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Observations of Sixty Discrete Sources at 1423 Mc

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Sources with galactic latitude numerically greater than ten degrees were chosen for this study from the surveys at 86 Mc by Mills, Slee, and Hill and the 159 Mc Third Cambridge Survey. The flux densities at 1423 Mc were measured with a 60-ft antenna and maser radiometer. The spectral indices of the sources have a narrower range than previously reported. The distribution of spectral indices of sources identified with nearby galaxies seems indistinguishable from that of other sources. No correlation was found between the spectral index and the flux density of these sources such as has been described by other observers.

I. INTRODUCTION

A SIXTY-FOOT antenna and maser radiometer were used to measure the flux density of sixty discrete sources at galactic latitudes numerically greater than 10° at 1423 Mc. The sources were selected from the two surveys at 86 Mc by Mills, Slee, and Hill (1958, 1961) and from the Third Cambridge Survey of Edge *et al.* (1959) at 159 Mc.

The antenna has a half-power beamwidth of 53 minutes of arc in right ascension and declination. The radiometer (Cooper and Jelley 1961; Cooper 1961) is a switched or Dicke type, which measures the difference between the available power from the antenna and that from a reference source. The reference source is a coaxial resistor in a liquid-helium bath to which an adjustable amount of power from an argon discharge tube is added through a directional coupler. The reference temperature is set equal to the antenna temperature at the start of each observation to obtain maximum sensitivity in the presence of gain changes. The radiometer has an effective noise temperature of 100°K, which includes about 20°K from the antenna. With an integration time of 10 sec, and the maximum bandwidth of 2 Mc, the stability of the radiometer allows the measurement of changes in antenna temperature of 0.1°K on single records.

II. OBSERVATIONS

The observations were of two types: $\frac{1}{2}$-hr-long drift curves across the source in right ascension with the

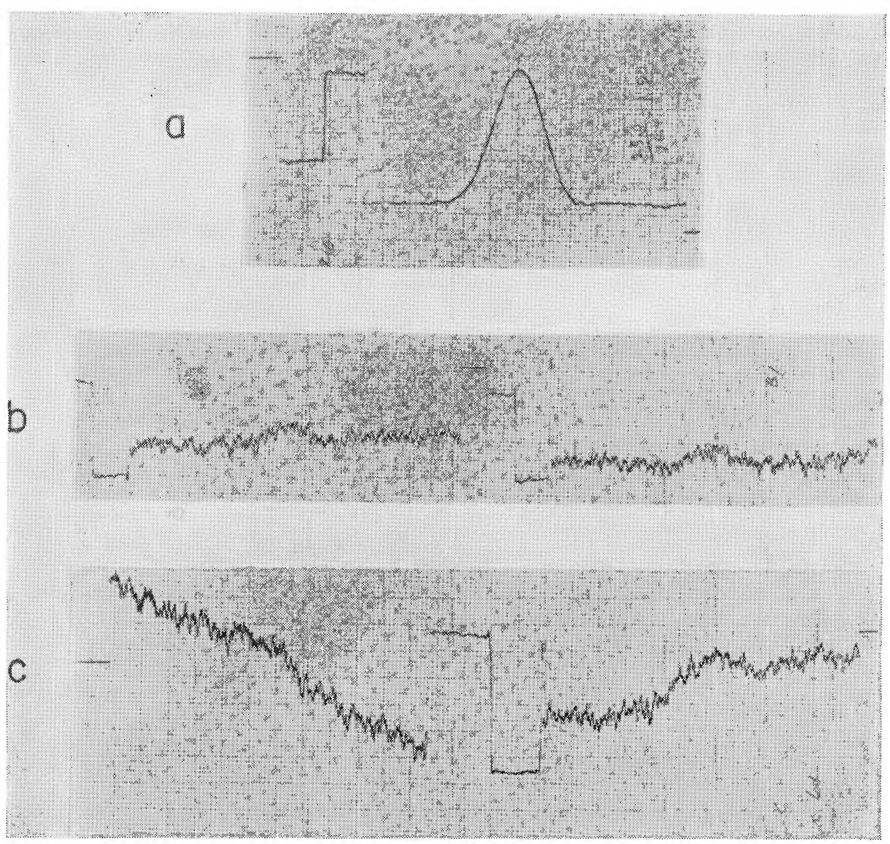

FIG. 1. Sample records. (a) Virgo A drift curve (calibration deflection corresponds to 6.1 °K). (b) and (c). Drift curves (b) and declination scans (c) for MSH 08-14, 3C 195 (calibration deflection corresponds to 1.2°K).

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TABLE I. Discrete sources observed on 1423 Mc.

	3C No.	MSH No.	Flux density 1423 Mc ($\times 10^{-26}$ mks)	rms deviation from mean (%)	Observation types		Spectral indices		Notes
					Drift	Δ-scan	x^{1423}_{159}	x^{1423}_{86}	
1.	17	00−09	8.0	10	1	3	.45	.76	A
2.		00−222	5.0	6	1	2		.63	NGC 253
3.	29	00−017	8.1	8	3	1	.34	.78	
4.	32	01−12	4.4	11	3	1	.69	.88	
5.	40	01−05	7.7	18	4		.56	.87	
6.	41		5.5	18	2	2	.20		
7.	48		17.	5	2	2	.49		
8.	63	02−07	4.4	14	2	1	.81	1.00	
9.	71	02−014	4.7	6	2	1	.39	.71	NGC 1068
10.	75	02+010	6.7	14	2	1	.79	.72	
11.	84		20.	8	2	1	.42		NGC 1275
12.		03−31	110.	5	4			.72	NGC 1316, B
13.	123		52.	5	5	1	.62		
14.		05−36	17.	15	2	2		.48	
15.	147		25.	12	2	2	.42		
16.		06−210	8.3	5	2	2		.74	
17.	195	08−14	4.5	6	2	2	.70	.78	
18.	196		17.	8	4		.62		
19.	208		3.6	8	3	1	.87		
20.	216		5.7	16	2	1	.65		
21.	218	09−14	46.	5	2	2	.69	.96	
22.	219		10.	13	2	2	.65		
23.	227	09+07	7.1	7	2	1	.89	.90	
24.	230	09+08	3.2	15	2	2	1.04	.86	
25.	231		8.6	5	1	2	.15		NGC 3034
26.	234		5.6	7	2	2	.77		
27.	237	10+01	6.1	9	3	1	.57	.57	
28.	238	10+02	4.7	8	2	2	.63	.75	C
29.	254		4.4	13	2	2	.72		
30.	264		5.2	9	2	2	.89		
31.	270	12+05	20.	5	1	2	.00	.57	
32.	273	12+08	39.	5	2	2	.32	.52	
33.	274		210.	5	4		.76	.87	NGC 4486
34.	278	12−118	5.9	6	2	1	.90	.78	NGC 4782/3
35.	279	12−020	7.9	6	2	2	.44	.55	
36.	280		6.3	9	2	2	.63		
37.	283	13−23	5.4	12	2	2	.87	.86	
38.		13−42	330.	5	4			.67	NGC 5128, B
39.	286		17.	6	2	2	.26		
40.	287		7.9	17	2	2	.59		
41.		13−33	14.	7	3			.57	IC 4296
42.		13−25	3.4	19	3			.84	NGC 5236, B
43.	295		22.	9	1	2	.55		
44.	298	14+05	6.1	8	3	1	1.05	1.04	
45.	310		7.7	6	4		1.02		
46.	315		4.9	10	3		.76		
47.	317	15+05	7.3	5	3	1	.92	1.05	
48.	327	16+01	8.6	5	3	1	.63	.87	
49.	338		3.6	9	3	1	1.19		
50.	345		6.9	5	1	2	.12		D
51.	348	16+010	50.	5	4		.82	1.02	E
52.		17+01	6.2	9	3			.74	F, E
53.	353	17−06	57.	5	2	2	.52	.75	
54.		19−23	7.2	8	4			.71	E
55.	403	19+010	7.4	7	3	1	.52	.77	E
56.		20−37	5.5	7	4			.71	B
57.		21−21	12.	15	2	2		.75	
58.	444	22−17	8.2	6	3	1	.82	.97	
59.	445	22−09	7.3	8	4		.47	.75	
60.	459	23+05	4.8	29	4		.75	.88	

Notes:
A MSH position 32′ south of source.
B no declination scans taken.
C 3C position 3° south of source.
D 3C position 24′ north of source.
E background radiation.
F extended at 1423 Mc.

antenna fixed, and scans of 5° extent in declination with the antenna tracking the source in right ascension. For three southern sources, the rapid change in the ground radiation intercepted by the antenna near the horizon made declination scans impractical. At least four observations of each source were obtained. About

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a third of the sources were observed at 1422.4 Mc with 1-Mc bandwidth, the remainder at 1423.4 Mc with a 2-Mc bandwidth. The radiometer time constant was 10 sec. Figure 1 (a) shows a sample record of the source Virgo A, typical of those taken regularly to test the radiometer performance; and Figs. 1 (b) and 1 (c) show drift curves and declination scans for a weaker source, MSH 08–14, 3C 195. A second argon discharge tube at the input of the radiometer made the calibration mark on each record.

For each source, three or more of the best records were used to obtain an average antenna temperature for the source. Observations of Cas A and the adoption of Findlay's (1961) value for the flux density allowed the conversion of antenna temperatures to flux densities (Findlay's value, 2.56×10^{-23} w m^{-2} cps^{-1} at 1440 Mc, and an adopted spectral index of 0.70 lead to the value 2.58×10^{-23} at 1423.5 Mc.) This method is not affected by the absolute temperature of the calibration source or the antenna collecting area as long as they are constant. Table I gives the results of these observations. The flux density listed for an extended source is the peak value seen by the antenna beam.

The column labeled "observation types" shows the types which were averaged to obtain the given flux density; it thus indicates the regions with respect to which flux density is measured.

The right ascensions of all the sources agreed within 7 minutes of arc of the published right ascensions at the lower frequencies. Three discrepancies between the declinations at 1423 Mc and the published values are noted in Table I.

An analysis of the diminution of the antenna temperature of a point source produced by the time constant of the final filter of the radiometer showed the maximum amount is 0.45%. No corrections were made for this diminution. Another analysis of the effect of the detector law on the measured antenna temperatures showed the maximum correction to be 0.5% for 58 of the 60 sources. No corrections were made for these sources but, corrections of 0.6 and 1.3%, respectively, have been applied for Virgo A (3C 274, NGC 4486) and Centaurus A (MSH 13–42, NGC 5128).

III. SPECTRAL INDICES

The spectral indices in Table I are obtained from the flux densities at 159 and 86 Mc and the present measurements with the equation

$$(f_2/f_1)X_1{}^2 = S_1/S_2,$$

where S_i is the flux density at the frequency f_i. Thus, the index is positive for all the sources, since all have flux densities that decrease with frequency. For sources listed in the MSH surveys as extended, the peak flux density was used in the calculation.

Figure 2(a) is a histogram of the spectral indices X_{86}^{1423}. The indices vary between 0.48 and 1.05, a

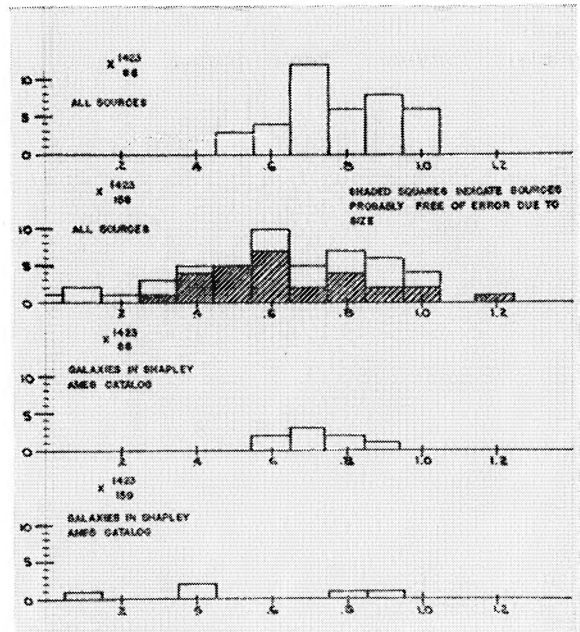

FIG. 2. Histograms of spectral indices. Abscissa, spectral index; ordinate, number of sources. Letters (a), (b), (c), and (d) in the text refer to the histograms in order starting from the top.

narrower range than previously reported. The average value is 0.78. Figure 2(b) shows the distribution of the indices X_{159}^{1423} and is similar to a histogram obtained by Harris and Roberts (1960) from their observations at 960 Mc. The indices X_{159}^{1423} vary between 0.00 and 1.19. The shaded squares represent sources that have been observed by Moffet (1961) at 958 Mc and that have angular sizes which, if the 958-Mc measurements apply to 159 Mc, will not cause an error in the flux density obtained at 159 Mc by the Cambridge interferometer. The average value of all the indices X_{159}^{1423} is 0.63, while the average value of those which are probably free of angular size error at 159 Mc is 0.67.

Figures 2(c) and 2(d) show the distribution of X_{86}^{1423} and X_{159}^{1423}, respectively, for the sources identified with galaxies in the Shapley Ames catalogue.

IV. DISCUSSION

These observations ought to yield accurate spectral indices for several reasons: (1) The weakest of the 60 sources causes a deflection on a single record several times that of the root-mean-square noise fluctuations. (2) The large ratio of frequencies reduces the effect of an error in obtaining the flux density ratio on the spectral index. A 26% error in S_{86}/S_{1423} causes a 0.1 error in X_{86}^{1423}; while a 22% error in S_{159}/S_{1423} causes a 0.1 error in X_{159}^{1423}. (3) The indices X_{86}^{1423} are not affected by the finite size of sources because both observers employed pencil beam antennas. However, since the spectral indices obtained herein are based on observations at widely spaced frequencies, they cannot offer information on fine structure in the spectra of sources.

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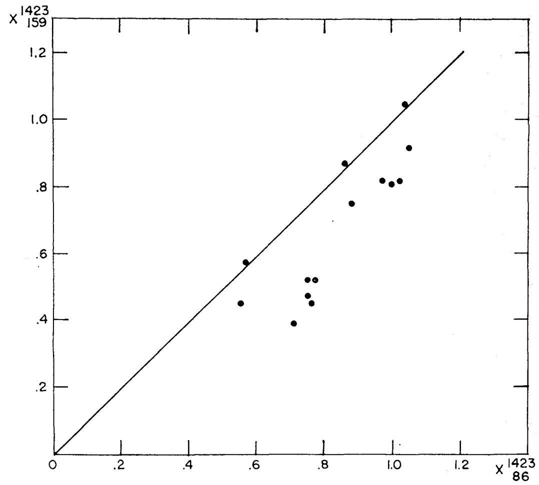

FIG. 3. Comparison of spectral indices determined from two different frequency baselines, for sources where Moffet's observations at 950 Mc indicate no error due to angular size at 159 Mc.

The distribution of X^{1423}_{159} has a lower average value than that of X^{1423}_{86} even for the sources that are probably free of error due to angular size. Figure 3 is a plot of X^{1423}_{159} vs X^{1423}_{86} for these latter sources. If sources had a spectral index independent of frequency, and if there were no errors in the measurements, all of the points in Fig. 3 would lie on the diagonal line. In fact, the points tend to lie below the line. A similar result can be obtained from the indices X^{960}_{159} and X^{960}_{86} by using the observations of Harris and Roberts (1960) or those of Kellerman and Harris (1960). Thus it is reasonable to conclude, unless all three sets of high-frequency observations are incorrect, that the 3C flux densities are systematically lower, or that the MSH flux densities are systematically higher than those predicted from the assumption that spectral indices are independent of frequency.

The indices X^{1423}_{86} for sources identified with one of the relatively nearby galaxies listed in the Shapley Ames catalogue seem to have a narrower range than that of the indices X^{1423}_{86} for all sources. However, since there are only eight of the former sources, a substantial probability exists that their distribution would appear narrower when the distributions were actually identical. I conclude that the distribution of indices X^{1423}_{86} of the sources identified with nearby galaxies is indistinguishable from that of all the sources from the present data. The same conclusion applies to the indices X^{1423}_{159}.

Table II shows a comparison of the spectral indices obtained above for sources identified with galaxies and those obtained by Heeschen (1960) at 1400 and 440 Mc. The agreement between the various indices seems good for the first six of these galaxies, and fair for the remaining two.

Heeschen has found four galaxies with much larger indices that have not been observed in the present program. These are discussed in Table III. The lack of confirmation of these observations may indicate that the galaxies do not have spectral indices greater than those in Table I. Heeschen (1961) has just published a more extensive set of observations of galaxies. For 12 galaxies with well-determined indices, he finds a range of 0.21 to 1.26.

TABLE II. Comparison of spectral indices.

Galaxy	X^{1400}_{400} Heeschen (1960)	X^{1423}_{159}	X^{1423}_{86}
NGC 1316	.72		.72
NGC 4486	.80	.76	.87
NGC 5128	.72		.67
16NOA (3C348)	.88	.82	1.02
NGC 253	.56		.63
NGC 5236	1.0		.84
NGC 1068	.48	.39	.71
NGC 1275	.64	.42	

Whitfield (1958) reported that sources with large indices tend to have low flux density. He based his indices largely on the 3C survey at 159 Mc and his own observations (1960) at 38 Mc. At least two instrumental effects could contribute to this result: (a) the partial resolution of sources by the 159-Mc interferometer, and (b) the presence of more than one source in the 4.5°×12° beam of the 38-Mc interferometer. Figure 4 shows a plot of peak flux density at 86 Mc against the spectral index X^{1423}_{86} for 39 sources. No

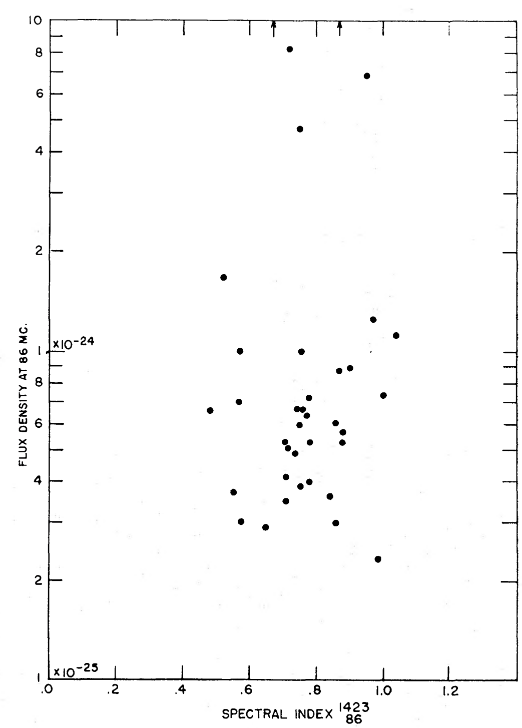

FIG. 4. Plot of 86-Mc peak flux densities vs spectral indices based on 86 Mc.

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TABLE III. Galaxies reported to have large spectral indices.

Galaxy	X_{440}^{1400} Heeschen (1960)	Comment
IC 342	1.75	The 960-Mc observations of Wilson and Bolton (1960) show this source is in a region with measurable radiation from our galaxy. This makes it a difficult task to disentangle the local and distant radiation.
NGC 891	>2.8	This source was observed at 159 Mc by Hanbury-Brown and Hazard (1953), who found a flux density of 10×10^{-26} w m^{-2} cps^{-1}. Heeschen's value at 440 Mc is 19×10^{-26} and, if his lower limit to the spectral index applies between 440 and 159 Mc, the flux density at 159 Mc ought to be greater than 330 $\times10^{-26}$.
NGC 3031	>1.75	Interpretation of this source is difficult because of the presence of 3C 231 (NGC 3034) about a degree away.
IC 1613	>2.1	Mills, Slee, and Hill state that their survey is complete for sources with flux densities of 20×10^{-26} in this region, but no MSH source is within 2.5 deg of its position. Using Heechen's flux density at 440 Mc and his lower limit to the spectral index to predict flux density at 86 Mc gives 72×10^{-26}.

correlation seems to exist between these quantities. Whitfield also found a substantial number of sources with indices between 1.2 and 2.2. The same instrumental effects must be at least partly responsible for these high values.

The Harvard radiometer can detect only the strongest MSH or 3C sources at 1423 Mc, if they have large indices. The 15 strongest sources of the high-latitude sources in the 1958 MSH catalogue (this includes the source Virgo A taken from *Encyclopedia of Physics*, volume 52) are all present in Table I. Of the 19 strongest high-latitude 3C sources, three were not on the observing program, and the remaining 16 are included in Table I. Thus, if there are sources with indices considerably higher than those reported above, they are relatively uncommon among the strong sources in the 3C and MSH catalogues, or else they exhibit their large values in a part of the spectrum not considered here.

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