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Diffuse Radio Emission from the Coma Cluster of Galaxies at Decametre Wavelengths

Ch. V. Sastry and R. K. Shevgaonkar
Indian Institute of Astrophysics, Bangalore 560034 and
Raman Research Institute, Bangalore 560080

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Abstract. We have observed the region of the Coma cluster at 34.5 MHz with a resolution of 26 arcmin × 40 arcmin. A map of the diffuse halo (Coma C) is presented. The size of the halo is found to be 54 arcmin × 30 arcmin. The position angle is 50° ± 10° and the integrated flux is 60 ± 11 Jy.

We have also found an extended source to the south of Coma A. The measured half-power widths of this source are 30 arcmin × 40 arcmin. The position angle is 135° and the integrated flux is ~ 15 Jy at 34.5 MHz. The spectral index in the frequency range 408 to 34.5 MHz is − 1.0. It is suggested that this source also belongs to the Coma cluster.

Key words: cluster of galaxies—intracluster medium—radio spectra

1. Introduction

Diffuse radio sources in clusters of galaxies have been extensively observed at high radio frequencies. It is believed that this diffuse radio emission is closely related to the X-ray sources found in clusters of galaxies. It has also been found that cluster X-ray sources have metre-wavelength spectra that are unusually steep. The diffuse radio emission from the Coma cluster (Coma C) has been mapped by Hanisch, Matthews & Davis (1979), Hanisch (1980) and others in the range 430 to 1400 MHz. These maps were made by observing the Coma cluster region with filled aperture radio telescopes, which are sensitive to extended emission, and then subtracting the contribution due to known point sources in the field of view. Such maps of the radio halo of the Coma cluster are, however, not available at low radio frequencies. Hanisch & Erickson (1980) determined the flux density of the Coma cluster at 43 MHz and 73.8 MHz using one-dimensional scans. We have recently started a programme of observations of extended cluster sources at 34.5 MHz and this paper deals with observations of the Coma cluster region.

2. Equipment and observations

The observations reported here were made with the low-frequency radio telescope at Gauribidanur (Longitude 77°27′07″ E and latitude 13°36′12″ N). The antenna system of the telescope consists of two broad-band arrays arranged in the form of a 'T'. The half-power beamwidths at the operating frequency of 34.5 MHz are 26 arcmin and 40 sec (δ − 14°.1) arcmin in the east-west and north-south directions respectively. The collecting area is approximately 250 λ^2. The telescope is of the transit type and the beam can be pointed anywhere along the meridian in the zenith angle range ± 45° using remotely-controlled diode phase shifters. A time-multiplexing system is used to cycle the beam through eight declinations sequentially, the beam being switched from one direction to another in a few milliseconds. The receiving system extracts the in-phase (cos) and the quadrature (sin) correlations between the two arms for each of the eight beam positions. Pre-detection bandwidths of 30 and 200 kHz and post-detection time constants ranging from 1 to 30 s are available. The output of the receiving system is recorded in both analog and digital forms. Full details of the telescope will be published elsewhere.

The observations on the Coma cluster were made with a 200 kHz bandwidth and 10 s time constant. Drift scans were taken in right ascension from $12^h 30^m$ to $13^h 30^m$ in the declination range 26°.5 to 29°.5 in steps of 24 arcmin. Thus the whole region of the Coma cluster was covered in one day. Each scan was calibrated using the radio source 3C 284, whose flux density at 34.3 MHz was taken to be 67 Jy (Hanisch & White 1981). To minimise ionospheric effects such as refraction, absorption and scintillation, and also interference due to terrestrial broadcasts, repeated scans were taken over many days. The source was actually observed sixteen times. Using the calibrated scans, a raw map of the Coma cluster region was constructed. The map thus obtained was CLEANed to eliminate side-lobe effects and the CLEAN components were convolved with a gaussian beam to obtain the final map.

3. Results and discussion

The map of the Coma cluster obtained as described above is presented in Fig. 1. The notable features are the two maxima at $\alpha = 12^h 56^m.6$, $\delta = 28°10′$ and $\alpha = 12^h 52^m$,

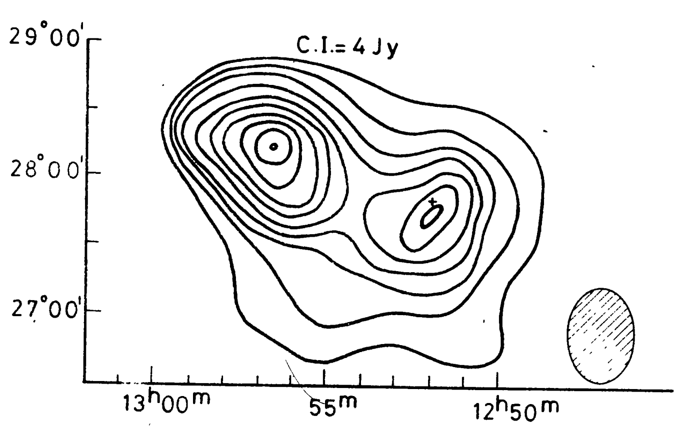

Figure 1. Map of the Coma cluster region at 34.5 MHz obtained with the low-frequency radio telescope at Gauribidanur. The contour interval is 4 Jy/beam. The lowest contour corresponds to 4 Jy/beam and is significant at the 3-sigma level. The position of the radio galaxy Coma A is shown by a cross.

$\delta = 24° 47'$. There is also extended emission surrounding both the peaks. The only other low-frequency map of this region is contained in the background survey of Williams, Kenderdine & Baldwin (1966) at 38 MHz with a resolution of 45 arcmin. We find that there is excellent agreement between the two maps, particularly in the region of Coma C. As already mentioned, the high-frequency maps of Hanisch, Matthews and Davis (1979) and Hanisch (1980) were made by subtracting the contribution due to the point sources from the observed region. The fluxes and positions of the two strong point sources, 5C 4.81 and 5C 4.85, were taken from the 5C4 survey of Wilson (1970). To make a comparison with the high-frequency maps, we have also subtracted the contributions due to these two sources from the map shown in Fig. 1. The total flux density (~ 16 Jy) of the combination of these two sources was estimated from the spectra given by Hanisch & Erickson (1980). The map obtained after subtraction of the contribution due to the two point sources (5C 4.81 + 5C 4.85) in the centre of Coma C is shown in Fig. 2. What is left is the halo of Coma C and a diffuse source around Coma A. The observed characteristics of these two diffuse sources are given in Table 1.

Table 1. Summary of the observed parameters of diffuse sources in Coma cluster at 34.5 MHz.

	Coma C	Coma A
Integrated flux of diffuse radio emission	60 ± 11 Jy	~ 15 Jy
Halo size (FWHM)	54 arcmin × 30 arcmin ± 5 ± 5	30 arcmin × 40 arcmin ± 5 ± 5
Position angle of the major axis	50° ± 10°	~ 135°
Spectral index of diffuse radio emission	− 13	− 1.0

A comparison of the low-frequency characteristics of the halo of Coma C obtained here with those at high frequencies observed by Hanisch (1980) shows that the dimensions of the diffuse component and the position angle of its elongation remain approximately the same in the frequency range 34.5 to 4.30 MHz. It is also interesting that

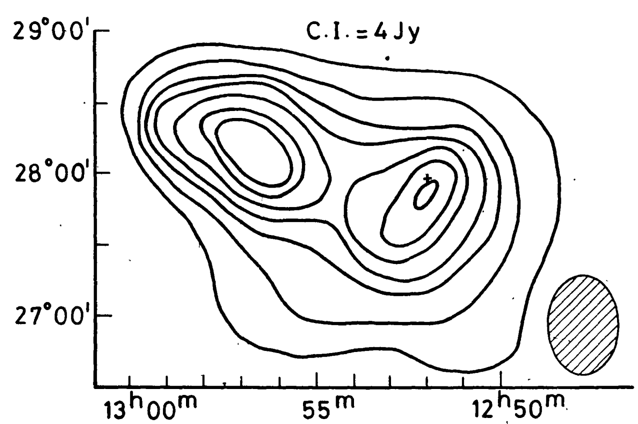

Figure 2. Map of the Coma cluster region after subtraction of the point sources 5C 4.81 and 5C 4.85. The position of the radio galaxy Coma A is shown by a cross.

Helfand, Ku & Abramopoulos (1980) have noted a distinct elongation of the central contours of their X-ray map at approximately the same position angle, and that the diffuse component of optical radiation detected by Welch & Sastry (1971), also has about the same orientation.

We have integrated our map between the limits $12^h\,54^m - 13^h\,00^m$ in right ascension, and $26°.5 - 28°.75$ in declination. As already noted above, the radio source 3C 284 was used as a calibrator. On this basis, the integrated flux density of the halo of Coma C is found to be 75 ± 11 Jy. A further correction to the flux must be made for the so-called 'pseudo-halo' due to the weak unresolved point sources in the cluster. An estimate of this correction at 43 MHz is given by Hanisch & Erickson (1980) as 14 Jy. At 34.5 MHz, this correction would be approximately 15 Jy, which makes the total integrated flux of the halo of Coma C at 34.5 MHz equal to 60 ± 11 Jy. The spectral index (defined as 'α' in the expression $S \propto \nu^{\alpha}$) computed using the integrated flux densities at 430 MHz given by Hanisch (1980) and the present measurement at 34.5 MHz, is -1.3 which is in good agreement with Hanisch's previous estimate of -1.32 ± 0.2 between 430 and 1400 MHz.

We note that the emission to the south of the source Coma A (3C 277.3) is also extended, as seen in Fig. 1. The measured half-power widths of this source are 30 ± 5 arcmin and 40 ± 5 arcmin along the major and minor axes respectively. The position angle of the major axis is approximately 135°. Jaffe & Rudnick (1979) have also noted that there is an extended emitting region of about one degree to the southwest of the cluster centre near 3C 277.3 at 610 MHz. They estimated the flux density to be about 1 Jy. Ballarati *et al.* (1981) have also reported an extended source to the south of 3C 277.3 of 22 arcmin × 10 arcmin in size and with position angle ≈ 125° at 408 MHz. They measured a total flux of $S_{408} = 1.18 \pm 0.10$ Jy for the extended feature. The same region was also mapped by Haslam *et al.* (1974) in their background survey of the northern sky at 408 MHz. There is an extended source near Coma A in their map, whose position angle is also around 135°.

We have integrated our map within the limits $12^h\,49^m - 12^h\,54^m$ in right ascension, and $26°.5 - 27°.7$ in declination. The integrated flux is found to be 50 ± 8 Jy. We have computed the spectrum of the unresolved source Coma A (3C 277.3), in the frequency range 1400 to 26 MHz; we find it to be straight with spectral index of -0.72 ± 0.02. On the basis, the expected flux density of Coma A at 34.5 MHz is about 35 Jy. Therefore, the flux density of the extended component at 34.5 MHz is ≈ 15 Jy and the spectral index in the frequency range 408 to 34.5 MHz is -1.0. While this estimate of the flux density of the extended feature depends on the boundaries over which our map is integrated, its existence, however, seems well established.

Jaffe & Rudnick (1979) have suggested that the extended feature discussed above is in fact associated with 3C 277.3. Miley *et al.* (1981) found a detailed coincidence between the extended radio emission structure of 3C 277.3 and the optical line emission, but their study refers to the structure within 3C 277.3 itself. That the galaxy with a redshift $z = 0.086$ identified with 3C 277.3 (Schmidt 1965) does not belong to the Coma cluster whose mean $z = 0.025$ has been argued by Ballarati *et al.* (1981). These authors have further suggested that the extended feature does belong to the Coma cluster, since its association with 3 277.3 would imply a very unusual asymmetric morphology and an extremely large size of ≥ 2.5 Mpc. The steep spectrum with an index of -1.0 between 408 and 34.5 MHz estimated by us lends support to their view.

The existence of diffuse radio sources in clusters of galaxies raises the important question of the generation and acceleration of electrons responsible for the emission. There are essentially two types of models suggested for the origin and propagation of these electrons in the intergalactic medium. The first type due to Jaffe (1977) and Dennison (1980) is based on the assumption that radio galaxies are the injectors of the electrons radiating in the halos. In the second type of model suggested by Blandford and Ostriker (1978) and Roland (1981), there is no direct connection between the halos and the active galaxies in the clusters. No particular origin is specified for the particles, but it is postulated that the accceleration takes places in the intergalactic medium in the cluster. According to Roland (1981), intracluster magnetic fields can be generated and relativistic electrons accelerated through turbulence in galactic wakes. According to Blandford and Ostriker (1978), it is possible that particle acceleration can result from shocks produced by the bow waves associated with the motion of the galaxies in the cluster. In the case of the halo of Coma C, it is believed that the radio emission is due to relativistic electrons generated within the central galaxy NGC 4874, and diffused into the intracluster medium (Hanisch, Matthews & Davis 1979). However, there is no galaxy in the central region of the extended component to the south of Coma A (Ballarati *et al.* 1981). Therefore, whatever the origin of the relativistic electrons, they must have been accelerated in the intracluster medium.

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