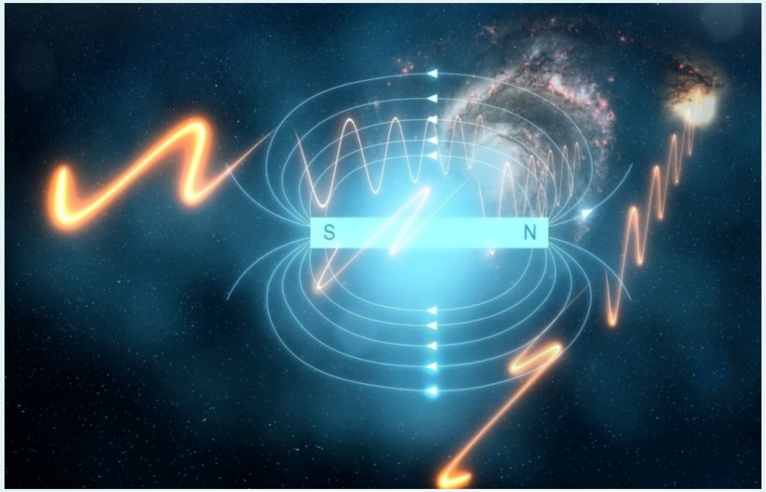
Large Scale Magnetic Fields in the Universe



Gabriele Giovannini – Physics and Astronomy Dept. – Bologna Univer.
INAF Istituto di Radioastronomia Bologna

Thanks to my collaborators: L. Feretti, A. Bonafede, F. Govoni, M. Murgia et al.

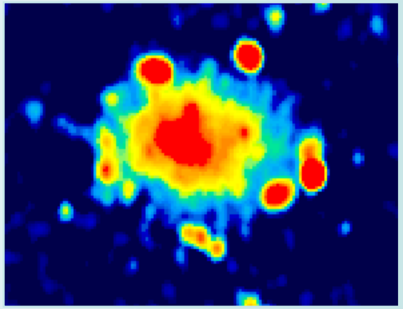
Observational diagnostics of B

Presence of field, direction, strength, scales, ordering

1 - Synchrotron emission: cosmic rays illuminate magnetic fields at the μG level in the ICM (direct measurement)

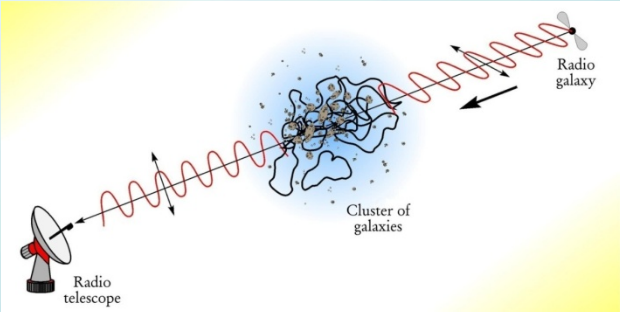
a- total intensity ➔ field strength $\perp$ - equipartition

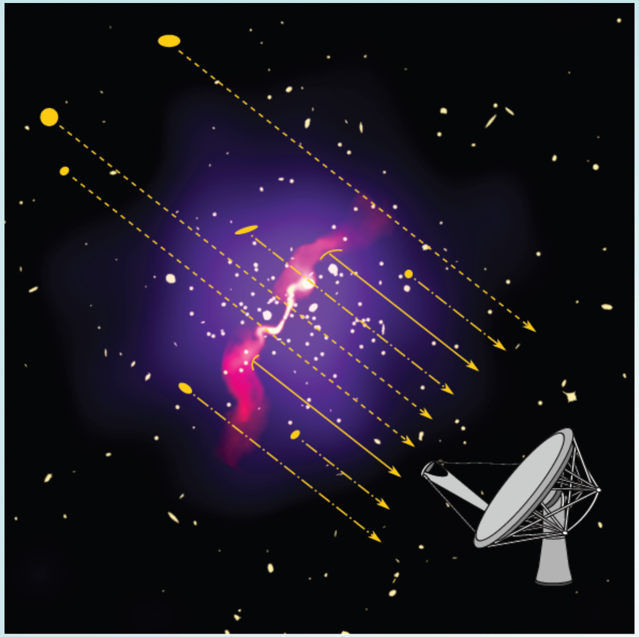
b- polarization ➔ field orientation and degree of ordering

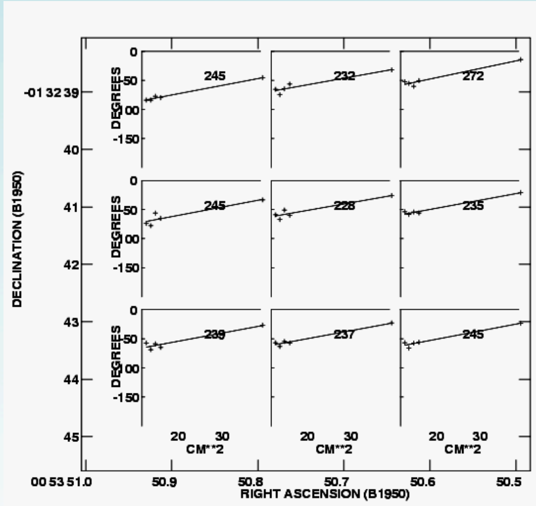


2 – Rotation Measure of imbedded or background radio sources (indirect measurement)

➔ field strength $\parallel$ and structure (spatial scales)







$$\chi = \chi_o + RM\lambda^2$$

RM is *the* PARAMETER THAT IS OBSERVED

RM SYNTHESIS to reconstruct the intrinsic polarized signal along a los (Brentjens and De Bruyn 2005)

$$RM = 812 \int_0^L n_e B_z \, dl \ (\mathrm{rad\,m^{-2}})$$

n_e is the electron density in cm^{-3}

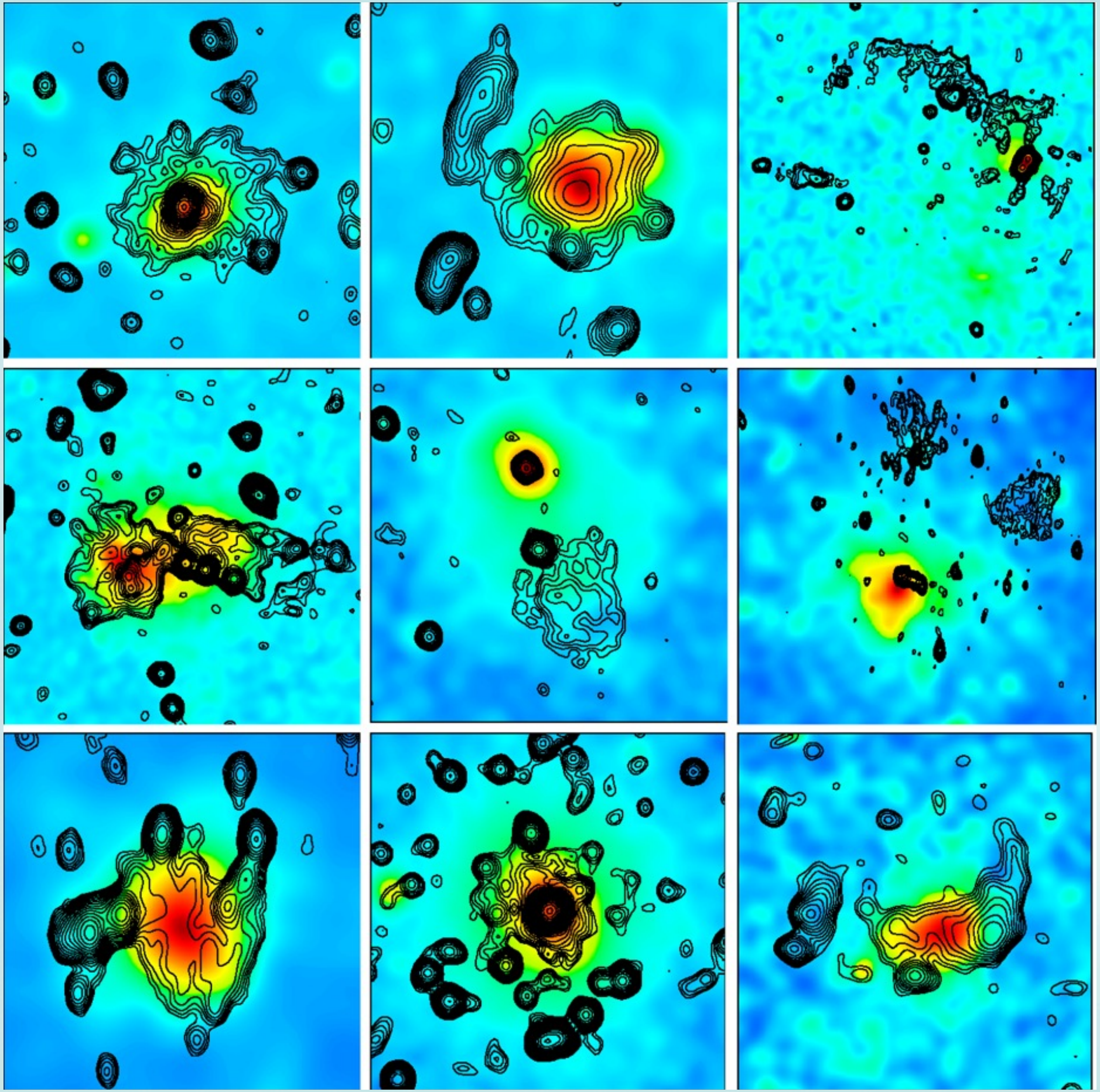
L is the path length in kpc

B_z is the line of sight component of the field in μG

Most bodies in the Universe are magnetized on all scales

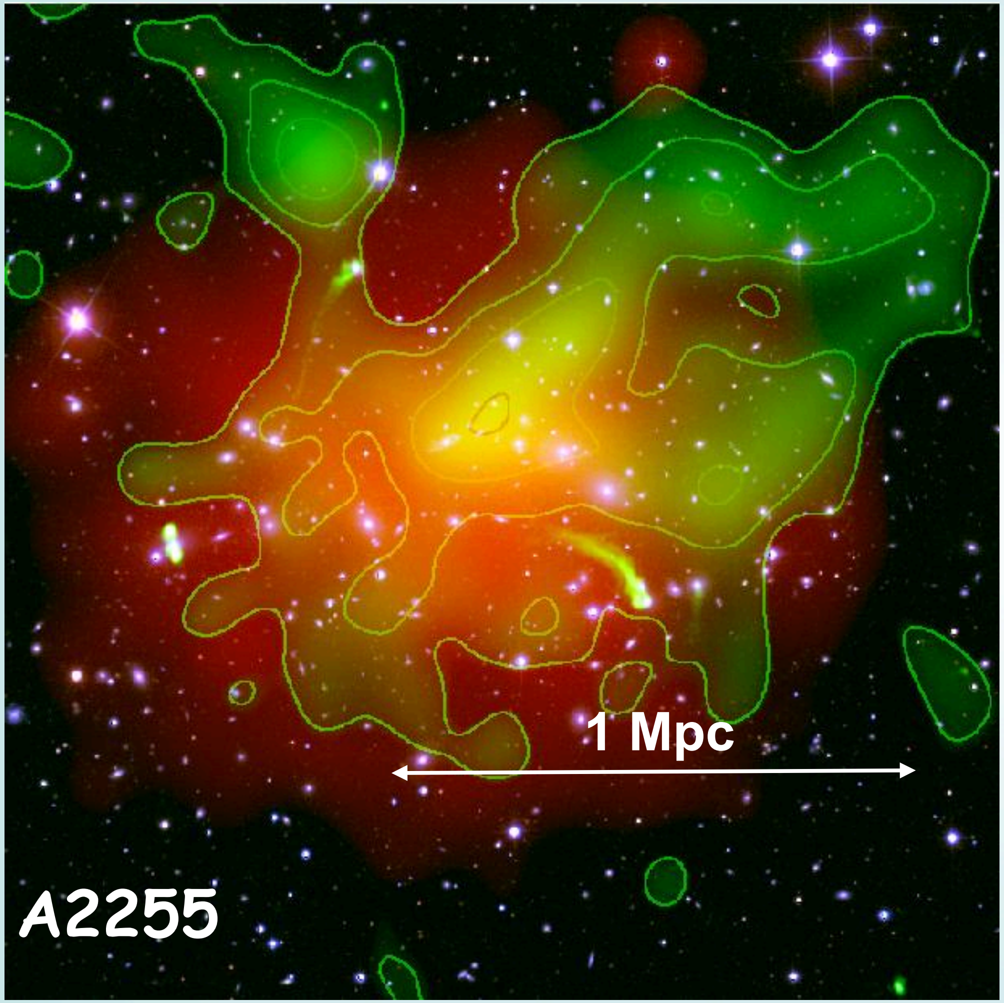
Clusters of galaxies

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



Magnetic fields in Galaxy Clusters

Govoni et al. (2005)

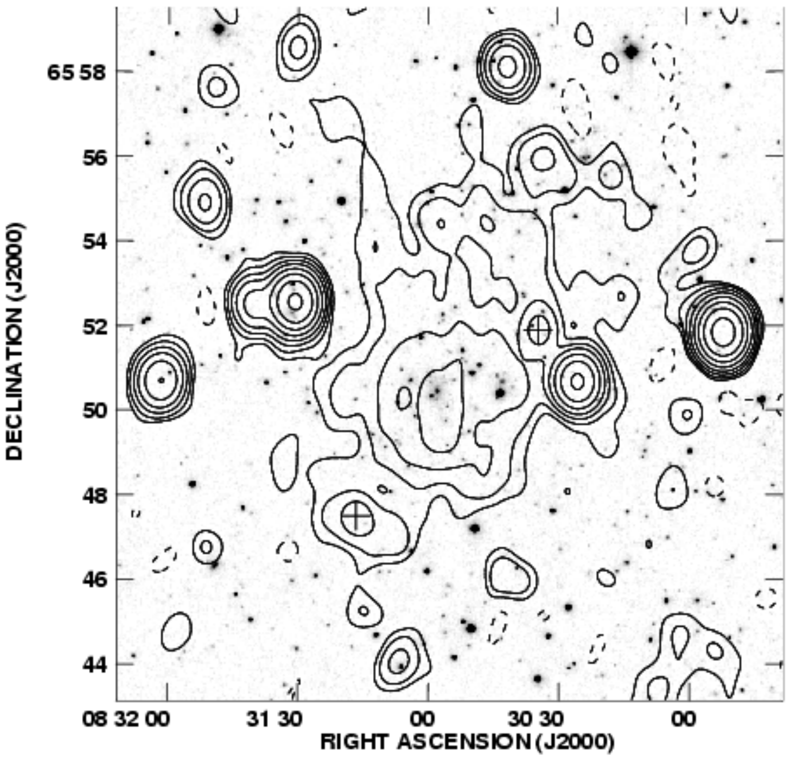


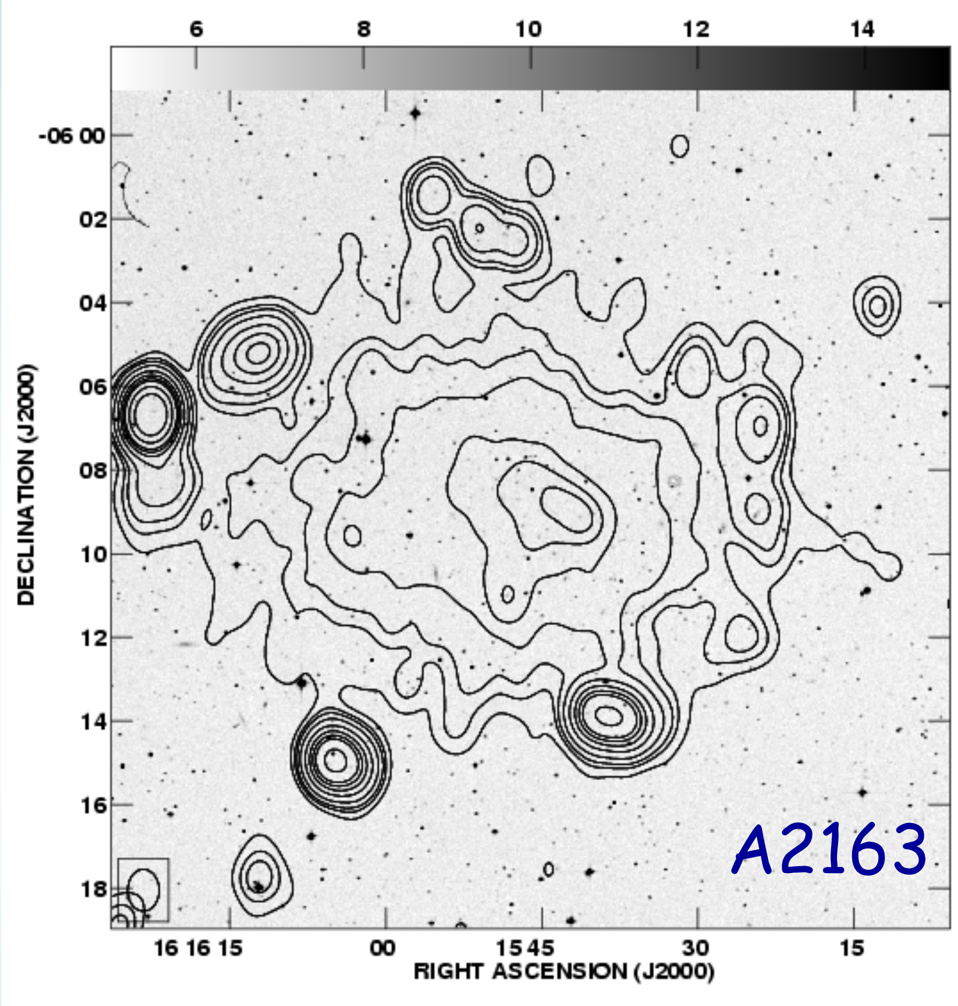
- Radio halos (at the cluster center)
- Radio relics (at the cluster periphery)
- Rotation measure of radio galaxies in clusters
- Magnetic field power spectrum

Ensslin & Vogt (2003),
Murgia et al. (2004),
Laing et al. (2008),
Kuchar & Ensslin (2011)

Cluster radio halos

A665





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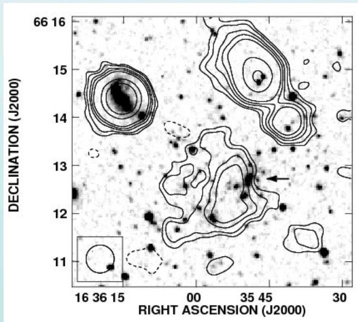
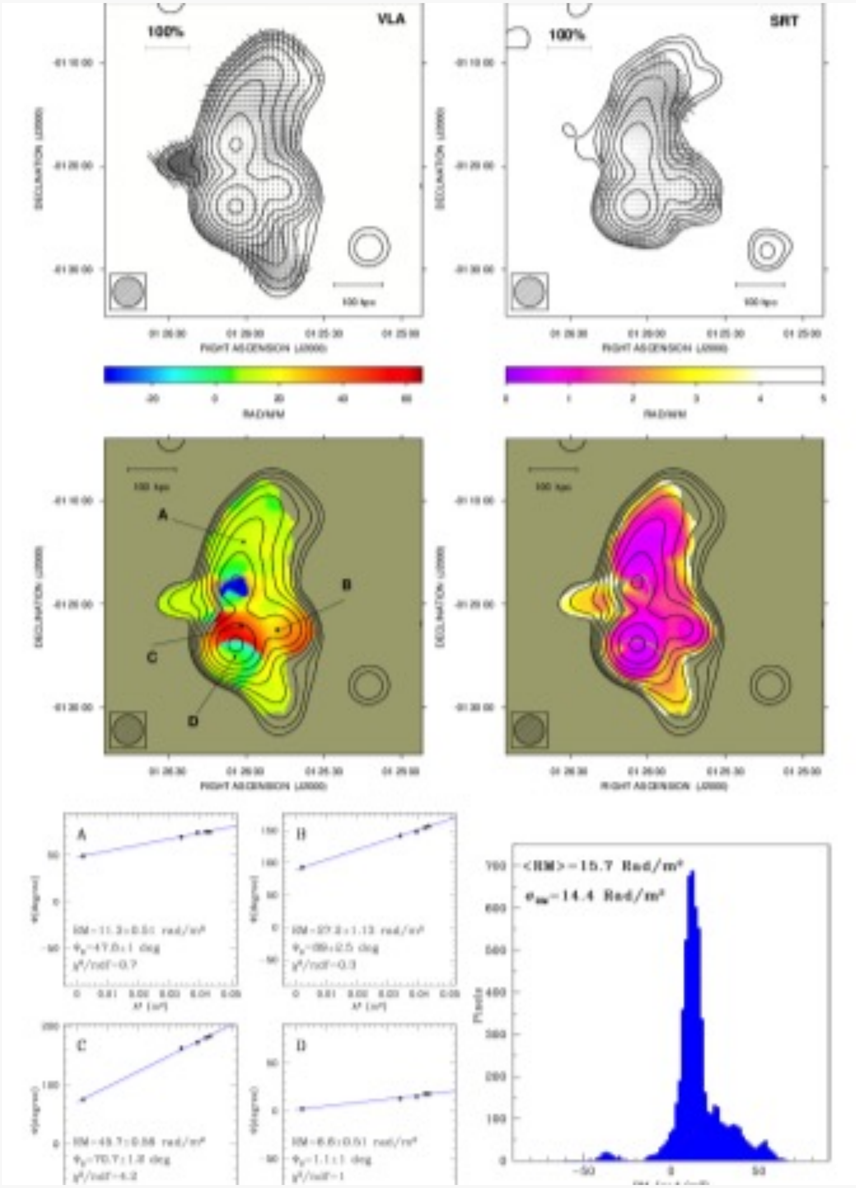
All in merging clusters

1 Mpc



A2218



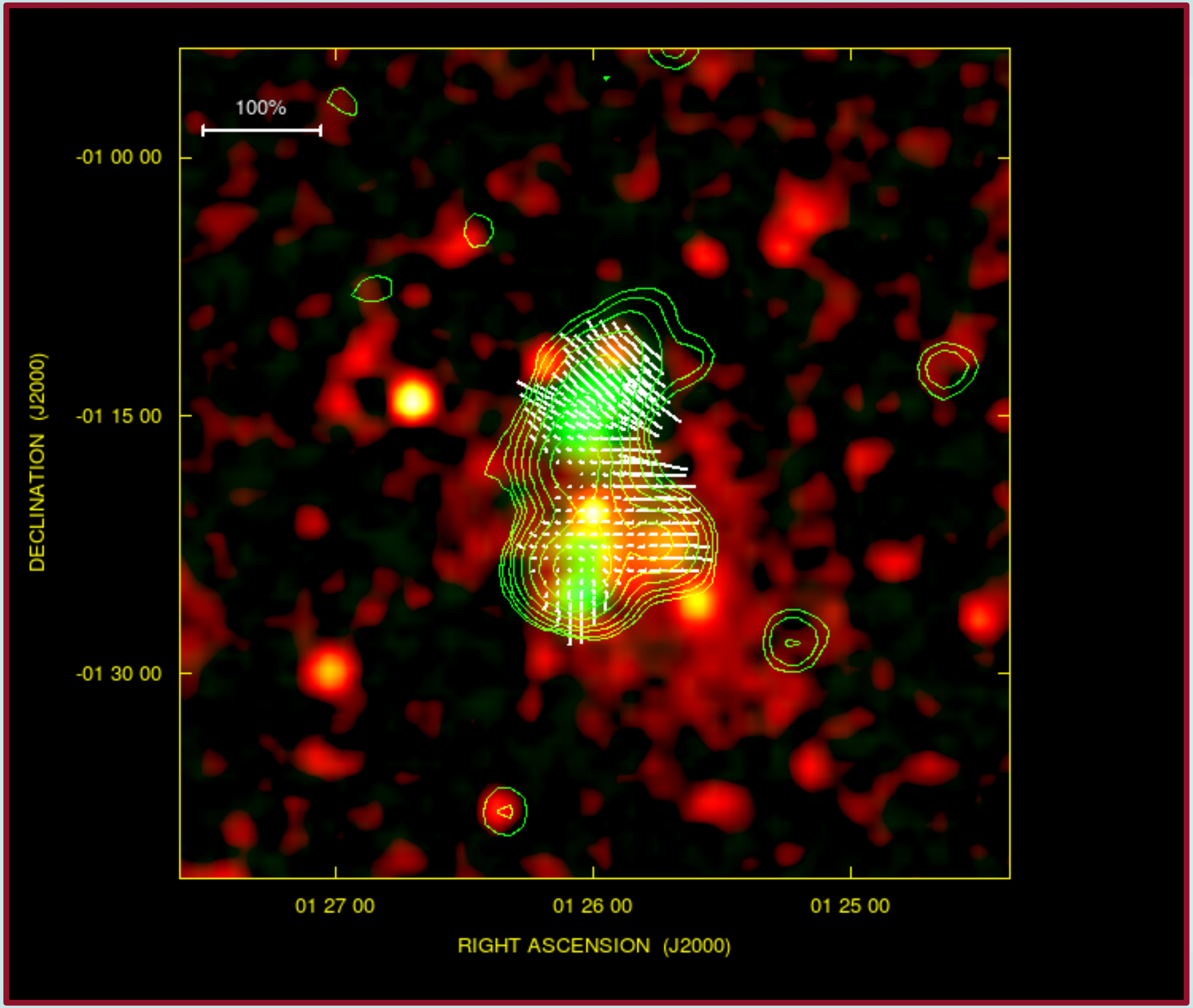
Example of RM obtained
using also SRT

A194 :

VLA around 1.4 GHz – 4 IF

SRT at 6.6 GHz

(SMOG, Murgia et al.)



100%
-01 00 00
-01 15 00
-01 30 00
DECLINATION (J2000)
01 27 00
01 26 00
01 25 00
RIGHT ASCENSION (J2000)

The Coma cluster

Using data for seven radio sources in the Coma cluster field

We derived the central magnetic field strength, and radial profile values that best reproduce the RM observations.

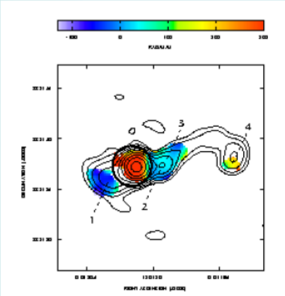
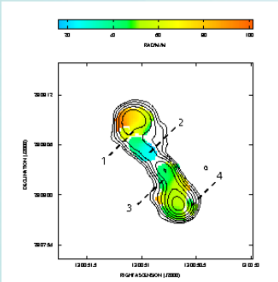
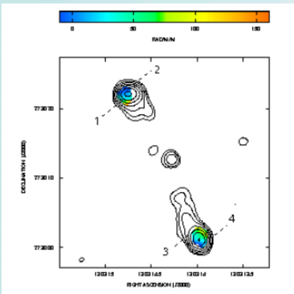
We find that the magnetic field power spectrum is well represented by a Kolmogorov power spectrum with minimum scale ~2 kpc and maximum scale ~34 kpc.

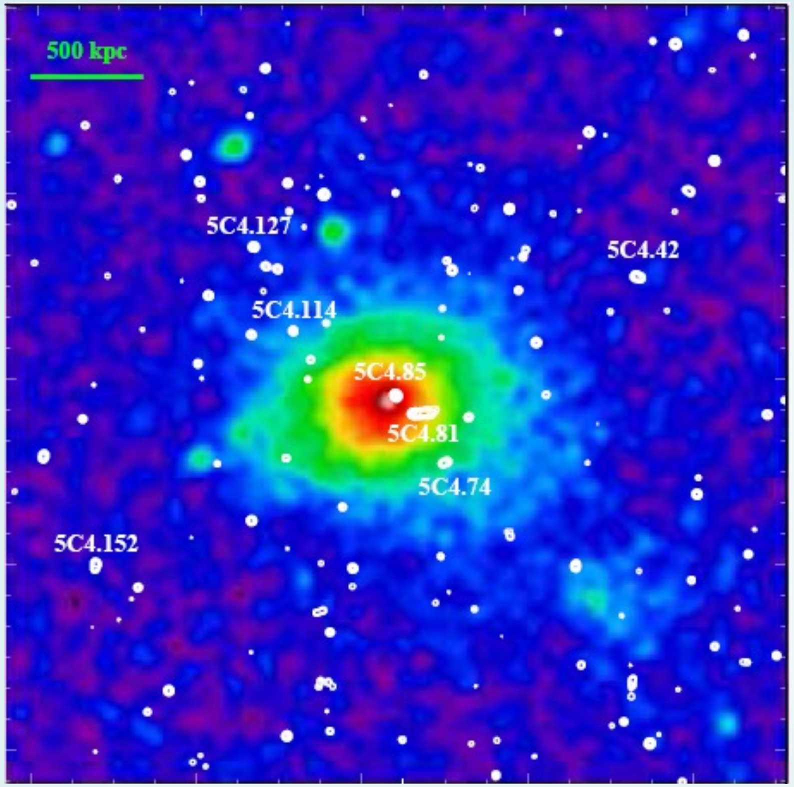
The best agreement between observations and simulations is achieved for B_0 = 4.7 muG;
Values of B_0 > 7 muG and <3 muG are incompatible with RM data at 99% confidence level.

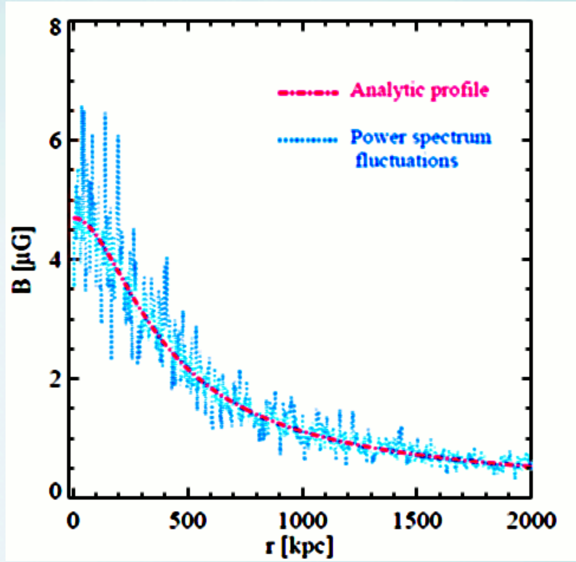
(Bonafede et al. 2010)

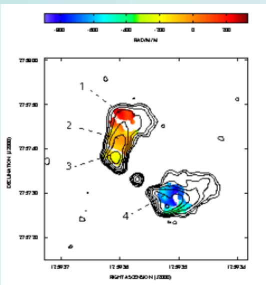
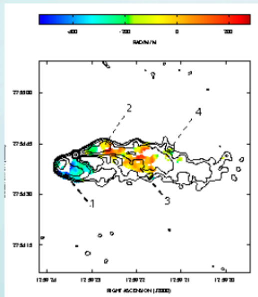
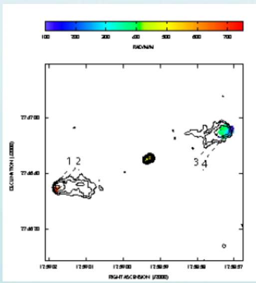
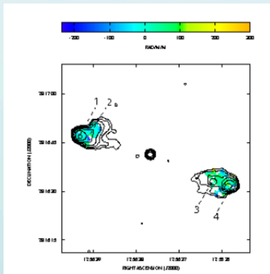
Coma Cluster

Bonafede et al. 2010

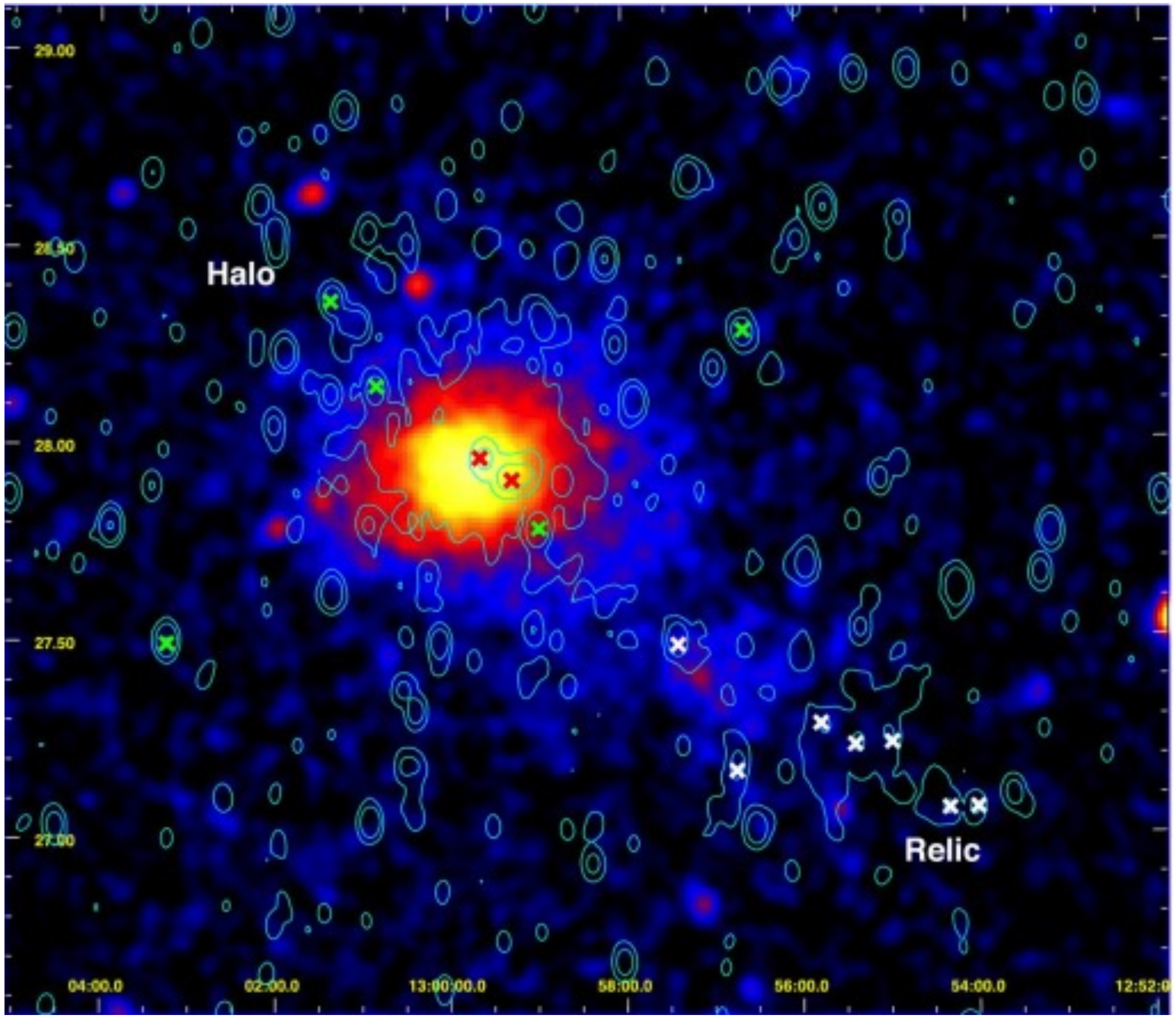




Magnetic field
- Strength
- Structure
- Radial decline

Colours: X-ray emission from the Coma cluster and the NGC 4839 group from the ROSAT All Sky Survey (Briel, Henry & Boehringer 1992).



Bonafede A et al. MNRAS 2013;433:3208-3226

MONTHLY NOTICES of the Royal Astronomical Society

We have studied also the peripheral region using seven sources in the region south-west of the Coma cluster, where the infalling group NGC 4839 and the relic 1253+275 are located.

The magnetic field model that gives the best fit to the Coma central region underestimates the RM in the south-west region by a factor of ~6, and no significant jump in the RM data is found at the position of the relic.

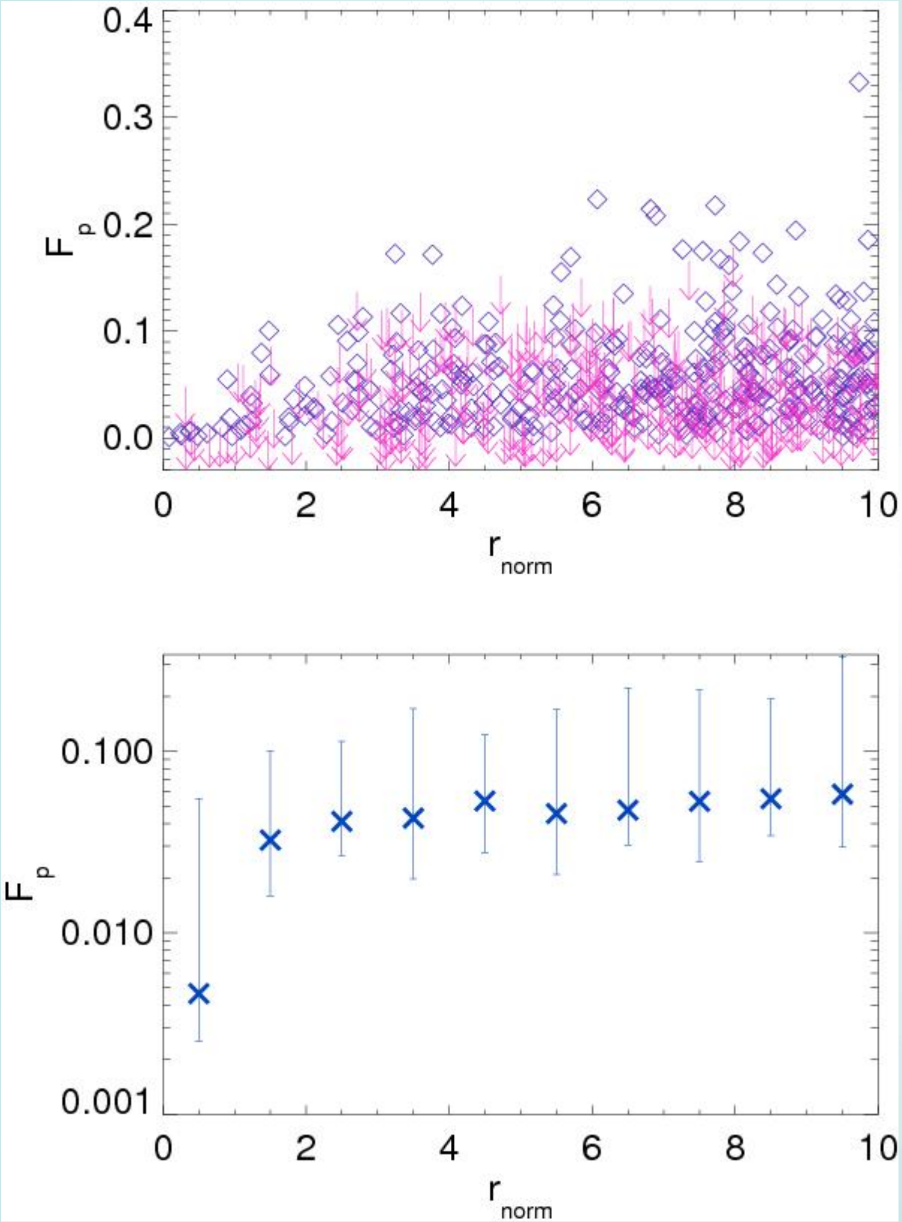
We explore different possibilities to reconcile observed and mock rotation measure trends, and conclude that an amplification of the magnetic field along the south-west sector is the most plausible solution.
Our data together with recent X-ray estimates of the gas density obtained with Suzaku suggest that a magnetic field amplification by a factor of ~3 is required throughout the entire south-west region in order to reconcile real and mock rotation measure trends.
The magnetic field in the relic region is inferred to be ~ 2 muG, consistent with inverse Compton limits.

A trend of the fractional polarization with the cluster impact parameter has been found by Bonafede et al. 2011

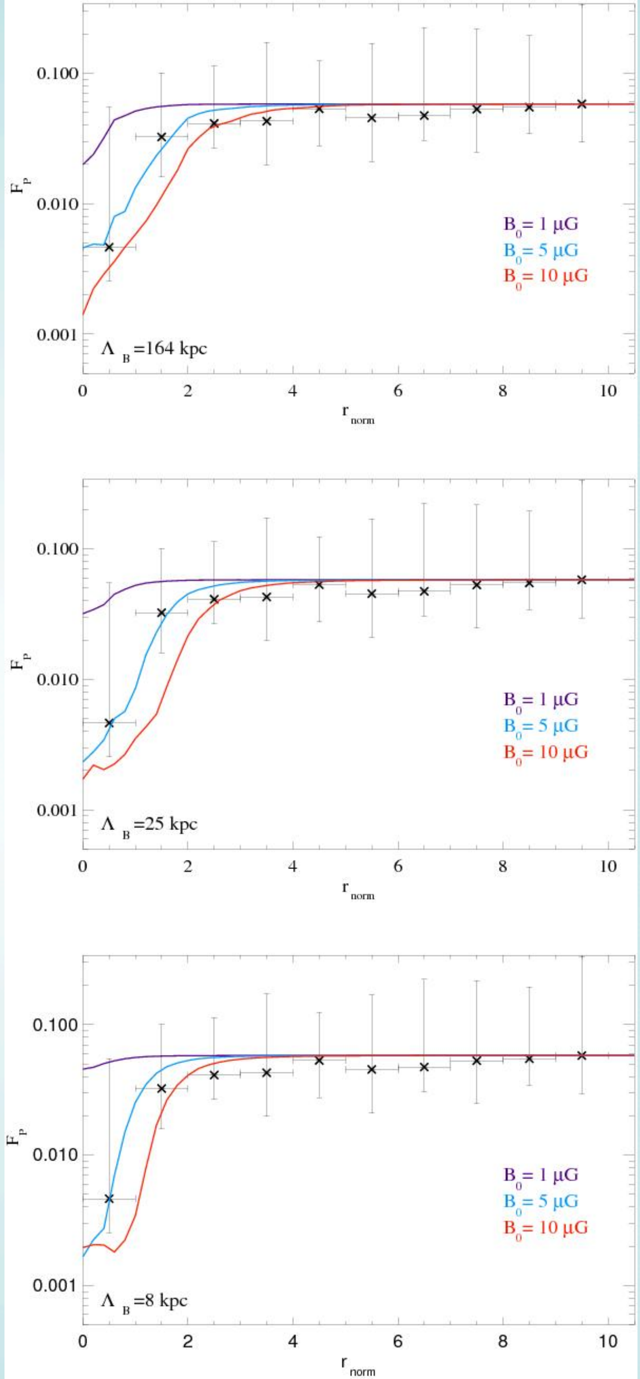
Fractional polarization is increasing at the cluster periphery and decreasing toward the cluster center.

Such trend can be reproduced by a magnetic field model with central value of few muG

Fig 2 e 3



F_p
r_norm
0.4
0.3
0.2
0.1
0.0
0.100
0.010
0.001
0
2
4
6
8
10



F_p
r_norm
B_0= 1 μG
B_0= 5 μG
B_0= 10 μG
Λ_B =164 kpc
Λ_B =25 kpc
Λ_B =8 kpc
0.100
0.010
0.001
0
2
4
6
8
10

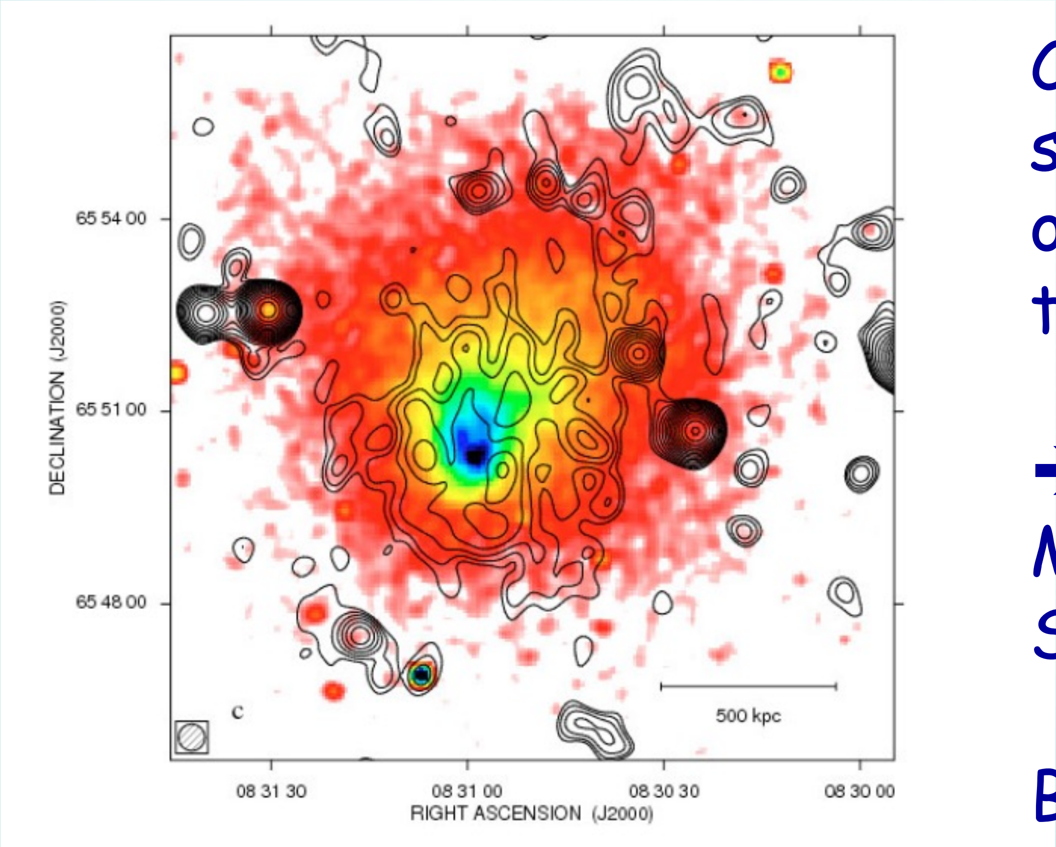
statistical test indicates that there are no differences in the depolarization trend observed in cluster with and without radio halo,

while the same test indicates significant differences when the depolarization trend of sources in clusters with and without cool core are compared.

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



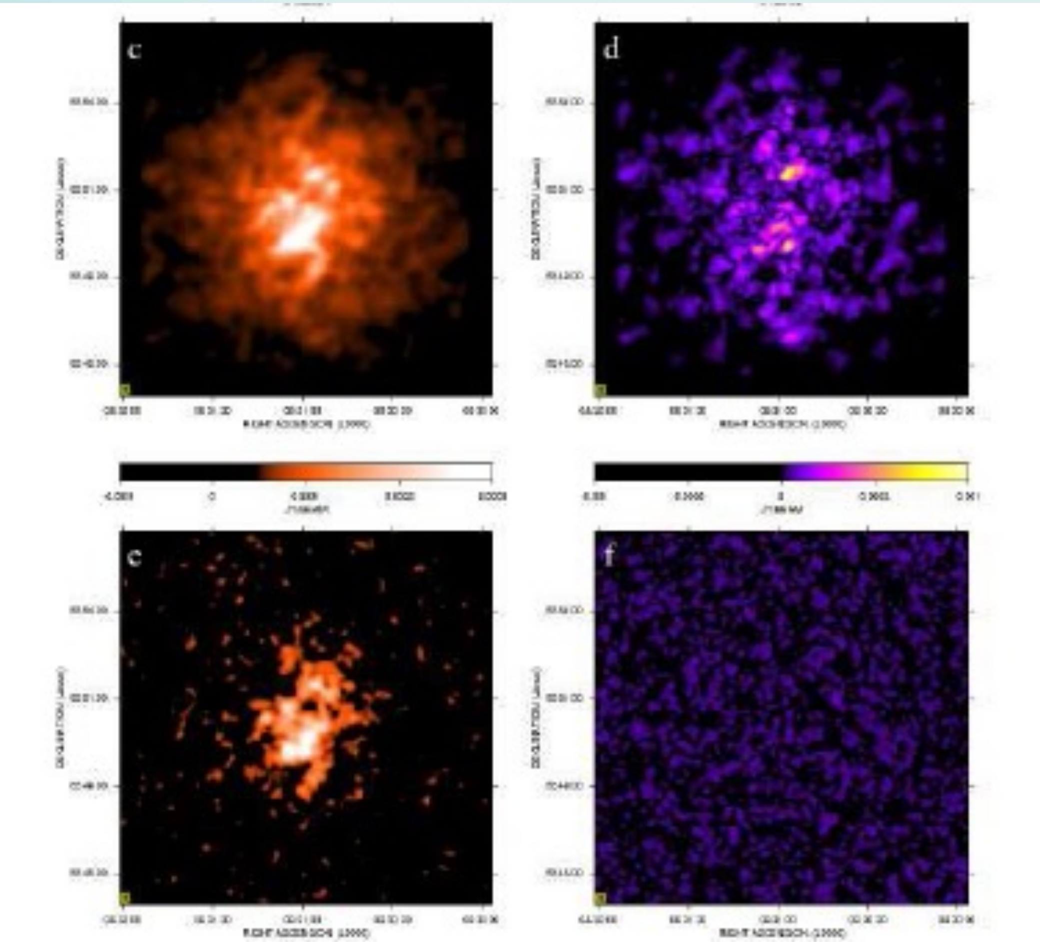
Compared with the synthethic image obtained assuming a 3D turbulent magnetic field

➔ 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 – A665

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

Conclusions

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

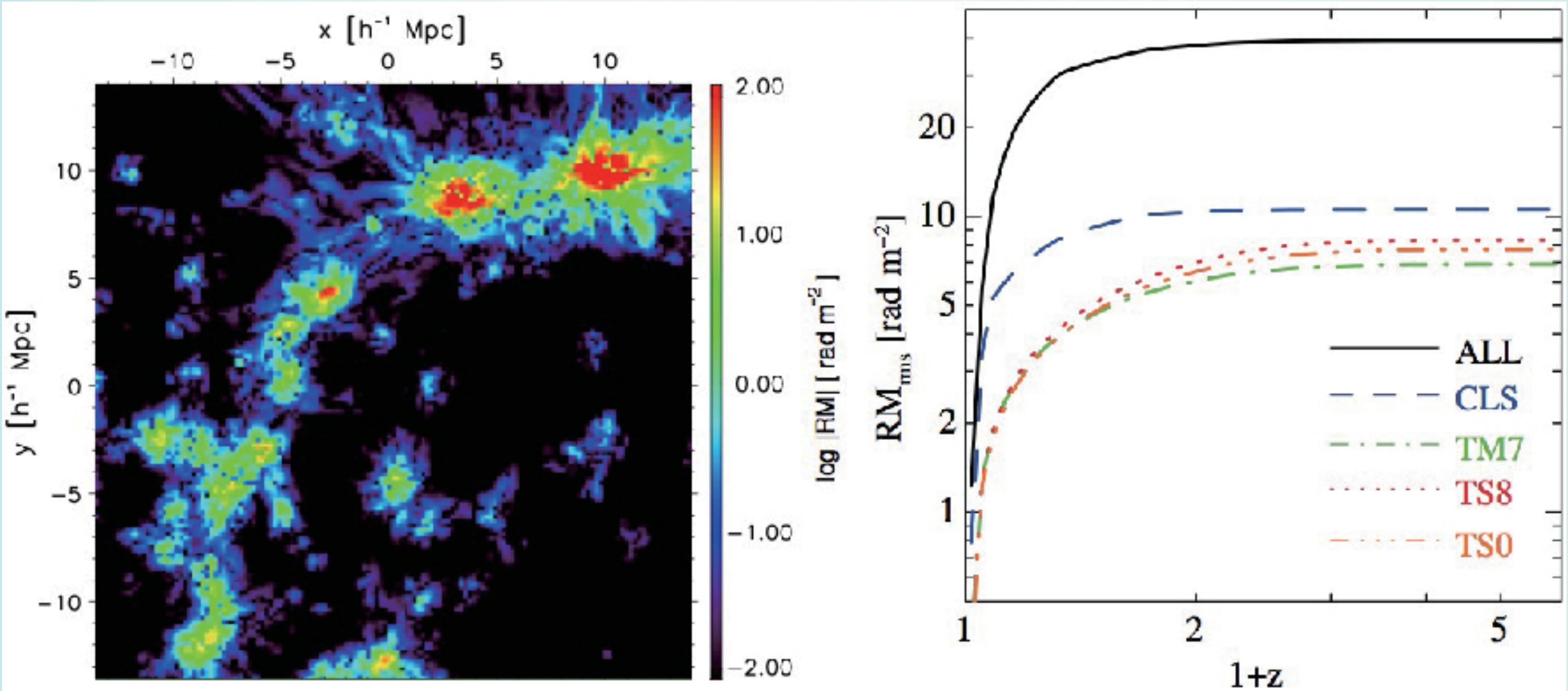
related to turbulence at the center
strong and ordered in peripheral shocked regions
radial decline
linked to gas density

strong in the cooling core cluster centers

high degree of ordering
coherence scales up to 100s kpc

Detection of magnetic fields in the Cosmic Web

- Can it be detected?
- How did it arise?
- What are its properties and relation to large scale structure of matter?

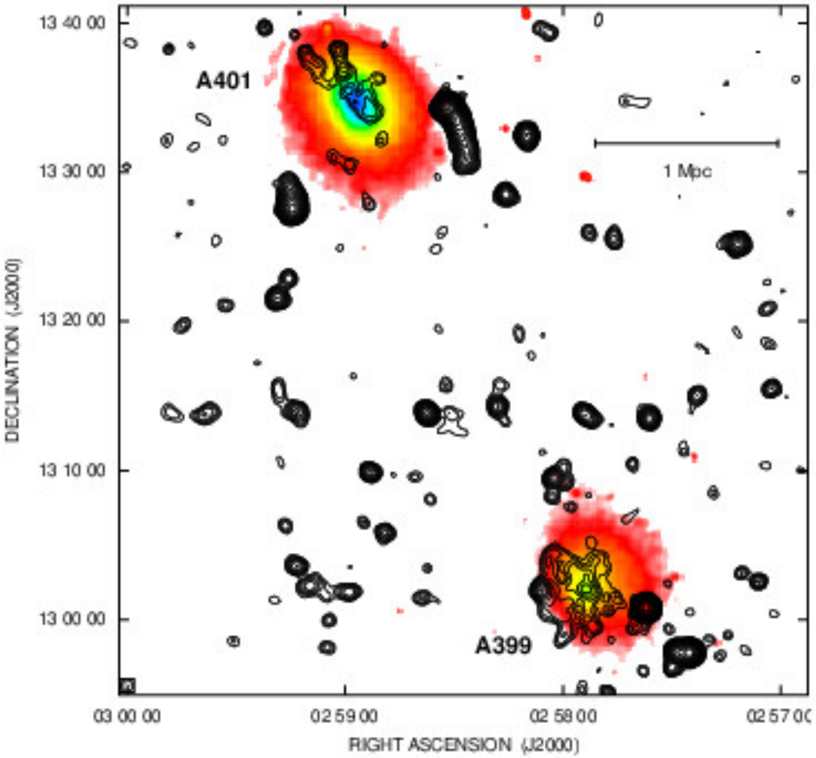


Akahori & Ryu (2010)

Detection of magnetic fields in the Cosmic Web

First example of a double radio halo

Murgia et al. 2009 **Planck**

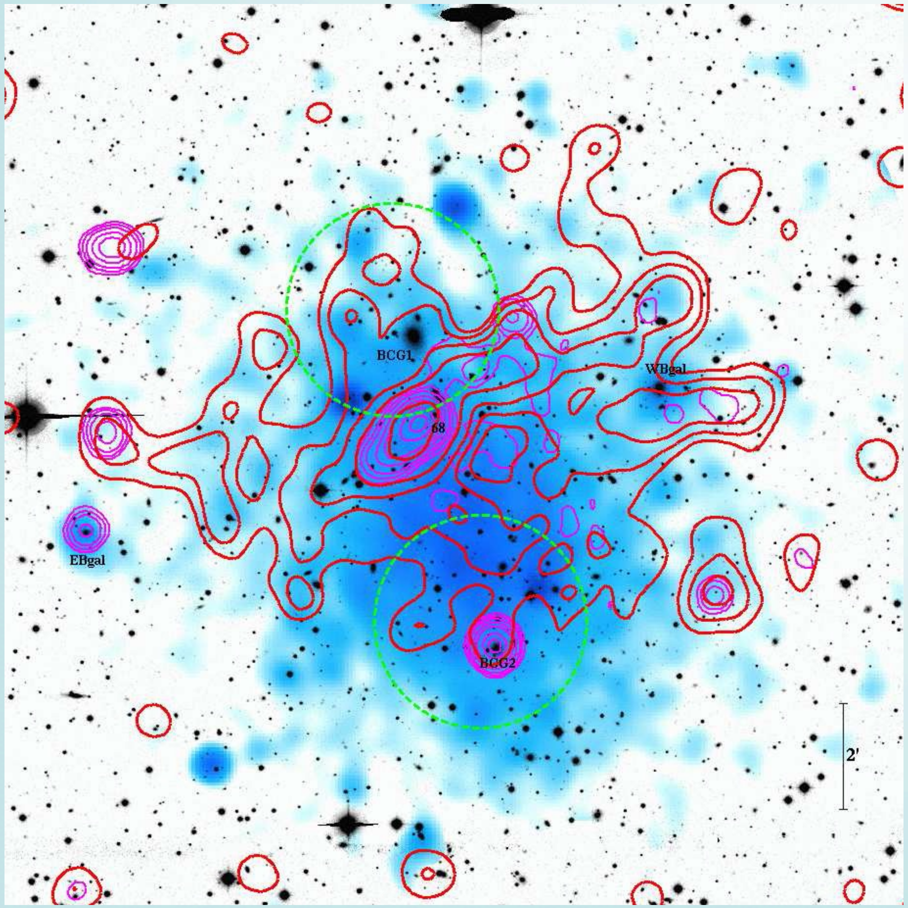


Total intensity radio contours at 1.4 GHz of the system A399-A401 overlaid on the XMM X-ray image

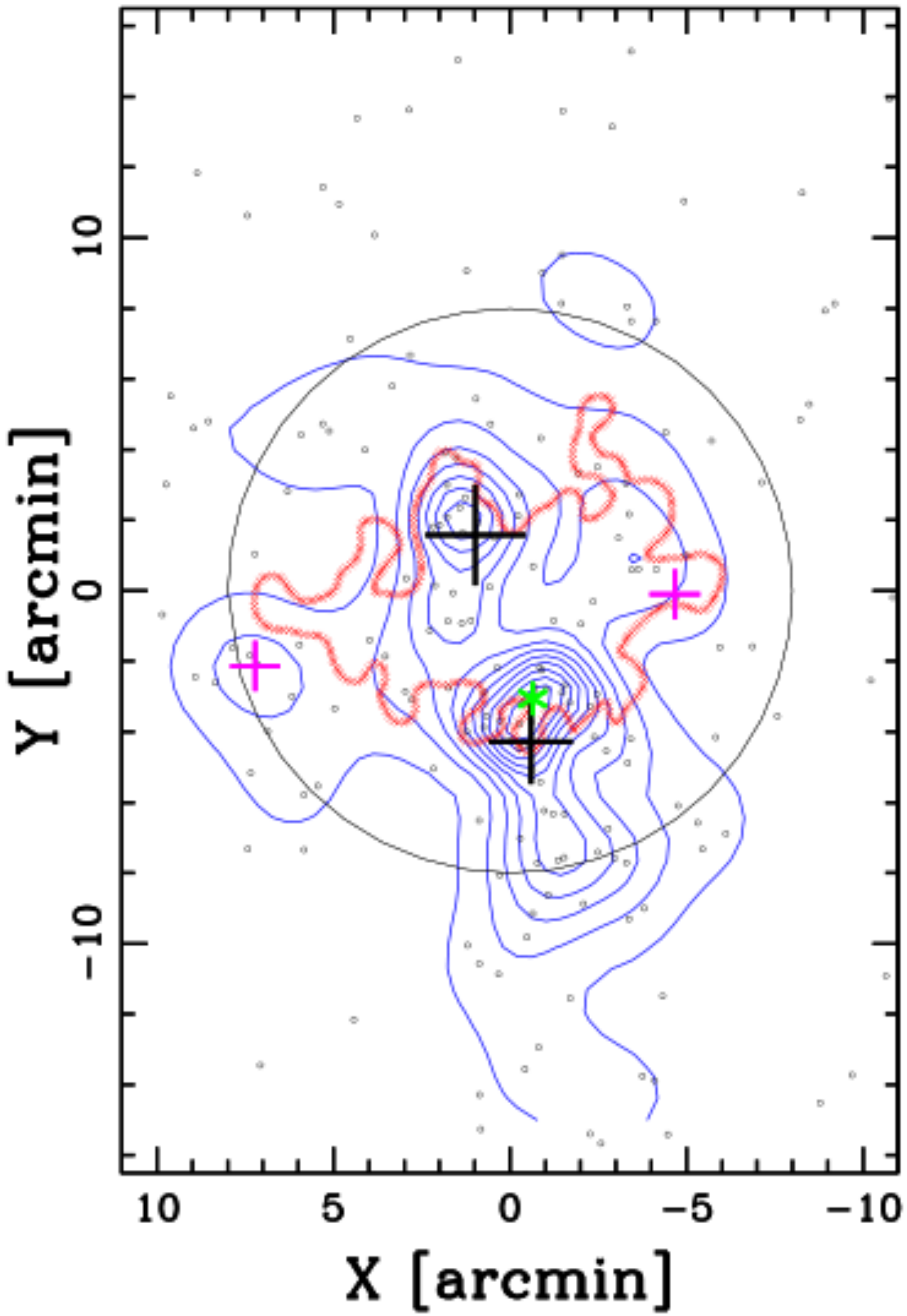
Sunyaev-Zel'dovich emission - bridge of hot gas between the pair of galaxy clusters

A523 hosts an extended and powerful diffuse emission with maximum linear size ~ $1.3\ h^{-1}_{70}$ Mpc and total radio power $P_{1.4}$ GHz ~$1.5\ 10^{24}$ W/Hz strongly elongated along the ESE-WNW direction (Giovannini et al. 2011)

The A523 radio halo is far from the typical one



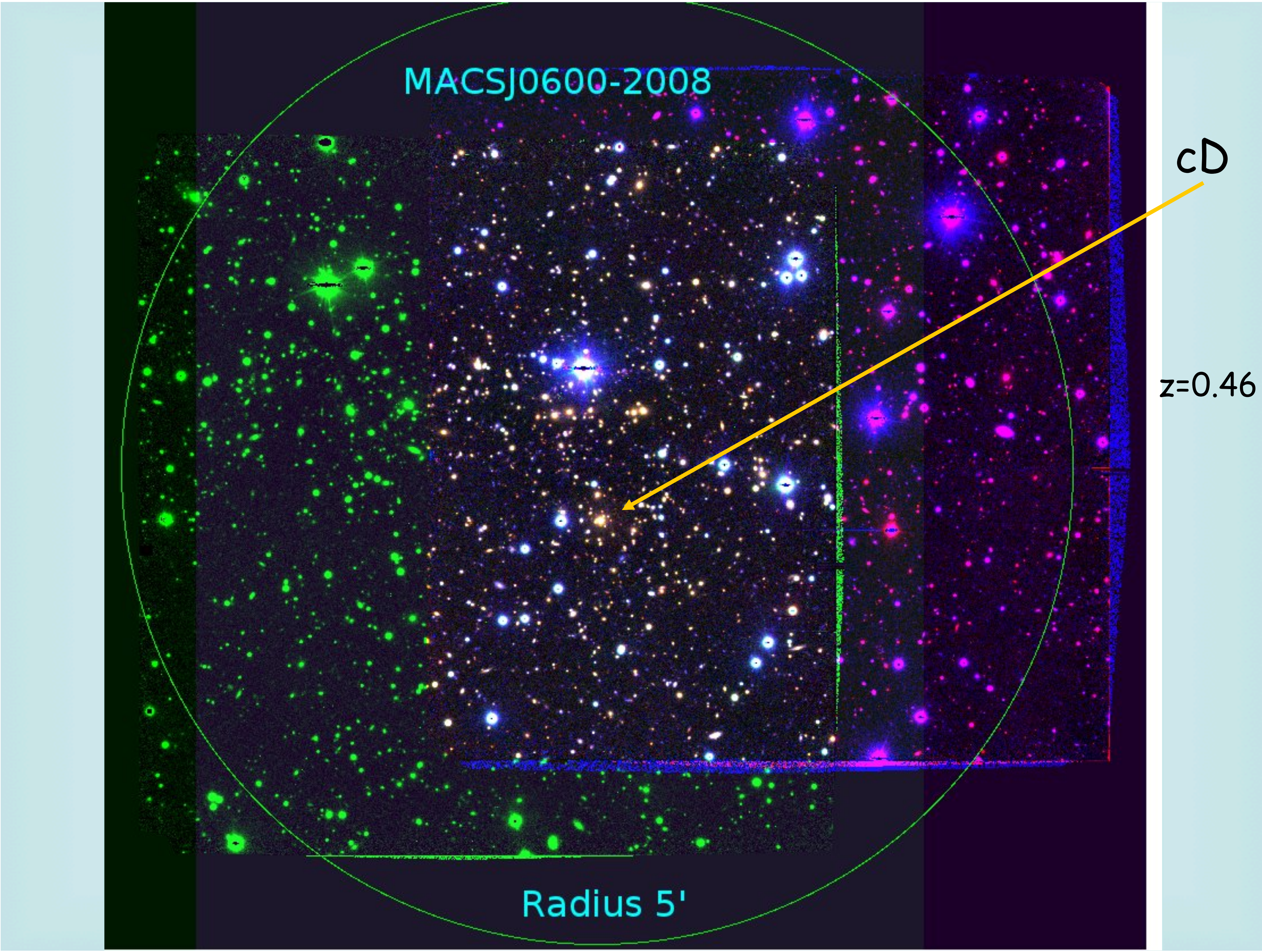
smoothed *Chandra* blue color,
thin magenta contours VLA radio at high–resolution
thick red contours VLA low–resolution image (with discrete sources subtracted
Green dashed circles highlight the centres of the the two merging clusters.

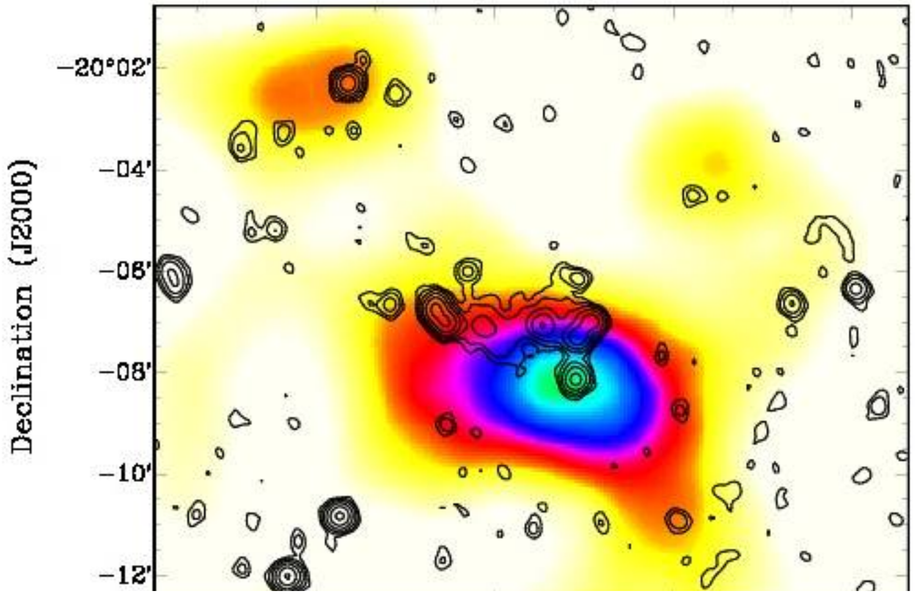


Spatial distribution on the sky of photometric cluster members The two black crosses indicate the position of BCG1 and BCG2 and the two magenta crosses indicate EBgal and WBgal, the dominant galaxies in the background structure .

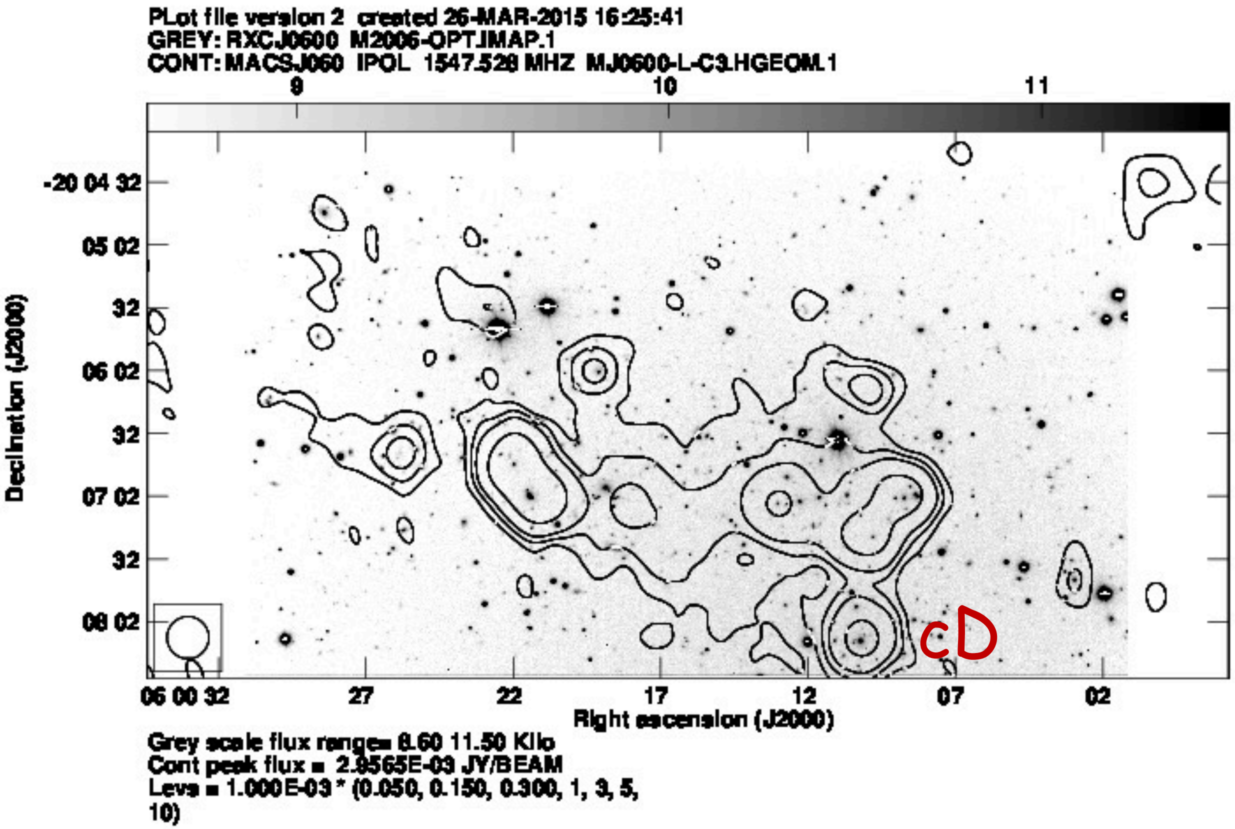
The green asterisk indicates the peak of the X-ray surface brightness

optical and radio data show some evidence in favor of a complex merger suggesting a scenario where A523 is forming at the cross of two filaments


MACSJ0600-2008
cD
z=0.46
Radius 5'

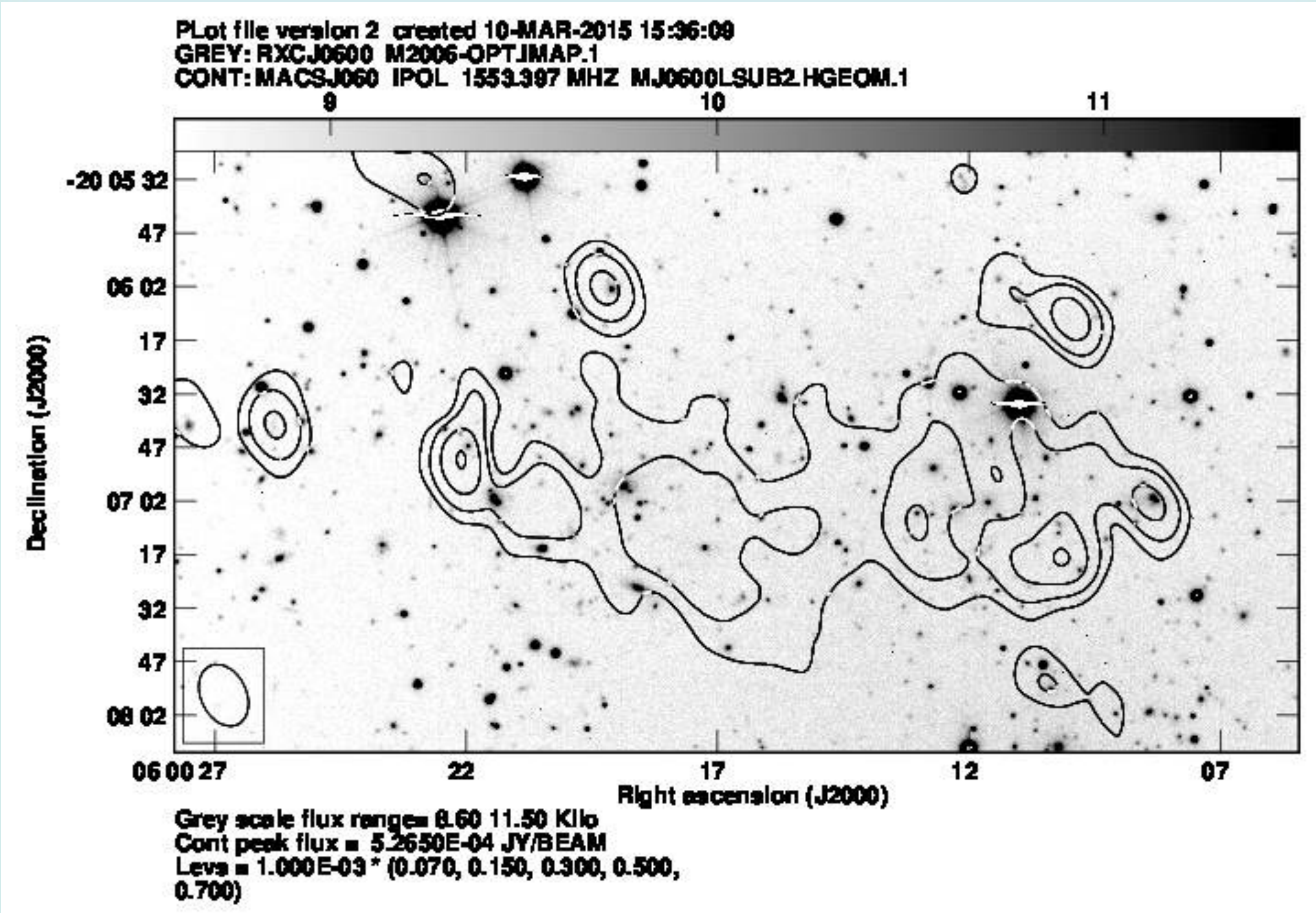


X-Ray ROSAT + radio

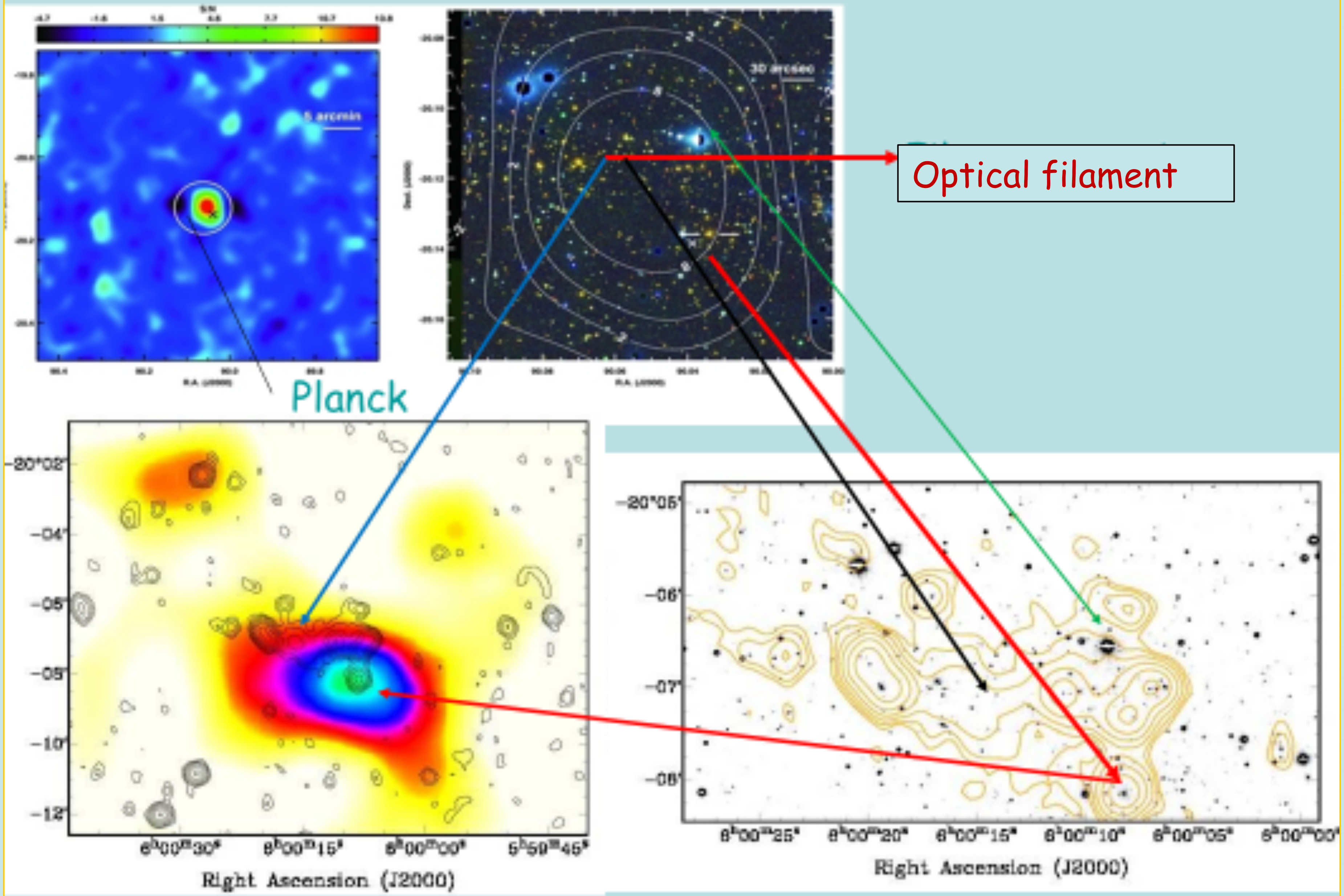


Radio + optical

Radio – optical   discrete sources have been subtracted



MACSJ0600
z=0.46



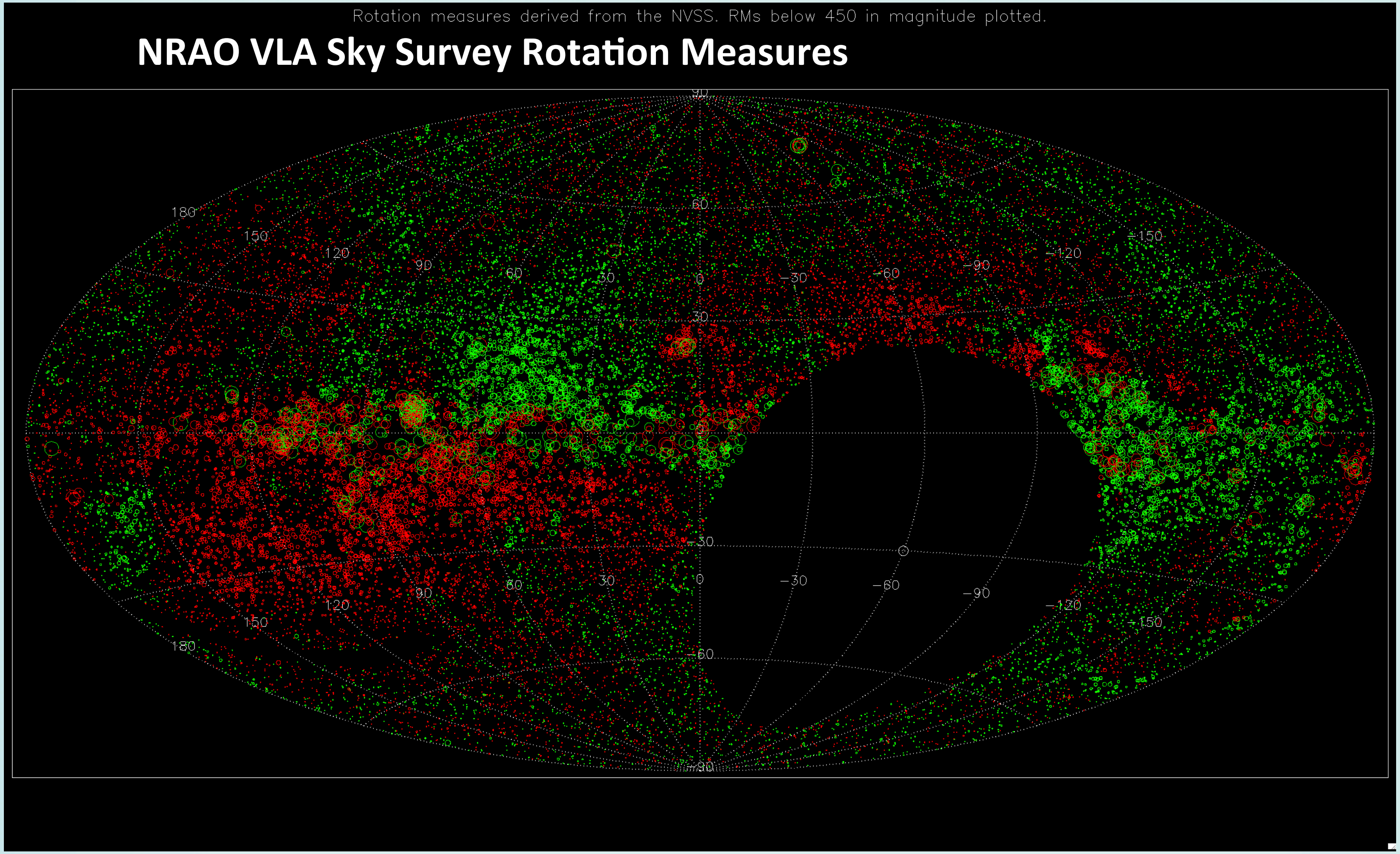
Conclusions

We are improving our knowledge on large scale (Mpc scale) magnetic fields

We are starting to ‘see’ magnetic fields beyond galaxy clusters in larger scale structures.
The new generation of radio telescopes (SKA and pathfinders) are expected to improve this field

Thanks

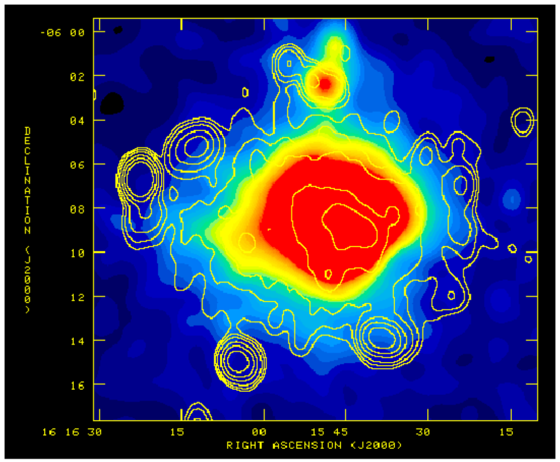
Milky Way

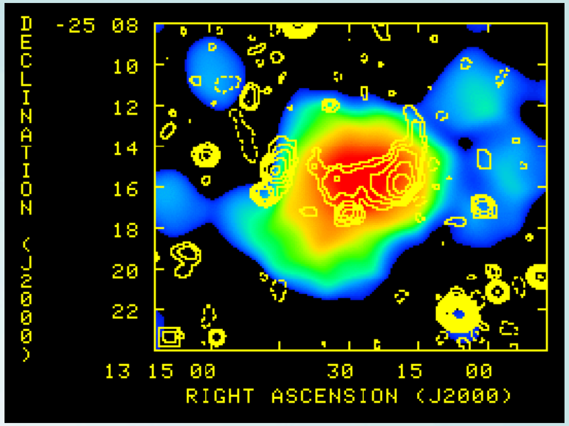


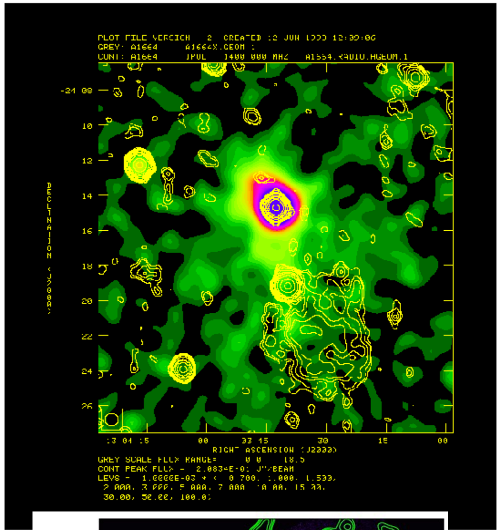
≈40000 sources (≈1 source per deg2)

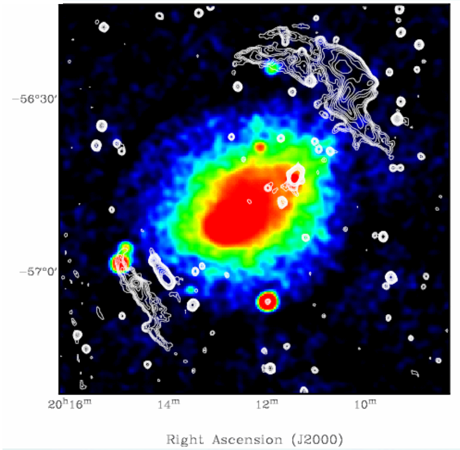
Taylor et al. (2009)

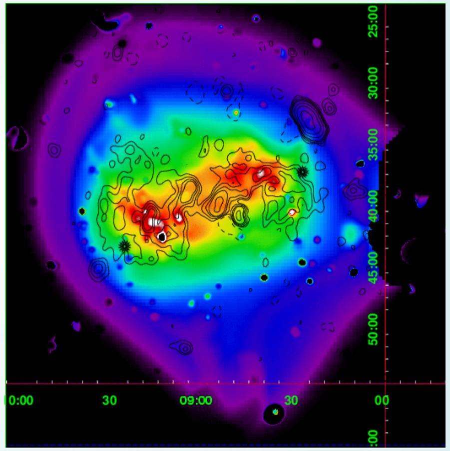
Synchrotron Emission

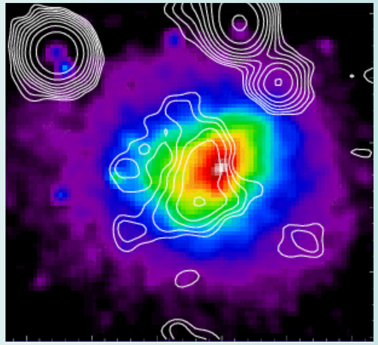


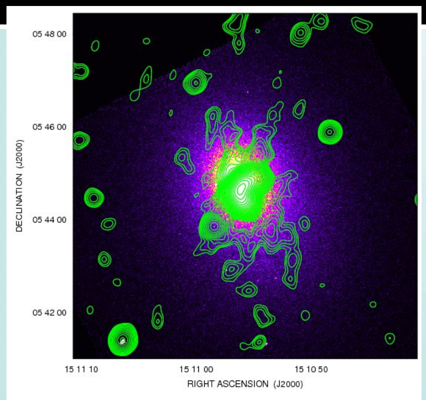


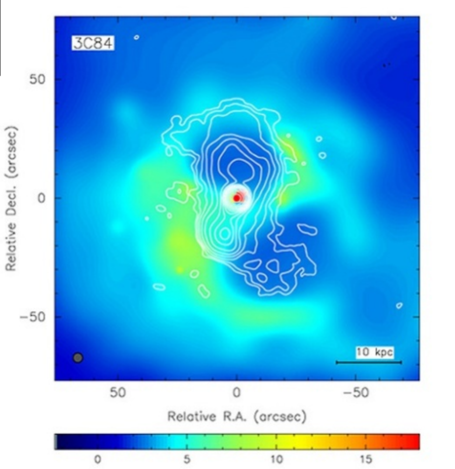


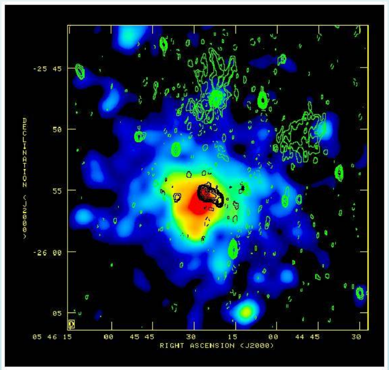


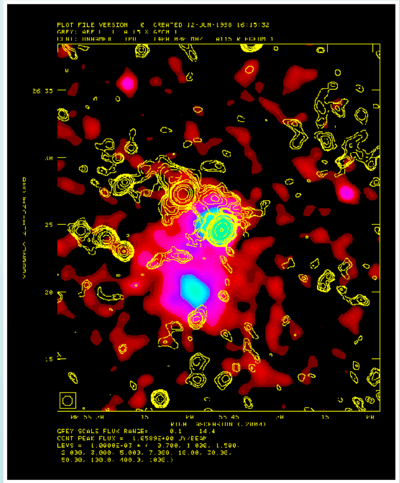












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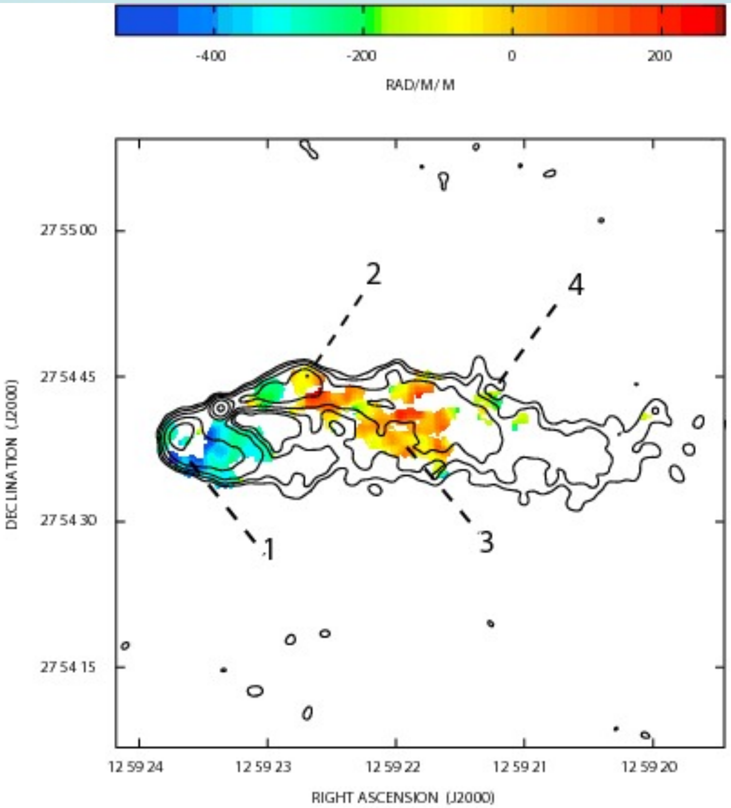
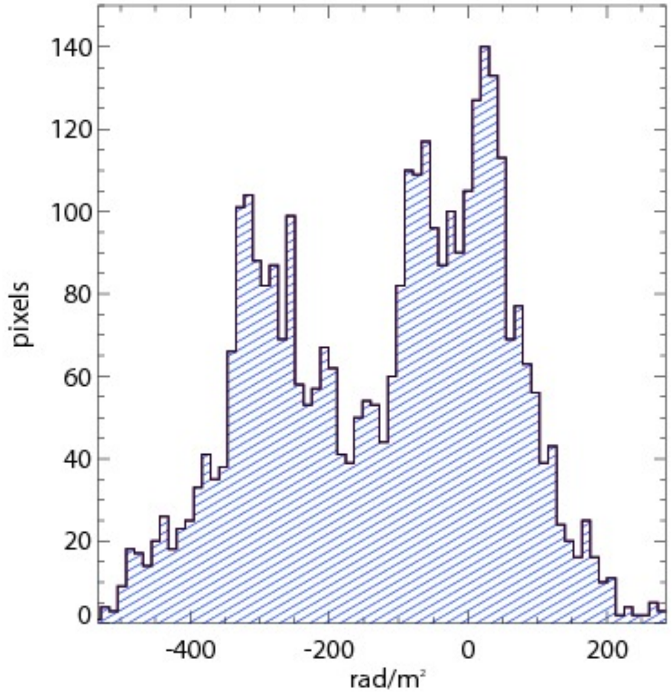
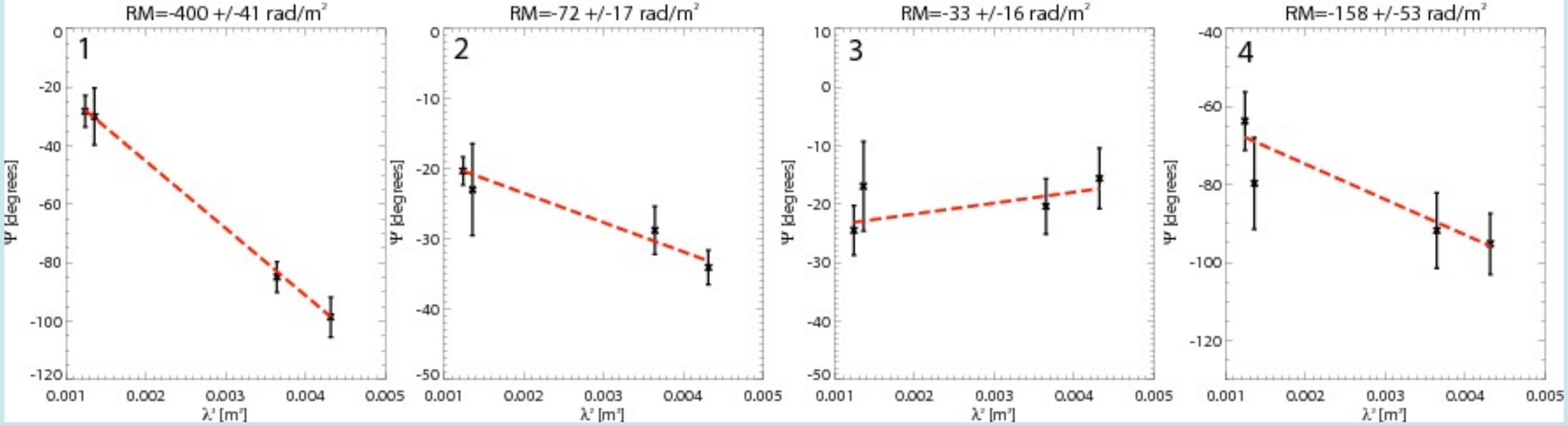


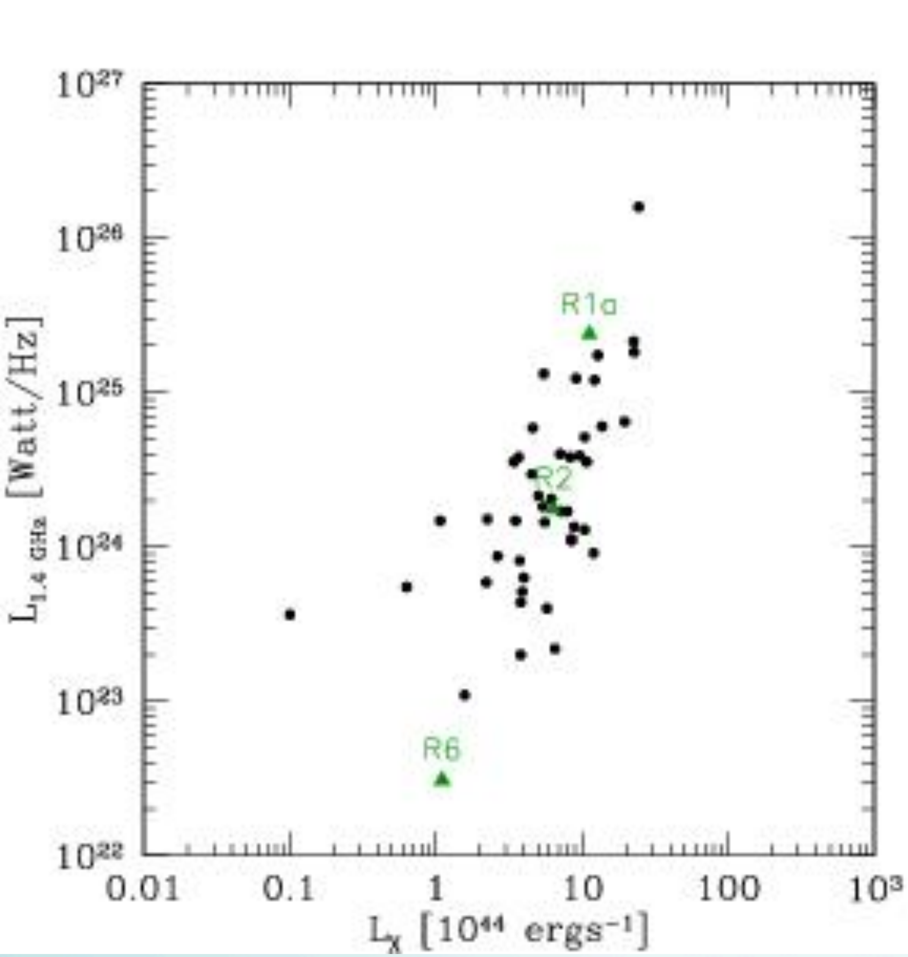
-400
-200
0
200
RAD/M/M
27 55 00
27 54 45
27 54 30
27 54 15
DECLINATION (J2000)
12 59 24
12 59 23
12 59 22
12 59 21
12 59 20
RIGHT ASCENSION (J2000)
1
2
3
4

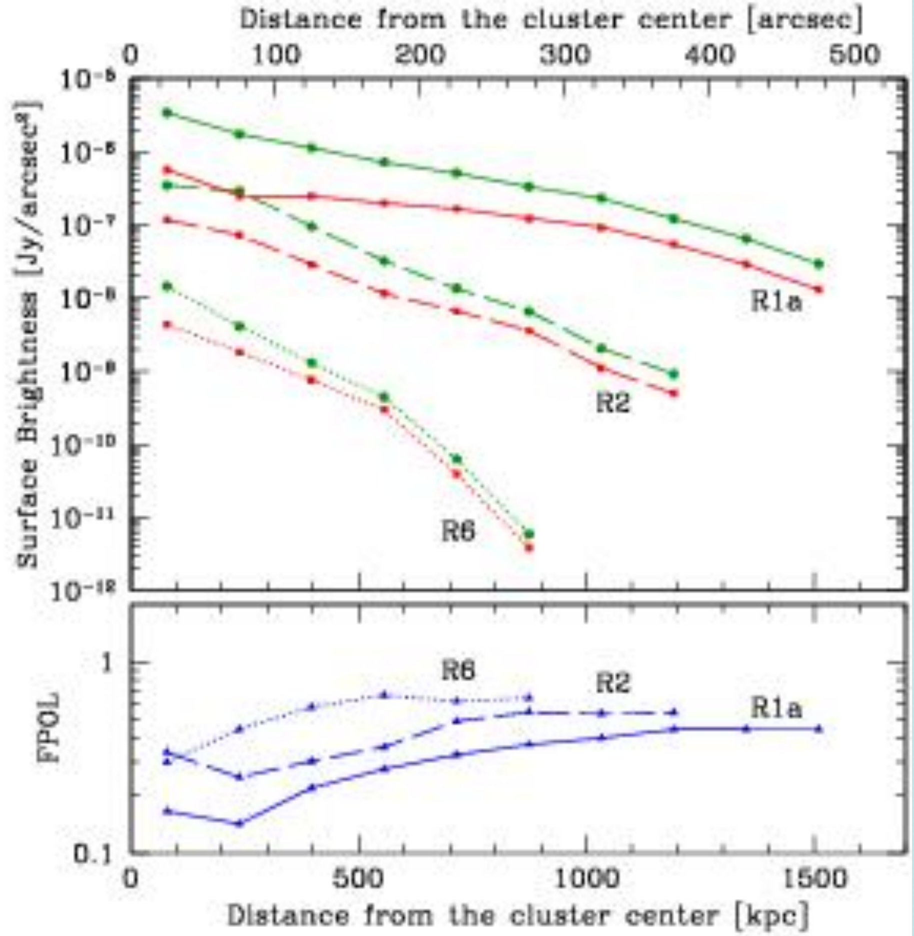


140
120
100
80
60
40
20
0
pixels
-400
-200
0
200
rad/m²



RM=-400 +/-41 rad/m²
RM=-72 +/-17 rad/m²
RM=-33 +/-16 rad/m²
RM=-158 +/-53 rad/m²
1
2
3
4
Ψ [degrees]
λ² [m²]





P-Lx observed + simulated clusters
R1a R2 R6

Averaged brightness profiles in
I and P and FPOL