OBSERVATIONS OF 31 RADIO SOURCES BETWEEN 40 AND 130 MHz

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Summary

Recent observations of 31 radio sources in the frequency range 40–130 MHz obtained at the Australian National Radio Astronomy Observatory, Parkes, N.S.W., are reported in this paper. The results obtained show that some useful information about source emission mechanisms may be deduced.

I. Introduction

Observations of radio sources in the southern sky at 85·5 MHz (Mills, Slee, and Hill 1958), 153 MHz (Hamilton and Haynes 1967), and in the Parkes catalogue at 408, 1410, and 2650 MHz (Bolton, Gardner, and Mackey 1964; Price and Milne 1965; Day *et al.* 1966) have shown that there are quite a number of sources with spectral curves that deviate significantly from a simple power law spectrum of the form $S \propto f^{-\alpha}$, where S is the observed flux density, f is the frequency, and α is the spectral index.

Although a number of these sources have been studied in detail by Broten *et al.* (1965) and Kellermann (1966) at higher frequencies, many have not been investigated in detail below 408 MHz. A number of different theoretical mechanisms can produce curvature in a spectrum, and differentiation between models is not possible unless the shape of the spectrum in the curved region is well defined. Recent results by the authors and by Mills, Slee, and Hill at 85·5 MHz, together with the results in the present paper, have made it possible to define the spectra, at least down to 80 MHz, of 31 radio sources with reasonable accuracy. Of these 31 radio sources, 6 have also been measured down to 42 MHz.

II. Observations

(a) Equipment

Receivers. In order to make observations over the frequency range 40–130 MHz, it was found necessary to use two total-power transistorized receivers that were tuned over the ranges 43–63 and 84–125 MHz. Each receiver had a bandwidth of 2·1 MHz and with a final detection time constant of 3 sec the peak-to-peak noise fluctuations were found to be 1·5 and 2·2 degK for the low and high frequency receivers respectively. The system was tuned remotely using a synchronous motor to drive the ganged condensers on the input stages of each receiver.

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Feed System. The feed system that was designed to work over the required frequency range consisted of a pair of broadband "cage" dipoles mounted at the focus of the 210 ft telescope. Tests of the dipoles for matching efficiency into a load of 100 ohms showed that they were better than 50% efficient from 43 to 160 MHz. Observations showed that the telescope beamwidth at 44 MHz was 7·6°.

(*b*) *System Calibration*

Using the results of Conway, Kellermann, and Long (1963), the source Hydra A (with Parkes catalogue number 0915−11) was taken as a standard reference source. Measurements of this source were used to calibrate a noise signal from a temperature-saturated noise diode. The diode signal was calibrated at close intervals of frequency across both pass bands of the receiver system.

Prior to the observations, the receivers were calibrated for the operating frequency using a d.c. monitoring voltage obtained from a potentiometer mounted on the front-end tuning gang of each receiver. This monitoring voltage was continuously recorded together with the antenna temperature on chart recorders during the source scans.

Because of the possibility of interference during the observations, source identifications were made with two of the standard receivers in use at Parkes (20 cm and 50 cm).

(*c*) *Suitable Sources for Observation*

At frequencies below 120 MHz the possible sources that may be successfully observed with the 210 ft dish at Parkes are limited by the following factors.

(1) *Resolution.* For reliable measurements of the flux density, a source must be separated from nearby sources according to the beamwidth of the telescope at the operating frequency, i.e. for measurements down to 44 MHz the source must be separated from nearby sources by 7·5°.

(2) *Background Emission.* Emission from the galaxy was found to be the chief factor limiting the observations, especially within 10° to 15° of the galactic plane. Away from the galactic plane the source was confused by background fluctuations in only three cases.

(3) *Source Strength.* Owing to the high background temperature, only in exceptional cases were sources observed with a flux density < 20 f.u.* at 85 MHz.

(4) *Interference.* Observations over the whole of the desired frequency band were not possible owing to regions of man-made interference. Such interference was especially intense near 50 and 80 MHz.

Taking into consideration the above limitations, the published catalogues of radio sources in the southern sky were used to locate suitable sources for observation. With the assumption that the telescope has a Gaussian beam, the background flux due to nearby sources in the vicinity of each source was deduced. As a result 45

* 1 flux unit = 10^{-26} W m^{-2} Hz^{-1}.

suitable sources were found where the background was small compared with the source strength.

III. Results

Of the 45 selected sources, 8 were found to be too weak to measure, either because the background emission was rapidly varying or because the source intensity was much smaller at these frequencies than previous observations at higher frequencies had indicated. After analysis, 6 of the source measurements were found to be confused due to interference. The results for the remaining sources are summarized in Table 1.

(a) *Errors in the Flux Density Measurements*

The flux densities listed in Table 1 are thought to be accurate to within 17% ±2 f.u. for the high frequency receiver, and 21%±6 f.u. for the low frequency receiver. The chief source of error in the measured results was due to the method of frequency-sensitivity calibration using the standard source Hydra A. Variations in the calibration signal from the saturated noise diode were found to be not greater than 7%. However, repeated scans of the calibration source over the frequency band showed variations in source intensity of up to 10% for the high frequency receiver and 14% for the low frequency receiver. Such fluctuations in source strength were probably due to small amounts of interference not detected at the time of observation.

Noise fluctuations from the receivers were less than 4 and 2 f.u. for the high and low frequency receivers respectively.

Any errors due to polarization of either the source or the background emission have been ignored since the polarization is probably small at these frequencies.

(b) *Notes on Table 1*

Table 1 contains a summary of the observations that have been completed for 31 radio sources at various frequencies between 43 and 130 MHz. Details of the columns of Table 1 are:

Column 1. Source catalogue number from the Parkes catalogue.

Columns 2 and 3. Frequency and flux density results between 43 and 130 MHz.

Columns 4–9. Flux densities (in f.u.) at frequencies of 85·5, 153, 159 (or 178), 408, 1410, and 2650 MHz respectively. Observations at 85·5 MHz are from the Mills, Slee, and Hill (1958) catalogue; at 153 MHz from Hamilton and Haynes (1967); at 159(178) MHz from the 3C catalogue; and at 408, 1410, and 2650 MHz from the Parkes catalogue.

Column 10. Comments and identifications. The abbreviations used are: P, polarization; ext, source extended at high frequencies; M, magnitude of galaxy; EW, east–west angular size. Other notation indicating the type of optical identification (I, II, III, E, N, D, db, QSO) follows that of Bolton, Gardner, and Mackey (1964) and Bolton, Clarke, and Ekers (1965).

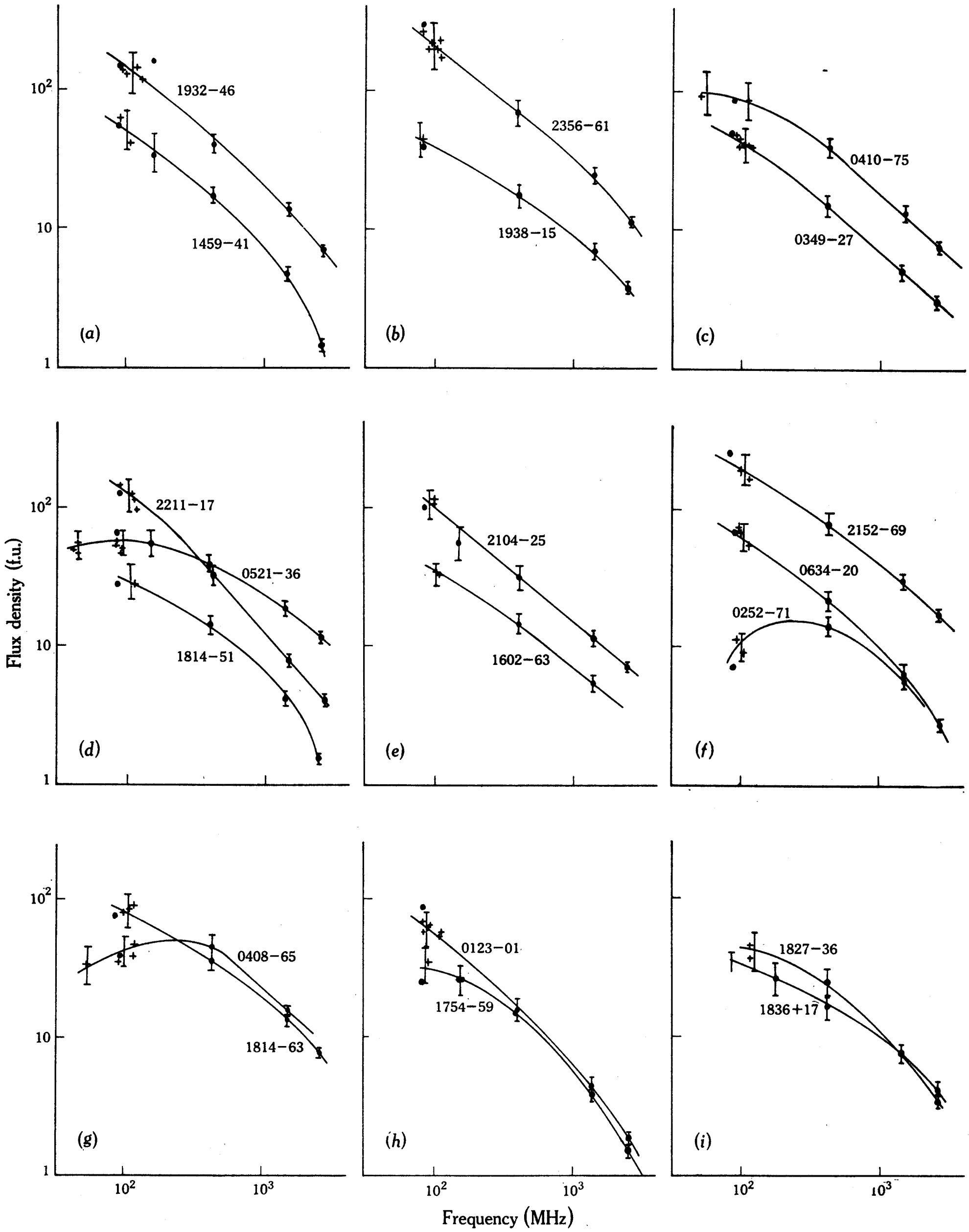
TABLE 1

FLUX DENSITIES OF OBSERVED SOURCES

(1) Parkes Cat. No.	(2) Present Results: Frequency (MHz)	(3) Present Results: Flux Density (f.u.)	(4) Other Flux Density Measurements at a Frequency (MHz) of: 85·5	(5) 153	(6) 159(178)	(7) 408	(8) 1410	(9) 2650	(10) Remarks
0123−01	82·7	59·6	88	25·1	26·0	16·4	4·5	(1·9)	I db 13·2M NGC545/7
	84·0	69·3							
	88·2	63·0							
	94·0	61·2							
	99·2	71·7							
	99·2	68·1							
	112·9	53·6							
	112·9	54·6							
	113·0	56·6							
0252−71	99·0	9·1	7·0			14·0	5·9		
	86·1	11·15							
0320−37	42·7	1255	950	474		249		89	NGC1316 P12% Fornax A
	46·3	1532							
	58·0	1309							
0349−27	86·5	50·1	53			15·8	5·2	3·1	P3·3% ext
	91·0	42·0							
	95·0	47·0							
	95·0	46·8							
	103·0	44·0							
	108·0	42·6							
	112·5	41·7							
0408−65	49·2	33·0	36·0			45·0	15·0		
	87·5	32·5							
	108·5	35·9							
	109·0	43·2							
0410−75	46·0	91·7	87·0	(55·3)		40·0	13·5	7·5	P<1%
	109·0	89·4							
0442−28	82·8	129·8	82·0	(66·0)		22·0	7·1	3·9	P3·7% ext
	86·2	95·5							
	91·5	86·1							
0518−45	44·0	774·2	570	343·0		166	66	30	Pictor A 19M P3%
0521−36	43·9	49·14	66	54·5		37	18·6	11·4	P3·5% N 16·8M (QSO) (Westerlund and Stokes 1966)
	46·3	45·5							
	46·3	55·0							
	88·0	55·3							
	88·0	51·3							
	93·2	47·4							
0522−69	102·2	5490	400			1100	620		L.M.C.
0532−05	42·2	73·7	(69)	41·6	45·0	(213)	(289)	(49)	HII Orion nebula
	47·3	89·0							
0634−20	88·0	71·8	67			21	7·0	2·8	P6% ext at 11 cm
	93·8	67·7							
	105	54·0							
1226+02	99·2	134·0	167·0		72	55·1	41·2	37·3	QSO 3C273

TABLE 1 (*Continued*)

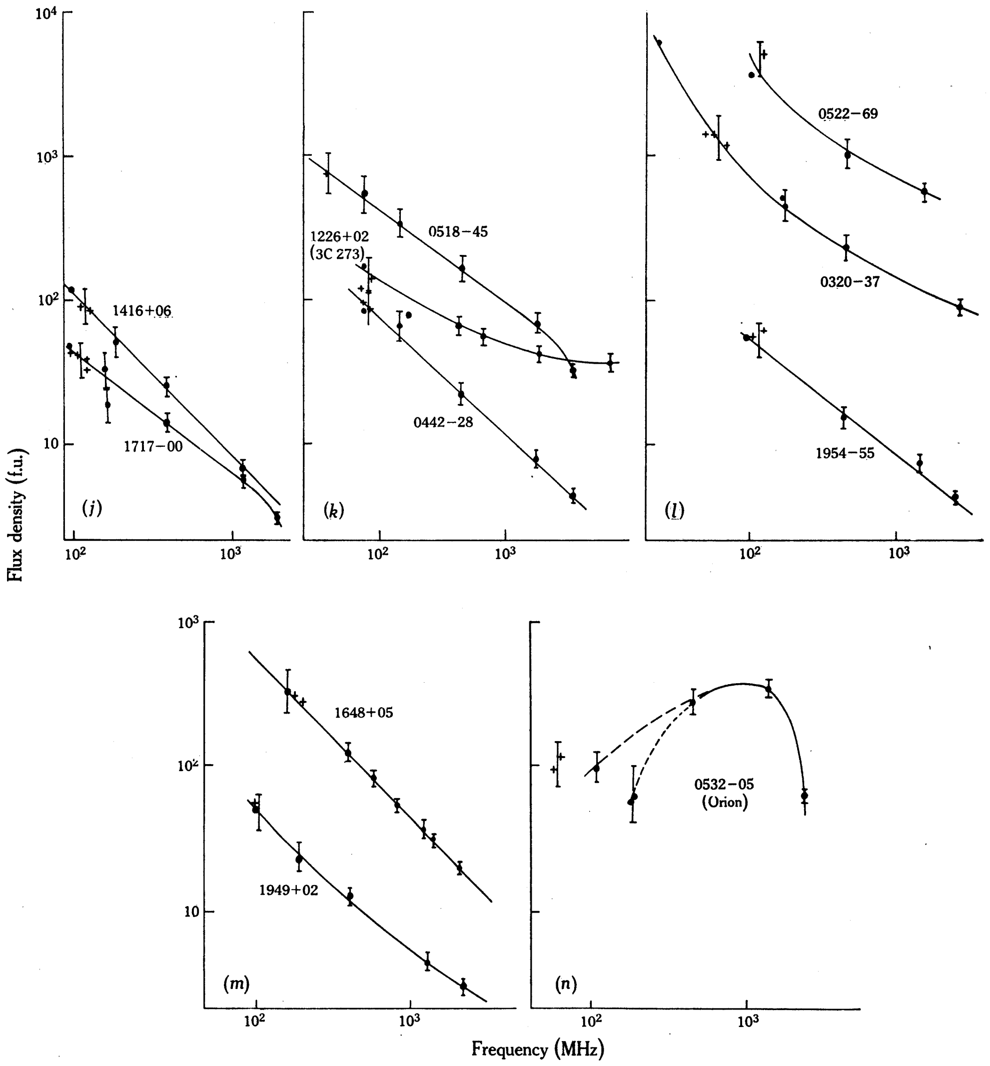
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Present Results		Other Flux Density Measurements at a Frequency (MHz) of:						
Parkes Cat. No.	Frequency (MHz)	Flux Density (f.u.)	85·5	153	159(178)	408	1410	2650	Remarks
1416+06	100·0 116·0	96·2 91·0	114		48·0	24·4	6·2	2·7	III QSO
1459−41	87·0 105·2	60·9 40·7	55		32·9	17·4	4·7	1·4	ext at 11 cm
1602−63	109·0 112·0	36·5 35·7				14·6	5·4		
1648+05	98·0 113·0	695·6 627·0	890		350	161	46·0	24·6	18M P1% Herc. A
1717−00	98·0 111·0 113·2	417·2 327·6 383·4	475		180	138	50·2	27·5	16·8M P3%
1754−59	93·2	39·14	25			15·0	3·9	1·5	P3·2%
1814−51	113·2	28·4	27·0			14·4	4·2	1·6	P2·6%
1814−63	94·0 108·0 113·2	74·6 80·0 86·4	71·0			34·0	14·2	7·5	<20″ EW
1827−36	111·8 112·0	35·9 42·2				23·0	7·4	3·2	
1836+17	Flux at 80 MHz <40 f.u.				26	15·9	7·6	(4·0)	I 16M ext
1932−46	89·0 115·8 97·0	136·0 111·8 124·0	141			39	13·4	6·9	P1·2%
1938−15	93·2	44·4	(39)			16·5	6·9	3·8	III–IV
1949+02	93·2	70·7	64		28	15·4	5·1	3·6	I E 16·5M (QSO)
1954−55	93·6 113·2	54·7 62·3	54			14·8	7·0	4·0	P<1·5%
2104−25	99·0	109·0	100	54·1		31·0	12·0	7·3	16M E P<1%
2152−69	89·0 99·0 112·5 113·2	218·7 198 160·7 168·9	253			80·0	32·0	17·5	25″ EW P2–3%
2211−17	85·0 101·0 106·0 112·9	147·1 126·4 113·2 95·81	127		49·0	31·3	7·9	4·2	II D 19M P1%
2356−61	84·0 98·0 99·0 109·0 109·0 115·0	254·8 214·2 208·4 190·3 194·4 165·0	296·0			66·0	23·7	10·4	P5% 40″ EW



Figs. 1(*a*)–1(*i*)

(*c*) *Source Spectra*

The new observations of 31 radio sources have shown that 26 have distinct curvature in their emission spectra. Measurements near 40 MHz for those sources that were not observed would be useful but, nevertheless, the results are adequate to determine the spectra of all 31 radio sources down to 80 MHz. Following the



Figs. 1(*a*)–1(*n*).—Spectral curves of all sources studied. The present observations (+, with standard deviations as indicated) are shown together with previous observations (●) at: 85·5 MHz by Mills, Slee, and Hill (1958); 153 MHz by Hamilton and Haynes (1967); 159 MHz by Edge *et al.* (1959); 178 MHz by Bennett (1962); 408, 1410, and 2650 MHz by Bolton, Gardner, and Mackey (1964), Price and Milne (1965), Day *et al.* (1966), and Shimmins, Clarke, and Ekers (1966).

notation of Bolton, Gardner, and Mackey, sources with curved spectra may be classified as follows.

Positive Curvature Sources: 0123−01, 0252−71, 0349−27, 0408−65, 0410−75, 0521−36, 0532−05, 0634−20, 1459−41, 1602−63, 1754−59, 1814−51, 1814−63, 1827−36, 1836+17, 1932−46, 1938−15, 2152−69, 2211−17.

Negative Curvature Sources: 0320−37, 0522−69, 1226+02, 1949+02.

Positive Curvature Sources at High Frequencies: 0518−45, 1717−00, 2356−61.

In particular, the source 0532−05 (Orion nebula) is obviously one that needs more investigation. Measurements by the authors at 153 MHz (Hamilton and Haynes 1967) were in excellent agreement with the results of Edge *et al.* (1959). However, the new results near 45 MHz are higher than expected to be consistent with these previous observations, although they are in better agreement with the results of Mills, Slee, and Hill (1958) at 85·5 MHz. Spectral measurements between 40 and 180 MHz would accurately determine the spectrum and give a better idea of the emission mechanism in the source. At intermediate frequencies this source shows the features of an HII region, having a black body radiation spectrum. However, due to inconsistencies in the measurements at lower frequencies, the optical depth and emission temperature of the source cannot be readily determined. Measurements at 1410 and 2650 MHz are also not accurate because of the extension of the source in relation to the beamwidth of the telescope at these frequencies.

Figures 1(*a*)–1(*n*) give the observed spectral shapes for all sources considered in the present paper.

IV. Conclusions

The flux density measurements of 31 radio sources reported here have added useful information about these sources below 408 MHz, and, although the frequency intervals of measurement were not as close together as we would have liked, there is perhaps now sufficient information available on these sources to undertake a theoretical investigation into possible emission and absorption mechanisms. These will be considered in a subsequent paper.

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