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5 GHz OBSERVATIONS OF SMALL-SCALE STRUCTURE IN DR21

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SUMMARY

The H II region DR21 has been observed with the Cambridge 5-km telescope at 5·00 GHz. It is resolved into four compact components of high density and small linear dimensions, surrounded by diffuse envelopes of lower density. The condensations may be at a higher electron temperature than the envelopes.

INTRODUCTION

DR21, which lies within the extended H II region W75, is the most intense of the radio sources located by Downes & Rinehart (1966) in their 5 GHz survey of the Cygnus X region. It was observed over a wide range of frequencies by Ryle & Downes (1967) who found it to be a thermal source of small angular diameter, its thermal nature being later confirmed by the detection of recombination line emission (Mezger *et al.* 1967). It was thus the first compact H II region to be recognized as such, although unlike most such regions it is not closely associated with OH emission, the nearest OH source, W75(S), being 3 arc min distant. Later 5 GHz observations with the Cambridge One-Mile telescope (Wynn-Williams 1971) showed the source to consist of two main components surrounded by a diffuse envelope, and further structural detail has been revealed in a map by Balick (1972) with a resolution of about 3 arc sec at 8·1 GHz. This paper reports new 5 GHz observations of DR21 with the Cambridge 5-km telescope.

RESULTS

The operation of the telescope, which consists of four fixed and four movable dishes, is described elsewhere (Ryle 1972); the half-power widths of the synthesized beam are 2·0 arc sec in R.A. and 3·0 arc sec in declination for DR21. The results are based on a 12-hr run (1973 January 2) with 16 spacings and were calibrated using the source 3C 147, assumed to have a flux density at 5·00 GHz of $8{\cdot}2 \times 10^{-26}$ W m^{-2} Hz^{-1}.

The map obtained (Fig. 1) shows more detailed structure than has been observed hitherto. The integrated flux density is $18{\cdot}5 \pm 1{\cdot}0 \times 10^{-26}$ W m^{-2} Hz^{-1}; this is slightly lower than the previous values at the same frequency of about $21{\cdot}0 \times 10^{-26}$ W m^{-2} Hz^{-1} (Downes & Rinehart 1966; Reifenstein *et al.* 1970; Wynn-Williams 1971) as expected in view of the fact that the spacing increment with a single 12-hr observation allows a proper mapping only of structure extending to a radius of 20 arc sec. The One-Mile observations show that there is in fact

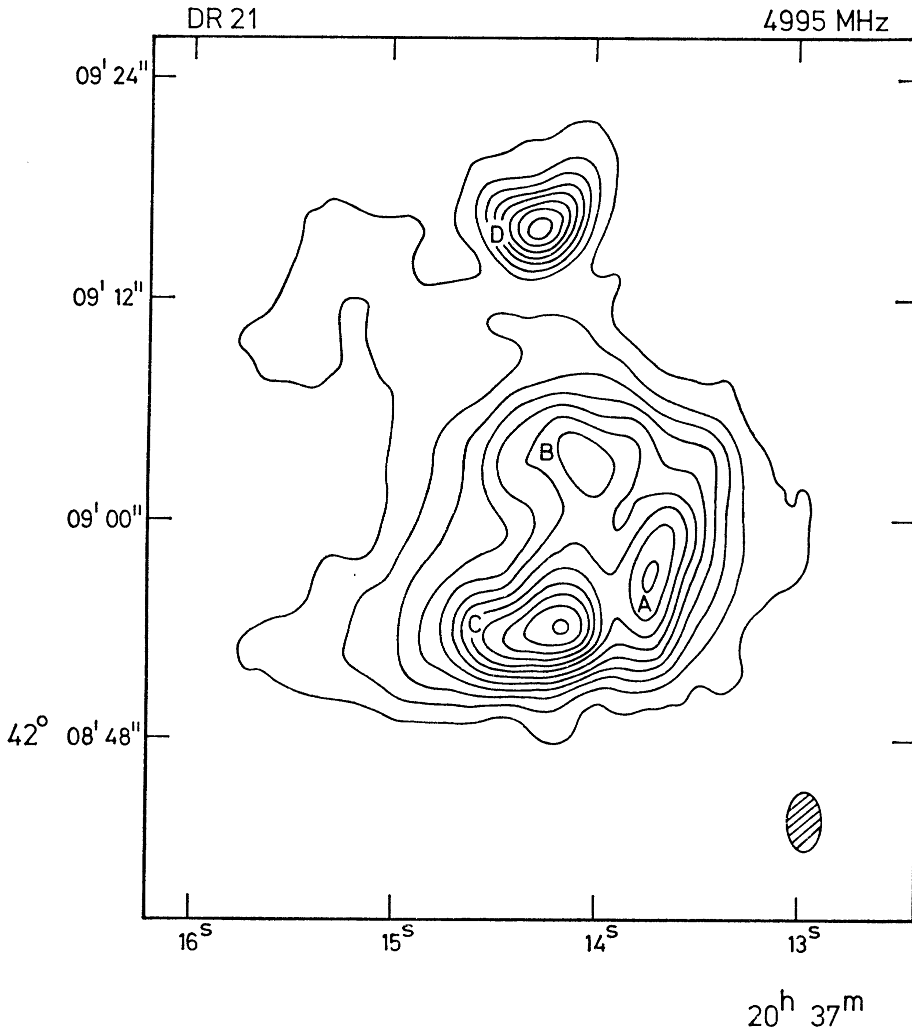

FIG. 1. *The distribution of brightness temperature of DR21 at 5 GHz. The contour interval is 392 K. The shaded ellipse shows the half-power beam area.*

structure on a larger scale; the difference of flux density could be accounted for by an outer extension with an area double that of the lowest contour shown and with a brightness temperature of 98 K (i.e. $\frac{1}{4}$ the contour interval). The composite map obtained by the addition of this outer contour has been used in the subsequent analysis.

DISCUSSION

The distance of DR21 is uncertain (Thompson, Colvin & Hughes 1969) but a value of 3 kpc has been adopted for the purpose of these calculations. It is apparent from the map that the southern component is now resolved into three very compact condensations which, at this assumed distance, are of the order of 0·1 pc across. They are surrounded by a diffuse envelope with a still more diffuse envelope surrounding both this and the compact northern component. These will be referred to as the inner and outer envelopes respectively, with the compact condensations labelled A, B, C, D, in order of increasing R.A. as shown in Fig. 1.

If a uniform electron temperature is assumed throughout the nebula the distribution of brightness at 5 GHz can be used to calculate the total flux at any other frequency. The method is described in detail by Martin (1973). It consists of using the relation:

$$T_{b_\nu} = T_e(1 - e^{-\tau_\nu})$$

and the fact that the optical depths at different frequencies are related by:

$$\frac{\tau_{\nu_i}}{\tau_{\nu_j}} = \left(\frac{\nu_i}{\nu_j}\right)^{-2 \cdot 1}$$

to derive the contours at different frequencies. The total flux at each frequency is then obtained from:

$$S_\nu = \frac{2k}{\lambda^2} \int T_{b_\nu} \, d\Omega.$$

The calculation was performed for a range of values of T_e and the results are compared in Fig. 2 with the integrated flux densities observed over a wide range of frequency; the best fit to these observations is obtained for an electron temperature $T_e = 8000 \pm 2000$ K. This agrees well with H109α recombination line values based on the assumption of local thermodynamic equilibrium, namely, $T_e = 7600 \pm 350$ K (Mezger *et al.* 1967) and $T_e = 7200 \pm 780$ K (Reifenstein *et al.* 1970). On the assumption that the electron temperature is 8000 K the optical depth and central emission measure of each component at 5 GHz were derived from its observed peak brightness temperature. These temperatures are given in the first column of Table I and the central emission measures *E* in column 2. The flux densities contributed by the individual components (column 3) were estimated

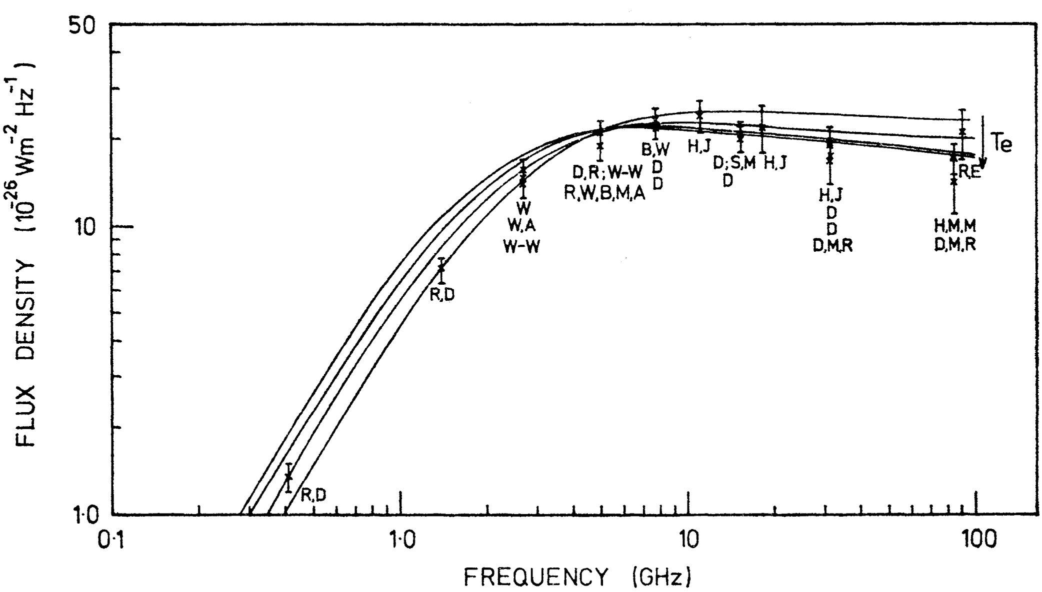

FIG. 2. *Calculated spectra for DR21. The electron temperatures are* 6000, 8000, 10 000, 12 000 *K. References for the data points are given by the initials of the authors. An error of* 10 *per cent in the flux has been assumed where none was quoted. References for the data points: B, W—Burke & Wilson* (1967)*; D—Dent* (1972)*; D, M, R—Downes, Maxwell & Rinehart* (1970)*; D, R—Downes & Rinehart* (1966)*; H, J—Hobbs & Johnston* (1971)*; H, M, M—Hobbs, Modali & Maran* (1971)*; R, W, B, M, A—Reifenstein, Wilson, Burke, Mezger & Altenhoff* (1970)*; R, E—Riegel & Epstein* (1968)*; R, D—Ryle & Downes* (1967)*; S, M—Schraml & Mezger* (1969)*; W, A—Webster & Altenhoff* (1970)*; W—Wendker* (1970)*; W-W—Wynn-Williams* (1971).

TABLE I

Physical parameters of the components

	Peak T_b (K)	E (10^6 pc cm^{-6})	S_{ff} (10^{-26} Wm^{-2} Hz^{-1})	θ_{sph} (arc sec)	$2R$ (pc)	N_e (10^3 cm^{-3})	M_{HII} ($M_\odot$)	U (pc cm^{-2})	L_c (10^{47} photons s^{-1})
Condensation A	4410	53	1·96	5·7	0·083	25·3	0·17	35·7	17·3
B	4020	46	0·82	4·0	0·058	28·3	0·06	26·7	7·3
C	5980	91	5·02	7·0	0·101	30·0	0·37	48·8	44·3
D	3630	40	0·82	4·2	0·062	25·5	0·07	26·7	7·2
Inner envelope	1270	11	4·47	20·4	0·296	6·2	1·8	47·0	39·4
Outer envelope	490	4	7·91	41·7	0·606	2·6	6·2	56·8	69·7

from the map on the basis of a simple spherical model for each, the corresponding angular and linear diameters being given in columns 4 and 5. The electron density, mass of ionized gas, and excitation parameter for each component (columns 6–8) could then be derived from the formulae of Schraml & Mezger (1969). The estimated error in electron temperature corresponds to errors of about 10 per cent in the masses and rather less in the other parameters.

The electron densities within the condensations are significantly higher than those previously obtained for this source (Wynn-Williams 1971) and are very much lower in the envelopes. Although a uniform electron temperature has been adopted for the purpose of the calculations, there is some indication from the spectra in Fig. 2 that the compact condensations are at a higher electron temperature than the envelopes. At low frequencies the former become optically thick so that the flux at these frequencies is dominated by the contribution from the diffuse envelopes. These points appear from the figure to indicate a lower electron temperature than that for the higher frequencies. Since the longer wavelength observations are likely to include a larger area of sky and hence give relatively larger flux densities, the effect apparent in Fig. 2 is probably underestimated.

The total rate of emission of Lyman continuum photons (L_c) from within each condensation (Table I, column 9) and also from the source as a whole has been derived on the basis of the formula given by Rubin (1968). According to his figures, the total L_c of $18{\cdot}5 \times 10^{48}$ photons s^{-1} could be accounted for by the presence of one star of spectral type O7–O8 in each of the condensations A, B, D and one of spectral type O5–O6 in condensation C. If DR21 is density bounded this value of L_c is a lower limit. It should be noted, however, that the relationship between spectral type and excitation parameter given by Prentice & ter Haar (1969) suggests that the excitation could be by O–B stars of later type.

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REFERENCES

Balick, B., 1972. *Astrophys. J.*, **176**, 353.
Burke, B. F. & Wilson, T. L., 1967. *Astrophys. J.*, **150**, L13.
Dent, W. A., 1972. *Astrophys. J.*, **177**, 93.
Downes, D., Maxwell, A. & Rinehart, R., 1970. *Astrophys. J.*, **161**, L123.
Downes, D. & Rinehart, R., 1966. *Astrophys. J.*, **144**, 937.
Hobbs, R. W. & Johnston, K. J., 1971. *Astrophys. J.*, **163**, 299.
Hobbs, R. W., Modali, S. B. & Maran, S. P., 1971. *Astrophys. J.*, **165**, L87.
Martin, A. H. M., 1973. *Mon. Not. R. astr. Soc.*, in press.
Mezger, P. G., Altenhoff, W., Schraml, J., Burke, B. F., Reifenstein III, E. C. & Wilson, T. L., 1967. *Astrophys. J.*, **150**, L157.
Prentice, A. J. R. & ter Haar, D., 1969. *Mon. Not. R. astr. Soc.*, **146**, 423.
Reifenstein, E. C., Wilson, T. L., Burke, B. F., Mezger, P. G. & Altenhoff, W. J., 1970. *Astr. Astrophys.*, **4**, 357.
Riegel, K. W. & Epstein, E. E., 1968. *Astrophys. J.*, **151**, L33.

Rubin, R. H., 1968. *Astrophys. J.*, **154**, 391.
Ryle, M., 1972. *Nature*, **239**, 435.
Ryle, M. & Downes, D., 1967. *Astrophys. J.*, **148**, L17.
Schraml, J. & Mezger, P. G., 1969. *Astrophys. J.*, **156**, 269.
Thompson, A. R., Colvin, R. S. & Hughes, M. P., 1969. *Astrophys. J.*, **158**, 939.
Webster, W. J. & Altenhoff, W. J., 1970. *Astr. J.*, **75**, 896.
Wendker, H. J., 1970. *Astr. Astrophys.*, **4**, 378.
Wynn-Williams, C. G., 1971. *Mon. Not. R. astr. Soc.*, **151**, 397.