610 MHz Observations of the Perseus Cluster of Galaxies with the Westerbork Synthesis Radio Telescope

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Summary. We have made observations of the Perseus cluster with the Westerbork Telescope at 610 MHz. Details of our observations and reduction procedure are given. The dynamic range within our maps exceeds 1000. A catalogue of 50 sources from the field is presented, together with spectral information, where available. Several newly detected sources are identified with cluster galaxies. A faint extension found close to NGC 1265 suggests that the main body of this tailed source has been bent by buoyancy forces. On the assumption that this is the case, we derive a conservative lower limit to the mass of the Perseus Cluster of \(1.4 \times 10^{15} M_\odot\). This reinforces previous arguments from the virial theorem that the cluster is bound. The origin of the extended component surrounding NGC 1275 is discussed and a 610/1415 MHz spectral index distribution for it is presented. Its amorphous structure may be influenced by the presence of the cluster gas, but comparisons with similar resolution X-ray observations are inconclusive. No evidence is found for the existence of the previously reported \(\sim 65\' \times 25\'\) cluster halo, 3C 84 B.

Key words: radio galaxies – clusters – tailed radio sources – buoyancy

I. Introduction

The Perseus Cluster of galaxies is one of the most fascinating systems accessible to extragalactic astronomers. It is among the brightest X-ray clusters known and was the first in which iron line emission was discovered (Mitchell and Culhane, 1977). Perseus is also distinguished by having the largest velocity dispersion reported for any cluster (Chincarini and Rood, 1971). In the radio domain the cluster contains three head tail galaxies, NGC 1265, IC 310 (Ryle and Windram, 1968) and CR 15 (Miley et al., 1972). The Perseus Cluster was the first in which such tailed radio sources were found and to date only Abell 2256 (Bridle et al., 1978) is known to contain a larger number.

At the easterly end of the prominent line of bright galaxies near the cluster center lies NGC 1275, the brightest member of the cluster and one of the most active galaxies known. This unique object is an early type galaxy with a Seyfert-like spectrum and a system of high velocity knots and filaments which may belong to a superimposed late-type galaxy (Rubin et al., 1977). NGC 1275 is a source of strong X-ray and radio emission in its own right. The radio source associated with NGC 1275 (Perseus A/3C 84) is one of the brightest radio sources known and has very complex structure on scales from milli-arc s (Pauliny-Toth et al., 1976) to several arc min (Miley and Perola, 1975).

Apart from the radio sources already mentioned which are associated with individual cluster galaxies, a large radio halo with an extent of \(\sim 1\) has been reported by Ryle and Windram (1968) and designated 3C 84 B.

Because the radio emission of the Perseus Cluster is so complex, high resolution radio telescopes with extremely good dynamic range properties are needed to map its structure. The excellent gain and phase stability of the Westerbork Synthesis Radio Telescope (WSRT) (Høgbom and Bouw, 1974; Baars et al., 1973) makes it one of the most suitable instruments for such studies. Previous investigations have been made with the WSRT at 1415 and 4995 MHz of individual galaxies in the cluster (Miley et al., 1972; Miley, 1973; Wellington et al., 1973; Miley et al., 1975; Miley and Perola, 1976; Ekers et al., 1976). This paper reports on measurements of the Perseus Cluster made with the WSRT at 610 MHz. At 610 MHz the field of view or 'primary beam' of the WSRT has a half power diameter of 83' and is comparable in size to the total extent of the cluster. Because of their relatively low frequency and large field of view, these observations have provided new information about low brightness radio components in the cluster.

II. Observations and General Reduction

The observations were obtained in four separate twelve-hour periods during early 1975 (see Table 1). The field center was chosen to be to the northwest of NGC 1275 in order that the strong sources associated with NGC 1275, NGC 1265 or IC 310 would not be affected greatly by the attenuation of the primary beam.

As we have previously mentioned, the large flux density of Perseus A (~23 Jy at 610 MHz) results in severe dynamic range requirements. For this reason particular care was taken with the calibration. Initially the observations were calibrated relative to the point sources 3C 48 and 3C 147, whose 610 MHz flux densities were assumed to be 15.7 and 21.6 Jy respectively and whose positions were taken from Elsmore and Ryle (1976). Each of the four observations was calibrated identically. The resultant combined map showed very weak residual grating rings whose locations indicated that they were due to slight remaining systematic phase differences between the separate observations. These residual rings had intensities \(\sim 0.2\%\) of the peak intensity on the map and were reduced further in the following manner. Separate maps were produced for each of the four observations.
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<td>dec (1950)</td>
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<td>42°05'3072±170</td>
<td>60.1±2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>337105681217</td>
<td>40°47'5877±179</td>
<td>109.1±7.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† The naming convention recently recommended by the WSRT Program Committee has been adopted here. 22 W is a (chronological) code prefix for all sources listed in the present survey. For example 3C 83.1 A could be referred to as 22 W 36

Notes to Table 2

(1) The source 22 W 36 (3 C 83.1 A) and the unresolved part of 22 W 43 (3 C 84) have been subtracted from the maps shown in the figures (see text).

(2) Head tail source (see text)

(3) Possible head tail source (see text)

(4) 22 W 3. The nature of the faint optical candidate is difficult to discern on Thuan’s plate, on the Palomar Sky Survey plates, or on a plate of the region kindly taken for us by S. Strom with the KPNO 4-m telescope. It is possible that the object is not a galaxy but is merely a chance alignment of stars.

(5) 22 W 10. The candidate galaxy UGC 2608 was described by Nilson (1973) as “disturbed”. Although the source 22 W 9 is only 100° away and could be associated with 22 W 10 we have catalogued both sources independently.

(6) Galaxy lies 90° west

and individually searched for the positions of the point source 3C 83.1 A and the peak of Perseus A. Tiny but consistent shifts in positions of ~0.1 were obtained between the different observations. We applied these shifts to the data and produced a new combined map in which the residual grating rings were reduced by a factor of two to the ~0.1% level.

In addition to standard resolution (70″ × 105″ HPBW) maps in all four Stokes parameters, we also made convolutions having circular synthesized beams with half power diameters of 3′ and 6′ respectively. The latter were used to make a more sensitive study of low brightness structure and to compare with various X-ray data. In order to study the spectral distribution of the 5′ component around NGC 1275 (Miley and Perola, 1976) we constructed additional maps at both 610 and 1415 MHz having resolutions which were as identical as possible. The 1415 MHz observations were also made with the WSRT and calibrated very carefully, with the object of achieving maximum dynamic range. Details of the various observations used and parameters of the resultant maps are given in Table 1.

In all cases the cleaning algorithm (Högbo, 1974; Schwartz, 1978) was used in order to remove both the real (far) diffraction grating rings and the distorting effects of near sidelobes. To
minimize the dynamic range necessary for cleaning, we first subtracted the strong point source 3C 83.1 A and the unresolved component of NGC 1275 from the maps. The point component of NGC 1275 had a peak intensity which was a factor of \( \sim 7 \) larger than the halo in which it is embedded. In the absence of subtraction the unresolved component would therefore have been convolved with the synthesized beam and would have significantly distorted the 5' halo. The parameters used in the subtraction were chosen to leave the halo center as smooth as possible.

### III. Results

In Fig. 1 we present our standard resolution map superimposed on an optical photograph of the cluster made by Thuan and Figs. 2 and 3 show the 3' and 6' radio maps.

The positions and flux densities for all sources in the field (including those subtracted in Fig. 1) are given in Table 2. Note that all flux densities in Table 2 are corrected for primary beam attenuation but the maps shown in Figs. 1–3 are not. Parameters of the point sources were measured by fitting the synthesized beam. Flux densities for the extended sources were derived by directly summing the intensities at all grid points within the source and normalizing by the summed intensity of the restoring beam (see, e.g. Bridle et al., 1978).

Because of the dynamic range limitations, the completeness level varies from point to point on the map. Between the residual grating rings all sources with map flux (flux density uncorrected for attenuation by the primary beam) larger than 20 mJy (2 contours in Fig. 1) are definitely real. A few of the one-contour sources may be spurious, and we have indicated one-contour
sources for which there are no confirmatory detections at another frequency by parentheses in Table 2.

Also included in Table 2 are 1415 MHz flux densities, where available, and the resultant two-frequency spectral indices. The 1415 MHz data were either taken from the WSRT observations referred to in Sect. 1 or from the catalogue of Willis et al. (1976). In columns 7 and 8 of the table we state whether a source is unresolved ('u') or resolved ('r') by the WSRT and in column 8 we give information on possible optical counterparts.

The maps of Stokes parameters $Q$, $U$, and $V$ corresponding to the total intensity map reproduced in Fig. 1 yielded no linear or circular polarized intensities larger than 0.1% of the peak intensity.

**IV. Source Identifications**

The map in Fig. 1 is dominated by sources associated with the three galaxies NGC 1275, NGC 1265, and IC 310. We shall discuss the former two in detail in Sect. V and VI including the possibility that the associated extended sources are partially due to other nearby galaxies.

Regarding IC 310, we note that in our 610 MHz observations the tail extends to $\sim 10'$ from the galaxy compared with only 6' at 1415 MHz (Miley, 1973), indicating a steepening of the spectrum in the far tail. This is consistent with the behaviour of other tailed sources.

In addition to the three dominant galaxies several other cluster galaxies have been detected as radio sources including NGC 1270, UGC 2608, UGC 2654, and the galaxy denoted as no. 15 by Chincarini and Rood (1971). At 1415 MHz this latter object was shown to be associated with a tailed radio source (Miley et al., 1972), but here at 610 MHz it is only just resolved.

Sources 3 and 47 also both have structures reminiscent of tailed radio sources and warrant further study. For source 3 the only candidate identification is faint, and although this source could be associated with a cluster galaxy of low luminosity, we believe that it is more likely a background object. Source 47 is identified with a 16th magnitude cluster elliptical but its apparently asymmetric radio structure could be an artifact of contamination by residual grating rings.

The Perseus cluster is distinguished with respect to most other clusters by the relatively large number of tailed radio sources it
Table 3. Radio luminosity statistics for galaxies with $M < -19.6$ ($H = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$)

<table>
<thead>
<tr>
<th>$P_{610}$ w Hz$^{-1}$</th>
<th>Perseus Cluster</th>
<th>Average of 5 clusters$^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&gt;10^{23.5}$</td>
<td>$3/25 = 12 \pm 7%$</td>
<td>$24.25/251 = 9.7 \pm 2.1%$</td>
</tr>
<tr>
<td>$&gt;10^{22.3}$</td>
<td>$4/14 = 29 \pm 16%$</td>
<td>$10.5/251 = 4.2 \pm 1.3%$</td>
</tr>
</tbody>
</table>

$^*$From the 1415 MHz results of Auriemma et al. (1977) converted to 610 MHz assuming a 610/1415 MHz spectral index of $-0.8$ and corrected to a Rubble Constant of $H = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

V. NGC 1265

a) The Low Brightness Radio Structure

The radio source associated with NGC 1265 (3C 83.1 B) is one of the most intensively studied tailed radio sources, with detailed maps available at many frequencies (Ryle and Windram, 1968; 1974), excluding the regions occupied by the extended sources around NGC 1275 and NGC 1265. Our gross results, and those of Auriemma et al. are shown in Table 3. The denominator in each fraction is the total number of galaxies in the given magnitude range which could have been detected at the given radio luminosity, and the numerator is the number which were actually detected. There is some evidence for an excess of strong radio galaxies in the Perseus cluster but the statistics are rather poor. We do not believe that this possible excess is connected with the presence of head-tail morphologies since Abell 2256, the only known cluster with more head-tail galaxies than the Perseus cluster, has a normal radio luminosity function (Bridle et al., 1978).
We have attempted to remove the contaminating grating ring from the NGC 1265 region on the assumption that the ring is antisymmetric under a 180° rotation. The result, shown in Fig. 4, is a plausible representation of the radio structure of NGC 1265 without the offending grating ring. The heavy contour and those outside it are from our corrected 610 MHz map whereas the dashed and inner contours are from the higher resolution 1415 MHz map of Miley (1973). The presence in the 1415 MHz map of a slight bulge in the direction of the northeastern extension lends additional credence to this feature.

b) Origin of the Northeast Extension

Having established that the extension is almost certainly real we note that there are a few galaxies in the region besides NGC 1265 which could be responsible for it. A notable candidate is the 15.6 mag Sab galaxy UGC 2639 in Fig. 1. However the density of cluster galaxies is relatively small at such a distance from the cluster center and we consider the probability of a chance superposition of an independent head tail galaxy on the NGC 1265 source to be small.

If such a feature extends from NGC 1265, how can we interpret it within the context of current models of head tail radio galaxies? Although the radio trail picture (Miley et al., 1973) is now generally accepted, an outstanding problem is the nature of the curvature observed in the bright tails of galaxies like NGC 1265 or 3 C 129. One of the most plausible mechanisms which has been invoked to explain such bending is buoyancy (Cowie and McKee, 1975; Gull and Northover, 1973).

It is tempting to think that the northeastern extension represents a residual remaining from the original trajectory of NGC 1265, while the main body of the tail has been lifted by buoyant forces to its present location. According to Cowie and McKee (1975) denser “detached plasmoids” may be left behind as light plasma rises through the cluster medium. On this assumption, we designate the northeastern extension as the heavy tail made up of detached plasmoids, and the main body of the tail as the buoyant tail. The trajectory of NGC 1265 deduced from the heavy tail is far more plausible than that indicated by the present position of the buoyant tail, since the cluster center is to the southeast of NGC 1265, as indicated by the arrows in Fig. 4. It lies between NGC 1275 and NGC 1272 (Bahcall, 1974).

Also, the steepness of the surface brightness profile at the northwestern tip of the bright tail is more consistent with this picture of the bright tail as a dynamically confined buoyant bubble (see Gull and Northover, 1973) than with an alternative interpretation of the tail curvature involving an intergalactic wind blowing from the direction of the cluster center. In the latter case, the steepest profile would occur on the windward, or southeastern side and this does not seem to be the case.

c) The Mass of the Perseus Cluster

Arguments based on buoyancy enable one to determine a lower limit for the mass of the Perseus Cluster inside NGC 1265. Following Cowie and McKee and adopting a slightly different notation we can write

\[ M_{\odot}(R) \approx \frac{R^2 v_k(\text{term})^2}{G} \frac{2 \sin \phi}{\pi} \left( \frac{\rho_{\text{term}}}{\rho_{\text{term}} - \rho_b} \right). \]  

where \( M_{\odot}(R) \) is the mass of the cluster enclosed by a sphere of radius \( R \), \( v_k(\text{term}) \) is the terminal velocity of a plasma blob rising through the medium, \( r \) is the blob radius, \( \phi \) is the angle between
the trajectory at the time the blob was emitted and the direction to the cluster center. \( \rho_{\text{icm}} \) and \( \rho_b \) are the respective densities of the ambient intracluster medium and of the blob.

From Fig. 5 we can write the distance from NGC 1265 to the cluster center as

\[
R = R_t \csc \beta, \tag{2}
\]

where \( R_t \) is the transverse component of \( R \) and \( \beta \) is the angle at NGC 1265 between the cluster center and the observer.

The angle \( \phi \) can be related to the observed quantities and the unknown projection angles (Fig. 5) by

\[
\cos \phi = \frac{l_{\text{bf}}(1 + \cos^2 \alpha) - R_t (\cos \xi + \cot \beta \csc \alpha)}{[(1 + \cos^2 \alpha) (R_t \cos^2 \beta + l_{\text{bf}}^2 (1 + \cos^2 \alpha) - 2 R_t l_{\text{bf}} (\cos \xi + \cot \beta \csc \alpha))]^{1/2}} \tag{3}
\]

where \( \alpha \) is the angle at NGC 1265 between the space velocity of the galaxy (relative to the cluster center) and the direction to the observer, and \( \xi \) is the angle measured in the plane of the sky between the axis of the heavy tail and the direction to the cluster center at NGC 1265. For appropriate values of the projection angles \( \alpha \) and \( \beta \) the angle \( \phi \) does not differ greatly from its projection \( \psi \), which can be measured at \( T \) in the plane of the sky. In what follows we will use \( \psi \) for \( \phi \).

Presuming that the plasma blob at the end of the buoyant tail has moved from \( O \) to \( B \) (Fig. 5) while the galaxy has moved from \( O \) to \( P \), the average velocity of the blob is

\[
v_{b(\text{ave})} \approx v_{pr} \left( \frac{l_{\text{bf}}}{l_{\text{bf}} / \sin \beta} \right), \tag{4}
\]

where \( v_{pr} \) is the radial velocity of the galaxy relative to the cluster center.

Combining (1), (2), and (4) we have

\[
M_{cl}(R) = \frac{2}{\pi G} \left( \rho_{\text{icm}} \frac{R^2}{R_t^2} \frac{l_{\text{bf}}^2}{l_{\text{bf}}^2 (v_{b(\text{term})}^2 / v_{b(\text{ave})}^2)} \right) v_{pr}^2 \tan^2 \alpha \csc^2 \beta \sin \psi. \tag{5}
\]

Using a mean radial velocity for the cluster of 5460 \( \text{km s}^{-1} \) (Chincarini and Rood, 1971) and a Hubble constant of 75 \( \text{km s}^{-1} \text{Mpc}^{-1} \), we obtain \( R_{\text{trans}} = 530 \text{ kpc} \) from Fig. 1. We also measure \( (l_{\text{bf}} / l_{\text{bf}}) = 0.6 \) and \( \psi = 42^\circ \). Taking \( r \sim 10 \text{ kpc} \) and \( (\rho_{\text{icm}} / \rho_{\text{icm}} - \rho_b) \sim 5/3 \) from Miley et al. (1975) and \( v_{pr} \sim 2200 \text{ km s}^{-1} \) from Chincarini and Rood (1971) we find

\[
M_{cl}(R) = 1.2 \times 10^{16} M_\odot \left( \frac{v_{b(\text{term})}}{v_{b(\text{ave})}} \right)^2 \tan^2 \alpha \csc^2 \beta. \tag{6}
\]

To obtain a lower limit to the cluster mass we set \( v_{b(\text{term})} / v_{b(\text{ave})} = 1 \) and \( \csc \beta = 1 \). Then the only unknown quantity is the angle \( \alpha \). Miley et al. (1975) argue that \( 20^\circ \leq \alpha \leq 40^\circ \) on the grounds that too large an angle of projection makes the galaxy's total velocity improbably large while too small an angle makes the source's total length improbably great. Putting \( \alpha = 20^\circ \) gives a minimum cluster mass of

\[
M_{cl}(R) \geq 1.6 \times 10^{15} M_\odot. \tag{7}
\]

An alternative method for obtaining an approximate value for the cluster mass is to assume that NGC 1265 is in a bound orbit about the cluster center. If the orbit is circular, we have

\[
M_{cl}(R) = \frac{R_t^2}{G}, \tag{8}
\]

where \( v_s = v_{pr} \sec \alpha \) is the total velocity of NGC 1265. If the orbit is elliptical, the mass will differ from that calculated from Eq. (8) by a factor \( [a/(2a - R)] \) where \( a \) is the semi-major axis. Since it is unlikely that NGC 1265 is near its closest approach to the cluster center, the mass calculated for an elliptical orbit will probably exceed the value given by Eq. (8).

By assuming Eq. (8) to give a correct value for the mass, and assuming \( v_{\text{term}} = v_{\text{ave}} \), we now demonstrate that we can constrain the projection angle \( \alpha \) to rather small values. Substituting the values of \( R_{\text{trans}} \) and \( v_{pr} \) given above, we find from Eq. (8)

\[
M_{cl}(R) = 5.9 \times 10^{14} M_\odot \sec^2 \alpha \csc \beta. \tag{9}
\]

Demanding consistency between the masses obtained from Eq. (6) and (9) would constrain \( \alpha < 12^\circ \) and \( M_{cl} > 6 \times 10^{14} M_\odot \). This calculation is meant to be illustrative only.

The mass limit derived from Eq. (8) is of course based on rather similar considerations to the virial theorem mass limit of \( \sim 10^{15} \) derived by Chincarini and Rood (1971) from the observed velocity dispersion of the whole cluster. However, the mass given by Eq. (7) was derived completely independently indicating that the cluster is bound.
VI. NGC 1275

a) 610 MHz Structure

The halo around NGC 1275 can clearly be seen in Figs. 1 and 6. The reader may compare the 610 MHz radio photograph in Fig. 6 with the 1415 MHz contour map with similar resolution published by Miley and Perola (1975). The features 'a' and 'b' seen in their map and marked in Fig. 1 are easily distinguished here. Some of the fainter structures in their map such as the extension toward source 44 in the east and the tongues to the northeast and northwest are also reproduced at 610 MHz. The source does not tail off into the noise. It ends abruptly at both frequencies and has a total extent of \( \sim 12'' (E-W) \) by \( \sim 10'' (N-S) \). The brightest part of the source, centered on the optical nucleus of the galaxy, is extended in a position angle \( \sim 170'\) in agreement with the main orientation of the smaller components down to a milli-arc s scale (Pauliny-Toth et al., 1975).

b) Spectral Distribution

Contours of the 610/1415 MHz spectral index are superimposed on the 610 MHz radio photo in Fig. 6. Although over the region shown the formal uncertainties in the spectral indices are \( \sim 0.1 \), the spectral distribution should be treated with caution. The somewhat subjective subtraction of the unresolved component will introduce unknown errors close to the center of component "a". However, the failure to subtract the (flatter spectrum) unresolved component would have distorted the spectral distribution of the halo much more severely.

Figure 6 suggests that the northern region of the halo has a systematically steeper spectrum and contains relatively older electrons than the southern part. This is consistent with the indications from the location of the 30'' component (Miley and Perola, 1975) that the axis of ejection of NGC 1275 is towards the south.

c) Origin of the Extended Source

The overall structure of the extended component surrounding NGC 1275 is peculiar. Unlike most large extragalactic radio sources it is largely amorphous with no pronounced structural characteristics. It is reasonable to assume that the peculiar morphology is at least partially due to the very special location of the source at the center of a rich X-ray cluster of galaxies.
One possibility is that it is a superposition of independent sources as is the case with the extended halo in Abell 2256 (Bridle et al., 1978). We note from Fig. 1 that there are several bright cluster members contained within the outer envelope of the NGC 1275 extended source. Among these are the NGC galaxies 1272, 1273, 1274, 1277, and 1278 and the Zwicky galaxy 0316.3+4124. Weak radio emission from any of these galaxies cannot be ruled out as it would be indistinguishable from the extended source. In particular, it is quite plausible that NGC 1273 and Zw 0316.3+4124 are weak sources in their own right, since they lie near the maxima in the two loops to the northwest. Although the extension towards source 44 suggests that this source may be connected with the main body of the halo we have catalogued the source separately in Table 2. A possible optical counterpart to source 44 is a faint galaxy which lies within the source contour about 35″ northeast of the radio intensity maximum. The component "b" does not coincide with any galaxy, to the limit of all available plate material, but lies approximately halfway between NGC 1275 and NGC 1272, and about 40″ to the west of a much fainter galaxy.

The overall C-shaped configuration of the halo might be expected if NGC 1275 and NGC 1272 were both head-tail sources, the former having a short stubby tail to the south and bending west, and the latter having a more extended tail to the east. It is plausible that these two galaxies are in orbit about each other and about the cluster center, which lies between them. NGC 1272, being fainter, quite reasonably has the higher velocity with respect to the cluster mean and therefore the longer tail. The radial velocity difference between the two galaxies is ∼1000 km s⁻¹ (Chincarini and Rood, 1971), which yields a mass sum of ≥2.7 x 10¹⁰ M☉ if the orbit is bound.

Another factor which must play a leading role in determining the structure of the NGC 1275 halo is the presence of a hot dense gas at the center of the Perseus Cluster. (The recent detection of X-ray line emission from highly ionized iron (Mitchell and Culhane, 1977) leads us to reject the alternative inverse Compton interpretation of the X-ray continuum emission.) The gas (T∼10⁸ K, ρ∼10⁻²⁷ g cm⁻³) exerts a pressure ∼10⁻¹² dyn cm⁻² compared with the minimum internal (equipartition) pressure of ∼10⁻¹⁴ dyn cm⁻² which we calculate from synchrotron theory for the relativistic plasma of the halo.

d) Comparison with X-ray Maps

It is of interest to compare our convolved 3′ and 6′ maps (Sect. II) with recent X-ray maps of similar resolution in order to elucidate the relationship between the hot gas emitting the X-rays and the radio emitting plasma. The radio plasma is presumably confined by the hot gas.

Cash et al. (1976) and Wolff et al. (1976) have published X-ray maps of the Perseus Cluster with a resolution of ∼6′, and a map at higher resolution (∼3′) has recently been made by Gorenstein et al. (1978).

The X-ray map of Cash et al. shows a structure which is similar in some respects to our map of NGC 1275. We both show the eastward extension toward radio source 44, and the westward extension toward NGC 1272. There is weak X-ray emission, however, extending much farther westward along the prominent line of bright galaxies than the radio emission.

The X-ray source in the map of Wolff et al. is different from that in Cash et al., and is roughly elongated in position angle ~30°. For comparison, the position angle of the radio elongation in Fig. 5 is roughly ~110°, and the inner source structures have p.a. ~170°. The map of Gorenstein et al. shows no prominent elongation.

From this rather confused picture of the X-ray structures in the Perseus cluster, it is difficult yet to draw any definitive conclusions concerning the interaction between the radio emitting plasma and the hot confining gas. If the X-ray map of Wolff et al. represents the density distribution of the gas, then the fact that the radio elongation in Fig. 5 is nearly perpendicular to the X-ray elongation finds natural explanation in the tendency of the light plasma to rise fastest where the density gradient is steepest. (The unconvolved map in Fig. 1 shows a different radio elongation from the map in Fig. 3, because some independent sources have merged together in the latter.) The picture of light relativistic plasma being generated in the nucleus of NGC 1275 and rising up through the denser gas in the cluster center is made attractive by the outer filamentary structures, seen in Figs. 1 and 6 and the map of Miley and Perola (1975), which resemble the tongues characteristic of a Rayleigh-Taylor instability. Also, in our discussion of NGC 1265 we have shown that this buoyancy mechanism has a natural application elsewhere in the cluster. Finally, circulation in the medium may be responsible for the overall "C"-shaped curvature of the source, best appreciated in Fig. 6.

VII. The Search for the Cluster Halo 3 C 84 B

The existence of a halo having the dimensions of the order of the whole Perseus cluster was inferred by Ryle and Windram (1968) from the differences between a low resolution (∼15′) synthesis and a high resolution (∼1′) synthesis. The smooth halo (3C 84 B) was thought to be extended along the line joining NGC 1275 and NGC 1265 with half-power size ~65′ × 25′ containing 12±4 Jy at 408 MHz.

As we described in Sect. 2, one of the reasons for producing the convolved 3′ and 6′ maps was to search for such extended structure. We find no evidence for a large intracluster halo on any of the maps (Figs. 1, 2, and 3).

Our measurements should be sensitive to structure smaller than λ/D radians where D is the length of the shortest projected baseline (Macdonald et al., 1969). Since this limit corresponds to extents of ~1′ both along and perpendicular to 3C 84 B we should be sensitive to the halo component. On our standard map the halo flux density should translate to an average brightness of ~9 mJy per beam area and should exceed this value on the line joining NGC 1275 and NGC 1265, where the halo is reputed to be stronger. But, averaging the intensities in a 4′ × 7′ source free area on this line, we find that the brightness level of smooth emission must be smaller than 5 mJy per beam area (3σ level).

A halo source in the Coma cluster was detected by Willson (1970). This source, Coma C, has an angular extent of ~40′ and a total flux density of 4 Jy at 408 MHz. It is therefore a factor of three fainter than 3C 84 B. Nevertheless, Coma C was detected at 610 MHz with the WSRT at a level of ~4 mJy per beam area (Jaffe et al., 1976; Valenti, 1978).

In addition, comparison of our map with the 610 MHz observations of the Perseus cluster made with the 300-ft NRAO telescope (FWHM ~10′) reveals no halo of strength comparable to that observed by Ryle and Windram (Jaffe and Rudnick, private communication).

Why, then, do we not see this halo? The individual sources in the Perseus cluster are particularly complex and it is difficult to separate such extended source features from a possible large...
halo in low resolution observations. A residual contribution from
NGC 1275, NGC 1265, and IC 310 in a very low resolution map
could result in a spurious halo with the structure that 3C 84 B is
claimed to have. For these reasons we regard the existence of
3C 84 B as unproven.

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