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Radio Halos in Merging Clusters

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Abstract. The number of known diffuse radio sources in clusters of galaxies (halos and relics) has grown in recent years, making it possible to derive statistical considerations on the physical conditions of these sources and on the properties of related clusters. We will discuss the percentage of clusters with a diffuse source and will show evidence that diffuse sources are associated with X-ray luminous clusters which have undergone recent merger processes.

1. Introduction

It is well established that an important component of the intergalactic medium (IGM) in clusters of galaxies is the hot gas, observed in X-Rays. In addition large scale magnetic fields are common in clusters as demonstrated by rotation measure studies (Clarke, Kronberg, & Böhringer 1999) and by the presence of synchrotron diffuse radio sources (halos and relics). Moreover, relativistic electrons may be commonly distributed over the cluster volume (Sarazin 2000).

Radio halos are diffuse sources at the cluster center with a regular shape, low surface brightness, low polarization degree and steep spectrum. Their size is generally large ($\gtrsim$1 Mpc with $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$) but also sources with a smaller size ($\sim$ 500 kpc) have been found. Radio relics are located at the cluster periphery, show an elongated or irregular structure, are highly polarized and have a large size.

Unlike the thermal X-ray emission, the radio emission is not a general property of the IGM: only some clusters show a large scale radio emission not related to the activity of single galaxies. The importance of halos and relics is that they represent large scale features, which are related to the cluster properties in the X-ray and optical domain, and are thus directly connected to the cluster history and evolution.

2. Frequency of Diffuse Sources

Until recently, the number of halos and relics was small, thus these sources were considered to be rare. Nowadays, thanks to the better sensitivity of radio

telescopes, the presence of a Halo or Relic source has been reported in about 50 clusters of galaxies. In a few clusters, a central Halo *and* a peripheral Relic or two Relic sources have been found.

To derive the frequency of diffuse sources, we need systematic radio data on a complete sample of clusters. Giovannini, Tordi, & Feretti (1999) used the NRAO VLA Sky Survey (NVSS) to search for diffuse sources associated with clusters of galaxies from the sample of Ebeling et al. (1996). In the complete sample, 4.6% of clusters have a Halo source and 5.6% show a peripheral Relic source. The detection rate increases with the X-Ray luminosity as follows (in parentheses the number of detected sources is given):

L_x(0.1–2.4 Kev) 10^{44} erg s^{-1}	Relics %	Halos %	Total %
0–3	1.3(1)	–	1.3
3–5	3.0(1)	3.0(1)	6.0
5–7	4.5(1)	4.5(1)	9.0
7–10	16.1(5)	9.7(3)	25.8
>10	8.3(1)	25.0(3)	33.3

The clusters hosting a diffuse source have a significantly higher X-Ray luminosity than clusters without a diffuse source (> 99.9% confidence level with a KS test). Moreover, a correlation is present between radio power and X-ray luminosity, which is more evident for halos than for relics. Since the cluster X-ray luminosity is correlated to cluster temperature and mass, it follows that the halo and relic radio power also correlates with the cluster temperature and mass.

3. Relevance of Merger Events

In previous studies the indication of the presence of merger processes in clusters containing a halo source was pointed out (e.g. Feretti 1999) from X-ray and optical structure and from X-ray temperature gradients. The connection between mergers and halos is confirmed in the sample presented by Giovannini et al. (1999), where the evidence of cluster merging has been reported in 10 clusters with a central halo. In other clusters with halos, no information is available in the literature to establish the presence of a merger event, but *at present we don't know any halo source in a cluster where the presence of merger was clearly excluded.*

Merger evidence has also been found in 9 clusters with a Relic source. For other Relic sources no data are available to confirm or reject the connection to merger.

A further indication that a cluster has undergone a recent merger is the absence of a strong cooling flow, since a merger process is expected to disrupt the cooling flow. In agreement with previous statements, no giant halo source has been found in cooling flow clusters. A halo of very small size (270 kpc) is detected in A2142 (Giovannini & Feretti 2000), which is a peculiar cluster since the central cooling flow has been disturbed but not destroyed by a merger (Markevitch et al. 2000; Ettori & Fabian 2000).

Most of the peripheral relics have been found in non–cooling flow clusters. A few sources are present in the peripheral regions of cooling flow clusters (e.g. A85, which however shows also a merger process).

4. Origin of Halo and Relic Sources

Since cluster size magnetic fields are common in clusters of galaxies, the crucial ingredient for the formation of a Halo or Relic source is the presence of relativistic particles. A possibility suggested in the past is that relativistic particles radiating in the halos could be supplied by extended cluster radio galaxies (mostly head-tail radio galaxies). In a recent study, Giovannini & Feretti (2000) find no connection between the presence of tailed radio galaxies at the cluster centers and the detection of radio halos. Therefore, the tailed radio galaxies could be a source of relativistic electrons, but they do not seem to be the main responsible for the halo formation.

From the observational results it is evident that central halos are strictly related to high luminosity X-ray clusters (high mass clusters) showing recent merger activity. The presence of a merger process is crucial to provide the energy for the relativistic particle re-acceleration and magnetic field amplification. However as pointed out before, not all clusters have a halo source and in particular not all merger clusters show a diffuse radio halo. Therefore, we suggest that also the dynamical history of the cluster is relevant: the formation process of a massive cluster seems to be crucial to trigger the formation of a halo (see the model by Brunetti et al. 2000).

Relic sources show the same strong connection as halos to the presence of recent mergers in the host clusters, but their relation to the cluster X-ray luminosity (and mass) is weaker. This could suggest a different origin for the relativistic electrons.

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