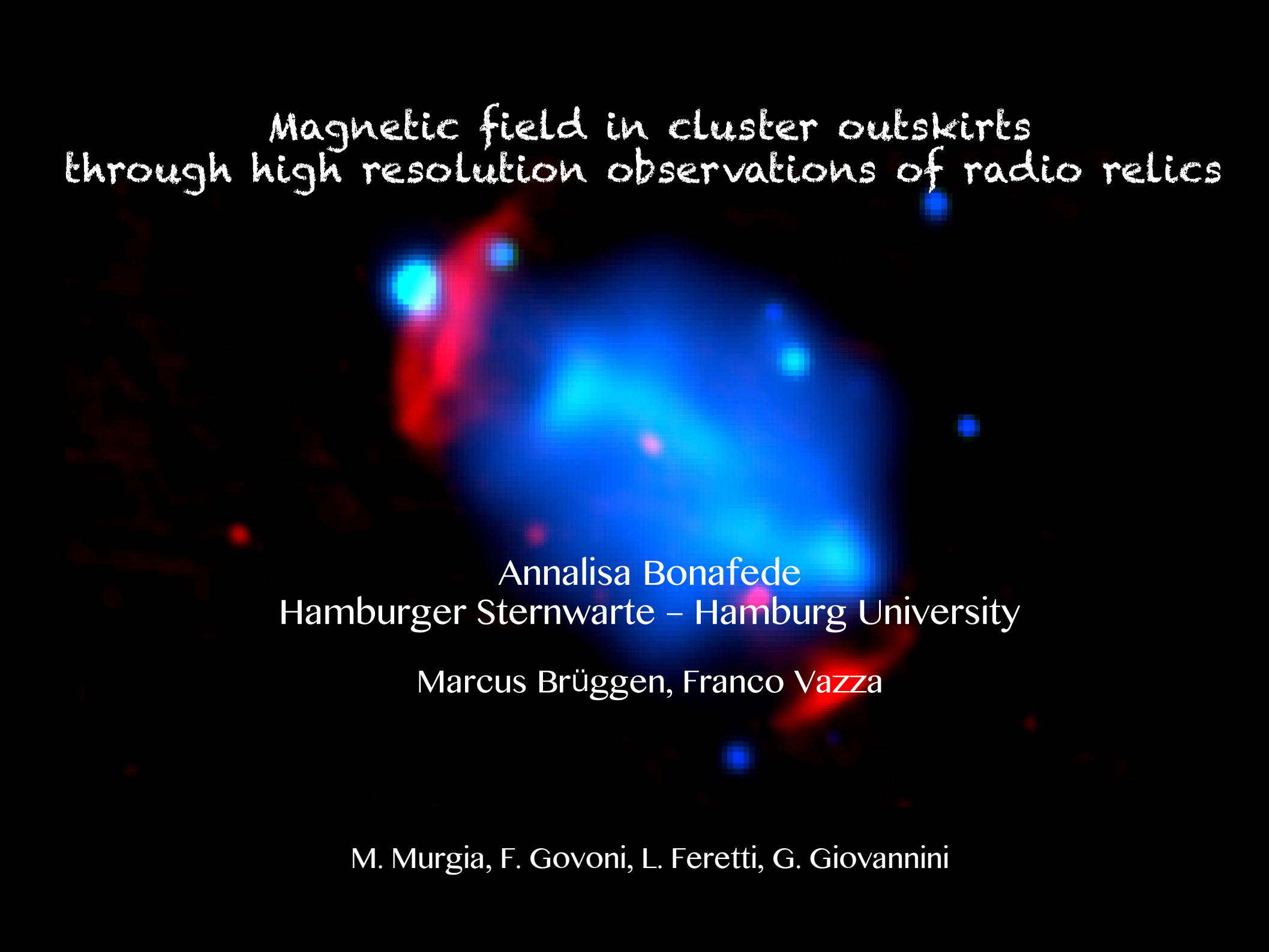
Magnetic field in cluster outskirts through high resolution observations of radio relics



Annalisa Bonafede
Hamburger Sternwarte – Hamburg University

Marcus Brüggen, Franco Vazza

M. Murgia, F. Govoni, L. Feretti, G. Giovannini

Outline:

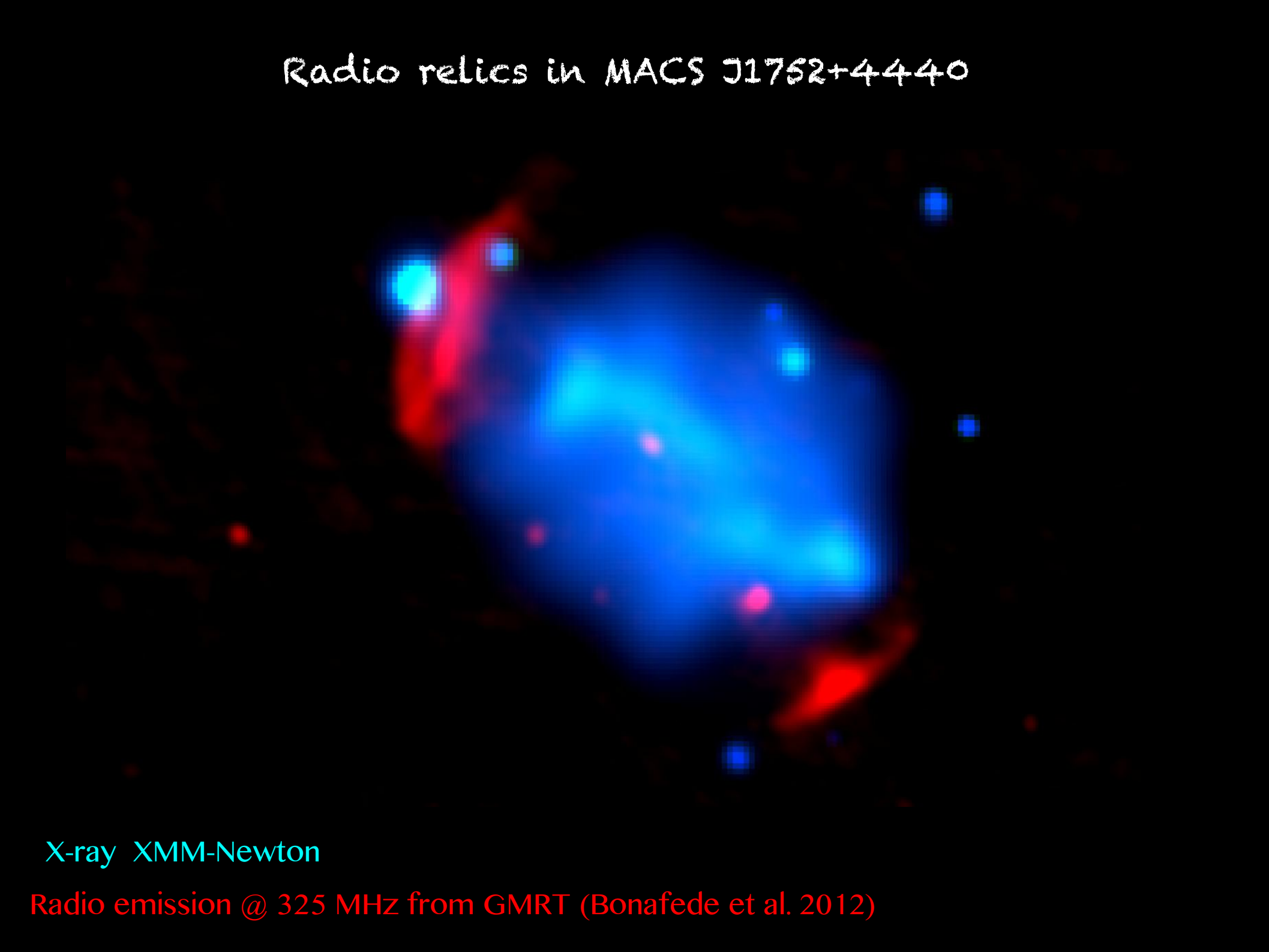
- Radio relics: the standard picture

- Limits on particle acceleration efficiency

- Challenges at high resolution

- Constraints on magnetic field through Faraday RM images

Radio relics in MACS J1752+4440

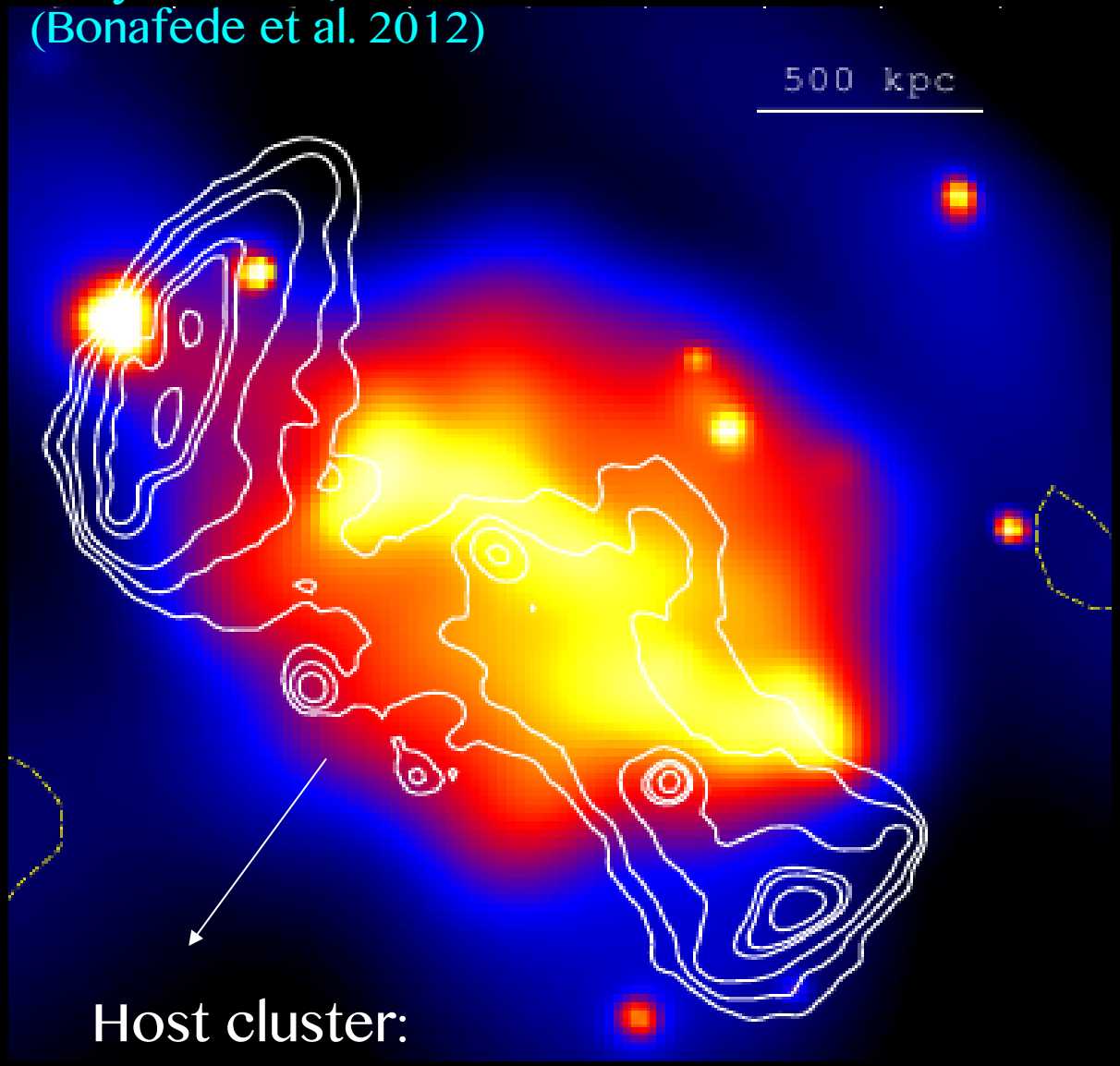


X-ray XMM-Newton

Radio emission @ 325 MHz from GMRT (Bonafede et al. 2012)

Radio relics in MACS J1752+4440

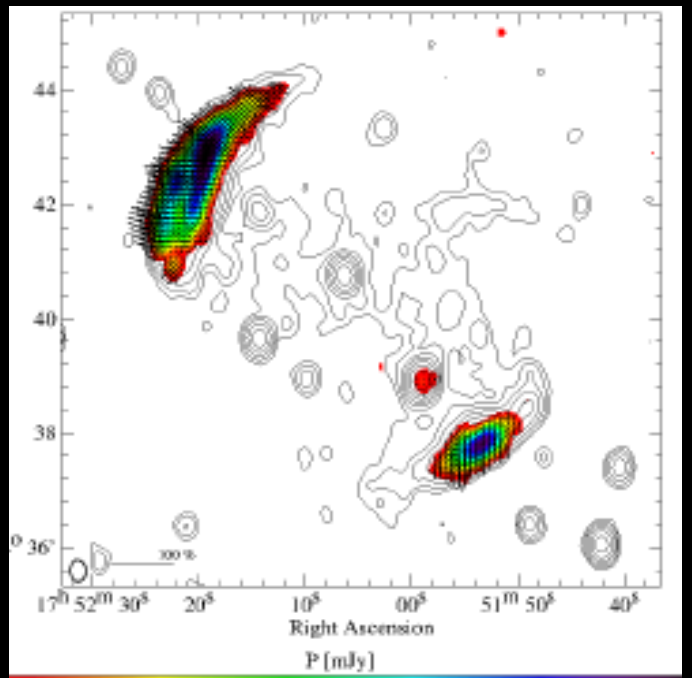
X-ray in colors, GMRT 325 MHz in contours
(Bonafede et al. 2012)



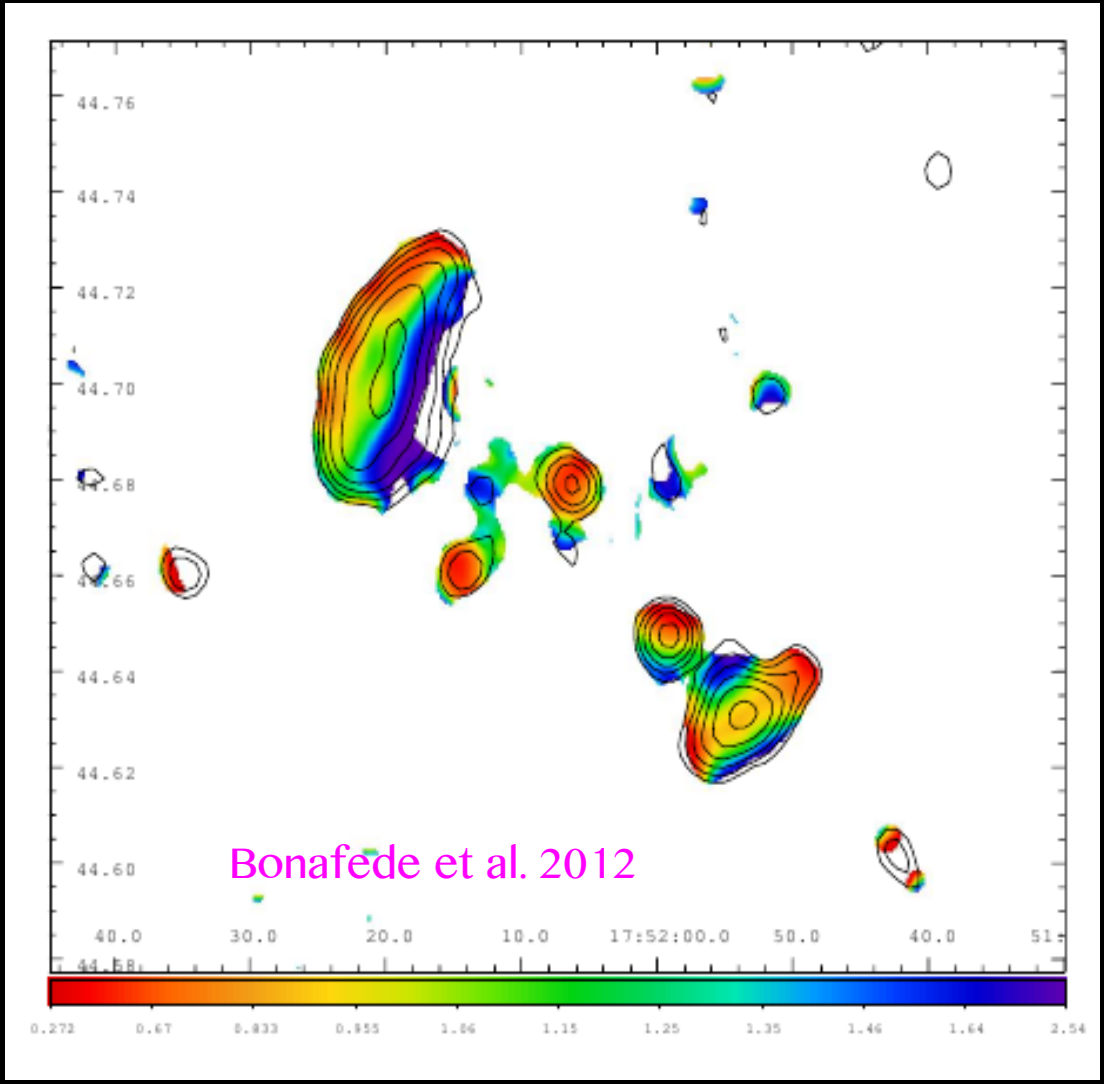
- Extended radio sources
- Low radio brightness
- Steep Spectrum α > 1

- Cluster peripheral regions

- Polarized 20-30%



Spectral index distribution - Mach Number



Bonafede et al. 2012

Spectral index 325 MHz – 1.4 GHz
Beam ~24" x 10"

Assumption:
Diffusive Shock Acceleration

Spectral steepening

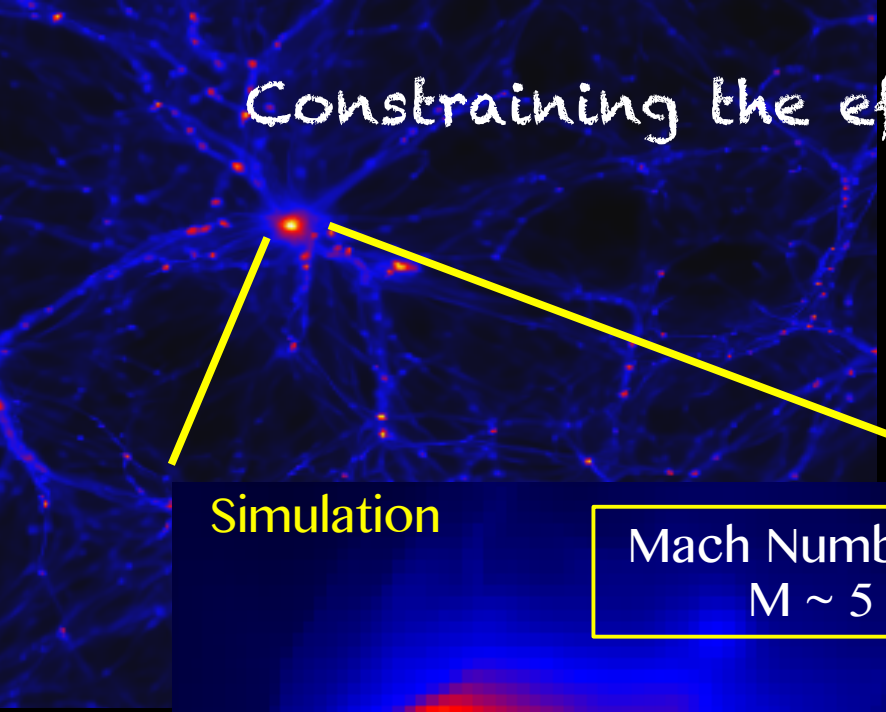
particle aging

$$\alpha_i = -\frac{1}{2} + \frac{M^2 + 1}{M^2 - 1}$$

Mach Numbers:
E relic: M ~ 3.3

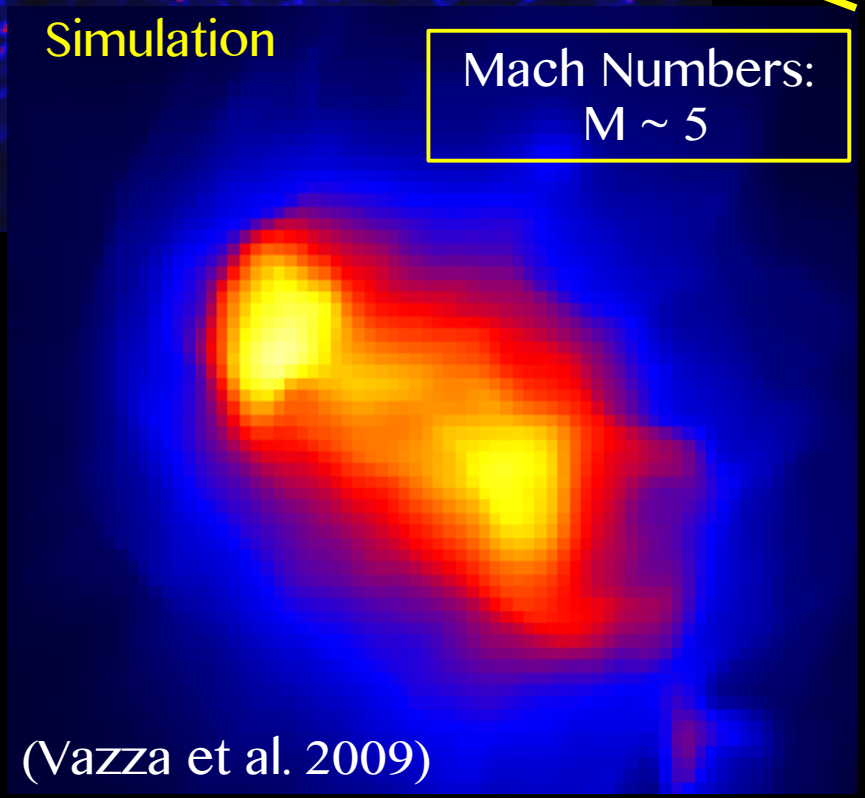
W relic: M ~ 4.6

Constraining the efficiency of shock acceleration



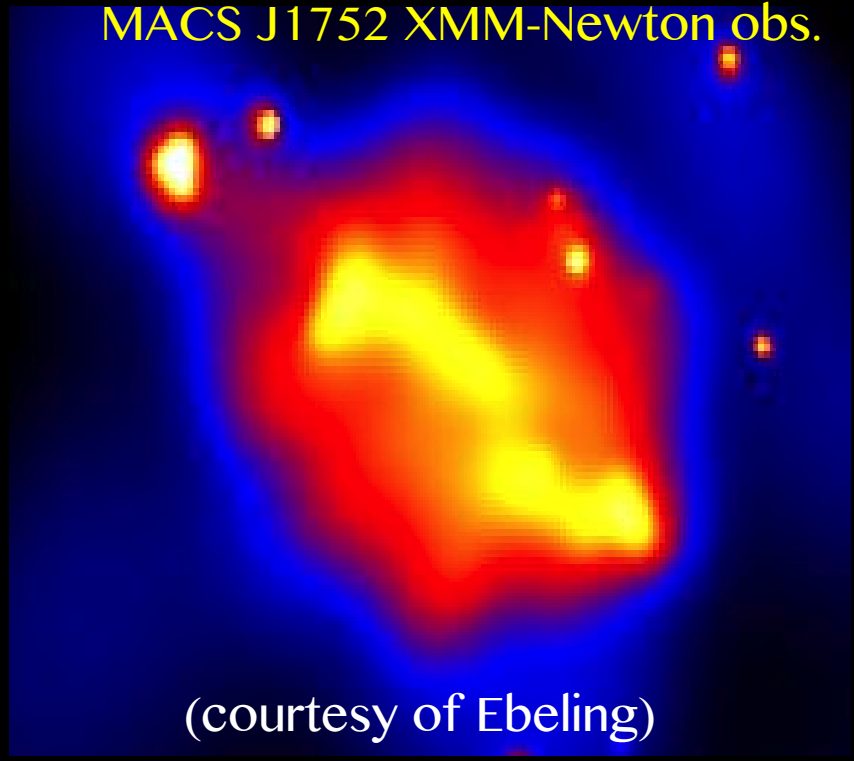
Simulation

Mach Numbers:
M ~ 5



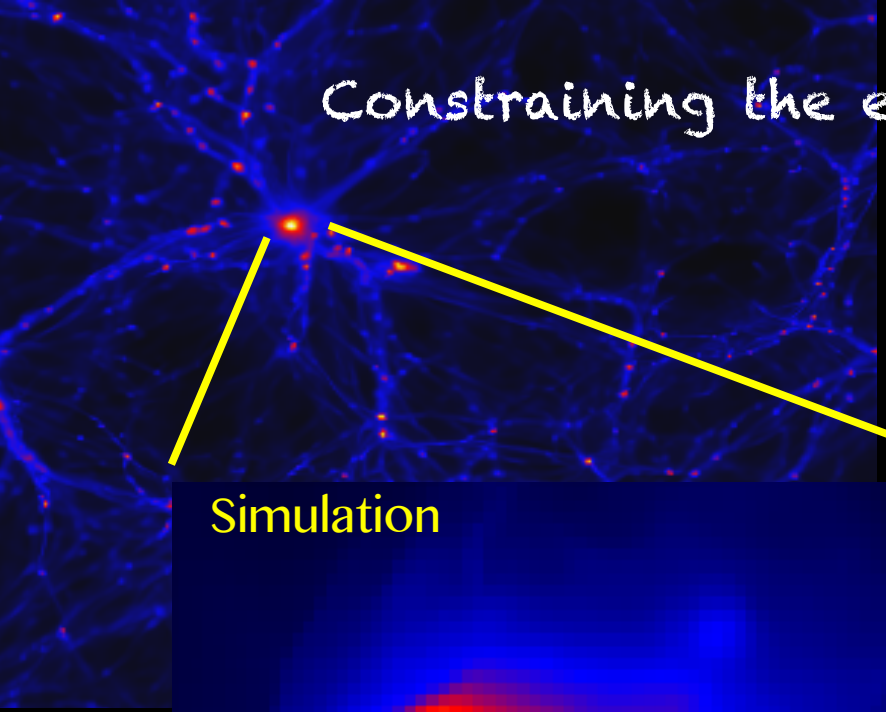
(Vazza et al. 2009)

MACS J1752 XMM-Newton obs.

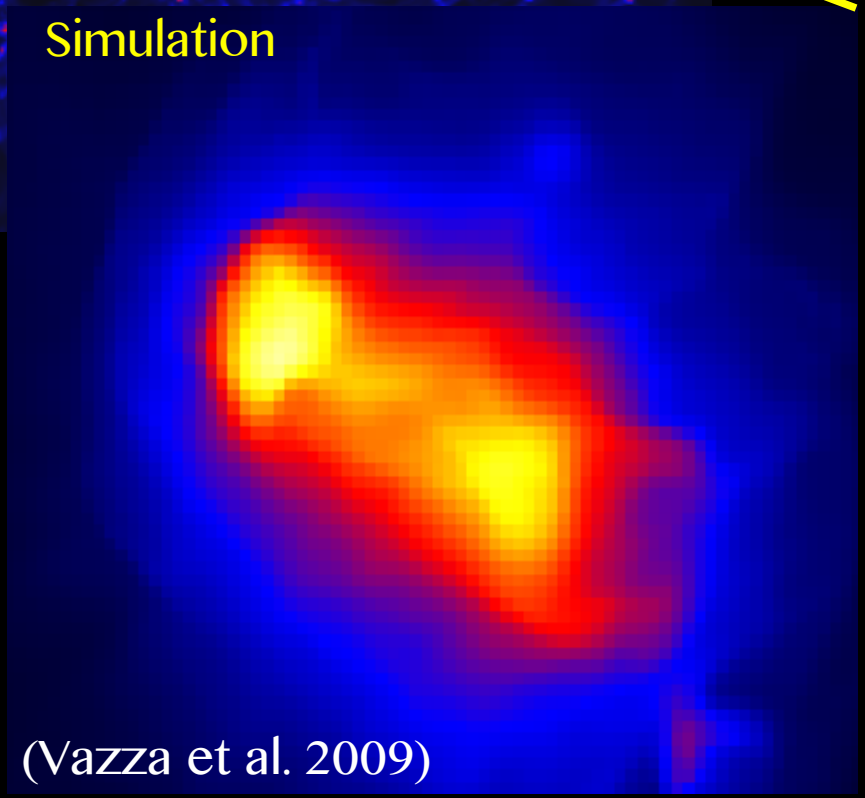


(courtesy of Ebeling)

Constraining the efficiency of shock acceleration

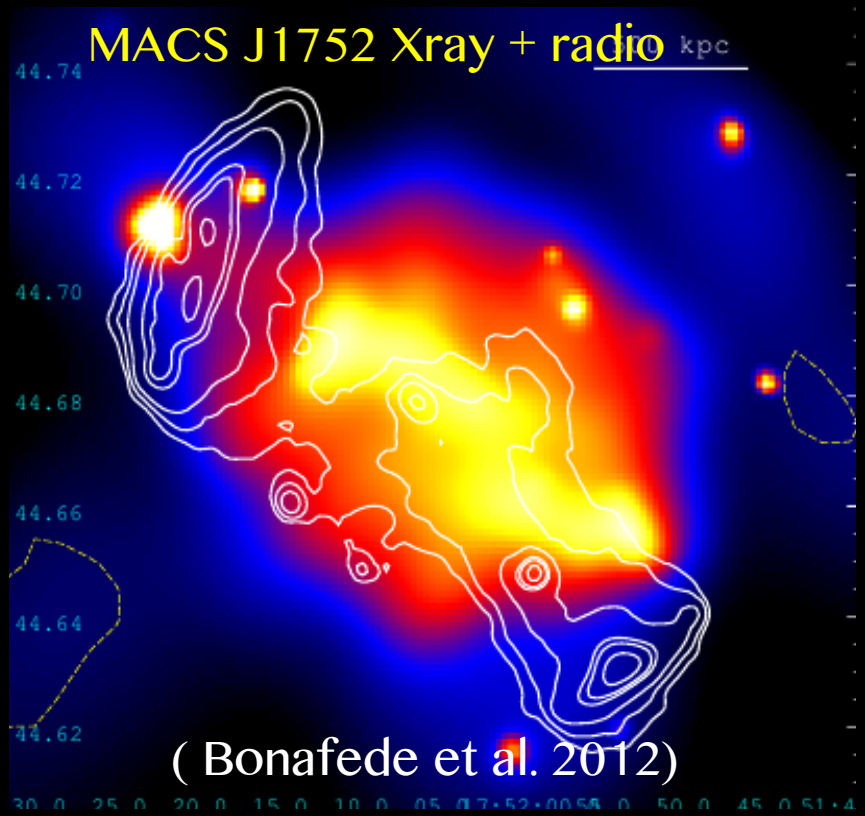


Simulation



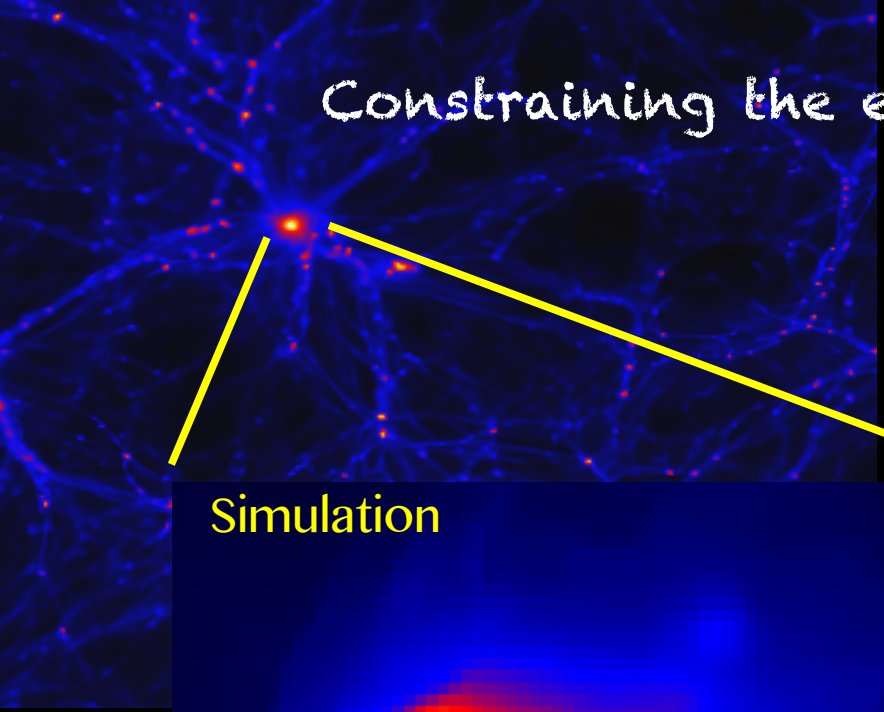
(Vazza et al. 2009)

MACS J1752 Xray + radio

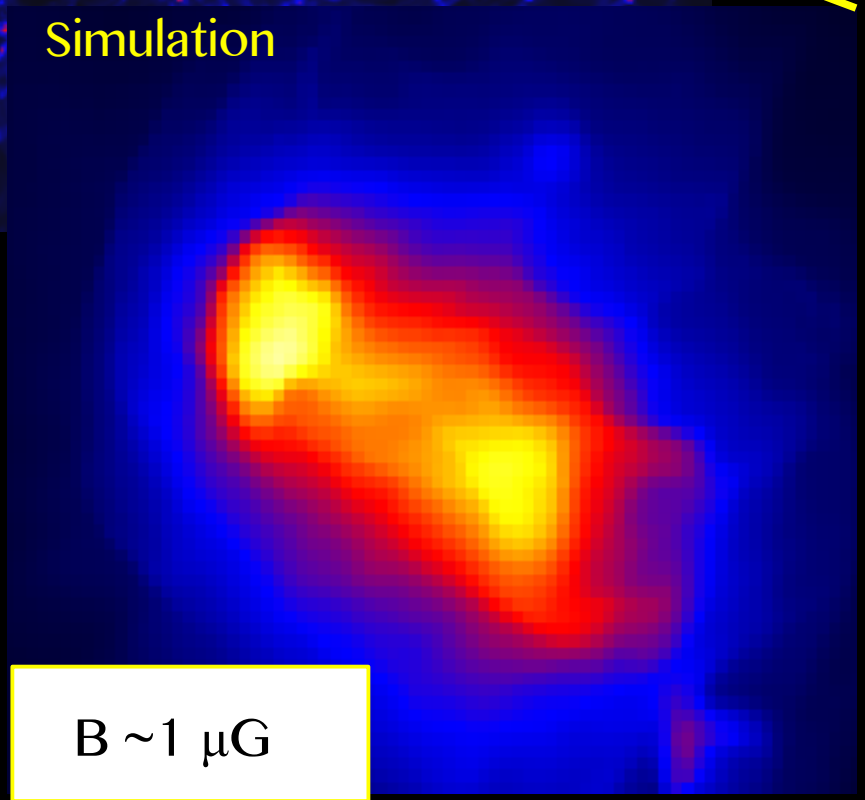


(Bonafede et al. 2012)

Constraining the efficiency of shock acceleration



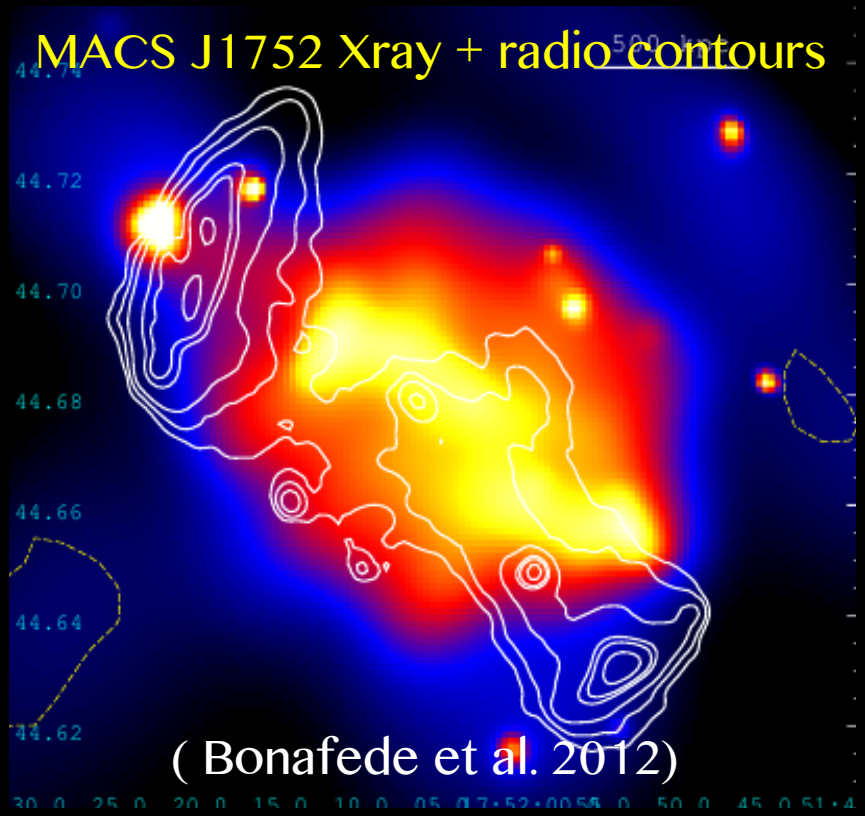
Simulation



B ~1 μG

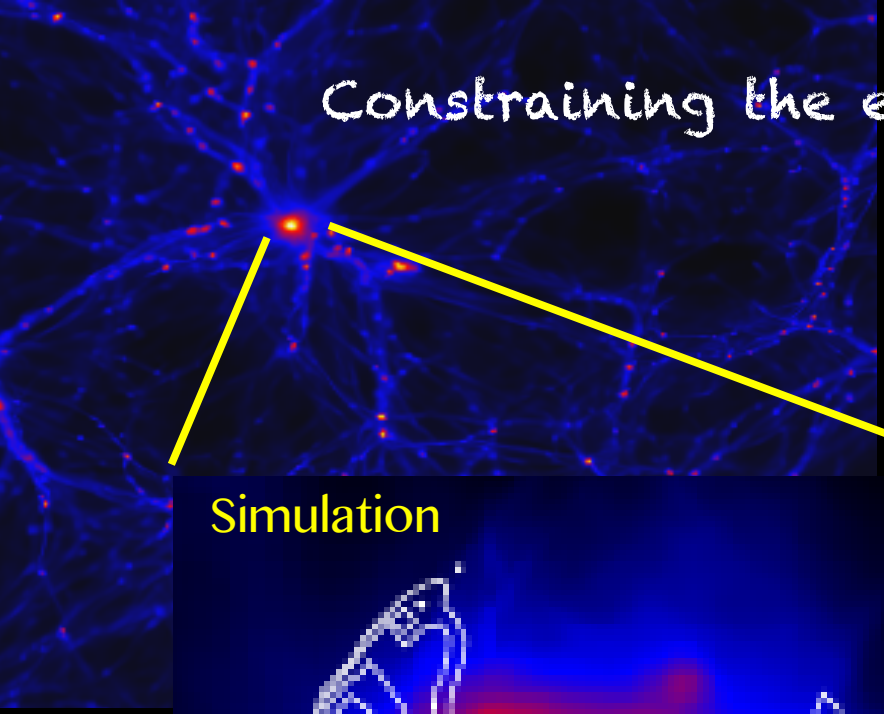
$$P_{\text{relic}} \sim A_s \Phi_{\text{shock}}$$

MACS J1752 Xray + radio contours

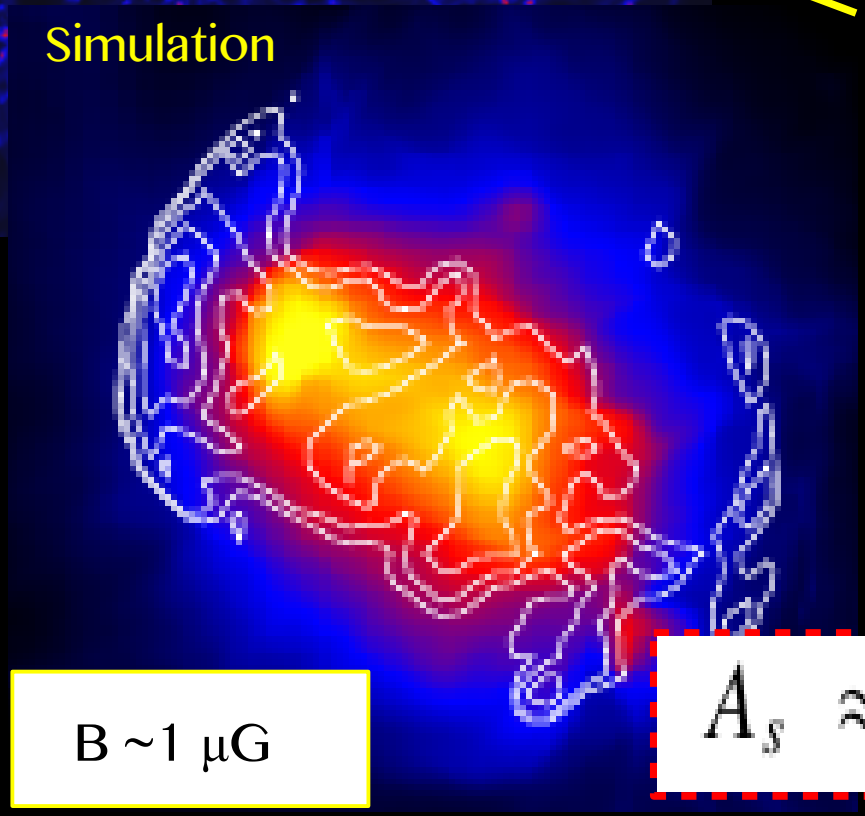


(Bonafede et al. 2012)

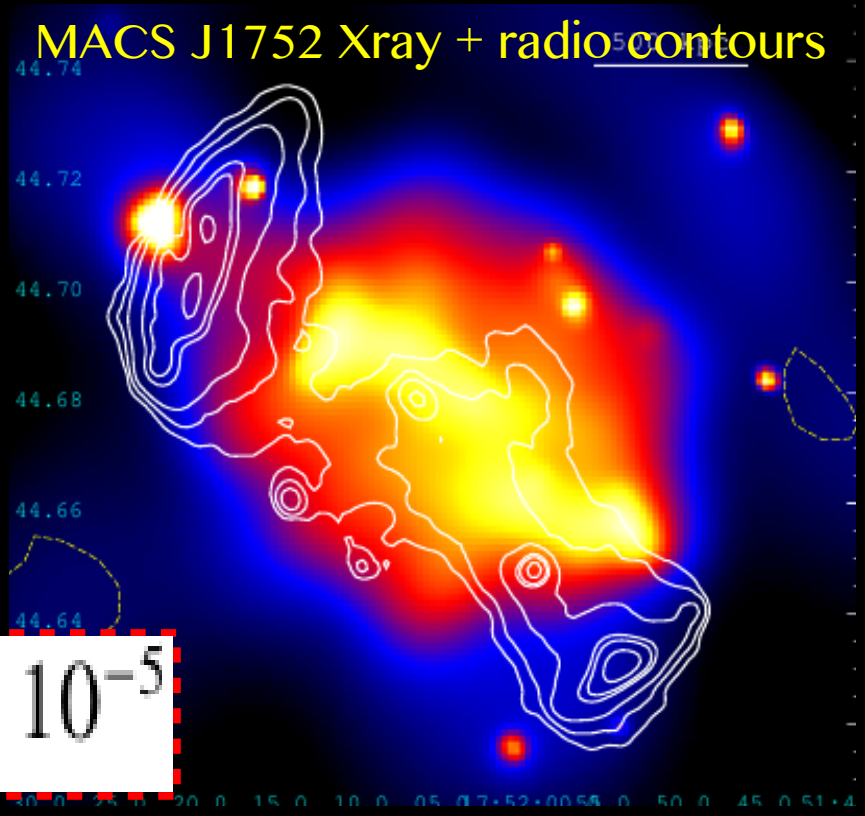
Constraining the efficiency of shock acceleration



Simulation



MACS J1752 Xray + radio contours



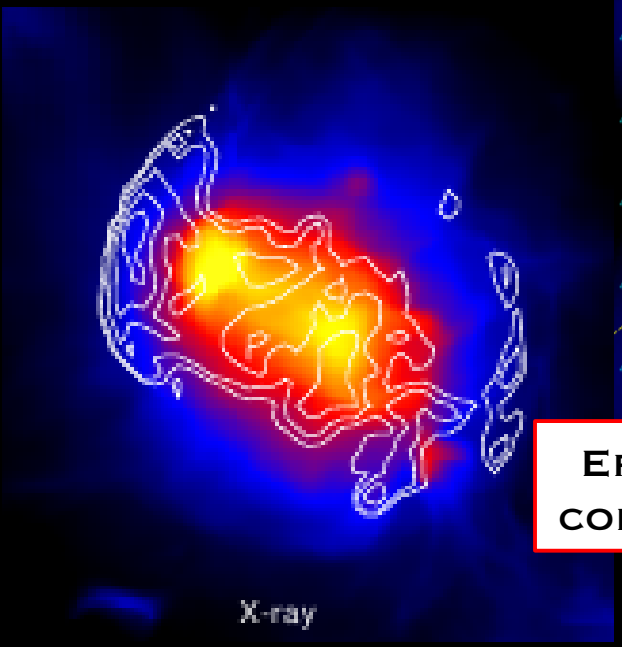
B ~1 μG

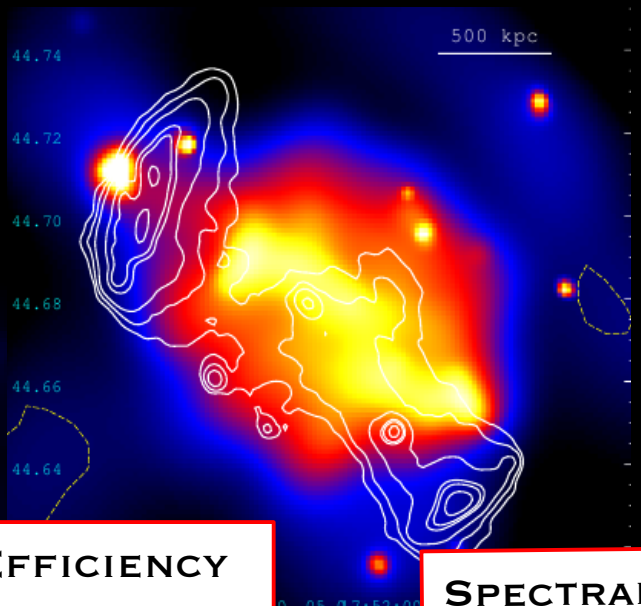
$$A_s \approx 10^{-5}$$

$$P_{\text{relic}} \sim A_s \Phi_{\text{shock}}$$

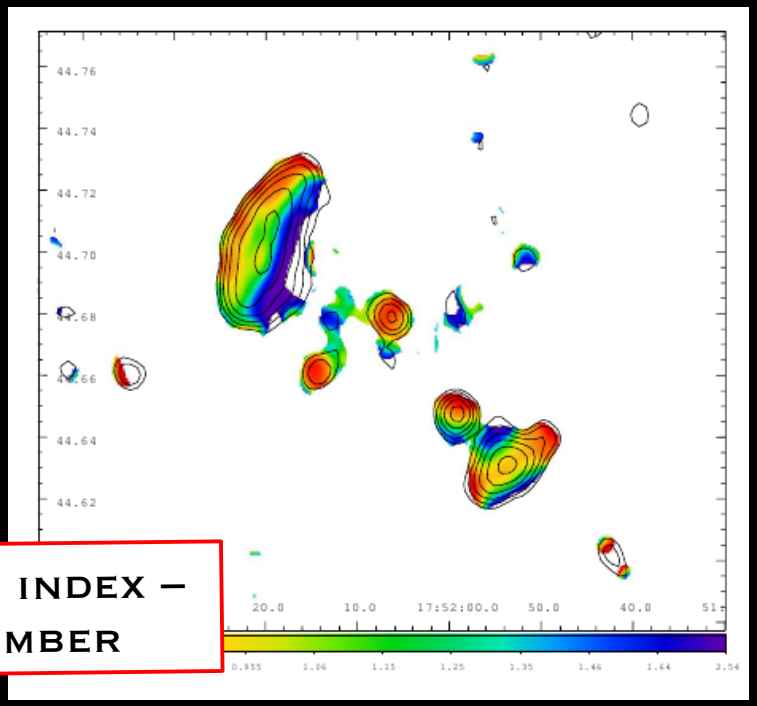
Good agreement with theoretical works (e..g. Hoeft & Brüggen 2007)

Conclusions so far...



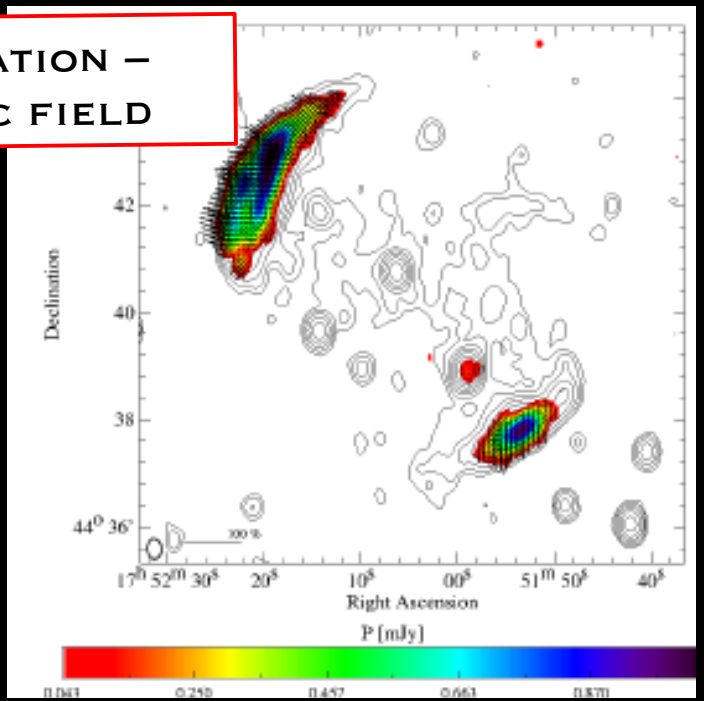


EFFICIENCY CONSTRAINED



SPECTRAL INDEX – MACH NUMBER

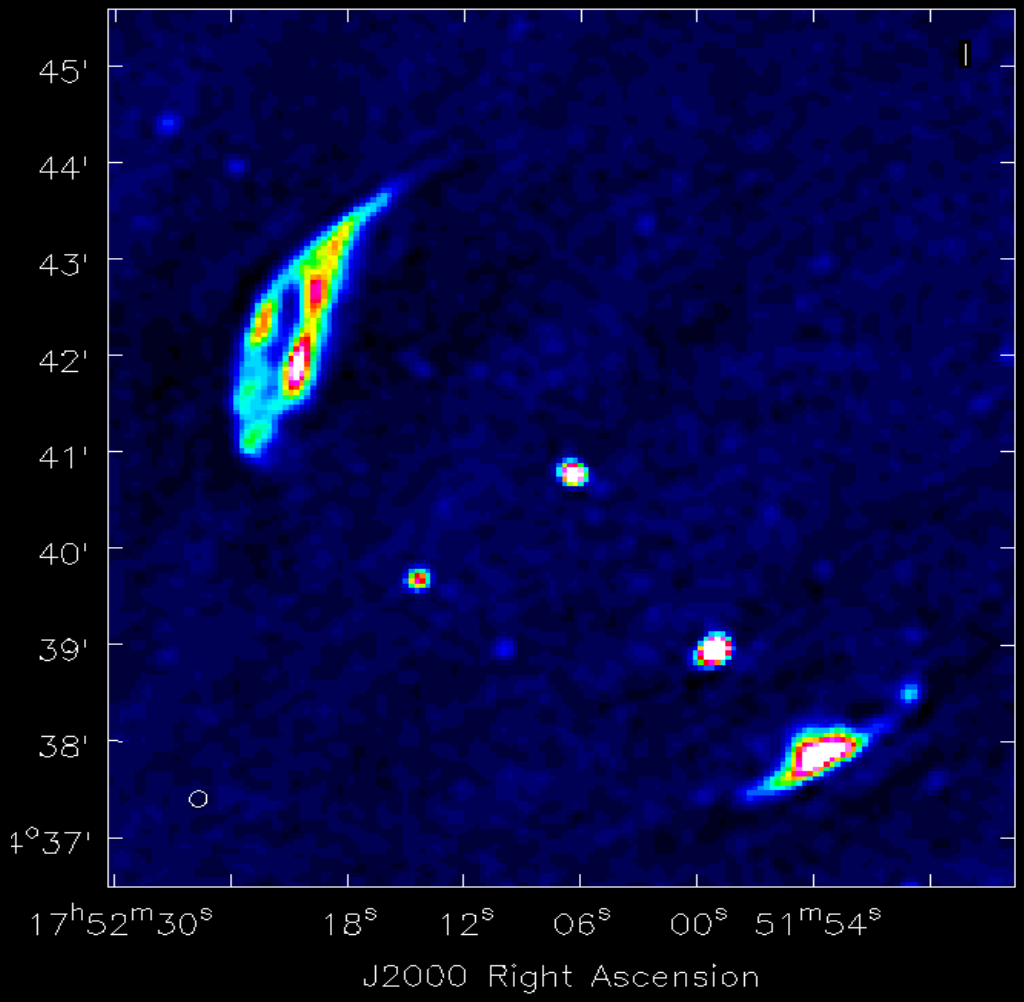
POLARISATION – MAGNETIC FIELD



Radio relics: probe average values and morphology of

- particle acceleration efficiency
- magnetic field

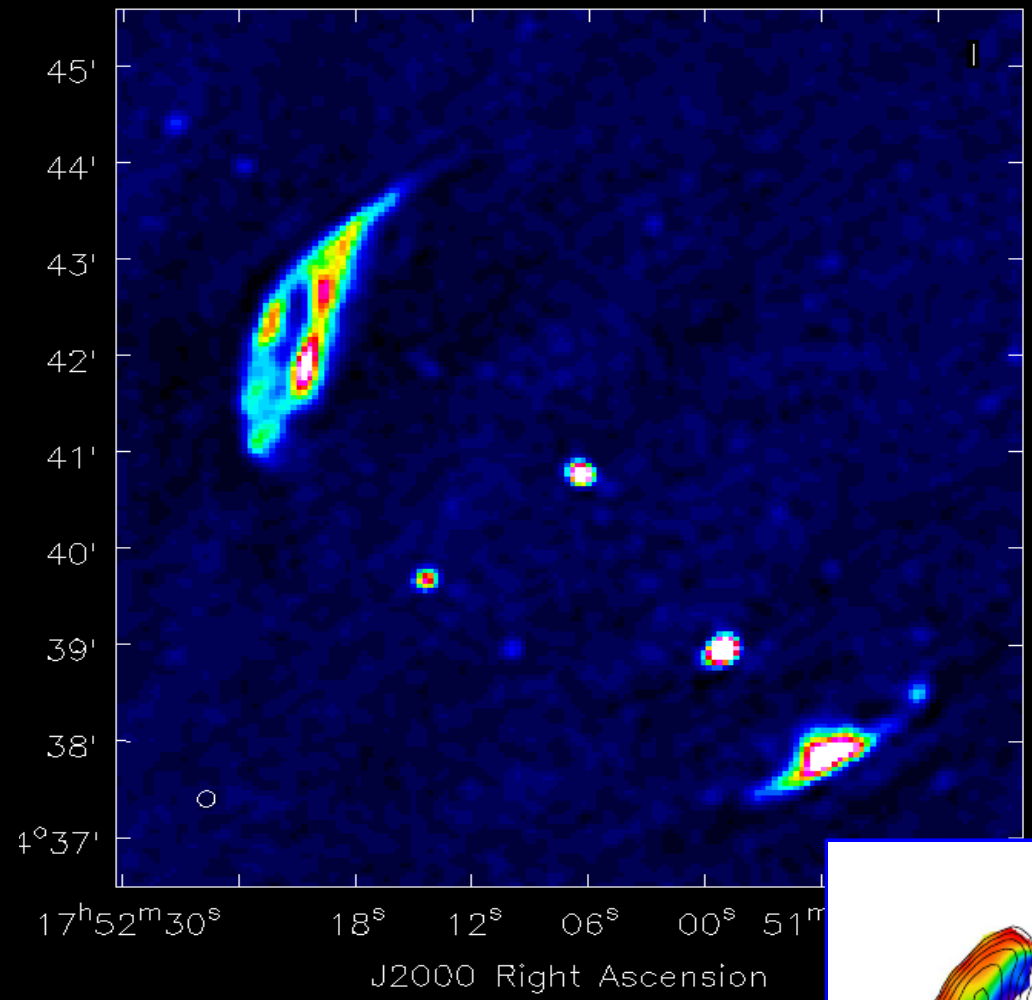
A higher resolution view



Jansky VLA 1-2 GHz image
Beam 8”x7”

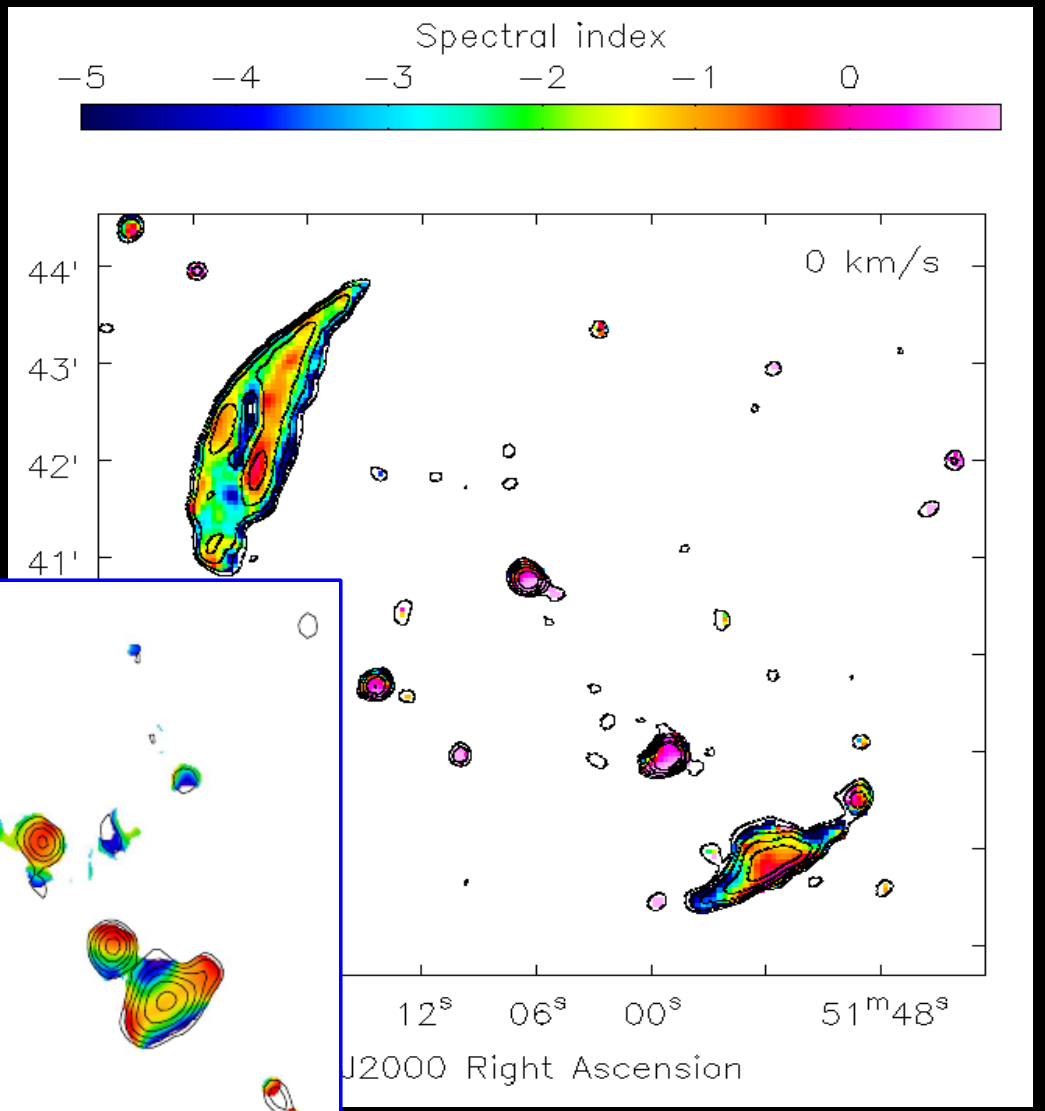
Multi frequency and multi-scale cleaning

A higher resolution view



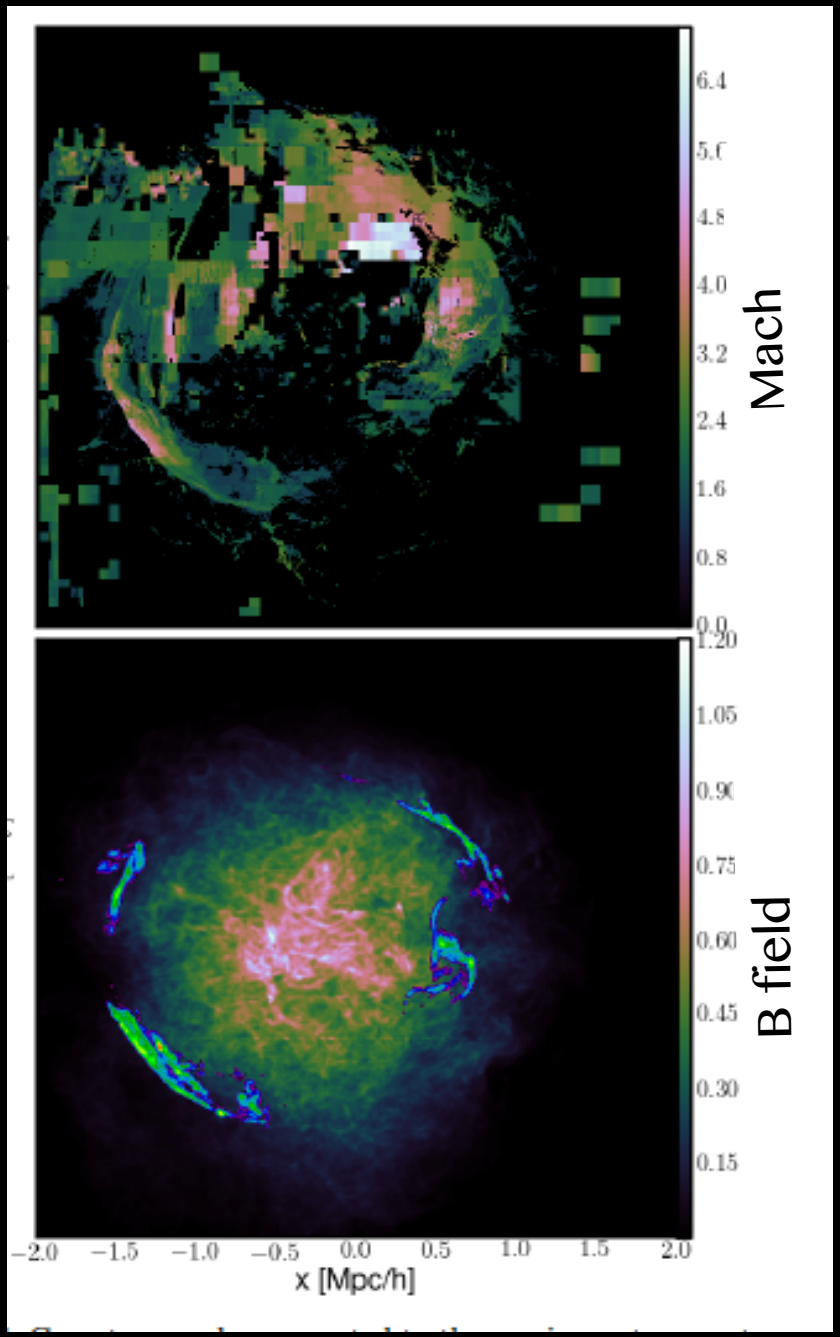
Jansky VLA 1-2 GHz image
Beam 8”x7”

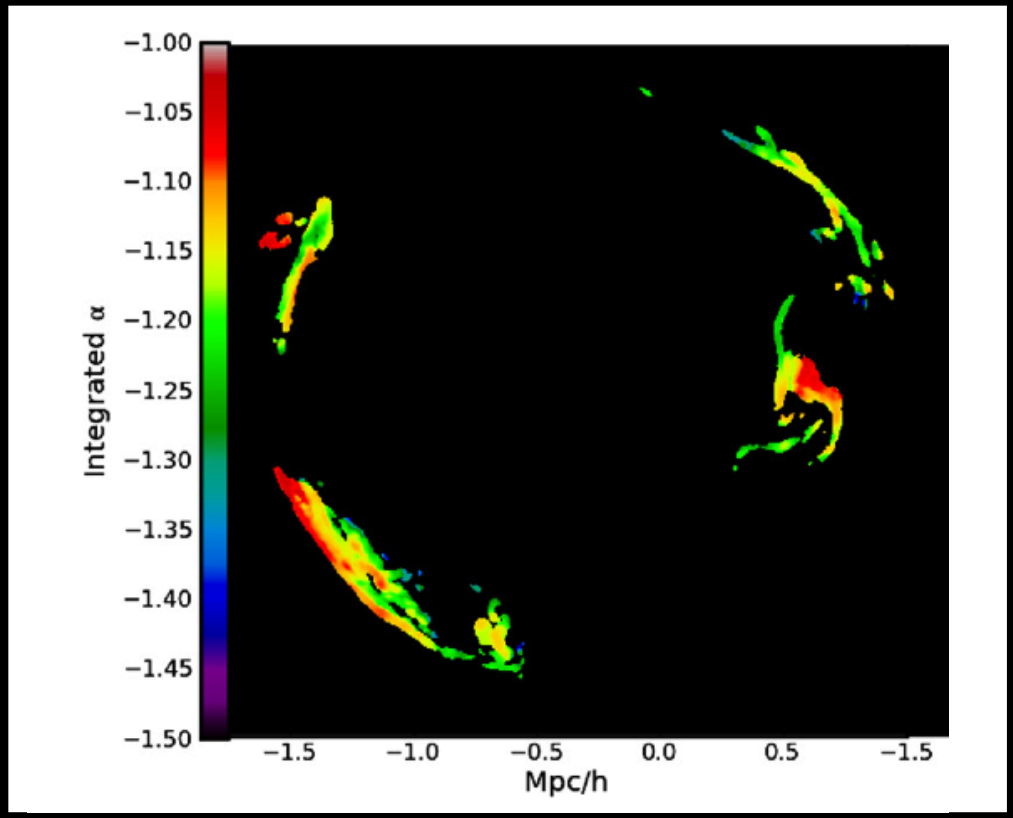
Multi frequency and multi-scale cleaning



High resolution and wide frequency coverage needed!

From cosmological simulations





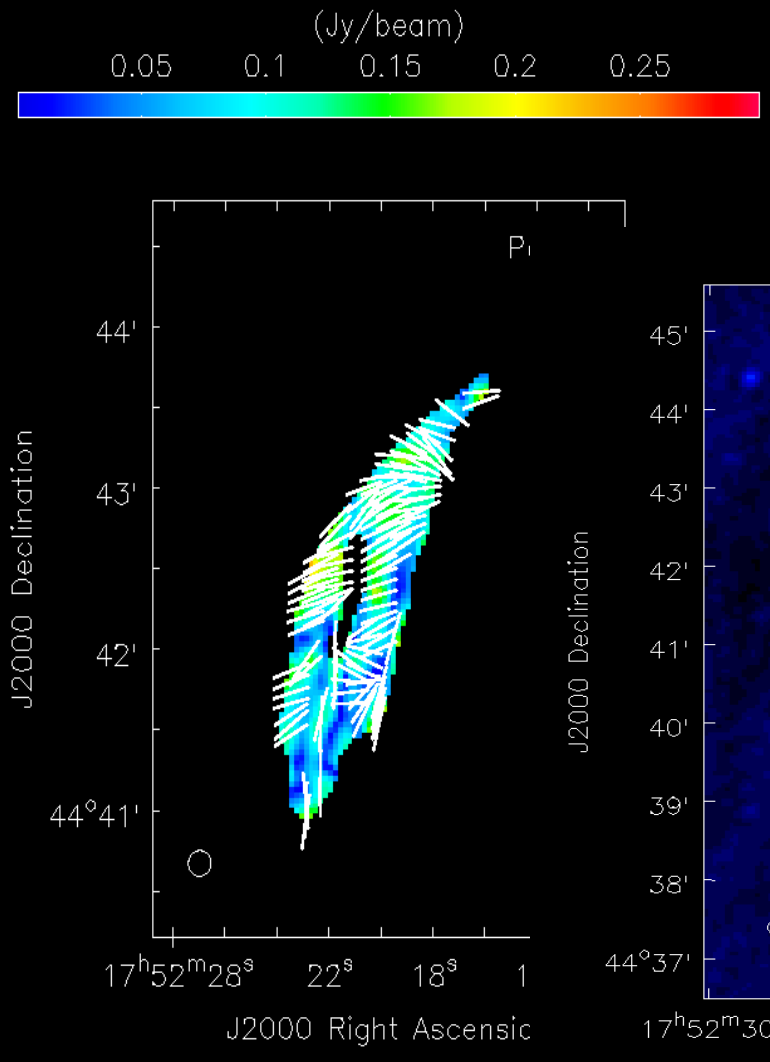
Distribution of Mach numbers → same steepening

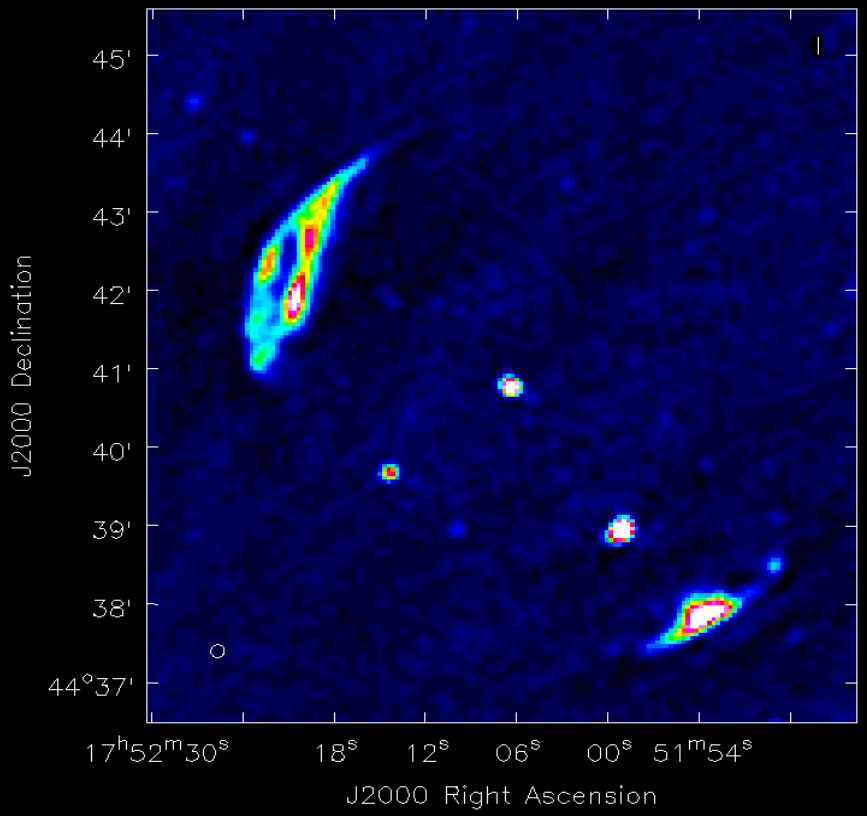
MHD simulations by Skillman et al. 2013

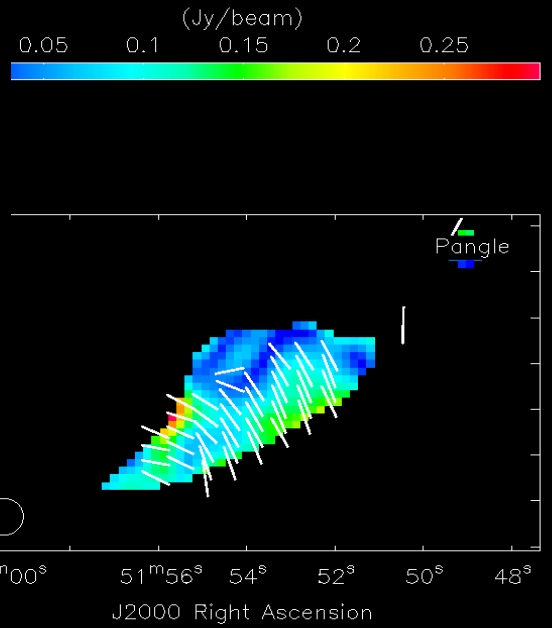
Polarisation at high resolution

Jansky VLA 1-2 GHz image

Multi frequency and multi-scale cleaning

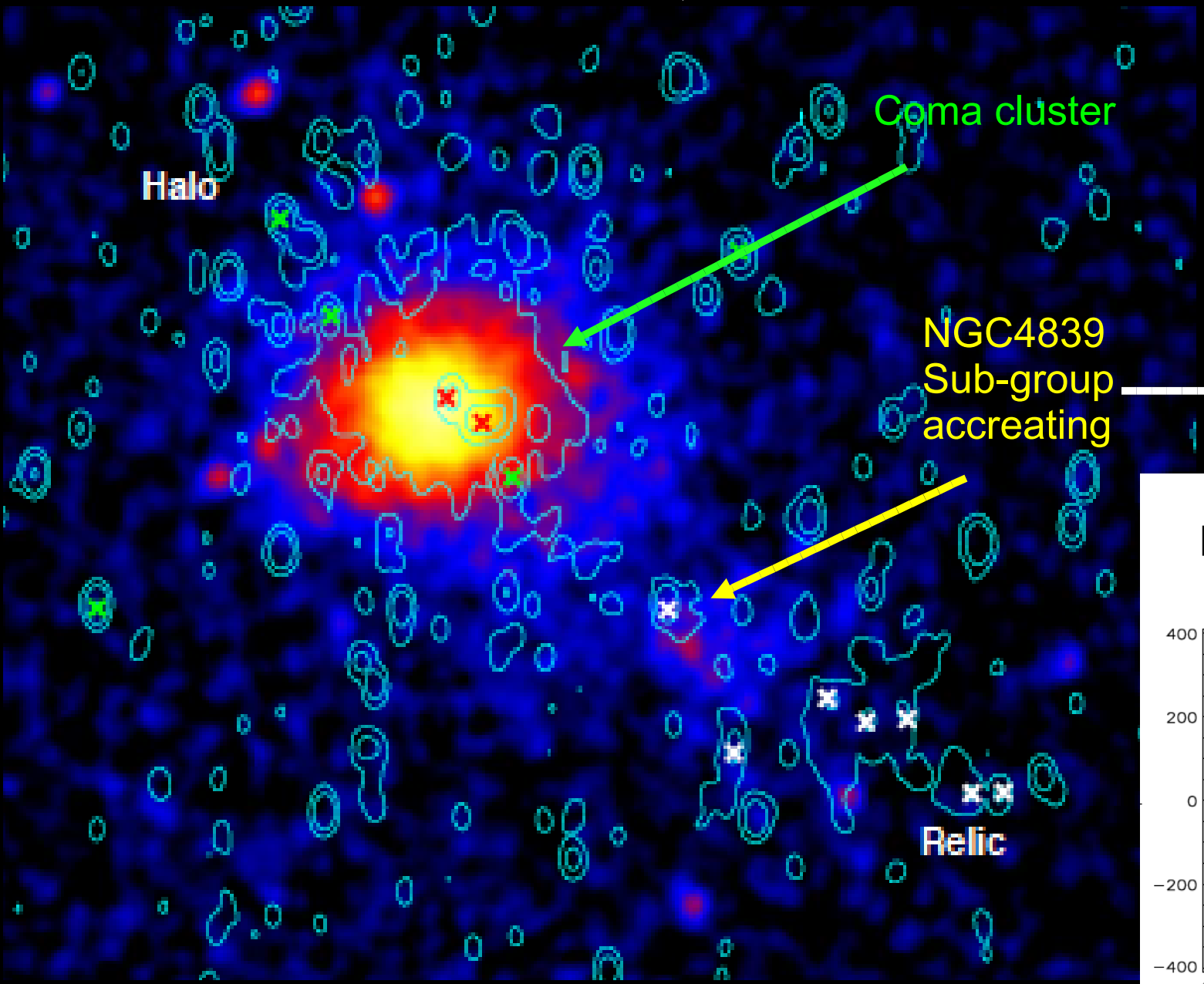




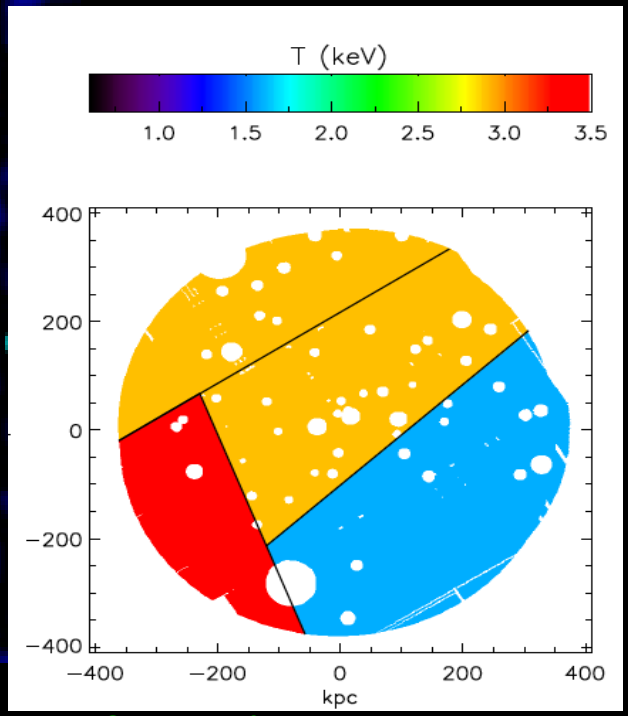


Magnetic field morphology more complex than usually assumed

Magnetic field estimates at the relic position: Faraday Rotation Measures



Shock wave
→ B amplified
→ e accelerated



Ogrean & Brüggen 2013

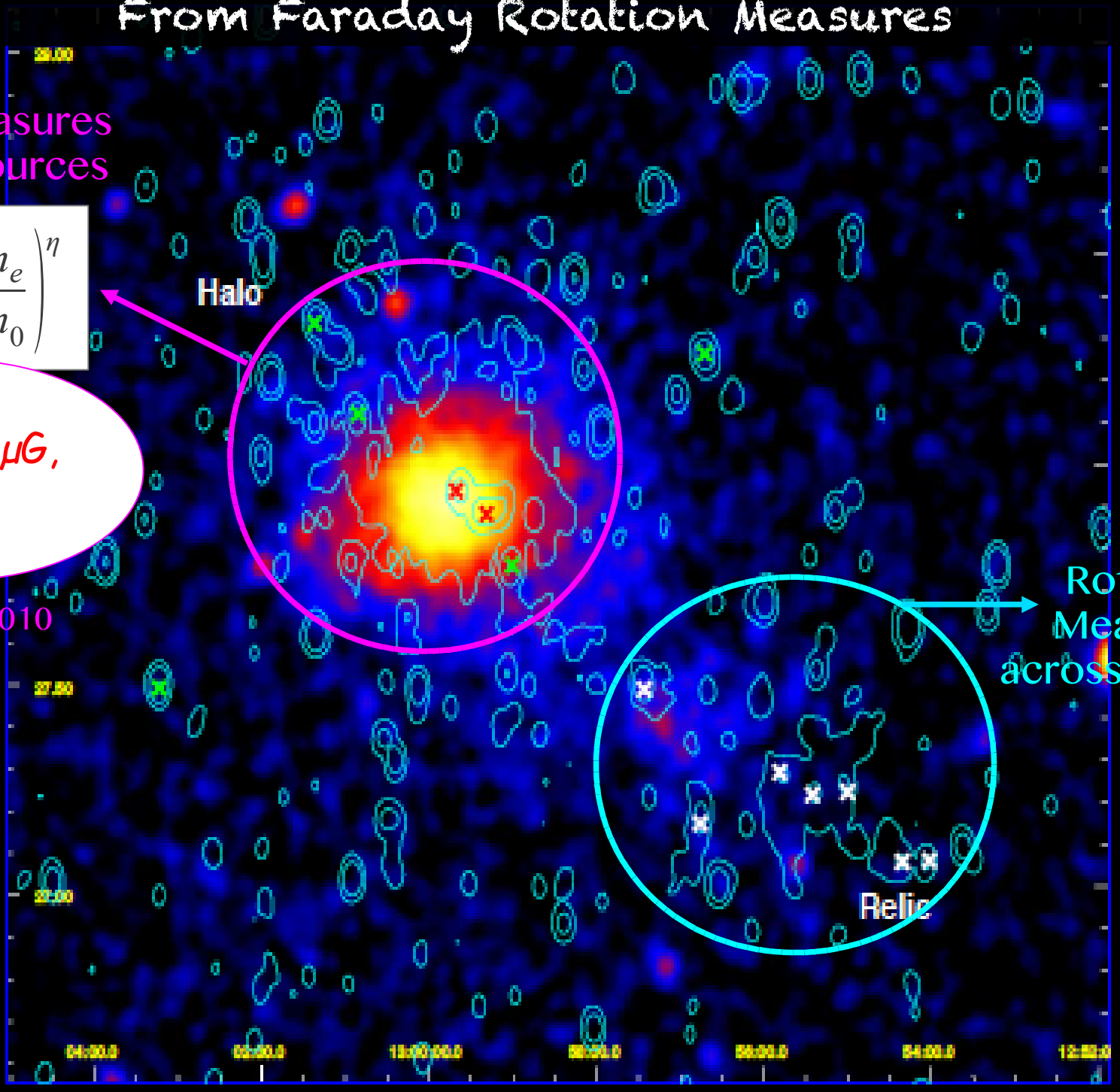
Magnetic field amplification in the Coma relic From Faraday Rotation Measures

Rotation Measures
Central sources

$$B(r) = B_0 \left(\frac{n_e}{n_0} \right)^{\eta}$$

Bo=4.7 μG,
η=0.5

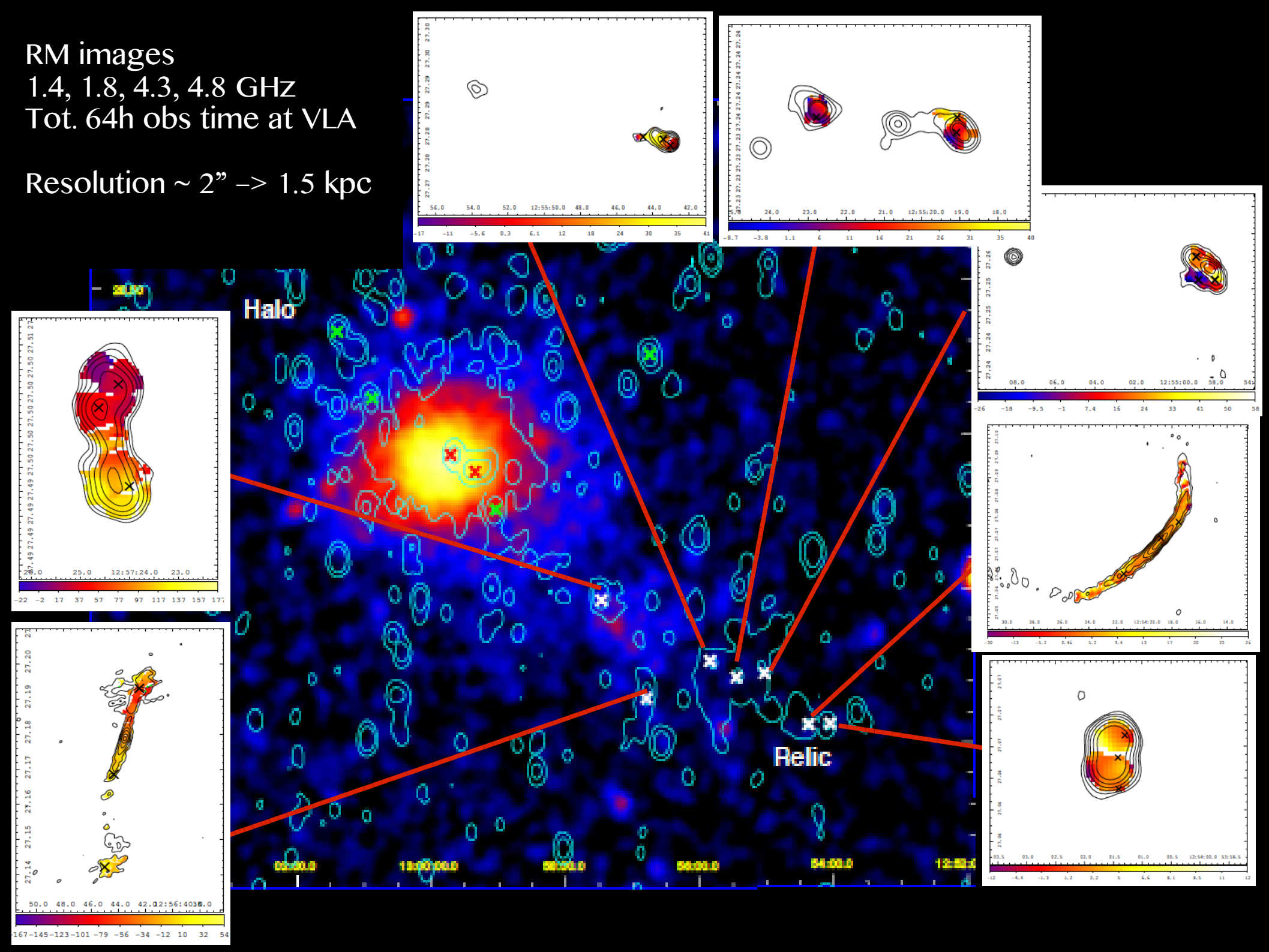
Bonafede et al. 2010



Rotation Measures across the relic

RM images
1.4, 1.8, 4.3, 4.8 GHz
Tot. 64h obs time at VLA

Resolution ~ 2” –> 1.5 kpc



Mock RM observations:

MiRo' code (Bonafede, Vazza, Brüggen et al. et al. Submitted)

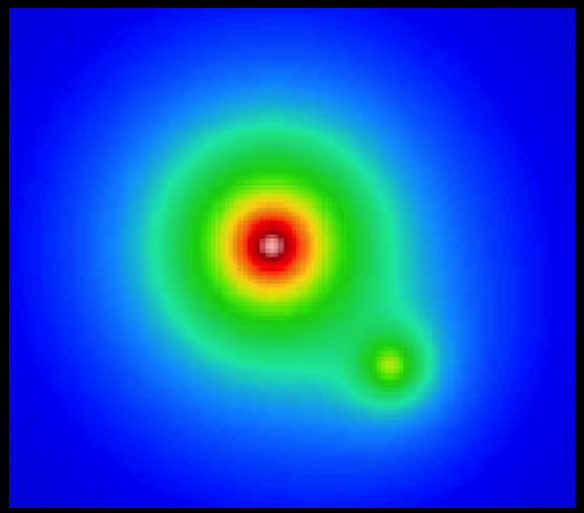
3D magnetic field simulations

$$RM \equiv \frac{\partial \psi}{\partial \lambda^2} \propto \int_0^d n_e H \cos\vartheta \, dl$$

Similar approach FARADAY code (Murgia et al. 2004)

Observed quantity

Model for the gas distribution:



2 isothermal gas spheres (clusters) in equilibrium

3D Model for the magnetic field

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

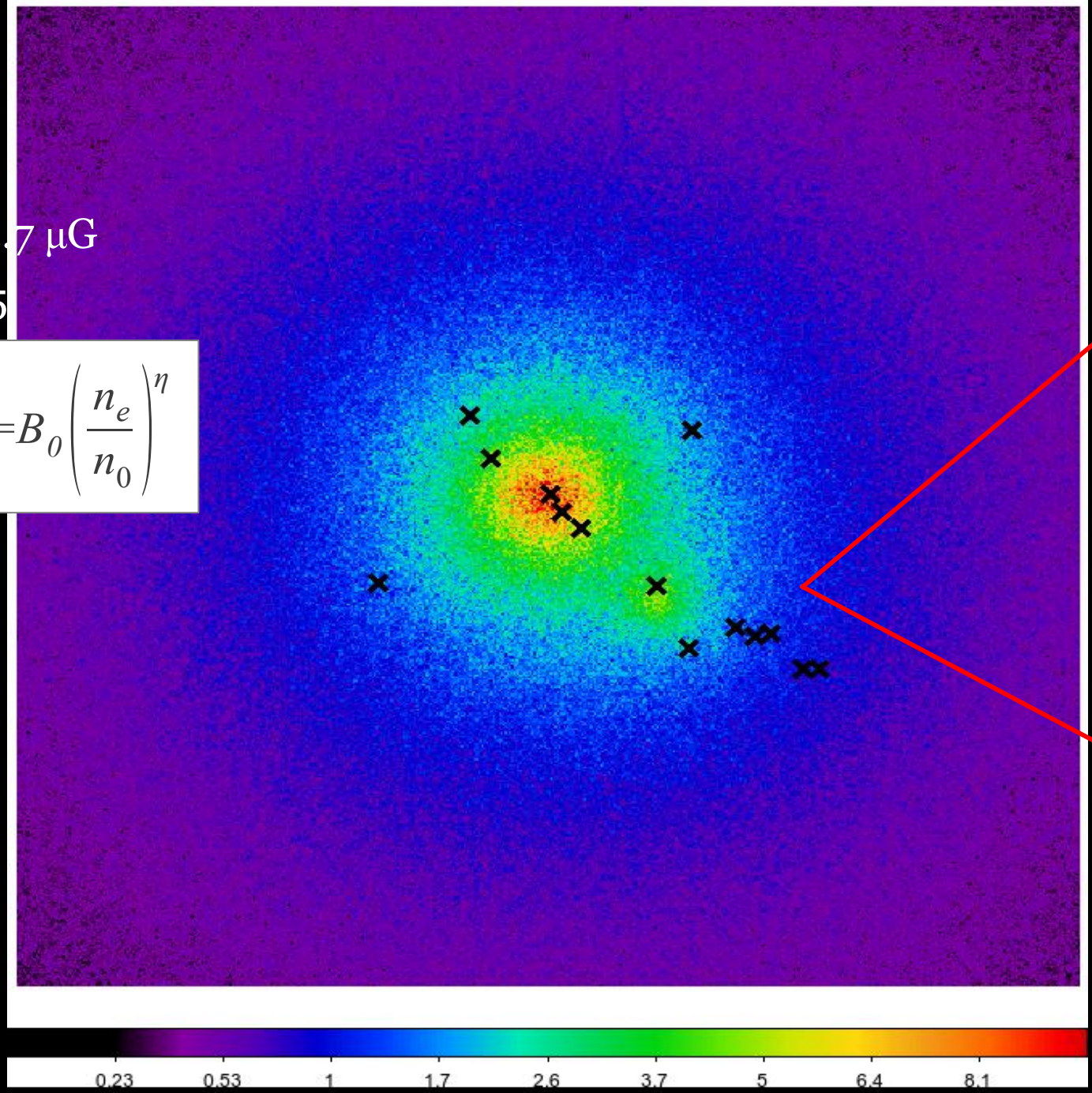
$$B(r) = B_0 \left(\frac{n_e}{n_0} \right)^{\eta}$$

Simulated RM maps

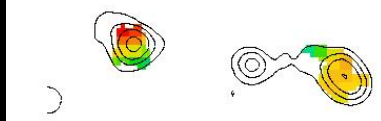
B_o =4.7 μG

η=0.5

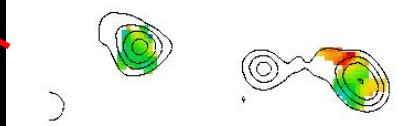
$$B(r) = B_0 \left(\frac{n_e}{n_0} \right)^{\eta}$$



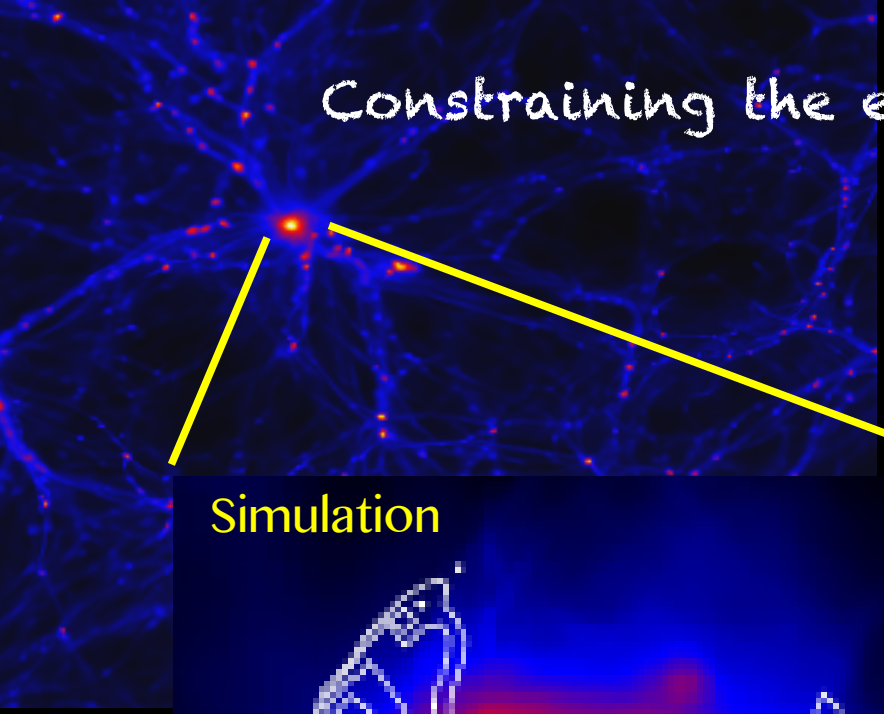
Observed RM



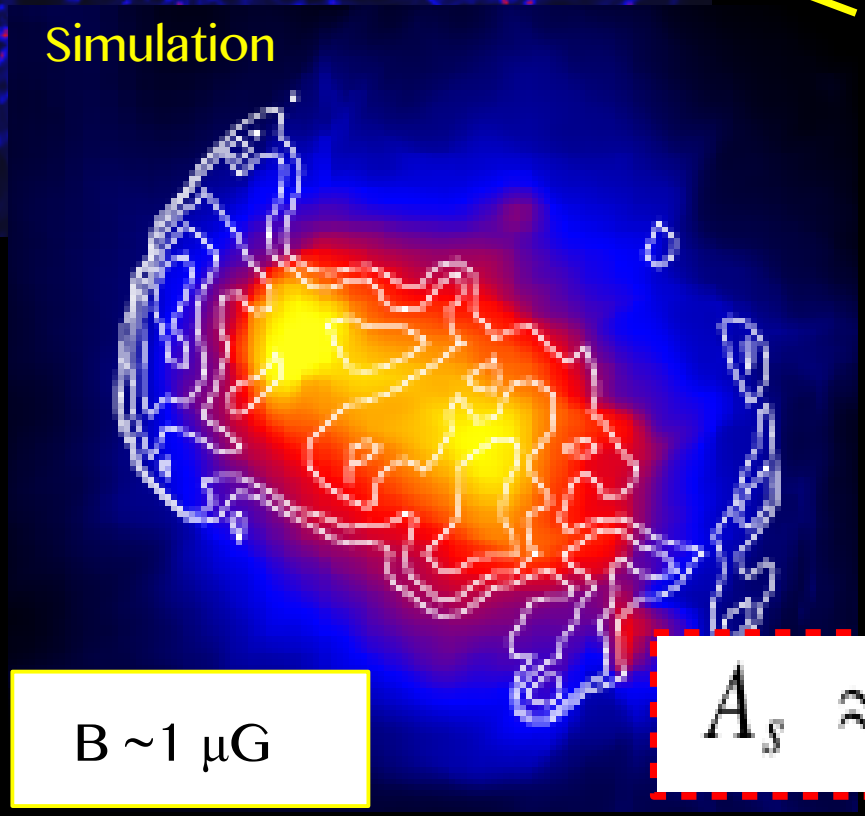
Simulated RM



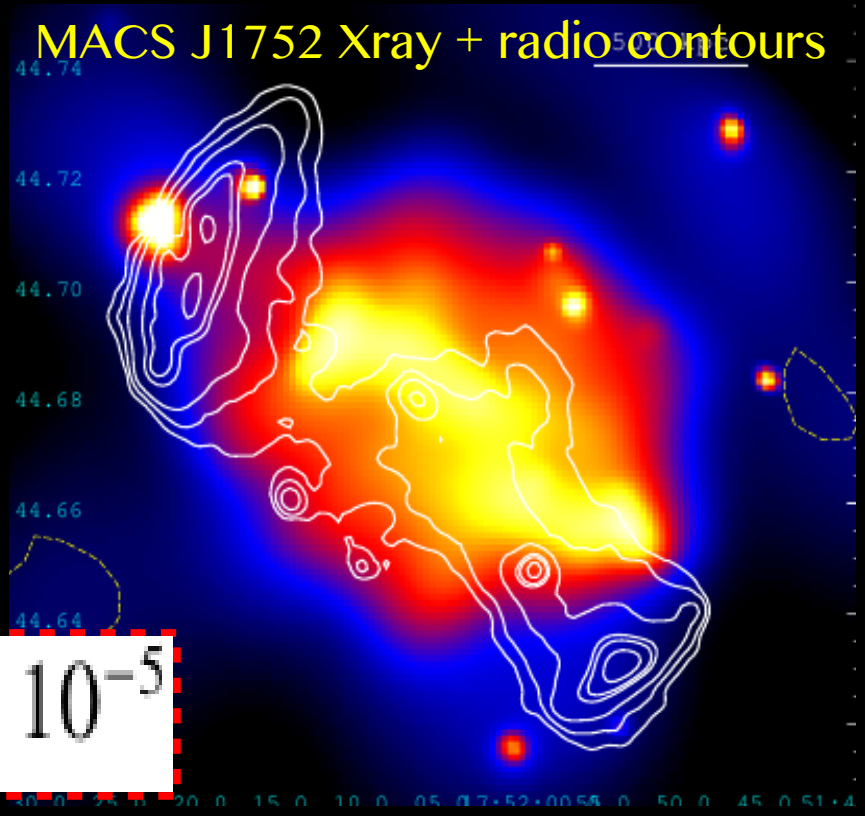
Constraining the efficiency of shock acceleration



Simulation



MACS J1752 Xray + radio contours



B ~1 μG

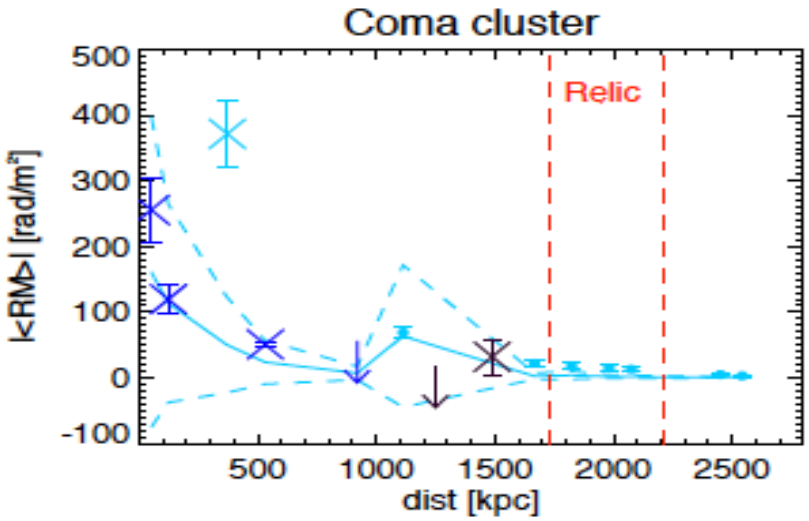
$$A_s \approx 10^{-5}$$

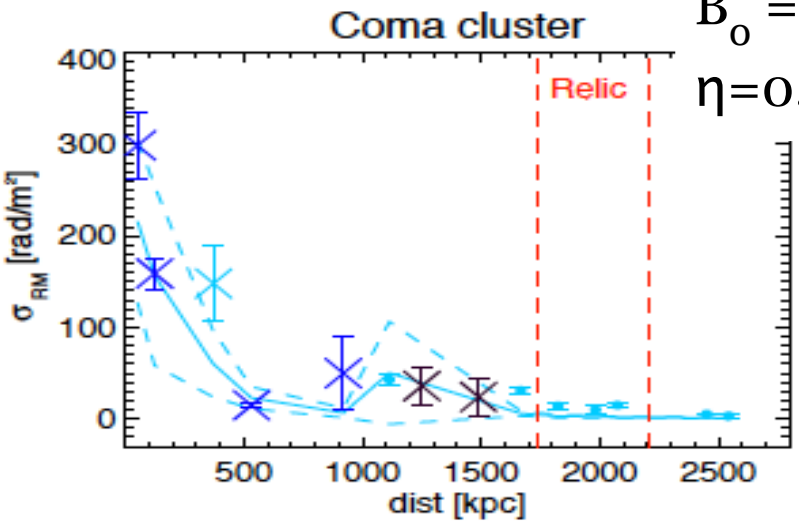
$$P_{\text{relic}} \sim A_s \Phi_{\text{shock}}$$

Good agreement with theoretical works (e..g. Hoeft & Brüggen 2007)

Results:

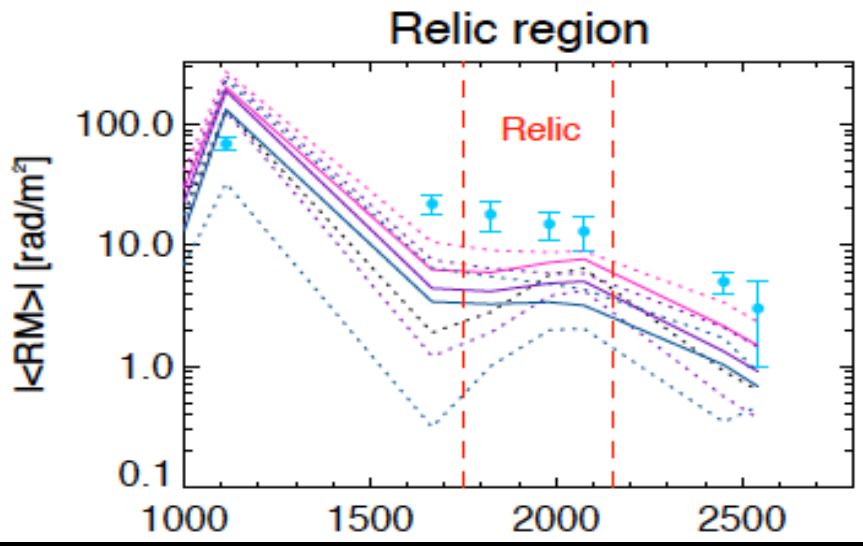
All sources Coma + group

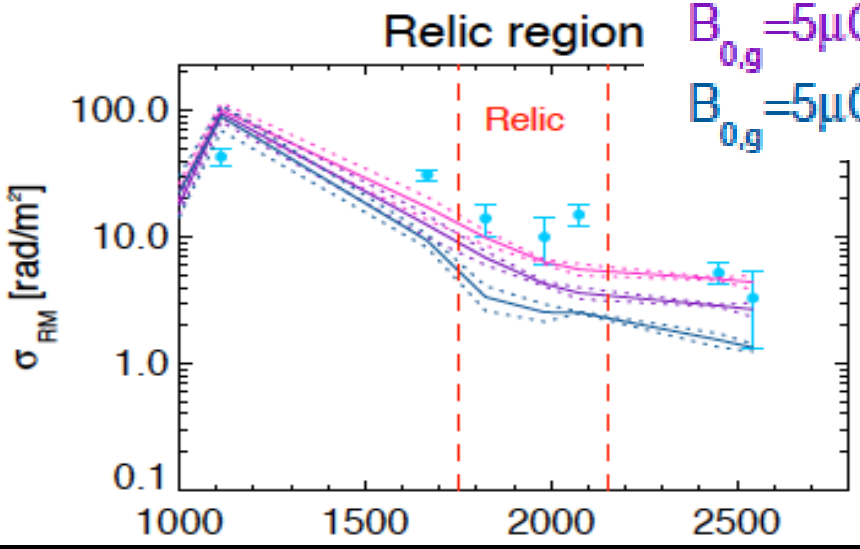




B_o =4.7 μG
η=0.5

Zoom in the relic region

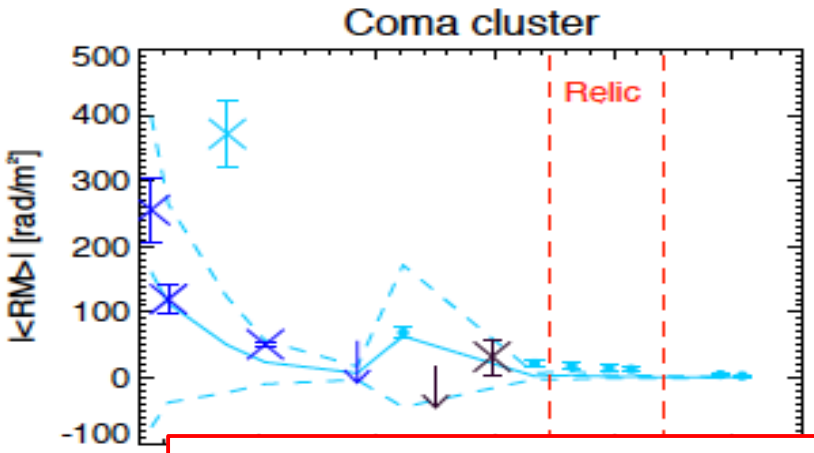


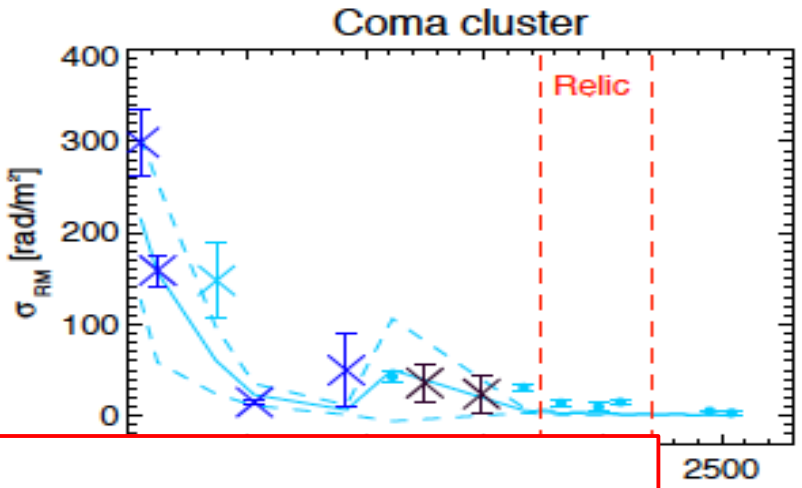


$B_{0,g}$=5μG, η=0.2
$B_{0,g}$=5μG, η=0.3
$B_{0,g}$=5μG, η=0.5

Results:

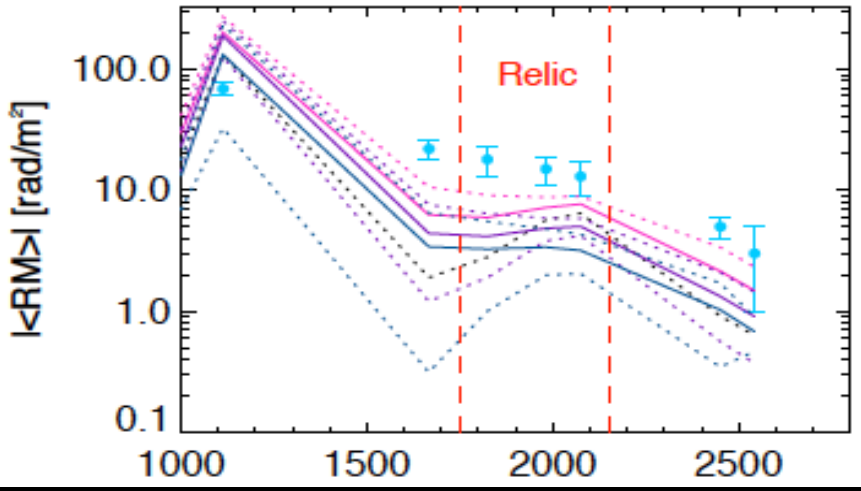
All sources Coma + group

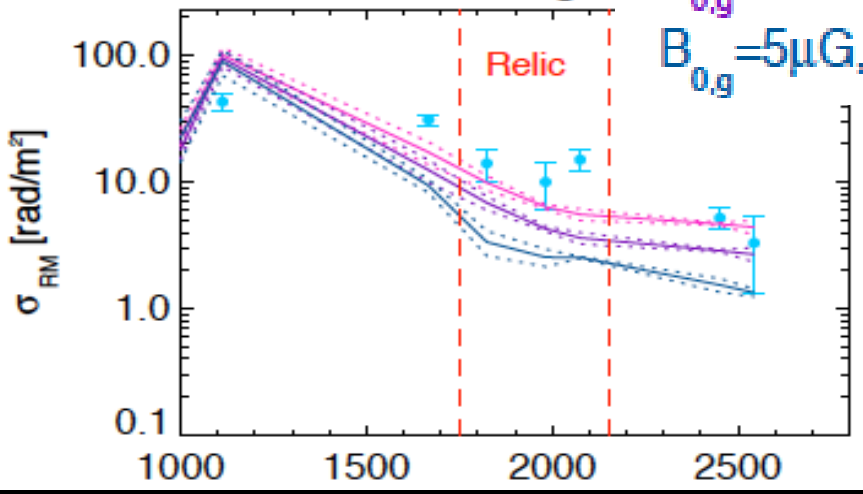




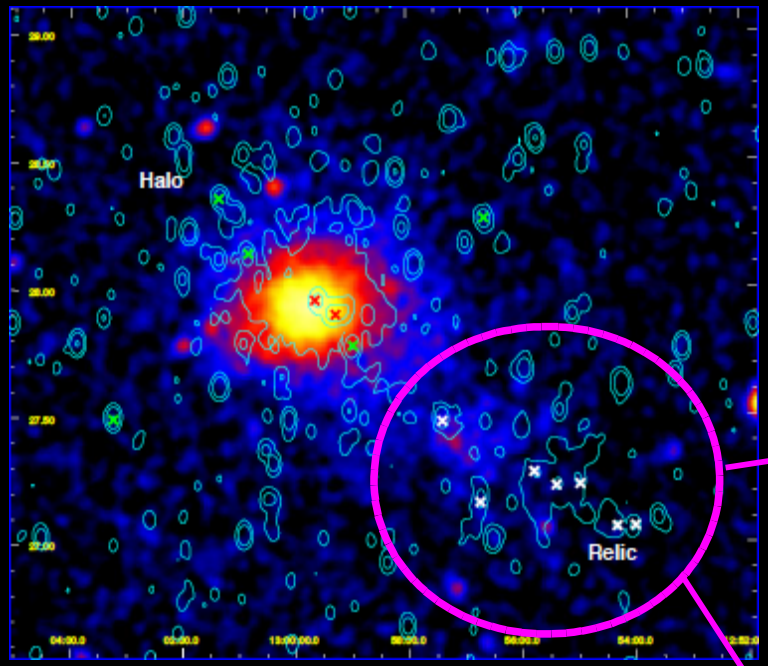
- RM need a boost by a factor 6-8 to recover observed values *throughout* the whole region

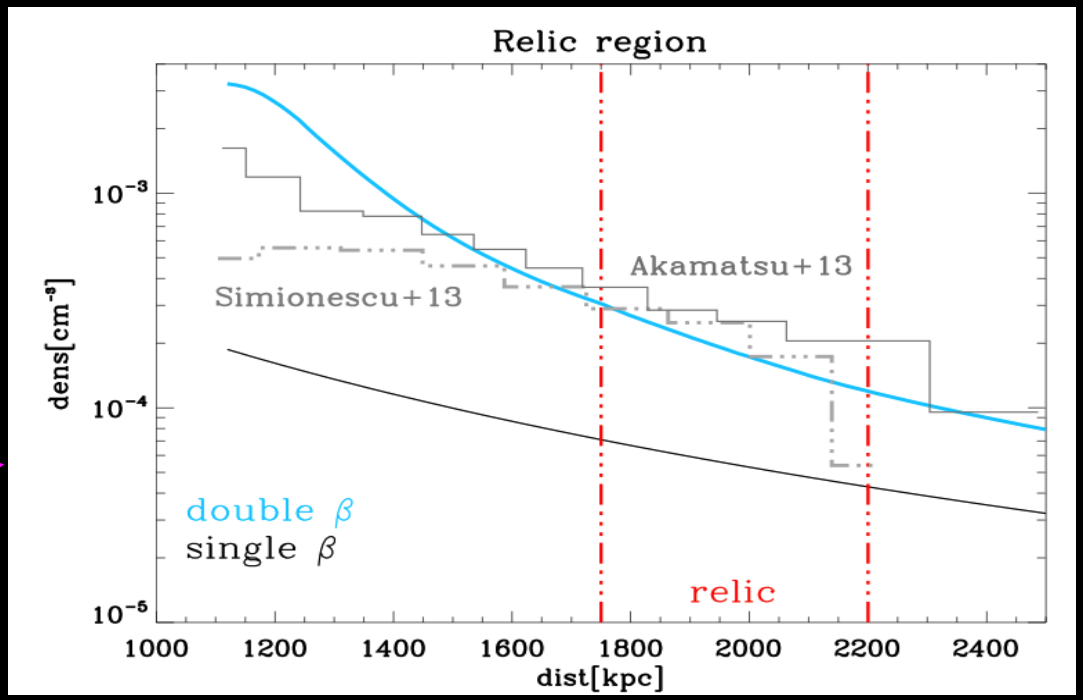
$B_{0,g}$=5μG, η=0.2
$B_{0,g}$=5μG, η=0.3
$B_{0,g}$=5μG, η=0.5

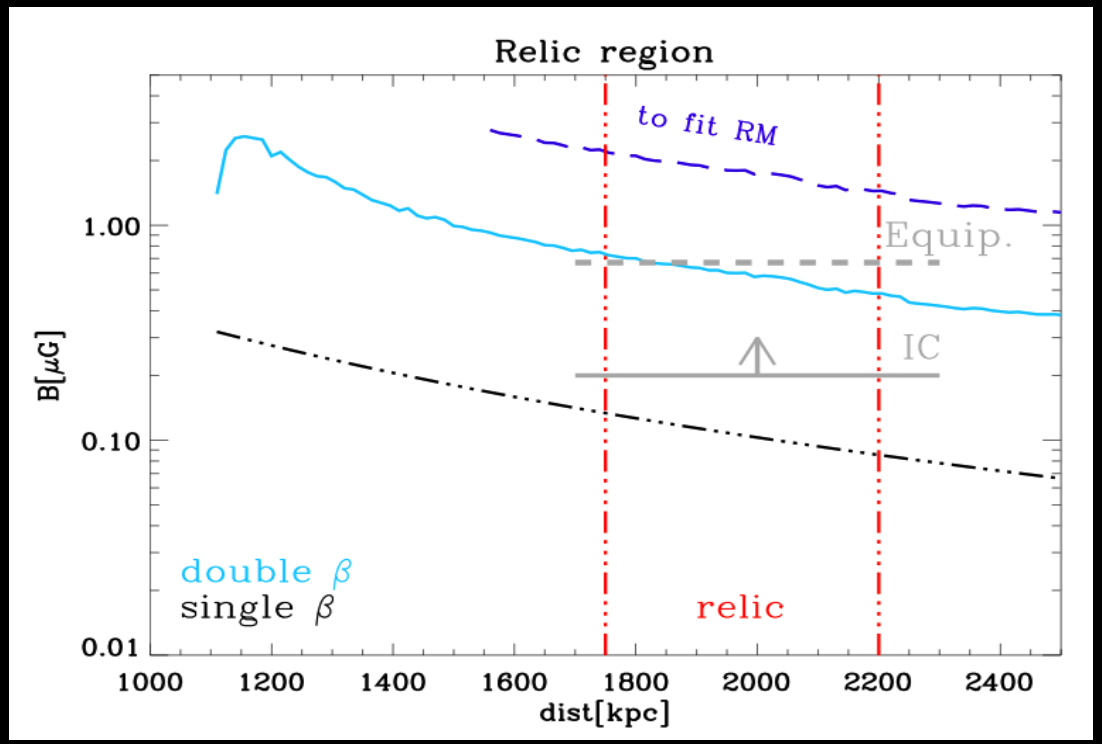




Results:







- density in agreement with recent Suzaku estimates

→ Magnetic field amplified by a factor 3

Consistent with IC limits

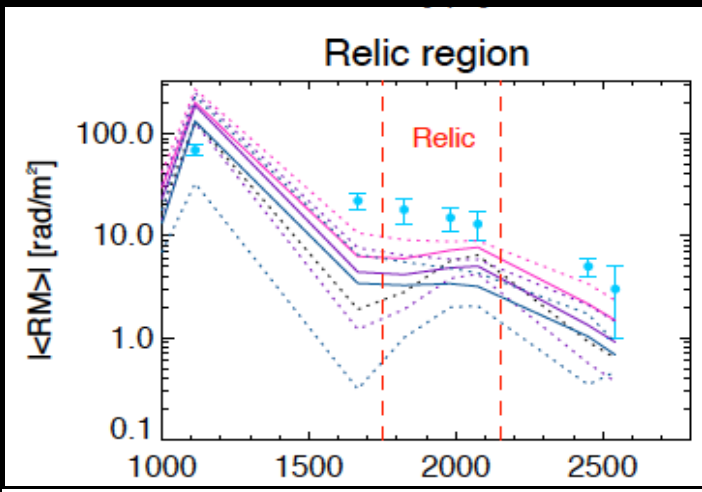
Summary

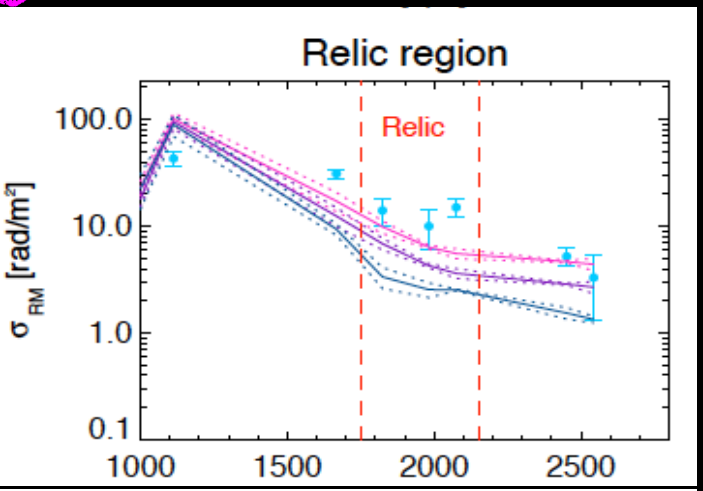
- Radio relics: new high resolution view
- spectral index: particle aging, B or Mach number distribution?
- Magnetic field complex morphlogy
- Faraday Rotation measures in the Coma relic region
  consistent with a magnetic field boost by a factor ~3
  B ~2 μG at the relic

Zoom in the relic region:

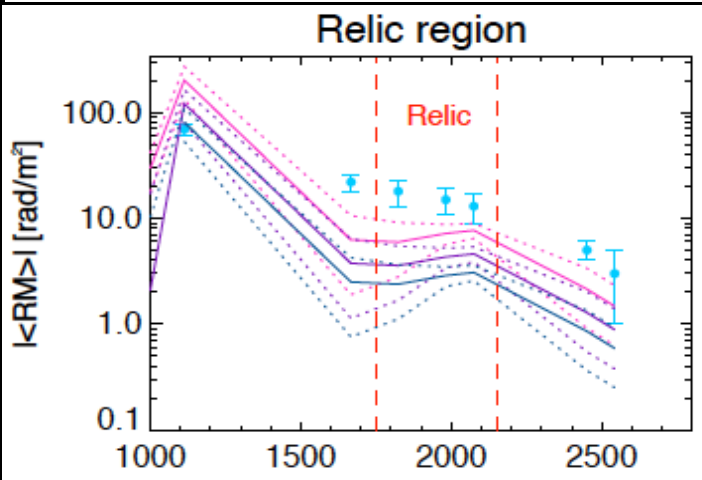
$$B(r) = B_0 \left(\frac{n_e}{n_0} \right)^{\eta}$$

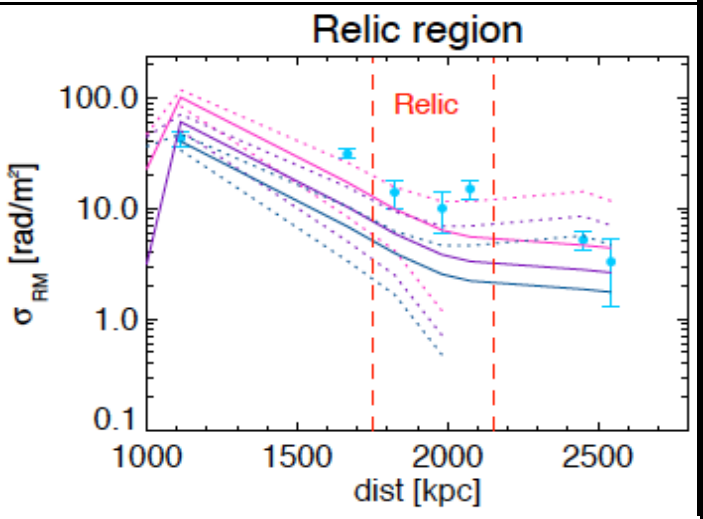
$B_{0,g}$=5μG, η=0.2
$B_{0,g}$=5μG, η=0.3
$B_{0,g}$=5μG, η=0.5



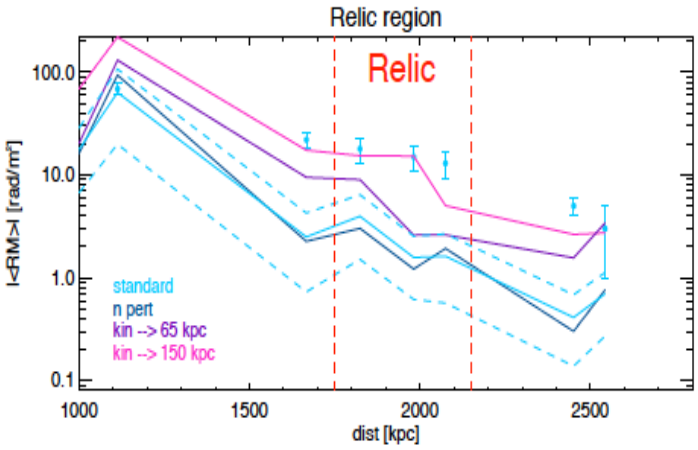


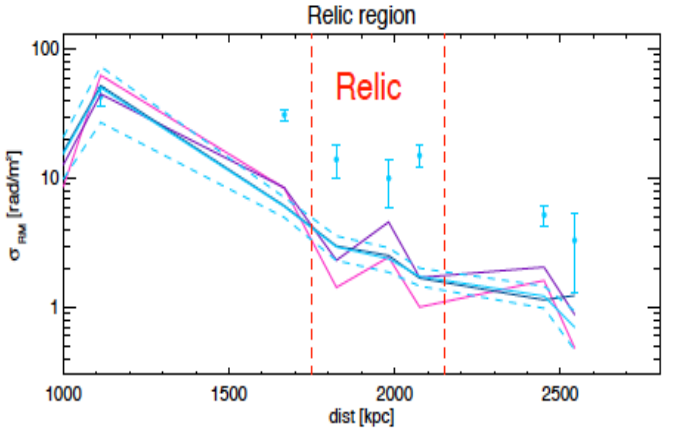
$B_{0,g}$=5μG, η=0.2
$B_{0,g}$=3μG, η=0.2
$B_{0,g}$=2μG, η=0.2





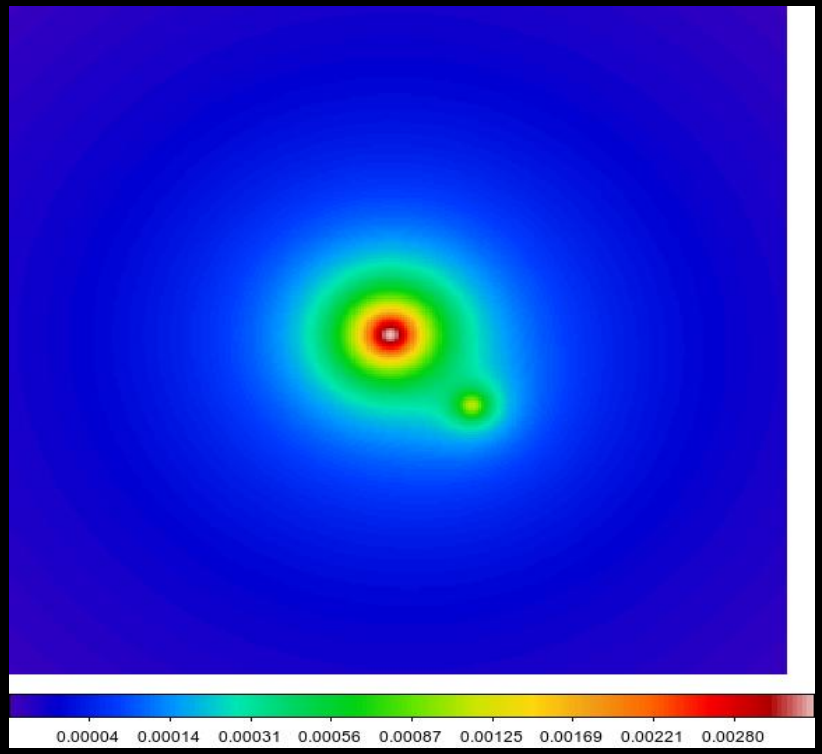
standard
n pert
kin --> 65 kpc
kin --> 150 kpc





New code for Mock RM observations

The gas component:



Gas model:
2 isothermal gas sphere (clusters) in equilibrium

The 3D magnetic field model:

- power spectrum for the vector potential A in the Fourier space

$$P_B(k) = |A_k|^2 \propto k^{-n}. \qquad k_{in} \leqslant k \leqslant k_{out}$$

- the resulting magnetic field has:

$$\nabla \cdot \vec{B} = 0 \qquad |B_k|^2 \propto k^{-n}$$

- B is normalized to follow the gas density

$$B(r) = B_0 \left(\frac{n_e}{n_0} \right)^{\eta}$$