OBSERVATIONS OF SOME RADIO SOURCES PREVIOUSLY IDENTIFIED WITH CLUSTERS OF GALAXIES

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Summary

The positions of 33 radio sources previously identified with distant clusters of galaxies were remeasured more accurately to check the identifications. Observations were made at 1410 and 2650 MHz with the 210 ft radio telescope of the Australian National Radio Astronomy Observatory at Parkes, and at 408 MHz with the east–west arm of the Mills Cross at the Molonglo Radio Astronomical Observatory of the University of Sydney. It was found that 21 sources are situated within 5 min of arc of the centres of the corresponding clusters. In three clusters the sources are outside the central area, while five sources are outside the clusters. The remaining four sources were not detected. The dimensions of all sources are much less than the diameters of the corresponding clusters of galaxies, which means that a single galaxy is responsible for the observed radio emission.

I. Introduction

It is known that some of the sources of cosmic radio emission are in clusters of galaxies. The first identifications of radio sources with distant clusters of galaxies were made by Mills (1960), van den Berg (1961), Tovmassian and Shahbazian (1961), and Tovmassian and Kalloglian (1962). The sources identified were those from the MSH catalogue (Mills, Slee, and Hill 1958, 1960) and from the 3C catalogue. Some further identifications were later made by Pilkington (1964). The uncertainties in the positions of the radio sources prevented an identification with individual members of the clusters, although it is well known that in some nearby clusters bright, centrally located galaxies are responsible for the observed radio emission. This fact was taken into account when a number of provisional identifications of sources with bright, peculiar, or double galaxies in the centres of clusters of galaxies were made by Tovmassian and Shahbazian (1961), Tovmassian (1962), and Tovmassian and Kalloglian (1962).

In the present paper we present the results of observations of 33 radio sources (listed in Table 1) that were previously identified with clusters of galaxies in the catalogue given by Abell (1958). The sources were studied with much higher resolution than previously and their positions were measured with greater accuracy to check the

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suggested identifications with definite members of the clusters. Because sources included in the Parkes catalogue of radio sources had already been observed with the 210 ft telescope, such sources were excluded when choosing sources for observation from the published lists of identifications.

The observations were made in 1965 with the 210 ft radio telescope of the Australian National Radio Astronomy Observatory at Parkes, N.S.W., and with the 1-mile-long east–west arm of the Mills Cross at the Molonglo Radio Astronomical Observatory of the University of Sydney, using the same method and equipment as in the search for radio emission from clusters of galaxies of distance group 5 that is described in the preceding paper (pp. 715–24 of the present issue). Since it was expected to find radio emission originating in the centre of the cluster under investigation, the search for a radio source was generally made by scanning through the centre of the cluster and not, except in a few cases, through the position of the catalogued radio source that had been identified earlier with the corresponding cluster.

The weakness of some of the detected sources could make their existence doubtful because they are near the confusion limit of the telescope. But the fact that the same sources were observed at other wavelengths with different beam shapes and better resolution removes the doubt of their existence.

II. Results

The results of the observations are presented in Table 1. The first and second columns of the table give the MSH or 3C designations of the sources and Abell's (1958) designations of the clusters of galaxies to which they are related. The distance groups of the clusters are given in column 3. Columns 4 and 5 contain the right ascensions and declinations of the clusters respectively, and columns 6 and 7 refer similarly to the radio sources. The coordinates of the radio sources were found after averaging the data for each type of scan and the source was assumed to be real if its coordinates measured at, at least, two different wavelengths coincided within the limits of error. Columns 8, 9, and 10 give the flux densities of the sources at 11, 21, and 75 cm respectively, together with the total numbers of scans (in parentheses) used for the determination of the positions and flux densities. Column 11 gives the spectral indices of the sources for the observed range of frequencies. The last column (12) contains references to the remarks given as footnotes to the table.

At 21 cm, 26 of the 33 sources were detected in our records. The absence of four of the sources, 12—1*11*, 22+0*15*, 23—2*3*, and 3C 464, may be explained in one of two ways. Either their spectra are so steep that they are too weak to be detected at 21 cm, or they are spurious sources. In four other cases, including 05—2*10*, which is counted as an identification, the regions are confused by nearby stronger sources.

Eight of the 26 sources detected at 21 cm were measured also at both 11 and 75 cm. Another 11 sources were observed at 11 cm, and 3 sources at 75 cm. Thus only 4 of the sources detected were measured only at 21 cm. Three of these latter sources (04—0*5*, 15—0*12*, and 15+0*11*) are situated outside the corresponding clusters of galaxies A477, A2103, and A2109. Table 1 includes 2 sources that were observed at two wavelengths (11 and 75 cm) and not at 21 cm. One of them is the source 22—*014*, which is in the centre of the cluster A2464. The other is the source 05—*210* in the nearby cluster A548 of distance group 1. In this latter cluster a second source is found that is nearer to the centre of the cluster than the first one. Probably the source 05—*210* is a blend of these two. A relatively strong source 23—*213* was observed at 11 cm only and is situated definitely outside the corresponding cluster A2663. One more source is included in Table 1 which was observed only at 75 cm; its right ascension only could be measured. The source is 05—*14* identified with the cluster A538. The measured right ascension of the source coincides extremely well with that of the source 05—*14* and the centre of the corresponding cluster.

From an inspection of the positions given in Table 1 we find that of the 33 radio sources from the MSH and 3C catalogues, which were identified earlier with clusters of galaxies and were suggested to be associated with centrally located, bright, peculiar, or double galaxies of the clusters, some 21 are really situated in the centres of the clusters. Taking into account the errors of our positional measurements ($\sim \pm 2'$ arc) and some uncertainties of the determination of a cluster centre, we assume that the source is in the centre of the cluster of galaxies if it is situated not further than 5′ arc from the position given by Abell (1958).

Of the remaining 12 clusters, in 4 cases sources were not detected, 4 sources (2 in one cluster) are not in the centres of the clusters, and 5 sources are outside the clusters.

Earlier comparisons between the mathematical expectation of the number of random coincidences of the positions of clusters of galaxies and radio sources and the number of coincidences actually found have indicated (Mills 1960; van den Berg 1961; Tovmassian and Shahbazian 1961; Tovmassian and Kalloglian 1962) that about 60–70% of the coincidences could be real physical associations of both objects. Our observations with accurate measurements of the positions of the radio sources show that 21 out of 33 sources investigated (i.e. 64% of them) are situated in the centres of the corresponding clusters. This value is in excellent agreement with the expected one. Thus we may conclude that in the cases of a real connection of radio sources with clusters of galaxies the radio sources are situated in the central area of the corresponding clusters. The same conclusion was obtained by the authors (preceding paper, pp. 715–24 of the present issue) as the result of a survey of radio emission from 137 clusters of galaxies of distance group 5 from Abell's (1958) catalogue.

Only two of the sources observed were resolved by our observations. One of them is the source 00—*14*, identified with cluster A2 and having a diameter equal to 1′·8 arc. The second source is 03—*11*, which is in the cluster A415 and is a double source with a separation between the components of about 2′ arc. The dimensions of the unresolved sources are smaller than 1′ arc if they were observed at 75 cm, and are not larger than 4′ to 5′ arc in other cases. The diameters of the most distant clusters of galaxies observed (distance group 6) are about 20′ arc.

The fact that all of the sources investigated have dimensions much less than the diameters of the corresponding clusters of galaxies shows that one or at most a few of the galaxies are responsible for the observed radio emission. The same conclusion

TABLE 1

OBSERVED RADIO SOURCES

(1) Source No.	(2) Identified Cluster No.	(3) Distance Group	(4) Cluster Position (1950·0) R.A. h	m	s	(5) Dec. °	′	(6) Source Position (1950·0) R.A. h	m	s	(7) Dec. °	′	(8) Flux Densities* (flux units) 11 cm	(9) 21 cm	(10) 75 cm	(11) Spectral Index	(12) Remarks†
00−*14*	A2	6	00	05	52	−19	55·3	00	05	51	−19	57	0·58(4)	0·79(4)	1·3(1)	0·4	1
00+*03*	16	5	00	15	09	+06	28·7	00	15	06	+06	25	—	0·28(4)	1·3(1)	1·2	2
00−*28*	27	5	00	22	17	−20	59·4	00	22	21	−21	00	0·34(3)	0·53(4)	—	0·7	3
3C 28	115	6	00	53	16	+26	04·0	00	53	16	+26	09	0·66(4)	1·90(4)	—	1·7	4
01−*21*	133	4	01	00	15	−22	04·3	01	00	43	−22	05	0·16(5)	0·26(4)	C	0·8	5
01−*113*	235	6	01	37	48	−17	40·6	01	37	57	−17	43	0·45(4)	0·75(4)	—	0·8	
3C 53	266	5	01	50	04	−04	23·6	01	50	00	−04	22	0·17(6)	0·32(4)	—	1·0	6
03−*11*	415	4	03	04	26	−12	14·5	03	04	36	−12	17	0·83(4)	1·67(4)	4·0(1)	0·8	7
03−*12*	416	6	03	04	54	−16	55·5	03	05	04	−16	52	0·24(7)	0·48(4)	—	1·1	
04−*05*	477	6	04	09	36	−01	59·7	04	09	35	−01	50	<0·10(4)	0·24(4)	—	—	8
04−*214*	499	6	04	35	02	−20	30·9	04	35	04	−20	34	0·22(5)	0·32(4)	1·0(1)	0·8	
04−*215*	500	4	04	36	45	−22	12·3	04	36	45	−22	09	—	0·20(3)	1·0(1)	1·3	9
04−*016*	513	6	04	45	48	−09	48·3	04	46	22	−09	40	0·34(4)	0·40(4)	0·7(1)	0·4	8
05−*14*	538	6	05	12	59	−15	45·0	05	13	06	—		—	C	1·9(1)	—	
05−*210*	548	1	05	45	03	−25	38·6	05	43	13	−26	22	0·23(5)	C	0·7(1)	0·6	10
								05	43	59	−26	30	—	0·88(4)	2·5(1)	0·8	
08+*010*	732	6	08	55	16	+03	22·5	08	55	09	+03	24	0·24(4)	0·32(10)	0·7(1)	0·6	11
12−*111*	1572	6	12	34	08	−14	25·4	—			—		—	<0·20(3)	—	—	
12−*113*	1583	6	12	37	51	−15	41·4	12	37	38	−15	39	—	0·31(6)	—	—	
12−*019*	1620	5	12	47	10	−01	19·2	12	47	26	−01	15	0·25(5)	0·50(5)	—	1·1	
12−*119*	1644	4	12	54	36	−17	06·0	12	54	38	−17	09	0·17(6)	0·30(4)	—	0·9	12
13−*27*	1791	5	13	46	05	−25	12·5	13	46	10	−25	14	0·20(5)	0·31(4)	—	0·7	13
14+*01*	1850	6	14	01	17	+09	22·3	14	01	16	+09	16	0·33(4)	0·54(5)	—	0·7	14
15−*012*	2103	5	15	37	18	−02	01·1	15	36	23	−02	06	—	0·44(4)	—	—	8

15+*011*	2109	6	15	38	10	+06	11·1	15	37	10	+06	11	—	0·20(3)	—	—	8
21−*120*	2382	4	21	49	19	−15	53·7	21	49	16	−15	51	0·42(5)	0·60(4)	1·0(1)	0·6	11
21−*121*	2384	4	21	49	30	−19	47·7	21	49	07	−19	59	1·30(4)	2·10(4)	4·7(1)	0·7	15
22−*014*	2464	6	22	36	38	−04	13·5	22	36	52	−04	16	0·24(6)	C	1·1(1)	0·8	
22+*015*	2512	5	22	57	04	+09	50·4		—		—		—	<0·20(8)	—	—	16
23−*23*	2556	5	23	10	22	−21	44·2		—		—		—	<0·20(4)	—	—	
23−*25*	2575	6	23	17	14	−22	21·9	23	17	15	−22	22	0·40(4)	0·83(4)	—	1·1	
23−*27*	2596	5	23	22	26	−23	41·8	23	22	30	−23	40	0·31(4)	0·45(4)	1·2(1)	0·7	17
3C 464	2626	3	23	33	58	+20	53·4		—		—		—	<0·20(7)	—	—	18
23−*213*	2663	6	23	47	08	−25	00·4	23	48	13	−25	14	0·68(3)	C	—	—	8

* C, record confused.

† Relevant remarks are:

1. Source is resolved by 75 cm observations and its dimension in right ascension is about 1′·8 arc.
2. Probably the detected source is not the source 00+*03*, the position of which is R.A. $00^h 14^m{\cdot}2$, Dec. +06° 48′.
3. Probably the observed source differs from 00−*28*, the position of which is R.A. $00^h 21^m{\cdot}2$, Dec. −21° 15′. Mills, Slee, and Hill (1960) noted that the source may be extended.
4. Source was also observed by Fomalont and Rogstad (1966).
5. Flux at 85 MHz is overestimated. There is a nearby stronger source. The record at 75 cm is confused.
6. Observed source probably differs from 3C 53 with coordinates R.A. $01^h 50^m 52^s$, Dec. −04° 17′.
7. Source is double with a separation in right ascension between the components equal to 1′·7 arc.
8. Source is outside the cluster.
9. Detected source is situated far from the position of 04−*215*, R.A. $04^h 34^m{\cdot}8$, Dec. −22° 32′. The flux at 85 MHz fits the spectra measured in the range 408−1410 MHz.
10. There are two sources in the cluster and neither is in the centre of it. The cluster is a nearby large one.
11. Flux at 85 MHz is overestimated.
12. Probably the detected source is not 12−*119*, R.A. $12^h 57^m{\cdot}0$, Dec. −17° 16′. The source 12−*119* is extended.
13. Flux at 85 MHz is overestimated. It is noted as uncertain.
14. Source is near the edge of the cluster and is considered as a chance situation in the position of the cluster.
15. Source is about 13′ arc away from the centre of the cluster.
16. Radio emission from the position of the cluster was found by Pilkington (1964).
17. Observed source probably differs from 23−*27*, R.A. $23^h 22^m{\cdot}9$, Dec. −23° 20′.
18. Source was observed in the 4C survey (Pilkington 1964).

was obtained also in the investigation of clusters of galaxies in the preceding paper. It is obvious that if the observed radio emission from a cluster of galaxies were the sum of the radiations of many members of the cluster then the dimensions of sources would be comparable with those of the corresponding clusters.

The observations of the sources at two or three wavelengths allowed their spectral indices to be determined. These are given in column 11 of Table 1. It is interesting that for almost half of the sources their flux densities at 85 and 159 MHz fit reasonably well to the extrapolated straight spectra determined for the range of frequencies 2650–408 MHz. For the other half of the sources the flux densities at 85 or 159 MHz were probably overestimated, an effect that can be due to the contribution of weak sources simultaneously observed by the wide beams of the corresponding telescopes.

Present observations restrict the positions of the studied sources within 5′ arc from the centres of corresponding clusters and thus confirm the probable identifications of radio sources with individual members of clusters of galaxies (Tovmassian and Shahbazian 1961; Tovmassian 1962; Tovmassian and Kalloglian 1962) in spite of the inaccuracies of the previous determinations of the positions of identified sources.

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