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THE RADIO SOURCE 0915+320: A "WIDE-ANGLE-TAIL" SOURCE IN A GROUP OF GALAXIES

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ABSTRACT

The radio source 0915+320 has been mapped with the VLA at a frequency of 4.9 GHz. Our observations provide the optical identification by detection of a small-diameter "core" component coincident with an elliptical galaxy which may be associated with a poor group of fainter spirals.

The extended radio structure has an almost-collinear, bifurcated distribution with the highest-brightness regions at the inner part of the radio lobes. This morphology is strikingly similar to the "wide-angle-tail" structures hitherto reported only in rich clusters of galaxies.

We suggest that this "wide-angle-tail" morphology may therefore be more typical of a given radio luminosity range $10^{\sim 24.5} < P_{2.7} < 10^{\sim 25.5}$ W Hz^{-1} than of physical processes peculiar to the cluster environment. Sources with pronounced radio jets emanating from one or both sides of the galaxy also occur in the same luminosity range as that of "wide-angle-tail" sources. The more distorted "head-tail" structures in this luminosity range have *internal* morphologies similar to those of the wide tails, suggesting that the interactions producing the bending of these sources are secondary to the processes defining the variation of radio brightness with distance from the galaxy.

Subject headings: galaxies: clusters of — radio sources: extended

I. INTRODUCTION

The radio source 0915+320 = B2 0915+320B (Colla *et al.* 1970) has been observed by Fanti *et al.* (1977) at 1.4 GHz and by Bridle and Fomalont (1978) at 2.7 and 8.1 GHz. The optical identification is problematic (Colla *et al.* 1975; Fanti *et al.* 1977). The source is about 4′ in extent and two galaxies, a 15 mag elliptical and a 16 mag spiral classified by Fanti *et al.* as an S0(?)., lie near the radio centroid.

We have observed this source at 4.9 GHz, using six antennas of the Very Large Array (VLA) now under construction in New Mexico by NRAO. We attempted to detect a small-diameter radio component which might aid in the identification of the source and to map the extended radio emission in detail to determine the radio morphology.

II. OBSERVATIONS AND REDUCTIONS

The source was observed at the VLA on 1977 July 24–25 at a frequency of 4.89 GHz, using six 25 m antennas on the southwest arm (34° south of west) of the VLA. The positions of the antennas were 0.0 m, 439.15 m, 926.65 m, 1545.07 m, 3143.24 m, and 5178.95 m along the arm. All antenna pairs were correlated, producing 15 interferometer pairs. The system noise temperature was ~70 K at each antenna, using parametric amplifiers cooled to a temperature of 20 K. Two independent 50 MHz channels sensitive to opposite circular polarizations were used. The source was observed over a period of 12.5 hours, alternating 13 minute observations with 7 minute observations of the unresolved calibrator DA 267—α(1950.0) = $09^h23^m55^s.321$, δ(1950.0) = 39°15′23″.56 (Wade and Johnston 1977). The pointing of the antennas and their relative positions were measured by using radio calibrators prior to the run. The pointing accuracy was 30″ (1/20 half-power beamwidth) and the antenna positions were obtained to an accuracy of 3 mm. The overall phase and gain stability after calibration was noticeably degraded by the effects of a patchy overcast during most of the run. Forty minutes of data were lost due to a thunderstorm near the beginning of the run. The poor weather conditions resulted in some loss of sensitivity in the maps.

Radio maps were made with the usual Fourier methods. A 2″ resolution map was made in which all samples at less than λ2500 separation in the (u, v)-plane were deleted to deemphasize the extended emission. This showed an unresolved (<1″) component of flux density 8 ± 1 mJy at $09^h15^m58^s.46$, 32°04′20″.08 ± 1″ in each coordinate. A 12″ resolution map was produced with this component removed and is shown in Figure 1.

III. RADIO MORPHOLOGY AND OPTICAL IDENTIFICATION

The map in Figure 1 is in good agreement with a lower-resolution 1.415 GHz map made at Westerbork by Fanti *et al.* (1977). The overall morphology closely resembles those of 0043+201 and 1155+266 (Owen, Rudnick, and Peterson 1977) and 1231+674 (Owen and Rudnick 1976). All three are "wide-angle-tail" sources

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in rich clusters of galaxies. The structure of 0915+320 is slightly bent and the brighter emission in each radio component is located closer to the galaxy than is the more extended emission. The weak emission to the southwest and northeast is seen on both the VLA and Westerbork maps (as well as on our unpublished 2.7 GHz map with the NRAO interferometer) and appears connected to the main part of the source at 1.4 GHz.

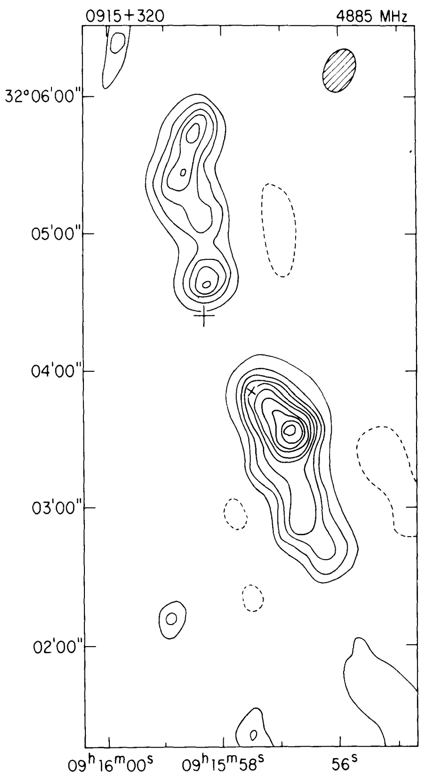

FIG. 1.—Radio map of 0915+320. Each contour level is 1.0 mJy per synthesized beam. An 8 mJy unresolved radio component has been removed and its position is shown by the cross which is also coincident with a 15 mag elliptical galaxy. The location of a 16 mag spiral galaxy is shown by the *X*. The synthesized beam is shown by the cross-hatched ellipse in the upper right.

The small-diameter core component coincides to within 1″ with the center of a 15 mag elliptical galaxy (Goodson, Palimaka, and Bridle 1978) marked by the cross in Figure 1. The high-resolution radio map places an upper limit of 1 mJy on any resolved 4.9 GHz component coincident with the other nearby galaxy (Colla *et al.* 1975; Fanti *et al.* 1977), which is marked by the *X* in Figure 1. This galaxy appears to be a spiral with a very bright nucleus (possibly a Seyfert galaxy); see Figure 2 (Plate L1).

The above radio and optical evidence strongly supports the identification of the entire radio source with the 15 mag elliptical galaxy. As in more than 90% of bifurcated radio galaxies, the identification is with the brightest elliptical galaxy near the centroid of the radio emission (Bridle and Fomalont 1978). The probability that the small-diameter component is a background source lying within 2′ of the radio centroid by chance is only 4%.

Heretofore, the "wide-angle tails" (WT) have been found predominantly in rich clusters of galaxies. Table 1 gives a list of WT sources whose morphology closely resembles that of 0915+320. The list was generated from a search of all published radio maps of sources which are bifurcated and nearly collinear and have the highest-brightness region in the inner part of each radio lobe; some also have compact radio components coincident with the galaxy. A few sources classified elsewhere as WT but having only one lobe displaying the high-low brightness disposition (e.g., 1433+553; Owen and Rudnick 1976) were not included. The source 3C 130 (Högbom and Carlsson 1974) displays a WT morphology but the optical field is obscured.

Of the WT sources in Table 1 within the areas of completeness of the Abell (1958) and Zwicky (1968) catalogs of clusters, only 0915+320 is *not* in a cataloged cluster. We therefore inspect both prints of the Palomar Sky Atlas over a 15′ (900 kpc) diameter region centered on the source and found seven galaxies brighter than $m_V \sim 18$ mag, the brightest of which are spirals 1 or 2 mag fainter than the identification (these galaxies are marked in Fig. 2). Only two galaxies brighter than 18 mag would be expected in this area randomly from the

TABLE 1

OBSERVED PARAMETERS OF "WIDE-ANGLE-TAIL" SOURCES

Source	Flux Density at 2.7 GHz	Largest Angular Size (arcsec)	Redshift	Cluster Name	Map Ref.
0043+201........	0.33	240	0.1028	Abell 98	1
0055+265........	1.1	180	0.0472	Zw 0056.9+2636	2
0214−480........	1.3	360	0.064	Anon.	3
0915+320........	0.22	290	0.062	No cluster?	4
1155+266........	0.52	260	0.146*	Abell 1425	1
1231+674........	0.49	110	0.146*	Abell 1559	5
1610−608........	16.0	780	0.0176	Anon.	3
1626+396........	1.27	85	0.0303	Abell 2199	6

* Based on cluster distance class (Abell 1958).

REFERENCES.—[1]Owen, Rudnick, and Peterson (1977); [2]Fanti *et al.* (1977); [3]Christiansen *et al.* (1977); [4]this *Letter;* [5]Owen and Rudnick (1976); [6]Rudnick and Owen (1977).

FIG. 2.—Optical field near 0915+320. The identification of the radio source is marked by the (Δ) symbols. Six galaxies brighter than 17 mag within 15′ of the radio source centroid are indicated. The field of view of the plate is 12′ by 10′.

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high-latitude galaxy counts given by Allen (1973). The source 0915+320 may therefore be associated with the dominant elliptical galaxy of a group whose brighter members are mainly spirals, but no firm conclusion should be drawn until the redshifts of the other galaxies are measured. It is evident, however, that 0915+320 is not in a *rich* cluster overlooked in the Abell or Zwicky catalog. We conclude from this that *the rich cluster environment cannot be the primary factor in the formation of a WT structure.*

IV. THE ROLES OF LUMINOSITY AND ENVIRONMENT IN THE FORMATION OF WIDE-ANGLE TAILS

Owen and Rudnick (1976) suggested that WT sources may be generically related to the "narrow-angle," or "head-tail," sources, since both types occur mainly in rich clusters and have the same relative order of high- and low-brightness regions with distance from the galaxy. On this view, both the location of the brighter emission closer to the galaxy and the noncollinearity of the source would be interpreted as a result of interaction of the source with the cluster environment, Because WT sources are relatively common compared with intermediate and narrow-tail sources, it is unlikely that most WT sources are simply narrow-tail sources seen in a projection which gives a nearly collinear appearance.

Table 2 lists the 2.7 GHz monochromatic powers ($P_{2.7}$) and the largest linear dimensions of the WT sources listed in Table 1. *The dispersion in both parameters is small;* the small range of luminosities may be particularly significant, as it corresponds to the *transition* between the DI and DII morphological classes of strong double sources (Fanaroff and Riley 1974). This and our conclusion from § III lead us to suggest that the main features of the WT morphology are more characteristic of the transitional *luminosity range* than of a given *environment.*

Specifically, in the luminosity range $10^{\sim 24.5} \lesssim P_{2.7} \lesssim 10^{\sim 25.5}$ W Hz^{-1}, double sources display *either* relatively weak "hot spots" located in the *inner* parts of the radio lobes or a jet or jets between the galaxy and more extended radio emission in the outer part of the lobe. Examples of the latter case are 3C 66 (Northover 1973), NGC 315 (Willis 1977), 0844+319 and 3C 310 (van Breugel and Miley 1977), 3C 31 (Burch 1977), NGC 6521 (Waggett, Warner, and Baldwin 1977), and 3C 449 (Högbom 1978). At higher radio luminosities the "hot spots" are located at the outer edges of the lobes, and become more dominant as total luminosity increases (Jenkins and McEllin 1977). At lower luminosities, $P_{2.7} < 10^{24}$ W Hz^{-1}, the general collimation process appears to break down and complex morphologies without significant "hot spots" or jets result.

We suggest that the "transitional" morphology and luminosity range are associated with sufficiently massive galaxies that, when in rich clusters, they less often have large peculiar velocities than do galaxies of more modest mass. Possibly the velocities of ejection of the radio plasmons from the galaxies also increase with radio luminosity. The radio structures of more massive, luminous galaxies may then be less likely to bend as a result of their translation through a dense ICM (Jaffe and Perola 1973; Pacholczyk and Scott 1976). These hypotheses would explain why WT structures are more often associated with dominant, optically luminous, low-velocity galaxies in a cluster, while the more bent structures are frequently associated with less dominant, high-velocity systems (Owen and Rudnick 1976; Miley and Harris 1977; Guindon and Bridle 1978; Simon 1978).

Some very bent sources in rich clusters have luminosities in the "transitional" WT luminosity range; examples are 3C 465 ($P_{2.7} = 1.9 \times 10^{25}$ W Hz^{-1}) and 3C 83.1B ($P_{2.7} = 7.2 \times 10^{24}$ W Hz^{-1}). *The brightness order of the radio features in such systems is the same as in the WT structures;* the brightest features are closest to the galaxy. We therefore suggest that the interaction with a dense ICM assumed to explain the *bending* of these structures does not significantly alter the *internal* morphology characteristic of the WT luminosity range. Models of radio sources in which the path of the energy transport can be curved without undergoing major disruption therefore seem desirable.

TABLE 2

PHYSICAL PARAMETERS OF "WIDE-ANGLE-TAIL" SOURCES

Source	$P_{2.7}$ (W Hz^{-1})	Distance (Mpc)	Linear Size (kpc)
0043+201..	1.8×10^{25}	630	650
0055+265..	1.1	290	230
0214−480..	2.4	390	600
0915+320..	0.38	380	470
0055+266..	5.1	900	860
1231+674..	4.8	900	360
1610−608..	2.2	110	390
1626+396..	0.53	180	70

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REFERENCES

Abell, G. O. 1958, *Ap. J. Suppl.*, **3**, 211.
Allen, C. W. 1973, *Astrophysical Quantities* (3d ed.; London: Athlone Press).
Bridle, A. H., and Famalont, E. B. 1978, *A.J.*, in press.
Burch, S. F. 1977, *M.N.R.A.S.*, **181**, 599.
Christiansen, W. N., Frater, R. H., Watkinson, A., O'Sullivan, J. D., Lockhart, I. A., and Goss, W. M. 1977, *M.N.R.A.S.*, **181**, 183.
Colla, G., *et al.* 1970, *Astr. Ap. Suppl.*, **1**, 281.
Colla, G., Fanti, C., Fanti, R., Gioia, I., Lari, P., Lequeux, J., Lucas, R., and Ulrich, M.-H. 1975, *Astr. Ap. Suppl.*, **20**, 1.

Fanaroff, B. L., and Riley, J. M. 1974, *M.N.R.A.S.*, **167**, 31p.
Fanti, C., Fanti, R., Gioia, I., Lari, C., Parma, P., and Ulrich, M.-H. 1977, *Astr. Ap. Suppl.*, **29**, 279.
Goodson, R. E., Palimaka, J. J., and Bridle, A. H. 1978, *A.J.*, submitted.
Guindon, B. 1976, Ph.D. thesis, Queen's University at Kingston, Canada.
Guindon, B., and Bridle, A. H. 1978, *M.N.R.A.S.*, in press.
Högbom, J. A. 1978, private communication.
Högbom, J. A., and Carlsson, I. 1974, *Astr. Ap.*, **34**, 341.
Jaffe, W. J., and Perola, G. C. 1973, *Astr. Ap.*, **26**, 423.
Jenkins, C. J., and McEllin, M. 1977, *M.N.R.A.S.*, **180**, 219.
Miley, G. K., and Harris, D. E. 1977, *Astr. Ap.*, **61**, L23.
Northover, K. J. E. 1973, *M.N.R.A.S.*, **165**, 369.
Owen, F. N., and Rudnick, L. 1976, *Ap. J.* (*Letters*), **205**, L1.
Owen, F. N., Rudnick, L., and Peterson, B. M. 1977, *A.J.*, **82**, 677.
Pacholczyk, A. G., and Scott, J. S. 1976, *Ap. J.*, **203**, 313.
Riley, J. M., and Branson, N. J. B. A. 1973, *M.N.R.A.S.*, **164**, 271.
Rudnick, L., and Owen, G. N. 1977, *A.J.*, **82**, 1.
Simon, A. J. B. 1978, *M.N.R.A.S.*, in press.
van Breugel, W. J. M., and Miley, G. K. 1977, *Nature*, **265**, 315.
Wade, C. M., and Johnston, K. J. 1977, *A.J.*, **82**, 791.
Waggett, P. C., Warner, P. J., and Baldwin, J. E. 1977, *M.N.R.A.S.*, **181**, 465.
Willis, A. G. 1977, paper presented, Copenhagen Symp. on Active Nuclei.
Zwicky, F., and Kowal, C. T. 1968, *Catalogue of Galaxies and Clusters of Galaxies*, Vol. **6** (Pasadena: California Institute of Technology).

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