OBSERVATIONS OF THE CARINA NEBULA (NGC 3372) AT 1410 AND 2650 Mc/s

By M. Beard* and F. J. Kerr*

[*Manuscript received July* 18, 1966]

Summary

The 2650 and 1410 Mc/s isophotes of an area of approximately 4 sq deg centred on the Carina nebula are presented. The aerial beamwidth of $7'\cdot4$ at 2650 Mc/s enables a useful comparison to be made with Hα photographs of the region taken at Mount Stromlo. No evidence of non-thermal radiation was obtained and a spectral index of $+0\cdot1$ was measured.

I. Introduction

The galactic emission nebula NGC 3372 was first detected as a radio source by Mills, Little, and Sheridan (1956) during their survey of the southern Milky Way at 85·5 Mc/s. Observations at 1400 Mc/s were carried out by Hindman and Wade (1959) and the significance of these observations in relation to the physical characteristics of the nebula was examined in a companion paper by Wade (1959). The half-power beamwidths at 85·5 and 1400 Mc/s were of the order of 1°, so that any conclusions drawn from the radio observations about the structure of the nebula included the effect of appreciable aerial smoothing. The diameter of the visible nebula is about 1° if the low intensity regions are neglected.

Wade (1959) used a distance of 1·4 kpc but the mean of more recent investigations by Faulkner (1963), Feinstein (1963), and Graham (1963) indicates a distance closer to 2·7 kpc.

Following a suggestion by Rodgers and Searle (1966) that there was evidence of optical synchrotron radiation from the star Eta Carinae, it was decided to examine the nebula again with the 210 ft diameter Parkes telescope. Observations were made at 2650 and 1410 Mc/s. The beamwidth is 7·4 min of arc at 2650 Mc/s, and convolution of the results to simulate the 14 min of arc beam at 1410 Mc/s enables a check to be made of the spectrum. In addition an attempt was made to measure polarization over a restricted area.

The Carina nebula has often been called the Eta Carinae nebula because the unusual star η-Carinae is near the centre of the area covered by the nebula. However, there is no evidence that the star and nebula are physically associated or are even at the same distance, and it was agreed at a recent Australian symposium that the name Carina nebula would be better (Rodgers 1966).

* Division of Radiophysics, CSIRO, University Grounds, Chippendale, N.S.W.

II. Equipment

The characteristics and design of the receivers used for the two sets of observations have been given by Gardner and Milne (1963) and Cooper, Cousins, and Gruner (1964). The rotating feed system, which can be set at any feed angle or maintained in a constant position angle, has been described by Cooper, Price, and Cole (1965). Beard (1966) has outlined the digital recording and reduction methods used to produce the contour diagrams in the present paper.

A summary of the receiver and aerial characteristics and other constants is given below.

Table 1

PARAMETERS OF RECEIVERS AND REFERENCE SOURCES

Parameters and Reference Sources	Frequency (Mc/s) 1410	2650
Receiver		
type	Parametric	Parametric
bandwidth (Mc/s)	10	100
system noise temp. (°K)	105	180
time constant (sec)	1	0·5
Beamwidth at half intensity (min of arc)	14·0	7·4
Full-beam solid angle (sr)	$1 \cdot 83 \times 10^{-5}$	$5 \cdot 15 \times 10^{-6}$
Reference source	Hydra A	3C 353
Flux density of source ($\mathrm{W\,m^{-2}\,(c/s)^{-1}}$)	45	32·5
Flux density/T_b (equation (1))	1·1	1·1
T_b/contour unit	0·9	1·65

III. Observing and Calibration Procedure

The area was scanned in declination at right ascension intervals equivalent to approximately one-quarter of the beamwidth. The right ascension interval was 30 and 15 sec for the 1410 and 2650 Mc/s surveys respectively. For each scan the feed angle was set so that the mean position angle of the electric vector during the scan was zero.

The scan rate at both frequencies was 1°/min, which, with the time constants of 1 and 0·5 sec (Table 1), necessitated only small corrections to the amplitude and delay of the receiver output signal. The output was recorded on punched paper tape at declination intervals of 0·5 min of arc.

Calibration of the observations was carried out through an argon noise source, which was coupled into the aerial feeder. The noise source was calibrated in turn against observations of Hydra A (at 1410 Mc/s) or of 3C 353 (at 2650 Mc/s). Flux densities for these sources have been provided by K. I. Kellermann (personal communication). These values are included in Table 1. The brightness temperature scale was fixed by observing the standard sources and using the relationship

$$T_b = S\lambda^2/2k\Omega_{fb}, \tag{1}$$

where Ω_{fb} is the effective full-beam solid angle obtained by integrating the beam contours and T_b is the peak apparent brightness temperature of the point source of flux S. Cooper, Price, and Cole (1965) describe the procedure and give values of Ω_{fb} for the Parkes aerial.

The base levels for the individual declination scans were related through two scans in right ascension at fixed declinations near the northern and southern ends of the area. An arbitrary zero temperature was taken as the minimum value in these reference scans. A correction was applied to allow for the small variation in the contribution from the ground due to the changing zenith angle.

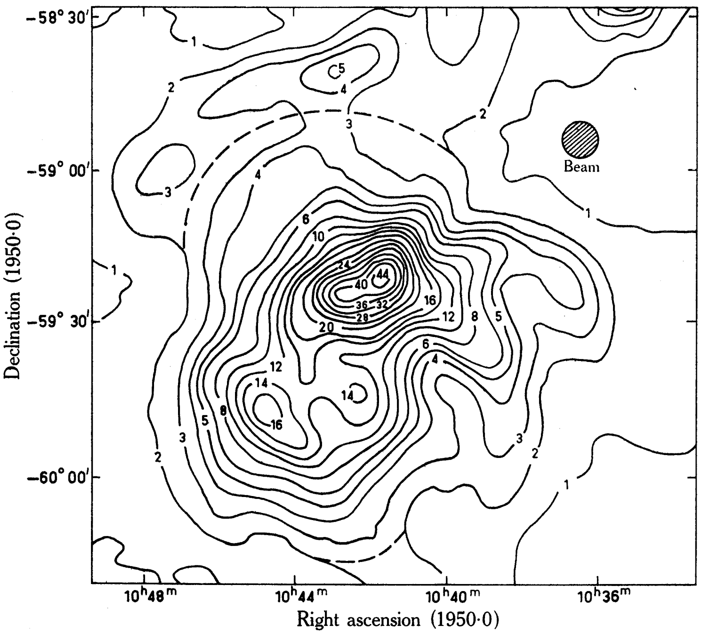

Fig. 1.—Isophotes of full-beam brightness temperature at 2650 Mc/s. One contour unit equals 1·65 degK brightness temperature. The dashed lines indicate the limit of the flux density integration.

IV. Results

(a) *Observations at* 2650 *Mc/s*

The contours obtained at 2650 Mc/s are shown in Figure 1. One contour unit corresponds to 1·65 degK brightness temperature. After removal of the background radiation the flux was estimated, from planimeter measurements, as 920 flux units (1 flux unit $= 10^{-26}$ W m^{-2} (c/s)$^{-1}$). The outer boundary of the area measured corresponded to the "2" contour ($T_b = 3 \cdot 3$°K), except where this passed outside the limits shown by the dashed lines. The background temperature was then assumed to be 3·3°K and to be constant over the area.

An attempt to measure polarization by rotating the feed was made at points corresponding to the peak emission and the position of η-Carinae. During these feed rotations there were variations in the total amplitude of up to 2%, but most of this was probably due to the effect of the complex nature of the background and slight beam asymmetry. We believe that any real polarization must be less than 1%.

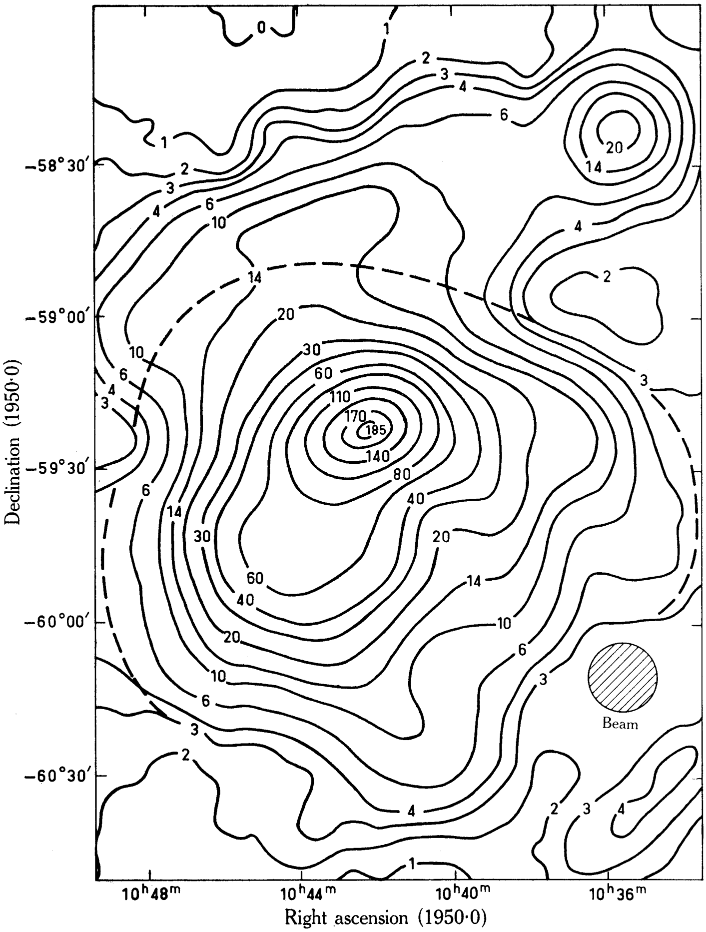

Fig. 2.—Isophotes of full-beam brightness temperature at 1410 Mc/s. One contour unit equals 0·9 degK brightness temperature. The dashed line indicates the limit of the flux density integration.

(*b*) *Observations at* 1410 *Mc/s*

The 1410 Mc/s contours are shown in Figure 2, in which one contour unit corresponds to 0·9 degK brightness temperature. An estimation of flux density made in a similar manner to the 2650 Mc/s measurement gave a value of 860 flux units. The area integrated was bounded by the "3" contour and the dashed line.

An estimate of the spectral index over the region may be made by comparing the 1410 Mc/s contours with 2650 Mc/s contours derived for an aerial with the same beamwidth. Figure 3 shows the result of convolving the 2650 Mc/s contours of

Figure 1 with a two-dimensional Gaussian function to give an effective resolution equal to that of the 1410 Mc/s beam.

The similarity of the contours of Figures 2 and 3 indicates that the spectral index is constant over the region. Allowing for uncertainties in the true zero level and errors in the adopted temperature scales, the index β obtained by comparing brightness temperatures is $-1\cdot9\pm0\cdot2$, where $T_b \propto f^{\beta}$.

This value agrees with the flux index $\alpha = +0\cdot1$ obtained by comparing the integrated flux densities given above ($\alpha = \beta+2$).

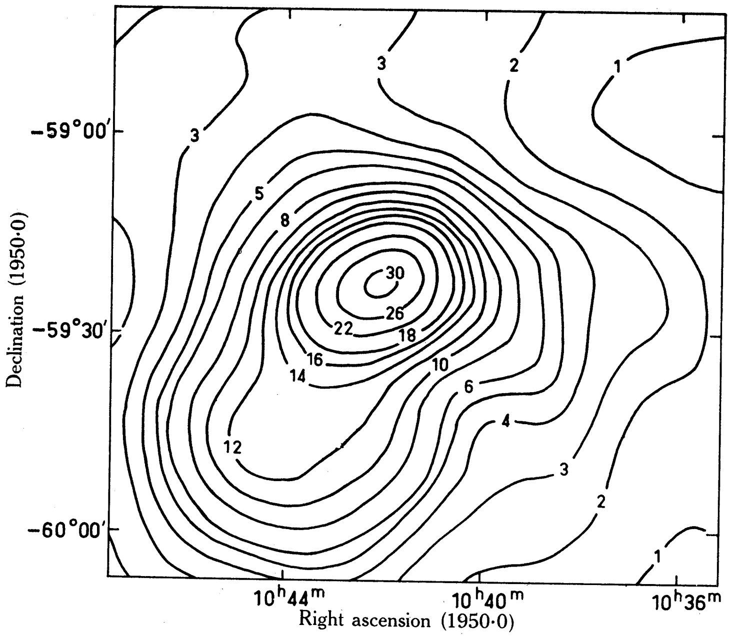

Fig. 3.—Isophotes obtained by convolving the 2650 Mc/s results of Figure 1 with a two-dimensional Gaussian function giving the effective resolution of the 1410 Mc/s beam. One contour unit equals $1\cdot65$ degK brightness temperature.

Mathewson, Healey, and Rome (1962), comparing surveys at 85 and 1400 Mc/s, obtained a flux index of $+0\cdot4$ and quoted a 1400 Mc/s integrated flux density of 950 flux units. An increase in the index is to be expected when extending the observations to lower frequencies because of the increasing opacity.

V. Comparison with Optical Features

Figure 4 (Plate 1) shows a photograph of the nebula in Hα light with some of the 2650 Mc/s contours of Figure 1 superimposed. The dashed lines enclose areas of high excitation as derived by Faulkner (1963).

The contour peaks at B, C, and D and the ridge at E correspond to the areas of high excitation on the photograph. The main peak A, however, must be due to emission from a part of the nebula that is obscured by overlying absorption.

There is no sign of emission from the star η-Carinae itself, but the position of the star relative to the secondary maximum on the contour diagram would make it difficult to detect a point source of less than 8 ± 2 flux units at 2650 Mc/s, or 16 ± 4 flux units at 1410 Mc/s. The background brightness temperature is approximately 60°K.

The position of the central part of the 2650 Mc/s contours relative to η-Carinae and other stars is shown more clearly in Figure 5 (Plate 2). The secondary maximum B is located near a bright arc, which is clearly visible in the original photograph. This arc, outlined in the figure, appears to form part of a circle of about 5 min of arc diameter, which can be seen in the fine structure of the bright northern quadrant. Dr. A. W. Rodgers of the Mount Stromlo Observatory made some observations on the bright arc area but was unable to find any correlation between Hα intensity measurements and the maximum B.

TABLE 2

SOME ESTIMATED PHYSICAL CHARACTERISTICS OF THE NEBULA

Parameter	Wade (1959)	Present Result	Optical Value
Core regions r.m.s. ion density (ions/cm^3)	71	62	60*
Central emission measure	54×10^3	80×10^3	80×10^3† 121×10^3‡
Mass (solar masses)	25×10^3	140×10^3	

* Bok (1932).
† C. S. Gum (unpublished optical measurements).
‡ Johnson (1960).

The radio observations can help in the interpretation of the dark areas seen in the photograph. Faulkner (1963) had already noted that the southern side of the bright northern portion of the nebula has an abrupt edge that seems to indicate overlying absorption, whereas the dark areas further to the south appear to be due to low excitation. The 2650 Mc/s results confirm this interpretation, because the contours of thermal emission carry right across the northern dark area but show troughs in the positions of the southern dark areas.

VI. Physical Characteristics

The physical characteristics of the nebula, as estimated by Wade (1959) would be altered by the latest estimate of distance and by the higher flux density measurement.

Table 2 shows the revised values and the optical measurements quoted by Wade (1959), as well as an additional reference to more recent optical data. The accuracy of the measurements does not justify altering the model used by Wade, who assumed that the gas is spherically symmetrical, has a uniform electron temperature, and consists entirely of singly ionized atoms.

CARINA NEBULA AT 1410 AND 2650 Mc/s

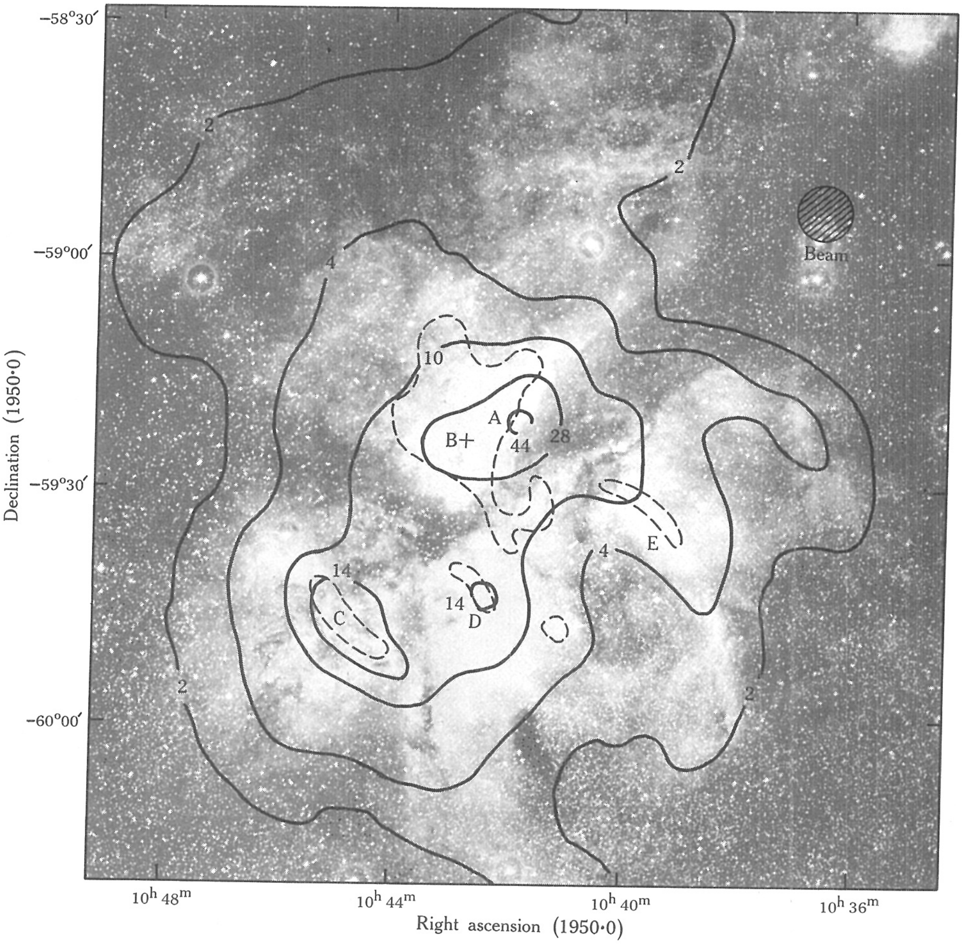

Fig. 4.—Photograph of the Carina nebula in Hα light. The full lines are the 2650 Mc/s isophotes. The dashed lines enclose regions of high excitation.

CARINA NEBULA AT 1410 AND 2650 Mc/s

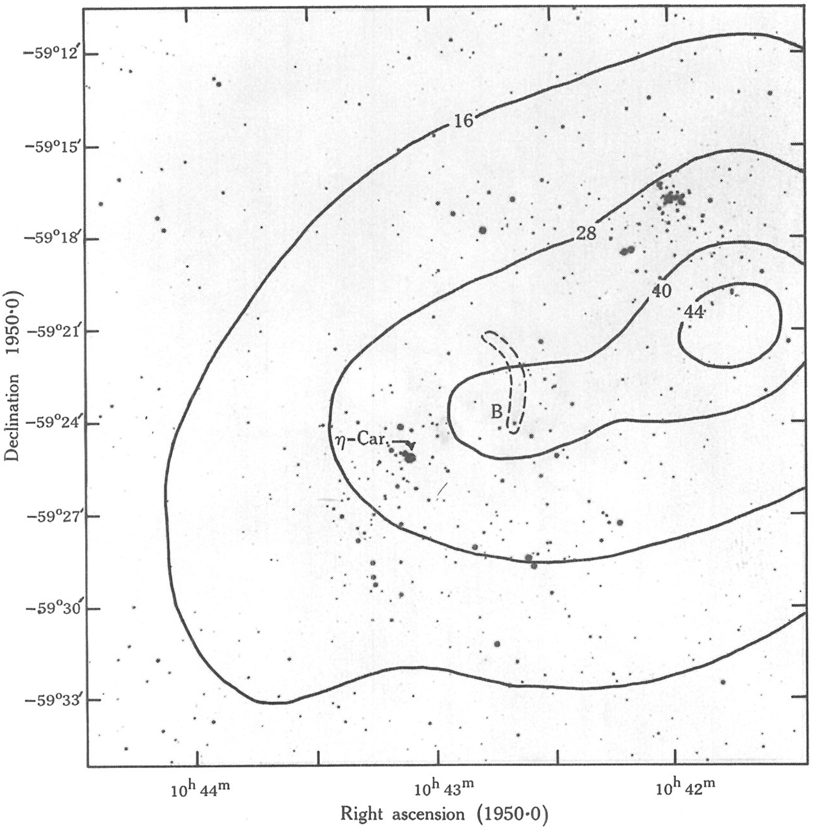

Fig. 5.—Photograph of η-Carinae and the Trumpler 14 and 16 clusters with superimposed 2650 Mc/s isophotes. The bright arc near the secondary peak has been outlined.

CARINA NEBULA AT 1410 AND 2650 Mc/s

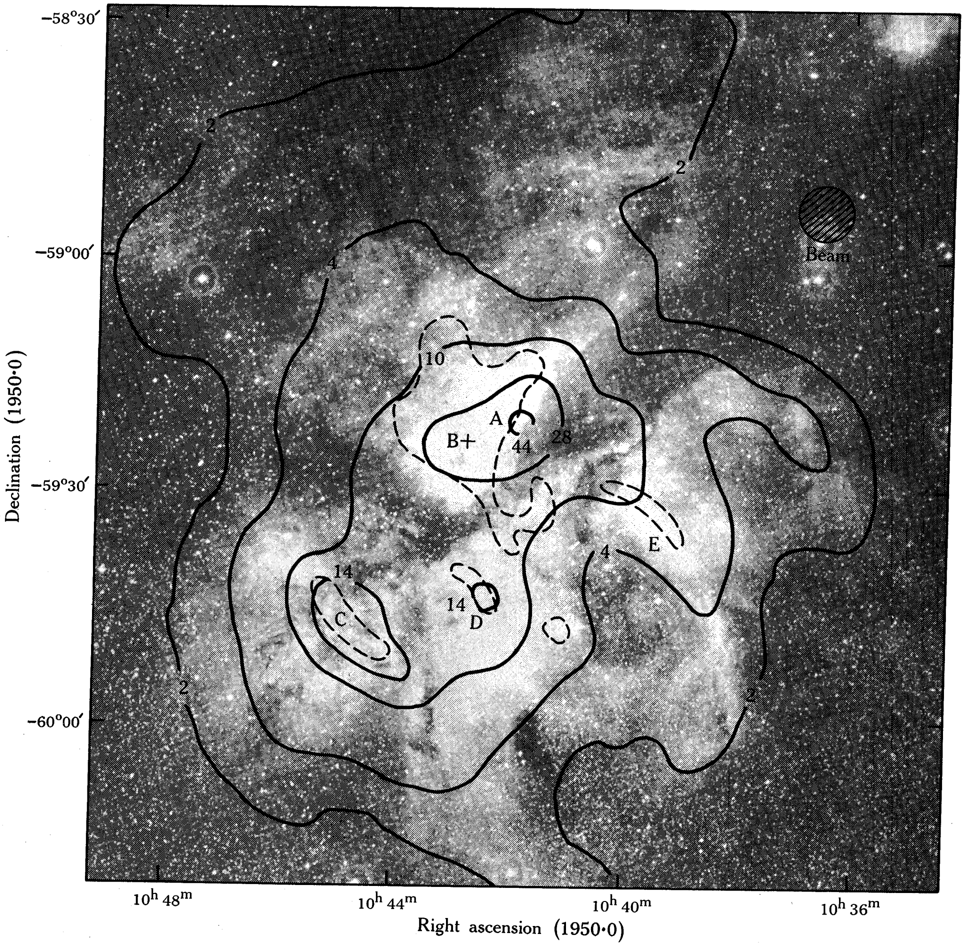

Fig. 4.—Photograph of the Carina nebula in Hα light. The full lines are the 2650 Mc/s isophotes. The dashed lines enclose regions of high excitation.

CARINA NEBULA AT 1410 AND 2650 Mc/s

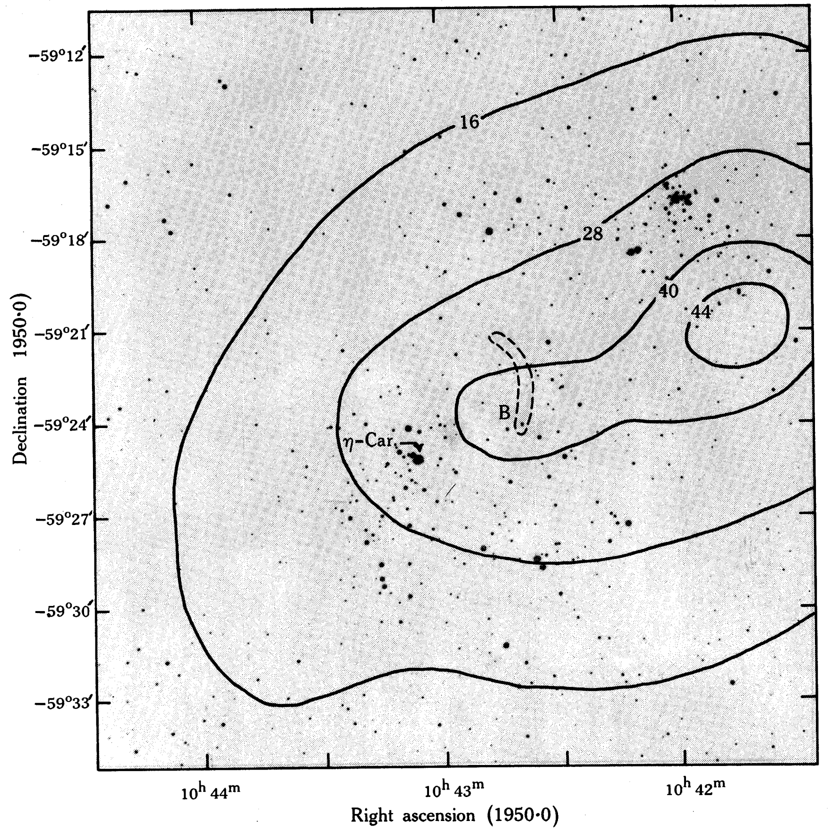

Fig. 5.—Photograph of η-Carinae and the Trumpler 14 and 16 clusters with superimposed 2650 Mc/s isophotes. The bright arc near the secondary peak has been outlined.

VII. Acknowledgments

Photographs of the Carina nebula region were supplied by Dr. A. W. Rodgers of the Mount Stromlo Observatory and our thanks are due to Dr. Rodgers and other members of the Observatory for useful discussions.

VIII. References

Beard, M. (1966).—*Aust. J. Phys.* **19**, 141–6.

Bok, B. J. (1932).—Astronomical Observatory of Harvard College Reprint No. 77.

Cooper, B. F. C., Cousins, T. E., and Gruner, L. (1964).—*Proc. Instn Radio Engrs Aust.* **25**, 221–7.

Cooper, B. F. C., Price, R. M., and Cole, D. J. (1965).—*Aust. J. Phys.* **18**, 589–625.

Faulkner, D. J. (1963).—*Publs astr. Soc. Pacif.* **75**, 269–77.

Feinstein, A. (1963).—*Publs astr. Soc. Pacif.* **75**, 492–7.

Gardner, F. F., and Milne, D. K. (1963).—*Proc. Instn Radio Engrs Aust.* **24**, 127–32.

Graham, J. A. (1963).—Ph.D. thesis, Australian National University.

Hindman, J. V., and Wade, C. M. (1959).—*Aust. J. Phys.* **12**, 258–69.

Johnson, H. M. (1960).—*Mem. Mt Stromlo Observ.* No. 15.

Mathewson, D. S., Healey, J. R., and Rome, J. M. (1962).—*Aust. J. Phys.* **15**, 354–68.

Mills, B. Y., Little, A. G., and Sheridan, K. V. (1956).—*Aust. J. Phys.* **9**, 218–27.

Rodgers, A. W. (1966).—Radio and optical studies of the Galaxy. Proc. Symp. at Mount Stromlo, May 3–5, 1966. p. 59.

Rodgers, A. W., and Searle, L. (1966).—*Mon. Not. R. astr. Soc.* (in press).

Wade, C. M. (1959).—*Aust. J. Phys.* **12**, 418–29.