RADIO EMISSION OF 158 GALAXIES

By H. M. Tovmassian*

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Summary

Radio observations of 158 mainly spiral galaxies have been made at 21 cm and additional observations have been made for some at 11 and 75 cm. The observations at 11 and 21 cm were made with the CSIRO 210 ft radio telescope at Parkes and those at 75 cm with the east–west arm of the Mills Cross at the Molonglo Observatory of the University of Sydney. Radio emission was detected from central regions of 20 of the galaxies.

I. Introduction

Optical investigation of the central parts of barred spiral galaxies (Kalloglian and Tovmassian 1964; Tovmassian 1965, 1966*a*) and their radio observations (Tovmassian 1966*b*) have shown that a definite correlation exists between the optical appearance of the nuclear region of a galaxy and its radio emission (Tovmassian 1966*c*). Enhanced radio emission, originating in the nuclear region of the galaxy, is observed only when there is optical evidence of activity at the nucleus. Such evidence may be that either (1) the galaxy possesses a starlike nucleus with Byurakan classification type 4 or 5, or (2) there is evidence of explosive phenomena at the nucleus (Byurakan type 2 or 2S).

The present paper contains the results of radio observations of 158 galaxies, most of which are spirals. The observations were undertaken to permit further investigation of the correlations between the likelihood of radio emission from galaxies and the structure of their central parts. In order to have sufficient overlap of the radio and optical studies (the latter being made at Byurakan by other observers), only galaxies north of declination $-20°$ were chosen for observation. However, in the final list (Table 1) of the galaxies investigated a few elliptical and irregular galaxies and a few southern galaxies are included. The photographic magnitudes of galaxies given in the table are corrected Harvard magnitudes from the catalogue compiled by de Vaucouleurs and de Vaucouleurs (1964). Morphological types of galaxies are from de Vaucouleurs (1963).

The basic survey of galaxies was made in August 1965 at 21 cm using the 210 ft radio telescope of the Australian National Radio Astronomy Observatory, CSIRO, at Parkes. The observing procedure and equipment employed were the same as for the observations of barred spiral galaxies and galaxies with peculiar spectra and colour that are described in two previous papers (Tovmassian 1966*b*, 1966*d*).

* Visiting Scientist, Division of Radiophysics, CSIRO, Box 76, P.O. Epping, N.S.W. 2121; present address: Byurakan Astrophysical Observatory, Armenia, U.S.S.R.

TABLE 1

LIST OF GALAXIES OBSERVED AT 21 CM

No.	Galaxy		Type	m_{pg}	No.	Galaxy		Type	m_{pg}
1	NGC	128	SOp	12·8	48	NGC	2217	SBO	12·0
2		134*†	SABbc	11·2	49		2613	SAb	11·2
3		157*†	SABbc	11·4	50		2716	SBO	13·6
4		210	SABb	11·9	51		2775*†	SAab	11·7
5		214	SABc	13·1	52		2784	SAO	11·8
6		428*†	SABm	11·8	53		2811	SBa	12·8
7	IC	1613	Im	9·8	54		2835	SBc	11·4
8	NGC	488	SAb	11·6	55		2855	SAOa	12·4
9		514	SABc	12·3	56		3109	Im	10·6
10		520*†	Pec	12·4	57		3145	SBbc	12·5
11		524	SAO	12·2	58		3162	SABbc	12·3
12		578	SABc	11·5	59		3169*	SAap	11·7
13		615	SAb	12·5	60		3190	SAap	12·6
14		681	SABab	13·0	61		3607	SAO	11·8
15		718	SABa	12·7	62		3611	SAap	13·0
16		772	SAb	11·5	63		3623	SABa	10·5
17		778	SAO/a	13·4	64		3626	SAO	12·1
18		864	SABc	11·9	65		3646	SAbcp	11·8
19		877*†	SABbc	12·3	66		3672	SAc	11·8
20		908*†	SAc	11·2	67		3887	SBbc	11·9
21		1084*	SAc	11·9	68		3955	IO	13·0
22		1087*†	SABc	11·7	69		4038/9*	IBmp	10·6
23		1140	Im	13·4	70		4123	SBc	12·3
24	HB	914	SBc	12·0	71		4162	SAbc	12·8
25	NGC	1156	IBm	12·6	72		4178	SBdm	12·2
26		1201	SAO	11·9	73		4212	SAbc	12·3
27		1297	SAc	13·0	74		4216	SABb	11·2
28		1302*†	SBO/a	11·8	75		4254*	SAc	10·6
29		1326	SBO	11·6	76		4273	SBc	12·5
30		1332	SAO	11·7	77		4281	SO	12·3
31		1359	SBmp	12·9	78		4324	SAO	12·6
32		1380*	SAO	11·6	79		4382	SAOp	10·5
33		1385*†	SBcd	12·1	80		4429	SAO	11·6
34		1415	SABO/a	12·7	81		4433*	SABab	13·1
35		1417*†	SABb	12·8	82		4438†	SAO/ap	11·2
36		1487	Pec	12·6	83		4450	SAab	11·4
37		1512	SBO	11·6	84		4459	SAO	12·1
38		1518	SBdm	12·4	85		4461	SBO	12·3
39		1533	SBO	11·9	86		4474	SAO	13·0
40		1543*	SBO	11·9	87		4517	SAcd	11·3
41	IC	2056	SBOp	12·7	88		4519	SBd	12·4
42	NGC	1637*†	SABc	11·5	89		4526*	SABO	10·8
43		1744*†	SBd	11·9	90		4527	SABbc	11·3
44		1832*†	SBbc	12·6	91		4535	SABc	10·8
45		1964	SABb	11·8	92		4565*	SAb	10·3
46		2139*†	SABcd	12·7	93		4567	SAbc	12·4
47		2207*†	SABbcp	12·0	94		4647	SABc	12·2

* Observed also at 11 cm. † Observed also at 75 cm.

TABLE 1 (*Continued*)

No.	Galaxy	Type	m_{pg}	No.	Galaxy	Type	m_{pg}
95	NGC 4666*	SABc	11·7	127	NGC 6753*	SAb	12·1
96	4691	SBO/ap	12·0	128	6769	SABap	12·7
97	4699	SABb	11·1	129	6771	SBO	13·8
98	4713	SABd	12·6	130	IC 4797	E5–6	12·5
99	4725	SABabp	10·2	131	HA 85	SO	12·4
100	4753	IO	10·8	132	NGC 6810	SAa	12·6
101	4762	SBO	11·7	133	6861	SAO	12·6
102	4781	SBd	12·1	134	IC 4889	E5–6	12·7
103	4900	SBc	12·2	135	NGC 6868	E2	12·3
104	4995	SABb	12·2	136	6962	SABab	13·1
105	5087	SAO	12·8	137	7029	E6	12·6
106	5101	SBO/a	11·9	138	7070A*	IO	—
107	5248*	SABbc	10·8	139	7171	SBb	12·7
108	5360*†	IO	11·1	140	7177	SABb	12·3
109	5363*†	IO	11·5	141	7218	SAcd	12·9
110	5364*†	SAbcp	11·2	142	7252	SAO	13·1
111	5468	SABcd	12·4	143	7302	SAO	13·4
112	5493	SOp	12·8	144	7332*	SOp	12·5
113	5668*†	SAd	12·2	145	7377	SAO	12·8
114	5746	SABb	11·6	146	7392	SABc	12·9
115	5806	SABb	12·6	147	7448	SABc	12·3
116	5838	SAO	12·1	148	7541*†	SBbc	12·7
117	5859	SBbc	13·6	149	7585	SAOp	12·8
118	5878	SAb	12·6	150	7606	SAb	11·7
119	5962*†	SAc	12·6	151	7625	SAap	13·2
120	6070	SAcd	12·5	152	7678	SABc	12·9
121	6181	SABc	12·8	153	7679	SBOp	13·3
122	6384*	SABbc	11·8	154	7716	SABb	13·2
123	IC 4662	IBm	12·0	155	7727	SABap	11·8
124	NGC 6574*	SABbc	13·3	156	7742	SAb	13·0
125	6674*	SBm	13·2	157	7769*	SAb	13·0
126	6699	SABb	12·7	158	7814*†	SAab	11·9

* Observed also at 11 cm. † Observed also at 75 cm.

With the 210 ft telescope and the degenerate parametric amplifier at 21 cm it is possible to detect sources as faint as 0·2 f.u., provided repeated scans are made across the position of the galaxy. A total of 158 galaxies were investigated.

The galaxies in or near the positions from which radio emission was detected at 21 cm were observed in September 1965 at 11 cm with the 210 ft telescope. The aim of these observations was to increase the accuracy of positional measurements of the detected sources and thus the reliability of identifications. The beamwidth of the telescope at 11 cm is about 7′·5 arc and thus is about one-half of the width at 21 cm. A total of 42 galaxies were investigated. Those with flux densities in excess of 0·2 f.u. could be easily recognized on the records. Owing to the weakness of the detected sources, their positions could only be determined with an accuracy that is estimated as 1′·5 to 2′ arc at either wavelength. Finally, in October 1965,

23 galaxies that had been detected at the shorter wavelengths were observed at 75 cm with the east–west arm of the Mills Cross at the Molonglo Radio Astronomical Observatory of the University of Sydney. The beamwidth of the telescope is about 1′·5 arc in right ascension and about 4° in declination. Sources with flux densities of about 1 f.u. could be detected with certainty.

The accuracy of flux density measurements for weak sources is about 30% at all three wavelengths. The calibration of the receiver equipment was achieved by injection of the standard signals from discharge tubes to the inputs of the receivers, and by observations (a few times each day) of strong radio sources with well-known positions and flux densities.

II. Results

(*a*) *Accuracy of Identifications*

The detected sources were assumed to be identified with corresponding galaxies when the discrepancies between their coordinates were not larger than 1′·5 arc. For the sources observed at 75 cm the maximum acceptable discrepancy in right ascension was taken as 1′ arc. Under these conditions 20 of the detected sources were identified with the corresponding galaxies.

To avoid false conclusions the expected number of chance coincidences of radio sources with galaxies must be calculated, and to do this we need to know the number of radio sources per unit solid angle having flux densities greater than a given value. The number of sources per steradian can be estimated using the source counts given in the Parkes catalogue of radio sources (Bolton, Gardner, and Mackey 1964; Price and Milne 1965; Day *et al.* 1966; Shimmins *et al.* 1966), which are based on observations with the same telescope and receivers. The catalogue extends to sources with flux densities as low as 0·4 f.u. at 21 cm. In the present list of identifications there are sources as weak as 0·25 f.u. Source counts given in the Parkes catalogue show that the graph of $(\log N)/(\log S)$ at 21 cm has a cutoff for sources with flux densities less than 1 f.u. Obviously this cutoff is due to the confusion of radio sources at 408 MHz, at which the finding surveys for the Parkes catalogue have been made. By linearly extrapolating the straight parts of the $(\log N)/(\log S)$ curves to sources with flux densities equal to 0·25 f.u., we find that the expected number of sources per steradian with flux densities greater than 0·25 f.u. is about 1800.

If the distribution of sources is random, it would thus be anticipated that within 158 areas, each 1′·5 arc in radius, less than 1 source would be found. In fact, 20 sources were detected not further than 1′·5 arc from the centres of corresponding galaxies.

On the other hand, from the known density of sources (1800 per steradian) at a level of 0·25 f.u. at 1410 MHz we are far from the confusion limit, because at this level there is 1 source per 42 beamwidths. In addition, this level is well in excess of the sensitivity limit of the telescope. Thus we may conclude that almost all the sources detected are real and are physically associated with the corresponding galaxies.

The fact that 14 out of 20 sources were also detected at 11 cm with better resolution increases appreciably the certainty of most of the identifications. The remaining 6 sources were observed at 21 cm only and the flux densities of 4 of them exceed 0·3 f.u., which is three times more than the limit sensitivity of the receiver. The existence of 2 of these sources is less certain than the others because of nearby confusing sources. None of the identified sources were detected at 75 cm.

TABLE 2

GALAXIES WITH DETECTED RADIO EMISSION

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NGC No.	R.A. (1950) h m	ΔR.A. m	Dec. (1950) ° ′	ΔDec. ′	Flux Density (f.u.)* at: 11 cm	21 cm	75 cm
134	00 27·9	0	−33 32	−1	0·25(4)	0·40(5)	<1·0(1)
520	01 22·0	0	+03 32	0	0·25(6)	0·25(6)	<1·0(2)
908	02 20·8	−1	−21 27	−1	0·25(4)	0·30(5)	<1·0(1)
1084	02 43·5	0	−07 47	−1	0·30(4)	0·40(4)	<1·0(1)
1385	03 35·2	+1·5	−24 40	−1	0·20(7)	0·30(5)	<1·0(1)
1832	05 10·0	+1	−15 47	+1·5	0·20(5)	0·30(15)	<1·0(1)
2207	06 14·3	0	−21 21	0	0·20(4)	0·40(6)	<1·0(1)
3109	10 00·8	+1·5	−25 55	+1·5	—	0·25(6)	—
4038/9	11 59·3	0	−18 35	0	0·40(4)	0·60(6)	—
4254	12 16·3	0	+14 42	0	0·40(4)	0·50(4)	—
4433	12 25·0	0	−08 01	+1	0·20(5)	0·25(4)	—
4438	12 25·3	+1	+13 17	0	—	0·30(7)	<1·0(1)
4527	12 31·6	−1·5	+02 56	0	—	0·30(6)	—
4567	12 34·0	+1·5	+11 32	+1	—	0·40(6)	—
4666	12 42·6	−1	−00 12	0	0·30(5)	0·60(4)	—
5248	13 35·1	−1	+09 08	+1	0·25(4)	0·35(7)	—
5363	13 53·6	0	+05 29	0	0·25(6)	0·25(4)	<1·0(2)
6384	17 29·9	+1·5	+07 06	+1·5	<0·20(8)	0·40(4)	—
6810	19 39·4	−1	−58 47	−1	0·25(6)	0·30(4)	—
7541	23 12·2	0	+04 15	+1	<0·20(6)	0·35(7)	<1·0(1)

* Number of scans is shown in parentheses after each value.

The list of the galaxies from which radio emission has been detected is given in Table 2. The first column of the table contains the NGC numbers of the galaxies. The right ascensions and declinations of the galaxies and the corresponding displacements of the sources are given in columns 2, 3, 4, and 5. Displacements of the sources to the east and to the north from the centres of the corresponding galaxies are given as positive. Columns 6, 7, and 8 contain the flux densities of the sources at 11, 21, and 75 cm respectively. The numbers of scans are given in parentheses.

(*b*) *Comparison with Other Radio Data*

Twenty-six of the galaxies on our list have been observed also by Heeschen and Wade (1964) at 1400 MHz; they found radio emission from six. The present observations confirmed the existence of radio emission from four of the galaxies: NGC 1084, 4254, 4753, and 5248. The radio sources in the regions of two other galaxies, NGC 157 and 1417, are displaced at about 6′ arc in declination from the

centres of corresponding galaxies and are therefore omitted from our list of identifications. However, radio emission was detected from two other galaxies in their list: NGC 4038 and 6384.

NGC 157 and 1084 are in the list of 22 galaxies observed by Kurilchik and Sytsko (1965) at 32 cm. They detected radio emission from the latter galaxy only.

(c) *Angular Sizes*

None of the sources were resolved by the present observations. Thus their dimensions are not larger than about 4′ to 5′ arc.

TABLE 3

SPECTRAL INDICES, RADIO MAGNITUDES, RADIO INDICES, AND ABSOLUTE RADIO MAGNITUDES OF SOURCES OBSERVED AT TWO WAVELENGTHS

(1) NGC No.	(2) α	(3) m_{21}	(4) R_{21}	(5) $-M_{21}$	(1) NGC	(2) α	(3) m_{21}	(4) R_{21}	(5) $-M_{21}$
134	0·7	12·5	2·5	18·5	4433	0·3	13·1	0·7	17·2
520	0·0	13·0	1·7	18·0	4438	1·1	12·8	2·5	17·5
908	0·1	12·9	2·4	18·2	4527	—	12·9	2·9	17·4
1084	0·7	12·4	1·1	17·8	4567	—	12·5	0·6	17·8
1385	0·5	13·0	1·4	18·2	4666	1·1	12·1	2·5	18·8
1832	0·8	13·0	1·0	17·5	5248	0·4	12·7	2·3	17·1
2207	0·8	12·5	2·6	18·4	5363	0·0	13·1	2·1	17·1
3109	—	13·0	4·0	13·4	6384	—	12·5	1·6	18·7
4038/9	0·5	12·1	2·1	19·8	6810	0·3	12·9	2·0	18·3
4254	0·4	12·3	2·0	18·0	7541	—	12·6	0·7	19·4

(d) *Spectral and Radio Indices*

Spectral indices of the radio sources observed at two wavelengths are given in Table 3. The spectral index α is defined by the expression $S \propto f^{-\alpha}$.

To calculate the radio indices $R = m_r - m_{pg}$ the radio magnitudes m_{21} (which are given in column 3 of Table 3) were determined from the relationship

$$m_r = 53{\cdot}45 - 2{\cdot}5 \log S,$$

as defined by Hanbury Brown and Hazard (1959).

(e) *Absolute Radio Magnitudes*

Values of the absolute radio magnitude are given in column 5 of Table 3. The distance moduli were taken from de Vaucouleurs (1968) for the galaxies in nearby groups of galaxies and from van den Berg (1960) for the others.

In calculating the radio indices (given in column 4 of Table 3) the photographic magnitudes of galaxies have been corrected for absorption in our Galaxy by $\Delta m = -0{\cdot}25 \operatorname{cosec} b$, and for absorption in the galaxies themselves according to Holmberg's (1957) results. For the irregular galaxy NGC 3109 the results for Sc galaxies were used.

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