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# THE STRUCTURE OF NGC 5128

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Table 1 lists the data of several plates taken by B. J. Bok and B. E. Westerlund with the 20-26 inch Schmidt telescope of the Uppsala Southern Station at the Mount Stromlo Observatory. No two plates are centered within several minutes of each other, and this is important to prevent any imperfections of the filters from reproducing spurious details in the image of NGC 5128 on different plates. All of the plates except plate 2924 are exposed to a sky density that is nearly optimum for faint details, but plate 2924 is underexposed.

TABLE 1

THE UPPSALA-MOUNT STROMLO PLATE DATA OF NGC 5128

| Plate | Date | Exposure | Emulsion | Filter (2 mm) | Passband | Observer |
|---|---|---|---|---|---|---|
| 1699 | 18/3/59 | $75^m$ | IIa-O | GG 13 | Blue | BJB |
| 1807 | 11/4/59 | 90 | 103a-E | RG 1 | Narrow red | BJB |
| 1828 | 12/4/59 | 90 | IIa-O | GG 13 | Blue | BJB |
| 2269 | 8/7/59 | 90 | 103a-F | RG 1 | Broad red | BEW |
| 2924 | 9/3/60 | 120 | 1-N | RG 5 | Infrared | BEW |

Dr. Bok and Dr. Westerlund have very kindly sent these plates to the writer and have permitted him to make positive copies and prints of them at high contrast in order to reveal structure in the faint parts of NGC 5128. Several materials and procedures were tried, but the best results came from contact copies on Kodalith Ortho film, enlarged and printed on Kodalith Ortho paper after sandwiching together the films of the two red plates or the two blue plates. The repetition of certain details on the prints made from the copies of individual original plates was the criterion for distinguishing real details from the artifacts which crop up in the process.

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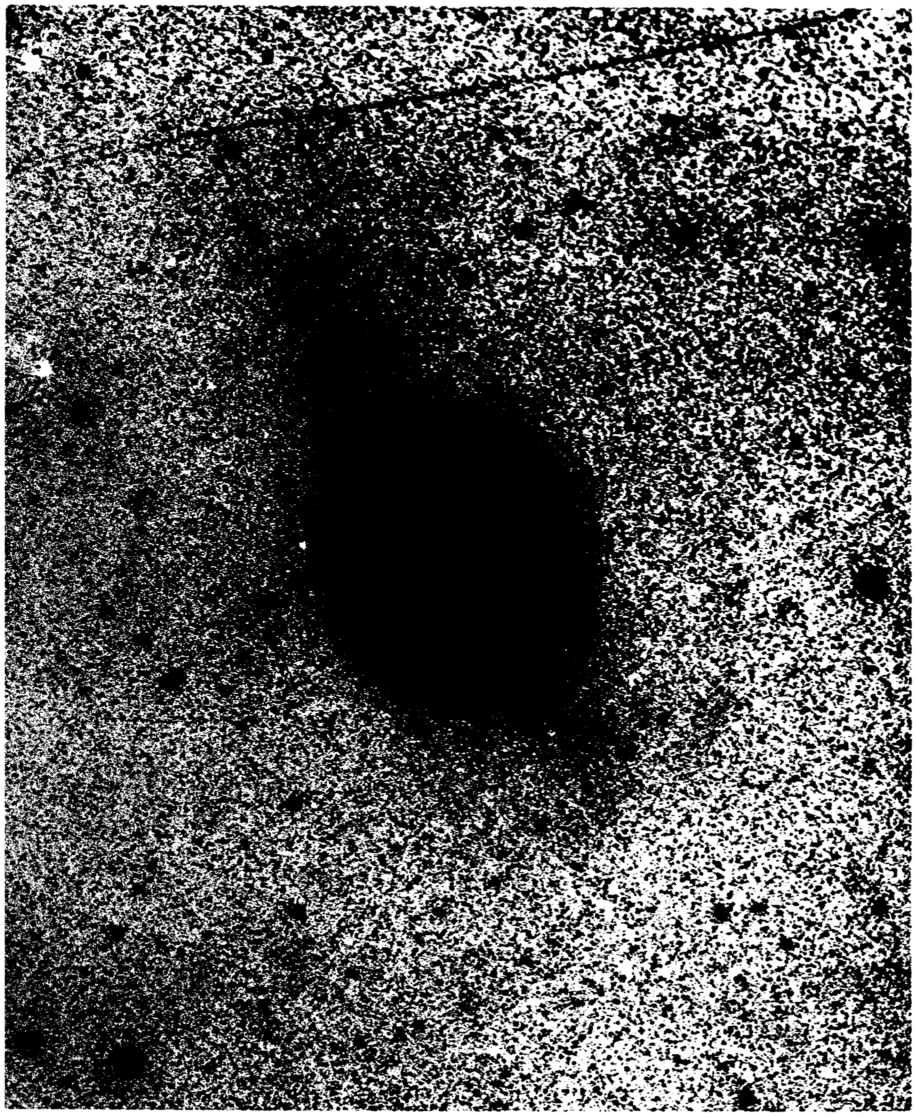

Fig. 1 -- A high contrast print of NGC 5128 showing faint outer structure projecting northeast and southwest from the nearly circular main body of the galaxy. The reproduction is made from a fusion of two red-sensitive plates. North is at the top, east is to the left. The scale is the same as that of Figure 5, where two declination circles are shown. At a distance of 4 or 5 mpc the object's total length of one degree is about 80 kpc.

Figure 1 shows NGC 5128 in the way just described, fusing plate 1807 and plate 2269 to give a red image. Figure 2 is a drawing of Figure 1, in which only the details that are confirmed with the individual plates are shown. The blue plates show apparently much the same detail in the faint outer extensions, except that they contain more noise or artifacts, and probably do not reach the same level of faintness. The best published long-exposure plate of NGC 5128, also in the red, shows the "extensions" of the image to the northeast and southwest only about half as far from the center as Figure 1 shows them (Figure 12 of Baade and Minkowski 1954). Furthermore, no structural details are apparent in Baade and Minkowski's reproduction, nor can any be seen by a direct inspection of original plates. The high contrast is required.

The dust belt of NGC 5128 is quite burnt out in reproductions that show the faint NE-SW extensions. That the dust belt does not silhouette in the extremities of the bright image shows that its length or diameter is less than the east-west diameter of NGC 5128. Figure 3 shows the dust belt somewhat more extensively than it can be traced on published reproductions (e.g., Figure 11 of Baade and Minkowski 1954, or page 50 in The Hubble Atlas of Galaxies). Figure 3 was made from a fusion of Harvard plates SB 2899 and SB 2902, two of three plates of NGC 5128 borrowed from the Harvard College Observatory by courtesy of the Director. The dust belt crosses the image of a galaxy that has been classified E0 despite the non-circular shape (Baade and Minkowski 1954). After crossing the bright part of the E0 galaxy, the dust belt widens at both ends and curves east and west from the central part so as to look S-shaped. The belt is slightly convex to the northeast in the central part. It silhouettes more strongly in the east half, where it appears double or triple. The structure becomes more confused and fainter in the west half, as though the dust dips farther into the E0 galaxy there. The northern edge of the western end of the belt appears to resolve into individual stars or clouds of stars. (These are not the Sérsic stars discounted by Sandage on page 50 of The Hubble Atlas.)

The dust belt may be traced on the original prints as far as $7\overset{'}{.}7$ from the center in PA = 101° and $6\overset{'}{.}0$ from the center in PA = 284°. There is a swarm of dust clouds, some of them as small as the smaller star images on the print, rising from the eastern end of the dust belt in the range $3\overset{'}{.}8 < r < 7\overset{'}{.}7$, through decreasing position angles around the center to about PA = 40°. This may be regarded as a continuation of the S-shaped belt in a projected helix. Unfortunately, it is not easy to see the "swarm" on Figure 3. It looks as though the belt is convex toward the sun, where it crosses in front of most of the E0 galaxy, and is tangential to the line of sight near its observed extremities. It is then twisting so as to suggest connections with the northeast and southwest extensions. Figure 4 illustrates the hypothetical geometry. (The southern edge of the belt shows signs of generating a broken elliptical loop of faint clouds surrounding a clear area in the southwest part of the E0 image. This is clearly apparent in the publications previously cited, and it is a feature that deviates from the S-shape of most of the dust.)

The structure of NGC 5128 should also be discussed with reference to Centaurus A, the radio source in the same area. In particular, we want to know whether synchrotron radiation in optical wavelengths can account for any of the details. Centaurus A is composed of two "central components" and a very extensive faint "halo" elongated

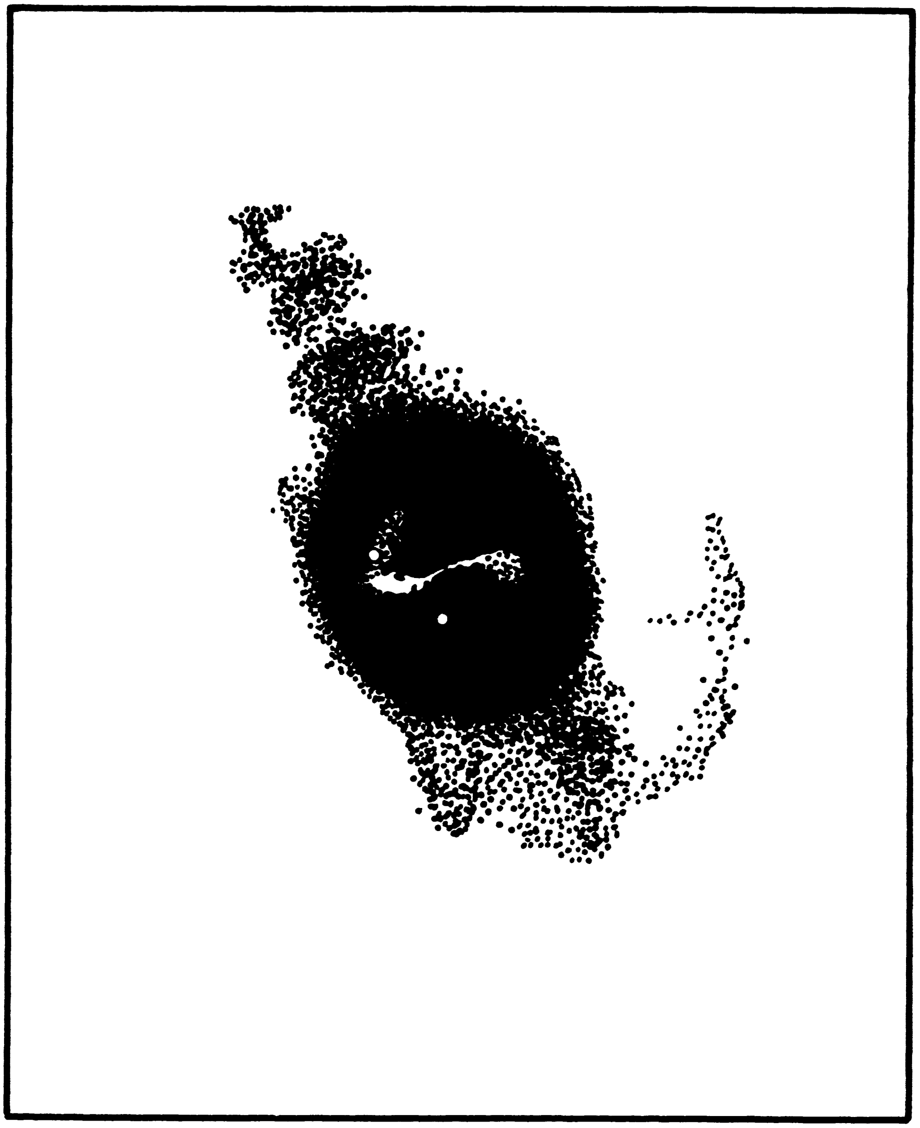

Fig. 2 -- A drawing made to emphasize the details of Figure 1 that are confirmed by presence on prints of different original plates, and to show the dust belt. The stars marked A and B on Figure 3 are shown as white dots here. The scale is equal to that of Figures 1 and 5.

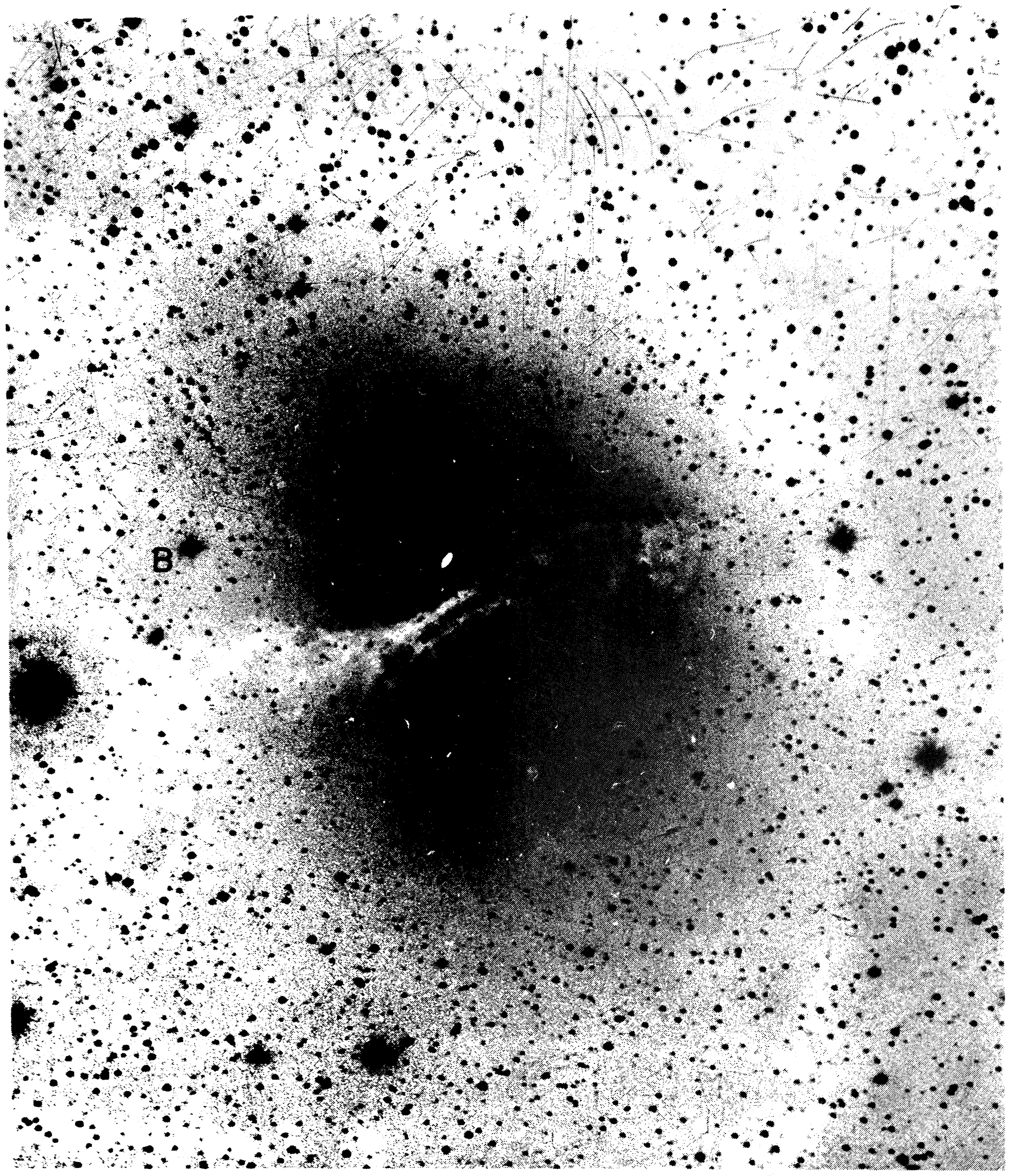


Fig. 3 -- A fusion of two Harvard Observatory plates of NGC 5128, showing extended dust-belt structure. The smaller scale and denser exposure of the plates of Table 1 make them less suitable for showing the details of the inner parts of NGC 5128. According to Bracewell (unpublished) the star marked B is at a distance of 8!2 from the star marked A, in PA = 47°. The scale differs from that of Figure 1.

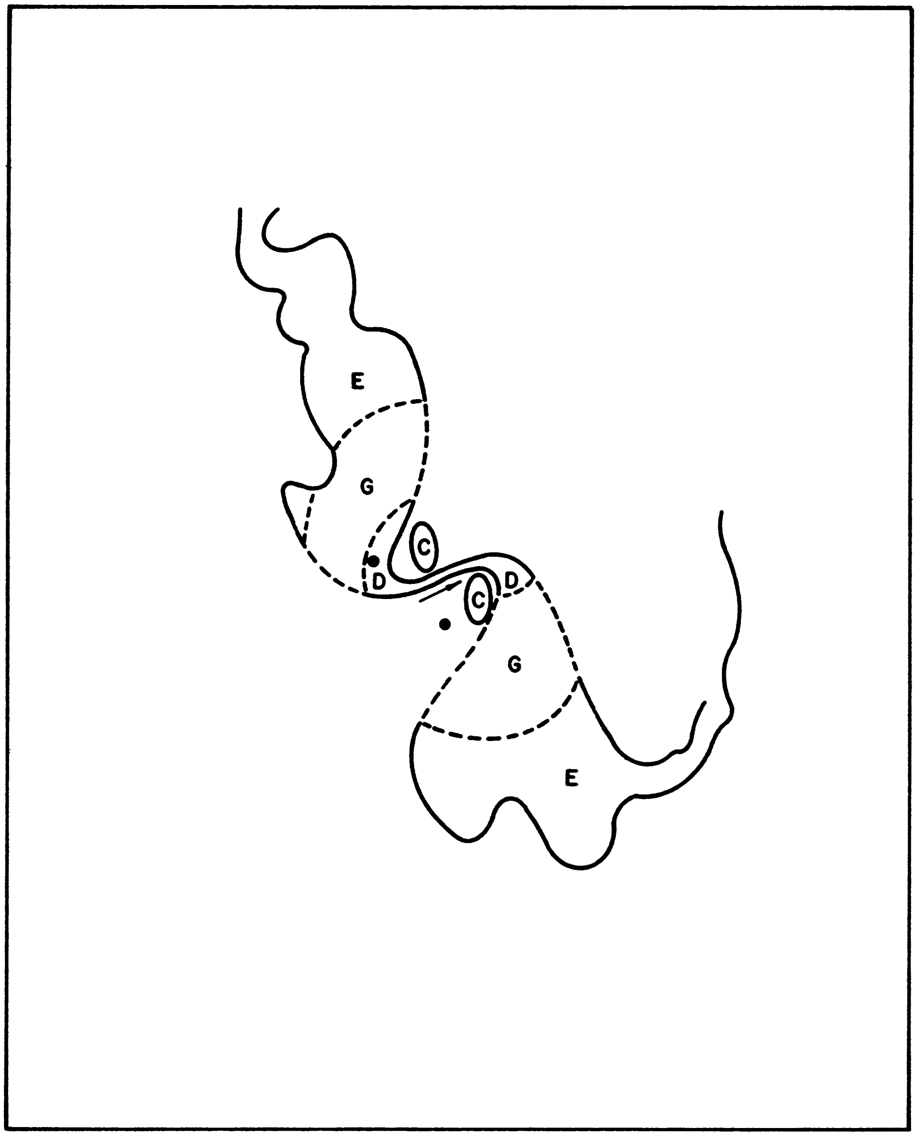


Fig. 4 -- The dust belt, zone DD, is shown as though connected with the faint bright extensions EE through interpolated zones GG where contrast with the starlight of the galaxy is very low. The stars marked A and B on Figure 3 are shown as black dots, and the central sources reported by Maltby and Moffet (1962) are marked CC. The figure is probably that of a projected helix. The arrow marks the direction of motion of the gas in the dust belt, and the probable sense of rotation of the E0 galaxy, according to spectrographic observations (Burbidge and Burbidge 1962). The scale is equal to that of Figures 1 and 5.

north-south. Maltby and Moffet (1962) describe the two central components at $\lambda$ = 31.3 cm: "... equal intensities ± 30 per cent, separation 7!1 ± 0!5 along major axis in PA = 46°5 ± 2°. One or both components are elongated in PA = 15° -- diameters 3!8 x 2!0." Bracewell, Cooper, and Cousins (1962) have discovered linear polarizations in the central components at $\lambda$ = 10 cm. Their observations are "consistent with the presence of two point sources lying on a line in PA = 43°, 7!0 apart, the northeast source being 15 per cent polarized in PA = 115°." Bracewell (unpublished) believes that the two sources are circular but possibly resolvable into sub-components.

We shall need the formula $\log b = \log F + 2 \log \lambda + \log \pi + 2 \log R_{\odot} - 0.4\,([m_{\lambda}] - m_{\lambda\odot}) - 17.477$ w $m^{-2}(c/s)^{-1}$ $ster^{-1}$ to convert $[m_{\lambda}]$ magnitudes per square second of arc at effective wavelength $\lambda$ into the units common in radio astronomy. Here $\lambda$ is measured in microns if $F_{\lambda}$ erg $sec^{-1}$ $cm^{-2}$ $\mu^{-1}$ $ster^{-1}$ is the intensity of the mean solar disk per unit wavelength range with spectrum lines smoothed (Allen 1955). $R_{\odot}$ is the angular radius of the sun in seconds of arc at one A.U. (Allen 1955), $m_{\lambda\odot}$ is the apparent magnitude of the sun's disk at one A.U. (Stebbins and Kron 1957), and the constant term enters from the conversion of units. There should be no confusion over the use of m for both stellar magnitude and for meter in this formula.

According to Lequeux (1962), the spectral index of the central components of Centaurus A is -0.25 for $\nu$ < 150 Mc/s and -0.80 for $\nu$ > 150 Mc/s. Taking $T_b$ = 15,000 °K at $\lambda$ = 0.313 m (Maltby and Moffet 1962), the brightness $b = 2.77 \times 10^{-23}\, T_b\, \lambda^{-2}$ = $4.2 \times 10^{-18}$ w $m^{-2}(c/s)^{-1}$ $ster^{-1}$; and taking $b \propto \nu^{-0.8}$, the brightness extrapolated to $\lambda$ = 5450 A is $1.0 \times 10^{-22}$ w $m^{-2}(c/s)^{-1}$ $ster^{-1}$. Can the central components be seen above the background starlight in NGC 5128? Sérsic (1958) has published an absolute optical photometry of NGC 5128 as a function of radius. He finds that the brightness in blue, yellow, or red varies almost exactly alike as a function of radius to r = 10!5 on the major axis (normal to the dust belt). He gives the brightness graphically in stellar magnitudes per square second of arc. At r = 3!5, the photovisual brightness is $21^{m}.7/\square''$ = $3.5 \times 10^{-21}$ w $m^{-2}(c/s)^{-1}$ $ster^{-1}$. The central components of Centaurus A are therefore 3 per cent as bright as the local background of the galaxy, and this probably predicts them to be just below optical visibility. Errors in the right direction might later require a change of spectral index between the radio and optical spectral regions.

Although the central components of Centaurus A are too weak to be visible optically, is it possible to account for the faint optical details in Figure 1 by the synchrotron emission of the halo? There are several difficulties in the way, chiefly that there is no measure of the absolute optical brightness beyond r = 10!5, where Sérsic's photometry ceases. There $[m_{pv}]$ = 24.2, and the writer estimates that $[m_{pv}]$ at r = 25' to the northeast is one to three magnitudes fainter still, leading to $b_{pv} = 1.4 \times 10^{-22}$ to $0.22 \times 10^{-22}$ w $m^{-2}(c/s)^{-1}$ $ster^{-1}$. Now $T_b$ = 25 °K at 1410 Mc/s near the same point, according to Cooper's map (Kerr 1962). This gives $b = 1.5 \times 10^{-20}$ w $m^{-2}(c/s)^{-1}$ $ster^{-1}$; and the corresponding mean spectral index over the range from 1410 Mc/s to 5450 A is -0.36 to -0.51. Unless the northeast photovisual brightness is 5.7 magnitudes fainter at r = 25' than it is at r = 10!5, the spectral index must average algebraically larger than -0.7, the value which Bolton and Clark (1960) find in Centaurus A, with "no variation of the spectrum with position over an eleven-to-one frequency range between 960 and 85 Mc/s." However, the great brightness of the central sources undoubtedly makes it difficult to measure the spectrum of the halo only 25' away. It looks rather unlikely that the faint optical extensions of NGC 5128 are so faint, and there is no theory of

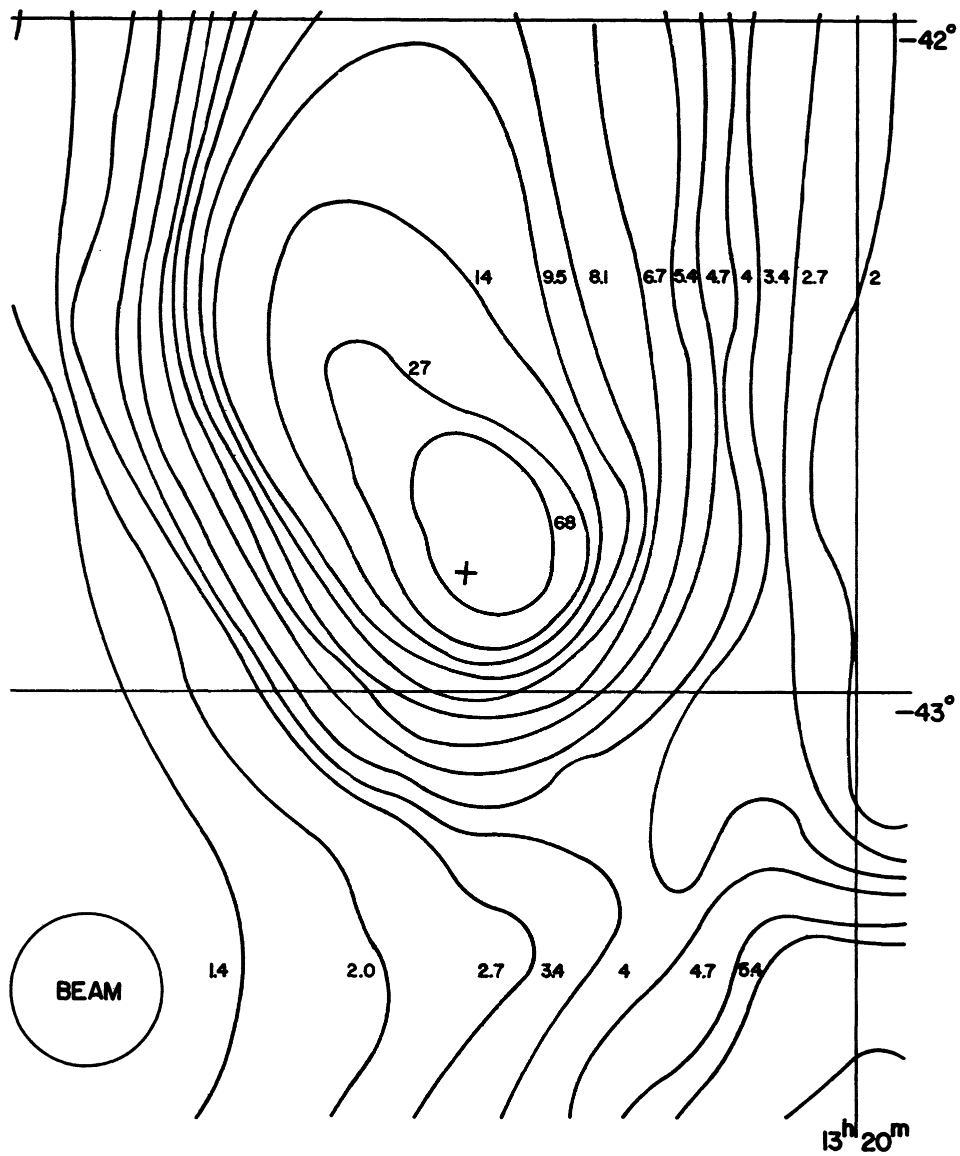


Fig. 5 -- A drawing made from Cooper's 210-foot telescope map of Centaurus A at 1410 Mc/s for the epoch 1962.2. Contour labels are °K of brightness temperature. The scale and area of the map are those of Figure 1 except for distortions of the orthogonal projection, which are nil near the center. The cross gives the NGC position of NGC 5128 precessed to 1962.2, which is within 1' of the optical center. The center of the dense image of Figure 1, about 26' x 28' in size, coincides with the cross within the errors of estimating its position. The scale is the same as that of Figure 1.

synchrotron radiation to account for a flattening of the spectrum with an increase of frequency. This calls into question whether the faint optical extensions are synchrotron radiation, despite the good agreement of their structure with the 1410 Mc/s contours reproduced in Figure 5 (after smoothing by the beamwidth).

It remains open to discuss Figure 1 in terms of stellar radiation or diffuse nebulae. The Burbidges (1962) have inferred from spectrographic observations that the E0 galaxy rotates on an axis that approximately coincides with the NE-SW extensions, and it is hard to accept the stellar nature of clumpy polar extensions and the peculiar arc at about $\underline{r} = 25'$ in the southwest, unless they are stellar products of the gas and dust as arranged in Figure 4.

Some arguments may be given against taking the features of the NE-SW extensions to be simply H II regions. First, they are practically equally strong on the two red plates, although 103a-F emulsion on plate 2769 perhaps doubles the sky background over 103a-E emulsion on plate 1807, relative to H$\alpha$ emissions in the passbands. Second, the ratio of blue intensity to red intensity appears to be greater than the corresponding ratio of intensities of galactic H II regions on the Palomar Sky Survey prints, although the Uppsala GG 13 filter cuts off more of the ultraviolet than the Palomar glass filter cuts off, and, in particular, the GG 13 filter transmits [ O II ] $\lambda$ 3727 perhaps half as well. However, H II emissions may be bright enough to account for the light in the faint extensions of NGC 5128. A column of gas 8 kpc long through an extension would radiate $8 \times 10^3 \times 3.08 \times 10^{18} \times 1.22 \times 10^{-25}\, \underline{N}_e^2/4\pi$ erg sec$^{-1}$ cm$^{-2}$ ster$^{-1}$ in H$\beta$ under standard conditions (Burgess 1958). Suppose that first this column and then a solar-type star were observed by means of a telescope with a focal diaphragm of 1 □ " and a filter of equivalent width 260 A centered on H$\beta$. The brightness of the star would equal the H$\beta$ brightness, if the star were of magnitude 26 and the electron density $\underline{N}_e$ were 0.1 cm$^{-3}$. The result, 26 magnitudes/□ ", is in the range of brightness estimated for the NE-SW extensions at $\underline{r} = 25'$. A region of uniform density 0.1 cm$^{-3}$ and radius 4 kpc could be photoionized by a group of hundreds of O-type stars, or by such numbers of cooler stars that the starlight alone would probably account for the brightness of the NE-SW extensions. The brightness temperature of the hypothetical H II region is about 0.1 °K at 1410 Mc/s.

If the NE-SW extensions are partly or wholly reflection nebulae, their light may be polarized, so that the distinction between scattered light and synchrotron radiation, also polarized, may depend on the position angle of the electric vector. It is perpendicular to the line joining the observed position and the center of NGC 5128 for scattered light, unless the scattering particles are asymmetrical and oriented non-randomly. Cooper and Price (1962) have made radiofrequency observations and taken account of Faraday rotation, predicting the electric vector in optical frequencies near $\alpha = 13^h\ 24^m\ 00^s$, $\delta = -42°30'$ (1962), for example, to be in $\underline{PA} = 55°$ at the source. At the same coordinates the electric vector of scattered light should be nearly in $\underline{PA} = 104°$ at the source, undergoing practically no Faraday rotation.

Balmer lines in emission are observed in the silhouetted dust belt of NGC 5128 but are not yet observed outside it in the galaxy. On wide-slit spectrograms, taken by the writer with the 74-inch Mount Stromlo telescope, H$\alpha$ appears to be probably an absorption feature 2' to 3' from the dust belt. There are no data beyond 3'. All parts of NGC 5128 should be examined with a spectral scanner, an observation as crucial as examination for polarization. Studies of the whole dust-cloud structure are also needed.

There are several subsystems in NGC 5128/Cen A with scarcely understood relationships: a giant elliptical galaxy; a pair of small bright radio sources situated symmetrically in the galaxy; and a belt of dust and gas which appears to be partially intertwined into the galaxy in an S-shape. In projection the belt is symmetrical with respect to the galaxy and to the pair of central radio sources, but the motion of the belt is not tightly bound to that of the galaxy. Finally there are faint extensions from the image of the galaxy. They resemble the inner isotherms of the large radio "halo" and perhaps they continue the dust and gas belt beyond the silhouetted parts.

## REFERENCES


Allen, C. W. 1955, Astrophysical Quantities (London: The Athlone Press).

Baade, W., and Minkowski, R. 1954, Ap. J., 119, 215.

Bolton, J. G., and Clark, B. G. 1960, Pub. A.S.P., 72, 29.

Bracewell, R. N., Cooper, B.F.C., and Cousins, T.E. 1962, Nature, 195, 1289.

Burbidge, E. M., and Burbidge, G. R. 1962, Nature, 194, 367.

Burgess, A. 1958, M. N., 118, 477.

Cooper, B.F.C., and Price, R. M. 1962, Nature, 195, 1084.

Kerr, F. J. 1962, Sky and Telescope, 24, 254.

Lequeux, J. 1962, C. R. 255, 1865.

Maltby, P., and Moffet, A. T. 1962, Ap. J. Supp. Ser. 7, 141.

Sérsic, J. L. 1958, Observatory, 78, 24.

Stebbins, J., and Kron, G. E. 1957, Ap. J., 126, 266.