*Mon. Not. R. astr. Soc.* (1978) **184**, 221–225

# Morphology and peculiar velocities of radio sources in rich clusters of galaxies

B. Guindon and A. H. Bridle *Queen's University at Kingston, Ontario K7L 3N6, Canada*

Received 1978 January 4

**Summary**. We examine data pertinent to a test for correlation between the peculiar velocities and the radio morphologies of radio sources in rich clusters of galaxies. The significance of the test is presently limited by the small amount of data on 'classical double' and 'wide tail' structures in rich clusters, but models wherein distortions from the 'classical double' form increase with the peculiar velocity of the parent galaxy are marginally favoured.

## Introduction

Recent high-resolution studies of radio sources in rich clusters of galaxies have shown that their structures are frequently distorted from the 'classical double' (CD) form. Rudnick & Owen (1977, and references therein) have classified the distorted structures as 'narrow', 'intermediate' and 'wide' tails (NT, IT, WT henceforth) according to the extent of their departure from collinearity. The WT structures are virtually collinear sources, distinguishable from CD structures mainly by the property that their high-brightness regions are closer to the parent galaxy than to the extremities of the source, and are therefore 'class I' morphologies in the nomenclature of Fanaroff & Riley (1974).

Theoretical models for the distorted structures have invoked: (a) large ratios between the peculiar velocity $v_p$ of the parent galaxy relative to a dense intracluster medium and the velocity $v_e$ with which the radio-emitting material is ejected from the parent galaxy (e.g. Jaffe & Perola 1973; Pacholczyk & Scott 1976), or (b) density gradients in an intracluster medium (e.g. Harris 1974; Christiansen 1974). Lea (1976) and Guindon (1976, 1978) have shown that the NT structures are not preferentially oriented towards the outward radii of their clusters as predicted by simple density-gradient models. In this communication we examine the evidence for the correlation between peculiar velocities and bent radio morphologies which might be pertinent to the first class of model.

## Three hypotheses

The radial (recessional) component of a galaxy's velocity relative to the mean velocity of its cluster can be estimated if the redshifts of the radio galaxy and of a sufficient number of other cluster members have been determined. Three possible relationships might be envisaged between this radial component of the peculiar velocity and the *observed* source morphology (the projection of the true morphology on to the plane of the sky):

(1) If the velocity-related models for the distortions are incorrect, we should find *no correlation between source morphology and peculiar radial velocity*; the peculiar velocities of CD and WT sources should be statistically the same as those of IT or NT sources.

(2) If the distortions are produced by motion of the galaxies through an ambient medium but the variety of observed morphologies arises more from the variety of possible projections than from variation in the peculiar velocities, then *the most apparently distorted structures (NT) would have* the highest transverse peculiar velocities and *the lowest radial peculiar velocities.*

(3) If the distortions are produced by motion of the galaxies through an ambient medium, and projection statistics are similar for the different classes of structure (so that the most apparently distorted structures are those with the highest three-dimensional peculiar velocities), *the most apparently distorted structures (NT) would have* the highest transverse peculiar velocities and *the highest radial peculiar velocities.*

The strengths of the correlations expected on the second and third hypotheses would depend on the extent to which variation in the ratio $v_p/v_e$ is produced by variation in the peculiar velocities $v_p$ rather than by variation in the ejection velocities $v_e$.

## Data

We have examined the above hypotheses using data from the literature for sources meeting all of the following requirements:

(a) the radio structure has been mapped with sufficient angular resolution to permit classification as CD, WT, IT or NT with reasonable certainty,

(b) the extremities of the structure are at a projected distance > 50 kpc from the parent galaxy ($H_0 = 50\,\mathrm{km/(s\,Mpc)}$, $q_0 = 0.5$) so there has been sufficient time for motion through an intracluster medium to affect the source morphology,

(c) the radial velocity $v_r$ of the radio galaxy is known, and

(d) the radial velocities of at least 10 other cluster members are known, so that the mean radial velocity $\langle v_r \rangle$ of the cluster can be estimated with reasonable accuracy.

Table 1 lists the sample meeting all four requirements. Column 1 gives the source designation (IAU convention) and column 2 its 'common name' from a radio survey (nomenclature as in Kesteven & Bridle 1977) or from the *Index Catalogues.* Below the common name is the name of the optical cluster. Columns 3–5 give optical data: column 3 the number of cluster members from which $\langle v_r \rangle$ was determined, column 4 the absolute value of the radial peculiar velocity of the radio source, $v_{p,r} = v_r - \langle v_r \rangle$, and column 5 the absolute visual magnitude of the parent galaxy. The data in column 5 were obtained by estimating the apparent visual magnitudes of the galaxies by comparing their images on the red and blue prints of the *Palomar Sky Atlas* with those of elliptical or S0 galaxies in the Coma Cluster for which accurate visual magnitudes were given by Rood (1969). These estimates (accuracy ~0.5 mag) have been corrected for mean galactic absorption using the law $\Delta m = 0.25(\csc|b| - 1)$. The K-correction for elliptical galaxies given by Oke & Sandage (1968) was applied.

Column 6 gives the 2.7-GHz monochromatic luminosity of the radio source in W/Hz. References to the original redshifts and radio data are codified in column 7 and in the footnotes to the table. The table is organized by morphological type in order of decreasing

**Table 1.** Cluster radio sources > 50 kpc in extent with measured peculiar velocities.

| (1) Designation | (2) Common name | (3) Number of velocities | (4) $\lvert v_r - \langle v_r \rangle \rvert$ (km/s) | (5) $M_V$ | (6) $P_{11}$ ($10^{22}$ W/Hz) | (7) References |
|---|---|---|---|---|---|---|
| NT structures: | | | | | | |
| 0255 + 133 | 4C 13.17A<br>Abell 401 | 14 | 2880 | −22.7 | 700 | 1, 2 |
| 0313 + 411 | IC 310<br>Abell 426 | 49 | 132 | −22.4 | 78 | 3, 4 |
| 0314 + 412 | 0314 + 41W<br>Abell 426 | 49 | 1037 | −21.5 | 2.9 | 3, 4 |
| 0314 + 416 | 3CR 83.1<br>Abell 426 | 49 | 2196 | −22.9 | 720 | 3, 4 |
| 1132 + 492 | IC 711<br>Abell 1314 | 16 | 436 | −22.7 | 140 | 5, 6 |
| 1256 + 281 | 5C 4.81<br>Abell 1656 | 206 | 64 | −21.9 | 40 | 7, 8 |
| 1706 + 787 | Abell 2256 | 14 | 487 | −22.8 | 77 | 9, 10 |
| 1712 + 640 | 4CT 64.20.1A<br>Abell 2255 | 15 | 256(412)$^\star$ | −23.6 | 740 | 11, 12 |
| Medians | | | ~460 | −22.7 | ~100 | |
| IT structures: | | | | | | |
| 1131 + 493 | IC 708<br>Abell 1314 | 16 | 547 | −23.4 | 290 | 5, 6 |
| 1601 + 173 | 1601 + 17W1<br>Abell 2151 | 15 | 575 | −23.1 | 240 | 13, 14 |
| 2335 + 267 | 3CR 465<br>Abell 2634 | 17 | 327 | −23.4 | 1900 | 15, 16 |
| Medians | | | ~550 | −23.4 | 290 | |
| WT structures: | | | | | | |
| 0043 + 201 | 4C 20.04<br>Abell 98 | 11 | 383 | −23.5 | 1800 | 9, 17 |
| 1433 + 553 | 4C 55.29<br>Abell 1940 | 14 | 84 | −23.7 | 3100 | 9, 18 |
| 1626 + 396 | 3CR 338<br>Abell 2199 | 19 | 53 | −24.1 | 530 | 19, 20 |
| Medians | | | 84 | −23.7 | 1800 | |
| CD structure: | | | | | | |
| 1713 + 641 | 4CT 64.20.1C<br>Abell 2255 | 15 | 16(652)$^\star$ | −24.1 | 680 | 11, 20 |

$^\star$Tarenghi & Scott (1976) suggest that Abell 2255 may be a superposition of two clusters with slightly different mean velocities, or a single cluster with an unusually broad velocity distribution. We prefer the latter interpretation (Guindon, in preparation) and have used the one-cluster hypothesis as the basis for our peculiar-velocity estimates. The velocities corresponding to the two-cluster hypothesis are given in parentheses. The mean velocity of Abell 98 is also sensitive to cluster-membership criteria (Faber & Dressler 1977).

(1) Hintzen, Scott & Tarenghi (1977)
(2) Slingo (1974), Vallée, J. P. (private communication)
(3) Chincarini & Rood (1971)
(4) Miley *et al.* (1972)
(5) Coleman *et al.* (1976)
(6) Vallée & Wilson (1976)
(7) Tifft & Tarenghi (1975)
(8) Jaffe & Perola (1974)
(9) Faber & Dressler (1977)
(10) Bridle & Fomalont (1976)
(11) Tarenghi & Scott (1976)
(12) Rudnick & Owen (1976)
(13) Burbidge & Burbidge (1959)
(14) Valentijn & Perola (preprint, 1977)
(15) Scott, Robertson & Tarenghi (1977)
(16) Miley & van der Laan (1973)
(17) Owen, Rudnick & Peterson (1977)
(18) Owen & Rudnick (1976)
(19) Minkowski (1961)
(20) Rudnick & Owen (1977)

distortion from the CD structure; under each set of entries is given the median value of each of the physical parameters in columns 3–6.

## Discussion

Table 1 demonstrates the following:

(1) There is a weak trend for the median velocity difference $v_r - \langle v_r \rangle$ to decrease with decreasing distortion from the CD structure, but the number of CD, WT and IT sources satisfying all of our criteria for inclusion is small and the trend could be an artefact of small sample size. The only velocity differences >1000 km/s occur in the NT group, however, so *the evidence is most consistent with the third hypothesis above (velocity-dependent distortion and random projection)* and least consistent with the second (projection-dominated statistics).

(2) The more distorted structures have parent galaxies of lower optical luminosity. If the mass to light ratios of the radio galaxies are similar from class to class, the evidence suggests (again subject to the uncertainties intrinsic to the small sample size) that *more massive radio galaxies are more likely to have small peculiar velocities relative to their clusters.* This may be consistent with equipartition of kinetic energy among the brightest cluster members (for a recent discussion see Bahcall (1977) and references therein).

(3) As noted previously by Rudnick & Owen (1977) the more distorted structures have lower radio luminosities. The association between 'optical dominance' and morphology noted by these authors may also be equivalent to result (2) above.

(4) *There is an urgent need for more observations of velocities of galaxies in clusters containing CD and WT structures* to free this test from the tyranny of small-sample statistics. For example, the peculiar velocity of the only CD structure meeting all of our criteria depends significantly on whether or not Abell 2255 is a single cluster or two overlapping clusters with similar redshifts (Tarenghi & Scott 1976; Guindon, in preparation).

**Table 2.** Rich clusters containing well-resolved CD or WT structures.

| Cluster name | Radio-source designation | Type | Radio reference |
|---|---|---|---|
| Abell 595 | 0745 + 521 | WT/CD? | Rudnick & Owen (1977) |
| Abell 643 | 0816 + 526 | CD | Rudnick & Owen (1977) |
| Abell 1213 | 1113 + 295 | CD | Riley (1975), Owen, Rudnick &Peterson (1977) |
| Abell 1425 | 1155 + 266 | WT/CD? | Riley (1975), Owen, Rudnick & Peterson (1977) |
| Abell 1446 | 1159 + 583 | WT | Owen & Rudnick (1976) |
| Abell 1559 | 1231 + 674 | WT | Owen & Rudnick (1976) |
| Abell 1562 | 1232 + 414 | CD | Rudnick & Owen (1977) |
| Abell 1763 | 1333 + 412 | CD/WT? | Rudnick & Owen (1977) |
| Abell 2214 | 1636 + 379 | WT | Owen & Rudnick (1976) |
| Abell 2304 | 1819 + 689 | WT/IT | Owen & Rudnick (1976) |

The NT structures have recently received much attention because of their striking morphologies and possible association with cluster X-ray emission. The present results show that *radial-velocity studies of the clusters containing less distorted structures are important for testing models of the distorted structures.* Table 2 lists rich clusters containing well-defined D or WT structures, whose mean velocities will be valuable for future tests of the three hypotheses examined here.

## Acknowledgments

We thank Dr Jacques P. Vallée for a critical reading of an earlier version of this paper. This work was supported by grants from the National Research Council of Canada and from the Advisory Research Committee of Queen's University.

## References

Bahcall, N. A., 1977. *A. Rev. Astr. Astrophys.*, **15**, 505.
Bridle, A. H. & Fomalont, E. B., 1976. *Astr. Astrophys.*, **52**, 107.
Burbidge, G. R. & Burbidge, E. M., 1959. *Astrophys. J.*, **130**, 629.
Chincarini, G. & Rood, H. J., 1971. *Astrophys. J.*, **168**, 321.
Christiansen, W. A., 1974. *Bull. Am. astr. Soc.*, **6**, 450.
Coleman, G. D., Hintzen, P., Scott, J. S. & Tarenghi, M., 1976. *Nature*, **262**, 476.
Faber, S. M. & Dressler, A., 1977. *Astr. J.*, **82**, 187.
Fanaroff, B. L. & Riley, J. M., 1974. *Mon. Not. R. astr. Soc.*, **167**, 31P.
Guindon, B., 1976. *PhD thesis*, Queen's University at Kingston, Canada.
Guindon, B., 1978. *Mon. Not. R. astr. Soc.*, **183**, 195.
Harris, A., 1974. *Mon. Not. R. astr. Soc.*, **166**, 449.
Hintzen, P., Scott, J. S. & Tarenghi, M., 1977. *Astrophys. J.*, **212**, 8.
Jaffe, W. & Perola, G. C., 1973. *Astr. Astrophys.*, **26**, 423.
Jaffe, W. & Perola, G. C., 1974. *Astr. Astrophys.*, **31**, 223.
Kesteven, M. J. L. & Bridle, A. H., 1977. *J. R. astr. Soc. Canada*, **71**, 21.
Lea, S. M., 1976. *Astrophys. J.*, **203**, 569.
Miley, G. K. & van der Laan, H., 1973. *Astr. Astrophys.*, **28**, 359.
Miley, G. K., Perola, G. C., van der Kruit, P. C. & van der Laan, H., 1972. *Nature*, **237**, 269.
Minkowski, R., 1961. *Astr. J.*, **66**, 558.
Oke, J. B. & Sandage, A., 1968. *Astrophys. J.*, **154**, 21.
Owen, F. N. & Rudnick, L., 1976. *Astrophys. J.*, **205**, L1.
Owen, F. N., Rudnick, L. & Peterson, B. M., 1977. *Astr. J.*, **82**, 677.
Pacholczyk, A. G. & Scott, J. S., 1976. *Astrophys. J.*, **203**, 313.
Riley, J. M., 1975. *Mon. Not. R. astr. Soc.*, **170**, 53.
Rood, H. J., 1969. *Astrophys. J.*, **158**, 657.
Rudnick, L. & Owen, F. N., 1976. *Astrophys. J.*, **203**, L107.
Rudnick, L. & Owen, F. N., 1977. *Astr. J.*, **82**, 1.
Scott, J. S., Robertson, J. W. & Tarenghi, M., 1977. *Astr. Astrophys.*, **59**, 23.
Slingo, A., 1974. *Mon. Not. R. astr. Soc.*, **168**, 307.
Tarenghi, M. & Scott, J. S., 1976. *Astrophys. J.*, **207**, L9.
Tifft, W. G. & Tarenghi, M., 1975. *Astrophys. J.*, **199**, 10.
Vallée, J. P. & Wilson, A. S., 1976. *Nature*, **259**, 451.