INTRACLUSTER MAGNETIC FIELDS

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Federica Govoni and Matteo Murgia (INAF-OAC)
and others...

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Outline

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1. Introdution
2. Radio halo technique
3. Rotation measure technique
4. Conclusions

Outline

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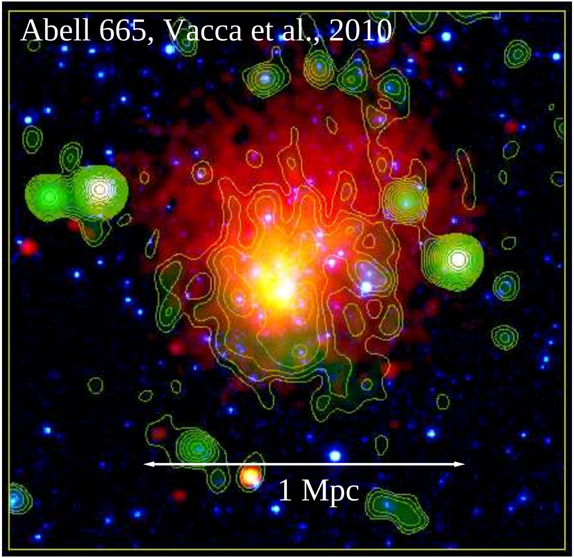
Magnetic fields in galaxy clusters

Optical emission
~1000 galaxies

X-ray emission
$T \sim 10^7$–10^8 K
$n_\mathrm{e} \sim 10^{-4}$–$10^{-3}$ cm^{-3}
$L_\mathrm{X} \sim 10^{44}$–$10^{45}$ erg/s

Radio emission
radio galaxies
radio halos
radio relics

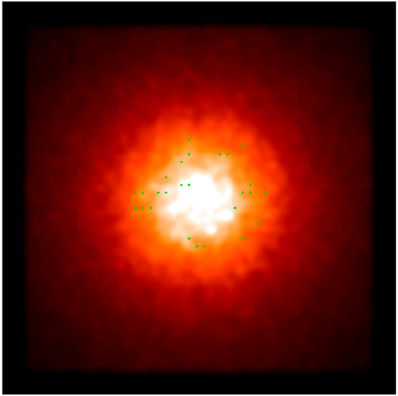


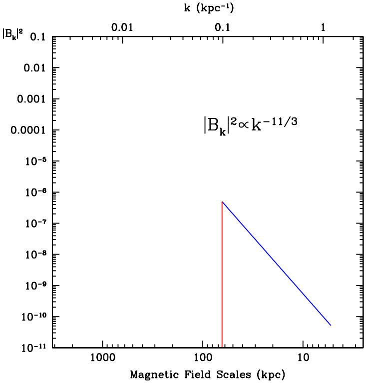
SYNTHETIC IMAGES AND POLARIZED VECTORS

for a turbulent Kolmogorov index magnetic field

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

Murgia et al. (2004)



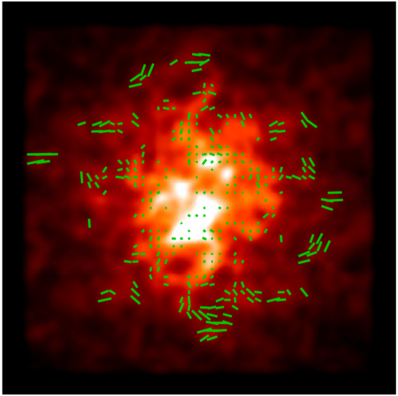


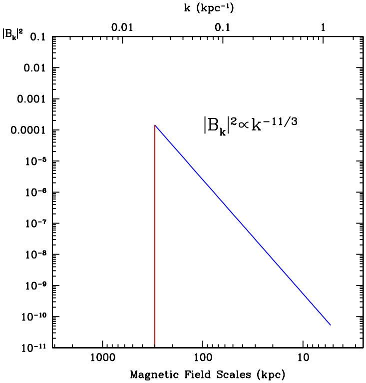
SYNTHETIC IMAGES AND POLARIZED VECTORS

for a turbulent Kolmogorov index magnetic field

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

Murgia et al. (2004)



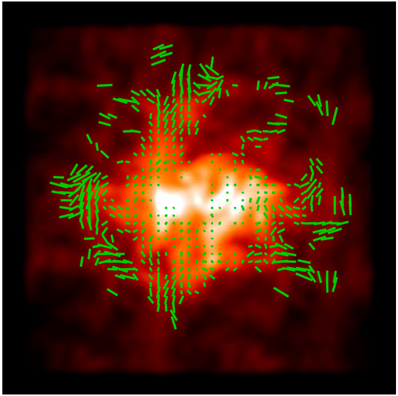


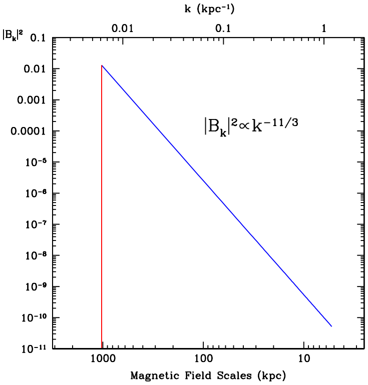
SYNTHETIC IMAGES AND POLARIZED VECTORS

for a turbulent Kolmogorov index magnetic field

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

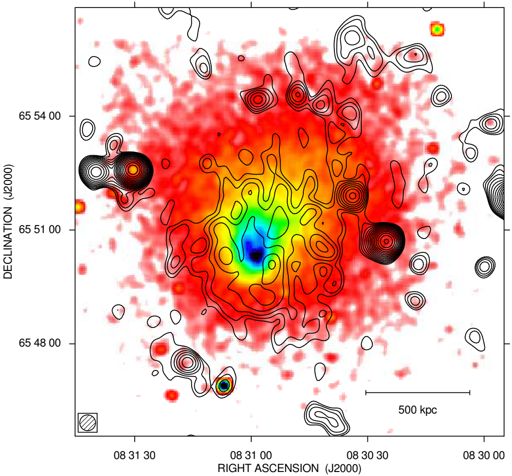
Murgia et al. (2004)





A665

distance 880 Mpc, $\langle B \rangle \simeq 0.75\,\mu\mathrm{G}$



VLA data at 1.4 GHz:

resolution

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

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

sensitivity

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

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

POLARIZED EMISSION UNDER NOISE LEVEL

Vacca et al. (2010)

PARAMETERS

FARADAY (Murgia et al. 2004)

PARAMETER	VALUE
magnetic field intensity at the cluster center	$\langle B_0 \rangle =$TBD
magnetic field radial decrease	$\eta =$TBD
magnetic field power spectrum index	n=11/3
minimum scale of fluctuation	$\Lambda_{\rm min} = 2\ kpc$
maximum scale of fluctuation	$\Lambda_{\rm max} =$TBD
minimum relativistic electron energy	$\gamma_{\rm min} = 100$
maximum relativistic electron energy	$\gamma_{\rm max} = \infty$
radio halo spectral index	$\alpha = (\delta - 1)/2 = 1$
β-model (Roussel et al. 2000)	$\beta = 0.763$ $r_c = 112''$ $n_{e0} = 3.40 \cdot 10^{-3}\ {\rm cm}^{-3}$

$$\langle B(r) \rangle = \langle B_0 \rangle \left(\frac{n_e(r)}{n_e} \right)^{\eta}$$

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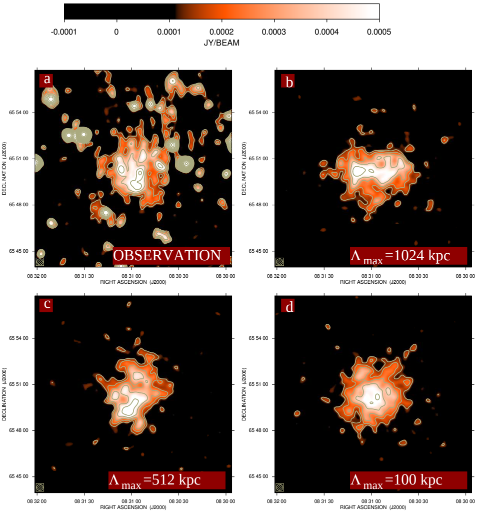
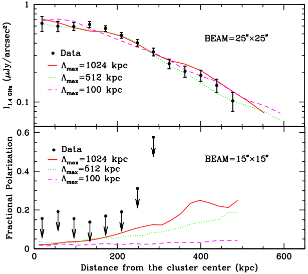
CENTRAL STRENGTH AND RADIAL DECREASE

This work made use of results produced by the Cybersar Computer Cluster



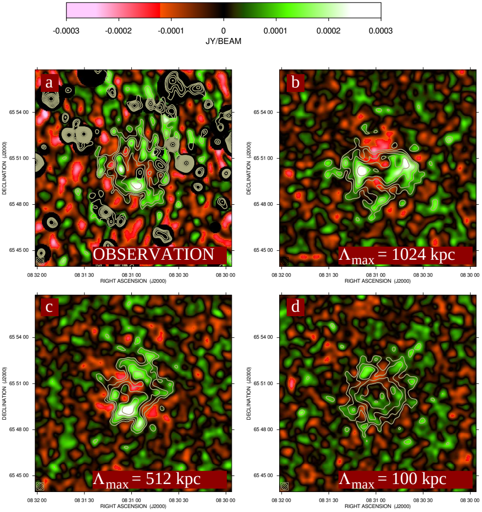


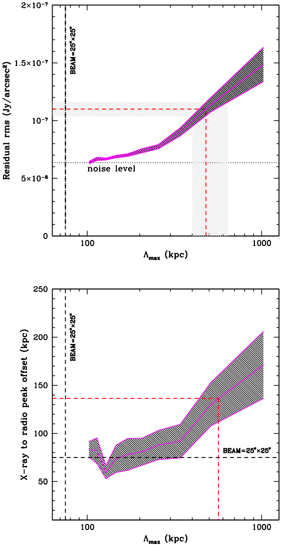
$$\langle B_0 \rangle = 1.3 \mu\mathrm{G}$$

$$\eta = 0.5$$

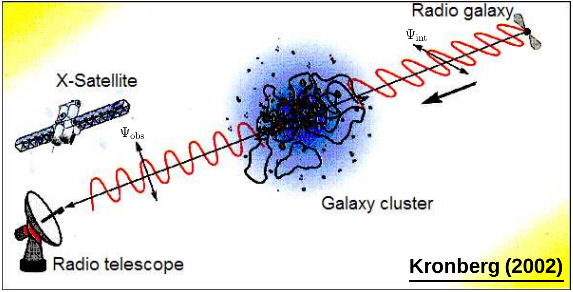
MAXIMUM FLUCTUATION SCALE

This work made use of results produced by the Cybersar Computer Cluster





FARADAY ROTATION



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

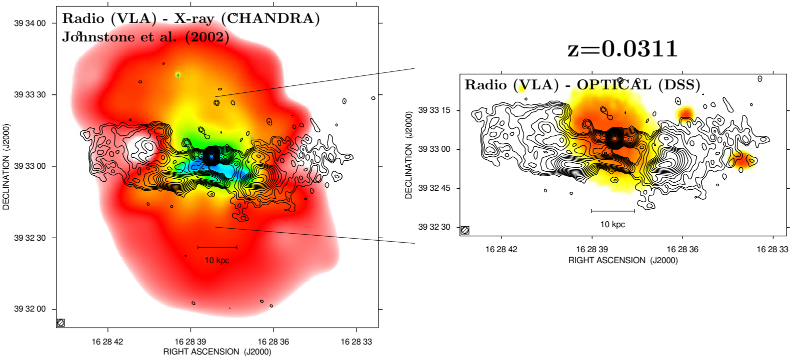
$$RM(\mathrm{rad/m^2}) = 812[\mathrm{g^{-1/2}cm^{1/2}s}] \int_0^{\mathrm{L(kpc)}} n_e(\mathrm{cm^{-3}}) B_{\|}(\mu\mathrm{G}) dl$$

A2199

distance 140 Mpc

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

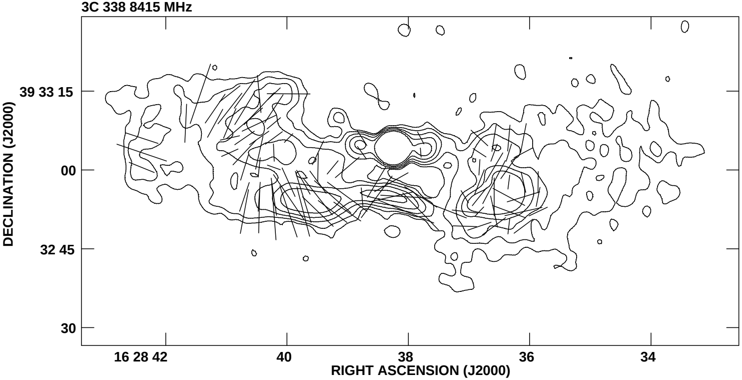
VLA observations at 1.4, 5, and 8 GHz



Vacca et al. (2012)

OBSERVED POLARIZATION PROPERTIES

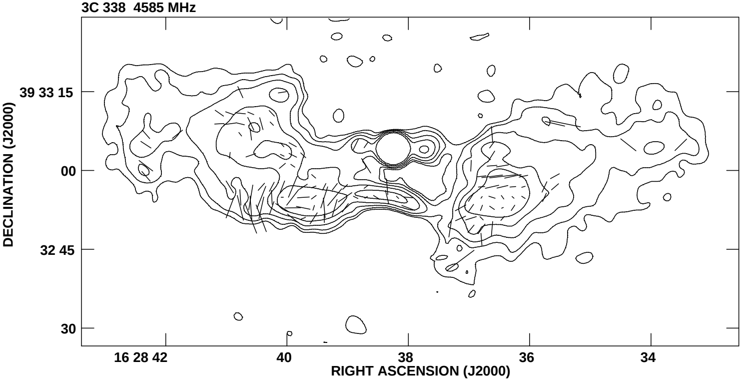
$$\Psi_{\mathrm{obs}} = \Psi_{\mathrm{int}} + \lambda^2 RM$$



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

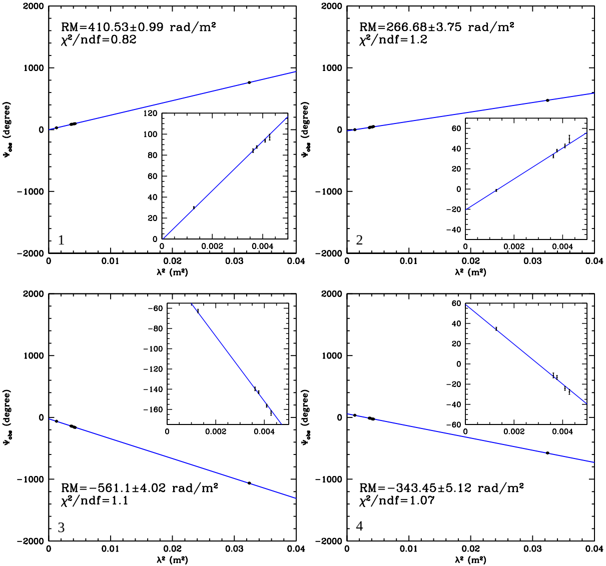
OBSERVED POLARIZATION PROPERTIES

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



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

ROTATION MEASURE IMAGE

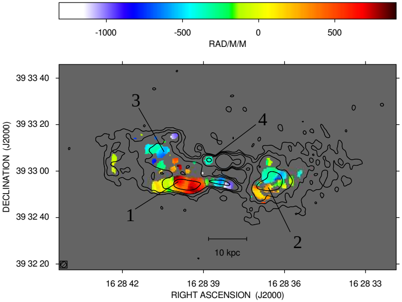


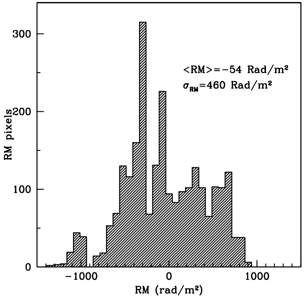
$$\Psi_{\text{obs}} = \Psi_{\text{int}} + \lambda^2 RM$$

ROTATION MEASURE IMAGE

$$RM \propto \int_{los} n_e(l) B_{\|} dl$$

RESOLUTION=2.5″=1.5 kpc





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

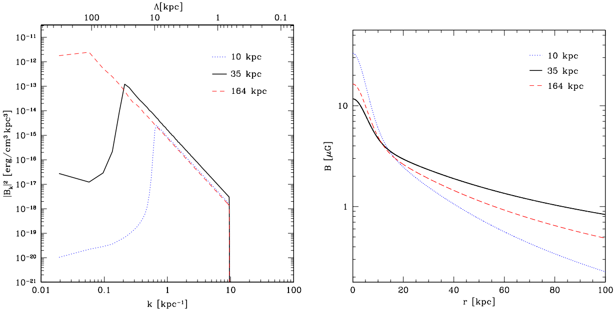
$$\Lambda_{\rm C} = \frac{3\pi}{2} \frac{\int_0^\infty |B_{\rm k}|^2 k dk}{\int_0^\infty |B_{\rm k}|^2 k^2 dk}$$

Felten (1996) Ensslin & Vogt (2003)

PARAMETERS

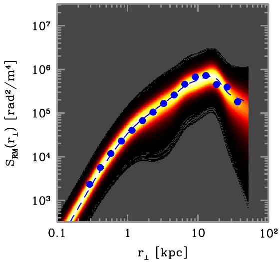
FARADAY (Murgia et al. 2004)

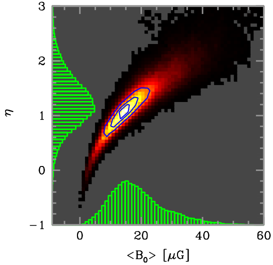
PARAMETER OF INTEREST
magnetic field intensity at the cluster center, $\langle B_0 \rangle$
magnetic field radial decrease, η, $\langle B(r) \rangle = \langle B_0 \rangle \left(\frac{n_e(r)}{n_0} \right)^{\eta}$
magnetic field power spectrum index, n (e.g., $n = 11/3$ Kolmogorov)
minimum scale of fluctuation, $\Lambda_{\rm min}$
maximum scale of fluctuation, $\Lambda_{\rm max}$



3D SIMULATIONS

This work made use of results produced by the Cybersar Computer Cluster





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

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

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

$$n = (2.8 \pm 1.3)$$
$$\Lambda_{min} = (0.7 \pm 0.1)\,\mathrm{kpc}$$
$$\Lambda_{max} = (35 \pm 18)\,\mathrm{kpc}$$
$$\langle B_0\rangle = (11.7 \pm 9.0)\,\mu\mathrm{G}$$
$$\eta = (0.9 \pm 0.5)$$

CONCLUSIONS

The radio halo emission in the merging cluster A665 is consistent with a moderate magnetic field central strength of about 1.3 μG and a large spatial scale of fluctuation, $\Lambda_{\rm B} \sim 100$ kpc, while the polarization properties of the radio galaxy at the center of the relaxed cluster A2199 reveal a high central magnetic field strength $\langle B_0 \rangle \sim 12\,\mu$G and a small fluctuation scale, $\Lambda_{\rm B} \sim 5.2$ kpc, in agreement with works available in literature for other galaxy clusters. Currently, a detailed study of the intracluster magnetic field is available just for few galaxy clusters. A larger statistical sample is necessary to draw a general picture and better understand magnetic fields on large scale structures. A fundamental contribution to the study of intracluster magnetic fields will be given by LOFAR and SKA.

THANK YOU!