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# Radio-bimodality in galaxy clusters and future observations at low radio frequencies: constraining the origin of giant radio halos

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Radio observations discovered large scale non thermal sources in the central Mpc regions of dynamically disturbed galaxy clusters (radio halos). The morphological and spectral properties of these sources suggest that the emitting electrons are accelerated by spatially distributed and gentle mechanisms, providing some indirect evidence for turbulent acceleration in the inter-galactic-medium (IGM). Radio and X-ray surveys allow to investigate the statistics of radio halos and unveil a bimodal behaviour of the radio properties of galaxy clusters: merging clusters host radio halos and trace the well known radio–X correlation, while more relaxed clusters do not host radio halos and populate a region well separated from that spanned by the above correlation. This appears consistent with the hypothesis that relativistic electrons are reaccelerated by MHD turbulence generated during cluster mergers. In the context of this model the population of radio halos consists of a mixture of halos with different spectral propertis, most of them with very steep spectrum and visible only at low radio frequencies. For this reason the future LOFAR surveys may provide a robust test to this theoretical hypothesis.

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## 1. Introduction

Radio observations of galaxy clusters prove the presence of non-thermal components, magnetic fields and relativistic particles, mixed with the hot Inter-Galactic-Medium (IGM) (e.g., Ferrari et al., 2008). These components deserve some attention since they provide an additional source of energy in the IGM and may drive still unexplored physical processes modifying our simplified view of the IGM (Schekochihin et al. 2005; Subramanian et al. 2006; Brunetti & Lazarian 2007; Guo et al. 2008).

During cluster mergers a fraction of the gravitational binding–energy of Dark Matter halos that is converted into internal energy of the barionic matter can be channelled into the amplification of the magnetic fields (e.g. Dolag et al. 2002; Subramanian et al. 2006; Ryu et al. 2008) and into the acceleration of particles via shocks and turbulence (e.g. Ensslin et al 1998; Sarazin 1999; Blasi 2001; Brunetti et al. 2001, 2004; Petrosian 2001; Miniati et al. 2001; Ryu et al. 2003; Hoeft & Bruggen 2007; Brunetti & Lazarian 2007; Pfrommer 2008).
Upper limits to the gamma ray emission from galaxy clusters, obtained by FERMI and Cherenkov telescopes (eg., Aharonian et al 2009a,b; Aleksic et al 2010; Ackermann et al 2010), together with constraints from complementary approaches based on radio observations (eg., Reimer et al 2004; Brunetti et al 2007) suggest that relativistic protons contribute to less than a few percent of the energy of the IGM, at least in the central Mpc–sized regions.
On the other hand, the acceleration of relativistic electrons in the IGM is directly probed by radio observations of diffuse synchrotron radiation from galaxy clusters. *Radio halos* are the most spectacular examples of cluster-scale radio sources, they are diffuse radio sources that extend on Mpc-scales in the cluster central regions and are found in about $1/3$ of massive galaxy clusters with complex dynamics (eg. Feretti 2002; Ferrari et al. 2008; Cassano 2009).
The origin of radio halos is still debated. According to a first hypothesis, radio halos are due to synchrotron emission from secondary electrons generated by p-p collisions (Dennison 1980; Blasi & Colafrancesco 1999; Pfrommer & Ensslin 2004), in which case clusters are (unavoidably) gamma ray emitters due to the decay of the $\pi^o$ produced by the same collisions. The non-detections of nearby galaxy clusters at GeV energies by FERMI significantly constrain the role of secondary electrons in the non-thermal emission (Ackermann et al. 2010). Most important, the spectral and morphological properties of a number of well studied radio halos appear inconsistent with a pure hadronic origin of the emitting particles (eg. Brunetti et al 2008, 2009; Donnert et al 2010a,b; Macario et al 2010).
A second hypothesis is based on turbulent reacceleration of relativistic particles in connection with cluster–mergers events (eg., Brunetti et al. 2001; Petrosian 2001; Fujita et al 2003; Cassano & Brunetti 2005). The acceleration of thermal electrons to relativistic energies by MHD turbulence in the IGM faces serious drawbacks based on energy arguments (eg., Petrosian & East 2008), consequently in these models it must be assumed a pre-existing population of relativistic electrons in the cluster volume that provides the seed particles to reaccelerate during mergers.

In addition to the spectral and morphological properties of radio halos and to the constraints on the gamma ray emission from clusters, the statistical properties of radio halos and their connection with cluster formation and evolution provide crucial insights into the physics and origin of non-thermal components in the IGM.



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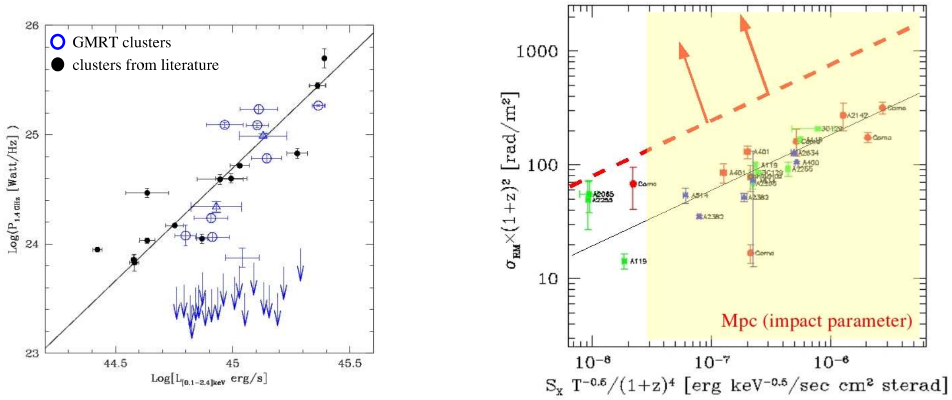


**Figure 1: Left Panel**: distribution of galaxy clusters in the radio – X-ray luminosity diagram (from Brunetti et al 2009). Blue symbols mark clusters of the GMRT sample. The solid line is the radio – X-ray correlation of radio halos. **Right Panel**: distribution of clusters (several line of sights per cluster) in the $\sigma_{RM}$–X-ray brightness diagram (from Govoni et al 2010). Solid thin line marks the case where all clusters have the same magnetic field properties, the thick dashed line mimics the effect of a magnetic field 3 times larger. Cluster sources at (about) $\leq$ Mpc (projected) distances from cluster centers fall in the shadowed region.

In this paper we focus on the most recent advances in the study of the statistical propertis of radio halos and their connection with cluster mergers (radio bimodality), and discuss the importance of future surveys at low radio frequencies to test present models.

## 2. The radio bimodality of galaxy clusters

A first observational settlement of the properties of radio halos, at $z \leq 0.2$, and of their connection with cluster mergers has been obtained by means of deep follow ups with the VLA of candidates radio halos identified with the NVSS and WENSS radio surveys (Giovannini et al., 1999; Kempner & Sarazin 2001). A step forward has been recently achieved through a project carried out with the Giant Metrewave Radio Telescope (GMRT, Pune-India) at 610 MHz, the "GMRT Radio Halo Survey" (Venturi et al. 2007, 2008).

The "GMRT Radio Halo Survey" allows to unveil a *bi-modal* behaviour of the radio properties of galaxy clusters (Fig. 1a), with radio-halo clusters and clusters without radio halos clearly separated (Brunetti et al. 2007). The radio bimodality sheads new light on the evolution of non-thermal components in galaxy clusters and on their connection with cluster dynamics. More recently Cassano et al.(2010a) found that the bimodal behaviour in Fig.1a has a correspondence in terms of

cluster dynamical properties, with radio halos found in merging clusters and “radio quiet” clusters being systematically more relaxed systems.
This suggests the following coupled evolution between radio halos and cluster dynamics :

- *i)* galaxy clusters host giant radio halos for a period of time, in connection with cluster mergers, and populate the $P_{1.4}$–$L_X$ correlation (Fig.1a);

- *ii)* at later times, when clusters become dynamically relaxed, the Mpc-scale synchrotron emission is gradually suppressed and clusters populate the region of the upper limits.

When restricting to clusters of the GMRT complete sample, Fig. 1a provides a fair statistical sampling of the evolutionary flow of X–ray luminous clusters in the $P_{1.4}$–$L_X$ plane at z=0.2-0.4. Radio-halo clusters in the GMRT sample, that are always dynamically disturbed systems, must be the “youngest” systems, where an ongoing merger, leading to their formation (or accretion of a sizable fraction of their mass), is still supplying energy to maintain the synchrotron emission. On the other hand, clusters with radio upper limits, that are more relaxed than radio halo clusters, must have experienced the last merger at earlier epochs : after the last merger they already had sufficient time for suppression of the synchrotron emission and consequently they should be the “oldest” systems in the GMRT sample. Clusters in the “empty” region may be “intermediate” systems at late merging phases, where synchrotron emission is being suppressed, or “very young” systems in the very early phases of a merging activity, where synchrotron emission is increasing.

19 clusters in the GMRT sample have $L_X \geq 8.5 \times 10^{44}$erg s$^{-1}$, in which case the radio power of giant radio halos is $\sim$1 order of magnitude larger than the level of the radio upper limits. Of these 19 clusters 5 host giant radio halos (and 2 mini-halos in cool-core clusters), 11 clusters are “radio quiet” and only RXJ1314 is in the “empty” region. This allows for estimating the life–time of radio halos, $\tau_{rh} \approx 1$ Gyr, and the time clusters spend in the “radio–quiet” phase, $\tau_{rq} \approx 2-2.5$ Gyr (Brunetti et al 2009). Most importantly, at these luminosities, the “emptiness” of the region between radio halos and “radio quiet” clusters in the $P_{1.4}$–$L_X$ diagram constrains the time-scale of the evolution (suppression and amplification) of the synchrotron emission in these clusters (Brunetti et al. 2007, 2009). The significant lack of clusters in this region suggests that this time-scale is much shorter than both the “life-time” of clusters in the sample and the period of time clusters spend in the radio halo stage. Monte Carlo analysis of the distribution of clusters in Fig. 1a shows that the time interval that clusters spend in the “empty” region (thus the corresponding time–scale for amplification and suppression of radio halos) is $\tau_{evol} \approx 200$ Myr, with the probability that $\tau_{evol}$ is as large as 1 Gyr $\leq 1\%$ (Brunetti et al. 2009).

## 3. Implications of bimodality for the origin of giant radio halos

The radio properties of galaxy clusters are driven by the evolution of the relativistic components (B and particles) in the IGM. The tight constraints on the time–scale evolution of the clusters radio properties, $\tau_{evol} \approx 200$ Myr, provides crucial information on the physics of the particle acceleration and magnetic field amplification.



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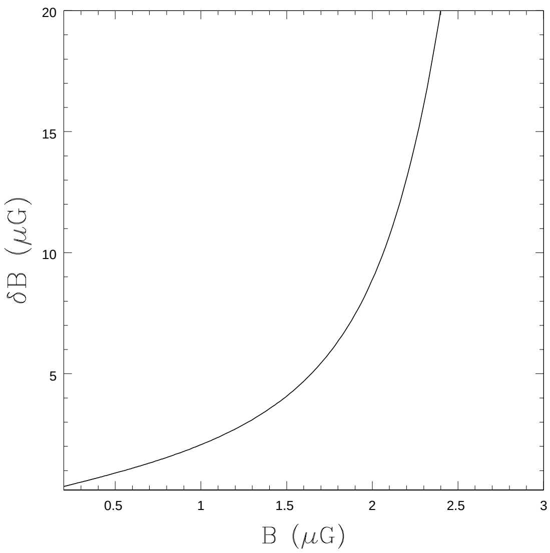


**Figure 2:** The minimum excess of magnetic field strength that is necessary to have a synchrotron amplification of about 10 times in radio halo clusters (at redshift 0.25) is shown as a function of the magnetic field in “radio quiet” clusters.

### 3.1 Magnetic field evolution ?

A first possibility to explain the bimodality is that cluster mergers amplify the magnetic field in the IGM leading to the amplification of the synchrotron emission on Mpc scales. In this case, merging clusters hosting radio halos have larger magnetic fields, $\delta B + B$, with the excess $\delta B$ being generated during mergers and then dissipated when clusters become “radio quiet” and more dynamically relaxed (Brunetti et al. 2007, 2009; Kushnir et al. 2009).
The condition for a suppression $\geq$10 in terms of synchrotron emission (Fig. 1a) constrains the ratio between the magnetic fields in radio halos, $B+\delta B$, and that in “radio quiet” clusters, $B$ :

$$(\frac{B+\delta B}{B})^{\alpha-1} \frac{1+(\frac{B_{cmb}}{B})^2}{1+(\frac{B_{cmb}}{B+\delta B})^2} \geq 10 \tag{3.1}$$

where $B_{cmb} = 3.2(1+z)^2 \mu$G is the equivalent field of the CMB and $\alpha \sim 1.3$ is the typical synchrotron spectral index of radio halos. The amplification factor of the magnetic field is shown in Fig. 2 for $z \approx 0.25$, typical of GMRT clusters. In the case $B+\delta B << B_{cmb}$, the energy density of the magnetic field in radio halo clusters should be $\geq$10 times larger than that in "radio quiet" clusters, and even larger ratios must be admitted if $B+\delta B >> B_{cmb}$.

This significant difference between the magnetic field strength in radio halo and "radio quiet" clusters disfavours an interpretation of the radio bimodality based on the amplification/suppression of the cluster magnetic field. Indeed Faraday Rotation measurements (RM) in galaxy clusters do not find any statistical difference between the energy density of the large scale (10-100 kpc coherent scales) magnetic field in radio halo clusters and that in "radio quiet" clusters (e.g., Carilli & Taylor 2002). For example, in a recent paper, Govoni et al (2010) presented a study of RM of radio sources in a sample of hot galaxy clusters, including both “radio-quiet” and clusters with well known radio halos (eg. Coma, A2255, ..). In Fig. 1b we show the $\sigma_{RM} - S_X$ distribution from Govoni et al., $\sigma_{RM}$ and $S_X$ being the $\sigma$ of the RM and the X–ray (thermal) cluster brightness measured along several radio sources at different (projected) distances from cluster centers. Since $\sigma_{RM} \propto \Lambda_c \int (n_{th} B_{\parallel})^2 dl$ ($\Lambda_c$ the field coherent scale) Fig.1b provides an efficient way to separate the magnetic and thermal properties of clusters. Although the still poor statistics, Fig.1b shows that the magnetic field strength in “radio–quiet” and radio halo clusters is similar (the thin solid line is obtained for a fixed value of $B$ and $\Lambda_c$). On the other hand, the dashed line in Fig.1b marks the region where radio halo clusters should have been found if the radio bimodality is driven by the magnetic field amplification/suppression (according to Fig. 2).

### 3.2 Bimodality and acceleration/cooling of relativistic particles

*RM suggests that a “single” mode exists for the magnetic field in galaxy clusters and consequently that the observed radio bimodality implies a corresponding bimodality in terms of the emitting relativistic particles in the IGM.*

#### 3.2.1 The case of pure secondary models

Theoretically relativistic protons are expected to be the dominant non-thermal particles component since they have long life-times and remain confined within galaxy clusters for a Hubble time (Völk et al. 1996; Berezinsky, Blasi & Ptuskin 1997; Ensslin et al 1998). The confinment of cosmic rays is a natural consequence of the Mpc sizes and magnetization of galaxy clusters. Assuming a Kolmogorov spectrum of the magnetic field fluctuations, the time necessary to diffuse on Mpc scale is (eg Blasi & Colafrancesco 1999) :

$$\tau_{diff}(Gyr) \approx 65 R^2_{Mpc} (\frac{E}{100GeV})^{-1/3} B^{1/3}_{\mu G} (\frac{\Lambda_c}{20kpc})^{-2/3} \quad (3.2)$$

Tangled magnetic fields with coherent scales $\Lambda_c \approx 10-30$ kpc are routinely derived through RM analysis of extended radio sources at different (projected) distances from cluster centres in both relaxed ("radio quiet") clusters and in radio halo clusters (eg. Clarke et al 2001; Murgia et al 2004; Govoni et al 2010) implying diffusion time–scales of cosmic rays of many Gyrs.
Consequently, classical hadronic models, where the emitting electrons are continuously generated by p-p collisions, predict a population of secondaries that is almost independent of the dynamical status of the hosting clusters (eg., Blasi et al 2007 for review). As a matter of fact suppression of radio halos on time–scales of $\sim$200 Myrs via (ad hoc) diffusion of cosmic rays from the central Mpc regions implies extreme diffusion velocities, $\approx 100 \times v_A$, in which case plasma instabilities (eg streaming instability) are expected to damp the diffusion process itself.
Thus the observed radio bimodality and the short $\tau_{evol}$ would be difficult to reconcile with these models.

#### 3.2.2 The case of turbulent acceleration

The radio bimodality and the constrained time–scale for the evolution of clusters radio properties suggest that relativistic electrons are accelerated in situ on Mpc–scales (and maintained) during cluster mergers and that they cool as soon as clusters become more relaxed. Remarkably the cooling time of GeV electrons in the IGM is $\sim 10^8$ yrs, much shorter than all the other relevant time–scales, and may potentially fit the short value of $\tau_{evol}$ as constrained by the distribution of galaxy clusters in Fig. 1a.

As soon as large scale turbulence in the ICM reaches smaller, resonant, scales (via cascading or induced plasma instabilities, e.g. Brunetti et al. 2004, Lazarian & Beresnyak 2006, Brunetti & Lazarian 2007), particles are accelerated and generate synchrotron emission. In the case of radio halos emitting at GHz frequencies the acceleration process should be relatively efficient and particles get accelerated to the energies necessary to produce synchrotron GHz–emission within a time-scale smaller than a couple of cooling times of these electrons, that is $\approx 100$ Myrs. Although the large uncertainties in the way large scale turbulence is generated in the IGM during cluster mergers, it is likely that the process persists for a few crossing times of the cluster-core regions, that is fairly consistent with a radio halo life-time $\tau_{rh} \sim 1$ Gyr as derived in Section 3.1.
Most importantly, the cooling time of the emitting electrons is smaller than (or comparable to) the cascading time-scale of the large-scale turbulence implying that the evolution of the synchrotron power depends very much on the level of MHD turbulence in the ICM (e.g., Brunetti & Lazarian 2010). Consequently, when the injection of MHD turbulence is suppressed (eg. at late merging-phase), then also the synchrotron emission at higher radio frequencies is suppressed, falling below the detection limit of radio observations, as soon as the energy density of turbulence starts decreasing.

Consequently in this scenario cluster *bi-modality* may be expected because the transition between radio halos and “radio quiet” clusters in the $P_{1.4}$–$L_X$ diagram is predicted to be fairly fast (Brunetti et al. 2007, 08) provided that the acceleration process we are looking in these sources is not very efficient, being just sufficient to generate radio halos emitting at a few GHz frequencies (in which case radio halos disappear as soon as a fraction of turbulence is dissipated). Interestingly, a relatively inefficient electron acceleration process in radio halos (with acceleration time about 100 Myrs) is in line with the steep spectrum observed in some halos and with the presence of a spectral steepening at higher frequencies discovered in a few halos (e.g., Thierbach et al. 2003, Brunetti et al. 2008, Dallacasa et al. 2009, Giovannini et al 2009).

## 4. Testing turbulent acceleration with LOFAR surveys

LOFAR promises an impressive gain of two orders of magnitude in sensitivity and angular resolution over present instruments in the frequency range 15–240 MHz, and as such will open up a new observational window to the Universe.

The steep spectrum of radio halos makes these sources ideal targets for observations at low radio frequencies suggesting that present radio telescopes can only detect the tip of the iceberg of their population (Enßlin & Röttgering 2002; Cassano et al. 2006).

In the picture of the *turbulent re-acceleration* scenario, the formation and evolution of radio halos are tightly connected with the dynamics and evolution of the hosting clusters. Indeed, the occurrence of radio halos at any redshift depends on the rate of cluster-cluster mergers and on the fraction of the merger energy channelled into MHD turbulence and re-acceleration of high energy particles. In the past few years, this has been modeled by Monte Carlo procedures (Cassano & Brunetti 2005; Cassano et al. 2006) that provide predictions verifiable by future instruments.

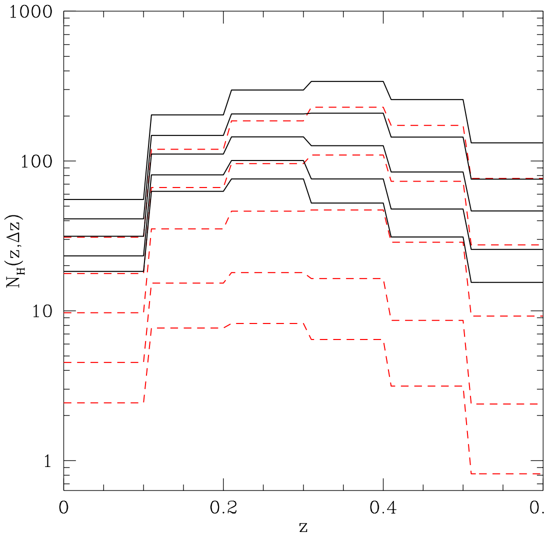


**Figure 3:** All sky number of expected radio halos (with $\nu_s \geq 120$ MHz) as a function of redshift assuming sensitivities = 0.1, 0.25, 0.5, 1.0, 1.5 mJy/beam (solid lines, from top to bottom) at 120 MHz (from Cassano et al 2010b). Dashed lines show number counts for very steep spectrum radio halos, with $\nu_s$ in the range 120–600 MHz.

Stochastic particle acceleration by MHD turbulence is believed to be rather inefficient in the IGM. Consequently, electrons can be accelerated only up to energies of $m_e c^2 \gamma_{max} \leq$ several GeV, since at higher energies the radiation losses are efficient and hence dominate. The consequent spectral steepening expected in the synchrotron spectrum makes it difficult to detect these sources at frequencies higher than the frequency, $\nu_s$, at which the steepening becomes severe; $\nu_s$ given by (eg Cassano et al. 2010b)

$$\nu_s \propto <B> \gamma_{max}^2 \propto \frac{<B> \chi^2}{\left(<B>^2 + B_{cmb}^2\right)^2} \tag{4.1}$$

where $\chi \simeq 4D_{\rm pp}/p^2$, $p$ is the momentum of the electrons and $D_{pp}$ is the electron diffusion coefficient in the momentum space due to the coupling with turbulent waves. In the case of a single merger between a cluster with mass $M_v$ and a subcluster of mass $\Delta M$, Cassano & Brunetti (2005) derived that $\chi$ can be approximated by

$$\chi \propto \frac{\eta_t}{R_H^3} \left(\frac{M_v + \Delta M}{R_v}\right)^{3/2} \frac{r_s^2}{\sqrt{k_B T}} \times \begin{cases} 1 & \text{if}\, r_s \leq R_H \\ (R_H/r_s)^2 & \text{if}\, r_s > R_H\,, \end{cases} \tag{4.2}$$

where $r_s$ is the stripping radius of the subcluster crossing the main cluster, i.e., the distance from the center of the subcluster where the static pressure equals the ram pressure (see Cassano & Brunetti 2005 for details), $R_H$ is the size of the radio halo, and $R_v$ and $T$ are the virial radius and temperature of the main cluster, respectively.
Combined with Eq. 4.1, this implies that higher values of $\nu_s$ are expected in the more massive clusters, $\nu_s \propto (M_v/R_v)^3/T \propto M_v^{4/3}$ (here considering for simplicity a fixed value of $B$, see Cassano

et al. 2006 for a more general discussion), and in connection with major merger events, $\nu_s \propto (1+\Delta M/M)^3$ ($r_s$ in Eq.4.2 also increases with $\Delta M/M$).
Consequently only the most energetic merger-events in the Universe can generate giant radio halos with $\nu_s \geq 1$ GHz (Cassano & Brunetti 2005). Similar energetics arguments can be used to claim that radio halos with lower values of $\nu_s$ must be more common, since they can be generated in connection with less energetic phenomena, eg major mergers between less massive systems or minor mergers in massive systems (eg Eqs. 4.1-4.2), that are more common in the Universe (eg Cassano et al. 2010b). *The existence of a large number of radio halos emitting preferentially at lower radio frequencies is a unique expectation of turbulent models which stems from the nature of the mechanism of turbulent acceleration that is a poorly efficient process.*

Based on recent Monte Carlo calculations (Cassano et al 2010b), Fig. 3 shows the expected all-sky number of radio halos with $\nu_s \geq 120$ MHz in different redshift intervals detectable by typical LOFAR surveys of different sensitivities (0.1 … 1.5 mJy/beam, see figure caption). The LOFAR all-sky survey, that should reach an rms=0.1 mJy/beam at 120 MHz, is expected to detect more than 350 radio halos at redshift $\leq$0.6, in the northern hemisphere ($\delta \geq 0$) and at high Galactic latitudes ($|b| \geq 20$). This will increase the statistics of radio halos by about a factor of 20 with respect to that produced by the NVSS.

The spectral properties of the population of radio halos visible by the future radio surveys at low frequencies are expected to change with the increasing sensitivity of these surveys. In Fig. 3 we show the total number of halos with $\nu_s \geq 120$ MHz (solid lines) and the number of halos with a spectral steepening at low frequencies, $120 \leq \nu_s \leq 600$ MHz (Cassano et al 2010b). The latter class of radio halos has a synchrotron spectral index $\alpha > 1.9$ in the range 250-600 MHz, and would become visible only at low frequencies, $\nu_o < 600$ MHz. About 55% of radio halos in the LOFAR all-sky survey at 120 MHz is expected to belong to this class of ultra-steep spectrum radio halos, while radio halos of higher $\nu_s$ are expected to dominate the radio halos population in shallower surveys.

## 5. Conclusions

The "GMRT Radio Halo Survey" allows to study the statistics of radio halos in a complete sample of X-ray luminous galaxy clusters (Venturi et al. 2008). These observations allows to unveil a cluster radio *bi-modality* with "radio quiet" clusters well separated from the region of the $P_{1.4}$–$L_X$ correlation defined by giant radio halos (Brunetti et al. 2007 and Figure 1a).

The connection between these radio halos and cluster mergers (Cassano et al 2010a) suggests that the Mpc-scale synchrotron emission in galaxy clusters is amplified during mergers and then suppressed when clusters become more dynamically relaxed. The separation between radio halo and "radio quiet" clusters in Figure 1a, and the rarity of galaxy clusters with intermediate radio power implies that the processes of amplification and suppression of the synchrotron emission takes place in a relatively short time-scale, $\tau_{evol} \approx 200$ Myr.
At the same time the analysis of the RM of radio sources in galaxy clusters suggests a single–mode in the clusters magnetic field properties where radio halo and "radio quiet" clusters have similar magnetic fields (Govoni et al 2010, see also Bonafede, these proceedings).

Clusters radio bimodality combined with the independent information on the magnetic field in these clusters, provides a novel tool to constrain models proposed for the origin of radio halos, namely the re-acceleration and hadronic model.

The short transition time-scale can be potentially reconciled with the hypothesis that the emitting electrons are accelerated by cluster-scale turbulence, in which case the synchrotron radiation emitted at GHz frequencies may rapidly decrease as a consequence of the dissipation of a sizeable fraction of that turbulence.

The most important expectation of the turbulent reacceleration scenario is that the synchrotron spectrum of radio halos should become gradually steeper above a frequency, $\nu_s$, that is determined by the energetics of the merger events that generate the halos and by the electron radiative losses (e.g., Fujita et al. 2003; Cassano & Brunetti 2005). Consequently, the population of radio halos is predicted to consist of a mixture of halos with different spectra, steep-spectrum halos being more common in the Universe than those with flatter spectra (e.g., Cassano et al. 2006). The discovery of these very steep-spectrum halos will allow us to test the above theoretical conjectures.

Despite the uncertainties caused by the unavoidable simplifications in present calculations, about 350 giant radio halos are expected in the future LOFAR surveys. This means that LOFAR will increase the statistics of these sources by a factor of $\sim 20$ with respect to present-day surveys. About $1/2$ of these halos are predicted with a synchrotron spectral index $\alpha > 1.9$ and would brighten only at lower frequencies, which are inaccessible to present observations. Most important, the spectral properties of the population of radio halos are expected to change with the increasing sensitivity of the surveys as steep spectrum radio halos are expected to populate the low-power end of the radio halo luminosity functions. The discovery of a large fraction of radio halos with spectra steeper than $\alpha \approx 1.5$ is expected to allow a robust discrimination between different models of radio halos, for instance in this case simple energetic arguments would exclude a secondary origin of the emitting electrons (e.g., Brunetti 2004; Brunetti et al. 2008).

Because of the large number of expected radio halos, a potential problem with these surveys is the identification of halos and their hosting clusters. LOFAR surveys are expected to detect radio halos in galaxy clusters with masses $\geq 6-7\times 10^{14}\mathrm{M}_\odot$ at intermediate redshift. On the other hand, statistical samples of X-ray selected clusters, which are unique tools for identifying the hosting clusters, typically select more massive clusters at intermediate z. In this respect the future surveys with eROSITA and with SZ–telescopes will provide crucial, complementary, information.

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