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Occultations of 50 radio sources at 327 MHz

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Radio positions and brightness distributions derived from lunar occultations observed with the Ooty radio telescope at 327 MHz are reported for 50 radio sources, most of them in the flux density range of $0.3–2 \times 10^{-26}$ Wm^{-2} Hz^{-1}. A large majority of the sources is resolved, with angular sizes of about 2–20 arcsec. Only 13 sources are identified with optical objects; nine with galaxies, three with blue-stellar objects and one with a stellar object.

IN this paper we present the fourth list of radio sources from the lunar occultation program being carried out with the Ooty radio telescope (Swarup *et al.* 1971a) at 327 MHz. In the earlier three lists (Swarup *et al.* 1971b; Kapahi *et al.* 1973a; Kapahi *et al.* 1973b) we have reported the observations of a total of 58 radio sources. The present list consists of 50 sources, most of them in the flux-density range of about 0.3–2 f.u. (1 f.u. $= 10^{-26}$ W m^{-2} Hz^{-1}), for which accurate radio positions and brightness distributions have been derived. Optical identifications have been attempted from the prints of the Palomar Sky Survey on the basis of the derived radio positions and source structures. Only 13 sources are definitely identified; nine with galaxies, three with BSO's, and one with a stellar object.

OBSERVATIONS AND RESULTS

The method of observation and analysis of occultations has been described earlier (Swarup *et al.* 1971b; Kapahi *et al.* 1973b). The sources reported in this paper were occulted during 1970 and 1971, and at least two occultations were observed for each source. The data for most of the sources was digitized manually from paper chart records of occultations, at intervals of about 0.5–4 sec depending on the chart speed and the Moon's limb velocity during the occultation.

The structural information on the 50 sources is summarized in Table I and the radio and optical positions are listed in Table II. The formats for the two tables are essentially similar to the ones used for the 4C sources reported in List 3 (Kapahi *et al.* 1973b), where detailed explanations to the tables are also given.

The flux values at 327 MHz, given in Table II are estimated to have standard errors of about $\pm 20\%$ for sources stronger than about 1.5 f.u. and about $\pm 30\%$ for the weakest sources. The radio positions are referred to the FK4 equinox. Optical positions of objects suggested as likely identifications and of objects closest to the radio positions have been estimated in most cases from measurements of X–Y coordinates, on contact plates of the Sky Survey prints, of reference stars from the SAO catalogue by the method described in List 3. The positions are estimated to have standard errors of ± 0.5 arcsec in each coordinate.

Finding charts for 11 new identifications are presented in Plate I (p. 1141).

Additional Comments on Some Sources

0042+082 and 0042+084. Both these sources lie within the compact cluster Zw 0042.5+0824 (Zwicky *et al.* 1965) and are likely to be associated with it. Neither of them, however, coincides with a galaxy in the cluster. The major axis of the 15.5-mag E-galaxy points approximately towards the source 0042+084.

0059+105. There is a possible second component with $\leqslant 30\%$ of the total flux, about 26 arcsec to the west. The optical field contains three other galaxies of ~18-mag each, within ~1.6 arcmin of the radio position.

0240+210. Possibly double with a component separation of ~7 arcsec in PA ~14°.

0416+270. There is a possible third component between A and B, with $\leqslant 20\%$ of the total flux, about 29 arcsec southeast of A along the line joining A and B. It has an angular size $\leqslant 10$ arcsec.

0604+266. Both the components have weak extensions inwards.

TABLE I. Structural data for 50 radio sources at 327 MHz.

(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	(9)	(10)	(11)
				Observed data				Derived structure			
Source OTL	Other Catalog No.	Flux 327 MHz	No. of occulta-tions	β_e	PA of occln.	Component sizes A	B	PA A to B	Comp. sepn.	Flux ratio A/B	Remarks
0042+082		0.3 f.u.	2	10″	96°	∼18″					
				8	180	∼ 8					
0042+084		0.3	2	8	64	∼12					
				10	216	∼16					
0059+105		0.4	2	8	27	< 7					(N)
				8	277	< 7					
0216+190		0.5	5	5	55	≪ 5					
				5	272	≪ 4					
0238+208		0.7	6	3.1	60	∼ 4					
				3.1	266	∼ 3					
0240+208		0.4	2	5	91	≪ 5					
				5	241	≪ 4					
0240+210		0.4	4	4	83	≪ 4					PD,(N)
				4	220	∼ 4					
0405+258	B2 0405+25	1.0	3	1.3	92	∼ 2					
				2.1	220	≪ 2					
0416+270	4C 27.13	2.8	4	8	18	∼15	⩽15	137°	72″	2.4	Cx,(N)
				8	319	∼18	∼40				
0435+270		0.6	2	5	109	∼ 5	≪ 4	89	10	1.5	
				5	222	≪ 4	∼ 5				
0437+273	B2 0437+27A	0.4	2	10	63	∼12					
				10	286	≪ 8					
0604+266	4C 26.19	3.7	2	2.2	103	∼ 4	∼ 4	54	60	1.5	(N)
				2.2	273	∼ 4	∼ 4				
0759+237	OI 299	0.3	2	5	107	∼15					PD,(N)
				10	313	∼18					
0815+229		0.6	2	8	82	∼10					PD,(N)
				8	315	∼13					
0914+175	VRO 17.09.02	1.2	2	5	87	∼10					
				10	325	∼ 9					
1020+104		0.7	4	2.1	10	∼ 4					
				3	123	∼ 4					
1127+012	4C 01.30	2.1	2	5	163	∼23					Cx,(N)
				5	275	∼33					
1129+014		0.5	2	4	8	≪ 4					
				4	73	∼ 5					
1130+008		0.7	2	3	141	≪ 3					(N)
				3	313	≪ 3					
1142−002	4C −00.46	3.0	2	1.2	21	∼ 6	∼ 1.3	72	29	0.3	
				2.1	62	∼ 6	∼ 2.4				
1302−112	OP−104 ?	1.1	2	10	108	∼14					PD,(N)
				8	328	∼20					
1304−101	OP−107	1.4	2	2.1	62	∼ 2					
				2.1	332	∼ 4					
1311−122	PKS 1311−12	2.2	3	2.2	57	≪ 2					
				2.2	187	≪ 2					
1354−176		2.4	4	2.2	110	< 1.5	∼ 2	80	10.5	0.55	(N)
				2.1	147	< 1.5	∼ 4				
1402−177		0.4	2	10	88	∼15					
				10	349	∼16					
1426−195		0.7	2	2.2	82	≪ 2					
				2.2	354	≪ 2					
1518−244		0.5	2	4	112	∼ 4.5					
				4	271	∼ 7.5					
1628−278		0.5	2	2.2	154	∼ 2					PD,(N)
				3.1	221	∼ 5					
1725−287		1.7	2	30	139	∼63					Cx,(N)
				15	248	∼23					
1859−274		0.4	2	15	18	∼30					Cx
				15	310	∼30					
1906−272		0.4	2	2.4	120	≪ 2					(N)
				4	192	3					
1911−259		1.0	2	5	19	∼ 8					(N)
				4	291	∼ 6					
1912−269	MSH 19−203	6.3	2	5	94	∼35	∼18	90	46	2.5	Cx,(N)
				5	243	∼28	∼22				
1945−250		0.8	2	2.2	48	≪ 2					(N)
				2.2	283	∼ 4					

TABLE I (*continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	(9)	(10)	(11)
				Observed data				Derived structure			
Source OTL	Other Catalog No.	Flux 327 MHz	No. of occulta-tions	β_e	PA of occln.	Component sizes A	B	PA A to B	Comp. sepn.	Flux ratio A/B	Remarks
1950−249		1.0	2	15	100	<12					(N)
				4	204	< 4					
1952−236		0.5	2	5	10	⩽ 4					
				5	297	⩽ 4					
2006−238		0.7	2	8	34	∼14	∼12	68	17	2	
				8	263	∼ 9	⩽ 8				
2040−219	OW−268 ?	1.3	2	8	141	∼20					Cx
				8	183	∼10					
2042−212	OW−271	0.6	2	5	27	∼ 8					
				5	278	∼10					
2053−201	PKS 2053−20	5.6	2	15	72	⩽12	∼12	52	27	1	(N)
				15	216	⩽12	∼14				
2054−198		0.6	2	10	73	⩽ 9					(N)
				15	213	∼15					
2103−195	OX−105	0.6	2	15	31	∼20					(N)
				8	255	⩽ 8					
2151−140	OX−185	1.7	2	8	10	∼16					PD,(N)
				8	270	∼ 8					
2200−130		0.7	2	5	116	∼ 9	∼10	50	27	0.6	
				5	194	∼ 7	∼ 8				
2204−115		0.8	2	5	0	∼ 6					
				4	283	∼ 4					
2205−118		0.4	2	10	60	∼12					PD,(N)
				10	220	∼15					
2248−075		0.3	2	10	112	< 8					
				10	169	⩽ 8					
2255−065		0.5	2	8	31	⩽ 7					(N)
				8	243	< 7					
2256−054	OY−094	0.9	5	5	14	< 4	< 4	128	19	0.3	(N)
				5	258	< 4	< 4				
2301−043	OZ−003	0.3	2	5	42	⩽ 4					
				5	253	⩽ 4					

0759+237. In immersion (PA 107°), the source is resolved into two components with a flux ratio of about 2:1 and a separation of ∼15 arcsec. The weaker component could be up to 25 arcsec in extent. The two components are poorly determined in emersion (PA 313°).

0815+229. Possibly double with a component separation of ∼16 arcsec in PA ∼20° or ∼9 arcsec in PA ∼112°. Optical observations are necessary to determine the nature of the 16-mag stellar object close to the radio centroid. The 18-mag BSO, only about 9 arcsec from the radio centroid, lies away from the possible axes of the source extension.

1020+104. The source lies in the region of the distant cluster Zw 1020.8+1031 (Zwicky *et al.* 1961) and is likely to be associated with it.

1127+012. Complex structure. Simplest interpretation is 3–4 components aligned approximately along PA ∼45°, with a separation of ∼52 arcsec between the outermost components. Merkelijn and Wall (1970) have classified the object as an N galaxy.

1130+008. There is a 16-mag galaxy, 114 arcsec east and 26 arcsec south of the 17-mag BSO identified with the radio source. There is another radio source, OTL 1130+009, about 8.6 arcmin east and 6.4 arcmin north of 1130+008. This nearby source has a flat spectrum and is identified with a 19-mag BSO (Kapahi *et al.* 1973a).

1302−112. Possibly double, with a component separation of ∼33 arcsec in PA ∼36°.

1354−176. The strip distributions along four position angles are shown in Fig. 1, along with a schematic model for the source. The component B has a sharp brightness gradient towards north and is extended by about 4–5 arcsec south in PA ∼190°, which is quite different from the position angle separating the components A and B. The position given in Table II for component B refers to its centroid. Component A is unresolved. The optical object identified with the source (19-mag BSO?) is sharper and slightly brighter in blue.

Another radio source, OTL 1354-174, about 3 arcmin east and 7.8 arcmin north of 1354-176, has a flat spectrum and is identified with an 18.5-mag BSO (Kapahi *et al.* 1973a).

1628−278. Possibly double with a component separation of ∼4 arcsec in PA ∼90°.

TABLE II. Radio and optical positions and notes on the optical fields.

(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)
	Position (1950.0)							
	Radio		Optical		Radio-Opt.			
Source OTL	Right ascension	Declination	RA	Dec	RA	Dec.	m_{pg}	Notes on optical objects
0042+082	$00^h42^m37^s.50 \pm 0^s.1$	$+08°13'17''.4 \pm 1''.5$	(36s.80	13'03''.9)	+10''	+13''	20	galaxy, nearest in cluster Zw 0042.5+0824; (N)
0042+084	00 42 42.45 0.1	+08 25 05.0 1.5	46.16	25 23.4	−55	−18	15.5	E galaxy, in cluster Zw 0042.5+0824; (N)
0059+105	00 59 23.16 0.15	+10 35 46.1 2	(23.03	35 32.6)	+ 2	+13	19	Red galaxy; other galaxies nearby; (N)
0216+190	02 16 02.61 0.05	+19 04 29.2 1	02.13	04 42.4	+ 7	−13	19.5	galaxy, only in red
0238+208	02 38 11.30 a	+20 51 50.3 a	(10.12	51 34.3)	+17	+16	19	galaxy, only in red
			(10.93	51 32.9)	+ 5	+17	20	galaxy, only in red
0240+208	02 40 10.05 0.1	+20 51 21.4 1.5	09.79	51 39.7	+ 4	−18	16.5	galaxy ?
0240+210	(C)02 40 06.16 0.1	+21 02 12.6 1.5	06.05	02 16.1	+ 2	− 3	19.5	[b] Red galaxy
			06.73	02 09.4	− 8	+ 3	19	Red galaxy
0405+258	04 05 08.52 0.07	+25 53 38.8 1	(06.89	53 33.5)	+22	+ 5	20	Only in red
0416+270	A 04 16 04.98 0.15	+27 05 18.6 2						Obscured field
	B 04 16 08.9 0.3	+27 04 22 5						
0435+270	A 04 35 05.39 0.1	+27 02 35.8 1.5	(07.60	02 36.4)	−30	− 1	19	Only in red
	B 04 35 06.11 0.15	+27 02 36.1 2			−20	0		
0437+273	04 37 21.41 0.1	+27 22 54.9 1.5	21.41	22 54.9	0	0	18.5	[b] Red galaxy
0604+266	A 06 04 33.83 a	+26 36 29.0 a						Crowded field, $b^{II}=3°.0$
	B 06 04 37.45 a	+26 37 04.6 a						
0759+237	(C)07 59 13.64 a	+23 44 21.0 a	15.15	44 04.9	−21	+16	16	Stellar
0815+229	08 15 56.99 0.15	+22 57 13.9 2	57.07	57 11.4	− 1	+ 2	16	[b] Stellar; (N)
			57.57	57 17.9	− 8	− 4	18	BSO with wisp in PA ~310°
0914+175	09 14 31.35 0.1	+17 30 24.2 1.5	(31.82	30 43.5)	− 7	−19	20	Only in red
1020+104	10 20 55.24 0.1	+10 27 12.7 2	55.13	26 47.9	+ 2	+25	17.5	galaxy in cluster; (N)
			53.42	27 24.6	+27	−12	17.5	galaxy in cluster
1127+012	11 27 47.25 0.15	+01 14 52.3 3	47.50	14 56.0	− 4	− 4	17.5	[b] E galaxy; (N) Merkelijn & Wall (1970)
1129+014	11 29 11.30 0.07	+01 24 56.0 1	(12.47	25 24.0)	−18	−28	20	Only in red
1130+008	11 30 12.01 a	+00 51 04.6 a	11.77	51 02.2	+ 3	+ 2	17	[b] BSO; (N)
1142−002	A 11 42 18.75 0.15	−00 15 04.5 1.5	(19.94	15 23.6)	−18	+19	21	Only in red
	B 11 42 20.56 0.07	−00 14 55.7 1			+ 9	+28		
1302−112	(C)13 02 10.67 0.2	−11 16 58.2 2			−18	−62	19.5	Only in red
1304−101	13 04 04.80 0.07	−10 10 13.4 1	00.86	10 32.5	+58	+19	19	Red galaxy; other galaxies nearby
1311−122	13 11 15.64 0.07	−12 14 30.3 1	15.00	14 29.1	+10	− 1	20	[b] BSO?, with a possible jet in direction of radio source
1354−176	A 13 54 09.10 0.03	−17 37 15.4 0.4	09.51	37 14.3	− 6	− 1	19	[b] BSO?, (N)
	B 13 54 09.82 0.03	−17 37 13.6 0.5			+ 5	+ 1		
1402−177	14 02 01.30 0.15	−17 44 14.3 2	59.19	44 05.5	+30	− 9	19.5	Red galaxy
1426−195	14 26 05.26 0.07	−19 32 28.6 1	05.45	32 40.4	− 3	+12	18	galaxy?
1518−244	15 18 50.13 0.07	−24 25 51.8 2	49.20	25 59.7	+13	+ 8	20	galaxy, in faint cluster
1628−278	16 28 14.68 0.07	−27 49 56.1 1						Crowded field
1725−287	(C)17 25 19.0 0.3	−28 43 45.4 4						Crowded field, $b^{II}=3.3°$
1859−274	(C)18 59 07.60 0.2	−27 25 27.7 3						Crowded field
1906−272	19 06 09.12 0.07	−27 16 50.5 1						Crowded field
1911−259	19 11 53.10 0.07	−25 57 12.8 1						Crowded field
1912−269	A 19 12 40.57 0.15	−26 58 10.2 2						Crowded field
	B 19 12 44.07 0.2	−26 58 09.7 3						
	C 19 12 50.0 0.5	−26 58 42 7						

TABLE II (*continued*)

(1)	(2)	(3)		(4)	(5)	(6)		(7)	(8)
	Position (1950.0)								
	Radio			Optical		Radio-Opt.			
Source OTL	Right ascension		Declination	RA	Dec.	RA	Dec.	m_{pg}	Notes on optical objects
1945−250	19 45 44.85	0.1	−25 05 37.2 1						Crowded field
1950−249	19 50 45.11	0.15	−24 58 07.3 1.5	46.52	58 35.4	−19	+28	15	Stellar
1952−236	19 52 40.66	0.1	−23 40 31.4 1.5	(40.57	40 30.6)	+ 1	− 1	19	[b] Red galaxy
2006−238	A 20 06 32.47	0.15	−23 53 28.1 3	31.85	53 33.3	+ 8	+ 5	16	Stellar
	B 20 06 33.65	0.2	−23 53 21.8 4			+25	+12		
2040−219	20 40 20.80	0.15	−21 55 23.8 2	(20.49	55 24.0)	+ 4	0	18	[b] galaxy? three more galaxies (18–19 mag) within ∼15 arcsec
2042−212	20 42 29.25	0.1	−21 15 39.0 1.5	(29.35	15 39.1)	− 1	0	18	[b] galaxy, nucleus brighter in blue
2053−201	A 20 53 12.39	0.1	−20 08 16.8 1.5	12.90	08 07.4	− 7	− 9	18	[b] E galaxy, in cluster
	B 20 53 13.93	0.1	−20 08 00.0 1.5			+14	+ 7		Bolton *et al.* (1965)
2054−198	20 54 47.01	0.15	−19 52 25.2 2	45.18	52 21.7	+26	− 3	18	Red stellar
2103−195	21 03 16.93	0.15	−19 35 36.2 3	17.55	35 25.6	− 9	−11	19	Red galaxy
2151−140	(C)21 51 06.80	0.1	−14 00 24.0 1.5	(04.72	00 33.1)	+30	+ 9	19.5	Only in red
2200−130	A 22 00 40.24	0.15	−13 05 44.6 3	40.82	05 36.8	− 8	− 8	19	[b] galaxy only in red
	B 22 00 41.64	0.1	−13 05 27.4 2			+12	+ 9		in faint cluster
2204−115	22 04 55.00	0.07	−11 33 56.9 1	56.35	33 39.4	−19	−17	18.5	Brighter in red
				56.43	34 14.7	−20	+18	19	galaxy, only in red
2205−118	22 05 12.33	a	−11 50 57.0 a	12.06	50 33.9	+ 4	−23	18	Red galaxy?
2248−075	22 48 58.29	0.1	−07 33 35.3 2	58.36	32 53.2	− 1	−42	16	Stellar
2255−065	22 55 08.60	0.1	−06 34 59.9 1.5	08.68	35 02.0	− 1	+ 2	16	[b] Red galaxy
2256−054	A 22 56 04.66	0.07	−05 26 51.0 1	(03.45	26 42.4)	+18	− 9	20	Only in red
	B 22 56 05.66	0.05	−05 27 02.6 0.7			+33	−20		
2301−043	23 01 52.89	0.15	−04 23 52.6 2	49.62	23 51.0	+49	− 2	18	Red galaxy

[a] Errors in radio position
0238+208 : ±0″.7 in PA 60° & ±1″.5 in PA 150°
0604+266A: ±0″.7 in PA 98° & ±3″ in PA 8°
0604+266B: ±1″ in PA 98° & ±5″ in PA 8°
0759+237 : ±2″ in PA 120° & ±4″ in PA 30°
1130+008 : ±1″ in PA 137° & ±5″ in PA 47°
2205−118 : ±1″ in PA 50° & ±4″ in PA 140°

[b] = Definite or likely identification
(N) = Additional notes in text

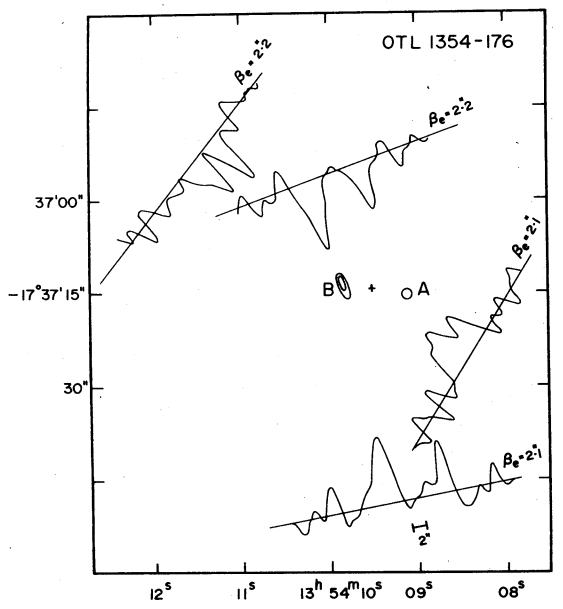

FIG. 1. Strip-brightness distributions and a schematic model for the source 1354-176. The brightness profiles are plotted along appropriate position angles of the four occultations. The position of the 19-mag BSO is indicated by a cross.

1725—287. Complex structure, extended along PA 136°±15°. Most of the flux is in two components separated by ~40 arcsec.

1906—272. There is a possible second component with ⩽35% of the total flux and ⩽3 arcsec in extent (in PA 192°), about 8 arcsec southwest along PA ~210°.

1911—259. The occultation records show the possible presence of a second very broad component of about 1 f.u. extending up to 2–3 arcmin in the southwest direction.

1912—269. The third component, C (whose position is listed in Table II), (Fig. 2) contains ~16% of the total flux and has an angular size ~55 arcsec in PA's 94° and 241°.

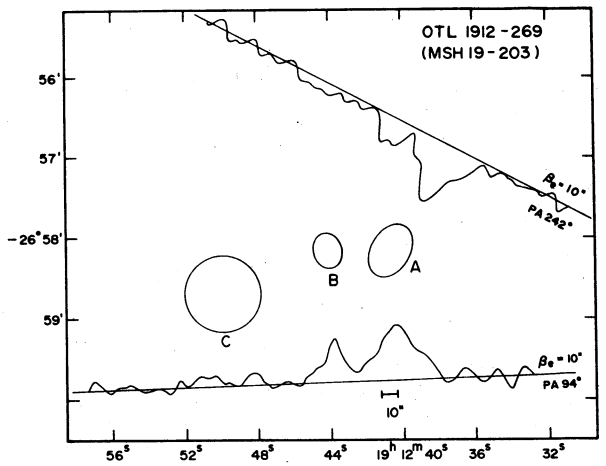

FIG. 2. Brightness profiles and a schematic model for 1912–269.

1945—250. A possible second component of size ⩽3 arcsec with ⩽35% of the total flux, about 10 arcsec north or ~5 arcsec southwest.

1950—249. Angular resolution limited by the presence of ionospheric scintillations during the occultation.

2053—201. Resolution limited due to ionospheric scintillation. The positions and structures of components are in agreement with those derived by Hazard (1972) from three occultations at 408 MHz.

2054—198. Resolution limited by ionospheric scintillation.

2103—195. Doubtful extended component of low surface brightness in the emersion record (PA ~255°).

2151—140. Possibly double with a component separation of ~12 arcsec in PA ~25° and a weak bridge or extension between the two.

2205—118. Possibly double with a component separation of ~10 arcsec in PA ~60°.

2255—065. Doubtful weak extended structure up to 20 arcsec in extent.

2256—054. Possible weak "bridge" between the two components.

CONCLUSION

Accurate radio positions and structures have been derived for 50 radio sources, most of them with flux densities <2 f.u. at 327 MHz. There are eight sources with flux density >2 f.u. of which seven are well resolved and show the double or more complex radio structure. In most of these, the individual components are also resolved. Of the 42 sources with flux density between 0.3–2 f.u., 31 are resolved in one or more position angles and have overall angular sizes ⩾2 arcsec. Only 11 sources have not been resolved with resolutions between 2–10 arcsec. Thus, it is interesting to note that a majority of the sources at these flux levels have angular extents varying between 2–20 arcsec. Many of these may, however, contain part of their flux in compact components smaller than 0.5 arcsec, since interplanetary scintillation surveys of stronger sources (e.g., Harris and Herdebeck 1969; Bhandari *et al.* 1973) indicate that over 50% of the sources have scintillating components.

A detailed discussion of the angular extents and radio-optical associations for several hundred radio sources being studied in the lunar occultation program with the Ooty radio telescope will be presented later.

ACKNOWLEDGMENTS

We thank C. R. Subrahmanya for help with the optical identifications.

[*Note added in proof:* Two of the weak sources in this list, 0059+105 and 2248–075, were not detected at 408 MHz ($S_{408}<0.2$ f.u.) during recent observations of Ooty sources at Molonglo by G. Swarup and J. Sutton. The sources could be spurious as their occultation records are of poor quality.]

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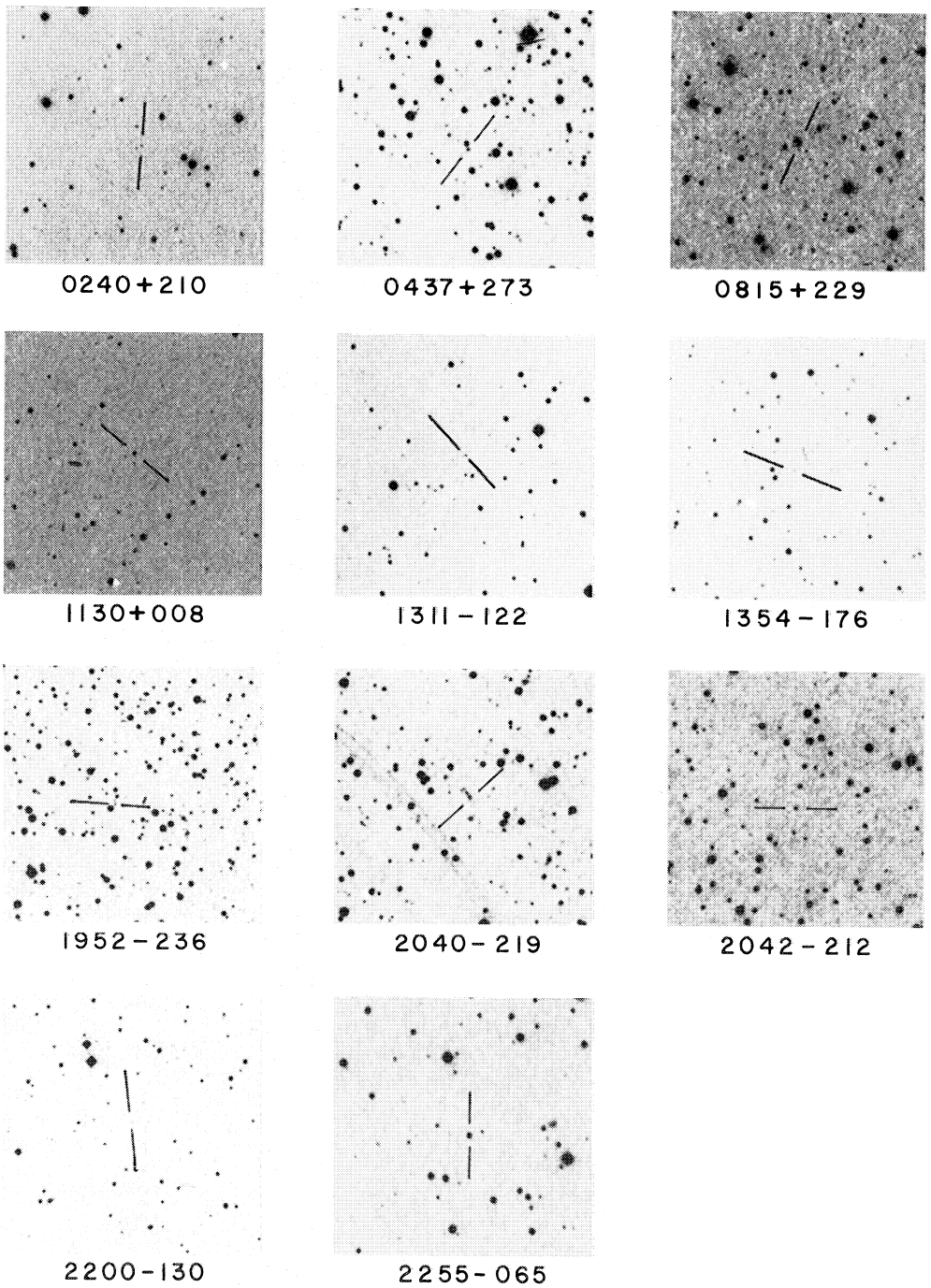

PLATE I (Joshi, *et al.*, p. 1023). Finding charts for 11 radio sources identified from the Palomar Sky Survey prints. The top left corner represents the northeast direction. The field shown covers 9.4 arcmin on the side.