Astrophysical Letters, 1973, Vol. 15, pp. 21–25

Galactic Rotation and the Origin of Double Radio Sources

A. H. BRIDLE and G. W. BRANDIE *Astronomy Group, Department of Physics, Queen's University at Kingston, Ontario, Canada*

Comparison of optical and radio position angles of double radio sources associated with elliptical galaxies usefully reduces the range of double-source models that is compatible with observation. Results from a preliminary investigation readily agree with the predictions of the gravitational-slingshot source model, and with the synchro-Compton model for prolate galaxies. The synchro-Compton model for oblate galaxies, and rotating-magnetoid models, can be supported only if it is assumed that their source-collimating regions carry small fractions of their galaxies' angular momenta.

INTRODUCTION

Twenty years have elapsed since the discovery (Jennison and Das Gupta 1953) of essentially double radio structures associated with elliptical galaxies, yet there have been few theories of the formation, as opposed to the confinement and evolution, of such structures. If the origin of the double structures could be elucidated, important insight might be gained into the particle-accelerating mechanisms and the ultimate energy reservoirs of the extragalactic radio sources. Studies of such properties of the double sources as their spectra, luminosities, and polarizations have not yet, however, led to a generally accepted model of their origin.

We report preliminary results of a study of the orientations of elliptical galaxies relative to their associated radio sources. Even though only a small sample of sources can presently be studied in this way, the results usefully narrow the range of acceptable models of the origin of double radio sources.

MEASUREMENTS

We have determined the position angles of the major axes of the light distributions of a sample of elliptical radio galaxies whose radio structures have been well resolved by the interferometers at Cambridge (Macdonald *et al.* 1968, Mackay 1969, Branson *et al.* 1972) or Caltech (Fomalont 1971). Our measurements were made on enlargements of prints from the Palomar Sky Survey using a technique that will be described elsewhere.

An initial sample of 37 galaxies with estimated photovisual magnitudes less than 17.5 mag was reduced to 18 after inspection of the Sky Survey prints. The magnitude cutoff was arbitrarily imposed for this preliminary study because of the increasing difficulty of measuring the orientations of fainter galaxies. For reasons of convenience, only galaxies north of $-10°$ were included. Nineteen galaxies from the initial sample were rejected because their images on the Sky Survey were circular or confused, or because their identification with the radio sources appeared to us to be uncertain or ambiguous. We also rejected sources where more than one conspicuous galaxy might be associated with the radio components.

The position angles of the major axes of the remaining 18 galaxies were measured. Where both a bright central region and an outer envelope of the galaxy could be distinguished, the position angles of both features were determined; in four cases, these 'central' and 'envelope' position angles differed by more than 20°. In two cases, only one of these position angles could be measured. The images of the 18 galaxies were also inspected on a plate copy of the Sky Survey to ensure that no ambiguities or spurious features on the lower-resolution print copy unduly influenced our measurements. The accuracy of our position-angle measurements is estimated to be generally of order $\pm 5°$, and is in all cases better than $\pm 10°$. The radio position angles given by the radio observers have been used; the accuracy of these position angles is thought to be generally better than $\pm 10°$. The optical and radio position angles of the galaxies in the final sample are given in Table 1.

Figure 1a shows a histogram of the 17 differences

TABLE 1

Optical and radio position angles of 18 galaxies

Source designation	3C number	Position angle Radio	'Envelope'	'Central'
0053 + 26	28	146°	171°	85°
0106 + 13	33	20	162	133
0300 + 16	76.1	109	160	133
0325 + 02	88	65	157	157
0356 + 10	98	25	64	64
0819 + 06	198	38	92	80
0938 + 39	223.1	13	41	41
1216 + 06	270	90	158	158
1251 + 27	277.3	165	Circular	30
1319 + 42	285	79	129	Asymmetric
1559 + 02	327	100	137	137
1615 + 32	332	17	35	35
1626 + 39	338	82	34	56
1726 + 31	357	110	77	77
1833 + 32	382	53	80	80
1842 + 45	388	68	51	33
1957 + 40	405	109	152	152
2117 + 60	430	36	112	112

in position angle between the 'envelope' major axes and the radio structures. Figure 1b shows the histogram obtained using the 'central' position angles. The significant features of both histograms are the frequent occurrence of position-angle differences between 15° and 45°, and the absence of position-angle differences less than 15°. The latter feature contrasts with the high proportion of alignments noted by Mackay (1971). Comparison of Table 1 with Mackay's data shows that this discrepancy does not arise entirely from differences in our estimates of the position angles, but mainly from differences in the selection of our samples. Our sample appears to be more stringently selected (Table 2): many of Mackay's alignments involve identifications that we consider ambiguous, complex radio structures, or faint galaxies whose optical orientations are difficult to determine. Because the numbers of galaxies in both his sample and ours are small, further work is necessary to establish whether or not the discrepancy is merely a chance fluctuation.

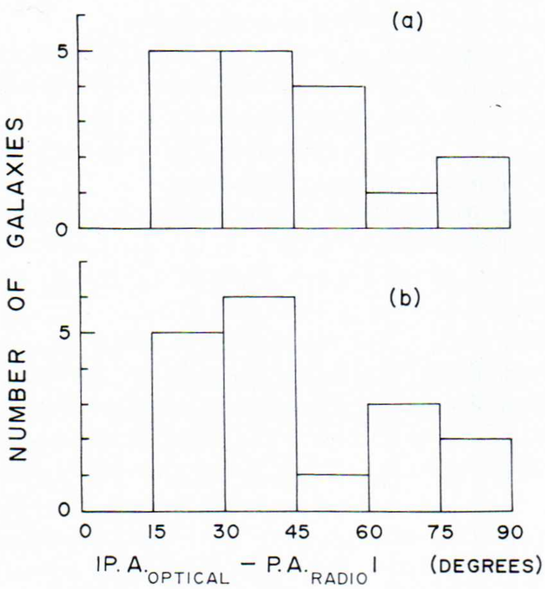

FIG. 1. Observed differences in position angle between optical major axes and radio component separations for 17 elliptical galaxies brighter than 17.5 mag; optical axes defined by (a) outer envelopes, (b) bright central regions.

TABLE 2

Galaxy-radio source alignments noted by Mackay

Source designation	3C number	Comments
0651 + 54	171	19.5 mag galaxy; too faint for our sample.
0951 + 69	231	M82; not a double radio source and not an elliptical galaxy; not in our sample.
1251 + 27	277.3	Our 'central' position angle of 30° is estimated from Sky Survey *plates*; there is an appearance of structure in the envelope which could be the image of another galaxy.
1420 + 19	300	18 mag galaxy; too faint for our sample.
1615 + 32	332	Our optical position angle differs from Mackay's by 4°; the source now contributes to the 15°–30° bins in Figure 1.
1825 + 74	379.1	We judge the optical image to be circular.
1940 + 50	402	Ambiguous identification; there are two VV galaxy systems within the radio structure.
2229 + 39	449	Ambiguous identification and radio position angle; galaxy VV6–49–29 has major axis near the position angle of the *inner* radio components (see Mackay 1969).
2356 + 43	470	19.5 mag galaxy; too faint for our sample.

DISCUSSION

Many models of the origin of double radio sources have associated their collimation with the dynamical symmetries of the parent objects. We have considered three classes of model.

The 'magnetic' models of Piddington (1970) and of Ozernoi and Somov (1971) invoke rotationally-induced distortion of a pre-existing magnetic field during the formation of a galaxy or compact object to collimate the ejection of radiating particles. In these models, the radio components emerge *close to the rotation axes* of the parent objects.

The 'synchro-Compton' model of Rees (1971) suggests that the radio sources are excited by low-frequency electromagnetic waves radiated by compact spinning objects in galaxies. This model explains the double radio structures by invoking initial collimation of the low-frequency waves by the galactic nuclear mass distributions; such waves are more likely to escape in directions *perpendicular to these mass distributions* than in directions parallel to them.

The 'gravitational-slingshot' model of Saslaw *et al.* (1973 private communication) associates the ejection of radio sources with dynamical instabilities of multi-body systems of massive objects in galactic nuclei. This model predicts that the radio sources should emerge in directions *close to the rotational equators* of the galaxies.

We have compared our observed position-angle difference histograms with a number of theoretical distributions corresponding to each of these three types of model. The theoretical distributions were obtained by numerically simulating the position-angle statistics for ejection with specified directional constraints from galaxies oriented randomly with respect to the line of sight. Each distribution was defined by 3400 ejections; the numerical routine included the effects of dispersion in the ejection directions.

The comparison with observation is complicated by the fact that the directions of the rotation axes of most elliptical radio galaxies are unknown. It is normally assumed (by analogy with spiral galaxies) that elliptical galaxies are oblate rotators. Although this assumption is observationally validated for NGC 1316 = Fornax A (Burbidge and Burbidge 1959), there is evidence that the outer extensions of NGC 5128 = Centaurus A (Searle 1965) and the galaxy identified with 3C 33 (Matthews *et al.* 1964) are prolate rotators. In the absence of definitive optical data, we have considered both oblate and prolate rotation to be possible. Conventional assumptions about galactic evolution imply that the light distributions in the galaxies should share the rotational symmetries, so that projected rotation axis directions can be determined from the orientations of symmetrical elliptical galaxy images.

The comparison of the theoretical and observed distributions showed that models in which the radio components are ejected in the general directions of the galactic rotation axes are inconsistent with our data. Even if the radio components are assumed to be ejected randomly over 120° cones centred on the rotation axes of the galaxies, the expected position-angle difference histograms show strong peaks at position-angle differences near 90° for oblate rotators or 0° for prolate rotators. The observed histograms are inconsistent with either such peak at the 99.9 per cent confidence level (determined from χ^2 tests).

We therefore conclude that allowable magnetic models must be restricted to those in which the parent objects rotate about axes that are oblique to the galaxy light distributions. This restriction could be satisfied if the objects producing the radio sources rotate obliquely to the galaxies which contain them, or if for some reason radio galaxies generally rotate about axes oblique to their light distributions as seen on the Sky Survey.

Our results place a similar restriction on the synchro-Compton model for oblate galaxies, for which the geometry is identical to that of the magnetic models. For oblate systems, the source-forming regions envisaged by the synchro-Compton model must have mass distributions that are generally inclined to those of the galaxies containing them.

The gravitational-slingshot model, and the synchro-Compton model for prolate galaxies, predict radio source ejection approximately in the equatorial planes of the galaxies. Figure 2 shows the position-angle difference histograms expected for oblate galaxies if radio source ejection occurs (a) in the equatorial planes or (b) randomly within 30° of the equatorial planes of the galaxies. Distributions such as that of Figure 2b are consistent with our data. The distributions expected for approximately equatorial ejection from prolate galaxies are essentially mirror images of the distributions shown in Figure 2; these too are consistent with our observations.

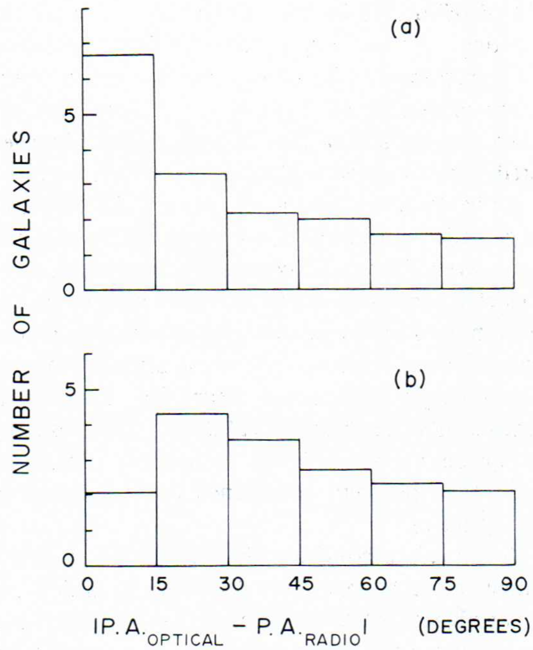

FIG. 2. Expected differences in position angle between optical major axes and radio component separations for 17 oblate galaxies with radio sources ejected at random longitudes (a) in their rotational equators, (b) randomly within 30° of their rotational equators.

CONCLUSIONS

Comparison of the optical and radio orientations of well-resolved radio galaxies appears to be a useful technique for discriminating among proposed models of the origin of double radio sources. This preliminary study, based on a small sample of galaxies, has reduced the range of models which are compatible with observation.

Our measurements are readily in agreement with predictions of the gravitational-slingshot model for oblate galaxies and with both the gravitational-slingshot model and the synchro-Compton model for prolate galaxies.

Our measurements are compatible with the predictions of the synchro-Compton model for oblate galaxies only if the collimating mass distributions are assumed to be generally misaligned with those of the galaxies containing them. Our measurements similarly require magnetic models of radio source generation to specify that the rotators are misaligned with the apparent angular momenta of the rest of their galaxies. For both types of model, it is implied that the regions producing source collimation have only small fractions of their galaxies' angular momenta. Galaxies such as those in Table 1 in which sub-systems of different surface brightness appear to exhibit different orientations may deserve more detailed study in this context.

The above discussion has been based on the assumption that the galaxy-radio source alignments have been dominated by the generating mechanism within the parent galaxies and that present orientations reflect this origin. It may be, however, that the radio sources are collimated by a mechanism external to the galaxies. One such mechanism could be interaction with an intergalactic magnetic field (van der Laan 1963, Levy 1971). Alternatively, it could be hypothesized that the rotation axes of radio galaxies precess in space on time scales comparable to those for the formation of double sources, leading to misalignments between the optical images and the observed radio source axes.

We conclude that comparison of optical and radio orientations of radio galaxies assists the search for acceptable models of the origin of the sources. We are attempting to enlarge the present body of data which may be used for this comparison by extending this study to southern galaxies and to fainter galaxies, and by determining more radio structures for known galaxy identifications.

We thank Gretchen Hagen for facilitating our inspection of the plate copy of the Palomar Sky Survey at the David Dunlap Observatory of the University of Toronto, Bob Baran for photographic assistance, and Dr W. C. Saslaw for a stimulating discussion and for communicating his work in advance of publication. This research was supported by the National Research Council of Canada.

REFERENCES

Branson, N.J.B.A., Elsmore, B., Pooley, G. G., and Ryle, M., 1972, *Monthly Not. Roy. Astron. Soc.*, **156,** 377.

Burbidge, E. M., and Burbidge, G. R., 1959, *Astrophys. J.*, **129,** 271.

Fomalont, E. B., 1971, *Astron. J.*, **76,** 513.

Jennison, R. C., and Das Gupta, M. K., 1953, *Nature*, **172,** 996.

Laan, H. van der, 1963, *Monthly Not. Roy. Astron. Soc.*, **126,** 535.

Levy, E. H., 1971, *Astrophys. J.*, **164,** 23.

Macdonald, G. H., Kenderdine, S., and Neville, A. C., 1968, *Monthly Not. Roy. Astron. Soc.*, **138,** 259.

Mackay, C. D., 1969, *Monthly Not. Roy. Astron. Soc.*, **145,** 31.

Mackay, C. D., 1971, *Monthly Not. Roy. Astron. Soc.*, **151,** 421.
Matthews, T. A., Morgan, W. W., and Schmidt, M., 1964, *Astrophys. J.*, **140,** 35.
Ozernoi, L. M., and Somov, B. V., 1971, *Astrophys. Space Sci.*, **11,** 264.
Piddington, J. H., 1970, *Monthly Not. Roy. Astron. Soc.*, **148,** 131.
Rees, M. J., 1971, *Nature*, **229,** 312.
Searle, L., 1965, *Nature*, **207,** 1282.

Received 10 July 1973