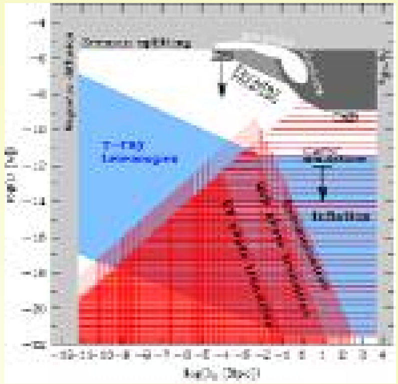


Magnetic fields
in
clusters of galaxies

Luigina Feretti

Istituto di Radioastronomia INAF, Bologna, Italy

Thanks to my collaborators:

A. Bonafede, G. Giovannini, F. Govoni, M. Murgia, V. Vacca

Paris, 13-15 Dec 2010

Outline

- Diffuse radio emission as probe of relativistic e- and magnetic fields in the ICM

- Merging clusters : halos and relics
  turbulence and shocks

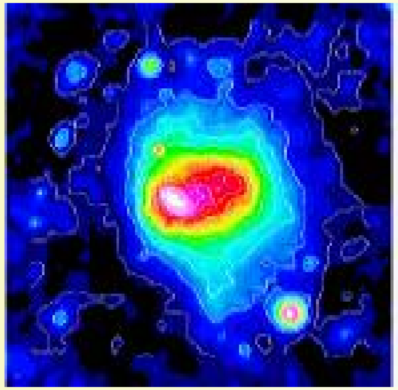
- Cooling core clusters: minihalos, minirelics
  turbulence and AGN interaction

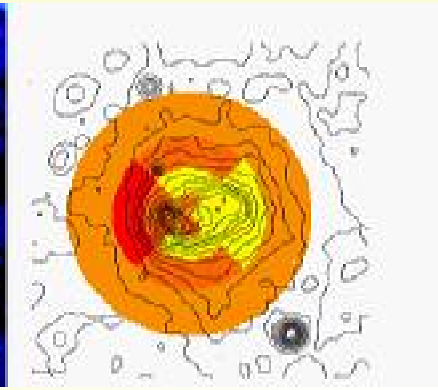
Most bodies in the Universe are magnetized on all scales

Clusters of galaxies:

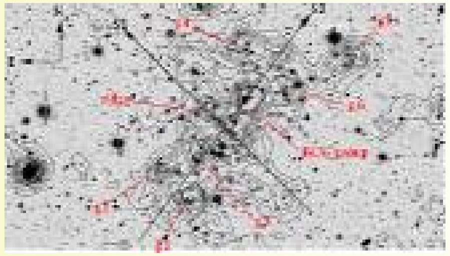
being the largest systems in the Universe, they represent an ideal laboratory to test theories for the origin of extragalactic magnetic fields

Merging vs relaxed clusters





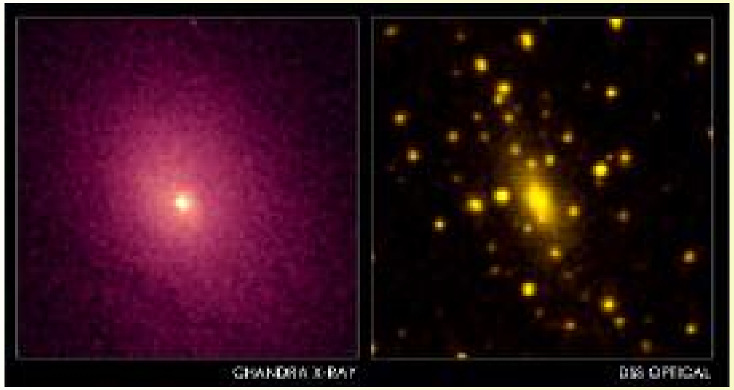
Xray brightness Temperature



Optical

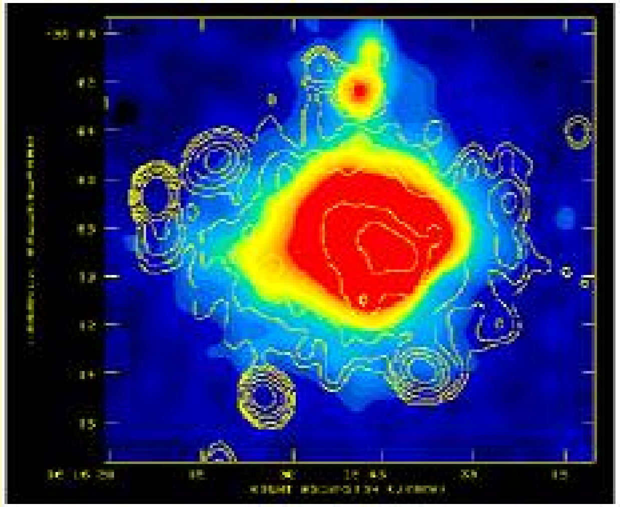
Mergers are the most energetic phenomena in the universe after the Big Bang
➔E ~ 10^{63-64} erg

SHOCKS - TURBULENCE

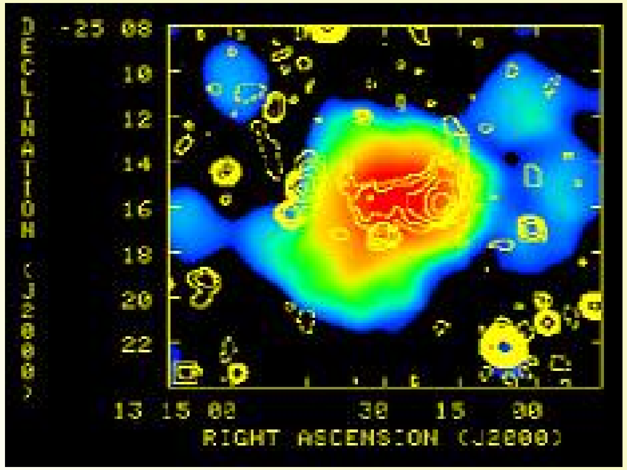


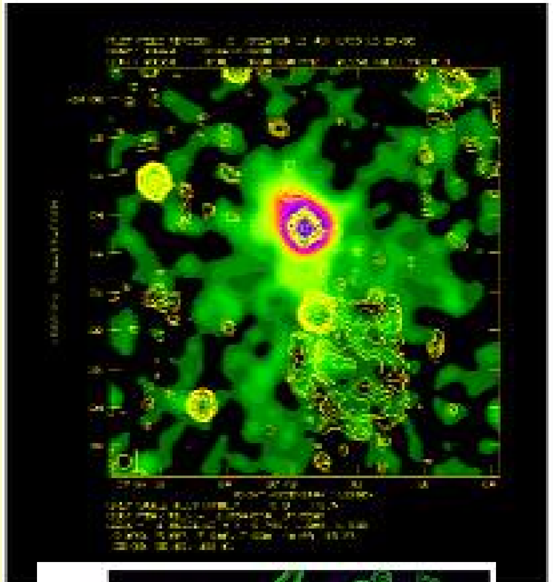
Xray brightness Optical

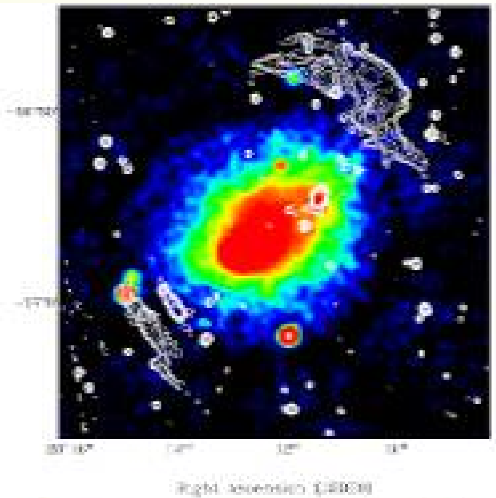
Central AGN
Cooling Core
Turbulence in the CC region
BH-ICM feedback

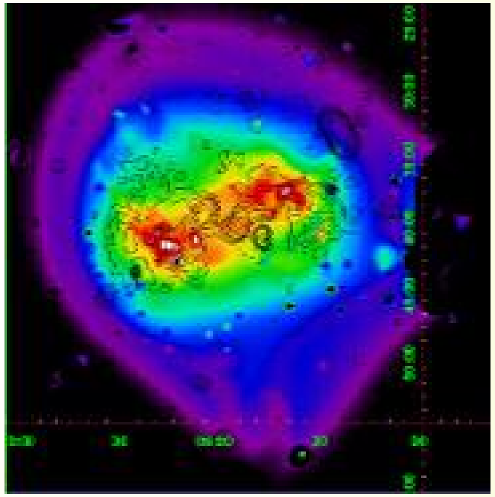


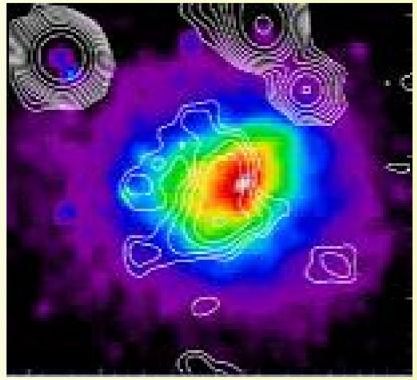
Synchrotron Emission

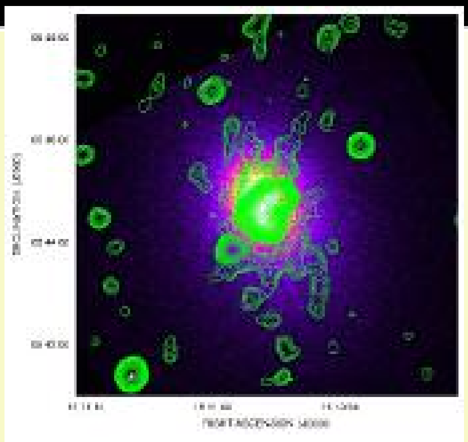


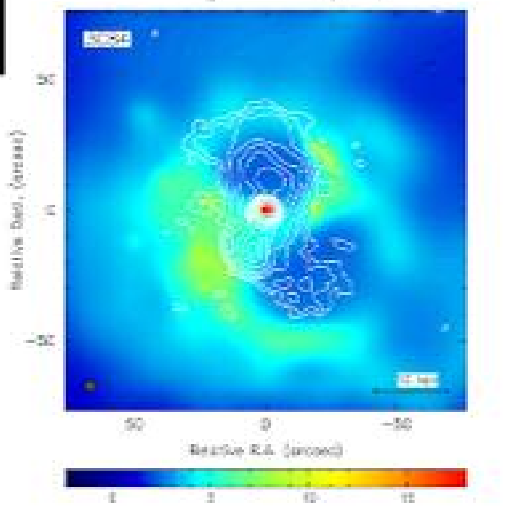


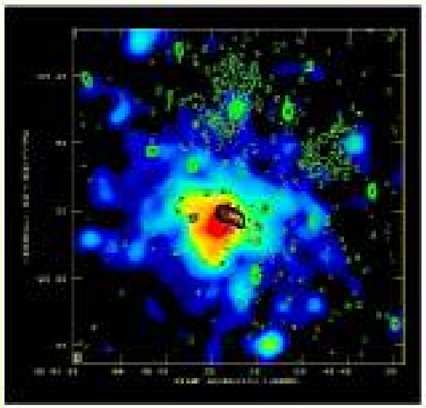


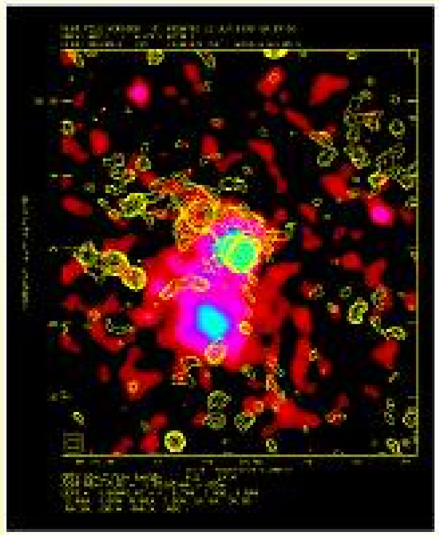












Previous slide

A2163: Feretti, Fusco-Femiano, Giovannini, Govoni, 2001

RXJ 1314.4-2515: Feretti, Schuecker, Böhringer, Govoni, Giovannini, 2005

A1664:Govoni, Feretti, Giovannini, Böhringer, Reiprich, Murgia, 2001

A3667: Rottgering, Wieringa, Hunstead, Ekers, 1997

A754: Bacchi, Feretti, Giovannini, Govoni, 2003

A2218: Giovannini, Feretti, 2000

A2029: Govoni, Murgia, Markevitch, Feretti, Giovannini, Taylor, Carretti, 2009

PERSEUS: Böhringer, Voges, Fabian, Edge, Neumann, 1993

A548b: Solovjeva, Anokhin, Feretti, Sauvageot, Teyssier, Giovannini, Govoni, Neumann, 2008

A115: Govoni, Feretti, Giovannini, Böhringer, Reiprich, Murgia, 2001

Presence of Relativistic plasma in clusters:
→ WELL ESTABLISHED

Diffuse radio emission → synchrotron
e^- plus magnetic fields

Cosmic rays illuminate magnetic fields at the ~μG level in the intracluster plasma

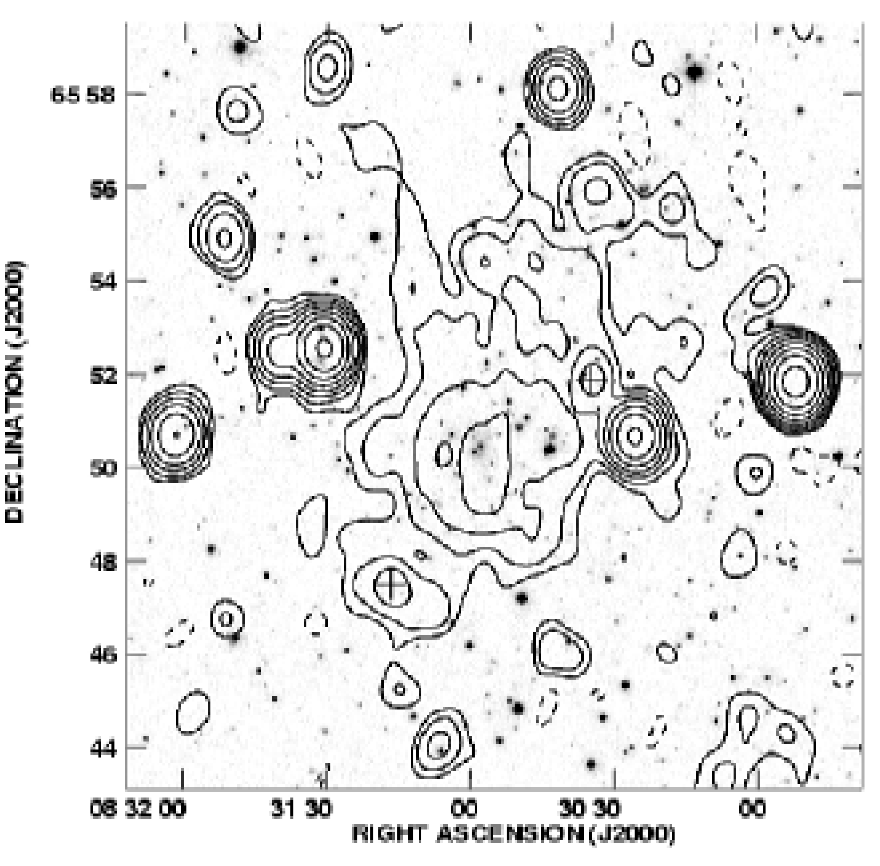
Magnetic fields also proved by Rotation Measure

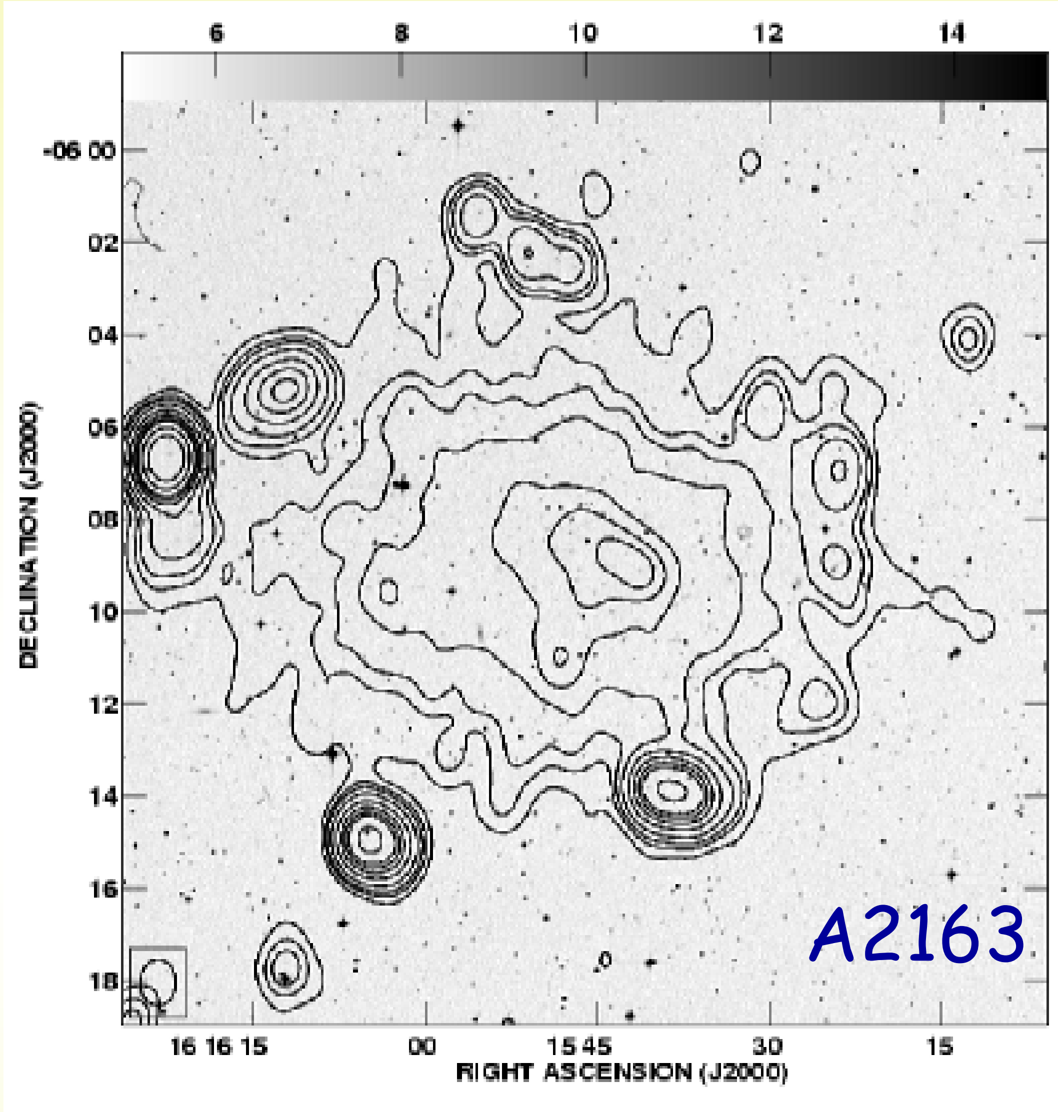
Classification of diffuse radio sources

Merging Cl	Cooling Core Cl
Halos	Mini - Halos
Relics (periphery)	Mini Relics (off center)
	Bubbles

Cluster radio halos

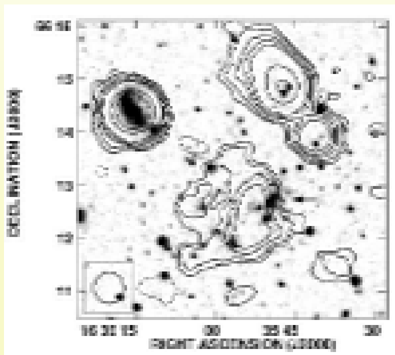
A665





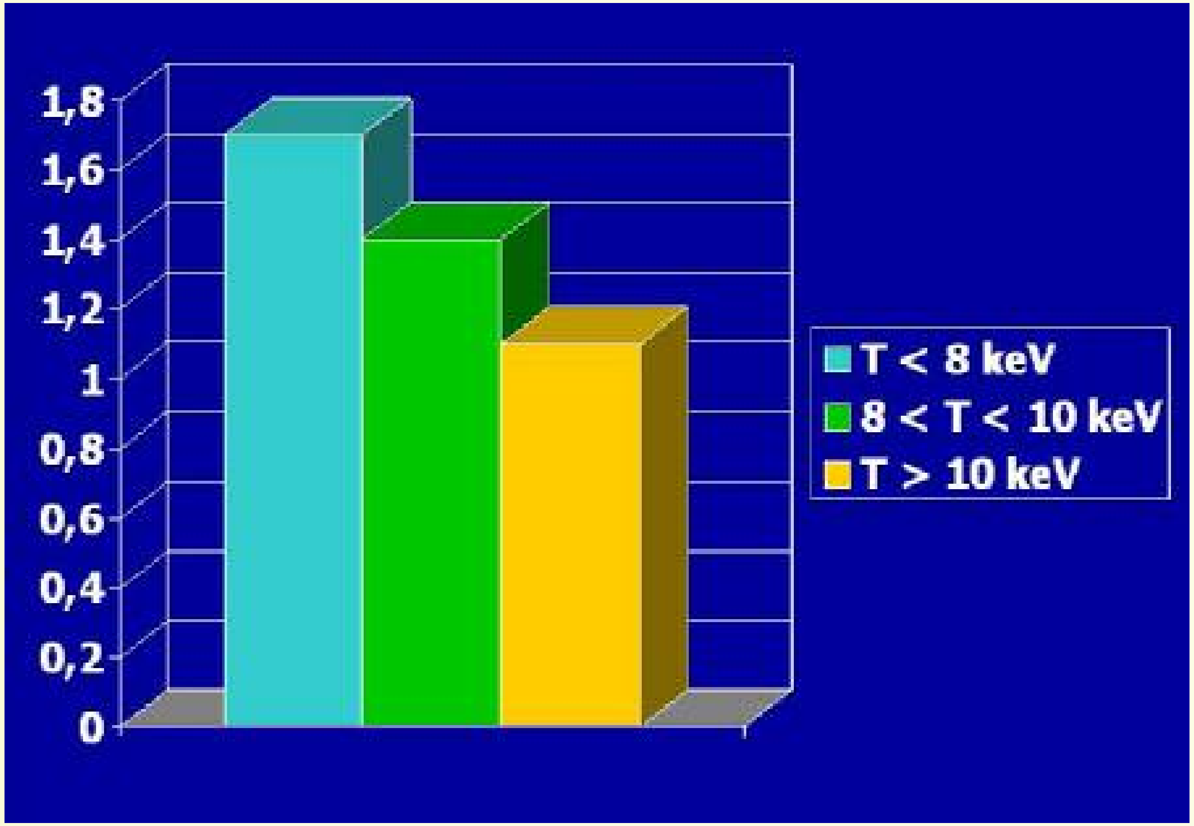
All in <u>merging clusters</u>

1 Mpc



A2218

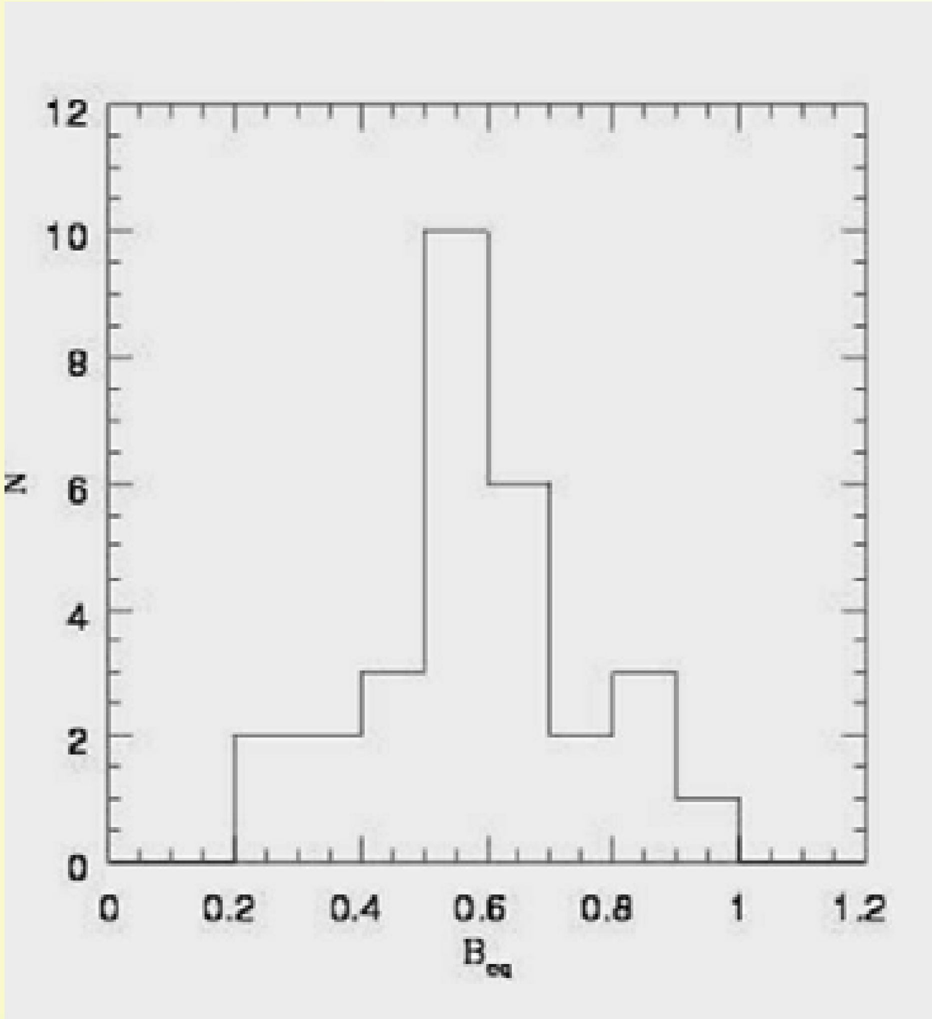
Halo Radio spectral index vs cluster temperature



Giovannini et al. 2009

In support of the Halo – Merging connection
Hot clusters → more massive → more energetic merging processes → more energy availale

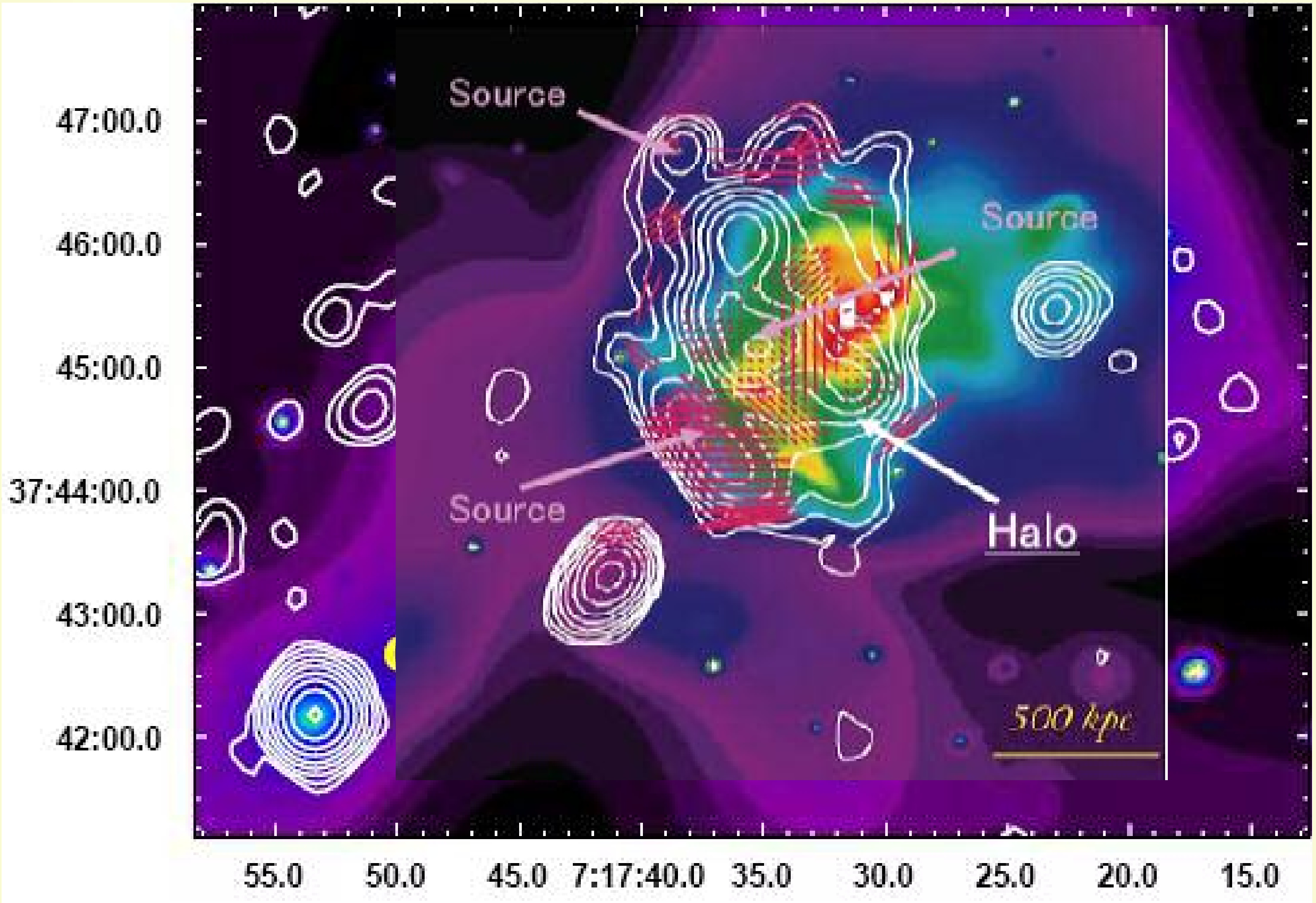
Magnetic field values from Halos Under Equipartition Conditions



classical estimate
(frequency range)

➔ Eq. Debated !

The cluster Macs J0717+3745



(Bonafede et al 2009)

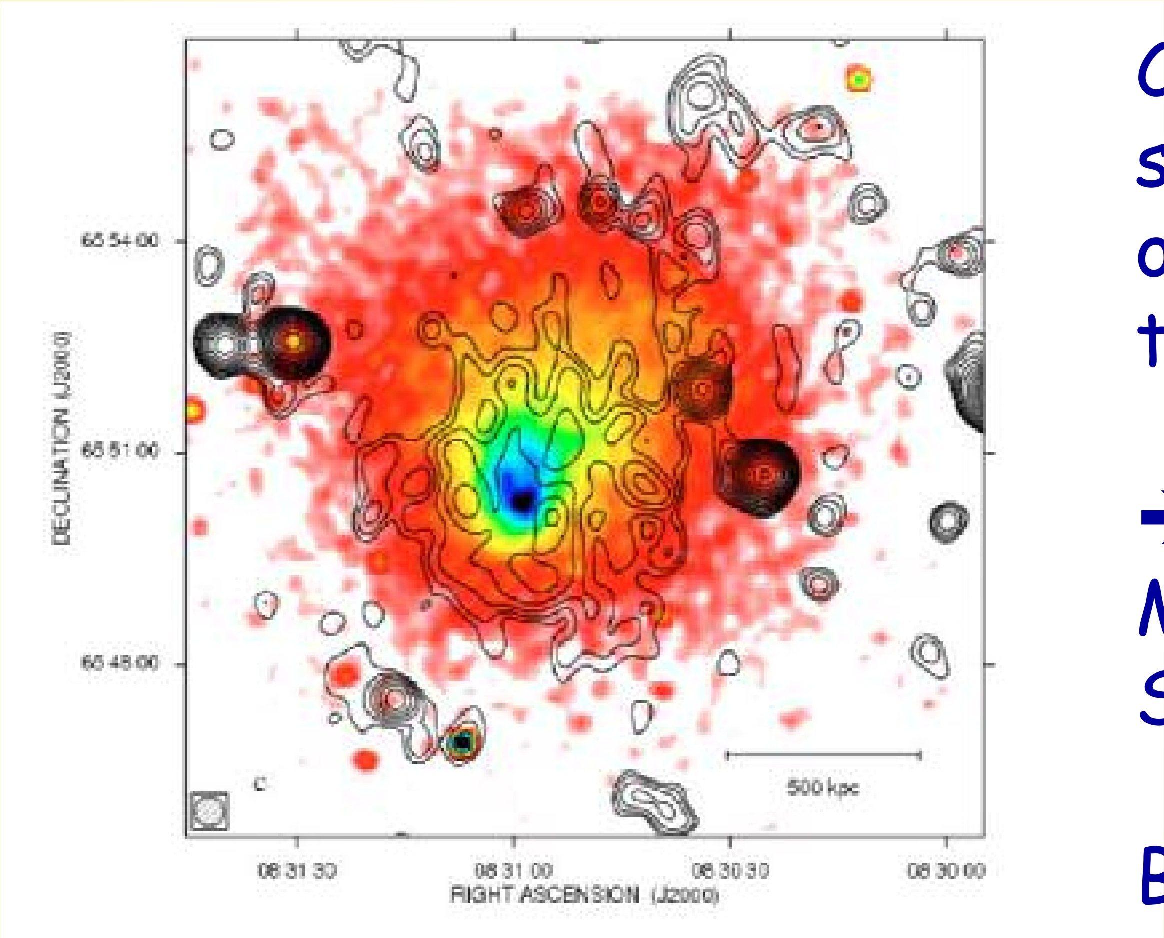
most distant & most powerful radio halo, also showing polarization at ~5 %

z= 0.55, $P_{1.4\ GHz}$~1.6 10^{26} W/Hz

The intracluster magnetic field power spectrum in Abell 665

V. Vacca[1,2], M. Murgia[2,3], F. Govoni[2], L. Feretti[3], G. Giovannini[3,4], E. Orrù[5], and A. Bonafede[3,4]

A&A 2010



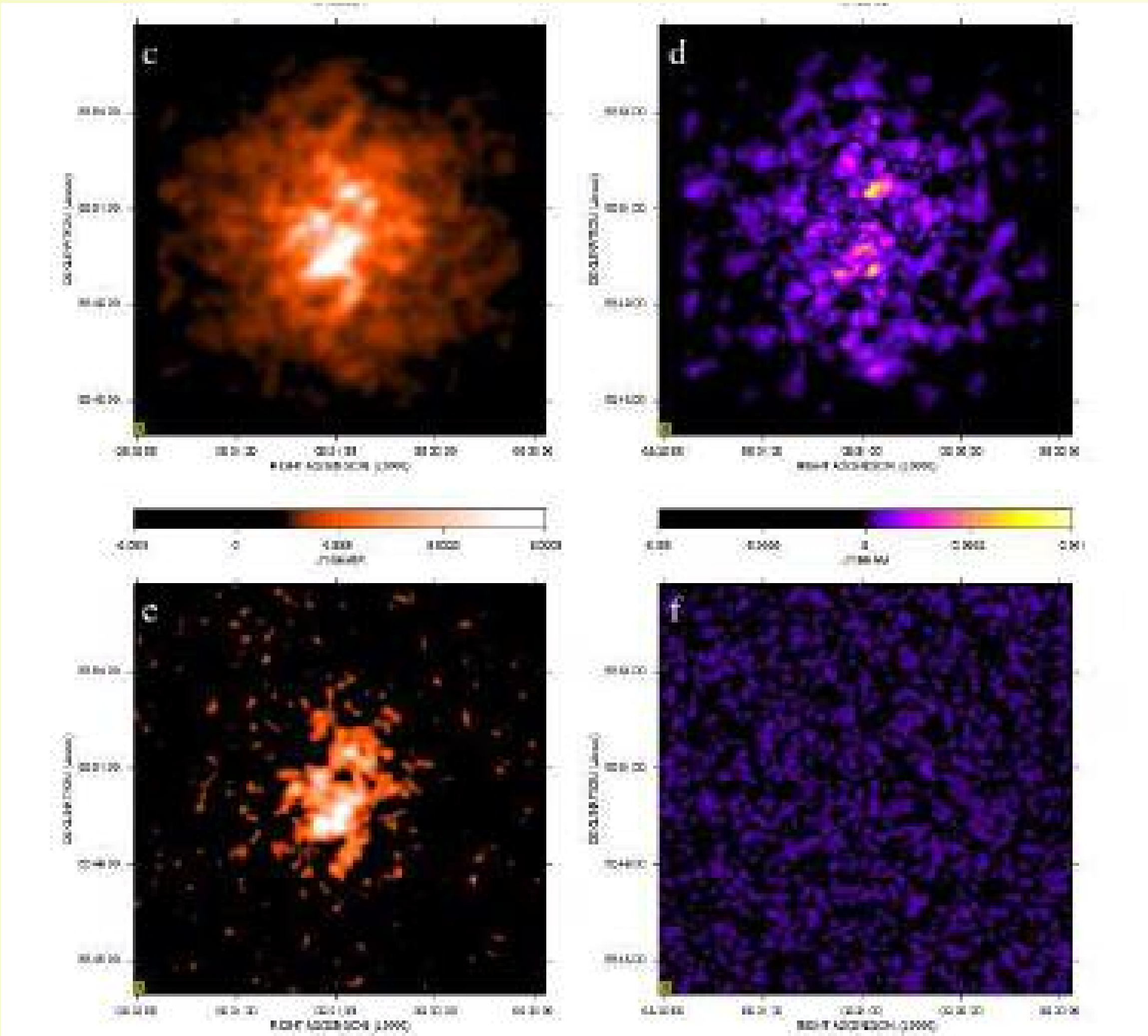
Compared with the synthethic image obtained assuming a 3D turbulent magnetic field

→ Constrain Magnetic field Strength and Structure

B ~ 1.3 μG

VLA C+D 1.4 GHz

Polarization in Radio Halos : expected with turbulent magnetic field



15" resolution, for cluster at z=0.2 expected pol 7%

Noise added

Simulations by Vacca et al. 2010

Coherence length

5 – 10 kpc

but : a single scale cell model is not suitable

field ordering + tangling

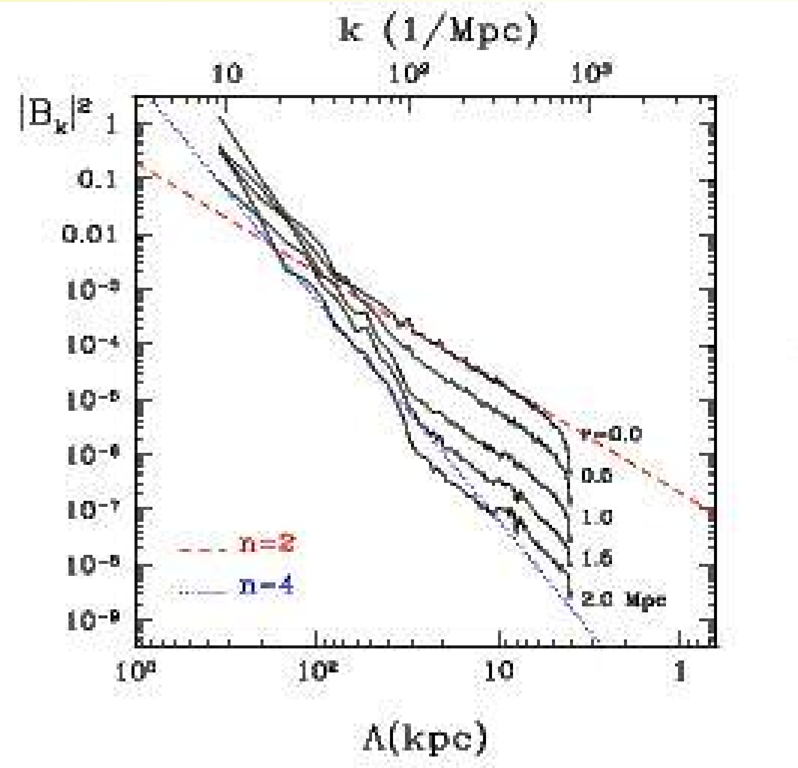
Power spectrum

(Ensslin & Vogt 2003, Vogt & Ensslin 2003, Murgia et al. 2004, Govoni et al 2006, Guidetti et al. 2008, Bonafede et al. 2010)

$$|B_k|^2 \propto k^{-n}$$

Index n = 2 – 4, Spatial scale in range 30 – 500 kpc

A2255 : variable index

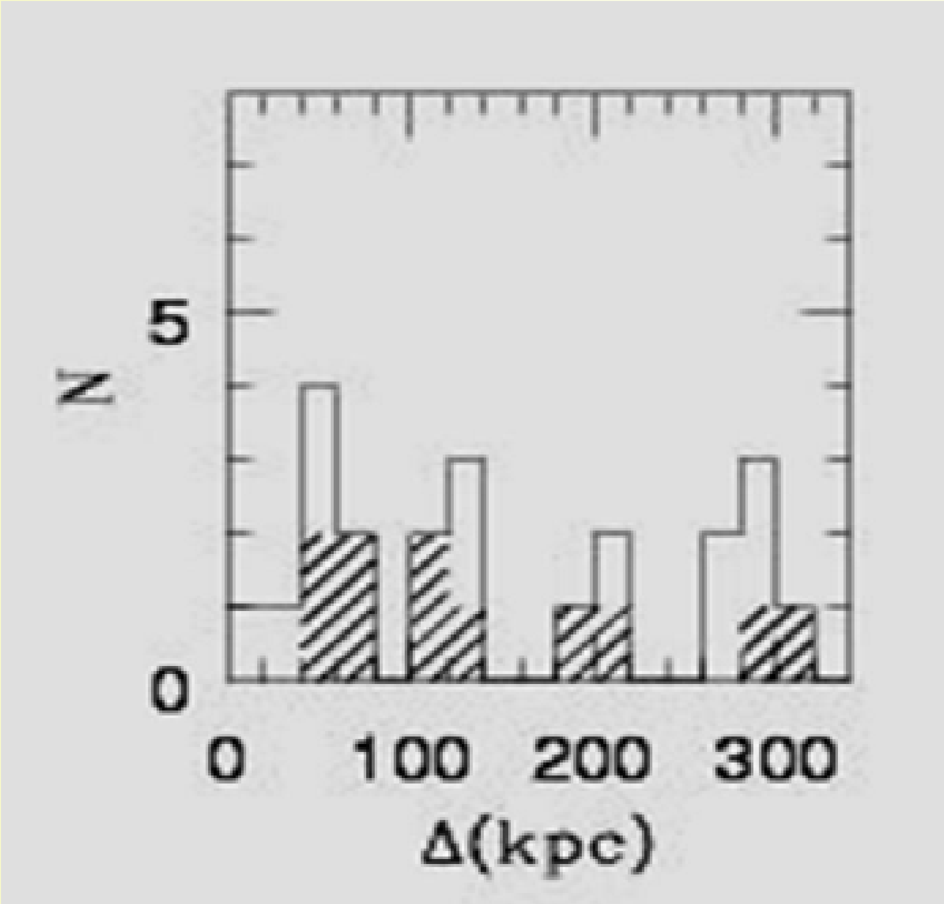


(Govoni et al. 2006)

n flatter at the center, steeper at the periphery :
➔small scales dominant at the cluster center large scales at the cluster periphery

➔ could be related with turbulence development/decay
small scales decay first, turbulence decay more efficient at the periphery (Subramanian et al. 2006)
➔ simulations

Radio vs X-ray brightness distribution



Offset between the radio and X-ray centroids in kpc

in 22 clusters

Dashed areas refer to giant halos (≥ 1 Mpc)

(Feretti et al. 2009)

Interpretation:

- halos can be very asymmetric with respect to the X-ray gas distribution, and this becomes more relevant when halos of smaller size are considered.

- asymmetry in the structure could originate by magnetic field fluctuations as large as hundreds of kpc: see magnetic field modeling Vacca et al., 2010

Cluster Magnetic field vs Temperature

Comparison RM - X-ray surface brightness
(Dolag et al. 2001)

$S_X \propto \int n^2 T^{1/2} dx$

$\sigma_{RM} \propto \int n B \, dx$

➔

σ_{RM} vs S_X reflects the trend of B vs n

(if the $T^{1/2}$ dependance is taken into account)

any further relation of B to T would be enhanced

Rotation measures of radio sources in hot galaxy clusters★

F. Govoni[1], K. Dolag[2], M. Murgia[1], L. Feretti[3], S. Schindler[4], G. Giovannini[3,5], W. Boschin[6,7], V. Vacca[1,8], and A. Bonafede[3,5]

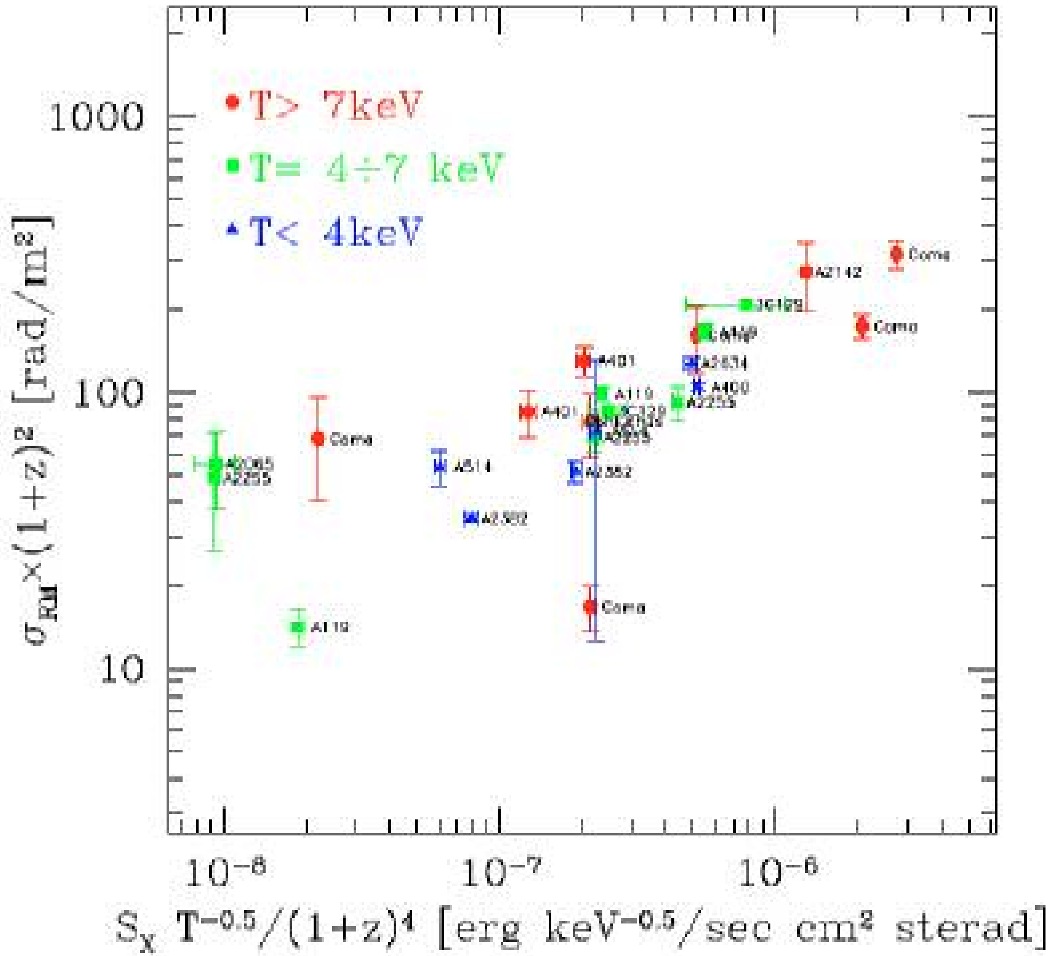
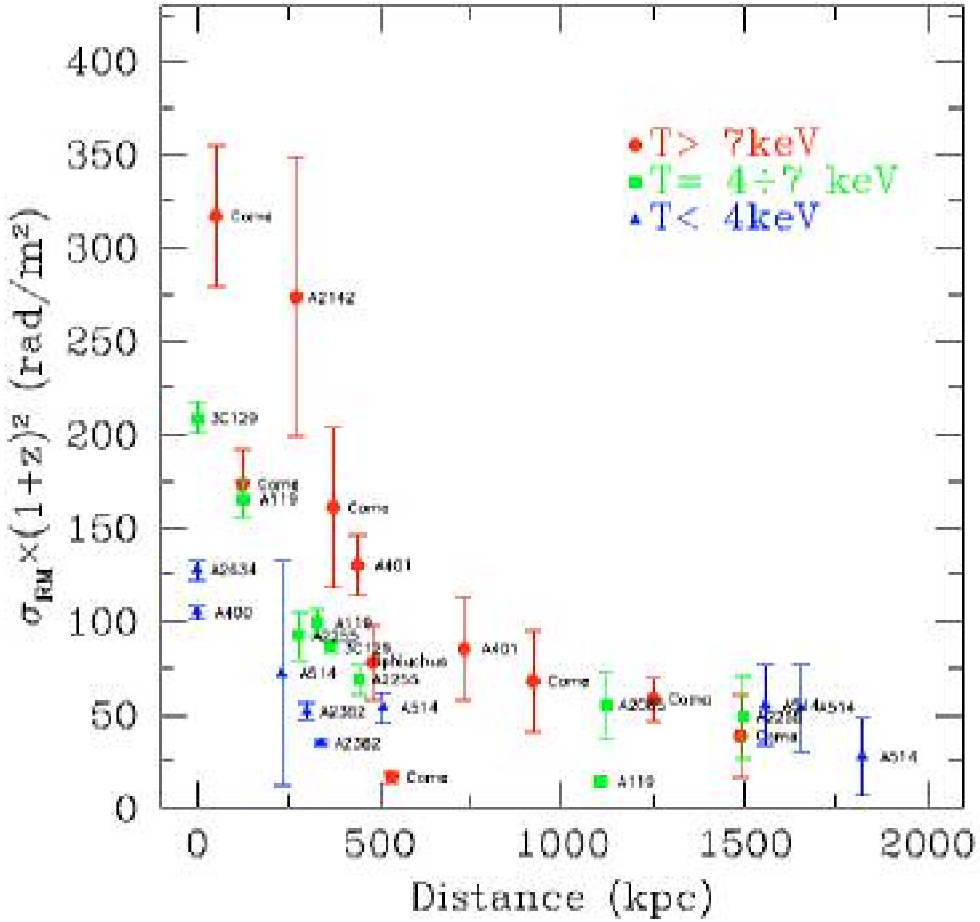


Fig. 18. Dispersion of the rotation measure distribution as a function of the X-ray surface brightness of the intracluster gas in the source location. The different symbols represent the cluster temperature taken from the literature (red >7 keV, green 4–7 keV, blue <4 keV).

(A&A 2010)

Govoni et al. A&A 522, A105 (2010)



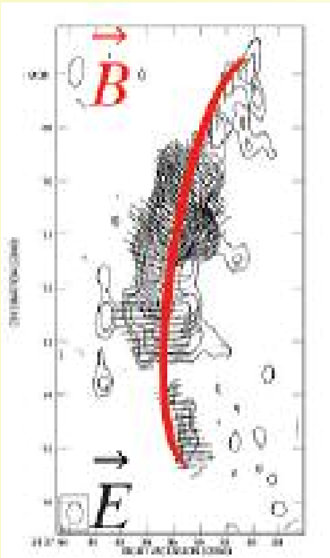
For a fixed projected distance, clusters with high T show a higher RM dispersion

➔ B linked to n

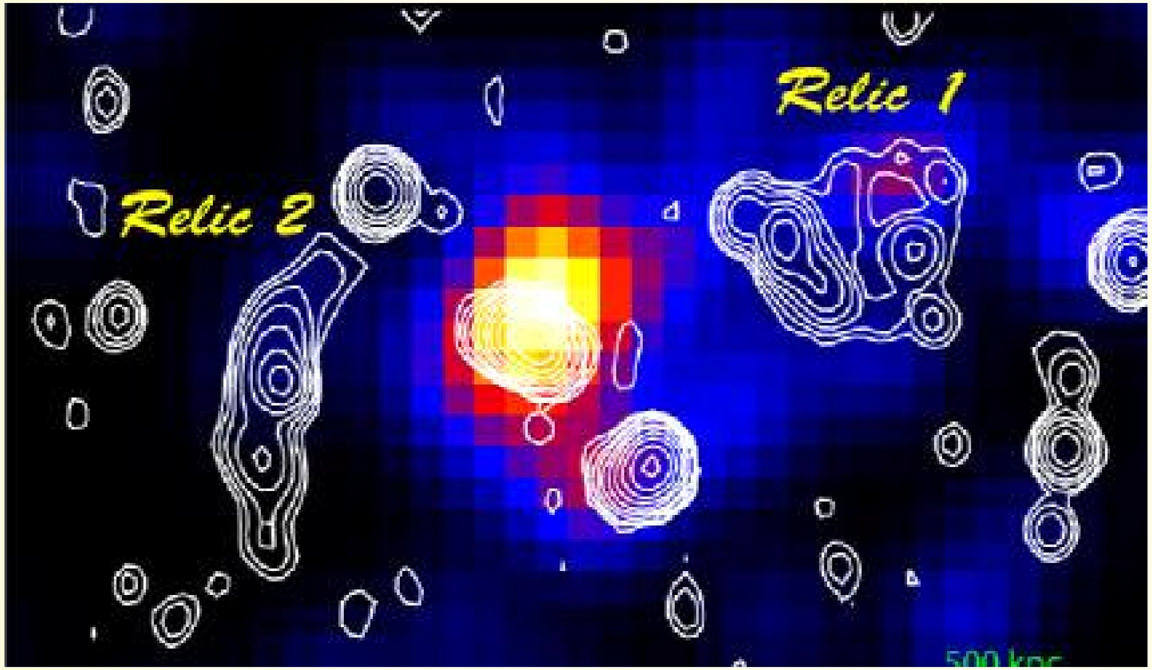
Cluster peripheries : RELICS

A2345 z= 0.177

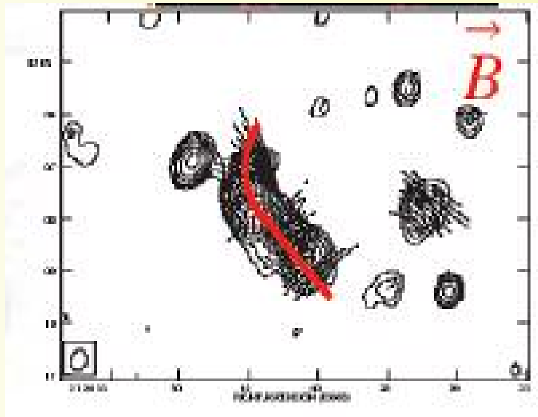
(Bonafede et al. 2009)



24%



1 Mpc

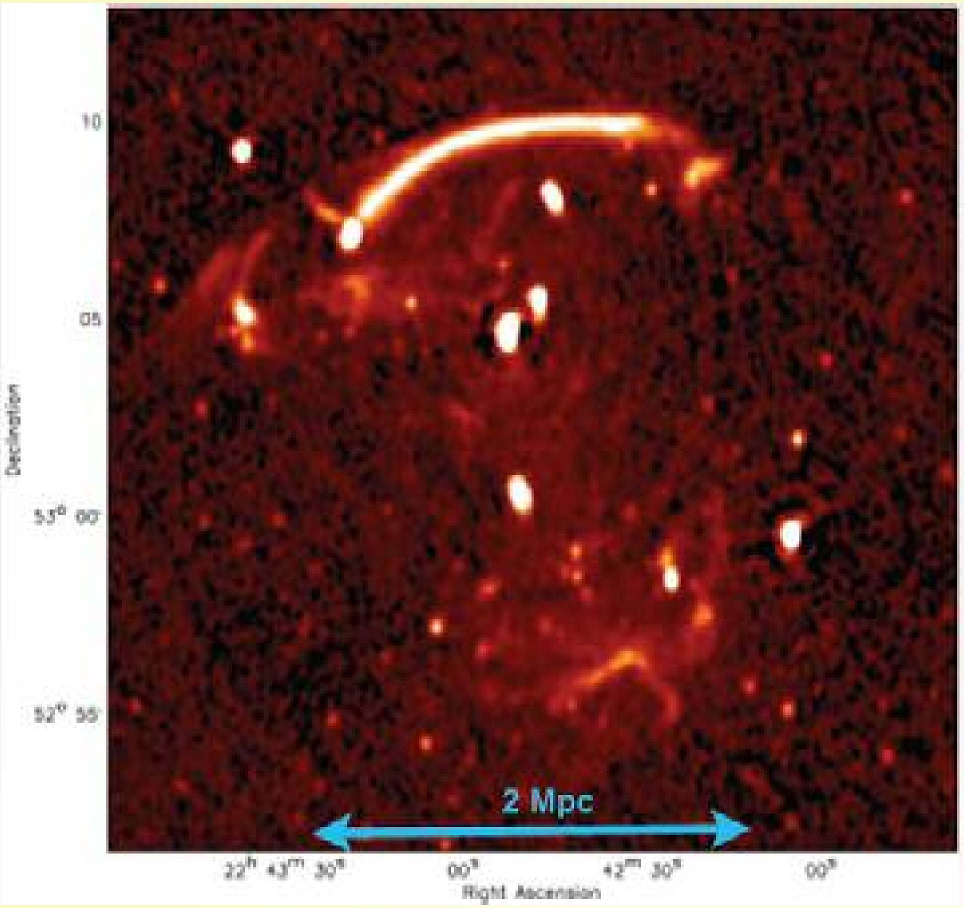


20%

Magnetic field aligned with relic major axis

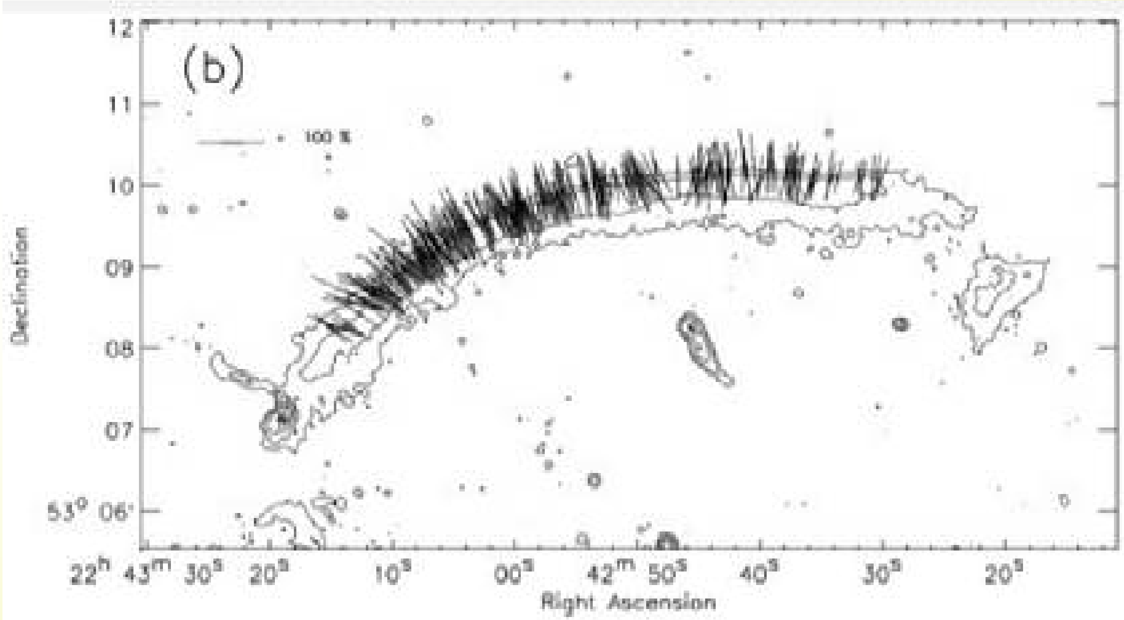
CIZA J2252.8+5301: SAUSAGE

Van Weeren et al 2010



WSRT 1.4 GHz

+ GMRT 0.6 GHz, 1.3 GHz



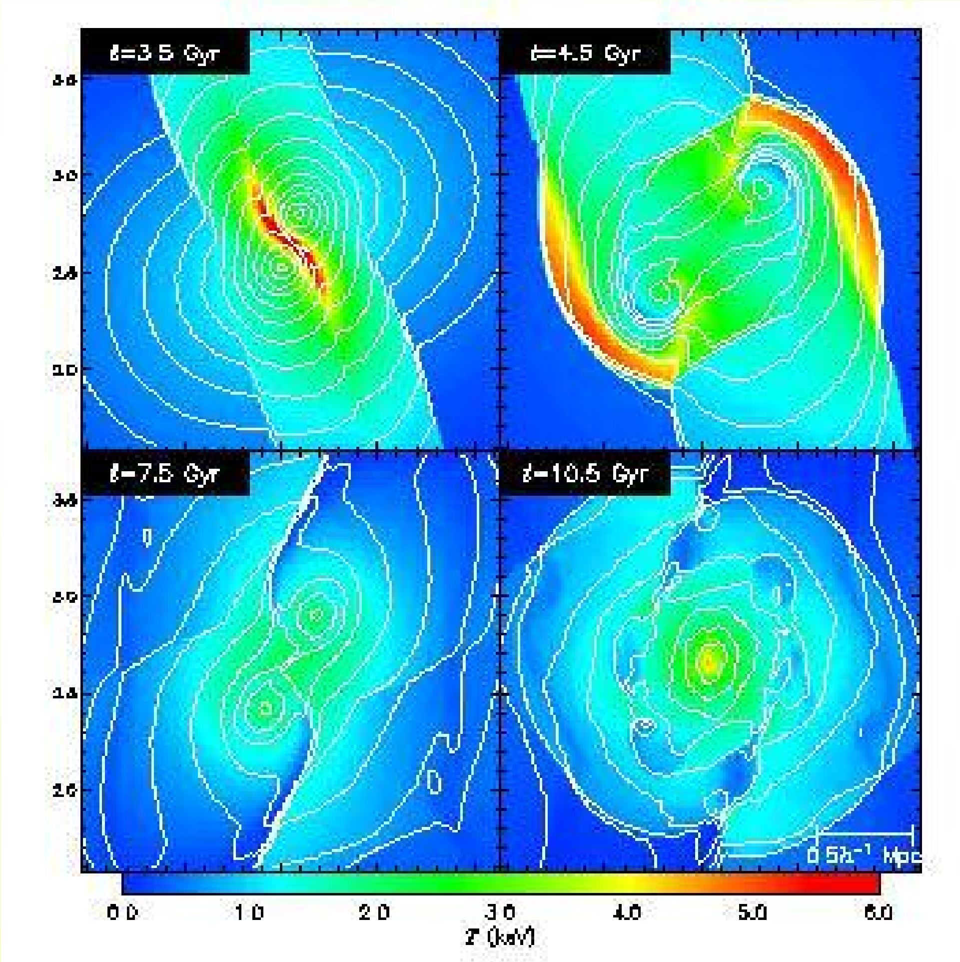
VLA 4.9 GHz
E vectors corrected for FR

B ~ 6 μG

Relics trace merger shocks where particles are accelerated by DSA mechanism

Shocks now detected
e.g.
in A548b (Solovyeva
et al. 2008)

A3667 (Finoguenov
et al. 2010)

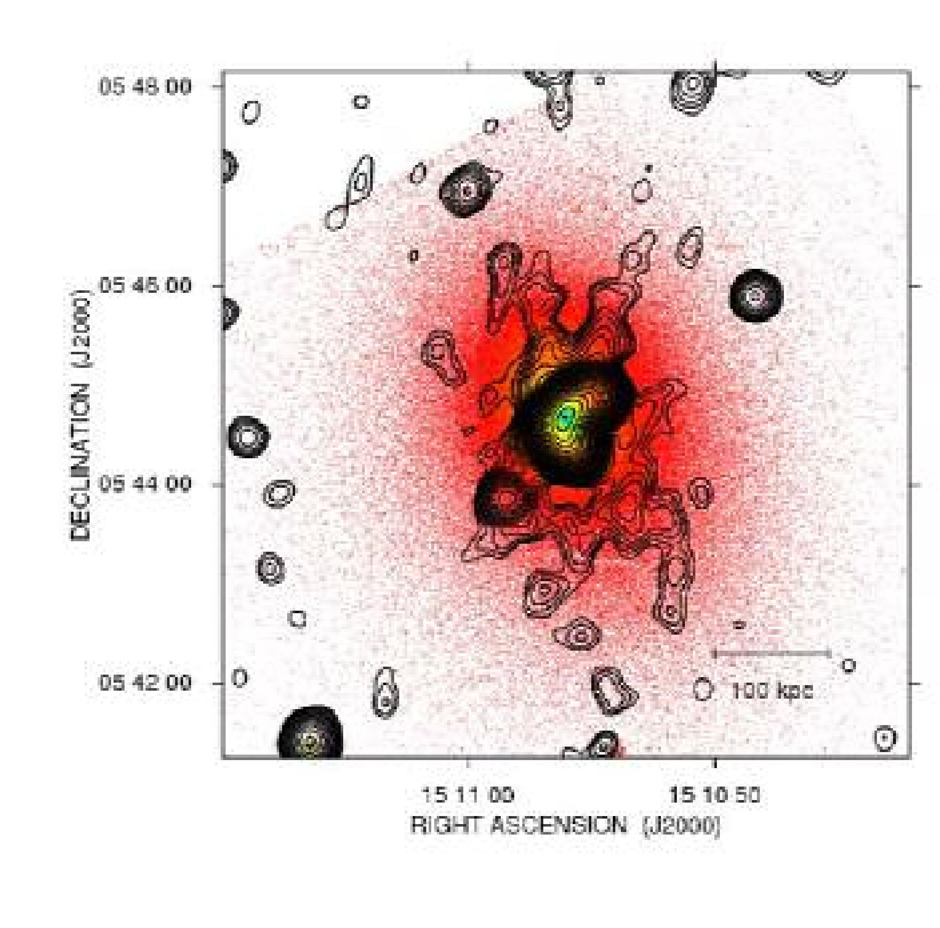


(Ricker & Sarazin 2001)

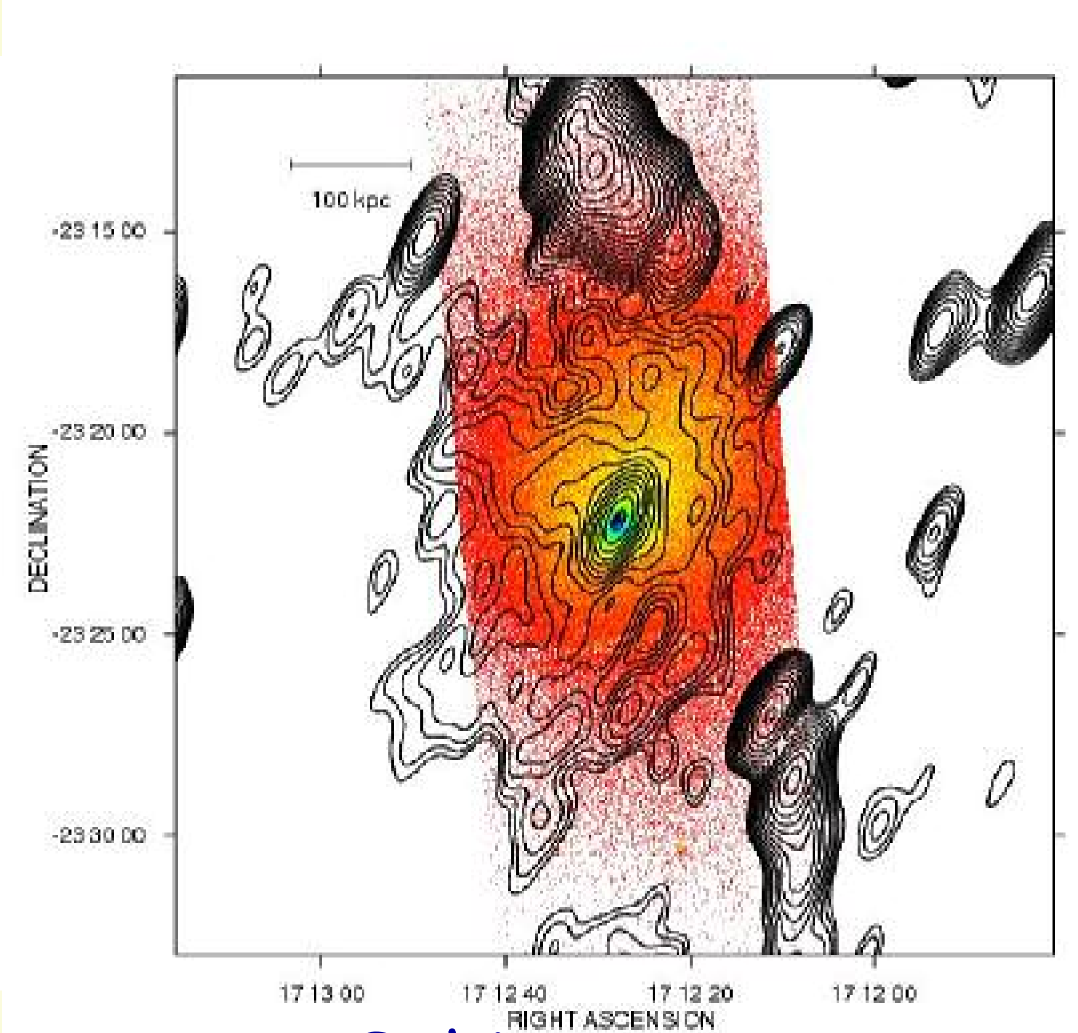
Color = temperature, Contours = X-ray brightness

Cooling Core Clusters

Cluster **MINI- HALOS** : in cool core clusters
➔ Perseus



A2029



Ophiucus

A search for diffuse radio emission in the relaxed, cool-core galaxy clusters A1068, A1413, A1650, A1835, A2029, and Ophiuchus

F. Govoni[1], M. Murgia[1,2], M. Markevitch[3], L. Feretti[2], G. Giovannini[2,4], G. B. Taylor[5,*], and E. Carretti[2]

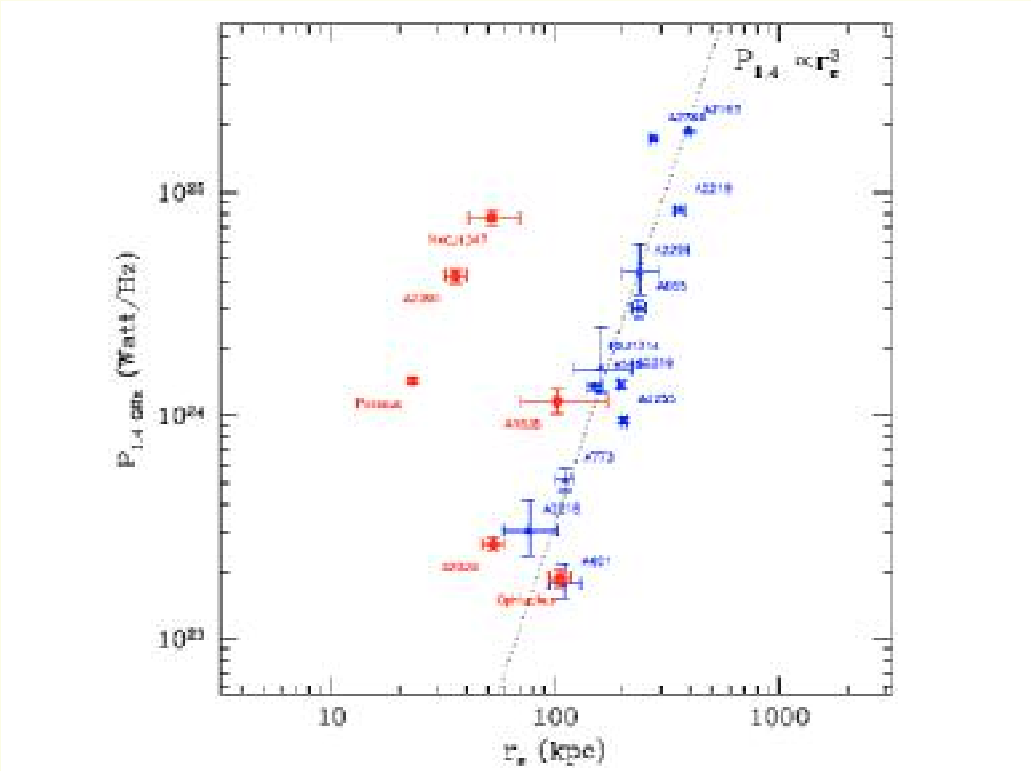
A&A 2009

0.1 Mpc

Comparative analysis of the diffuse radio emission in the galaxy clusters A1835, A2029, and Ophiuchus

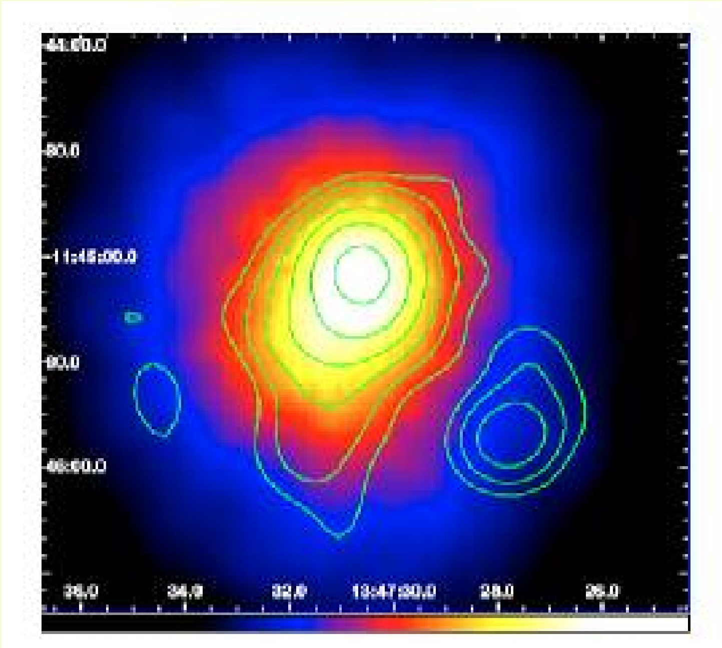
M. Murgia[1,2], F. Govoni[1], M. Markevitch[3], L. Feretti[2], G. Giovannini[2,4], G. B. Taylor[5,*], and E. Carretti[2]

A&A 2009



Some mini-halos appear to be scaled down versions of giant halos, some others are more peaked and of higher emissivity

➔ different emission mechanisms ?



Borderline example
of mini-halo
Cluster with Strong CC +
Disturbed dynamical
State in S-E region

450 x 600 kpc

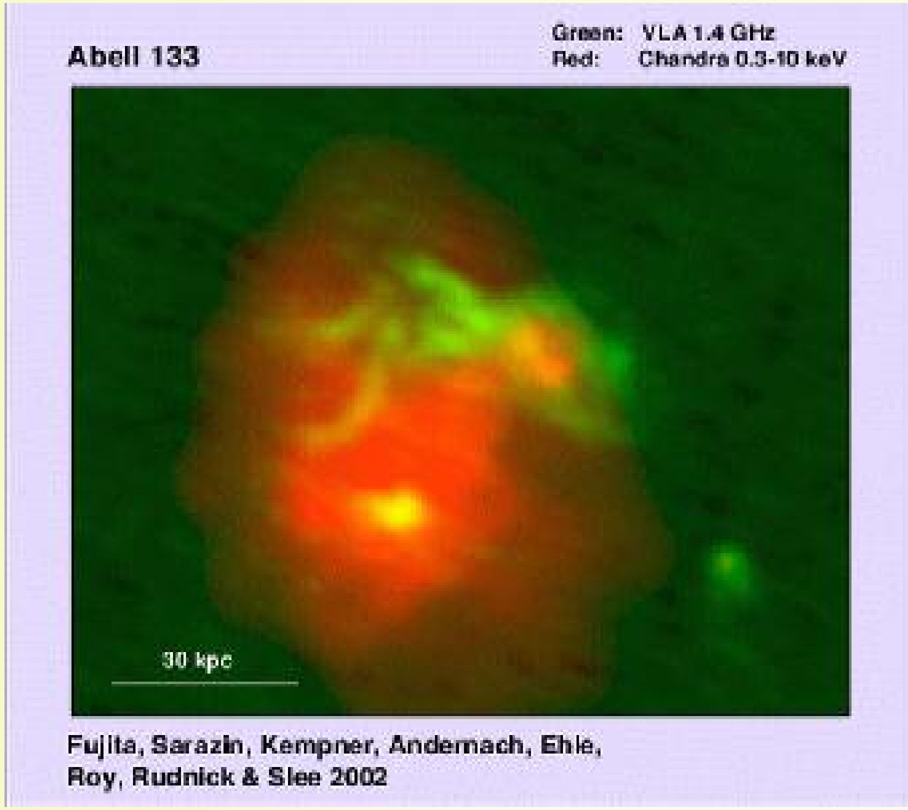
LETTER TO THE EDITOR

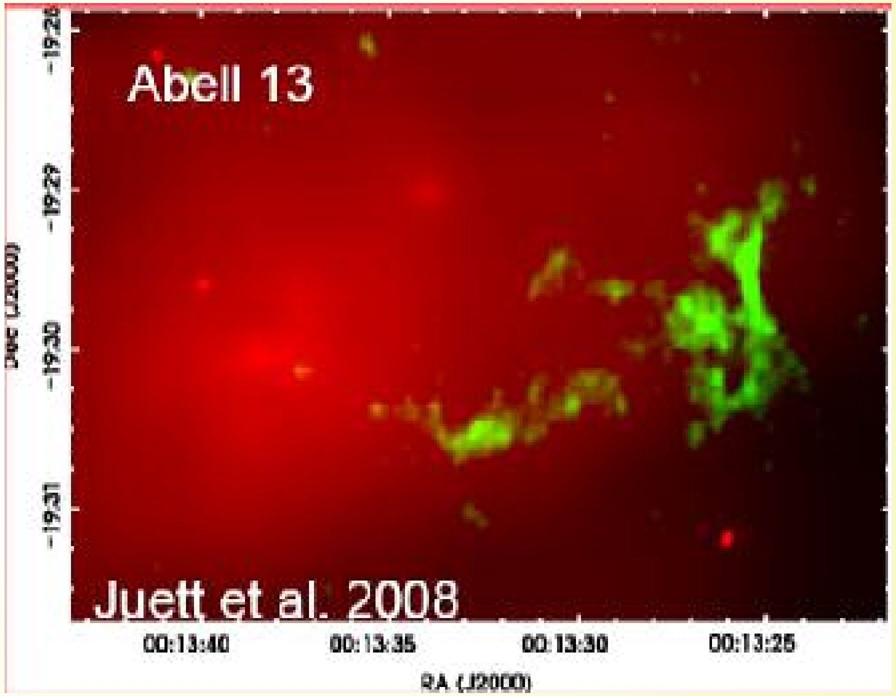
Discovery of diffuse radio emission at the center of the most X-ray-luminous cluster RX J1347.5−1145

M. Gitti[1], C. Ferrari[2], W. Domainko[3], L. Feretti[4], and S. Schindler[2]

A&A 470, L25–L28 (2007)

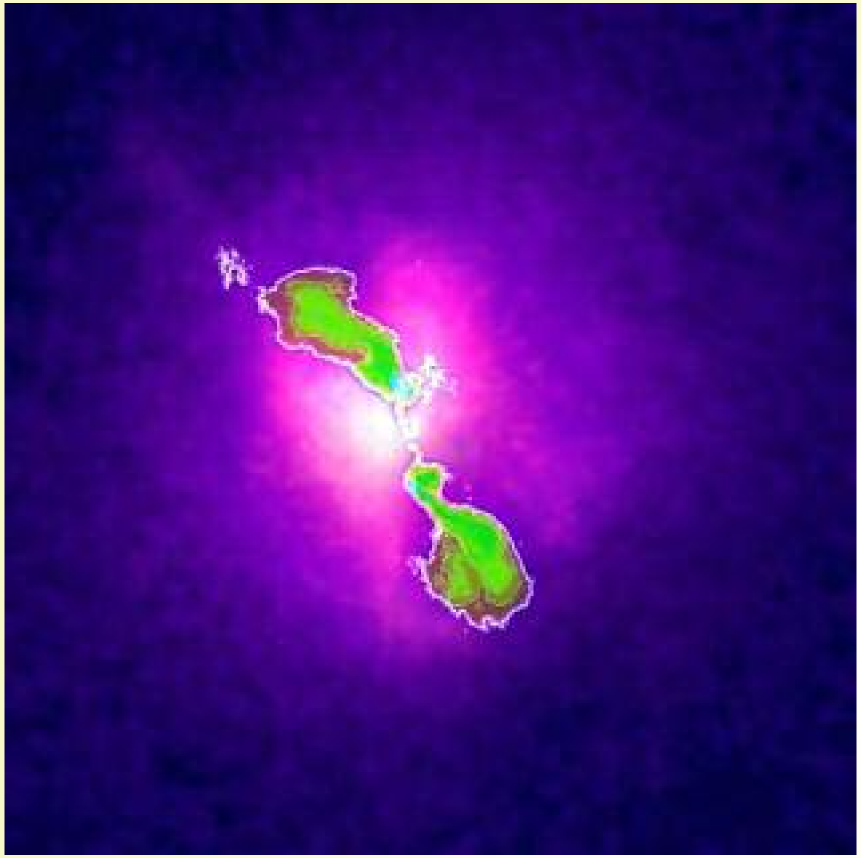
Mini relics



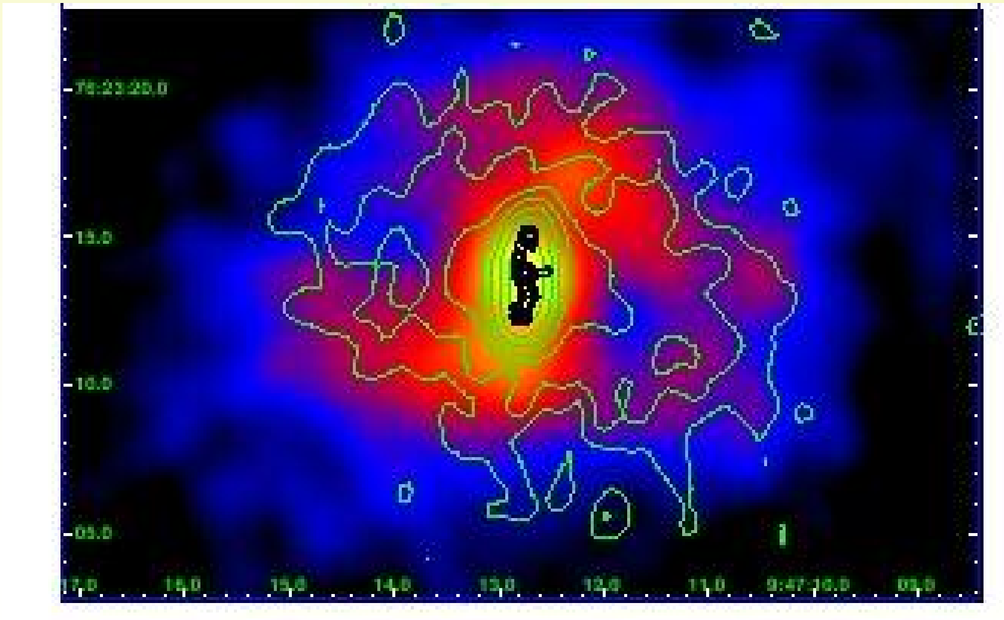


very steep radio spectra $\alpha > 2$
very high polarization degree

X-ray cavities in Cooling Clusters



Hydra A - X-ray Chandra
Mc Namara et al. 2000
Radio : Taylor et al. (VLA)



RBS797 (Gitti Feretti Schindler 2006)

Radio galaxies in X-ray cavities (FRI)

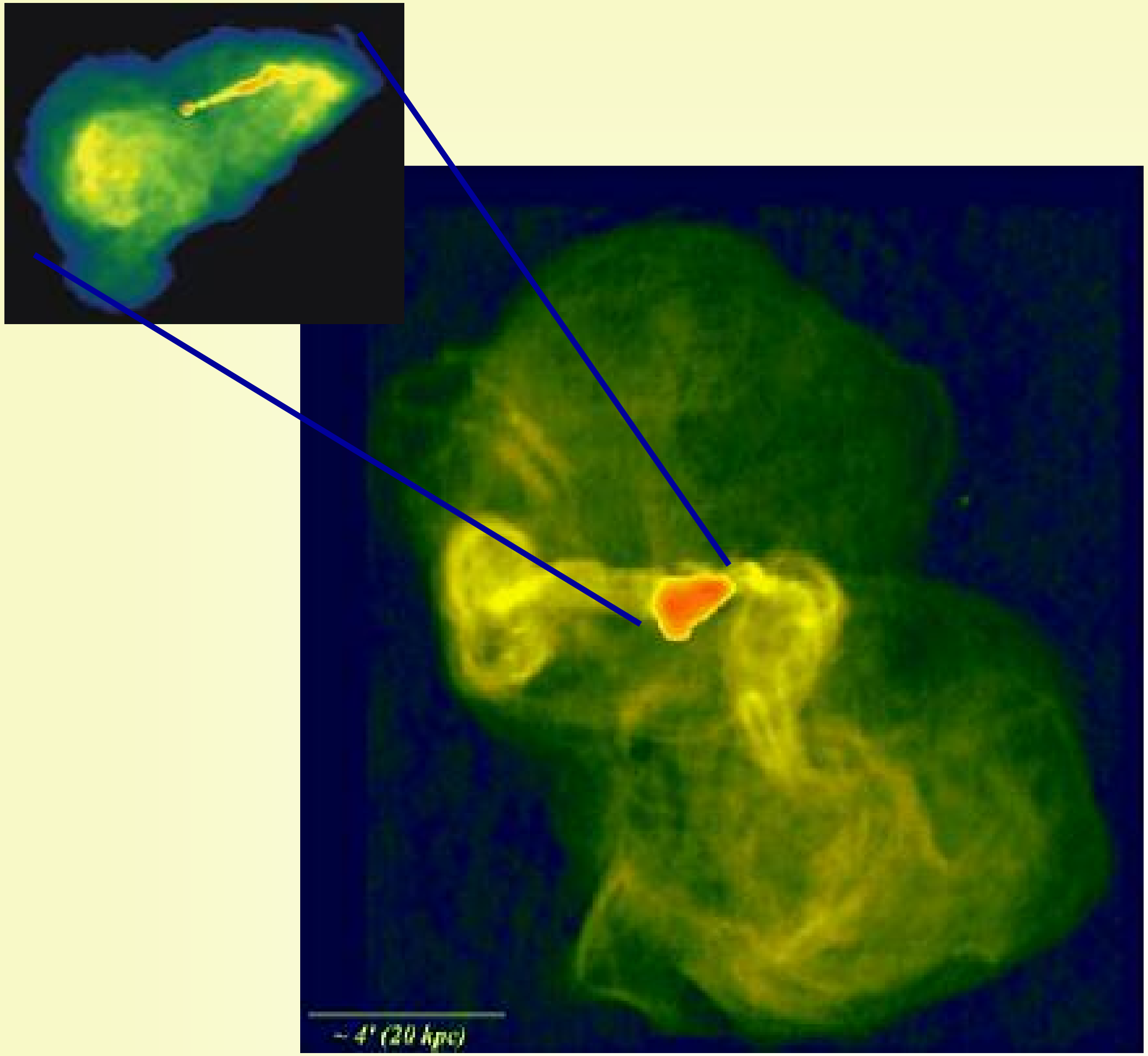
Radio source – ICM interaction in Cooling Core Clusters

-Feedback mechanism between BH and environment:
cooling of gas can feed the AGN which can reheat the gas through one strong or several small episodes of energy release

- Cavities are filled with cosmic rays which inflate the cavities and form a much larger lobe

- Bubbles can rise to the cluster outskirts

-Eventually the cosmic rays diffuse away from cavities, impact with/ leak into the surrounding medium giving rise to mini relics



M87 (Virgo)

A buoyant BUBBLE in the center of a Cool Core Cluster

The radio features are buoyant bubbles

Energy is transferred from the relativistic to the thermal plasma.

(Owen et al. 2000, Churazov et al. 2001, Böhringer et al. 2001)

Conclusions

Magnetic fields are common in clusters
Detected so far up to z=0.55

related to turbulence at the center
strong and ordered in peripheral shocked regions
radial decline
linked to gas density
possibly linked to gas temperature

strong in the cooling core cluster centers
interaction between AGN and ICM

high degree of ordering
coherence scales up to 100s kpc

THANK YOU