Unravelling the origin of large-scale magnetic fields in galaxy clusters and beyond

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And the SKA magnetism working group
Magnetic fields on the large-scales: galaxy clusters

The Coma cluster,
LOFAR 150 MHz  Bonafede et al (in prep)
Magnetic fields on the large-scales: galaxy clusters

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\sim 3.3 \text{ Mpc}
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Magnetic fields on the large-scales: galaxy clusters

The Coma cluster,
LOFAR 150 MHz Bonafede et al (in prep)

\( B \sim \text{few } \mu \text{G} \)

\( \sim 3.3 \text{ Mpc} \)

Dolag 2005

\( I_B [\mu \text{G}] \)

\( \rho / \langle \rho \rangle \)

Saturation

Major Mergers

Turbulence
Magnetic fields on the large-scales: galaxy clusters

-> Magnetic field amplification

-> Physics of the intra-cluster medium

The Coma cluster,
LOFAR 150 MHz  Bonafede et al (in prep)
Magnetic fields in clusters: methods

3D magnetic field simulations

\[ \int n_{gas} B_z = RM \]

Gas model (from X-rays)

(e.g. Murgia et al 2004, Bonafede et al, 2013)
Magnetic fields in clusters: methods

3D magnetic field simulations (e.g. Murgia et al 2004, Bonafede et al, 2013)

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Gas model (from X-rays)

Numerical model

\[ |A_k| \propto k^{-\zeta} \]

\[ B_k = i k \times A_k \]

\[ B(r) = B_0 n_{gas}^n \]
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Simulated RM image

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Magnetic fields in clusters: current results

Bonafede et al. 2010, 2013
**Magnetic fields in clusters: current results**

\[ B(r) = B_0 n_{gas}^{\eta} \]

- \( B_0 \sim 5 \mu G \)
- \( \eta \sim 0.5 \)

Bonafede et al. 2010, 2013
MAGNETIC FIELDS IN CLUSTERS: CURRENT RESULTS

Limit: Number of sources detectable through the cluster

\[ B(r) = B_0 n^{\eta_{gas}} \]

\[ B_0 \sim 5\mu G \]

\[ \eta \sim 0.5 \]

Bonafede et al. 2010, 2013
SKA1: A “Coma-like” cluster

315 polarised sources / sq degree at 1 microJy at 1.6 arcsec resolution (Rudnick & Owen 2014)

\[ M \sim 10^{15} M_\odot \]

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Simulated RM map
SKA1: A “Coma-like” cluster

Simulated RM map

|RM| [rad/m²]

VLA observations

SKA1-survey

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SKA1: A “Coma-like” cluster

VLA data $\rightarrow \chi^2$ plane

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$$B(r) \propto B_0 n_{\text{gas}}^\eta$$
SKA1: A “Coma-like” cluster

VLA data $\rightarrow \chi^2$ plane

$M \sim 10^{15} M_{\odot}$

$B(r) \propto B_0 n_{gas}^\eta$

$B_0 = 3.9 \mu G, \eta = 0.4$

$B_0 = 4.7 \mu G, \eta = 0.5$

$B_0 = 5.5 \mu G, \eta = 0.7$
SKA1: Lower Mass clusters and groups

\[ B(r) \propto B_0 n_{\text{gas}}^{\eta} \]

\[ M \sim 10^{13} M_{\odot} \quad \text{and} \quad M \sim 10^{14} M_{\odot} \]

- \( B_0 = 1\mu G, \eta = 0.5 \)
- \( B_0 = 3\mu G, \eta = 0.5 \)
- \( B_0 = 5\mu G, \eta = 0.5 \)
More realistic cluster models

Cosmological simulations (Vazza et al. 2010)

20 Massive clusters  Resolution 25 kpc/h -> resampled at 12 kpc/h

Post - Merger  Pre- Merger  “Relaxed”
More realistic cluster models

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Post - Merger  Pre- Merger  "Relaxed"
SKA-1 PERSPECTIVES - SHOCKS AND RADIO EMISSION

Taken from a cosmological simulation (ENZO amr Vazza et al. 2009)
SKA-1 Perspectives - Shocks and Radio Emission

X-ray emission

Temperature

Shock wave

8 Mpc

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(ENZO amr Vazza et al. 2009)
SKA-1 PERSPECTIVES - SHOCKS AND RADIO EMISSION

X-ray emission

Temperature

8 Mpc

Shock wave

GAS DENSITY + RADIO EMISSION

“Radio Relic”

Taken from a cosmological simulation (ENZO amr Vazza et al. 2009)
Assuming $B \sim n^{0.5}$
Kolmogorov power spectrum (17 - 40 kpc)
resolution $\sim$8.5 kpc
normalization at the cluster centre (4 $\mu$G)
$\sim$2 $\mu$G at the relic

Lower limit!
(only compression)
SKA-1: SHOCKS AND RADIO EMISSION

Assuming $B \sim n^{0.5}$
Kolmogorov power spectrum (17 - 40 kpc)
resolution $\sim 8.5$ kpc
normalization at the cluster centre (4 $\mu$G)
$\sim 2$ $\mu$G at the relic

Johnston-Hollitt & Ekers
2004
Magnetic field in intergalactic filaments

0917+75

$z=0.138$

galaxies connecting 2 clusters

(Girardi et al in prep.)

$d \sim 4$ Mpc

Size $\sim 1.7$ Mpc

No X-ray detected

(ROSAT, XMM)

Slide courtesy of G. Giovannini
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(A3411 - A3412)

ZwCL 2341

1.2 Mpc

VLA

KAT-7

Slide courtesy of G. Giovanninni
Conclusions

RM grid SKA I-survey:
- B in massive galaxy clusters and groups $10^{15} - 10^{13} \, M_{\text{sun}}$
- 10x RM sampling in a Coma-like cluster
- B amplification due to shock waves
- diffuse emission in intergalactic filament
