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THE STRUCTURE OF FORNAX A

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ABSTRACT

High-resolution observations of Fornax A (IAU 03S3A) at 3000 Mc/s are described. These show that the source is double, with the associated galaxy (NGC 1316) lying between the radio components, which are separated by 30' of arc. They are unequal in intensity, one being about twice as strong as the other. The apparent dimensions of each to half-brightness are somewhat larger than the 16' half-power beamwidth. Details of the observed distribution suggest that there is still much unresolved structure. The integrated flux density at 3000 Mc/s is $(7.3 \pm 0.4) \times 10^{-25}$ w m^{-2}(c/s)$^{-1}$. The overall dimensions of the object are of the order of 300 kiloparsecs. Detailed comparison of Fornax A with the extended component of Centaurus A shows that these sources are basically similar. In form they probably are typical of the majority of the intrinsically strong extragalactic radio sources.

I. INTRODUCTION

The radio source Fornax A (IAU 03S3A) was discovered by Stanley and Slee (1950) during one of the early Sydney sea interferometer surveys. Later interferometric observations (Mills 1952; Shain and Higgins 1954; Bolton, Westfold, Stanley, and Slee 1954) yielded rather inconsistent positions. But the material did agree in indicating an appreciable angular size for the source, perhaps 15' - 30' of arc diameter. Further, the records contained evidence of modulation such as might be caused either by a blend of two or more sources, or by complex structure within a single source. Although Fornax A is one of the strongest sources in the southern sky, its position was so poorly known that no serious attempt at identifying it seemed justified. Thus the interferometers revealed an intriguing object without disclosing much definite information about it.

It was only after the 85.5 Mc/s Mills cross came into operation that Mills (1954) was able to identify Fornax A reliably with the peculiar galaxy NGC 1316, thereby confirming earlier suggestions of Shklovsky and Kholopov (1952) and de Vaucouleurs (1953). The cross observations, made with a beamwidth of 0°8, showed that the source is elongated, having a greatest angular extent of nearly a degree. The quality of the data permitted Mills to compare Fornax A with Centaurus A, and several interesting similarities were found. Mills' work at 85.5 Mc/s was confirmed and extended by Sheridan (1958), who found that the dimensions of the source are roughly 0°7 by 0°5 between half-brightness points (corrected for antenna beamwidth), with its major axis lying near

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position angle 115°. He obtained a flux density of $(9.5 \pm 1.5) \times 10^{-24}$ w m^{-2}(c/s)$^{-1}$.

Sheridan's work was followed closely by that of Shain (1958) with the 19.7 Mc/s Mills cross. Ionospheric effects and the larger beamwidth (1°4) of this instrument made detailed study difficult, but Shain was able to confirm the elliptical appearance of the object. He found that the source is somewhat larger at 19.7 Mc/s than at 85.5 Mc/s, the corrected dimensions between half-brightness points being 1°1 by 0°8 at the lower frequency. He measured a flux density of 43×10^{-24} w m^{-2}(c/s)$^{-1}$. From a careful consideration of the available data, he concluded that Fornax A is generally similar to Centaurus A.

Using the 85-foot telescope at NRAO at 1400 Mc/s, Heeschen (1961) observed the source with a 35' beamwidth, the sharpest yet used. The elongated appearance noted at the lower frequencies is still evident, but there is now a marked skewness, with the contours being displaced farther and farther to the west with increasing intensity. This effect probably reflects the higher resolution rather than a true change in surface brightness distribution.

The present paper reports observations made at 3000 Mc/s with a 16' beamwidth. The large size and relatively high flux density of the source have made possible a fairly detailed study of its structure. The present material shows that Fornax A is double; further comparison with Centaurus A confirms the earlier suggestions that these sources are generally similar.

II. INSTRUMENTATION AND CALIBRATION

The observations described in the present paper were made with the 85-foot Tatel paraboloidal antenna. At the time of the Fornax A observations (December 1960), the half-power beamwidths of the antenna were 16'.1 (east-west) and 15'.9 (north-south), with an uncertainty of $\pm$ 0'.1 in each direction. The pointing accuracy for an object as far south as Fornax A is not as high as for more northerly declinations because of the paucity of suitable calibration sources in the south. The estimated uncertainty of the positional data given here is $\pm 4^s$ in right ascension and $\pm$ 1' in declination.

The travelling-wave tube receiver is similar to the 8000 Mc/s radiometer described by Drake and Ewen (1958). It operates at a nominal frequency of 3000 Mc/s with a fixed bandwidth of 200 Mc/s and a measured noise figure of 6.3 db. Because of the presence of short-term gain fluctuations, the threshold sensitivity of the receiver is not so high as one would expect from the Dicke formula. The actual sensitivity of the system will be treated in more detail below. The baseline stability is very good. An internal gas discharge tube noise source provides a reference signal for calibration purposes. Parallel analog and digital outputs are available for recording the observational data. The analog record serves primarily as a check on interference and the general behavior of the receiver. The digital output system, which has been described by Heeschen (1961), produces a printed record and a punched teletype tape to facilitate machine reduction of the data.

Fundamental calibration of the receiving system was not attempted because accurate flux densities for several bright discrete sources at 3200 Mc/s have recently become available (Broten and Medd 1960). These afford a simple and direct means of finding the equivalent brightness temperature of the internal calibration noise source in the receiver. Since the receiver has no measurable nonlinearity over the range of signal strengths encountered among discrete sources at 3000 Mc/s, the change D in receiver output level induced by a change ΔT_b in the apparent brightness temperature in the antenna beam is directly proportional to ΔT_b. We can write

$$\Delta T_b = cD. \tag{1}$$

Calibration then consists of finding the value of the proportionality constant c. If we express D in terms of the change in output level caused by turning on the internal noise source, c is the brightness temperature equivalent of the noise source. Now the flux density of a discrete source at wavelength λ is given by

$$S = \frac{2k}{\lambda^2} \int_{\text{source}} \Delta T_b \, d\Omega. \tag{2}$$

From (1) and (2) we obtain

$$c = \frac{\lambda^2 S}{2k \int_{\text{source}} D \, d\Omega} . \tag{3}$$

Taurus A was adopted as the reference source because of its ready availability for checking whenever Fornax A is above the horizon. A series of observations fixed

$$\int_{\text{TAU A}} D \, d\Omega = 3.37 \times 10^{-4} \; (\pm 0.5\,\%) \text{ steradians.}$$

It remains to extrapolate to 3000 Mc/s the flux density measured by Broten and Medd at 3200 Mc/s. According to unpublished data compiled by Heeschen, the spectral index of Taurus A is -0.37. The flux density at 3200 Mc/s is $(71 \pm 3) \times 10^{-25}$ w m^{-2} (c/s)$^{-1}$; the extrapolated flux density at 3000 Mc/s is then $(73 \pm 3) \times 10^{-25}$ w m^{-2}(c/s)$^{-1}$. With $\lambda = 0.1$ m, equation (3) now gives

$$c = 7.9 \,°\text{K}$$

for the equivalent brightness temperature of the internal noise source. The estimated uncertainty of this result is ± 5 per cent, most of which is due to the probable error of Broten and Medd's measurement.

A statistical analysis of the data gathered in the present program shows that the probable error of a single observation made with 5 °K receiver unbalance and an integration time of τ seconds is

$$\text{p.e.} \; (\Delta T_b) = \pm \tau^{-1/2} (0.7 + 0.2 \Delta T_b) \,°\text{K}$$

in apparent brightness temperature. The linear dependence of the probable error on the strength of the received signal is attributable to the presence of short-term gain fluctuations in the receiver. The instability almost certainly lies in the audio amplifier immediately preceding the phase detector. The gain sometimes changes by as much as 5 per cent in a few minutes. The characteristic time of the fluctuations is of the order of one minute. Fornax A is a sufficiently strong source that the short-term instability caused no serious difficulty in observing it. But it is clear that the gain instability raises the threshold sensitivity of the receiver considerably and that it is therefore a serious impediment to the observation of weak sources or subtle details of strong ones. The practical effect of the instability is to make the receiver behave as if its noise figure were some 10 db greater than the measured value.

III. OBSERVATIONS

The observations consist of drift curves taken at intervals of 6' in declination between right ascension limits $3^h\,16^m$ and $3^h\,28^m$. The limiting declinations were -36° 58' and -37° 46'. Seven drift curves were obtained for each of the nine declinations included in the program. All of the drifts were made with the antenna stationary in order to avoid changing the amount of ground radiation entering the system during the run; this was a necessary precaution since Fornax A never rises more than 14° above the horizon at Green Bank. The calibration signal was read at the beginning of each drift. Taurus A was observed at the beginning and end of each day's work as a check on the long-term stability of the noise source. The integration was performed in the digitizing system; an integration time of $18^s\!.5$ was used for each data read-out. Because $1^s\!.5$ is required for reading, printing, and punching, this resulted in read-outs every 20^s of right ascension, corresponding to 4' of arc at the declination of Fornax A. The greatest error in intensity due to blurring by the finite integration time never exceeded 1 per cent, a negligible distortion. The observations were reduced with a Bendix G-15D digital computer. The reduction program automatically removed the linear component of any zero-level change occurring during the course of an observation. The individual drifts for each declination were averaged by the computer. The final result was a table of apparent brightness temperatures, with the probable error of each, over a grid of points spaced 4' east-west and 6' north-south. From this table, the flux density of the source was calculated, its centroid located, and the final map drawn.

The flux density was computed by the summation method of Bracewell (1956), which was judged to be simpler and less subject to error than integration of the contour map with a planimeter. Bracewell showed that

$$\int_{\text{source}} \Delta T_b \, d\Omega = \alpha\beta \sum_{\text{source}} \Delta T_b \tag{4}$$

where α and β are the grid spacings in radians, provided both α and β are less than twice the peculiar interval for the antenna. The peculiar interval for our antenna is about 0.4 of the beamwidth, or a little over 6' of arc at 3000 Mc/s. Thus (4) should hold for grid spacings less than 12', a condition fulfilled by our data. Substituting (4) into (3), we obtain

$$S = \frac{2k\alpha\beta}{\lambda^2} \sum_{\text{source}} \Delta T_b . \tag{5}$$

Application of this formula yields a flux density of 7.3 X 10^{-25} w $m^{-2}(c/s)^{-1}$ for Fornax A at 3000 Mc/s. The uncertainty of the result derives from two causes. Firstly, there may be a systematic error owing to imperfect knowledge of the brightness temperature equivalent of the calibration signal. The error from this source should not exceed ± 5 per cent. The remaining uncertainty arises from the statistical random errors of the individual point values of ΔT_b. The probable error of the sum of n values each having a probable error ϵ is $\epsilon \sqrt{n}$. In the present case, the values of ΔT_b have an average probable error of $\pm$ 0.05 °K, and the summation was carried over 279 points; from this, the probable error of $\sum_{\text{source}} \Delta T_b$ is $\pm$ 0.84 °K. Since $\sum_{\text{source}} \Delta T_b$ is 133 °K, the statistical uncertainty amounts to $\pm$ 0.6 per cent. Our final result for the flux density is then

$$S = (7.3 \pm 0.4) \times 10^{-25} \text{ w m}^{-2}(c/s)^{-1}.$$

A more precisely determined quantity is the ratio of the flux densities of Fornax A and Taurus A at 3000 Mc/s; this is

$$\frac{S(\text{Fornax A})}{S(\text{Taurus A})} = 0.0996 \pm 0.0010.$$

The observed distribution of apparent (i. e., uncorrected for antenna smoothing) brightness temperature is shown by Figure I. In addition, the optical boundaries of NGC 1316 are indicated by a dotted ellipse. The equatorial coordinates refer to epoch 1950.0. The contour interval is 0.5 °K. The map does not show a very faint ($\sim$0.2 °K), broad feature which runs southward at right ascension $3^h\ 22^m$. The boundaries of this extension are very poorly defined by our data, but it may continue as far south as declination -37° 50'. No other faint extensions were noted.

The most striking feature of the map is the clear resolution of the source into two unequal components, each somewhat broader than the antenna beam. Further particulars are given in Table I. The maxima of the condensations are separated by 30' of arc; the line joining them lies at position angle 100°. The details of the contours suggest that there is still considerable unresolved structure in each condensation. Each is distinctly skew; the westerly component falls off most steeply on its south side, and

TABLE I

THE RADIO COMPONENTS OF FORNAX A AT 3000 MC/S

	East Component	West Component
Right ascension of peak (1950.0)	$3^h\ 22^m\ 05^s \pm 4^s$	$3^h\ 19^m\ 39^s \pm 4^s$
Declination of peak (1950.0)	-37° 27' $\pm$ 1'	-37° 23' $\pm$ 1'
Maximum apparent brightness temperature	(2.45 $\pm$ 0.08) °K	(3.87 $\pm$ 0.10) °K
Fraction of total flux	$\sim$ 0.35	$\sim$ 0.65

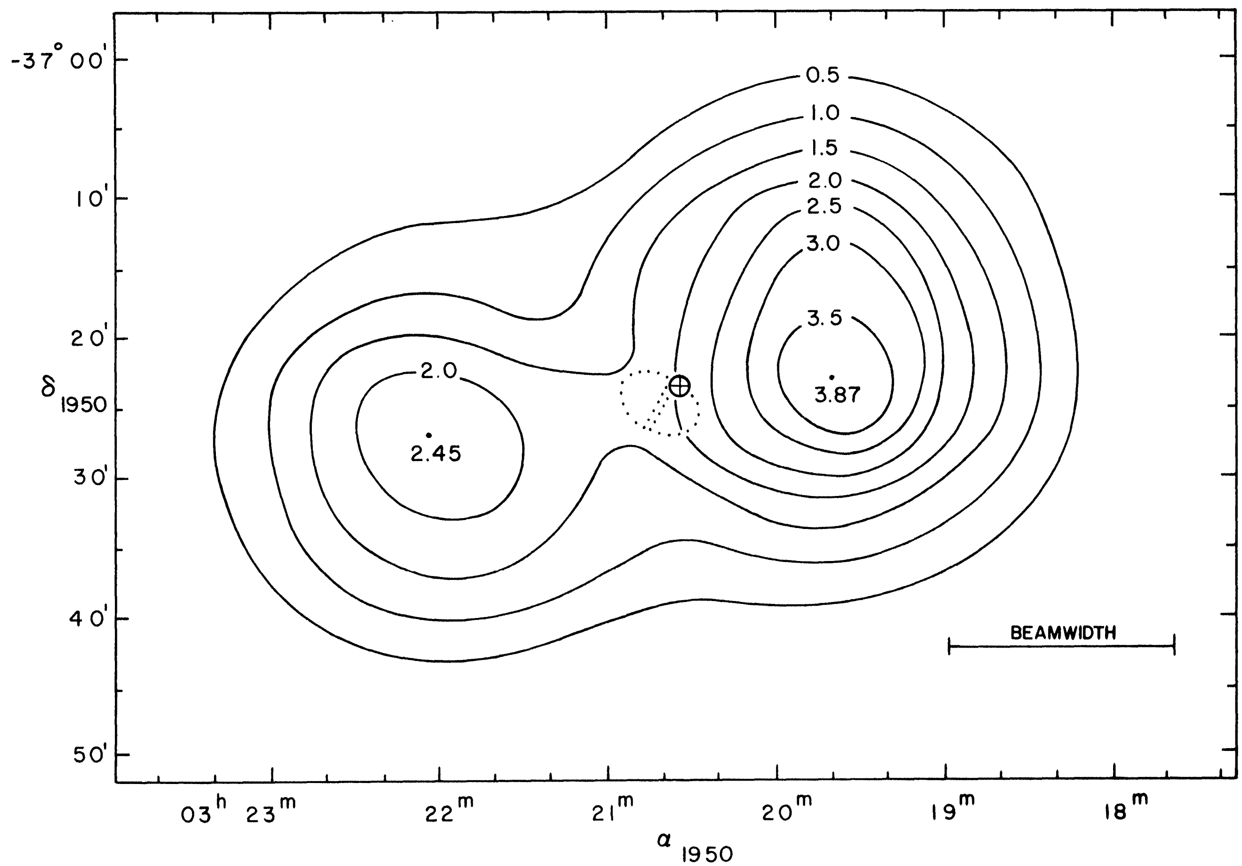

Fig. 1 —— Map of Fornax A at 3000 Mc/s. The contour interval is 0.5 °K in brightness temperature. The optical boundary of NGC 1316 is shown by the dotted ellipse, and the orientation of the belt of absorbing matter is indicated. The symbol ⊕ marks the centroid of the radio emission.

the easterly component on the north. More subtle features enhance the impression of unresolved complexity.

The centroid of the observed distribution is at $3^h 20^m 33^s \pm 4^s$, $-37° 24' \pm 1'$ (1950.0). The most accurate previous positional measurement is that of Sheridan (1958), who placed the centroid at $3^h 20^m 36^s \pm 12^s$, $-37° 23' \pm 3'$ (1950.0). These positions agree well within their uncertainties. Indeed, the close agreement is particularly striking when one remembers that our measurement was made at 3000 Mc/s and Sheridan's at 85.5 Mc/s; the centroid of the source does not shift by a measurable amount over a frequency range of 35 times. The most plausible explanation is that much the same spectral law applies to all parts of the source, at least over the range of frequencies considered here. The radio centroid lies within the optical boundary of NGC 1316, the position of which is $3^h 20^m 42^s$, $-37° 25'$ (1950.0) (de Vaucouleurs 1956). It is doubtful, however, whether there is any real significance in the near coincidence of the optical and radio centroids, since the structures and dimensions differ so radically at optical and radio wavelengths.

Our result that Fornax A is double accounts for the large and hitherto unexplained error in the right ascension Mills (1952) measured during a program which yielded excellent positions for five other strong discrete sources. As his primary interferometer Mills used two antennas 900 feet apart on an east-west baseline, operating at a frequency of 101 Mc/s. A third antenna was placed 200 feet from one of the first two on the same baseline in order to resolve ambiguities as to the transit time of the source under observation. The lobes of the primary interferometer were $31\overset{\prime}{.}8$ apart. Since the components for Fornax A have nearly the same separation, their contributions to the interferometer output were almost exactly in phase. On the other hand, the lobe separation of the secondary interferometer was about five times the source separation. Since the westerly component is twice as strong as its companion, it dominated the response of the secondary interferometer and accordingly its right ascension was assigned to the source. The value given by Mills is $3^h 19^m 30^s \pm 6^s$ (1950.0), which does not differ significantly from our value for the stronger component. The slight difference between the lobe spacing and the source separation accounts qualitatively for the modulation of the interference pattern which Mills noted. It probably also explains the slightly erroneous declination ($-37° 18' \pm 3'$) which he obtained.

IV. COMPARISON OF FORNAX A AND CENTAURUS A

The early pencil-beam observations of Fornax A indicated that this source resembles Centaurus A (IAU 13S4A) in a number of ways (Mills 1954; Sheridan 1958; Shain 1958). Previously de Vaucouleurs (1953) had pointed out certain similarities between the associated galaxies, NGC 1316 and NGC 5128. It was shown that both sources are extremely large objects, with linear dimensions probably of the same order; that the ratio of light to radio emission is comparable in both cases, and that the ratio of optical to radio size is nearly the same; and that each source is highly elongated. The total radiated powers were found to be of the same order, and their radio spectra were quite similar. Since the publication of these comparisons, much more has been learned about the two sources and their associated galaxies. It is appropriate to review the subject once more in the light of the most recent data.

(a) The Radio Brightness Distributions

It has long been known that Centaurus A comprises two distinct brightness distributions: a small source a few minutes of arc in diameter, apparently located in the optical body of NGC 5128; and a very large source several degrees in extent (Mills 1953; Bolton, Westfold, Stanley, and Slee 1954). Pencil-beam observations subsequently yielded reasonably detailed maps of the object over a wide range of frequencies (Sheridan 1958; Shain 1958; Hindman and Wade 1959; Bolton and Clark 1960; Heeschen 1961). It is possible to remove the small source from the observed distribution; when this is done one is left with a map of the extended part alone (Wade 1959; Bolton and Clark 1960). Figure 2 shows the extended component as it appears at 85.5 Mc/s. A very similar picture is found at 960 Mc/s, indicating that there is no significant variation in the spectrum as a function of position. The similarity of the extended component of Centaurus A to Fornax A is obvious. In each case, the radio emission comes principally from two large condensations placed more or less symmetrically on either side of the associated galaxy. The condensations seem to be enclosed within a tenuous envelope or halo of much lower brightness. Thus, in their general appearance, the two systems have much in common. The presence of the small source in NGC 5128, however, is a marked difference. This feature accounts for 25 per cent of the radiation of Centaurus A, yet nothing resembling it is seen in Fornax A. Recent interferometric observations have shown that the small source itself is double (Twiss, Carter, and Little 1960). It remains to be seen to what extent this feature of Centaurus A is a significant difference between the two systems.

A further similarity appears when we compare the separations of the radio condensations with the angular diameters of the associated galaxies. According to de Vaucouleurs (1956), the greatest angular extents of NGC 5128 and NGC 1316 are respectively 28' and 6' of arc; the separations of the radio components are respectively 2° 40' and 30'. Thus the ratio of radio separation to optical size is about five to one in each case. The actual dimensions of the systems will be considered below.

Fornax A is less symmetrical than the extended component of Centaurus A. The two condensations of Centaurus A are about the same in size and radiated power, whereas one component of Fornax A is definitely larger than its companion and radiates twice as much power. It is interesting, although perhaps accidental, that the fainter component of Fornax A is about twice as far from NGC 1316 as the other, with the result that the centroid of the radio emission as a whole coincides with the galaxy.

(b) The Associated Galaxies

NGC 1316 and NGC 5128 are remarkably alike in some respects and rather different in others. The similarity of their radio counterparts encourages close comparison. Perhaps the two galaxies are fundamentally alike, and the differences we see are more of degree than of kind. But it is also possible that the radio emission is quite unrelated to any observable optical feature, and that therefore we have no reason to expect them to be similar optically. The actual relationship, if any, between the radio and optical features of such objects is unclear. At present we must be content with pointing out such similarities and differences as we can.

Table II summarizes the available optical data on the two systems. It is evident from the table that the galaxies are much alike in size and luminosity. Both are super-

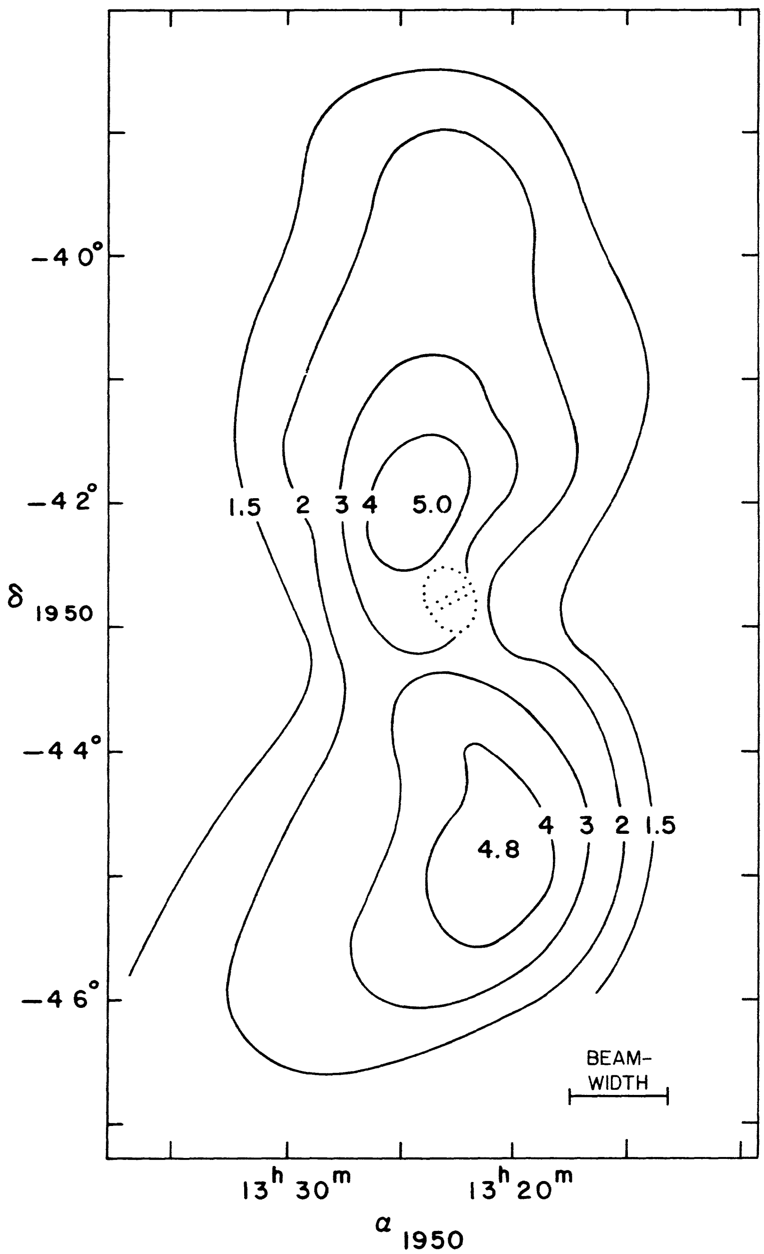

Fig. 2 —— The extended component of Centaurus A at 85.5 Mc/s (Wade 1959). The optical boundary of NGC 5128 is delineated by the dotted ellipse; the gap indicates the obscuring band. Based on observations made by K. V. Sheridan with the 1500-foot Mills Cross at Fleurs, near Sydney.

giant systems; but this is not particularly relevant, since it now seems probable that all galaxies associated with intrinsically strong radio emission are exceptionally large and bright.

TABLE II

DATA FOR NGC 1316 AND NGC 5128

	NGC 1316	NGC 5128	Reference
Galaxy type	SOp	SOp	(1)
Photographic magnitude	9.8	7.6*	(2)
Distance modulus	31.0	27.9 ± 0.2	(2)
Distance in megaparsecs	15.8	3.8 ± 0.4	
Absolute photographic magnitude	-21.2	-21.2*	(2)
Overall angular dimensions	6:' X 4!2	28' X 20'	(1)
Linear dimensions in kiloparsecs	28 X 19	31 X 22	

* Corrected for internal absorption.
(1) de Vaucouleurs 1956.
(2) Sersic 1960.

According to de Vaucouleurs, both galaxies are peculiar SO systems. The peculiarity in each case is the presence of unusually large amounts of interstellar matter for galaxies of this type. In NGC 5128, this takes the form of a broad, heavy bar of obscuration which cuts across the face of the galaxy. There are a number of HII regions in the bar (Sérsic 1960). The corresponding feature in NGC 1316 is far weaker and narrower, as well as rather patchy, although it is undoubtedly present. Most of the dust in the Fornax galaxy resides in large clouds which can be seen near the ends of the absorption lane. No emission regions have been found, and the spectrum of the object is devoid of emission lines (Minkowski, private communication). In both systems the dust lane lies nearly at right angles to the major axis of the bright body. Thus the objects are similar in having a bar of obscuring matter lying across their minor axes; but they differ markedly in the strength of the absorption. Furthermore, emission lines are found only in NGC 5128.

If the optical features do in fact have some genetic relation to the radio emission, one might expect a consistent relationship between the orientations of the optical and radio features. Here the data are inconclusive. The line joining the peaks of the condensations of the extended component of Centaurus A is inclined 17° to the major axis of NGC 5128, while the corresponding angle for Fornax A and NGC 1316 is 37°. Although the relative radio and optical orientations do not differ radically in either case, there is no evident basis for saying there is a consistent relationship between them. The picture is confused further by the fact that we see only two components of the spatial orientations involved.

(c) Dimensions, Luminosities, and Spectral Indices

Using the distances to NGC 1316 and NGC 5128 quoted in Table II, we find that the transverse (i.e., perpendicular to the line of sight) component of the linear separations of the peaks of the radio condensations is 136 kiloparsecs for Fornax A and 180 kiloparsecs for Centaurus A. Since we have no means of estimating the line-of-sight component, these values must be regarded as lower limits to the actual separations. It is reasonable to assume that the radio condensations are separated by roughly 200 kiloparsecs in each case.

No determination of the flux density of Centaurus A at 3000 Mc/s is available, but Heeschen (1961) has made accurate relative flux measurements at 1400 Mc/s. From his data, we see that the flux density of Fornax A is 0.0907 times that of Centaurus A. Adopting the distances given in Table II, we find that Fornax A is radiating about 1.6 times more energy than Centaurus A at 1400 Mc/s.

Heeschen's data for 440 Mc/s and 1400 Mc/s show that both sources have the same spectral index, -0.77, over this frequency range. Hence their spectra are similar, if not identical. But spectral indices near this value are found for most of the intrinsically strong extragalactic sources, so the agreement could easily be fortuitous. Nevertheless, it is reasonable to conclude that the total powers radiated by Fornax A and Centaurus A are in the same ratio as found above for 1400 Mc/s; i.e., that Fornax A is some 60 per cent more powerful than Centaurus A. Since 25 per cent of the radiation of the latter is due to the small source in or near NGC 5128, the extended component of Centaurus A is only about half as strong as Fornax A.

On the whole, it appears that the broad similarities between the two systems outweigh their differences. It is difficult to avoid the conclusion that the origins and histories of Fornax A and Centaurus A are much the same, and that they are in comparable stages of development.

V. DISCUSSION

We have concluded that Fornax A and Centaurus A probably are fundamentally similar objects. The outstanding characteristic of each is that most of the radio emission comes from two large, clearly separated regions well outside the associated galaxies. For some time Cygnus A also has been known to be double, and this source was compared with the extended component of Centaurus A in a previous paper (Wade 1959). Such bifurcation is readily detectable by interferometry, even in very distant objects. Recent work at the California Institute of Technology shows that a large proportion of the extragalactic sources either are resolvable into two components, or are elongated, which probably indicates incipient resolution (Moffet and Maltby 1961). Many of the remaining sources are very small, well below the resolution limit of the interferometer used by

Moffet and Maltby. In about 10 per cent of the clearly resolved cases the components have nearly equal intensities; Cygnus A falls into this group. The remainder exhibit varying degrees of asymmetry. Thus Fornax A fits the prevailing pattern.

Heeschen (1960) has published a preliminary radio color-absolute magnitude diagram for extragalactic sources. It has two well defined branches. The upper branch, occupied by sources identified with "peculiar" galaxies, contains the intrinsically most powerful radio emitters. The lower branch is made up of the much weaker sources associated with "normal" galaxies. Since the publication of the preliminary diagram, Heeschen has added many more objects to it (private communication). Nearly all of the galaxies associated with sources on the upper branch are ellipticals, SO's, or unclassifiable, while most of those on the lower branch are late type spirals. The one optical characteristic common to all of the galaxies associated with radio emission is high intrinsic luminosity. The double sources, and these are the ones with the largest absolute dimensions, seem to be restricted to the upper branch of Heeschen's diagram. The radio dimensions of the objects on the lower branch are comparable to the optical, in marked contrast to the situation among the upper-branch systems, where the radio-emitting volumes frequently exceed the stellar volumes by two orders of magnitude. It appears that the position of a source on the Heeschen diagram is a very significant datum.

The space density of the upper-branch sources is undoubtedly much less than that of those on the lower branch. Nevertheless most we observe belong to the upper branch, because of their much greater luminosities, and the majority of these evidently are doubles. Since binaries predominate among the observable extragalactic sources, it is fortunate that two of them, Fornax A and Centaurus A, are near enough to permit detailed study with existing pencil beams. There probably is a great deal of as yet unresolved structure in each. Further study should yield results of great value in our efforts to understand this class of object.

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