Magnetic field turbulence in galaxy clusters

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ICM Physiscs and Modeling

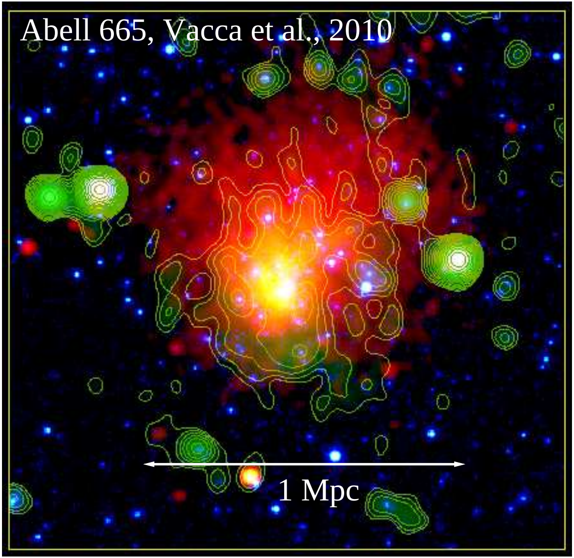
OUTLINE

GALAXY CLUSTERS

Optical emission
100 – 1000 galaxies

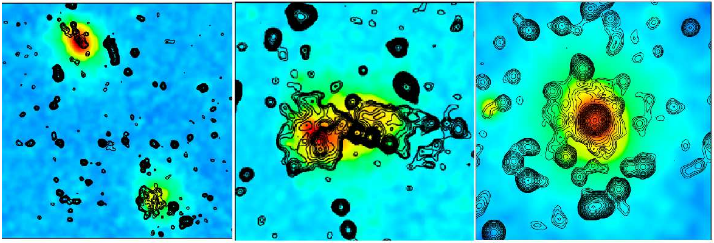
X-ray emission
T=10^7–10^8 K
$n_e = 10^{-4}$–$10^{-3} cm^{-3}$
$L_X \sim 10^{44}$erg/s

Radio emission
radio galaxies
radio halos



DIFFUSE RADIO EMISSION IN GALAXY CLUSTERS

- halos: merging clusters
- mini-halos: cool-core clusters
- relics: merging clusters and cool-core clusters with minor or off-axis mergers



A399-A401, A754, A2029 **Feretti et al. (2012)** and references therein

MAGNETIC FIELD INVESTIGATION

Observed Luminosity:

$$L_\nu = J_\nu V$$

Synchrotron emissivity:

$$J_\nu \propto E_{\rm el} B^2 \qquad \alpha = 1$$

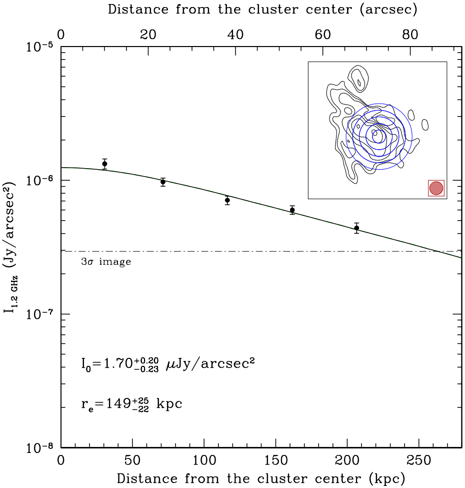
Under equipartition

$$E_{\rm el} \approx \frac{B^2}{8\pi}$$

$$\downarrow$$

$$L_\nu \propto B^4 V$$

A1689



$$I(r) = I_0 e^{-\mathrm{r}/\mathrm{r_e}}$$

$$V_{\mathrm{cm}^3} = \frac{4\pi}{3}(3r_\mathrm{e})^3 = 1.10 \times 10^{73}\,\mathrm{cm}^3$$

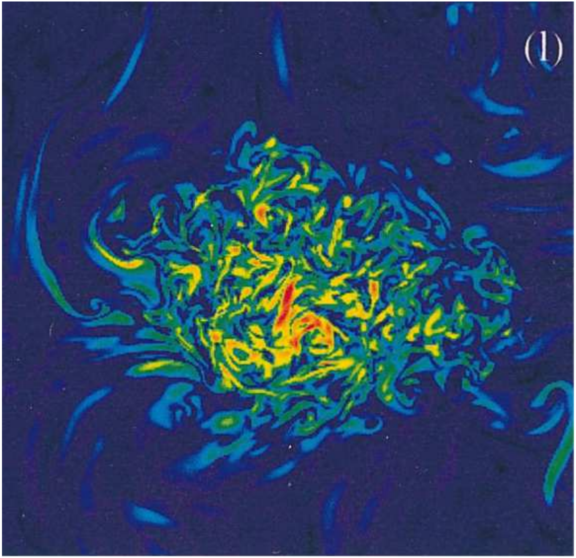
$$L_{1.4\,\mathrm{GHz}} = 1.58 \times 10^{24}\,\mathrm{W\,Hz}^{-1}$$

$$\downarrow$$

$$\langle B_0 \rangle \sim \mathit{few}\,\mu\mathrm{G}$$

Vacca et al. (2011)

TURBULENCE



Roettiger et al. (1999)

SIMULATIONS

FARADAY (**Murgia et al. 2004**)

- Gaussian random field magnetic field

$$|B_{\rm k}|^2 \propto k^{-{\rm n}}, \qquad \langle B(r)\rangle = \langle B_0\rangle \left(\frac{n_{\rm e}(r)}{n_{\rm e0}}\right)^{\eta}$$

- Relativistic electrons

$$N(\gamma)d\gamma = N_0\gamma^{-\delta}d\gamma$$

- Thermal gas β-model (**Cavaliere & Fusco-Femiano 1976**)

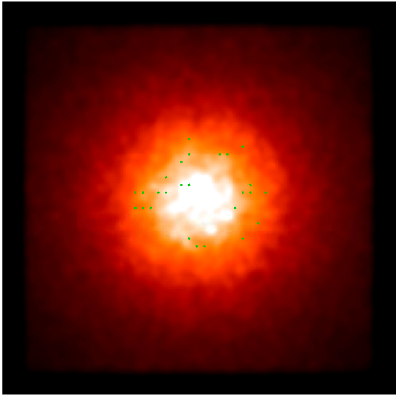
$$n_{\rm e}(r) = n_0\left[1+\left(\frac{r}{r_{\rm c}}\right)^2\right]^{-\frac{3}{2}\beta}$$

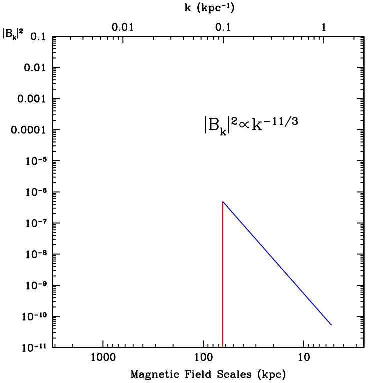
SYNTHETIC IMAGES AND POLARIZED VECTORS

for a turbulent Kolmogorov index magnetic field

$\Lambda_{\max} = 64\ kpc$

Murgia et al. (2004)



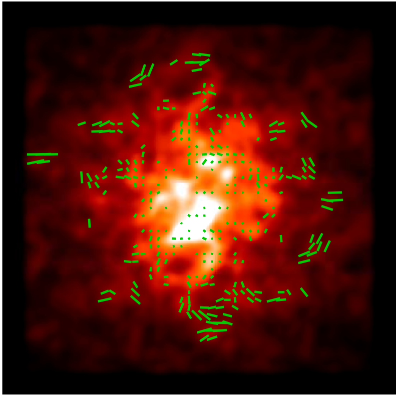


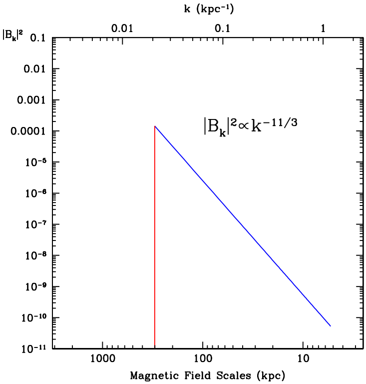
SYNTHETIC IMAGES AND POLARIZED VECTORS

for a turbulent Kolmogorov index magnetic field

$\Lambda_{\rm max} = 300\ kpc$

Murgia et al. (2004)



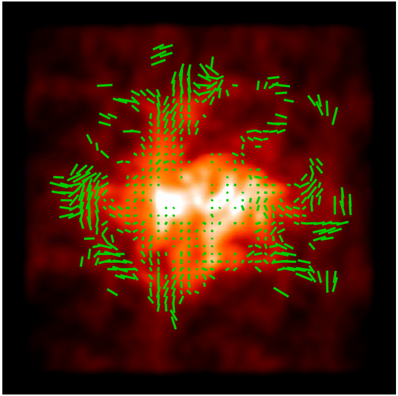


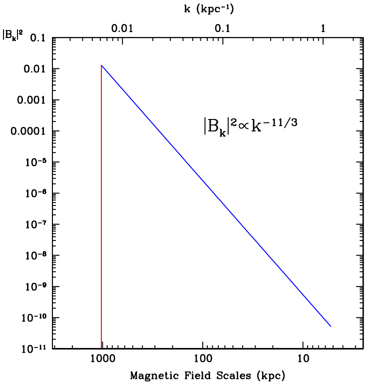
SYNTHETIC IMAGES AND POLARIZED VECTORS

for a turbulent Kolmogorov index magnetic field

$\Lambda_{max} = 1024\, kpc$

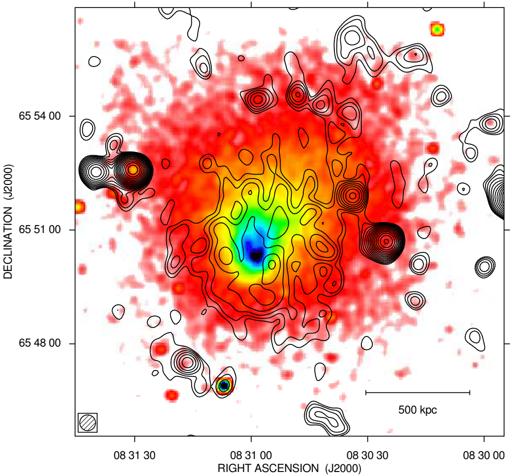
Murgia et al. (2004)





A665

$$\langle B \rangle \simeq 0.75\,\mu\mathrm{G}$$



resolution

$25'' \simeq 75\,\mathrm{kpc}$

($1\,\mathrm{kpc} = 3.09 \times 10^{19}\,\mathrm{m}$)

sensitivity

$6.35 \times 10^{-8}\,\mathrm{Jy/arcsec^2}$

($1\,\mathrm{Jy} = 10^{-26}\,\mathrm{W\,Hz^{-1}\,m^{-2}}$)

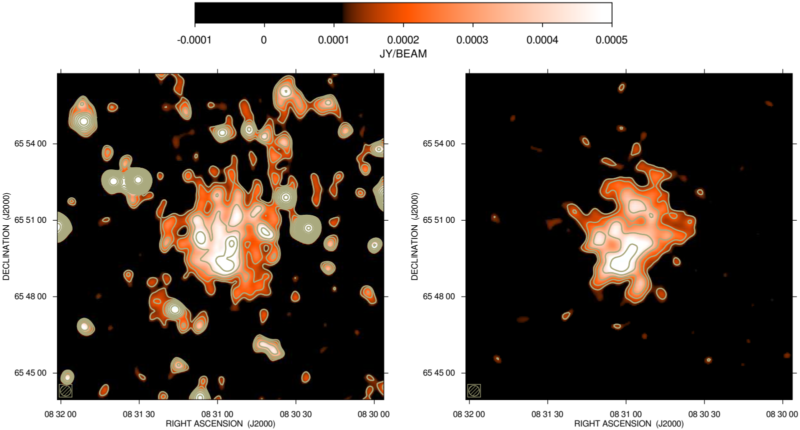
distance

880 Mpc

POLARIZED EMISSION UNDER NOISE LEVEL

Vacca et al. (2010)

OBSERVATIONS VS SIMULATIONS

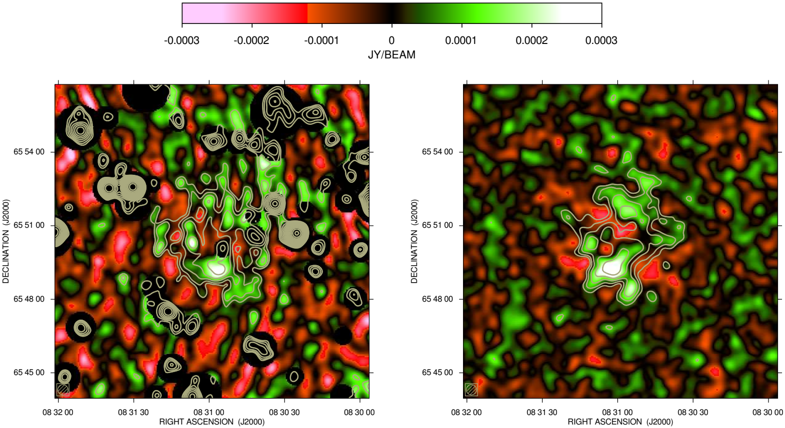


OBSERVATIONS

SIMULATIONS

$\Lambda_{max} = 512\,\mathrm{kpc}$

OBSERVATIONS VS SIMULATIONS

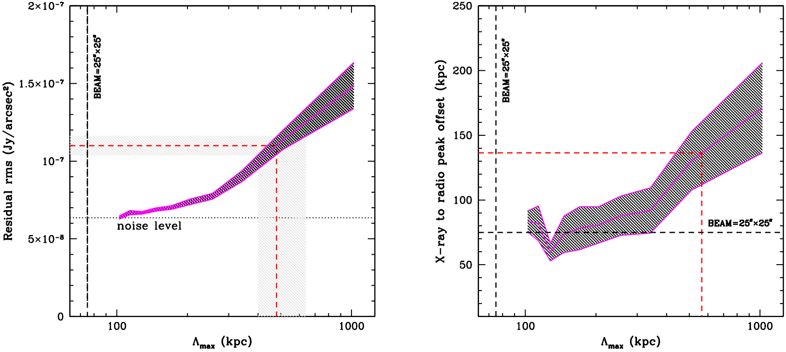


OBSERVATIONS

SIMULATIONS

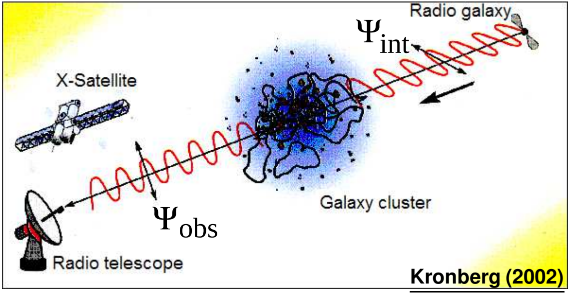
$\Lambda_{\mathrm{max}} = 512\,\mathrm{kpc}$

OBSERVATIONS VS SIMULATIONS



$$\langle B_0 \rangle \simeq 1.3\,\mu\mathrm{G},\ \Lambda_{\max} \simeq 450\,\mathrm{kpc},\ \Lambda_C \simeq 100\,\mathrm{kpc}$$

FARADAY ROTATION



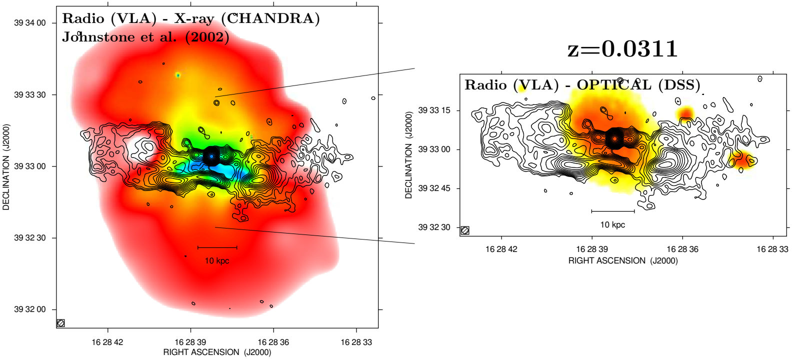
$$\Psi_{\rm obs} = \Psi_{\rm int} + \lambda^2 RM$$

$$RM \propto \int_0^L n_{\rm e} B_{\parallel} dl$$

A2199

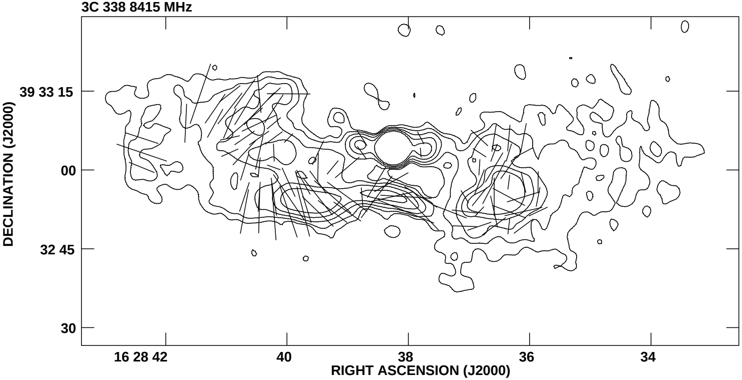
Vacca et al. (2012)

3C 338: the radio galaxy at the center of A2199



OBSERVED POLARIZATION PROPERTIES

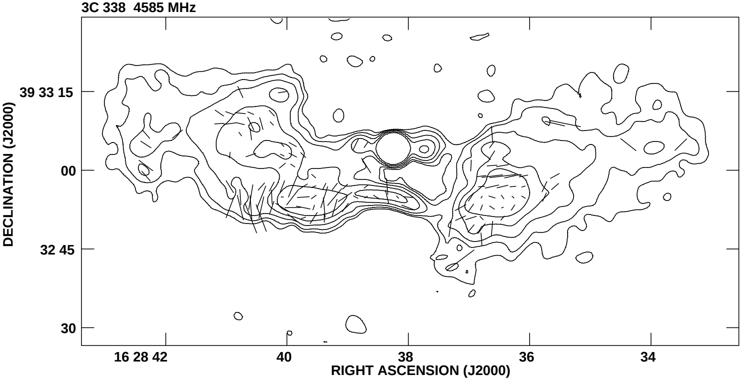
$$\Psi_{\rm obs} = \Psi_{\rm int} + \lambda^2 RM$$



$$FPOL = (41.7 \pm 0.6)\%$$

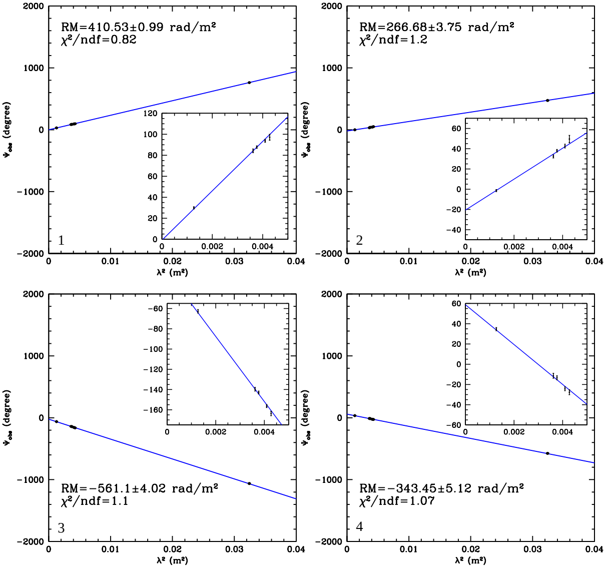
OBSERVED POLARIZATION PROPERTIES

$$\Psi_{obs} = \Psi_{int} + \lambda^2 RM$$



$$FPOL = (13.6 \pm 0.3)\%$$

ROTATION MEASURE IMAGE

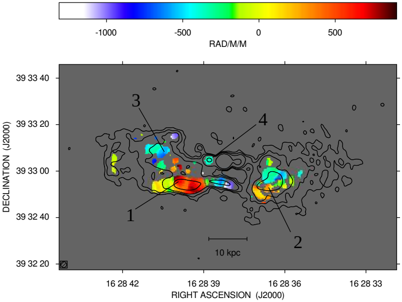


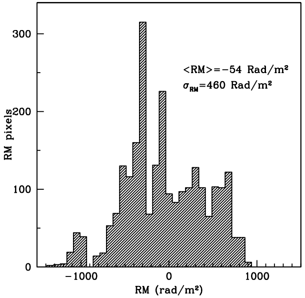
$$\Psi_{\rm obs} = \Psi_{\rm int} + \lambda^2 RM$$

ROTATION MEASURE IMAGE

$RM \propto \int_{\rm los} n_{\rm e}(l) B_{\|} dl$

RESOLUTION=2.5″=1.5 kpc





$$\sigma^2_{\rm RM}(r_\perp) = \frac{K^2 B^2 \Lambda_{\rm C} n_0^2 r_{\rm c}}{\left(1 + \frac{r_\perp^2}{r_{\rm C}}\right)^{\frac{6\beta-1}{2}}} \frac{\Gamma(3\beta - \frac{1}{2})}{\Gamma(3\beta)}$$

$$\Lambda_{\rm C} = \frac{3\pi}{2} \frac{\int_0^\infty |B_{\rm k}|^2 k dk}{\int_0^\infty |B_{\rm k}|^2 k^2 dk}$$

Felten (1996)

Ensslin & Vogt (2003)

SIMULATIONS

FARADAY (**Murgia et al. 2004**)

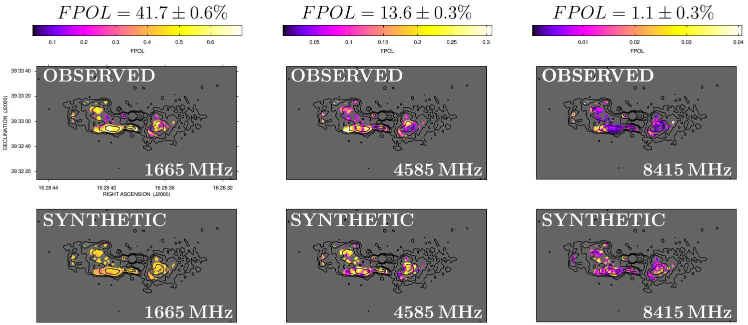
- Gaussian random field magnetic field

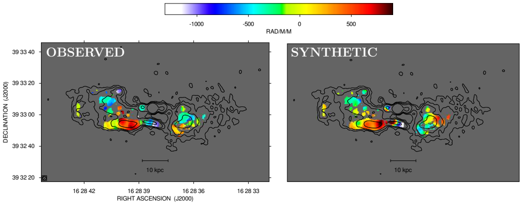
$$|B_{\rm k}|^2 \propto k^{-\rm n}, \qquad \langle B(r)\rangle = \langle B_0\rangle \left(\frac{n_{\rm e}(r)}{n_{\rm e0}}\right)^{\eta}$$

- Thermal gas double β-model

$$n_{\rm e}(r) = n_{0,\rm int}\left[1+\left(\frac{r}{r_{\rm c,int}}\right)^2\right]^{-\frac{3}{2}\beta_{\rm int}} + n_{0,\rm ext}\left[1+\left(\frac{r}{r_{\rm c,ext}}\right)^2\right]^{-\frac{3}{2}\beta_{\rm ext}}$$

OBSERVATIONS VS SIMULATIONS





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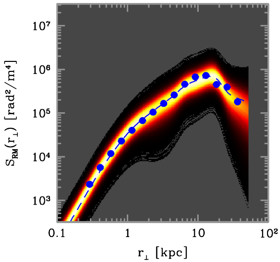

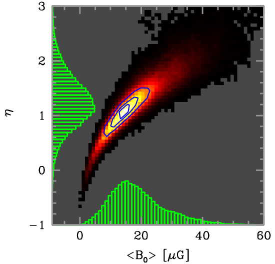

$$|B_k|^2 \propto k^{-n}, \qquad \langle B(r)\rangle = \langle B_0\rangle \left(\frac{n_e(r)}{n_{e0}}\right)^\eta$$

$$S_{RM} = \left\langle |RM(r'_\perp) - RM(r'_\perp + r_\perp)|^2 \right\rangle_{r'_\perp} =$$

$$= 2(\sigma^2_{RM} + \langle RM\rangle^2) - A_n \int_0^\infty J_0(kr_\perp)|B_k|^2 k dk$$

$$\langle B_0\rangle = (11.7 \pm 9.0)\,\mu G$$

$$\Lambda_{min} = (0.7 \pm 0.1)\,\mathrm{kpc}$$

$$\Lambda_C \simeq 5\,\mathrm{kpc}$$

CONCLUSIONS

1. Magnetic field turbulence can be studied via radio observations
2. Small scales of fluctuations are best studied with RM while large scales with radio halos
3. Magnetic fields in merging galaxy clusters appear characterized by scales of fluctuations larger than in relaxed clusters.