Astron. Astrophys. 73, L1—L3 (1979)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Radio Galaxies with Dust Lanes

C. G. Kotanyi and R. D. Ekers

Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700 AV Groningen, The Netherlands

Received December 15, 1978

Abstract

Eight radio galaxies associated with an elliptical galaxy showing a band of dust are discussed. In the 7 unambiguous cases the band of dust is nearly perpendicular to the major axis of the radio source. This result implies a close connection between the mechanism leading to the double radio morphology and the rotation axis of the dust.

Key words: Radio galaxies - dust lanes - rotation axes.

I. Introduction

Among the elliptical galaxies identified with powerful radio sources, a small number show a band of absorption crossing the galaxy. The history of these absorption bands started with Centaurus A, one of the first identifications of a radio galaxy with its optical counterpart (Bolton et al., 1949). Shklovski (1953) then proposed the identification of Fornax A on the basis of its similarity to Centaurus A and this was later shown to be correct (Minkowski, 1955). The identification of Cygnus A (Baade and Minkowski, 1954) gave further support to the view that radio galaxies are abnormal systems. Later Wade (1960a) suggested the identification of 3C272.1 with M84 on the basis of its dust band and this has also been verified by higher resolution observations (e.g. Riley, 1972). However the subsequent identification work showed that the vast majority of identifications were with galaxies with no obvious absorption features.

Send offprint requests to: C.G. Kotanyi

New cases have been found recently as a result of a systematic study of the radio properties of SO galaxies (SO being the usual classification fate of an elliptical galaxy with a dust lane). In this paper we briefly describe all such radio galaxies known to us, and discuss some of their general properties.

II. The data

Table 1 lists 8 radio galaxies which show a dust lane crossing the associated elliptical galaxy. The entries in the Table are self-explanatory. The position angles of the radio axis and dust lane have been determined from the observations indicated by the references in the Table.

NGC612 (PKSO131-36) The identification was made by Westerlund and Smith (1966). The galaxy has a thin, sharp dust lane and a fairly well-developed luminous disk seen almost edge-on. The radio map shows a wide double with components of unequal intensity (Ekers et al., 1978b). Smaller scale structure is present in both components.

NGC708 (B2 0149+35B) This is the brightest elliptical in the cluster A262. The identification and a map of the radio source at 1.4 GHz were given by Fanti et al. (1977). The dust lane was noticed by B. Marano and P. Vettolani (private communication) on a plate taken as part of an extensive photometric and spectroscopic study of the cluster, at the 1.2 m Loiano Telescope of the University of Bologna. The lane is very thin, at the limit of plate resolution. The radio map suggests a relatively weak radio galaxy with an angular size of 40".

Table 1 Radio galaxies with dust lanes

Galaxy	Hubble type (a)	cz / H (b) (Mpc)	Mpg	log P (1.4 GHz) (W Hz^{-1}ster^{-1})	Position angles (d) (degrees)			Ref.
					Dust lane	Radio axis	Difference	
NGC 612	SO	90.5	-20.7	23.7	168°	100°	68°	1
NGC 708	E2	50.2	-19.1	21.3	176	76	80	2
NGC 1316	SO	16.3	-21.0	23.4	–	110	–	3
NGC 3665	SO	20.1	-19.2	20.6	33	135	78	4
NGC 4374	E1	11.0 (c)	-19.4	21.8	86	176	90	5
NGC 5128	SO	4.7	-21.2	23.4	120	58	62	6
3C305	-	124.8	-21.2	23.8	117	46	71	7
Cyg A	-	170	-21.0	25.7	25	110	85	8

Notes

(a) Adapted from de Vaucouleurs, 1964
(b) H = 100 km s^{-1} Mpc^{-1}
(c) Virgo Cluster
(d) Measured North through East. The errors are mostly ± 5°.

References

1. Ekers et al., 1978b
2. Fanti et al., 1977; Marano and Vettolani, private communication
3. Wade, 1960b
4. Kotanyi, 1979
5. Jenkins et al., 1977; Wade, private communication
6. Christiansen et al., 1977
7. Pooley and Henbest, 1974; Sandage, 1966
8. Hargrave and Ryle, 1974

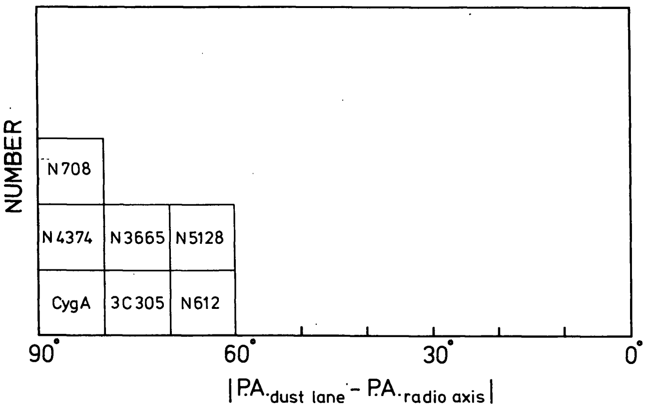

Figure 1 Relative orientations of dust lanes and radio axes for radio galaxies in Table 1.

NGC1316 (Fornax A, Arp 154) The very irregular and prominent dust pattern makes this one of the most outstanding radio galaxies (e.g. Wade, 1960b). The radio source is a wide double with a remarkable shell structure in each component (Cameron, 1971; Lockhart, 1971). A kinematic study by Searle (1965) suggested that the dust is in a plane seen nearly "face-on", possibly explaining the irregular appearance. Here it is not possible to define the position angle of the dust plane as for the other galaxies.

NGC3665 (B2 1122+39) The identification with the B2 source was made by Braccesi et al. (1967). The dust lane and radio structure were described by Kotanyi (1979). Although the galaxy appears as a normal E2 on the prints of the Palomar Sky Survey, a sharp dust lane is present in the inner 20" (Morgan, 1958). The radio source is weak, comparable in power to the most luminous spirals, but it has a typical radio galaxy morphology with an elongated structure and an inner double with a separation of 2 kpc. The position angle in Table 1 correspons to the inner double.

NGC4374 (M84, 3C272.1) The galaxy is one of the brightest elliptical galaxies in the Virgo Cluster. It has been studied in detail by various authors and surface photometry showed a normal elliptical galaxy light distribution (e.g. King, 1978). A thin dust lane is present in the central 10" (Wade, 1960a). The radio emission was studied at high resolution by Riley (1972), Högbom and Carlsson (1974) and Jenkins et al. (1977). The source shows a well defined S-shape with brightness rising smoothly to a peak in the nucleus. The position angle of the radio axis in Table 1 corresponds to the inner part.

NGC5128 (Centaurus A, Arp 153) This is the nearest radio galaxy, and it has been widely studied (see e.g. van den Bergh, 1976a for references). The band of absorption is very wide and a large number of stars, presumably newly formed, were found in its outskirts (Van den Bergh, 1976b). The motions of the gas were studied by Burbidge and Burbidge (1959), Sérsic (1969), Gardner and Whiteoak (1976) and Graham (1977). The gas was found to rotate about an axis at position angle 40°. The radio source has a double double structure. In the outer double the position angle of the radio major axis varies from -20° to 20° with distance from the centre (e.g. Cooper et al., 1965). The position angle in Table 1, measured on a high-resolution map made by Christiansen et al. (1977), corresponds to the inner double.

3C305 The identification is due to Longair (1965) and the redshift to Sandage (1966) who gave a photograph showing the dust lane. As noted by Sandage, the lane shows a remarkable tilt of about 50° with respect to the optical major axis. The radio source was mapped by Pooley and Henbest (1974) at 5 GHz. The map shows two components of unequal brightness situated in the centre of the galaxy and separated by 3".4.

Cygnus A (3C405) A number of optical studies were made of this galaxy which is strongly dimmed by galactic obscuration (e.g. Kronberg et al., 1977). The radio source is a well known powerful double (Hargrave and Ryle, 1974). It is now generally accepted that the double appearance of the optical image of the galaxy is due to a very wide dust lane. The rotation axis measured from the optical emission lines is aligned with the radio axis (Simkin, 1978). The nuclear radio component was shown to be elongated in the same position angle as the outer double (Kellermann et al., 1975).

III. Discussion

A histogram of the position angle differences between the radio axes and the dust lanes for 7 galaxies exluding NGC1316 is shown in Figure 1. This distribution is concentrated in the interval between 60° and 90°. Part of the spread is due to the uncertainties in the radio position angles resulting from the complexity of the radio structures: e.g. in NGC5128 and in NGC3665 the outer radio structures generally line up better with the perpendicular to the dust lane than the inner structures, which were taken because their axis is better defined. However at least part of the spread is real.

The correlation of optical and radio axes has been investigated previously on the basis of the optical ellipticities (Mackay, 1971; Bridle and Brandie, 1973; Gibson, 1975; Sullivan and Sinn, 1975). Although the general result was a lack of correlation these studies were limited by the difficulty of determining an optical axis from the ellipticity, since isophote orientations may vary appreciably with radius (e.g. King, 1978). Furthermore, the physical meaning of the optical major axes in elliptical galaxies e.g. the relationship with rotation is presently in debate (e.g. Binney, 1978). Examples of an oblate and of a prolate galaxy may be provided by NGC3665, where the dust lane is aligned parallel to the optical major axis (Kotanyi, 1979), respectively by NGC5128, where the dust lane is perpendicular to the optical major axis (which coincides with the rotation axis of the dust; see also Bertola and Galletta, 1978).

Without referring to the interpretation of the shapes of elliptical galaxies, the kinematics of the gas in NGC1316, NGC5128 and Cygnus A indicate the existence in these radio galaxies of a rotation axis, defined by a rotating gaseous disk. We may surmise that the dust lanes in the other galaxies discussed, where kinematical data are not yet available, are also rotating gaseous disks seen nearly edge-on. The present study then shows that the radio sources tend to form along the rotation axes.

In addition to the orientation problem it is of interest to ask whether there is a correlation between the presence of a dust lane and the radio emission. It is striking that out of the four closest radio galaxies (NGC1316, NGC4374, NGC4486 and NGC5128) three have dust lanes but this also suggests that the dust lanes may be too difficult to see in more distant systems. In order to remove the bias caused by having more detailed optical data for radio galaxies we need an optically selected sample. The Ep classification of Morgan (1958) is one possibility since it applies to elliptical galaxies containing dust (and all three galaxies from Table 1 included in Morgan's list have this classification). Radio information is available for 13 Morgan Ep galaxies and in the brightest absolute magnitude ranges 5 out of 8 are radio emitters compared with an expectation of 2 based on the bivariate radio luminosity function of Auriemma et al. (1978). This may suggest an unusually high detection rate. Finally, it may be noted that the classification for the SO galaxies in Table 1 was based solely on the presence of dust in otherwise normal elliptical galaxies. Surface photometry available for NGC3665, NGC4374 and NGC5128 has revealed no exponential disk in these systems. It may be added that, especially in NGC5128, the dust is in a remarkably broad ring unlike the flat disk found e.g. in the Sombrero (NGC4594), suggesting that this ring structure is of a nature quite different from that found in true disk systems. E.g. it might be conjectured that the dust rings in radio galaxies are of a transient nature (Sérsic, 1970; Rodgers, 1978) rather than stable structures such as the disks of spirals.

IV. Conclusions

The tendency for a perpendicularity of the gaseous disk and radio axis in radio galaxies indicates that the radio axis is related to the rotation axis of the gas. This confirms previous evidence in giant radio galaxies (e.g. Bridle et al., 1976) ruling out models requiring ejection in a plane perpendicular to the rotation axis (Saslaw et al., 1974).

Radio source models taking account of these results will depend strongly ou the assumed origin of the gas. If the gas is a remnant of incomplete star formation or originates from stellar mass loss (e.g. Matthews and Baker, 1971), galactic rotation is required to distribute it into a plane. The radio axis is then related to the galactic rotation axis, and the lack of correlation between radio and optical major axes (e.g. Gibson, 1975) must be related to the dynamics of elliptical galaxies.

Alternatively the gas may originate by capture from the intergalactic medium (e.g. Gisler, 1976); then the radio axis will be related to the initial angular momentum of the gas, explaining the lack of correlation between radio and optical major axes. If the gas rotates about an axis other than the (presumed) symmetry axis of the mass distribution in the galaxy, it will undergo differential precession and dissipation until it settles down to this axis. Precession of the radio axis is suggested by the shell structure in the lobes of NGC1316 and by the fan-type structure in the lobes of many other radio galaxies (Miley, 1976; Ekers et al., 1978a).

While rotation is likely to play a dominant role, a large-scale magnetic field could also determine (or be determined by) the formation of both the gaseous disk and the radio source. E.g. a dipole-type magnetic field anchored to the nucleus but not exactly aligned with the rotation axis could also explain the fan-type structures.

It remains open whether structures similar to dust lanes exist in radio galaxies in general on scales too small for present observations.

Acknowledgements

We would like to thank Drs. B. Marano and P. Vettolani, C.M. Wade, A. Sandage, E. Hummel and S. van den Bergh for providing us with unpublished material, and Dr. R.H. Sanders for clarifying discussions. C.G.K. is grateful to the Netherlands Organization for the Advancement of Pure Research (Z.W.O.) for financial support.

References

Auriemma, C., Perola, G.C., Ekers, R.D., Fanti, R., Lari, C., Jaffe, W.J., Ulrich, M-H. 1978, *Astron. Astrophys.* (in press).
Baade, W., Minkowski, R. 1954, *Astrophys. J.* **119**, 206.
Bergh, S. van den 1976a, *Astrophys. J.* **208**, 673.
Bergh, S. van den 1976b, *Zenit* **3**, 49.
Bertola, F., Galletta, G. 1978, *Astropys. J.* **226**, L115.
Binney, J. 1978, *Monthly Notices Royal Astron. Soc.* **183**, 561.
Bolton, J.G., Stanley, G.J., Slee, O.B. 1949, *Nature* **164**, 101.
Braccesi, A., Fanti-Giovannini, C., Fanti, R., Formiggini, L., Vespingniani, G. 1967, *Nuovo Cimento B* **52**, 254.
Bridle, A.H., Brandie, G.W. 1973, *Astrophys. Letters* **15**, 21.
Bridle, A.H., Davis, M.M., Meloy, D.A., Fomalont, E.B., Strom, R.G., Willis, A.G. 1976, *Nature* **262**, 179.
Burbidge, E.M., Burbidge, G.R. 1959, *Astrophys. J.* **129**, 271.
Cameron, M.J. 1971, *Monthly Notices Royal Astron. Soc.* **152**, 439.
Christiansen, W.N., Frater, R.H., Watkinson, A., O'Sullivan, J.D., Lockhart, I., Goss, W.M. 1977, *Monthly Notices Royal Astron. Soc.* **181**, 183.
Cooper, B., Price, R., Cole, D. 1965, *Austr. J. Phys.* **18**, 589.
Ekers, R.D., Fanti, R., Lari, C., Parma, P. 1978a, *Nature* **276**, 588.
Ekers, R.D., Goss, W.M., Kotanyi, C., Skellern, D.J. 1978b, *Astron. Astrophys.* **69**, L21.
Fanti, C., Fanti, R., Gioia, I.M., Lari, C., Parma, P. 1977, *Astron. Astrophys. Suppl.* **29**, 279.
Gardner, F.F., Whiteoak, J.B. 1976, *Proc. Astron. Soc. Austr.* **3**, 63.
Gibson, D.M. 1975, *Astron. Astrophys.* **39**, 377.
Gisler, G.R. 1976, *Astron. Astrophys.* **51**, 137.
Graham, J.A. 1977, *Bull. A.A.S.* **9**, 630.
Hargrave, P.J., Ryle, M. 1974, *Monthly Notices Royal Astron. Soc.* **166**, 305.
Högbom, J.A., Carlsson, I. 1974, *Astron. Astrophys.* **34**, 341.
Jenkins, C.J., Pooley, G.G., Riley, J.M. 1977, *Mem. Roy. Astron. Soc.* **84**, 61.
Kellermann, K.I., Clark, B.G., Niel, A.E., Shaffer, D.B. 1975, *Astrophys. J.* **197**, L113.
King, I.R. 1978, *Astrophys. J.* **222**, 1.
Kotanyi, C.G. 1979, *Astron. Astrophys.* (in press).
Kronberg, P., Bergh, S. van den, Button, S. 1977, *Astron. J.* **82**, 315.
Lockhart, I. 1971, Thesis, Australian Natl. University, Canberra.
Longair, M.S. 1965, *Monthly Notices Royal Astron. Soc.* **129**, 419.
Mackay, C.D. 1971, *Monthly Notices Royal Astron. Soc.* **151**, 421.
Matthews, W.G., Baker, J.C. 1971, *Astrophys. J.* **170**, 241.
Morgan, W.W. 1958, *Publ. Astron. Soc. Pacif.* **80**.
Miley, G. 1976, in Physics of Non-Thermal Radio Sources, ed. G. Setti (Reidel, Dordrecht), p. 1.
Minkowski, R. 1955, in I.A.U. Symposium no. 4 "Radio Astronomy" Ed. H.C. van de Hulst, Cambridge, University Press, p. 107.
Pooley, G.G., Henbest, S.N. 1974, *Monthly Notices Royal Astron. Soc.* **169**, 477.
Rodgers, A.W. 1978, *Astrophys. J.* **219**, L7.
Ryle, M., Longair, M.S. 1967, *Monthly Notices Royal Astron. Soc.* **136**, 123.
Riley, J.M. 1972, *Monthly Notices Royal Astron. Soc.* **157**, 349.
Sandage, A. 1966, *Astrophys. J.* **145**, 1.
Saslaw, W.C., Valtonen, M.J., Aarseth, S.G. 1974, *Astrophys. J.* **190**, 253.
Shklovski, I.S. 1953, *Astr. J. U.S.S.R.* **30**, 30.
Searle, L. 1965, *Nature* **207**, 1282.
Sérsic, J.L. 1969, *Nature* **224**, 253.
Sérsic, J.L. 1970, in Periodic Orbits, Stability and Resonances, Ed. G.E.O. Giacaglia (Reidel, Dordrecht), p. 314.
Simkin, S.M. 1978, *Astrophys. J.* **217**, 45.
Sullivan, W.T., III, Sinn, L.A. 1975, *Astrophys. Lett.* **16**, 173.
Vaucouleurs, de G. and A. 1964, The Reference Catalogue of Bright Galaxies.
Wade, C.M. 1960a, *Observatory* **80**, 235.
Wade, C.M. 1960b, *Pub. N.R.A.O.* **1**, 6.
Westerlund, B.E., Smith, L.F. 1966, *Austr. J. Phys.* **19**, 181.