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OBSERVATIONS OF NGC 7538 AT 2·7 AND 5 GHZ

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SUMMARY

The H II region NGC 7538 has been mapped at 2·7 and 5 GHz with a maximum resolution of 2 arcsec. The source consists of a diffuse region visible optically together with two much more compact components. The latter are close to or coincident with an infra-red source, an OH maser, and a region of molecular line emission.

1. INTRODUCTION

The presence of compact structure in some H II regions was originally inferred by Mezger, Schraml & Terzian (1967) from an analysis of the radio spectra. Subsequent observations with increasingly high angular resolution have confirmed the existence of these 'compact H II regions' or 'bright knots' (the terms are used without distinction) and have shown them to be usually (a) optically obscured, and (b) close to sources of molecular line emission, particularly the very bright OH and water vapour maser sources. Such an object is NGC 7538, an H II region in Cassiopeia near which OH emission was discovered by Downes (1970). Since this particular nebula is visible optically, radio studies provide the opportunity of comparing optical and radio data. In this paper I present radio observations of NGC 7538 with the Cambridge One-Mile and 5-Kilometre telescopes.

2. OBSERVATIONS

Descriptions of the One-Mile and 5-Kilometre telescopes may be found in Elsmore, Kenderdine & Ryle (1966) and in Ryle (1972), respectively. Both instruments synthesize elliptical beams with major axes oriented north–south. In the present work observations were made at 2·7 GHz in 1971 June–August with the One-Mile telescope, using eight 12-hr runs, and at 5 GHz in 1972 December with a single 12-hr run of the 5-Kilometre telescope. The beamwidths and radii of the first grating responses, which determine the maximum angular size of structure which can be mapped, are given in Table I, together with the rms noise level (T_m) on each map.

TABLE I

	HPBW		Grating ellipse radii		
	R.A.	Dec.	R.A.	Dec.	T_m
GHz	″	″	″	″	K
2·7	11	12·5	240	270	50
5	2	2·3	40	45·5	65

3. RESULTS

The maps are shown in Figs 1 and 2. We see from the 2·7 GHz map that the nebula consists of a relatively large, diffuse region some 4 arcmin across, with a much more compact source on its south-east edge. At 5 GHz the grating ring separation of 40 arcsec in right ascension was too small to permit observations of the whole nebula, and hence Fig. 2 shows only the compact components.

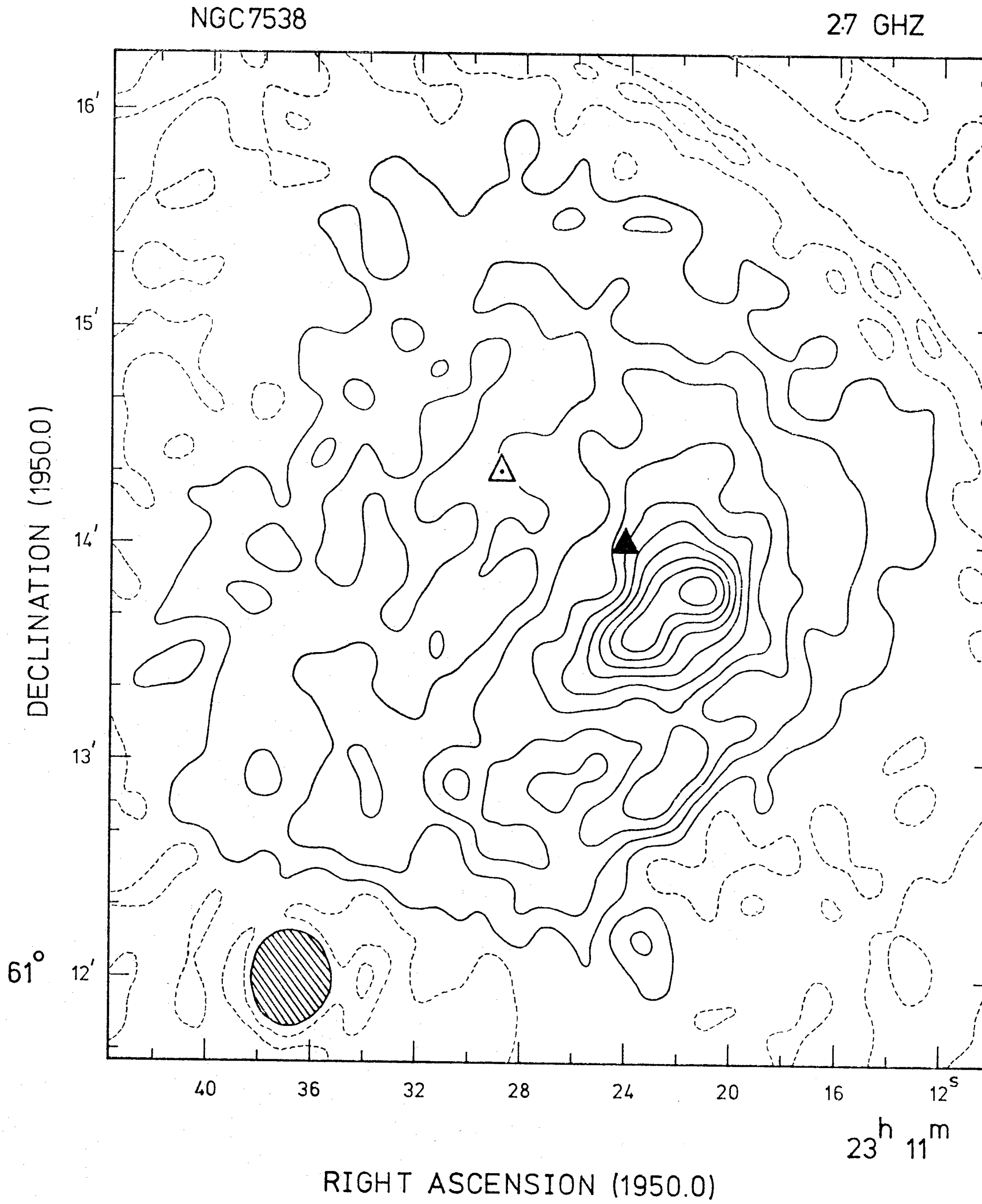

FIG. 1. *2·7 GHz map of NGC 7538. The hatched ellipse shows the position of the unresolved compact source. The contour interval is 55 K of brightness temperature. The triangles mark the positions of the two bright stars referred to in the text; the filled triangle is the exciting O7 star.*

The diffuse region

This source is almost as large as the grating ring separation at 2·7 GHz, and any low-brightness extension would not show up on the present map. Habing, Israel & de Jong (1972) did indeed find such an extension at 1·4 GHz in the form

PLATE I. *Photograph of NGC* 7538 *taken with the* 98-*inch Isaac Newton telescope in red light. The horizontal bar represents a distance of* 1 *arcmin.*

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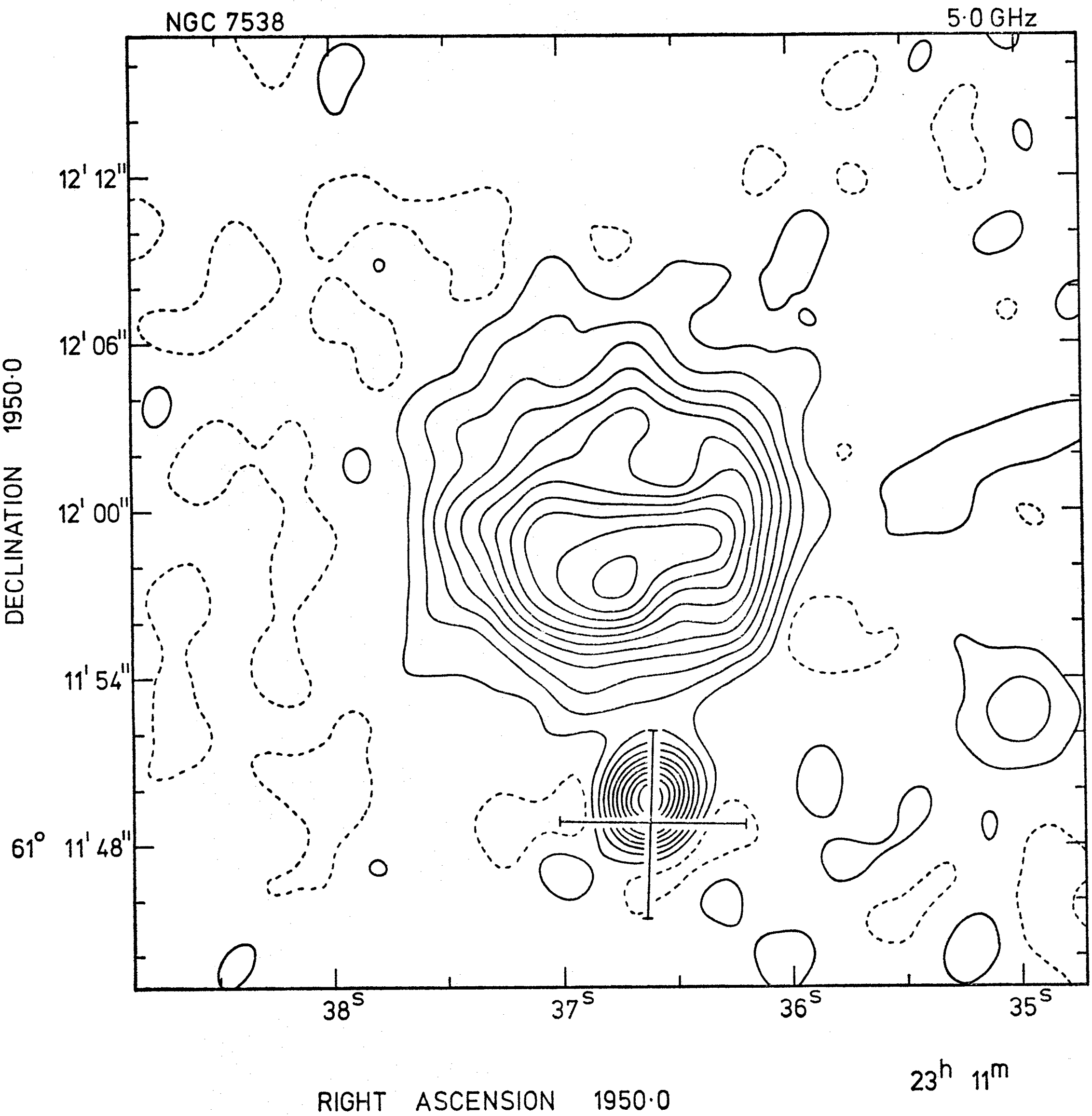

FIG. 2. *5 GHz map of the compact source. The contour interval is 170 K of brightness temperature. The cross marks the OH position; the size of the cross represents the uncertainty in position.*

of an incomplete shell-like structure open towards the east. The large size of the source also makes it difficult to determine the true zero level for the map. The total flux density is therefore rather uncertain; we find $S_{2\cdot7} = 15 \pm 5$ flux units (1 flux unit $= 10^{-26}$ W m^{-2} Hz^{-1}) which may be compared with the value of $S_{15} = 20{\cdot}7$ flux units found by Schraml & Mezger (1969) at 15 GHz. The peak brightness temperature is about 500 K. If the electron temperature is 10^4 K, which is typical for H II regions, we may estimate the central emission measure $E = 1{\cdot}2 \times 10^6$ pc cm^{-6}.

Plate I shows an optical photograph of NGC 7538 in red light, kindly supplied by Dr L. Webster of the Royal Greenwich Observatory. It is immediately apparent how closely the radio and optical features agree; both the bright radio core and the southward extension are clearly visible on the photograph. Evidently any obscuring dust in the diffuse region must be very evenly distributed. Two bright stars are visible near the centre of the nebula; their positions are plotted in Fig. 1. The more southerly is of type O7 and is the exciting star for the diffuse region (Lortet-Zuckerman, quoted in Habing, Israel & de Jong 1972). It is noteworthy that this star lies some 1 arcmin from the point of maximum brightness; in the photograph there is a suggestion of a hole surrounding it. A possible explanation is that the star originally formed near one edge of a dense cloud, and the resulting H II region is density bounded to the east but ionization bounded to the west. However, the photograph clearly shows another star almost coincident with the radio peak; there seem to have been no spectral observations of this star, and it may be that it contributes to the excitation. In any case the evident complexity of structure serves as a warning against taking too seriously the customary models of H II regions as spheres of uniform density.

The compact region

At 5 GHz this is well resolved into two main components with one other fainter source believed to be definitely real. The OH position has recently been remeasured by C. G. Wynn-Williams, M. W. Werner and W. J. Wilson (private communication); it coincides with the southernmost continuum component, source B. Peak positions, halfwidths and flux densities are listed in Table II, together with the position of the OH source, marked with a cross in Fig. 2.

TABLE II

	Position (1950·0)						Uncorrected half-widths		$S_{5\,GHz}$
	α			δ			θ_α	θ_δ	
	h	m	s s	°	′	″ ″	″	″	10^{-26} W m^{-2} Hz^{-1}
A	23	11	36·75±0·05	61	11	57·7±0·2	8·9×8·0		1·4 ±0·1
B	23	11	36·62±0·05	61	11	49·6±0·2	2·1×2·6		0·12±0·02
OH	23	11	36·6 ±0·4	61	11	49 ±5	—		—
C	23	11	35·0 ±0·1	61	11	52·8±0·1	2·4×2·8		0·02±0·01

This OH source is unusual, in that there is strong emission in both the main line at 1665 MHz and the satellite line at 1720 MHz (Hardebeck 1972). Most other OH sources near H II regions emit most strongly at 1665 MHz and 1667 MHz. Cook (1968) has suggested that OH emission occurs in a shocked region of neutral gas at the edge of an expanding H II region. This picture is supported by recent observations of W3 (OH) (Baldwin, Harris & Ryle 1973), but a test of the hypothesis for NGC 7538 requires a more accurate OH position.

The electron temperature of an H II region can in principle be derived from a knowledge of its spectrum below the turnover point. The form of the spectrum is, however, determined not only by the temperature but also by the distribution of emission measure across the source. In the present case this was taken into account as follows. A set of electron temperatures covering the likely range was chosen and for each temperature the observed map of brightness temperature was converted into a map of optical depth at 5 GHz. These optical depths were then scaled to another frequency, and the integrated flux density calculated. In Fig. 3 are shown the calculated curves for four electron temperatures together with the observed flux densities. It will be seen that a temperature of around 7500 K seems to fit best,

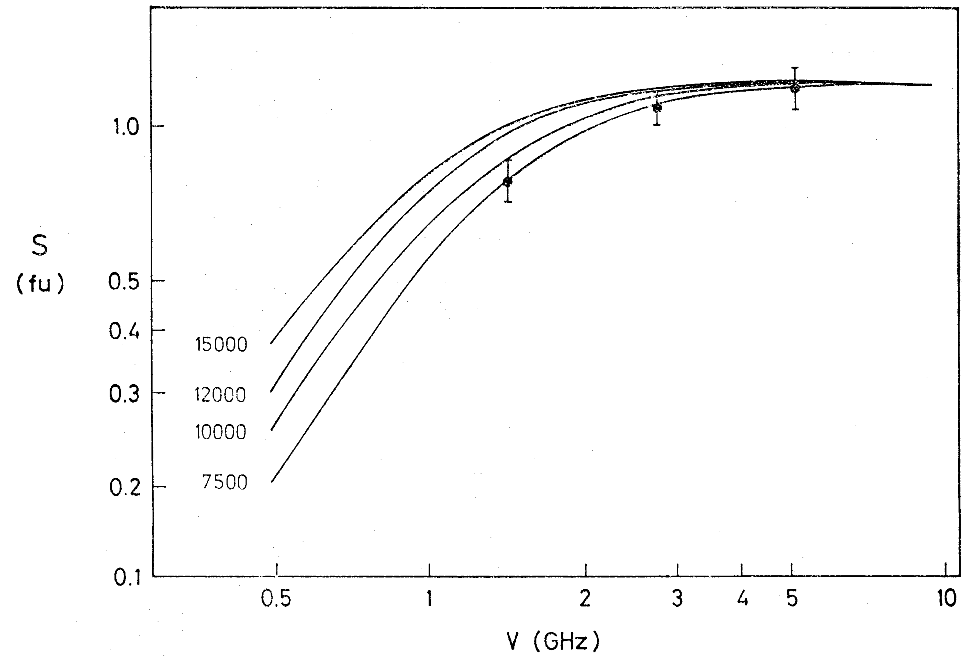

FIG. 3. *Radio spectra of the compact components (sources A and B), derived as described in the text. The number labelling each curve is the electron temperature. The point at* 1·4 *GHz comes from Habing, Israel & de Jong* (1972); *I have estimated its error as* 10 *per cent.*

but in view of the limited observational data no strong faith should be placed in this result.

There is no prominent optical feature at the position of A or B, showing that there must be heavy obscuration in front of the source. Recent infra-red observations of NGC 7538 by Wynn-Williams, Becklin & Neugebauer (private communication) have revealed an intense source of infra-red radiation coincident with sources A and B, and with a flux density of 700 f.u. at 20 μ. The infra-red contours follow closely those of the radio map, and there are separate peaks at the positions of A and B. Adopting a dust model, in which dust heated by starlight is responsible for the infra-red emission, we deduce that the dust and gas must be well mixed. The physical parameters of these sources are presented in Table III. They have

TABLE III

	Angular diameters $\theta_\alpha \times \theta_\delta$ ″ ″	Linear diameters R pc	Emission measure E cm^{-6} pc	Electron density N_e cm^{-3}	Ionized mass $M_{\mathrm{H\,II}}$ $M_\odot$	Ionizing photon flux L_c s^{-1}
A	10·9×7·8	0·15×0·11	14×10^6	10 700	0·30	$1·0\times10^{48}$
B	1·2×2·0	0·02×0·03	42×10^6	45 200	0·005	$8·3\times10^{46}$
C	2·4×3·0	0·03×0·04	$2·4\times10^6$	8 100	0·005	$1·4\times10^{46}$

been derived following the usual procedure in which the sources are assumed to be uniform spheres with an electron temperature of 7500 K. Although the kinematic distance derived from radial velocity measurements is 4·9 kpc, an O7 star, such as is identified with the exciting star of the diffuse region, could not provide sufficient ionization were the nebula truly at this distance. Since there is also evidence for systematic deviations from circular motion in this part of the galaxy (Rickard 1968), we follow Schraml & Mezger (1969) in taking $D = 2{\cdot}8$ kpc.

Column 7, L_c, gives the flux of ultra-violet photons beyond the Lyman limit required to keep each source ionized. If the source is indeed ionization bounded, this number is then equal to the flux of Lyman continuum photons from the exciting star or stars, and depends on the spectral type. Recently P. Palmer (private communication) has discovered NH_3 and HCN emission from around sources A and B, requiring densities of at least 10^4 cm^{-3} in atomic or molecular hydrogen to account for the excitation. This suggests that the ionized condensations are indeed surrounded by neutral gas and are thus ionization bounded.

In that case, we require an O8 star in source A, an O9·5 star in source B and a star of later type than B0·5 in source C, following Hjellming's (1968) figures. A crude estimate of the age of the condensations is given by dividing the observed radius by the speed of sound in ionized hydrogen at 7500 K. We find an age of 20 000 yr for A and about 3000 yr for B and C. The exciting stars seem then to have formed within a timespan very short compared with their main-sequence lifetimes of 10^6–10^7 yr.

4. CONCLUSIONS

NGC 7538 is another of the class of objects represented by W51, Orion A and Sgr B2 in which a relatively diffuse H II region is associated with compact components, OH and other molecular sources, and infra-red emission. Several stars of spectral types from O7 to cooler than B0·5 have formed together within the last 20 000 yr.

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