Observations of diffuse radio emission in cool-core clusters

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Radio minihalos

VLA 1.4 GHz image of the minihalo in Perseus (Pedlar et al. 1990)

See talk by M. Gendron-Marsolais

Diffuse radio emission surrounding central radio galaxy

Reaches ~450 kpc in WSRT 0.3 GHz image (Sijbring 1993)
Radio minihalos

Centrally-located, diffuse radio sources on core scale, $r \sim 50\text{-}300\text{ kpc}$ ($\leq 0.2\ R_{500}$)

Not directly connected to central radio galaxy

Non-thermal, synchrotron radiation from GeV electrons accelerated in $\sim\mu G$ magnetic fields (Brunetti & Jones 2014 for review)
Minihalos bounded by sloshing cold fronts

Mazzotta & Giacintucci 2008, Giacintucci et al. 2014
Minihalos bounded by sloshing cold fronts

617 MHz radio contours on Chandra X-ray image

Giacintucci et al. 2014

Radio emission drops at cold front
Sloshing cool core in A3444

Chandra X-ray image

200 kpc

Giacintucci et al. in preparation
Sloshing cool core in A3444

Chandra X-ray image

Giacintucci et al. in preparation
Sloshing cool core in A3444

X-ray surface brightness profiles across cold fronts
Radio minihalo in A3444

Chandra X-ray image

GMRT 610 MHz contours on X-ray

GMRT 610 MHz

Giacintucci et al. in preparation
Minihalo confinement in A3444

X-ray/radio surface brightness profiles across the NW outer cold front

GMRT 610 MHz contours on X-ray

Radio emission drops at cold front

Giacintucci et al. in preparation
Turbulent particle acceleration in sloshing cool cores

Sloshing can generate moderate turbulence (~ 200 km/s) in the cool core

ZuHone et al. 2013
Turbulent particle acceleration in sloshing cool cores

Projected turbulence velocity

Sloshing can generate moderate turbulence (~ 200 km/s) in the cool core

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

ZuHone et al. 2013
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Turbulent particle acceleration in sloshing cool cores

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Sloshing-driven turbulence can reaccelerate low-$\gamma$ electrons to $\gamma \sim 10^4$ energies and produce diffuse radio emission within the sloshing region.
What are minihalo clusters?
What are minihalo clusters?

Mass-selected (Planck) statistical sample of 57 clusters

- **CC** (Cool Cores)
  - $12/15$ (80%) of CC clusters have a minihalo

- **nCC** (Non Cool Cores)

**Criteria**:
- $M_{500} > 6 \times 10^{14} \, M_{\odot}$
- $z < 0.35$

**12 minihalos**
- $50 \, \text{kpc} < r < 0.2 \, R_{500}$

**Graph**:
- **TOTAL MASS, $M_{500}$ ($M_{\odot}$)**
- **Chandra-derived core entropy $K_0$, keV cm$^2$**

- **Minihalo**
- **Candidate minihalo**
- **Larger halo (or candidate)**
- **No detected central diffuse emission**

Giacintucci et al. 2017
What are minihalo clusters?

Planck statistical sample 57 clusters + non-statistical sample of 49 clusters

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

Fraction of minihalos may be lower in lower-mass clusters

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

Giacintucci et al. 2017
An exceptional AGN outburst in the Ophiuchus cluster

M. Markevitch (GSFC), M. Johnston-Hollitt (Peripety Scientific), Q. Wang (UMD), D. Wik (University of Utah), T. Clarke (NRL)

Credit: NASA/GSFC Conceptual Image Lab
Ophiuchus cluster

Chandra 0.5-7 kev

z=0.028
M=1.2x10^{15} M_{\odot}

Werner et al. 2016

S. Giacintucci
A concave discontinuity at the cool core boundary, $r \sim 120$ kpc

Chandra 0.5-7 kev

Chandra residual image, Werner et al. 2016
Radio emission in Ophiuchus

GMRT 150 MHz on ROSAT PSPC
Murgia et al. (2010)

1.4 GHz contours of the minihalo
Govoni et al. 2009, Murgia et al. 2010

patch of diffuse emission

0.2 \( R_{500} = 0.3 \) Mpc
A giant AGN bubble?

\[ r \sim 180 \text{ kpc} \]

\[ \rho V \text{ work } \sim 5 \times 10^{61} \text{ erg} \]

\[ r \sim 100 \text{ kpc} \]

\[ pV_{\text{tot}} \sim 1.6 \times 10^{61} \text{ erg} \]

\[ \text{McNamara et al. 2005, 2009} \]

\[ \text{MS 0735.6+7421} \]

\[ \text{\(
\text{\sim several times greater than the outburst in MS 0735+74}
\end{equation}

\[ S. \text{ Giacintucci} \]
vi. We find a surprising, sharp SB discontinuity that is curved away from the core, at $r \approx 120$ kpc to the south-east of the cluster centre. We conclude that this feature is most likely due to gas dynamics associated with a merger and not a result of an extraordinary AGN outburst. \textit{Werner et al. 2016}

$pV$ work $\approx 5 \times 10^{61}$ erg $\leftarrow$ several times greater than the outburst in MS 0735+74
It is an extraordinary AGN outburst!

XMM-Newton mosaic image
It is an extraordinary AGN outburst!

Based on XMM curvature radius, the cavity is ~250 kpc in radius

S. Giacintucci
Low-frequency radio emission fills the cavity

New analysis of GMRT 235 MHz data previously published by Perez-Torres et al. 2009 and Murgia et al. 2010

S. Giacintucci
Low-frequency radio emission fills the cavity

New analysis of GMRT 150 MHz data previously published by Murgia et al. 2010

S. Giacintucci
Low-frequency radio emission fills the cavity

MWA GLEAM 72-80 MHz – 2’ resolution
XMM mosaic image

A fossil radio lobe

S. Giacintucci
The spectrum of the fossil radio lobe is very steep

$$\alpha = 3.45$$

Johnston-Hollitt et al. in prep.

S. Giacintucci
Steepest extended cluster radio source in GLEAM

GLEAM covers $\frac{3}{4}$ of the sky

cluster extended sources  
Johnston-Hollitt et al. in prep.

$\alpha = 3.45$

GMRT 150 MHz

GMRT 235 MHz

Johnston-Hollitt et al. in prep.
Origin of the fossil lobe is not straightforward

GMRT 235 – 90” resolution

Central AGN is very faint and has no jets on kpc scale

Murgia et al. 2010, Werner et al. 2016

1.4 GHz
Size < 1 kpc

α = 0.6

1400 MHz luminosity : $5 \times 10^{22} \text{ W/Hz}$
235 MHz luminosity : $1.5 \times 10^{23} \text{ W/Hz}$

Fossil lobe: $1.3 \times 10^{24} \text{ W/Hz}$ at 235 MHz
How did the cool core survive?

the AGN explosion could have triggered the sloshing by giving the cool core a strong push, somehow avoiding to blow it up completely.

Where is the counter lobe?

It may have propagated in less-dense ICM on the opposite side and faded away or cluster-wide bulk motions from a merger have moved the counter lobe in the outskirts, where it faded away.

Approved new XMM and uGMRT observations