HYDROGEN RECOMBINATION LINE AND CONTINUUM OBSERVATIONS AT 5000 MHz OF 13 SOUTHERN HII REGIONS

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Abstract

Hydrogen 109α recombination line observations are presented for 13 southern HII regions. For four of these and for one additional HII region new continuum observations at 5000 MHz are also given. Four of the HII regions had previously been incorrectly categorized as supernova remnants. For a number of the other HII regions comparisons are made between the HII velocities and those of associated OH detected in either emission or absorption.

I. Introduction

The present sources were selected for observation because either (1) there was doubt as to whether the source was an HII region (thermal) or a supernova remnant (nonthermal) or (2) OH in emission or absorption had been detected in the direction of the source but either HII region recombination line velocities or high resolution maps of the area were not available.

The observing equipment comprised a cryogenic parametric amplifier, with nominal centre frequency 5000 MHz, installed on the Parkes 64 m radio telescope. This yielded a beam size of $\sim 4'$ arc (the exact value depended on the feed horn used and was different in each observing period). The intensity calibration in flux units† and full-beam brightness temperature was based on observations of Hydra A, which was assumed to have an integrated flux density of $13\cdot5$ f.u. (corresponding to a peak value of $13\cdot05$ f.u. when observed with the $4'$ arc beam). For the continuum observations the nominal bandwidth was 500 MHz. Under good weather conditions the r.m.s. noise using Dicke switching against a helium-cooled reference load was $\lesssim 0\cdot02$ K T_b when a $0\cdot7$ s output time constant was used. For the observations of the H 109α recombination line (rest frequency $5008\cdot923$ MHz) the Parkes 64-channel filter spectrometer was used with 100 kHz filters.

II. Results

(*a*) *Continuum*

A summary of results for the sources observed in the continuum is given in Table 1. With the resolution used, the sources G274·0−1·1 and G345·4−1·0 approximate well to simple Gaussian brightness distributions, and only orthogonal scans were made. For the other sources the surrounding regions were mapped; the areas shown in Figures 1(*a*), 1(*b*), and 1(*c*) are somewhat smaller than those actually

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† 1 flux unit (f.u.) = 10^{-26} W m^{-2} Hz^{-1}.

mapped since the edges with no significant emission have been omitted. The outer regions which showed no significant variations of intensity were used to define the arbitrary zero levels of the maps. No nearby position calibration sources were observed and thus the positional accuracy is limited by telescope pointing errors to between 0′·5 and 1′·0 arc.

TABLE 1

CONTINUUM MEASUREMENTS AT 5000 MHz

Galactic source number	Position of peak (1950) R.A. h m s	Dec. ° ′	Integrated flux density (f.u.)	Half-intensity width of equiv. Gaussian R.A. × Dec.	Map
G253·6−0·2	08 14 17	−35 24·5	17·9*	—	Fig. 1(*a*)
G274·0−1·1	09 22 49	−51 46·7	25·9	2′·2 × 2′·1	
G307·6−0·3	13 29 17	−62 31·8	10·5	~3′·1 × 5′·3	Fig. 1(*b*)
G307·6−0·6†	13 29 12	−62 49·7	0·95	1′·7 × 1′·7	Fig. 1(*b*)
G345·4−1·0	17 06 08	−41 31·9	34	1′·6 × 1′·8	
G351·6−1·3	17 25 56	−36 37·5	~29‡	~2′·6 × 2′·2	Fig. 1(*c*)
G351·7−1·2	17 25 44	−36 32·0	~13‡	~2′·5 × 2′·5	Fig. 1(*c*)

* In deriving the integrated flux density, the zero level of the map was adopted as the baselevel but the angular extent of the integration was limited to the 0·05 K contour.

† Spectral and recombination line data for G307·6−0·6 are not available.

‡ The combined flux density of G351·6−1·3 and G351·7−1·2 is 44±4 f.u.

(*b*) *Recombination Lines*

The recombination line measurements are summarized in Table 2. The positions at which the observations were made and the corresponding continuum temperatures are given in columns 2, 3, and 4. It should be noted that in some instances these positions are slightly displaced from the continuum maximum. The parameters of the line (columns 5, 7, and 8) are those corresponding to a Gaussian fit to the line shape so that the integral of the brightness temperature T_L with respect to the frequency ν, taken over the linewidth, is given by $1\cdot06\,T_L\,\Delta\nu$. Column 6 gives the r.m.s. noise on a 100 kHz channel; the linewidths to half-intensity are generally four to five channels, so that the uncertainty in the peak intensity is considerably less than the noise on a single channel. References to high resolution continuum data for each region are indicated in column 10.

III. DISCUSSION

(*a*) *Discrimination between HII Regions and Supernova Remnants*

In some instances the purpose of the recombination line observations was to determine whether sources suggested as probable supernova remnants by earlier work were in fact HII regions. From studies of a large number of both thermal and

Fig. 1.—Continuum observations at 5000 MHz of (*a*) G253·6−0·2, (*b*) G307·6−0·3 and G307·6−0·6, and (*c*) G351·7−1·2 and G351·6−1·3. Contours are labelled in units of full-beam brightness temperature. The half-power beamwidth is 4′·3 arc. The position of HD 69464, a possible exciting star of G253·6−0·2, is indicated by the cross in (*a*).

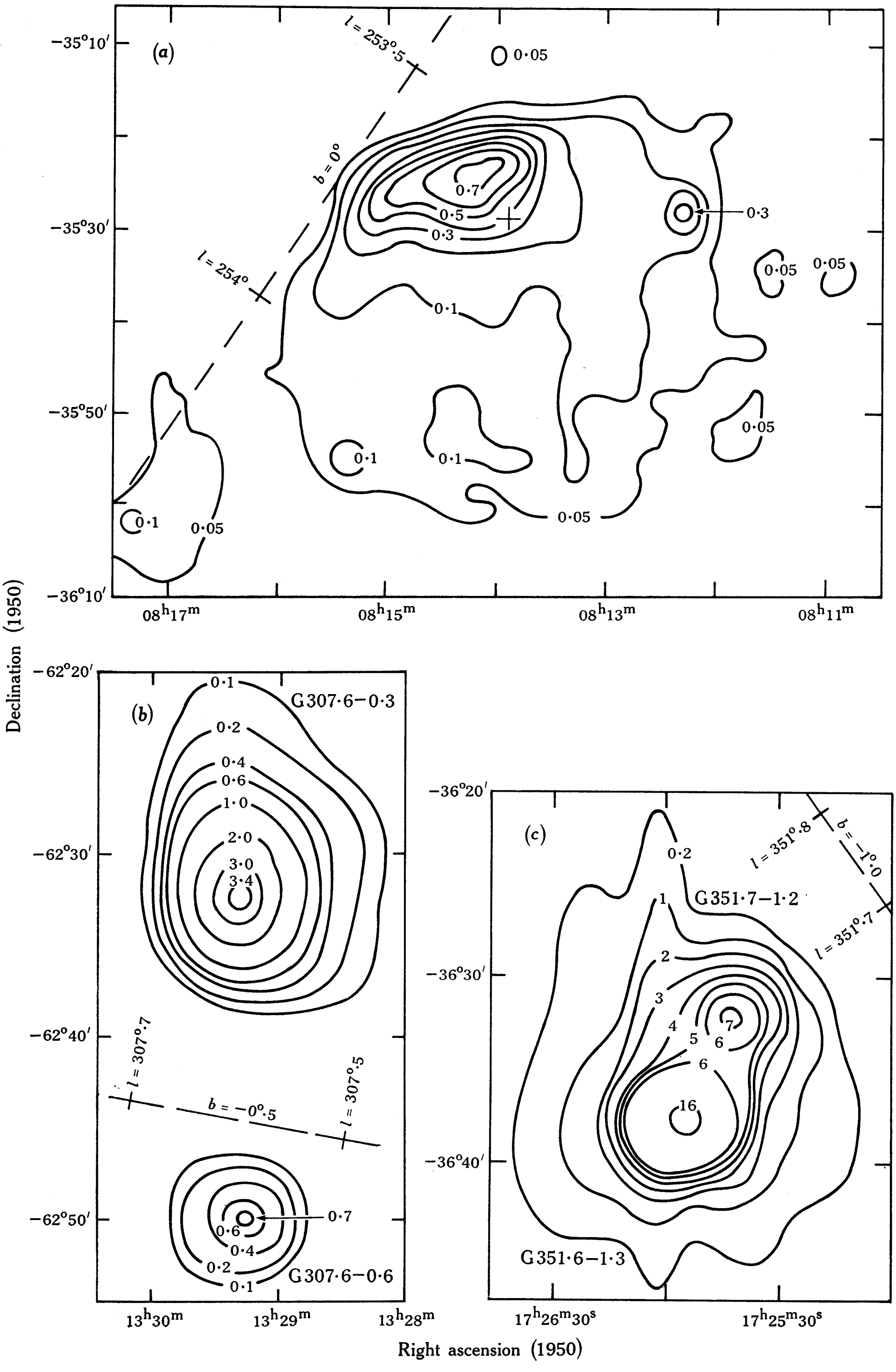
(a)
−35°10′
−35°30′
−35°50′
−36°10′
l = 253°.5
b = 0°
l = 254°
0·05
0·7
0·5
0·3
0·1
0·3
0·05
0·05
0·05
0·1
0·1
0·1
0·05
0·05
08h17m
08h15m
08h13m
08h11m
Declination (1950)
(b)
G307·6−0·3
−62°20′
−62°30′
−62°40′
−62°50′
0·1
0·2
0·4
0·6
1·0
2·0
3·0
3·4
l = 307°.7
b = −0°.5
l = 307°.5
0·7
0·6
0·4
0·2
0·1
G307·6−0·6
13h30m
13h29m
13h28m
(c)
−36°20′
−36°30′
−36°40′
l = 351°.8
b = −1°.0
l = 351°.7
0·2
G351·7−1·2
1
2
3
4
5
6
7
6
16
G351·6−1·3
17h26m30s
17h25m30s
Right ascension (1950)

Fig. 1

nonthermal sources it appears that recombination line emission is present in all investigated HII regions, with a line:continuum intensity ratio in the case of H 109α invariably $> 2 \cdot 5\%$. On the other hand, it appears to have never been detected in association with supernova remnants, the limit to the ratio being $< 1\%$ in many cases (Milne *et al.* 1969). Thus in order to distinguish between thermal and nonthermal sources we provisionally adopt the criterion that if the ratio is $> 2 \cdot 5\%$, the source is an HII region. It is of course desirable to obtain corroborative evidence in each case.

TABLE 2

H 109α RECOMBINATION LINE MEASUREMENTS

(1) Galactic source number	(2) Position (1950) of H 109α obs. R.A. h m s	(3) Dec. ° ′	(4) Continuum brightness temp. T_C (K)	(5) Line profile Peak temp. T_L (K)	(6) R.M.S. noise (K)	(7) Median radial vel. of line V_{lsr} (km s^{-1})	(8) Line-width $\Delta\nu$ (kHz)	(9) T_L/T_C (%)	(10) References to continuum data*
G253·6−0·2	08 14 18	−35 25·9	0·7	0·06	0·02	+38·3	450	8·6	1
G274·0−1·1	09 22 47	−51 47·0	17·3	0·70	0·04	+39·2	550	4·0	1
G307·6−0·3	13 29 15	−62 32·0	3·5	0·28	0·04	−38·7	400	8·0	1
G328·2−0·6	15 54 29	−53 50·5	1·5	0·18	0·04	−42·9	450	12·0	2
G333·0+0·8	16 11 23	−49 42·3	5·4	0·42	0·04	−52·1	400	7·8	3,4
G340·1−0·2	16 44 42	−45 15·5	1·8	0·12	0·02	−51·8	400	6·7	3
G345·4−1·0	17 06 08	−41 31·9	22·6	1·00	0·05	−21·1	450	4·4	1
G349·1+0·1	17 13 00	−37 56·5	2·5†	0·12	0·02	−74·0	300	4·8	5
G24·5+0·2	18 32 25	−07 27·2	2·1	0·20	0·03	+116·0	400	9·5	4
G45·5+0·0	19 12 04	+11 04·2	6·0†	0·22	0·04	+57·4	500	3·7	3,4
G45·5+0·1	19 11 48	+11 07·2	2·0†	0·10	0·04	+53·0	500	5·0	3,4
G51·4−0·0	19 23 44	+16 14·0	2·3	0·13	0·03	+49·8	500	5·6	6
G54·1−0·1	19 29 32	+18 36·0	1·3	0·10	0·03	+37·4	550	7·5	6

* References: 1, present results; 2, Day, Thomas, and Goss (1969); 3, Goss and Shaver (1970); 4, Shaver and Goss (1970*a*); 5, Beard, Thomas, and Day (1969); 6, Day, Caswell, and Cooke (1972).

† Measurements made at OH position, not at continuum maximum.

Notes on some of the individual sources observed are given below.

G253·6−0·2. Optically there is excellent agreement with the nebula Str 10 (Gum 1955), which is also listed by Rodgers, Campbell, and Whiteoak (1960) as RCW 19. The weaker radio source visible on the present map (Fig. 1(*a*)) near R.A. $08^h 17^m$, Dec. $-36° 00'$ corresponds to the fainter nebula Str 11 (RCW 20). This high resolution map of the region shows more detail than, but is generally in good agreement with, the 2700 MHz map obtained with an $8' \cdot 2$ arc beamwidth by Day, Caswell, and Cooke (1972). In the Parkes catalogue (Ekers 1969) the major condensation in G253·6−0·2 is listed as PKS 0814−35 with a flux density at 408 MHz of 13·9 f.u.; with the beam size of 48′ arc, this value will not have been greatly reduced by partial resolution. The spectrum derived from this 408 MHz flux density, the present data, and the measurement of Day, Caswell, and Cooke (1972) is thermal. Gardner and Davies (1966), having observed the peak of the source at 2700 MHz, reported a small amount of linear polarization ($2 \cdot 6\% \pm 1 \cdot 2\%$), which, in conjunction with the shell structure, raised the question of whether the source might be a supernova remnant. However, the polarization measurement cannot be regarded as a positive detection on account of the quoted error, and in view of the other evidence (flat spectrum, optical appearance, and detection of recombination line emission by the present observations) the object seems definitely to be an HII region. The recombination line radial velocity of $+38 \cdot 3\ \mathrm{km\,s^{-1}}$ (l.s.r.) corresponds to a kinematic distance of $3 \cdot 7 \pm 0 \cdot 8$ kpc on the Schmidt (1965) rotation model; the error quoted corresponds merely to an allowance of $\pm 10\ \mathrm{km\,s^{-1}}$ for noncircular motions. Georgelin and Georgelin (1970) noted that HD 69464, an O7f star with a photometric distance of 3·0 kpc, is probably the exciting star for the nebula. Its 1950 position (R.A. $08^{\mathrm{h}}\,13^{\mathrm{m}} \cdot 9$, Dec. $-35^{\circ}\,29'$) is marked on Figure 1(*a*) with a cross. Following Higgs and Ramana (1968), a distance to the nebula may be computed using the radio flux density and the u.v. emission expected from this exciting star. The nebula was assumed to be ionization bounded and an electron temperature of 4500 K was adopted (the value derived from the recombination line measurement assuming conditions of local thermodynamic equilibrium). The resulting distance was 3·1 kpc which agrees very satisfactorily with the other two estimates.

G307·6—0·3. Milne (1970) suggested that G307·6—0·3 was a supernova remnant on the grounds of its apparent nonthermal spectrum. However, his spectral index of $\alpha = 0 \cdot 45$ (where $S \propto \nu^{-\alpha}$), derived from intensities at only the two closely spaced frequencies of 1410 and 2650 MHz, has considerable uncertainty. The addition of the present flux density value at 5000 MHz suggests in fact a value of $\alpha \approx 0 \cdot 1$, the spectral index expected for an HII region over the frequency range where it is optically thin. The present unambiguous detection of an H 109α line with a quite high line: continuum intensity ratio (8%) indicates conclusively that the source is thermal and that it should not continue to be classed as a supernova remnant.

G333·0+0·8. Shaver and Goss (1970*b*) classified this source as a supernova remnant because the spectral index they derived (0·17) is apparently that of a nonthermal source. However, this value is not significantly different from 0·1, and the present positive detection of H 109α line emission indicates that the source is indeed an HII region and not a supernova remnant.

G24·5+0·2. Shaver and Goss (1970*b*) derived a spectral index of 0·22, from which they concluded that the source is a supernova remnant. The errors are such that a thermal spectral index of 0·1 cannot be excluded. The present positive detection of H 109α emission indicates that G24·5+0·2 is in fact an HII region rather than a supernova remnant.

G45·5+0·1. Milne (1970) and Downes (1971) have both suggested that this source is a supernova remnant on the basis of the report by Reifenstein *et al.* (1970) that the source exhibited no recombination line. This earlier non-detection of H 109α emission appears to have been spurious since there is no doubt about the present detection, which is also confirmed by the recently published H 109α observations of Wynn-Williams, Downes, and Wilson (1971). The spectral index also suggests that the source is thermal (Holden and Caswell 1969; Shaver and Goss 1970*b*). Two major components separated by 4′ arc are evident in the very high resolution 2700 MHz continuum map of Wynn-Williams, Downes, and Wilson (1971) and the positions of these components agree closely with the two positions from which main line 1665 and 1667 MHz OH emission arises (Caswell and Robinson, unpublished data). This type of OH emission commonly occurs in association with compact HII regions, thus corroborating the conclusion that both continuum components are thermal. The present H 109α measurements were made at the two OH positions. Near the weaker continuum component, the H 109α line:continuum intensity ratio was undiminished relative to that of the major component, and although the two were not fully resolved by the present beam this again tends to confirm that both components are thermal.

G51·4—0·0. This feature is embedded in the extended source CTB 74, which Holden and Caswell (1969) classified as an HII region. Some doubt as to whether the source might be nonthermal remained owing to a possible detection of continuum emission from the source at 38 MHz. The map of highest resolution yet obtained is that of Day, Caswell, and Cooke (1972) at 2700 MHz with $8'\cdot 2$ arc beamwidth. Their map shows two major peaks, G51·4—0·0 and G51·1+0·1, within a more diffuse region of diameter $\sim 20'$ arc. The present 5000 MHz scans showed the feature G51·1+0·1 to be diffuse on the scale of the $4'$ arc beam whereas G51·4—0·0 was quite compact and yielded a higher central brightness temperature. Consequently the latter position was searched for H 109α emission and a line was conclusively detected here showing that this feature, at least, is thermal. Reifenstein *et al.* (1970), observing with a $6'$ arc beam at a point between the peaks, also reported a weak line but cautioned that for such a weak feature their data were uncertain because of baseline problems.

G54·1—0·1. The 2700 MHz map of Day, Caswell, and Cooke (1972) shows this source to be situated in a complex of somewhat weaker sources. The present detection of H 109α emission shows that the component G54·1—0·1 is thermal. Holden and Caswell (1969) concluded that at low frequencies (38 and 178 MHz) the chief contribution to the emission is from an extended supernova remnant; however, it is not clear whether any of the other features visible at high frequencies are also thermal or whether they all are parts of the supernova remnant.

(*b*) *Sources where OH Has Been Detected*

Sources for which OH emission has been detected are listed in Table 3. We see that in general there is close agreement between the recombination line velocities and those of the OH detected in either emission or absorption. Further data for some of the sources are given below.

G274·0—1·1. In addition to the observations at 5000 MHz (see Table 1) this HII region (identified optically with the nebula RCW 42) was observed at 8·9 GHz with a half-power beamwidth of $2'\cdot 5$ arc. These measurements gave a flux density of 22·4 f.u. and source widths to half-intensity of $1'\cdot 7$ and $1'\cdot 6$ arc respectively in right ascension and declination ("deconvolved" by assuming Gaussians for both source intensity distribution and beam shape). These values are more accurate estimates of the source size than those made with the larger beam at 5000 MHz. Observations were also made of the H 90α recombination line (rest frequency 8872·569 MHz) which gave a median velocity of 42·2 km s^{-1}, a line:continuum intensity ratio of 8·6%, and a width to half-intensity of 1150 kHz. These are in fair agreement with the values expected by extrapolation from those measured for H 109α, assuming conditions of local thermodynamic equilibrium: the median velocity is essentially the same, the half-intensity width (38·9 km s^{-1}) is somewhat larger (33 km s^{-1} for H 109α line), and the line:continuum ratio, expected to increase by the factor $(8872/5009)^{1\cdot 1} = 1\cdot 88$, has actually increased by the factor 2·12, a difference which may not be significant.

G349·1+0·1. In the direction of this source, in addition to the OH emission discovered by Robinson, Caswell, and Goss (1971) at a velocity of $-80\cdot7\ \mathrm{km\,s^{-1}}$, OH emission at a velocity of $+14\ \mathrm{km\,s^{-1}}$ has been reported by Turner (1970). The present recombination line data show that the continuum source is chiefly due to an HII region with velocity $-74\ \mathrm{km\,s^{-1}}$ and that, if an HII region with a velocity corresponding to Turner's OH source exists, it is weak and/or displaced somewhat from the position at which the recombination line measurement was made.

Table 3

COMPARISON OF H 109α AND OH LINE OBSERVATIONS

HII region	H 109α velocity V_{lsr} ($\mathrm{km\,s^{-1}}$)	OH velocity V_{lsr} ($\mathrm{km\,s^{-1}}$) Absorption	Emission	OH emission source
G274·0−1·1	+39·2	+37*	—	—
G328·2−0·6	−42·9	—	−41·2†	OH 328·2−0·5
G340·1−0·2	−51·8	—	−51·9†	OH 340·1−0·2
G345·4−1·0	−21·1	−22†	—	—
G349·1+0·1	−74·0	—	−80·7†	OH 349·1+0·1
G351·7−1·2	−12·2	−12*†	—	—
G45·5+0·0	+57·4	—	+65·2*	OH 45·5+0·0
G45·5+0·1	+53·0	—	+59·2*	OH 45·5+0·1

* OH data from Caswell and Robinson (unpublished results).

† OH data from Robinson, Caswell, and Goss (1971).

G351·7−1·2 and G351·6−1·3. These sources had not previously been resolved as separate sources and the position of the centroid, G351·7−1·2, had been used to refer to the combined source. The continuum map (Fig. 1(*c*)) shows that even with the smallest beam size yet used for 18 cm OH studies (12′ arc) both components are contained in the beam. However, emission on the 1612 MHz OH transition is present, and its position R.A. $17^{\mathrm{h}}\,25^{\mathrm{m}}\,58^{\mathrm{s}}$, Dec. $-36°\,37'\cdot8$ (Caswell and Robinson, unpublished data) shows that it is closely associated with the more intense continuum component G351·6−1·3. The recombination line observation of Reifenstein *et al.* (1970) also relates chiefly to the more intense feature and shows its velocity to be in good agreement with both the emisson and absorption velocities of the OH.

IV. Conclusions

The present observations have shown that several sources formerly classified as supernova remnants are actually HII regions. For some of the sources the recombination line observations have enabled comparisons to be made between the velocities of recently discovered OH features and those of their associated HII regions.

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