Halo and Relic Sources in Clusters of Galaxies

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Abstract

New images of 7 radio halos and relics, obtained with the Very Large Array at 20 or 90 cm, are presented here. The existence of a cluster-wide radio halo in the clusters A 665 and CL 0016+16 is confirmed. Both these clusters share the properties of the other clusters with radio halos, i.e. are luminous in X-rays, have high temperature, and show recent merger processes.

No diffuse sources are detected in a sample of clusters showing at least a tailed radio galaxy within 300 kpc from the cluster center, indicating that the connection between tailed radio galaxies and halos is not relevant. For these clusters we give limits to the surface brightness and to the angular size of possible undetected diffuse sources.

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1 Introduction

Diffuse radio sources in clusters of galaxies are the probe of the existence of non-thermal emission from the cluster intergalactic medium (IGM). These sources have no optical identification, steep radio spectrum and size of $\sim 1$ Mpc. Diffuse sources with regular shape, permeating the cluster center are called radio halos, the prototype being the radio halo Coma C in the Coma cluster (Giovannini et al. 1993). Other similar sources, with irregular morphologies, located in cluster peripheral regions are named relics. In a few clusters, both a central halo and a peripheral relic are present.

The difficulty in explaining these diffuse sources arises from the combination of their large size and the short lifetimes of radiating electrons. Several theoretical models have been proposed: (i) in-situ acceleration by turbulent gas motion or shocks produced in the intergalactic medium during the merger of a subgroup into the main cluster, (ii) diffusion of relativistic electrons out of the present head-tail radio galaxies, (iii) secondary particle production by hadronic interaction of relativistic protons with the background gas of the IGM.

The knowledge of the physical properties of these sources, and of their origin and evolution is limited by the low number of halos and relics well studied up to now. To search for new sources of this class and to test the possible correlation between the presence of tailed radio galaxies and diffuse sources suggested by Giovannini et al. (1993), we have obtained observations with the Very Large Array (VLA) of 21 clusters with the following selection criteria: a) 10 clusters where the possible presence of a diffuse source was suggested in the literature, but the angular resolution and sensitivity of the available images was not good enough to confirm its existence and derive the source parameters; b) 11 clusters showing at least a tailed radio galaxy within 300 kpc (0.1 Abell radius) from the cluster center in the sample of O'Dea and Owen (1985).

To properly map these extended sources one needs large sensitivity to the extended features, but also with the high resolution necessary to distinguish a real halo from the blend of unrelated sources. Observations were carried out using different VLA configurations at 20 cm for more distant clusters whereas the nearest clusters were observed at 90 cm. We present here sensitive images of the detected diffuse sources. For the computation of intrinsic parameters, a Hubble constant $H_0=50$ km s$^{-1}$ Mpc$^{-1}$ and a deceleration parameter $q_0=0.5$ are assumed.

3 The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.
2 Observations and data reduction

The list of observed cluster of galaxies is given in Table 1 where the observing frequency and the VLA configurations are also given.

The bandwidths in the 1.4 GHz observations are of 25 MHz for the B array, and of 50 MHz for the C and D arrays. At 0.3 GHz, the bandwidth is of 3.125 MHz.

The observing frequency and array were chosen in order to have a good sampling of short spacings, ensuring that a halo-type source similar to Coma C could be easily detected and imaged. We note that Coma C is completely resolved out from the VLA at 20 cm also in its more compact array (D), because of missing short spacings. For the most distant clusters in the present sample, the VLA in D configuration at 20 cm was found to be suitable, whereas for the nearest sources observations at 90 cm were necessary. The signal to noise ratio achieved by our observations should be enough to map halo sources with a surface brightness 3-5 times lower than Coma C. Moreover, each cluster was observed with higher angular resolution to allow the separation of the discrete sources from the diffuse cluster emission.

The data were calibrated and reduced with the Astronomical Image Processing System (AIPS), following the standard procedure: Fourier-Transform, Clean and Restore. Self-calibration was applied to minimise the effects of amplitude and phase fluctuations. At each frequency, the data of different arrays were combined to obtain the final maps. Images were produced at different angular resolutions to study both the extended structures and the discrete sources. In the caption of each figure, we give the Half Power Beam Width (HPBW) and the noise level of the maps. A comparison with available maps from the NRAO VLA Sky Survey (NVSS, Condon et al. 1998) and the Faint Images of the Radio Sky at Twenty-cm (FIRST, Becker et al. 1995) Survey was also made.

3 Results

Among the 10 clusters where the presence of a diffuse sources was suggested by previous authors, we have detected diffuse sources in 7 clusters. The parameters of these sources are given in Table 2. We have not detected halos or relics in the sample of clusters selected because of the presence of tailed radio galaxies. In Table 3 we give the surface brightness limit for the undetected extended sources and the largest size detectable in our observations. In fact, we cannot exclude the presence of a source with size larger than the limit,
### Table 1

**Observed clusters of galaxies**

| Name   | $z$    | $\nu$ | Array | Int. time | Selection |
|--------|--------|-------|-------|-----------|-----------|
| A 84   | 0.103  | 1.4   | B,C,D | 60        | 1         |
| A 85   | 0.0555 | 0.3   | B,C   | 40        | 2         |
| A 119  | 0.0441 | 0.3   | B,C   | 40        | 1         |
| A 401  | 0.0739 | 0.3   | C     | 20        | 3         |
| A 610  | 0.0956 | 1.4   | C,D   | 170       | 4         |
| A 629  | 0.138  | 1.4   | C,D   | 40        | 1         |
| A 665  | 0.1818 | 1.4   | C,D   | 240       | 5         |
| A 754  | 0.0542 | 0.3   | B,C   | 40        | 3         |
| A 1132 | 0.1363 | 1.4   | C,D   | 40        | 1         |
| A 1190 | 0.0794 | 0.3   | B,C   | 40        | 1         |
| A 1314 | 0.0341 | 0.3   | B,C,D | 60        | 1         |
| A 1609 | 0.113  | 1.4   | C,D   | 40        | 4         |
| A 1775 | 0.0696 | 0.3   | B,C   | 40        | 1         |
| A 2142 | 0.0894 | 1.4   | C,D   | 40        | 6         |
| A 2218 | 0.1710 | 1.4   | C,D   | 40        | 5         |
| A 2220 | 0.1106 | 1.4   | C,D   | 40        | 1         |
| A 2250 | 0.0654 | 0.3   | C     | 20        | 1         |
| A 2289 | 0.2276 | 1.4   | C,D   | 40        | 1         |
| A 2572 | 0.0384 | 0.3   | C,D   | 40        | 1         |
| CL 0016+16 | 0.5545 | 1.4 | B,C,D | 200 | 5 |
| 0917+75 | 0.125  | 1.4   | C,D   | 40        | 7         |

**Selection criterion.** 1: cluster containing at least one tailed radio galaxy at the cluster center; 2: Joshi *et al.* 1986 (relic); 3: Harris *et al.* 1980 (halo); 4: Valentijn 1979 (halo); 5: Moffet & Birkinshaw 1989 (halo); 6: Harris *et al.* 1977 (halo); 7: Harris *et al.* 1993 (halo).

because of the missing short spacings. Notes on the clusters hosting diffuse sources, and on some other interesting clusters are given in the following. We present images of all the diffuse sources, as well as a few maps of extended and/or peculiar radio galaxies detected in this study.
Table 2
Clusters with a diffuse source

| Name     | \(\nu\) | S   | \(\log P_{1.4}\) | L.A.S. | L.L.S. | M.L.S. | Type          |
|----------|---------|-----|------------------|--------|--------|--------|---------------|
|          | GHz     | mJy | W/Hz            | "      | kpc    | Mpc    |               |
| A 85     | 0.3     | 2739| 23.97\(^1\)    | 350    | 510    | 2.64   | Relic         |
| A 610    | 1.4     | 18.6| 23.88           | 185    | 438    | 2.13   | Relic         |
| A 665    | 1.4     | 43.1| 24.82           | 600    | 2360   | 3.55   | Halo          |
| A 2142   | 1.4     | 18.3| 23.82           | 120    | 270    | 2.01   | Halo          |
| A 2218   | 1.4     | 4.7 | 23.81           | 130    | 490    | 3.39   | Halo          |
| CL 0016+16 | 1.4   | 5.5 | 24.95           | 150    | 1100   | 6.66   | Halo          |
| 0917+75  | 1.4     | 100.6| 24.86         | 520    | 1530   | 2.66   | Relic         |

Caption. Col. 1: cluster name; Col. 2: observing frequency; Col. 3: total flux density at the previous frequency, after subtraction of discrete sources; Col. 4: logarithm of radio power at 1.4 GHz; Col. 5: Largest Angular Size measured on the radio images as the largest extension of the 2\(\sigma\) level, deconvolved by the HPBW; Col. 6: Largest Linear Size corresponding to the largest angular size; Col. 7: Maximum Linear Size detectable with the available interferometric observation; Col. 8: type of diffuse source.

Note: 1 Radio power at 1.4 GHz has been computed assuming a spectral index = 2.5 (flux density at 1.4 GHz = 68.4 mJy)

3.1 Notes on individual clusters of galaxies with diffuse sources

A 85. This cluster was studied in detail by Bagchi et al. (1998). In Fig. 1 we present the image of the central cluster region obtained at 90 cm, with angular resolution of 25\(^\prime\). A small size radio emission is detected from the central cD galaxy (A), and two head-tail radio galaxies are visible (B,C).

Moreover, two extended regions of radio emission with no obvious optical identification are present: they are labelled 'R' and 'D' in Fig. 1. Source 'R' is the well known relic source of steep spectrum studied by Joshi et al. (1986) and Bagchi et al. (1998). In this image, the relic has an irregular structure. An image with slightly better angular resolution (see Fig. 2) shows that the relic has a complex structure with evidence of internal substructures and filaments. This is confirmed by the high resolution image presented by Andernach et al. (2000). The total flux density (2.74 Jy) is lower than the total flux density measured with the Ooty Synthesis Radio Telescope at the same frequency (3.15 Jy, Joshi et al. 1986). We refer to Bagchi et al. (1998) for the total radio spectrum of this source. We obtained a spectral index map between 90
Table 3
Cluster without diffuse source

| Name | \( \nu \) | HPBW  | \( \sigma_{\text{noise}} \) | M.L.S. |
|------|--------|--------|-----------------|--------|
|      | GHz    | " × " | mJy/b Mpc        |        |
| A 84 | 1.4    | 40×40  | 0.1             | 2.23   |
| A 119| 0.3    | 60×55  | 5.0             | 2.14   |
| A 401| 0.3    | 65×62  | 2.5             | 3.41   |
| A 629| 1.4    | 49×40  | 0.2             | 2.88   |
| A 754| 0.3    | 109×88 | 6.5             | 2.59   |
| A 1132 | 1.4 | 54×38  | 0.14            | 2.85   |
| A 1190 | 0.3 | 77×71  | 6.8             | 3.63   |
| A 1314 | 0.3 | 188×153| 2.7             | 3.93   |
| A 1609 | 1.4 | 43×36  | 0.18            | 2.45   |
| A 1775 | 0.3 | 72×63  | 5.1             | 3.24   |
| A 2220 | 1.4 | 48×35  | 0.16            | 2.41   |
| A 2250 | 0.3 | 74×69  | 5.2             | 3.06   |
| A 2289 | 1.4 | 52×35  | 0.20            | 4.15   |
| A 2572 | 0.3 | 190×182| 2.4             | 4.39   |

Caption. Col. 1: cluster name; Col. 2: observing frequency; Col. 3: Half Power Beam Width of the observation; Col. 4: noise level; Col. 5: Maximum Linear Size detectable with the available interferometric observation.

and 20 cm, combining our image with the 20 cm image retrieved from the NVSS, presented in Giovannini et al. 1999.) Because of the low resolution of the NVSS image (45′′), the substructures are smoothed in the maps used for the spectral comparison. The spectrum in very steep (\( \alpha \sim 2.5 - 3.0 \)) with no evidence of substructure.

The sources ‘B’ and ‘D’ are blended together in the 90 cm image by Bagchi et al. (1998), where the extended feature formed by these two sources is suggested to be another possible diffuse source. From the present high resolution image, we distinguish the tailed radio galaxy ‘B’ and remark the existence of the extended feature labelled ‘D’, which has a steep spectrum (\( \alpha^{1.4}_{0.3} \sim 2 - 2.5 \), obtained by comparison with the NVSS) and a total extent of about 2′, corresponding to \( \sim 175 \) kpc. Its shape and the presence of a nearby galaxy with a possible faint radio emission at about the 3σ level suggests that this structure could be a dying tailed radio galaxy, where the nuclear emission has almost
completely ceased.

**A 610.** We detect a faint diffuse emission (Fig. 3), coincident with the halo source detected by Valentijn et al. (1979). It is elongated in shape and displaced from the cluster center, thus we classify it as a relic source. The high resolution image given in Fig. 4 confirms that the source is diffuse. Using the flux at 0.6 GHz from Valentijn et al. (1979), $S_{0.6\ GHz} = 59$ mJy, a spectral index $\alpha_{0.6}^{1.4} = 1.4$ is derived.

**A 665.** Moffet & Birkinshaw (1989) detected a diffuse emission coincident with the cluster center. Our image (Fig. 5) shows that this halo source is very extended and elongated in the SE-NW direction. The highest resolution map (not shown here) indicates that 2 faint discrete sources are present within the diffuse radio emission (crosses in Fig. 5) and that the radio emission is asymmetric with respect to the cluster center, being brighter and more extended toward NW.

**A 2142.** The presence of a halo in this cluster was suggested by Harris et al. (1977). We confirm the presence of diffuse emission, located around the brightest cluster galaxy (Fig. 6), as also detected in the NVSS (Giovannini et al. 1999). The radio emission could be more extended in S - SW direction up to 27\°10' in declination (2 sigma level), but more sensitive observations are necessary to confirm the reality of this feature. In the FIRST survey, the diffuse emission is completely resolved out, and no emission is detected at a flux level of 0.4 mJy/beam (3$\sigma$) from any of the bright galaxies present in the region of the extended radio emission. The radio source could therefore be classified as a cluster halo. We note, however, that this source is much smaller than radio halos commonly found in clusters. We cannot rule out the possibility that it is the remnant of a single galaxy which was active in the past.

**A 2218.** We confirm the existence of the diffuse source found by Moffet & Birkinshaw (1989). It is slightly displaced from the cluster center, toward East (Fig. 7). In a deep image obtained by Zwaan et al. (2000) the diffuse source is more extended, with radio emission of very low surface brightness also to the West of the cluster center. This halo source is smaller than typical cluster-wide radio halos. It is similar, both in structure and in size, to the halo in A 1300 (Reid et al. 1999). As in the case of A 1300, the diffuse radio source is located in the same direction as the extension of the cluster X-ray emission detected by the ROSAT HRI (Markevitch 1997).

At 5 GHz, the flux density of the halo is reported to be 0.6 mJy (Partridge et al. 1987). Comparison of this flux with the present measurement at 1.4 GHz provides a spectral index $\alpha_{1.4}^{5} \sim 1.6$, which should however be taken cautiously since the two maps at the two frequencies do not have matched
Fourier coverage.

**CL 0016+16.** We confirm the presence of a diffuse emission near the cluster center found by Moffet & Birkinshaw (1989). Unfortunately, our high resolution observations (VLA configurations B and C) are strongly affected by interferences therefore we cannot produce a higher resolution map. The diffuse radio emission (Fig. 8) is located at the cluster center, and is extended more than 1 Mpc, therefore it is a typical radio halo. We note the presence of a fainter radio emission west of the halo, at around RA$_{2000} = 00^h 18^m 25^s$, DEC$_{2000} = 16^\circ 26' 48''$, coincident with a galaxy group visible in the DPSS (see Fig. 8).

**0917+75.** This source was studied in detail by Dewdney et al. (1991) and Harris et al. (1993). Our image (Fig. 9) shows that the diffuse source is elongated in the E-W direction, with flux density and morphology in very good agreement with their data.

As discussed in the above mentioned papers, this source cannot be obviously associated with a well defined cluster of galaxies. In the region, there are the 3 clusters A 786, A 787 and A 762, at redshift larger than 0.1, belonging to the Rood Group of clusters of galaxies #27, but the source is located at very large distance from their centers (respectively 30', 45', and 44', corresponding to $\sim$ 5 Mpc, $\sim$ 8 Mpc and $\sim$ 8 Mpc). Thus, although the radio emission is reminiscent of the giant radio relic in A 3667 (Röttgering et al. 1997), its very large distance from the cluster center would favour the hypothesis that this diffuse source is related to a possible group near the source center (see the optical DPSS image in Fig. 9) or to the supercluster. This makes this source quite unique.

### 3.2 Notes on individual clusters without diffuse sources

**A 84.** An extended head-tail radio galaxy is present in the cluster center region, as reported by Rudnick & Owen (1976) and O'Dea & Owen (1985). In our map, the tailed radio galaxies is detected to a much larger extent than previously believed, and for the first time a prominent bend of the tail is visible (Fig. 10).

Moreover, a faint extended radio emission is detected at about 2' SE of the tailed radio galaxy. This feature has no obvious optical counterpart, and is completely resolved out in a higher resolution map. Its structure and the presence of a galaxy at the boundary of the radio emission might support the hypothesis that it is the remnant of a tailed radio galaxy, where the nuclear emission has ceased, but it could also be a distant unrelated source with no optical counterpart.
**A 119.** This cluster was studied in detail by Feretti et al. (1999). The present data at 90 cm confirm the absence of diffuse emission.

**A401** - Our image at 90 cm shows the same features detected by Harris et al. (1980) and Roland et al. (1981), in particular the two components A and B (see Fig. 11). On the contrary, the faint extended emission detected near the central cD galaxy in the NVSS (see Giovannini et al. 1999) at 20 cm is not seen here. With the present data, the existence of diffuse emission in this cluster remains quite dubious, as well as the classification of source B as a cluster halo.

**A 629.** No diffuse emission is detected in this cluster, which is characterized by the presence of an extended wide-angle-tail radio galaxy and of a head-tail radio galaxy at the center (see Owen & Ledlow 1997).

**A 754.** The extended emission at the cluster center, reported by Harris et al. (1980) and also visible in the NVSS image (Giovannini et al. 1999) is at the limit of significance in our map at 90 cm. This implies that this feature cannot have a steep spectral index between 90 and 20 cm ($\alpha_{20}^{90} < 0.7$) and confirms the suggestion of Giovannini et al. (1999) that the radio emission might be the blend of many bright cluster galaxies in this region, rather than a diffuse halo. The diffuse emission detected in the NVSS in the eastern peripheral region (Giovannini et al. 1999) cannot be seen in the 90 cm image because of the too low angular resolution.

**A 1609.** The radio halo suggested by Valentijn (1979) has not been detected in our image, which shows several radio sources. The extended radio galaxy with a tailed structure (Fig. 12) is actually the blend of two tailed radio galaxies (Rudnick, private communication).

**A 1775.** The head-tail radio galaxy in this cluster (B1339+266B) shows a very narrow tail (Fig. 13), extended $\sim 8'$ (850 kpc), i.e. twice more than in the image of Owen & Ledlow (1997). A similar head-tail radio galaxy, but with a shorter extent ($\sim 550$ kpc) is found in the cluster A 2256.

**A 2250.** The head-tail radio galaxy near the cluster center (B1709+397) is much more extended than in the previous map by O’Dea and Owen (1985) ($\sim 6'$, corresponding to $\sim 600$ kpc), but no diffuse halo is visible (Fig. 14).

### 4 Discussion and conclusions

The present paper increases the number of halo and relic sources with detailed radio information. The new data on the two clusters A 665 and CL 0016+16...
are of great importance in the study of cluster-wide radio halos, since they represent two more examples of giant sources of this class. Both the halos in A 665 and in CL0016+16 are more powerful than the Coma halo.

The cluster A 665 has a bolometric X-ray luminosity of $4.2 \times 10^{45}$ erg s$^{-1}$ (Wu et al. 1999), a temperature of 8.3 keV (Wu et al. 1999) and no cooling flow (White et al. 1997). From X-ray data, it is suggested to be in a postmerger state, with an asymmetric X-ray brightness distribution, extended in the NW direction (Markevitch 1996, Gomez et al. 2000). This is also the orientation of the radio structure (Fig. 15 and Sect. 3), indicating a spatial correlation between the radio and X-ray structure, as found in other clusters (see e.g. Feretti 2000).

The cluster CL 0016+16 has a bolometric X-ray luminosity of $2.81 \times 10^{45}$ erg s$^{-1}$ (Wu et al. 1999). Its X-ray emission has been studied by Neumann & Böhringer (1997) who obtain a temperature of 8.2 keV, conclude that the cluster has not yet formed a steady cooling flow, and report strong evidence of substructure which is possibly due to merging of a galaxy group with the main cluster. The radio-X-ray overlay, presented in Fig. 16, shows that the radio halo is located at the cluster center, at the position of the X-ray peak.

In the clusters A 2142 and A 2218, diffuse halos of about 500 kpc in size, or less, are detected. Both these clusters are characterized by signatures of recent merger events (Markevitch 1997, Markevitch et al. 1998). No cooling flow is detected in A 2218, whereas the cluster A 2142 has a massive cooling flow (Peres et al. 1998) centered on the diffuse radio source. The presence of a radio halo in a cooling flow cluster is quite uncommon (Feretti 2000). The fact that the halo in A 2142 has a small size could be related with the presence of the cooling flow. Future deep observations of more clusters of galaxies are necessary to understand if these sources have a different nature with respect to the giant cluster-wide halos, or if they are the low power-small size tail of the same class of radio sources.

We have detected no radio halos in the 11 clusters showing tailed radio galaxies at the cluster center. In the Coma cluster, Giovannini et al. (1993) suggested that the tailed radio galaxy NGC4869, which is orbiting around the cluster center, could be responsible for the supply of relativistic electron radiating within the radio halo Coma C. Also in the clusters A 2255 (Feretti et al. 1997a) and A 2319 (Feretti et al. 1997b), tailed radio galaxies are found within the diffuse radio emission, or close to it, supporting the hypothesis that the tailed radio galaxies could provide relativistic electrons to the radio halo. In the sample of tailed radio galaxies presented by O’Dea and Owen (1985), there are 15 clusters with at least a tailed radio galaxy within 300 kpc from the cluster center (Giovannini et al. 1993). These are the 11 clusters studied here, plus A 85, A 1656 (Coma), A 2255 and A 2256. The last 3 clusters show a halo
source, while A 85 hosts a relic radio emission (Sect. 3). For the 11 clusters observed here, we only give a limit in size and brightness for the presence of a possible extended source. The lack of detection of bright halos in these clusters would imply that the connection between halos and tailed radio galaxies seems not relevant. On the other hand, we cannot exclude that these tailed radio galaxies are not really at the cluster center but simply projected onto it, or that they are crossing the cluster center and not orbiting at the cluster center, as needed to fuel a diffuse source. From rotation measure studies of the sources in A 119 (Feretti et al. 1999), where no halo is detected, it was derived that the two powerful tailed radio galaxies are genuinely located at the cluster center. We note, in addition, that no tailed radio galaxy is found to be present in A 665, hosting a cluster-wide radio halo. We conclude that the tailed radio galaxies could be a source of relativistic electrons, but they are not a necessary ingredient for the halo formation. These results are in line with the model developed by Brunetti et al. (2000a), who suggest that relativistic particles radiating within the halos were injected in the cluster volume by past major merger events, starburst and AGN activity. Following a recent suggestion by Brunetti et al. (2000b), the relativistic particles deposited by the tailed radio galaxies could account for the emission of extreme ultraviolet radiation.

According to Bliton et al. (1998), the clusters containing narrow-angle tailed radio galaxies are in general dynamically complex systems undergoing merger events. Actually, structure and other merger signatures have been detected in all the clusters of Table 3 (e.g. A 754, Henry & Briel 1995; A 119, Markevitch et al. 1998) which have been adequately observed in optical or X-ray, except for A 401, which is a rather unusual cD cluster with neither a merger activity nor a cooling flow. Therefore, we confirm that the presence of a recent merger is not sufficient for the formation of a radio halo.

Recent studies have shown that radio halos are found in merging clusters which are also characterized by high X-ray luminosity, i.e. high temperature and large mass (Giovannini et al. 1999, Feretti 2000). The halos in A 665 and CL 0016+16 are fully confirming the above result. The connection between halos and mergers, and the presence of halos in hot, massive, X-ray bright clusters can be interpreted in the framework of the two-phase model suggested by Brunetti et al. (2000a) and successfully applied to Coma C. According to this model, relativistic particles produced in the early cluster history, are reaccelerated by the energy supplied from shocks and turbulence in a recent merger event. Alternative models and the theoretical implications of non-thermal emission from the intracluster medium are reviewed by Enßlin (2000).
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Fig. 1. Isocontour map at 90 cm of the central region of A85 overimposed on the optical image from the Digitized Palomar Sky Survey (DPSS). A is the central cD galaxy, B and C are cluster radio galaxies with head-tail morphology. R is the steep spectrum relic source while D is an extended steep spectrum source probably related to the near cluster galaxy (see text). The HPBW is 25"; the noise level is 1.1 mJy/beam. Contour levels are: 3, 5, 10, 30, 50, 70, 120, 150 mJy/beam.

Fig. 2. Radio image at 90 cm of the relic source in A85, with HPBW of 20". The noise level is 1.5 mJy/beam. Contour levels are: 5, 10, 20, 30, 40, 50, 70, 100 mJy/beam.

Fig. 3. Isocontour map at 20 cm of the central region of A 610 overimposed the optical image from the DPSS. The position of the cluster center given by Abell et al. (1989) is RA$_{2000}$ = 07$^h$ 59$^m$ 15.6$^s$, DEC$_{2000}$ = 27$^\circ$ 06$'$ 48$''$. The HPBW is 50"×45"(PA=0°); the noise level is 0.15 mJy/beam. Contour levels are: -0.4, 0.4, 0.8, 1.5, 3, 6, 12, 15, 25, 50, 100 mJy/beam.

Fig. 4. Isocontour map at 20 cm of the central region of A610 overimposed the optical image from the DPSS. The HPBW is 18.0"×16.7"(PA=13.5°); the noise level is 0.14 mJy/beam. Contour levels are: -0.4, 0.4, 0.8, 1.5, 3, 6, 12, 15, 50 mJy/beam.

Fig. 5. Isocontour map at 20 cm of the central region of A 665 superimposed onto the optical image from the DPSS. Crosses mark two unrelated sources, of flux ∼1.2 mJy each. The HPBW is 52"×42"(PA=0°); the noise level is 0.065 mJy/beam. Contour levels are: -0.2, 0.2, 0.4, 0.8, 1.5, 3, 6, 12, 25 mJy/beam.

Fig. 6. Isocontour map at 20 cm of the central region of A2142. The HPBW is 40" and the noise level 0.15 mJy/beam. Contour levels are: -0.3, 0.3, 0.5, 0.7, 1, 2, 3, 5, 10, 20, 30, 40, 60 mJy/beam.

Fig. 7. Isocontour map at 20 cm of the central region of A 2218. The cluster dominant galaxy is indicated by an arrow. The source to the north-east is a foreground S galaxy. The HPBW is 35" the noise level is 0.09 mJy/beam. Contour levels are: -0.2, 0.2, 0.3, 0.5, 0.7, 1, 3, 5, 10 mJy/beam.

Fig. 8. Isocontour map at 20 cm of the central region of CL 0016+16. The HPBW is 60"×45"(PA=0°); the noise level is 0.09 mJy/beam. Contour levels are: -0.2, 0.2, 0.4, 0.8, 1.5, 3, 6, 12, 25, 50, 100 mJy/beam.

Fig. 9. Isocontour map at 20 cm of the extended source 0917+75. The HPBW is 30"; the noise level is 0.08 mJy/beam. Contour levels are: -0.2, 0.2, 0.5, 0.7, 1, 1.5, 2, 3, 5, 7, 10, 30, 50 mJy/beam.

Fig. 10. Isocontour map at 20 cm of the head-tail radio galaxy in A 84 overimposed the optical image from the DPSS. The HPBW is 11.5"; the noise level 0.03 mJy/beam. Contours are: 0.1, 0.3, 0.5, 1, 5, 10, 30, 50, 70, 90 mJy/beam.
Fig. 11. Isocontour map at 90 cm of A 401 overimposed onto the optical image from the DPSS. The HPBW is $65'' \times 62'' (PA=64^\circ)$. Contour levels are: -5, 5, 10, 20, 40, 80, 120, 200 mJy/beam.

Fig. 12. Isocontour map of the central region of A 1609 overimposed the optical image from the DPSS. The arrows indicate the two radio emitting galaxies, which give raise to the extended tailed structure. The HPBW is $12.5'' \times 11.4'' (PA=-14^\circ)$; the noise level is 0.18 mJy/beam. Contour levels are: -0.3, 0.2, 0.5, 1.5, 2, 3, 5, 10, 20 mJy/beam.

Fig. 13. Isocontour map at 90 cm of the head tail radio galaxy B1339+266B in A 1775 overimposed the optical image from the DPSS. The HPBW is $72'' \times 63'' (PA=83^\circ)$; the noise level is 5.1 mJy/beam. Contour levels are: 10, 15, 20, 30, 50, 70, 100, 200, 500 mJy/beam.

Fig. 14. Isocontour map at 90 cm of the tailed radio galaxy B1709+397 in A 2250 overimposed the optical image from the DPSS. The HPBW is $74'' \times 69'' (PA=-53^\circ)$; the noise level is 5.1 mJy/beam. Contour levels are: -15, 15, 30, 50, 100, 200, 300, 500, 700, 1000 mJy/beam.

Fig. 15. Overlay of the contour radio image of A 665 onto the grey-scale X-ray image obtained with the ROSAT PSPC

Fig. 16. Overlay of the contour radio image of CL 0016+16 onto the grey-scale X-ray image obtained with the ROSAT HRI
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