Observations of diffuse radio emission in galaxy clusters

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Plan of the talk

PART 1:
Diffuse radio emission in unrelaxed galaxy clusters

PART 2:
Diffuse radio emission in relaxed galaxy clusters

Chandra X-ray images
PART I: diffuse radio emission in merging clusters

Abell 2163 (z=0.2) – 1.4 GHz

Unresolved radio sources (AGNs)

Diffuse radio halo

Tailed radio galaxies
Diffuse radio halos in merging clusters

Abell 2163 (z=0.2) – 1.4 GHz

Source subtracted and low angular resolution

2 Mpc
Diffuse radio halos in merging clusters

Abell 2163 – 1.4 GHz

Source subtracted, low resolution

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Flux (Jy)</th>
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<tbody>
<tr>
<td>10</td>
<td>100</td>
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<tr>
<td>100</td>
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<tr>
<td>1000</td>
<td>1</td>
</tr>
<tr>
<td>10000</td>
<td>0.1</td>
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$S \propto \nu^{-\alpha}$

$\alpha > 1$

Coma cluster (Thierbach 2003)

1.4 GHz radio contours on X-ray XMM-Newton image

2 Mpc
Diffuse radio halos in merging clusters

Abell 2163 – 1.4 GHz

Source subtracted, low resolution

Synchrotron radiation from relativistic electrons accelerated in large-scale μG magnetic fields

Abell 2163

1.4 GHz radio contours on X-ray XMM-Newton image

2 Mpc
What is the origin of the radio-emitting electrons?
What is the origin of the radio-emitting electrons?

The “diffusion problem” – Jaffe 1976

Electrons must be continuously injected/accelerated \textit{in situ}

\[ T_{\text{diff}} (\sim 10^{10} \text{ yr}) >> T_v (\sim 10^8 \text{ yr}) \]
Radio halo / cluster merger connection

RXC2003.5-2323 - 1.4 GHz

A754 - 1.4 GHz

A521 - 240 MHz

A2744 - 327 MHz

DISTURBED CLUSTERS

Radio contours on X-ray emission

Relaxed cluster

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Radio halos from cluster-wide turbulent reacceleration

Turbulence driven by cluster-cluster collisions can reaccelerate seed electrons ($\gamma \sim 100-200$) in the cluster volume to $\gamma >> 1000$ (G. Brunetti’s talk)

Radio halos are a transient phenomenon
(e.g., simulations by Donnert & Brunetti 2014)
PART I : RADIO HALOS IN UNRELAXED CLUSTERS

- TAKEAWAYS -

• Radio halos probe **relativistic electrons and magnetic fields** in clusters

• May trace sites of **turbulent particle acceleration** in galaxy clusters

• **Transient phenomenon** associated with cluster mergers

• GHz-emitting halos are **rare** (about 40 known so far) -> massive clusters, energetic mergers

• Less massive merging clusters and/or less energetic mergers are expected to produce low-frequency (<1 GHz) radio halos -> **dominant halo population**

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LOFAR

30-80 MHz, 120-240 MHz

MWA

80-300 MHz

uGMRT

50-1500 MHz
PART 2 - Diffuse radio emission in relaxed clusters

XMM-Newton X-ray image of a relaxed cluster with pronounced cool core
A vibrant downtown

Present activity

radio emission

cold front

cavities from past activity

Perseus cluster

Turbulence

Hitomi collaboration (2016)

Gas sloshing simulation

2.3 Gyr


ZuHone & Kowalik (2016)
Perseus cluster

Blue: X-ray emission
Magenta: radio emission

Synchrotron emission on cluster core scale \((r \sim 50 - 300 \text{ kpc})\)

230 - 470 MHz
Gendron-Marsolais et al. 2017

Diffuse radio mini-halos

NGC 1275
Blue: X-ray emission
Magenta: radio emission

S. Giacintucci
Diffusion problem for minihalos

Minihalos cannot be produced by electrons diffusing out of the central active radio galaxy.

Electrons must be continuously injected/accelerated *in situ*.
Minihalos are often bounded by sloshing cold fronts

**SLOSHING COLD FRONTS**: gas density discontinuities resulting from a recent gravitational perturbation of the cluster potential (e.g., Ascasibar & Markevitch 2006)
Moderate turbulence ($\delta_v \sim 200$ km/s) can be driven by the sloshing motions in the cool core.

Lower-energy electrons ($\gamma \sim 10^2$) can build up in the core over time due to their longer cooling time.

These particles can be reaccelerated by sloshing-driven MHD turbulence and produce radio emission within the cold front envelope.
Seed electrons for the reacceleration

Buoyant radio bubbles from past AGN activity are a possible source of low $\gamma$ electrons (e.g., Cassano et al. 2008)

Sloshing can redistribute these particles (ZuHone et al. 2013)

In the absence of reacceleration, electrons in disrupted bubbles cool rapidly

Hadronic processes can be an alternative/additional source of seed electrons
2A0335+096: evidence for 3 cycles of AGN activity

617 MHz contours on Chandra residual map

Older relic lobe, $t_{\text{sync}} \approx 60$ Myr

Relic lobes, $t_{\text{sync}} > 28$ Myr

Current activity at 1.4 GHz on HST

Relic lobes well detected also at 150 and 235 MHz

Low-contrast cavity in XMM-Newton image

Sanders et al. 2009
Giacintucci et al. in prep.
2A0335+096: 3 cycles of AGN activity and a minihalo

1.4 GHz on Chandra residual map

Minihalo from reaccelerated electrons

\[ r \sim 70 \text{ kpc minihalo} \]

What are minihalo clusters?

The study of minihalos has so far been limited by their small number (11 detections as of 2011)

Giacintucci et al. 2014: systematic search for new minihalos in a sample of ~100 clusters ➔ doubled the number of minihalos

As of today: 28 minihalos (including 6 candidates)
What are minihalo clusters?

Mass-selected (SZ Planck) statistical sample of 56 clusters with $M_{500} > 6 \times 10^{14} M_{\text{sun}}$

- 12 minihalos
  - (50 kpc < r < 0.2 $R_{500}$)

- 12/15 (80%) of CC clusters have a minihalo

Giacintucci et al. 2017
What are minihalo clusters?

SZ Planck statistical sample of 56 clusters + non-statistical sample of 49 clusters

COOL CORES

NON COOL CORES

28 minihalos
(50 kpc < r < 0.2 R_{500})

Fraction of minihalos may be lower in lower-mass clusters

Total mass, M_{500} \left( M_{\odot} \right)

\[ \times 10^{15} \]

Chandra-derived core entropy K_0, keV cm^2

Giacintucci et al. 2017

Uncertain classification

Minihalo

Candidate minihalo

Larger halo (or candidate)

No detected central diffuse emission

⚠️ needs proper statistical analysis that accounts for selection effects and upper limits

Giacintucci et al. 2017
PART II : MINIHALOS IN RELAXED CLUSTERS

- TAKEAWAYS -

• Minihalos are statistically associated with relaxed clusters with a central cool core
• Minihalos probe relativistic electrons and magnetic fields in cool cores
• Minihalo may trace turbulence in cool cores
• Minihalos hosts are the most extreme systems among the cool-core cluster population: massive and hot clusters with strong cool cores
• Minihalos are more common than previously believed: 80% of massive cool-core clusters possess a minihalo
• The fraction of minihalos appears to drop in less massive clusters, but proper statistical analysis is needed