RADIO OBSERVATIONS OF CLUSTER MERGERS

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Abstract

A very important aspect of the radio emission from galaxy clusters is represented by the diffuse radio sources associated with the intracluster medium: radio halos and relics. These radio sources indicate the existence of large scale magnetic fields and of a population of relativistic electrons in the cluster volume. The observational results provide evidence that these phenomena are related to cluster merger activity, which supplies the energy to the re-acceleration of the radiating particles. The details of the halo-merger connection are investigated through the comparison between the radio and the X-ray emission.

1 Introduction

Clusters of galaxies are the largest gravitationally bound systems in the Universe. Most of the gravitating matter in any cluster is in the form of dark matter ($\sim$ 80%). Some of the luminous matter is in galaxies ($\sim$ 3–5%), the rest is in diffuse hot gas ($\sim$ 15–17%), detected in X-ray through its thermal bremsstrahlung emission. This thermal plasma, consisting of particles of energies of several keV, is commonly referred to as intracluster medium (ICM). In recent years it has become clear that the ICM can also contain highly relativistic particles. While the energy density is less than 1% of the energy density in the thermal plasma, these relativistic particles are very important in the cluster formation and evolution.

We do not know yet how common this non-thermal component is in all clusters. The most detailed studies of this component come from the radio observations. A number of clusters of galaxies is known to contain large-scale diffuse radio sources which have no obvious connection with the cluster galaxies, but are rather associated with the ICM. These sources are classified in two groups, *radio halos* and *relics*, according to their location at the cluster center or cluster periphery, respectively. The synchrotron origin of the emission from these sources requires the presence of cluster-wide magnetic fields of the order of $\sim$ 0.1–1 μG, and of a population of relativistic electrons with Lorentz factor $\gamma \gg 1000$ and energy density of $\sim 10^{-14}$–10^{-13} erg cm^{-3}.

Clusters are formed by hierarchical structure formation processes. In this scenario, smaller units formed first and merged to become larger and larger units over the course of time. Merger activity appears to be continuing at the present time, and explains the relative abundance of substructure and temperature gradients detected in Abell clusters by X-ray observations. The ICM in merging clusters is likely to be in a violent or turbulent dynamical state. It is found that the diffuse sources are detected in clusters which have recently undergone a merger event, thus leading to the idea that they are energized by turbulence and shocks in cluster mergers (see Giovannini & Feretti 2002, and references therein).

The Coma cluster is the first cluster where a radio halo (Coma C) and a relic (1253+275) have been detected (Willson 1970, Ballarati et al. 1981). A typical example of a cluster radio halo is shown in Fig. 1. The radio halos permeate central cluster regions, with typical extent of $\gtrsim$ 1 Mpc and a steep spectrum. Limits of a few percent on the polarized emission have been derived. Relic sources are similar to halos in their low surface brightness, large size, and steep spectrum, but they are typically found in the cluster peripheral regions (see Fig. 2). Unlike halos, relics are highly polarized ($\sim$ 20%).

The formation and evolution of halo sources is still under debate. Several suggestions were made for the mechanism transferring energy into the relativistic electron population and for the origin of relativistic

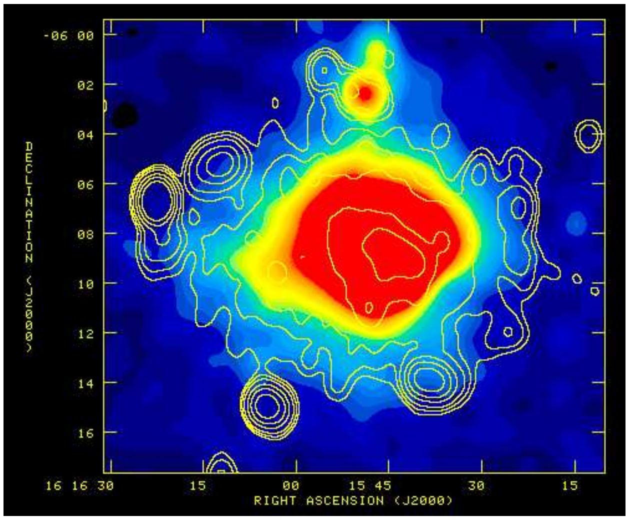

Figure 1: The cluster A2163 at z = 0.203 in radio and X-rays. The contours represent the radio emission in A2163 at 20 cm, showing an extended radio halo (from Feretti et al. 2001). The color scale represents the *ROSAT* X-ray emission. The extended irregular X-ray structure indicates the presence of a recent cluster merger. This radio halo is one of the most powerful and extended halos known so far. It shows a regular shape, slightly elongated in the E-W direction.

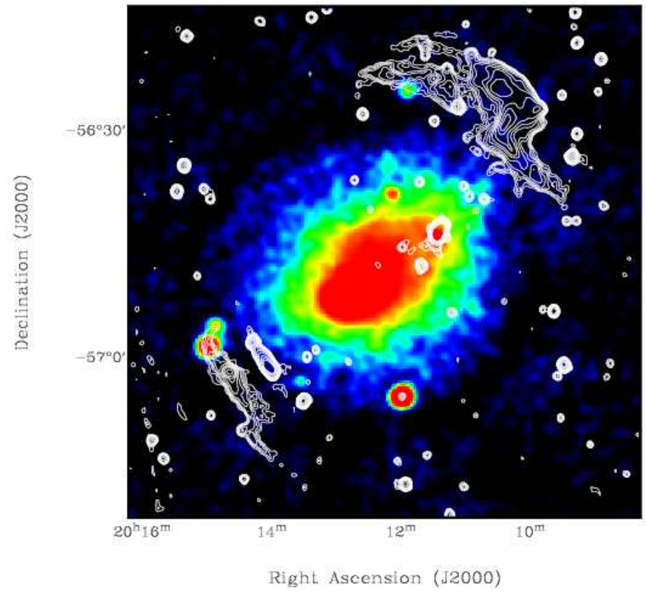

Figure 2: The cluster A3667 at z = 0.055 in radio and X-rays. The contours represent the radio emission at 843 MHz (from Röttgering et al. 1997). The color scale represent the *ROSAT* X-ray image emission. Two radio relics are located on opposite sides of the cluster along the axis of the merger, with the individual radio structures elongated perpendicular to this axis.

electrons themselves. Current models have been reviewed by Brunetti (2003). The relativistic particles could be injected in the cluster volume by AGN activity (quasars, radio galaxies, etc.), or by star formation in normal galaxies (supernovae, galactic winds, etc). Most of the particle production has occurred in the past and is therefore connected to the dynamical history of the clusters. This population of *primary electrons* needs to be re-accelerated (Brunetti et al. 2001, Petrosian 2001) to compensate for the radiative losses. A recent cluster merger is the most likely process acting in the re-acceleration of relativistic particles.

Another class of models for the radiating particles in halos involves *secondary electrons*, resulting from inelastic nuclear collisions between the relativistic protons and the thermal ions of the ambient intracluster medium. The protons diffuse on large scale because their energy losses are negligible. They can continuously produce in situ electrons, distributed through the cluster volume (Blasi & Colafrancesco 1999, Miniati et al. 2001).

Different models have been suggested for the origin of the relativistic electrons radiating in the relics. There is increasing evidence that the relics are tracers of shock waves in merger events. This is consistent with their elongated structure almost perpendicular to the merger axis (Fig. 2). Active radio galaxies may fill large volumes in the ICM with radio plasma, which becomes rapidly invisible to radio telescopes because of radiation losses of the relativistic electrons. These patches of fossil radio plasma are revived by adiabatic compression in a shock wave produced in the ICM by the flows of cosmological large-scale structure formation (Enßlin et al. 1998, Enßlin & Gopal-Krishna 2001).

For completeness, we wish to mention also another class of diffuse radio sources associated with the ICM, the *mini-halos*. They are detected around a dominant powerful radio galaxy at the center of cooling core clusters, and have a total size of the order of $\sim$ 500 kpc, as detected in the Perseus cluster (Fig. 3). Unlike radio halos and relics, mini-halos are typically found at the centers of cooling core clusters and thus are not connected to recent cluster mergers. Although these sources are generally surrounding a powerful central radio galaxy, it has been argued (Gitti, Brunetti & Setti 2002, Gitti et al. this volume) that the energetics necessary to their maintenance is not supplied by the radio galaxy itself, but the electrons are re-accelerated

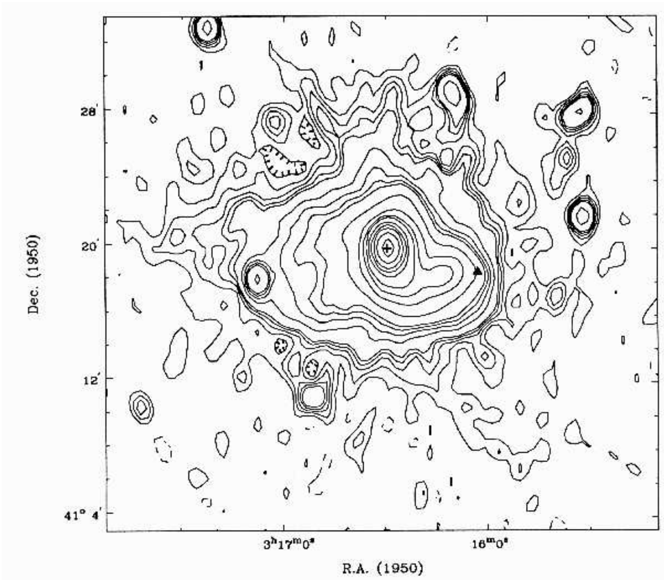

Figure 3: Radio contour map of the mini halo in the Perseus cluster, obtained at 92 cm with the WSRT at a resolution of 51″×77″ (RA×DEC). The cross indicates the position of NGC1275, the triangle marks the position of NGC1272. The mini-halo size in this image is $\sim$ 25′. This image is from Sijbring (1993).

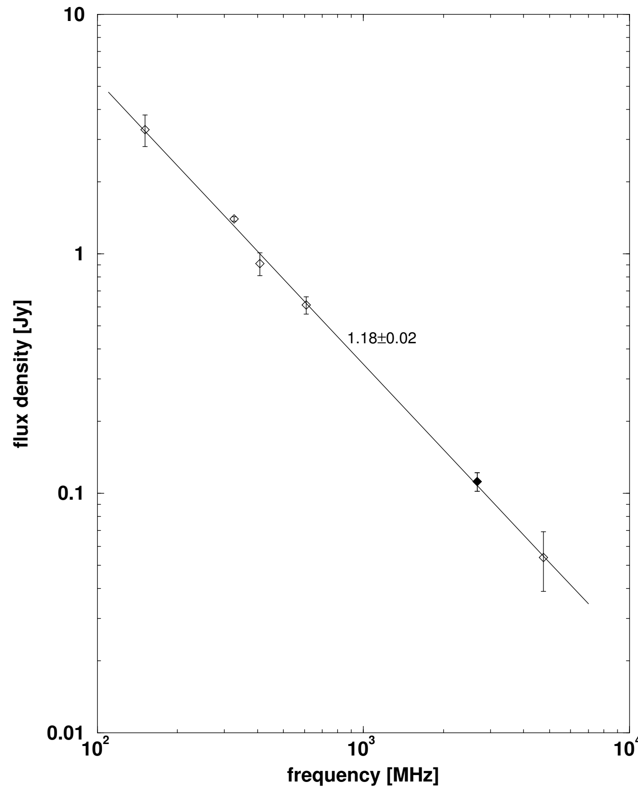

Figure 4: Total radio spectrum of the Coma relic 1253+275 (from Thierbach, Klein & Wielebinski 2003).

by magneto-hydrodynamic turbulence in the cooling core region. The possibility of a hadronic origin of the relativistic electrons from the interaction of cosmic ray protons with the ambient thermal protons has been suggested by Pfrommer & Enßlin (2003).

The observational properties of radio halos and relics are presented here, with emphasis on the information that is derived by the comparison between the radio and X-ray emission. The intrinsic parameters quoted in this paper are computed with a Hubble constant H_0 = 50 km s^{-1} Mpc^{-1} and a deceleration parameter q_0 = 0.5.

2 What do we know from the radio data

The typical radio powers of halo and relic sources are of the order of 10^{24}–10^{25} W Hz^{-1} at 1.4 GHz. The minimum energy densities in diffuse sources, computed with standard assumptions, are between $\sim$ 5×10^{-14} and 5×10^{-13} erg cm^{-3}. The equipartition magnetic fields are of the order of $\sim$ 0.1–1 μG.

Important information on the physical conditions in the radio sources is obtained from the radio spectra, which reflect the energy distribution of the radiating electrons.

The spectra of halos and relics are steep, typical of aged radio sources ($\alpha \gtrsim 1$[1]). As an example, the spectrum of the relic in the Coma cluster has a spectral index = 1.18 (Fig. 4). The spectral index between 0.3 and 1.4 GHz of the radio halo in A665 is $\alpha_{0.3}^{1.4}$ = 1.04. In the cluster A2163, shown in Fig. 1, the spectral index between the same frequencies is $\alpha_{0.3}^{1.4}$ = 1.18 (Feretti et al. 2004).

The spectrum of the Coma cluster halo is characterized by a steepening at high frequencies, which has been recently confirmed by single dish data (Fig. 5). The spectrum of the radio halo in A1914 (Fig. 6) is very steep, with an overall slope of $\alpha \sim 1.8$. A possible high frequency curvature is discussed by Komissarov & Gubanov (1994). In A754, Bacchi et al. (2003) estimate $\alpha_{0.07}^{0.3} \sim 1.1$, and $\alpha_{0.3}^{1.4} \sim 1.5$, and infer the presence of a possible spectral cutoff. Indication of a high frequency spectral steepening is also obtained in the halo of A2319, where Feretti et al. (1997) report $\alpha_{0.4}^{0.6}$ $\sim$ 0.9 and $\alpha_{0.6}^{1.4} \sim 2.2$.

In general, from the spectra of diffuse radio sources, it is derived that the radiative lifetime of the rela-

[1] $S_\nu \propto \nu^{-\alpha}$ through out this paper

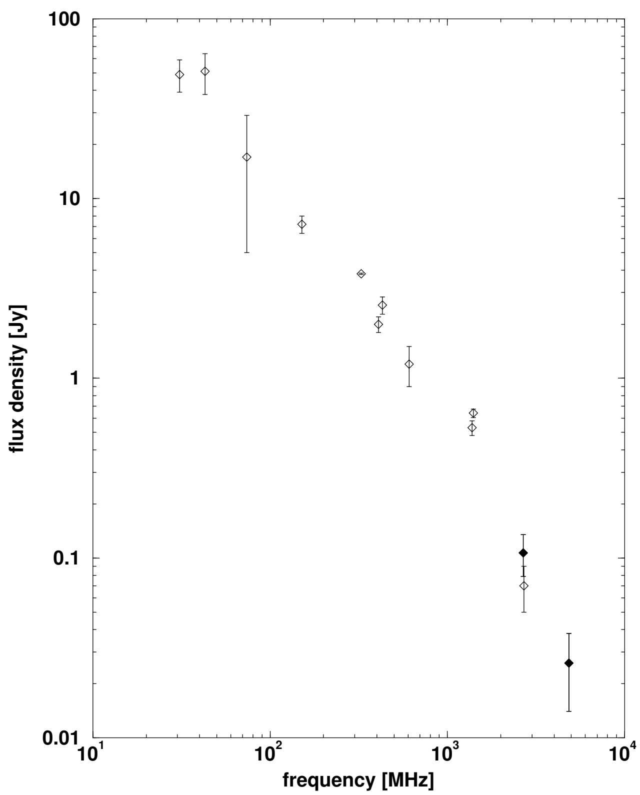

Figure 5: Total radio spectrum of the radio halo Coma C (from Thierbach, Klein & Wielebinski 2003).

tivistic electrons, considering synchrotron and inverse-Compton (IC) energy losses, is of the order of $\sim 10^8$ yr. This is too short to allow the particle diffusion throughout the cluster volume. Thus, the radiating electrons cannot have been produced at some localized point of the cluster, but they must undergo *in situ* energization.

3 What do we know from the radio - X-ray comparison: relativistic plasma and cluster merger

The arguments in favor of a connection between the presence of radio halos and the existence of merger processes have been reported in several papers (see, e.g., Feretti 2003, and references therein). Studies at the X-ray energies are of major importance in this respect since the thermal gas, which is directly observed in X-rays, bears the most evident signatures of cluster mergers. Complementary information on the cluster evolution can also be obtained by optical data (Girardi & Biviano 2002), as shown by the recent analysis of the halo cluster A2219 presented by Boschin et al. (2004).

In all clusters with halos and relics, substructures, distortions in the brightness distribution, temperature gradients and gas shocks are detected, which can be interpreted as the result of strong dynamical activity and sub-clump interaction. Cluster mergers are among the most energetic phenomena in the Universe, releasing gravitational binding energies of about 10^{64} erg. They generate shocks, bulk flows, turbulence in the ICM. These processes would provide energy to re-accelerate the radiating particles all around the cluster.

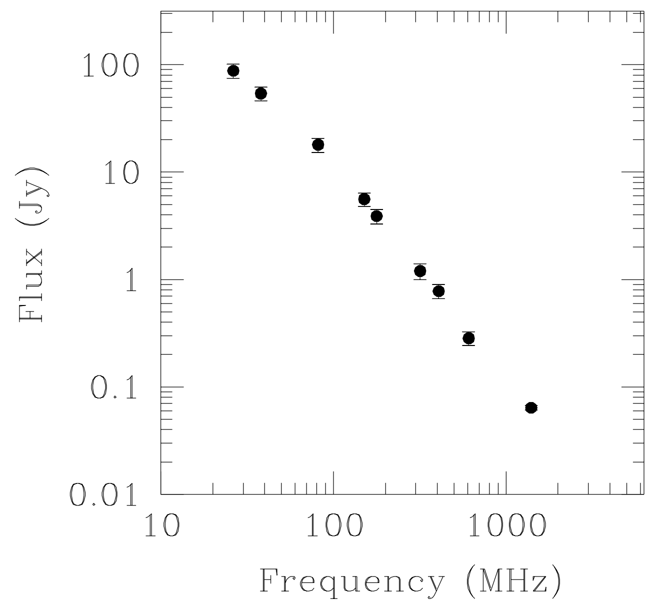

Figure 6: Integrated spectrum of the diffuse source in A1914 (Bacchi et al. 2003).

The connection to cluster mergers would explain at least in part why the diffuse emission is not detected in all clusters. Unlike the thermal X-ray emission, the presence of diffuse radio emission is not common in clusters of galaxies. In a complete sample, 5% of clusters have a radio halo source and 6% have a peripheral relic source (at the National Radio Astronomy Observatory Very Large Array Sky Survey surface brightness limit, e.g., Giovannini & Feretti 2002). The detection rate of diffuse radio sources increases with the cluster X-ray luminosity, reaching $\sim$ 35% in clusters with X-ray luminosity larger than $\sim 10^{45}$ erg s^{-1}. We note, however, that not all clusters showing recent mergers do exhibit a halo and/or a relic. A peculiar example is given by the cluster A3667, presented in Fig. 2, which shows two opposite relics, but not a radio halo, despite of the existence of a violent recent merger (Vikhlinin, Markevitch & Murray 2001). This case, and similar cases, will be discussed in Sect. 3.3.

3.1 Radio structure versus X-ray structure and gas temperature

A close similarity between the radio halo structure and the X-ray cluster structure detected by the *ROSAT* satellite was first noted by Deiss et al. (1997) for the Coma cluster, and quantitatively confirmed in Coma and in other clusters by Govoni et al. (2001). This similarity indicates a close link between the physical conditions of the radio source and those of the thermal component. Since the structure of the X-ray emission is generally related to a cluster merger process, a close connection between the structure of the halo and that of the X-ray gas supports a connection between the halo radio emission and the merger. A *Chandra* observation of A2744 (Kempner & David 2004) shows that the strong correlation between the radio and X-ray surface brightness found in the lower resolution *ROSAT* data is also visible at high resolution. In addition, *Chandra* data reveals that the main cluster is in a highly disturbed state, with several shocks in the cluster core. Also, there is a small merging subcluster, which is being ram-pressure stripped by its interaction with the main cluster.

High resolution *Chandra* X-ray data have been recently analyzed for a sample of clusters with halos or relics. In some clusters there is a correlation between the radio halo emission and the hot gas regions (Govoni et al. 2004). In all these clusters temperature gradients and gas shocks are detected, confirming the presence of mergers (Govoni et al. 2004; Markevitch, this volume). Although it may be difficult in several case to disentangle the geometry of the cluster merger, it is generally deduced that the cluster merger is likely to supply the energy for the electron re-acceleration. Velocities inferred for merger shocks at the cluster centers have Mach numbers of the order of $\sim$ 1–2 (Markevitch, Vikhlinin & Forman 2003, and references therein), which seem too low to accelerate the radio halo electrons (Gabici & Blasi 2003). This lends support to turbulent re-acceleration models for radio halo formation.

High resolution X-ray data of the Coma cluster have been obtained with *XMM-Newton*. There evidence of recent merger activity at scales larger than $10'$, whereas the cluster core is suggested to be in a basically relaxed state (Arnaud et al. 2001).

3.2 Radio spectral index maps versus X-ray emission

Spectral index maps represent a powerful tool to study the properties of the relativistic electrons and of the magnetic field, and to investigate the connection between the electron energy distribution and the ICM. By combining high resolution spectral information and X-ray images it is possible to study the thermal-relativistic plasma connection both on small scales (e.g., spectral index variations versus clumps in the ICM distribution) and larger scales (e.g., radial spectral index trends).

The first spectral index image of a radio halo has been obtained by Giovannini et al. (1993) for Coma C, using data at 327 MHz from the Westerbork Synthesis Radio Telescope (WSRT) and data at 1.4 GHz from the Very Large Array (VLA) and the Dominion Radio Astronomy Observatory. The image shows a flat spectrum in the center ($\alpha \simeq 0.8$) and a progressive steepening with increasing distance from the center (up to $\alpha \simeq 1.8$ at a distance of about $15'$). This trend is confirmed by a new spectral index map derived by comparing the 1.4 GHz image obtained with the Effelsberg single dish by Deiss et al. (1997), and the 327 MHz image obtained from the combination of VLA and WSRT data (Giovannini et al. 2003). The high sensitivity of the images allows the computation of the spectral index up to $\sim 30'$ from the cluster center, where the spectral index is $\alpha \simeq 2$.

Since the diffusion velocity of relativistic particles is low with respect to their radiative lifetime, the radial spectral steepening cannot be simply due to aging of radio emitting electrons. Therefore the spectral steepening must be related to the intrinsic evolution of the local electron spectrum and to the radial profile of the cluster magnetic field. It has been shown by Brunetti et al. (2001) that a relatively general expectation of models invoking re-acceleration of relic particles is a radial spectral steepening in the synchrotron emission from radio halos. The steepening, which is difficult to reproduce by other models (such as those invoking secondary electron populations), is due to the combined effect of a radial decrease of the cluster magnetic field strength and the presence of a high energy break in the energy distribution of the re-accelerated electron population. In the framework of re-acceleration models, the radio spectral index map can be used to derive the physical conditions prevailing in the clusters, i.e.,

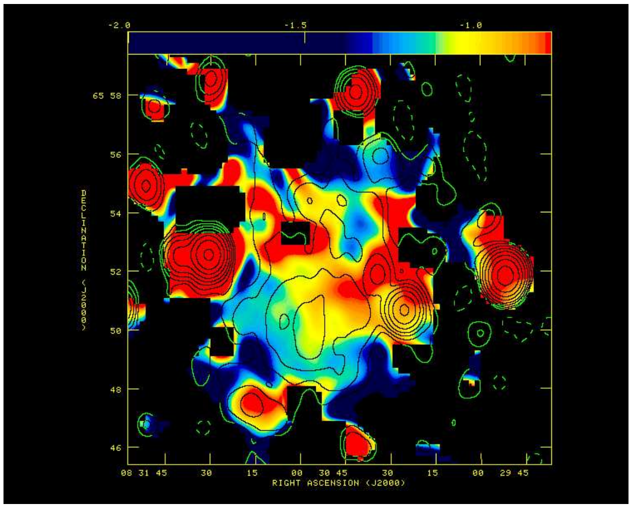

Figure 7: Color-scale image of the spectral index of A665 (at $z = 0.1818$) between 0.3 GHz and 1.4 GHz. The contours indicate the radio emission at 1.4 GHz (from Giovannini & Feretti 2000). The radio emission is asymmetric with respect to the cluster center. It is brighter and more extended toward the NW, which is the region of flatter spectrum.

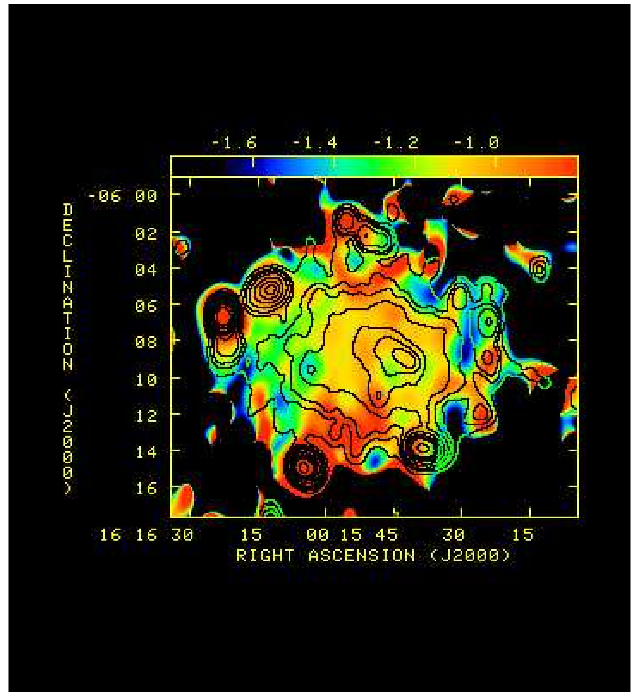

Figure 8: Color-scale image of the spectral index of A2163 (at $z = 0.203$) between 0.3 GHz and 1.4 GHz. The contours indicate the radio emission at 1.4 GHz (from Feretti et al. 2001). The spectrum is flatter in the vertical region across the cluster center.

re-acceleration coefficients (efficiency) and magnetic field strengths. From the application of this method to Coma C, Brunetti et al. (2001) obtained large scale re-acceleration efficiencies of the order of $\sim 10^8$ yr^{-1} and magnetic field strengths ranging from 1–3 μG in the central regions down to 0.05–0.1 μG in the cluster periphery.

Maps of the radio spectral index between 0.3 GHz and 1.4 GHz have been very recently obtained for two more radio halos, those in A665 and A2163, using VLA data with an angular resolution of the order of $\sim 1'$ (Feretti et al. 2004).

The spectral index map in A665 is clumpy (Fig. 7). The spectrum in the central halo region is rather constant, with spectral index values between 0.8 and 1.2 within one core radius from the cluster center (i.e., within $\sim 95''$). In the northern region of lower radio brightness, the spectrum is flatter. This is the region where asymmetric extended X-ray emission is present, indicating the existence of a recent major merger. The gas temperature here (Markevitch & Vikhlinin 2001, Govoni et al. 2004) shows strong variations, from about 12 keV in the N-E to about 8 keV in the S-W. Therefore it seems that this region, which is presently strongly influenced by the merger, is a shocked area where the gas at different temperatures is still in the process of mixing. In the southern cluster region the spectrum steepens significantly from the center to the periphery, with the spectral index gradually increasing from $\alpha \sim 1$ to $\alpha \gtrsim 2$ at a distance of about $4'$. In the southern bright edge of the radio halo the presence of a hot shock has been revealed by *Chandra* X-ray data (Markevitch & Vikhlinin 2001). No significant spectral flattening is detected at this position. This is consistent with the fact that shocks in major mergers are too weak for particle acceleration (Gabici & Blasi 2003) and indeed the Mach number of the shock in A665 is ~ 2 (Markevitch & Vikhlinin 2001). Our result supports the scenario that cluster turbulence might be a major source of energy input for the radiating electrons.

The spectral index map of A2163 is rather constant in the central region with the spectral index values between 1 and 1.1. On larger scales it is clumpy with the evidence that the western halo region has a flatter spectrum than the eastern region. Particularly, there is a vertical region crossing the cluster center and showing flatter spectrum, with a clear evidence of spectral flattening both at the northern and southern halo boundaries. The X-ray data show a complex morphology and temperature distribution, indicating that the cluster central region is in a state of violent motion (Markevitch & Vikhlinin 2001, Govoni et al. 2004). The N-S extent of the region with flat spectrum is in support of a merger occurring in the E-W direction, as indicated by the X-ray brightness distribution. The complexity of the merger is reflected in the complexity of the spectral index map.

The spectral index maps presented above show features (flattening and patches) which are indicative of a complex shape of the radiating electron spectrum, and are therefore in support of electron re-acceleration models. Regions of flatter spectrum are found to be related to the recent merger activity in these clusters. This is the first strong confirmation that the cluster merger supplies energy to the radio halo. We estimated that the energy injected into the electron population in the region directly influenced by the merger is larger by a factor of ~ 2.5. Alternatively, if electrons have been re-accelerated in the past and they are simply aging, the flatter spectrum would reflect a spectral cutoff at higher energies. We estimate that the electrons in the flat spectrum regions have been re-accelerated more recently by $\sim 5\ 10^7$ yr.

In the undisturbed cluster regions the spectrum steepens with the distance from the cluster center. This is interpreted as the result of the combination of the magnetic field profile with the spatial distribution of the re-acceleration efficiency, thus allowing us to set constraints on the radial profile of the cluster magnetic field (see Feretti et al. 2004 for the details).

A study of the spectral index distribution in the relics of A3667 has been performed by Johnston-Hollitt (2003). A steepening from the external to the internal rim, consistent with electron re-acceleration in the merger shock, is found.

3.3 Radio quantities versus X-ray quantities

A correlation between the monochromatic radio power of the halo at 1.4 GHz and the bolometric X-ray luminosity of the parent cluster (Fig. 9) was first noted by Liang et al. (2000) and confirmed by later studies (see, e.g., Giovannini & Feretti 2002). Using only clusters with giant radio halos (size > 1 Mpc) the best fit between radio and X-ray luminosity is $P_{1.4GHz} \propto L_X^{1.68\pm0.15}$. An overall correlation is still present, although with a larger dispersion, if halos of smaller extent and/or relics are added.

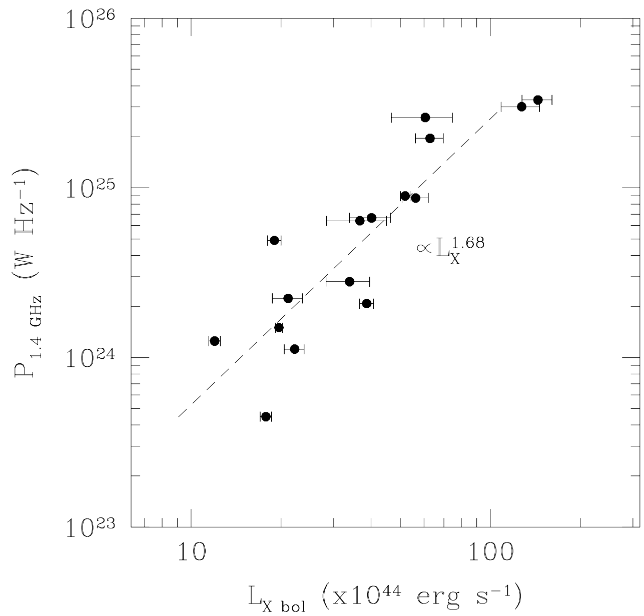

Figure 9: Monochromatic radio power at 1.4 GHz of halos larger than 1 Mpc versus cluster bolometric X-ray luminosity. The dashed line represents the best fit to the data.

We stress that this correlation is only valid for clusters showing radio halos, i.e., merging clusters, thus it cannot be generalized to all clusters of galaxies. It is not clear if it can be extrapolated to low radio powers and low X-ray luminosities. Moreover, it is difficult to extend such a correlation by including the upper limits for the undetected halos, since the computation of an upper limit to the radio power would imply the knowledge of the total size of a possible radio halo.

Figure 10 shows the radio surface brightness of the halo at 1.4 GHz versus the X-ray surface brightness, which are two directly observable parameters. The radio brightness is the average over a cluster central region within one cluster core radius. For convenience, it is expressed in the same units as the radio brightness of the NRAO VLA Sky Survey images, which are obtained with an observing beam of 45″. The X-ray brightness is the average over the same region as the radio brightness, and has been obtained using *ROSAT* X-ray images, thus it refers to the *ROSAT* energy band 0.1–2.4 keV. This plot contains a limited number of clusters, because of the difficulty in deriving the X-ray surface brightness.

Figure 11 presents the radio surface brightness computed as above versus the clusters bolometric X-ray luminosity. This choice of parameters is convenient because the cluster luminosity is available for a large

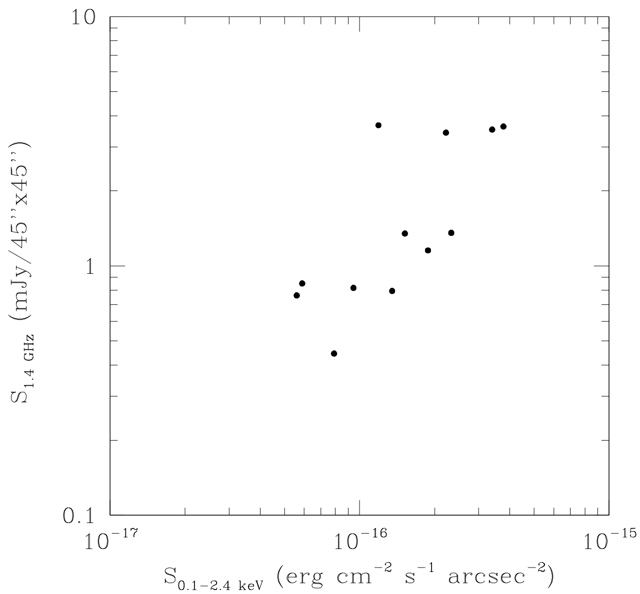

Figure 10: Radio brightness at 1.4 GHz in mJy beam^{-1} (45″×45″) versus cluster X-ray brightness in the *ROSAT* band.

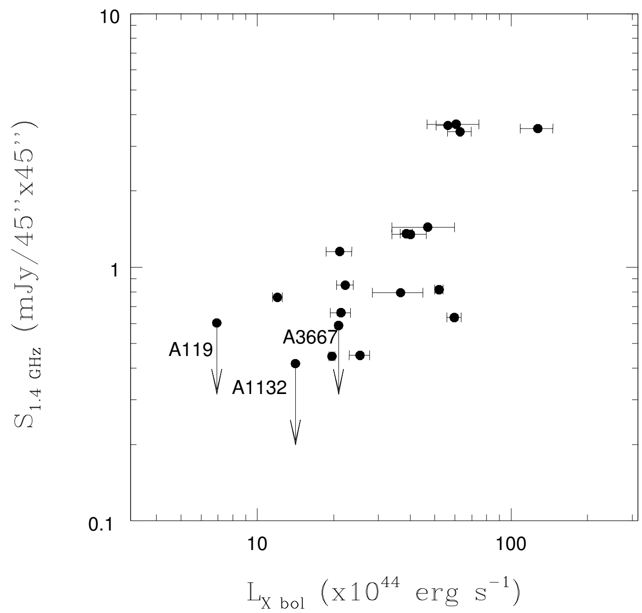

Figure 11: Radio brightness at 1.4 GHz in mJy/(45″×45″) versus cluster bolometric X-ray luminosity. Upper limits to the radio brightness of a possible halo are given for the merging clusters A119, A1132 and A3667.

number of clusters, observed by different X-ray satellites. This correlation can be used to set upper limits to the radio emission for those clusters where a radio halo is not detected. One of these clusters is A3667, which hosts two radio relics, but no central radio halo. We report also limits for two other merging clusters observed by Giovannini & Feretti (2000). It is interesting to note that these upper limits are consistent with the correlation, thus indicating that merging clusters with low X-Ray luminosity might host faint radio halos which could only be detected by very sensitive radio observations possibly with future generation instruments (LOFAR, SKA). Future data will indeed clarify if all merging clusters host a radio halo.

4 Radio - X-ray comparison: non-thermal emission

X-ray emission of non-thermal origin is expected in clusters with diffuse radio sources, as the high energy relativistic electrons ($\gamma \sim 10^4$) scatter off the cosmic microwave background, boosting photons from this radiation field to the hard X-ray domain by IC process. Since the X-ray and radio emissions are produced by the same population of electrons undergoing IC and synchrotron energy losses, respectively, the ratio between the X-ray and the radio luminosities is proportional to the ratio between the CMB and the magnetic field energy densities. Thus the comparison between radio and hard X-ray emission enables the determination of the electron density and of the mean magnetic field directly, without invoking equipartition.

A significant breakthrough in the measurement of hard X-ray emission was recently obtained owing to the improved sensitivity and wide spectral capabilities of the *BeppoSAX* and the *Rossi* X-ray Timing Explorer (*RXTE*) satellites (see the review by Fusco-Femiano et al. 2003, and references therein). The detection of significant non-thermal hard X-ray emission at energies $\gtrsim$ 20 keV has been reported for the two clusters Coma and A2256. From a recent 300 ks exposure on Coma, obtained with *BeppoSAX*, the detection in this cluster was confirmed and strengthened by Fusco-Femiano et al. (2004). On the other hand, Rossetti & Molendi (2004) could not confirm the non-thermal X-ray detection. However, they analyzed the data using a different software probably less sensitive to faint emission.

The 20–80 keV flux in Coma is $\sim 1.5\times10^{-11}$ erg cm^{-2} s^{-1}, which leads to a magnetic field of $\sim$ 0.2 μG. In A2256, the flux in the same energy range is $\sim 9\times10^{-12}$ erg cm^{-2} s^{-1}. A magnetic field of $\sim$ 0.05 μG is derived for the northern cluster region, where the radio relic is detected, while a higher field value, $\sim$ 0.5 μG, could be present at the cluster center, in the region of the radio halo.

A detection has been obtained for A754, but the presence of point sources in the field of view makes the IC interpretation unlikely. For the clusters A119, A2163, A2199 and A3667, only upper limits to the non-thermal X-ray emission have been derived. A possible detection of localized IC emission associated with the radio relic and with merger shocks has been claimed in A85 from *ROSAT* data (Bagchi, Pislar & Lima-Neto 1998).

BeppoSAX ceased its activity in April 2002. Future studies of non-thermal X-ray emission in clusters will be possible with *INTEGRAL*, whereas the satellite *XMM-Newton* will be suitable for the investigation of clusters of low temperature.

5 Conclusions

Massive clusters of galaxies showing strong dynamical activity and merger processes can host diffuse radio emission, which demonstrates the existence of relativistic particles and magnetic fields in the ICM.

From the comparison between radio and X-ray emission there is evidence that recent merger phenomena would provide the energy for the relativistic electron re-acceleration, thus allowing the production of a detectable diffuse radio emission.

The connection between halos and mergers favors halo models where the radiating particles are primary electrons re-accelerated in situ. The spectral index properties in radio halos (high frequency cutoff and radial steepening) can be easily reproduced by models invoking the re-acceleration of the relativistic particles.

Spectral index maps of the halos of A665 and A2163 show regions of flatter spectrum that appear to trace the geometry of recent merger activity as suggested by X-ray maps. No evidence of spectral flattening at the location of the hot shock detected in A665 is found, favoring the scenario that cluster turbulence might be primarily responsible for the electron re-acceleration. This scenario is also supported by the relatively low Mach numbers of shocks at the cluster centers.

It seems that ongoing violent mergers may play a crucial role in determining the conditions of the radiating particles and of the magnetic fields in clusters. A question which is still unanswered is whether all merging clusters have cluster-wide radio halos. This will be answered by systematic deep studies with future instruments.

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