head-tail class of radio sources, only with larger angles between their twin tails. Sources with widely diverging tails usually seem to be associated with one of the more dominant galaxies in a rich cluster, unlike radio galaxies with long, thin tails. These wide-tail sources are also usually of higher radio luminosity than those with narrower tails. Some possible explanations of these correlations are discussed.

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

I. INTRODUCTION

Recent observational and theoretical work supports the picture that head-tail radio sources are the result of radio galaxies plowing through the intergalactic medium (IGM) in clusters of galaxies, leaving a trail of emission behind them (e.g., Miley, Wellington, and van der Laan 1972; Jaffe and Perola 1974; Rudnick and Owen 1976). Observations of 3C 129 and 3C 83.1 B reveal a twin-tailed structure which has been interpreted by Jaffe and Perola (1973) as due to the stretching out of permanent dipolar magnetic fields by rapid motion through the IGM. However, this magnetospheric model and other possibilities need to be considered in more detail both theoretically and observationally before a single explanation of these phenomena can be adopted. In any case if motion through the IGM is important in determining the radio structure, one might expect to find wider angles between the twin tails of galaxies with lower relative velocities. Possible examples of such sources are 3C 465 and 3C 338 (Riley and Branson 1973; Jaffe and Perola 1973, 1974). In this *Letter*, we present new observations of six sources discovered during our survey of Abell clusters of galaxies with the NRAO interferometer (Owen and Rudnick 1976; Rudnick and Owen 1976). We suggest that the structures of these sources can be interpreted as wider angle twin tails, resulting from their relatively slower motion through the IGM. We also discuss the physical parameters and the optical fields of these sources in comparison to those of sources with narrower tails.

II. OBSERVATIONS AND RESULTS

Observations and reductions were made in the manner described by Rudnick and Owen (1976, hereafter Paper I). The cleaned maps at 2695 MHz are presented in Figure 1 for each of the six sources. Peak flux densities which are not shown on the maps are listed in the legend. The optical finding charts from the E prints of the Palomar Sky Survey are shown in Figure 2 (Plate L1). The physical parameters of the six sources derived from the respective brightness distributions are summarized in Table 1. The calculation of these parameters was carried out as in Paper I. In all cases, the equipartition fields and equivalent static thermal pressures have been calculated for the region of highest apparent surface brightness in the tail. Slightly larger equipartition fields and equivalent pressures are found for some of these sources than for the classical head-tail sources discussed in Paper I. Since no evidence exists for further bifurcation of the individual wide tails, it may be less likely that large overestimates of the emitting volumes have been made than was the case for the sources in Paper I. This may explain the slightly larger fields in wide tails. The values are all still consistent, however, with X-ray data for similar rich clusters, which suggest pressures (p) such that $p/k = nT \approx 10^5$ K cm^{-3} (e.g., Lea *et al.* 1973; Kellogg, Baldwin, and Koch 1975).

The properties of the optical fields of the new wide tail sources are listed in Table 2, along with those of 3C 465 and 3C 338. As can be seen, most of these sources are associated with optically dominant galaxies, in contrast to the narrow-tail sources discussed in Paper I.

III. DISCUSSION

In general, the sources discussed here have pronounced linear structures and a significant degree of misalignment with respect to their parent galaxy. Several of the sources (e.g., 1159+583, 1636+379, 3C 465) have most of their tail-like structure farther away from the central galaxy than their outlying components of highest surface brightness. This is unlike the structure of classical double sources (e.g., Cygnus A, 3C 33, 3C

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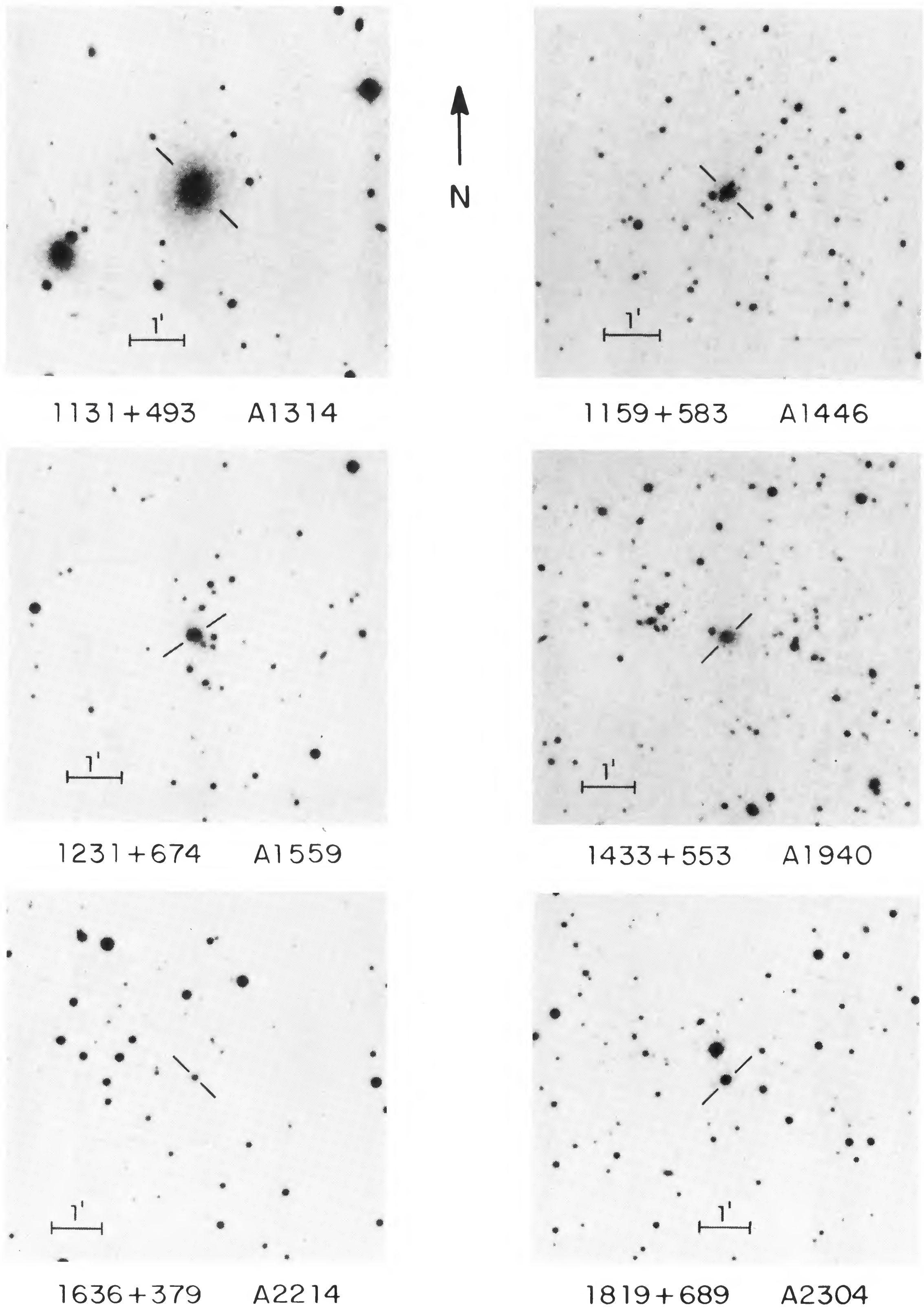

FIG. 2.—Finding charts for wide-tail sources. © *National Geographic Society—Palomar Sky Survey*. Reproduced by permission from the Hale Observatories.

OWEN AND RUDNICK (*see* page L1)

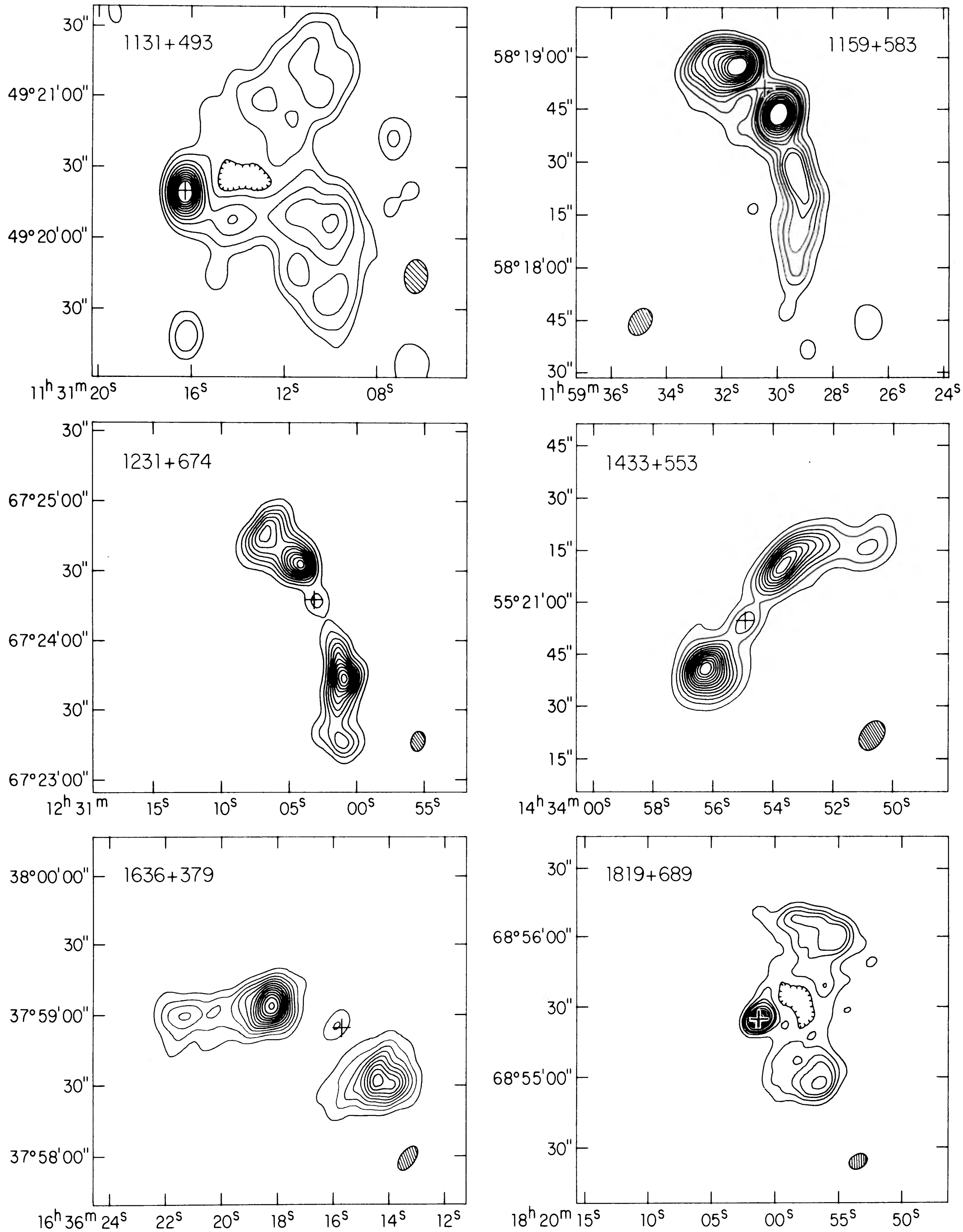

FIG. 1.—Total intensity maps at 2695 MHz. Contour levels are at equally spaced multiples (unless otherwise noted) of the flux densities per clean beam area listed below. 1131+493, levels at (1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20) × 3.0 mJy, peak = 111 mJy, 1159+583, levels at (1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20) × 1.9 mJy, peak of NE comp = 67 mJy, SW comp = 76 mJy. 1231+674, 3.6 mJy. 1433+553 3.5 mJy. 1636+379, 2.8 mJy. 1819+689, levels at (1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18, 20) × 3.7 mJy, peak = 74 mJy. The clean beams are shown as shaded ellipses on the maps.

TABLE 1

PHYSICAL PARAMETERS

Source	Luminosity ($h^{-2}\times10^{42}$ ergs s^{-1})	Spectral Index	z^2S_{2695}(mJy)	Equipartition Field ($h^{2/7}\times10^{-6}$ gauss)	Density$\times$ Temperature ($h^{4/7}\times10^4$ K cm^{-3})
1131+493........	0.8	1.1	0.6	5	1
1159+583........	5.4	0.9	7.4	22	14
1231+674........	6.4	0.9	10.4	10	3
1433+553........	2.8	0.8	5.0	15	6
1636+379........	5.5	0.8	10.3	9	2
1819+689........	4.1	0.7	8.6	7	1

NOTES TO TABLE 1.—Column (1) gives the source name. Column (2) is the total luminosity of the source, using the overall spectral index given in column (3), defined by $S \propto \nu^{-\alpha}$. Column (4) gives the monochromatic luminosity at 2695 MHz. Column (5) is an estimate of the equipartition magnetic field for the component of highest surface brightness, using α from column (3) or from our data at 8085 MHz when possible. Column (6) 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}, and h was assumed = 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; Kellermann *et al.* 1969; Riley 1973; Owen 1974; Owen 1975b.

TABLE 2

OPTICAL FIELD DATA

Source	Cluster	Richness	Redshift	Opt. Dom. Type
1131+493........	A1314	0	0.034	2
1159+583........	A1446	2	0.131	1
1231+674........	A1559	1	0.146	1
1433+553........	A1940	3	0.131	1 (2?)
1636+379........	A2214	0	0.179	1
1819+689........	A2304	0	0.131	1
3C 338..........	A2199	2	0.031	1
3C 465..........	A2634	1	0.031	1

NOTES TO TABLE 2.—Measured redshifts are quoted for 3C 338, 3C 465, and 1131+493 and are estimated for the remaining clusters from the tenth brightest galaxy (Abell 1958) as summarized in Owen (1975*a*). The optical dominance classification is described in Paper I.

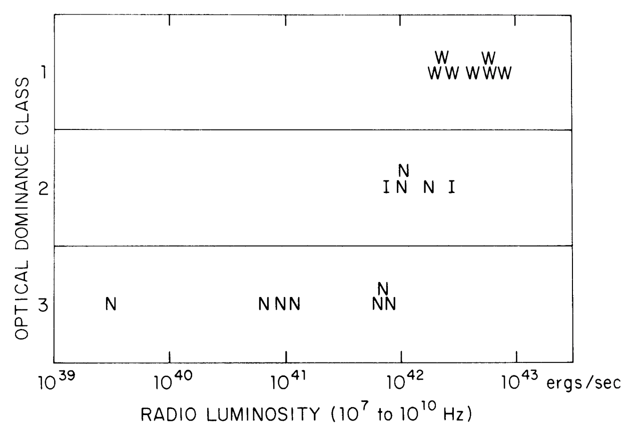

FIG. 3.—Comparison of properties of head-tail sources in Abell clusters. Sources are included in the figure as follows: N: 4C 13.17 A, IC 310, 3C 83.1 B, 0314+413, 0810+665, 1200+519, 5C 4.81, 1706+786, 1709+397, 1712+640. I: 0039+211, 1131+493. W: 1159+583, 1231+674, 1433+553, 1636+379, 1819+689, 3C 338, 3C 465.

390.3), but suggests a morphology similar to the carefully studied head-tail sources (e.g., 3C 129, 3C 83.1 B). The sources 0039+211 (Paper I) and 1131+493 appear to be cases intermediate between sources with very narrow tails, and those with wide-angle tails, suggesting a continuity in the properties of these sources. Thus, it seems appropriate to interpret these sources as further examples of a more general class of head-tail type radio galaxies. Their relationship to classical double sources is unclear, at present.

A comparison of the radio structure, radio luminosity, and optical dominance types (see Paper I) is presented in Figure 3 for the various types of head-tail sources near the centers of Abell clusters. Sources are subjectively classified N (narrow tail), I (intermediate), or W (wide tail), according to their radio structure. There is a strong tendency for sources with wider tails to be associated with more dominant galaxies. This would result if the ratio of the radial outflow velocity for relativistic particles to the velocity of the galaxy through the IGM were larger for more massive galaxies. A higher ratio could arise if more massive galaxies eject particles with larger bulk velocities than smaller radio galaxies (Jaffe and Perola 1973). However, another possible scenario for obtaining a higher ratio is that more dominant galaxies have smaller velocities relative to the IGM. The latter explanation would be valid if some equipartition of kinetic energy had taken place in the clusters. This seems likely to account at least in part for the observed correlation.

The correlation of luminosity with the width of the tails, or, alternatively, with the optical dominance class, would be expected if more massive galaxies simply produce more luminous radio events. On the other hand, the static pressure produced by the IGM around a dominant galaxy near the center of a cluster should be higher than that found in the vicinity of less massive galaxies. This would produce a larger magnetic field, and thus more radio emission. This possibility is not directly testable from the equipartition fields since their relation to the actual fields is not known. The fact that a correlation can be seen at all suggests that fairly similar conditions exist near the centers of many of these clusters.

IV. CONCLUSIONS

Our observations suggest the existence of a class of radio sources with wide-angle tails which are a simple extension of the head-tail phenomenon. Sources with wide tails are usually associated with more dominant cluster galaxies, and have higher radio luminosities than sources with narrower tails. The larger angle between the twin tails of some sources is probably due, at least in part, to the relatively slower velocities of the associated galaxies with respect to the IGM. The higher luminosities could be caused by higher total energies in the radio events, and/or higher thermal pressures around massive galaxies near the centers of these clusters.

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