DIFFUSE RADIO EMISSION IN THE COMA CLUSTER

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The Coma cluster is peculiar in the radio domain owing to the presence of cluster-wide diffuse sources: the radio halo Coma C, the relic source 1253+275, and the bridge between them. Diffuse radio sources in clusters are a rare and poorly understood phenomenon. We summarize here the properties of the diffuse radio sources in Coma and their relation to other cluster properties.

1 Radio emission in Coma

The radio emission in clusters of galaxies is due in the majority of cases to the individual radio emitting galaxies. The Coma cluster is indeed characterized by the presence of 29 cluster radio galaxies, of different optical morphological types. Moreover, the Coma cluster is permeated by diffuse radio emission, which is not identified with any individual galaxy and makes the Coma cluster exceptional in the radio domain. Cluster-wide diffuse sources witness the existence of relativistic electrons and large scale magnetic field, associated with the intergalactic medium. They are known to be present so far only in a few clusters, despite many efforts to detect them. The diffuse radio emission in Coma includes the central radio source Coma C, the peripheral diffuse source 1253+275, and the bridge of very low brightness between them. A radio image of the Coma cluster is presented in Fig. 1. A Hubble constant $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ is used throughout.

The radio galaxies: There are 29 cluster galaxies showing radio emission down to a power level of $\sim 10^{21} \text{ W Hz}^{-1}$: 10 are Ellipticals, 3 S0 + E/S0, and 16 Spirals + Irregulars. Among the extended radio galaxies identified with ellipticals, the dominant radio structure is the “tailed” structure, typically found in clusters, and determined by the drag exerted by the intracluster gas on the radio emitting plasma ejected from moving galaxies. In particular, the giant central galaxy NGC 4874 is known to be associated with a small ($\sim 15$ kpc) tailed radio source, which indicates that the galaxy is not stationary at the cluster center. Also the giant peripheral galaxy NGC 4839 shows a tailed radio morphology, with the low brightness tails oriented away from the cluster center. A prominent tailed radio source, extended about 300 kpc, is associated with NGC 4869, located at $\sim 4'$ from NGC 4874. Finally, the other tailed radio galaxies in Coma are NGC 4849, and NGC 4789, which
lie in the cluster periphery, at \( \sim 1.5^\circ \) from the center.

**The radio halo Coma C:** Coma C is the prototype and best studied example of cluster radio halos. It is at the cluster center, shows a rather regular shape, a size of \( \sim 1.1 \) Mpc, a low surface brightness (\( \sim 1 \) mJy at 1.4 GHz), and steep radio spectrum (\( \alpha = 1.34 \)). No polarized flux is detected down to a level of \( \sim 10\% \) at 1.4 GHz. The halo Coma C is the only radio halo, for which a high resolution map of the spectral index has been obtained so far. The spectral index distribution shows a central plateau with \( \alpha \sim 0.8 \), and an outer region with steeper spectrum, up to \( \alpha = 1.8 \). This behaviour provides evidence that the source of energy is more efficient at the cluster/halo center, in a region approximately coincident with the optical core radius. The radiative lifetime of the relativistic electrons estimated from the spectrum is \( \sim 10^8 \) yr. Recently, Deiss et al. obtained a map at 1.4 GHz of the halo, after subtraction of all discrete sources. They pointed out the close similarity between the X-ray and radio map: similar extension both in the E-W direction and toward the NGC 4839 group. This similarity indicates a close link between the physical conditions of the radio source and those of the thermal component.

**The relic 1253+275:** The peripheral diffuse source 1253+275 is at \( \sim 2.7 \) Mpc from the cluster center, in the direction of the cluster A1367. It is classified as a relic source, as it has been suggested to be the remnant of the radioemission of a currently inactive radio galaxy, but no compelling evidence of this has been found so far. Its largest size, brightness and spectrum are similar to those of Coma C. Unlike Coma C it shows an elongated shape, and is polarized at the 30\% level at 1.4 GHz. The high polarization degree in this source is naturally explained if a tangled magnetic field is associated with the cluster intergalactic medium. In this case, a larger number of magnetic field cells along the line of sight is present at the cluster center compared to the outer regions.

**The bridge:** A bridge of radio emission is present in the region connecting Coma C to 1253+275. The surface brightness of this diffuse emission is very low, and is only enhanced at low frequency and low resolution. From the recent map presented by Deiss et al., it is questionable if the bridge is a feature connecting Coma C to 1253+275, or an asymmetric extension of the central halo Coma C.

### 2 The magnetic field in Coma

The value of the equipartition magnetic field in the diffuse radio sources of Coma is \( \sim 0.4 \) \( \mu \)G. A much larger value is obtained with an indipendent argument, by studying the polarization properties of the radio galaxy NGC 4869, embedded within the intergalactic medium in the central cluster region. The
fluctuations in the rotation measure detected in this source imply that the magnetic field is tangled on scales of about 1.5 kpc, and has a strength of \( \sim 6 \mu \text{G} \). Such a large magnetic field has important implications on the energetics of the radio halo Coma C, and implies the existence of amplification mechanisms.

3 Origin of the diffuse emission

The relativistic electrons radiating in the diffuse radio emission through the synchrotron process, can travel at most a distance of \( \sim 100 \text{ kpc} \) over their radiative lifetime (\( \sim 10^8 \text{ yr} \)), with a diffusion velocity of \( \sim 1000 \text{ km/s} \) (the typical sound speed). This implies that “in situ” reacceleration of the relativistic electrons is needed to maintain the radio emission on a scale of more than 1 Mpc. It has been suggested that a recent merger between subgroups could provide the energy necessary to maintain the radio halos, i.e. reaccelerate the radiating electrons and amplify the magnetic field (see e.g. the review by Feretti & Giovannini). Böhringer et al. estimated that typically a power of the order of \( 3 \times 10^{45} \text{ erg s}^{-1} \) is available from a merger. This is enough to power the halo with reasonably low efficiency.

According to this scenario, the merger in the center of Coma, between the groups of NGC 4874 and NGC 4889 can be responsible for the energy supply to Coma C, while the merger between the NGC 4839 group and the main cluster could play a role in the energy supply to the bridge. The possibility that the group of NGC 4839 has already passed through the cluster core \( \sim 2 \text{ Gyrs ago} \) does not seem to be relevant for the formation of the radio halo Coma C, since it is difficult to reconcile the timescale of the merger event to the electron lifetime and to the spectral behaviour of Coma C. We do not see any connection between the peripheral relic source 1253+275 and a cluster merger. This could favour the possibility suggested in the literature that this is the remnant of a radio galaxy.

The connection between a merger process and the presence of a diffuse halo does not explain the rarity of radio halos, as mergers are relatively common in clusters of galaxies. According to Giovannini et al., the rarity of radio halos could be due to the difficulty in obtaining the relativistic electrons radiating within the radio halo. These authors suggested that tailed radio galaxies orbiting at the cluster center may be responsible for the deposit of relativistic electrons and estimated that the number of particles radiating in Coma C can be supplied by NGC 4869 in about 4 orbits. Alternatively, Deiss et al. suggested that the efficiency of the stochastic reacceleration mechanism operating in the intracluster medium can explain the close connection between radio emission and X-ray gas structure, and the rarity of radio halos. They argue...
that the reacceleration by turbulent gas motion originated by galaxy motions may depend on some details of the cluster structure, so that only in a few clusters the electrons gain enough energy to produce an observable halo. This process seems to be sufficiently strong to account for the emission in Coma C and to sustain the cluster-wide distribution of relativistic particles.

Therefore, the complex diffuse radio emission in Coma is not yet fully understood, and in particular the possibility that the merger process is not the only ingredient in its formation should be considered.

4 Conclusions

The Coma cluster is permeated by diffuse radio emission, which is a rare phenomenon in clusters of galaxies. It seems that merger processes can supply energy for the maintenance of the central radio halo, and the bridge, while the origin of the peripheral source 1253+275 is still puzzling. Models of dynamical evolution of the Coma cluster must account for the presence of the diffuse radio emission.

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Figure 1: Radio map of Coma, obtained with the Westerbork Synthesis Radio Telescope at 90 cm. The angular resolution is 51″ × 122″ (HPBW, RA × DEC). Contour levels are 2, 3, 5, 7, 10, 30, 50, 100, 300, 500 mJy/beam. The central halo Coma C is clearly visible, as well as the peripheral diffuse source 1253+275. The bridge between them is barely visible in this image, because of its very low brightness.