THE CENTRAL COMPONENT OF CENTAURUS A

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[*Manuscript received January* 24, 1966]

Summary

Transit observations of Centaurus A with a fan beam $1' \cdot 5$ wide at 73 cm show that the north-eastern component of the central source has an east–west width of $1' \cdot 7$ and that the south-western source has a width of $2' \cdot 3$. Since the situation at $9 \cdot 1$ cm is roughly the reverse of this, the two components must have sharply different spectra. The right ascensions observed are $13^{h}\,22^{m}\,48^{s} \cdot 0$ and $13^{h}\,22^{m}\,20^{s} \cdot 2 \pm 0^{s} \cdot 2$ (1950). The right ascension of the centre of NGC 5128 has been separately determined as $13^{h}\,22^{m}\,31^{s} \cdot 6 \pm 0^{s} \cdot 3$, showing that the two components are at significantly unequal distances from the optical object.

I. Introduction

The radio source Centaurus A comprises a halo extending over about 10° in declination and a compact central structure whose details have been emerging only gradually over many years. First reported as having an angular diameter less than 15′ by Bolton (1948), it was later found to have different diameters in different position angles, the centroid coinciding with that of NGC 5128 (Mills 1952, 1953). East–west interferometry by Twiss, Carter, and Little (1960, 1962) at 21 cm suggested that the central source was double, and Little (1963), observing at $9 \cdot 1$ cm with the east–west arm of the Stanford cross, confirmed this. The east–west spacing was $4' \cdot 7$, and the source widths were $2' \cdot 6$ and $1' \cdot 1$ (east and west).

The fact that the radio emissive region straddled, rather than coincided with, the optical object NGC 5128 suggested an evolutionary sequence of events in which pairs of radio emissive volumes were ejected from a galaxy, later to form extended diffuse haloes (Little, Cudaback, and Bracewell 1964).

Since a large proportion of radio sources have subsequently turned out to be double, the case of Centaurus A now appears to have more general significance than was apparent earlier. The approximate symmetry with which radio sources are generated is clearly of significance in relation to the manner of formation. However, the symmetry here is imperfect; for instance, Little's observations with the $2' \cdot 3$ fan beam showed a distinct difference in the widths of the two components.

A report by Maltby (1961) presents two components that are identical, and identically oriented with respect to the nebula, but it appears that an assumption of symmetry was made in advance in order to obtain an interpretation of an interferometer record. Consequently, it is not clear to what extent the interferometric observation requires the assumed symmetry.

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Preliminary scans made with the 210 ft radio telescope at Parkes with a beamwidth of 6′ at 10 cm failed to resolve the central structure, but Bracewell, Cooper, and Cousins (1962) were able, from a knowledge of the spatial configuration (Bracewell 1961), to separate them. This was done by driving the antenna simultaneously in both right ascension and declination so as to scan in directions approximately parallel to the line joining the components. The position angle of this line was found to be 43°.

Rotation of the feed horn, while pointed at each component in turn, then showed a sharp distinction between the two, the north-eastern component being 15% polarized, the other unpolarized. This observation confirmed the difference in character of the two components. The discovery that such strong polarization exists in radio sources which are observed with high directivity has now made polarimetry an indispensable part of high resolution microwave mapping (Cooper, Price, and Cole 1965).

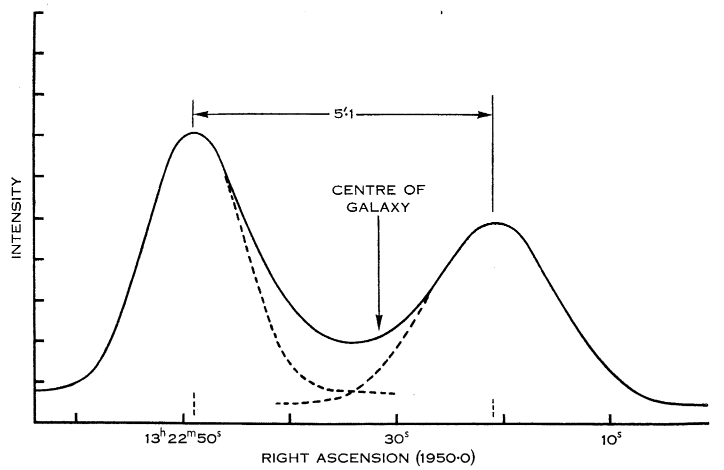

Fig. 1.—Observed transit of Centaurus A.

II. Equipment

Observations were made at a wavelength of 73 cm with the east–west arm of a cross antenna that has been described in detail by Mills *et al.* (1963). The east–west arm forms a fan beam 4° high in declination and 1′·5 wide in right ascension. The collecting area is approximately 10 000 m^2, and the bandwidth is 2·5 Mc/s; the time constant was 0·8 sec for a number of transit observations of Centaurus A taken on May 19, May 31, and June 1, 1965.

III. Observational Data

Figure 1 shows the observation made on June 1, 1965. The ratio of peak signal to r.m.s.-noise fluctuations is greater than 20 dB. There are two distinct peaks, whose right ascensions are in general agreement with values previously available (see Table 1). The tolerances quoted are probable errors.

In the figure, the broken lines show symmetrical curves obtained by reflection of the outer parts of the record in vertical lines through the two peaks. From this construction, it is apparent that the source cannot be represented as two components each symmetrical in itself. The figure shows that there is a bridge of emission connecting the two peaks, so that it is necessary to modify the previous interpretation that the object consists simply of two sources.

It is also clear that the peak brightnesses differ by a factor of about 1·5 and that the brighter peak is narrower than the less bright.

TABLE 1

RIGHT ASCENSIONS AND EAST–WEST SEPARATION OF CENTAURUS A PEAKS

Observer	Wave-length (cm)	Beam-width (min arc)	Right Ascensions (epoch 1950·0)		East–west Separation		Source Widths (corrected)	
			East Peak h m s	West Peak h m s	(min arc)	s	East (min arc)	West (min arc)
Cooper, Price, and Cole (1965)	6·0	4·1	13 22 47 ±2	13 22 20·5±2	4·9	26·5		
Little (1963)	9·1	2·3	13 22 47·8±0·9	13 22 22·4±0·9	4·7	25·4	2·6	1·1
Labrum *et al.* (1964)	21·1	1·6	13 22 44·2±0·9	13 22 16·4±0·9	5·1	27·8	2·7	2·1
Present observations	73	1·5	13 22 48·0±0·2	13 22 20·2±0·2	5·1	27·8	1·7	2·3

IV. Discussion

If one allows for the smoothing effect of the aerial beam, it is possible to say what the widths of the two sources must be in order to account for the observed widths, on the assumption that there are just two sources. If this is done, the results are 1′·7 for the east source and 2′·3 for the west.

These results at 73 cm are just the opposite of those obtained at 9·1 cm (Little 1963), and it now appears that both widths vary with wavelength but in opposite senses. Measurements with comparable resolving power at the intermediate wavelength of 21·1 cm by Labrum *et al.* (1964), however, do not indicate a simple variation with wavelength. All we can say is that the spectra of the two parts, or of the finer structures yet to be resolved, are sharply different.

The present observations suggest treating the source as an object with steep outer edges connected by a bridge; thus, rather than thinking of the object as two discrete volumes of relativistic particles travelling out from the galaxy, we think of an expansion with two sharp fronts followed by a train of less intense emission. One front is significantly brighter than the other, but the other has a more persistent train, so that the flux densities associated with the two halves are not substantially different at 73 cm.

The observations at 9·1 and 73 cm were made with the electric vector polarized east–west, and those at 21·1 cm were made with north–south polarization. No observations have been reported to indicate a substantial degree of polarization at 73 cm, but at the shorter wavelengths the widths and intensities of the components may be expected to show a dependence on polarization.

It is already known that the double source Cygnus A at 1400 Mc/s has a character resembling that of Figure 1 (Lequeux 1962). Observations at 9·1 cm with a 1′·0 fan beam do not reveal strong interior emission, but the explanation of interferometric observations at lower frequencies requires the presence of bridging emission that declines in relative importance with increasing frequency (Swarup, Thompson, and Bracewell 1963).

Thus, in two cases where high resolution observations permit, double sources assume similar forms. It remains to be seen from centimetre wavelength observations whether the spectral difference is confirmed also. The observations of Centaurus A by Labrum *et al.* at 21·1 cm, where the signal-to-noise ratio was not high, nevertheless appear to us to contain evidence of emission from a bridge.

V. Position Relative to NGC 5128

Since published positions for NGC 5128 do not possess the precision now needed for comparison with radio astronomical positions, the following new position, with estimated probable errors, has been obtained for a small dark marking that will be found to lie within about 0′·2 of the centre of the galaxy, depending on the way in which the centre is chosen (in the reproduction in the Hubble Atlas of Galaxies, this marking is at 163, 162, 122·5, and 119·5 mm from the left, right, top, and bottom edges respectively; south is at the top and west is at the left):

	R.A. (1950)	Dec. (1950)
Dark marking:	$13^h\,22^m\,31^s{\cdot}6\pm0^s{\cdot}3$	$-42°\,45'{\cdot}4\pm0'{\cdot}05$
Annual precession:	$+3^s{\cdot}508$	$-0'{\cdot}313$

The position is based on catalogue positions for the following stars:

A (1900)	$13^h\,19^m\,42^s{\cdot}76$	$-42°\,34'\,9''{\cdot}9$	Cape Zone Catalogue for 1900·00
A (1875)	$13^h\,18^m\,15^s{\cdot}8$	$-42°\,26'{\cdot}2$	Cape Photographic Durchmusterung
B (1875)	$13^h\,18^m\,48^s{\cdot}3$	$-42°\,20'{\cdot}6$	Cape Photographic Durchmusterung
C (1875)	$13^h\,17^m\,27^s{\cdot}3$	$-42°\,20'{\cdot}8$	Cape Photographic Durchmusterung

The 1875 positions enabled the scale factor and 1875 orientation of a photograph taken by R. Minkowski with the 200 in. telescope at Mount Palomar to be determined. Corrections of $+2^m\,55^s{\cdot}02$ and $-15'\,40''{\cdot}0$ were applied to the 1900 position to find the 1950 position of star A. The quoted position of the dark marking was measured off from star A, allowing for the change in orientation over 75 years; it is 4′·6 from star A in position angle −14°. Coordinates on a photograph can be established quickly and easily within about 1^s and 0′·1 by noting that star B is at a distance of 8′·2 from star A, in position angle 47°.

From Table 1, it is seen that the mean right ascensions of the two components are $13^h\,22^m\,46^s{\cdot}8\pm0^s{\cdot}7$ and $13^h\,22^m\,19^s{\cdot}9\pm0^s{\cdot}9$, where the errors are probable errors based on the spread of the data. The differences from the right ascension of the centre of NGC 5128 are $15^{s}\cdot2\pm0^{s}\cdot8$ and $11^{s}\cdot7\pm0^{s}\cdot9$. On the basis of the present observations alone, the two differences are $16^{s}\cdot4\pm0^{s}\cdot4$ and $11^{s}\cdot4\pm0^{s}\cdot4$. It is seen that the eastern component lies further from the centre of the galaxy by a significant amount.

VI. Conclusions

The central compact source in Centaurus A consists of two peaks that differ in width and brightness, together with a bridge of less intense emission between them.

The picture of two identical discrete sources is not correct, and in addition there is a conspicuous difference in the polarization of the emission from the two parts.

To account for the observed facts, it might be supposed that the outbreak that generates the emitting particles is channelled in opposite directions by a magnetic field that pre-exists in the neighbourhood of the galaxy. The ability of a quite weak field to channel a very energetic outburst may be understood by reference to a discussion by Gold (1966), who points out that expansion of a relativistic gas transversely to an extragalactic magnetic field is limited by the inertia of the ambient matter. Longitudinal flow of the relativistic gas, however, is not so impeded. Assuming that the initial outbreak was symmetrical, we could expect subsequent asymmetry to set in as a consequence of differences in detail of the extragalactic field. In the case of Centaurus A, it is known from polarization studies of the extended source that a magnetic field does exist over vast volumes of space outside the galaxy and that the field is not uniform (Cooper, Price, and Cole 1965). Then as the outpouring of relativistic gas takes place into the two established directions, differences in the degree of divergence, and other field parameters on the two sides, control the way in which each lobe pushes into galactic space.

The strong differences in spectrum of the parts of the source show that it is not valid to apply the theory of synchrotron emission to the overall parameters of unresolved sources as if the magnetic field, electron density, and energy spectrum were approximately homogeneous. If the expanding lobes contain relativistic gas pushing against magnetic fields on their boundaries only, and so radiating mainly at the boundaries, then source lifetime estimates on a homogeneous basis will have been too short by a large factor, and estimated source energies will have failed to include the interior energy content.

VII. Acknowledgments

The authors had the benefit of discussion with Professor B. Y. Mills and Professor T. Gold during the course of this work, which was supported by grants from the U.S. National Science Foundation, the Nuclear Research Foundation within the University of Sydney, and the Office of Scientific Research of the U.S. Air Force under contract AF 49(638)-1375. One of us (R.N.B.) wishes to thank Professor H. Messel for his invitation to make use of the facilities of the School of Physics of the University of Sydney.

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