

# Polarization, magnetic fields and radio galaxies in galaxy clusters

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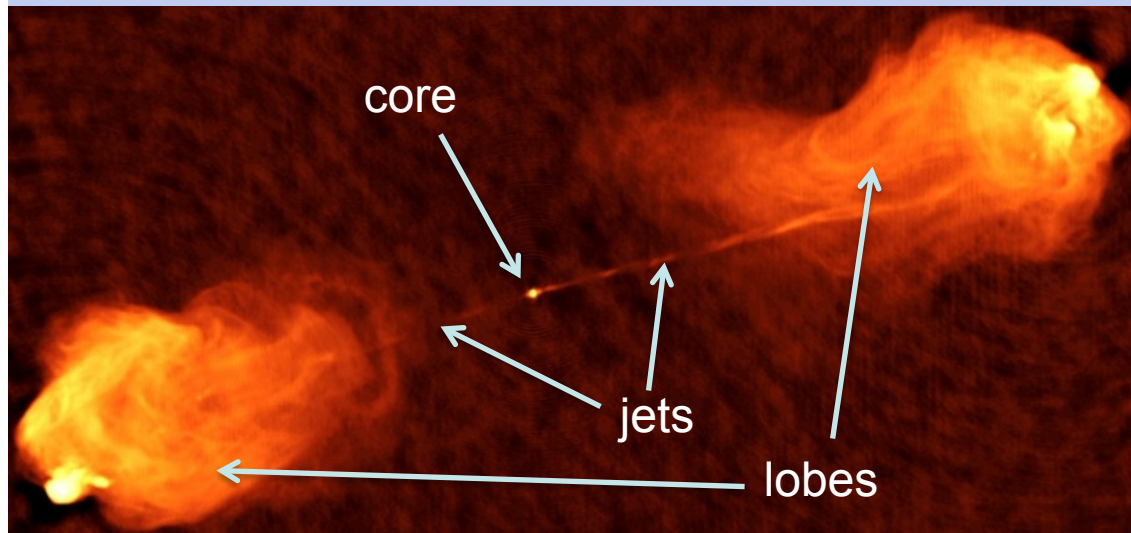
# Outline

- Part 1: Introduction
- Part 2: Perseus cluster
- Part 3: Centaurus cluster
- Part 4: MACS J0717.5+3745 cluster

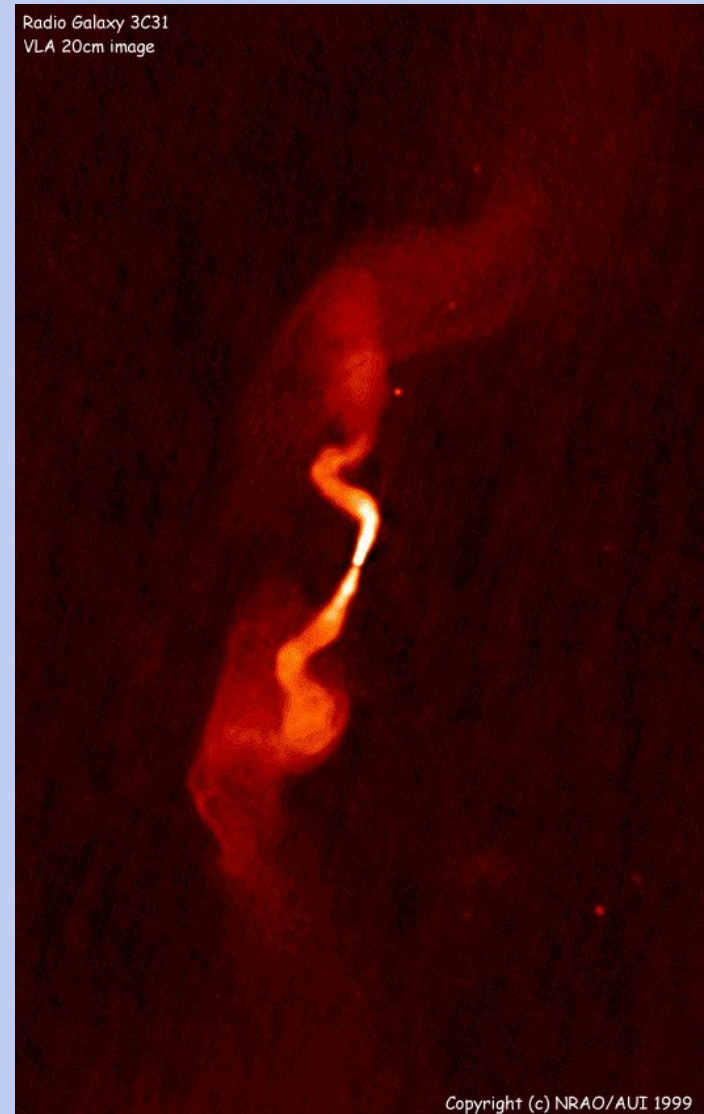
Part 1:

Introduction

# Radio galaxies



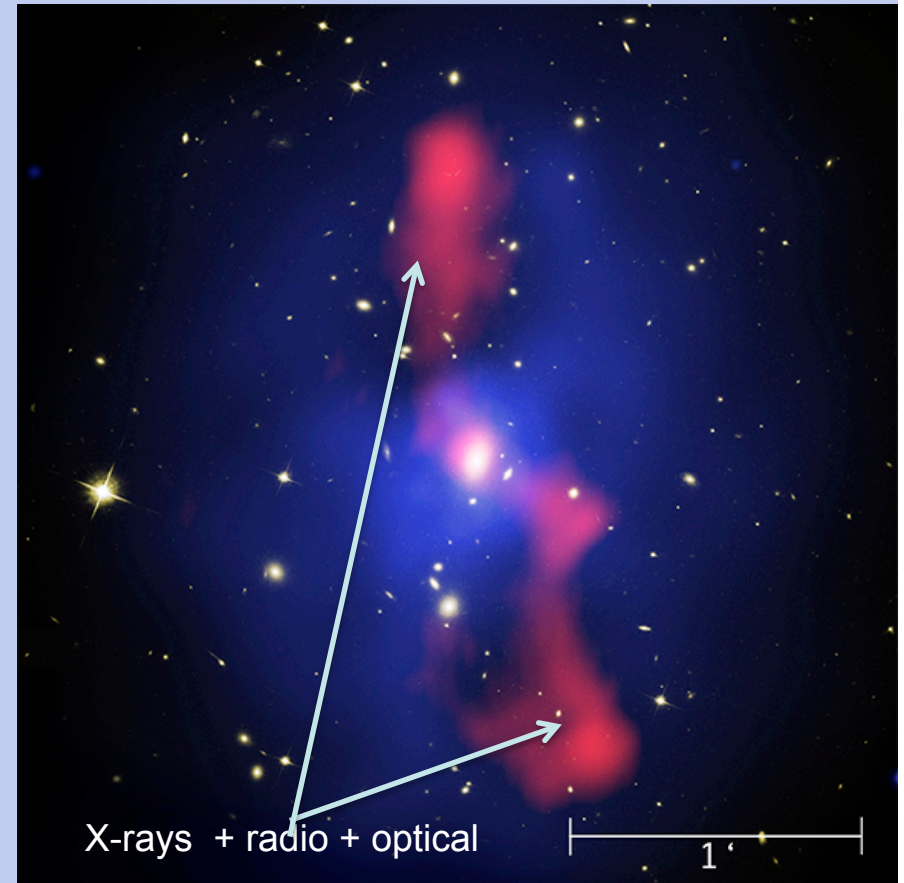
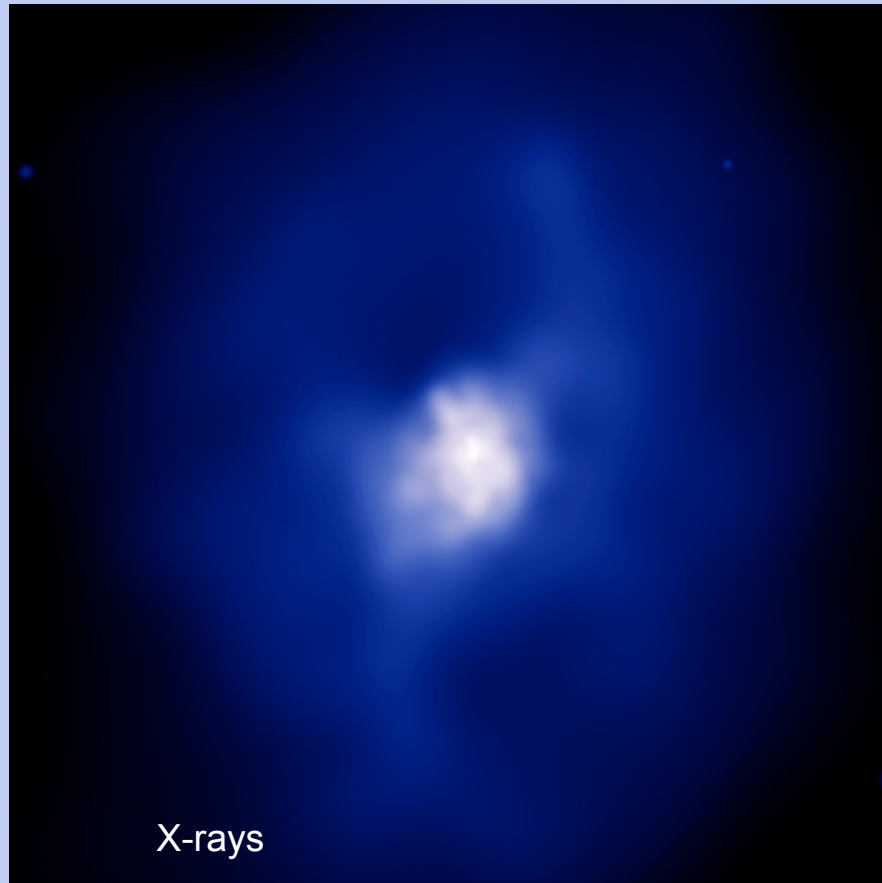
R. Perley, C. Carilli & J. Dreher, NRAO/AUI



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Radio galaxies come in all kinds of shapes

# Radio galaxies in galaxy clusters



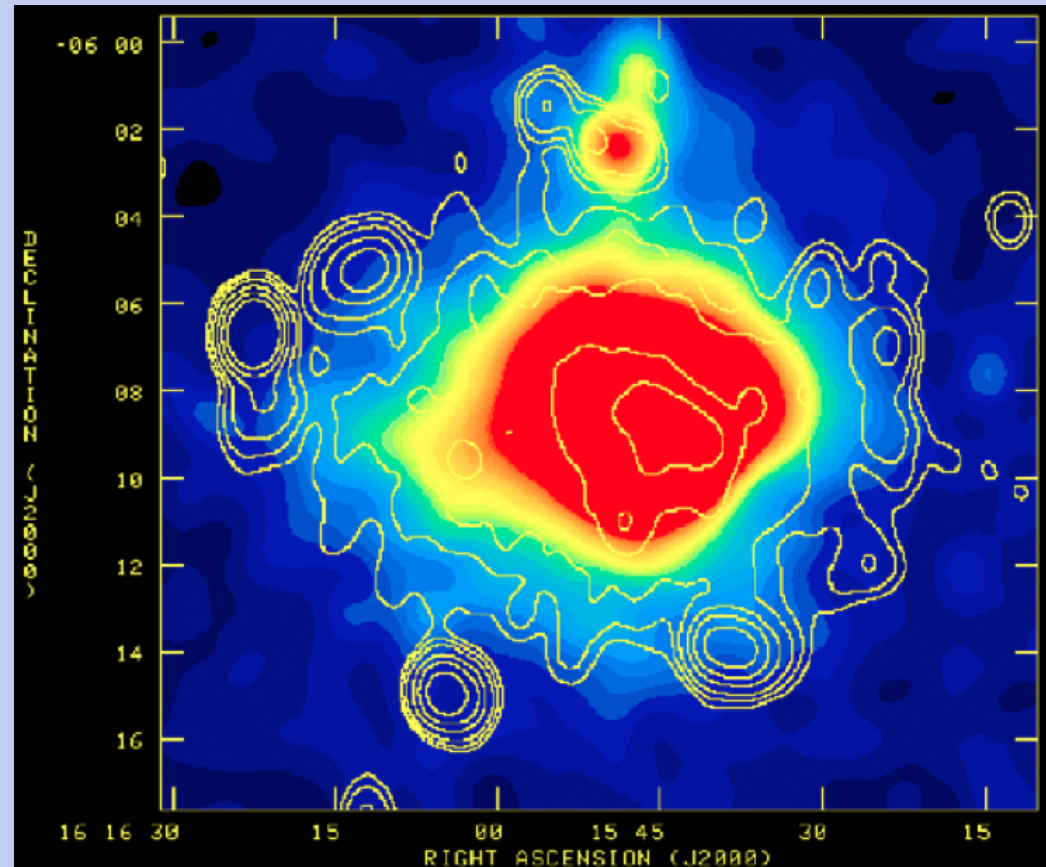
Galaxy cluster MS 0735.6+7421  
NASA/CXC/Univ. Waterloo/B.McNamara/Birzan

Radio lobes fill the cavities blown by the radio jets

# Radio halos

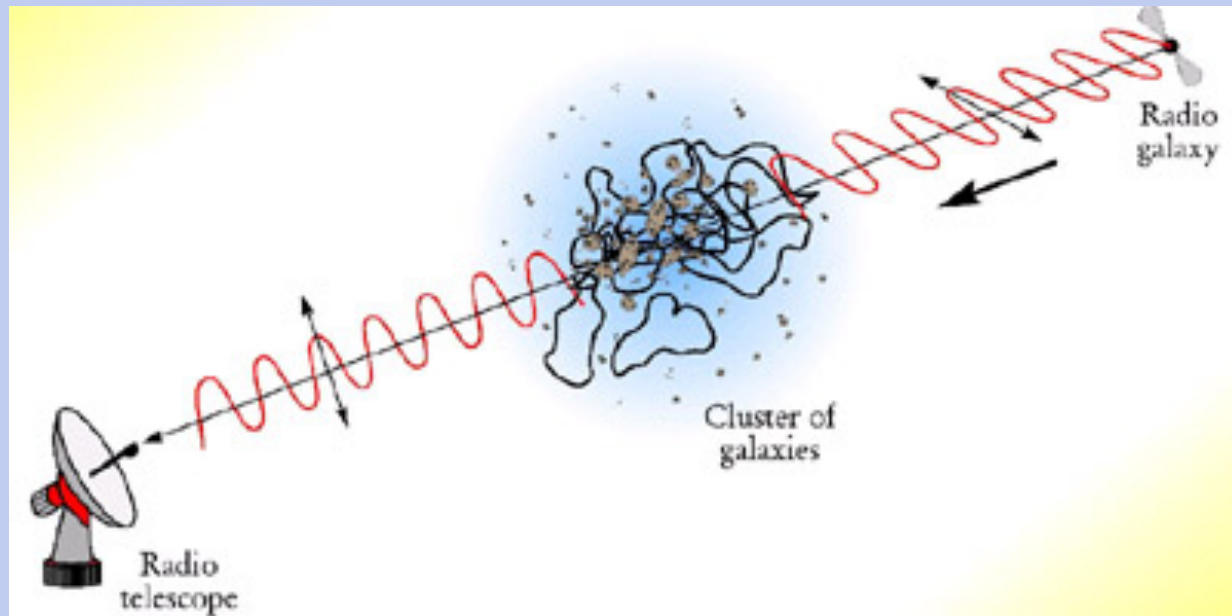
Radio halo:

- Diffuse radio emission in a cluster
- Not associated to individual galaxy
- Signature of merger of clusters



Galaxy cluster Abell 2163  
Contours: radio – Colour scale: X-rays  
Feretti et al. (2001)

# Rotation measure



Kronberg 2002

$$\frac{\Delta\psi}{\text{rad}} \propto \lambda^2 \int n_e H_{\parallel} dl = \lambda^2 \times (RM)$$

Observ. at different frequencies → rotation measure

→ orientation of electric and magnetic field

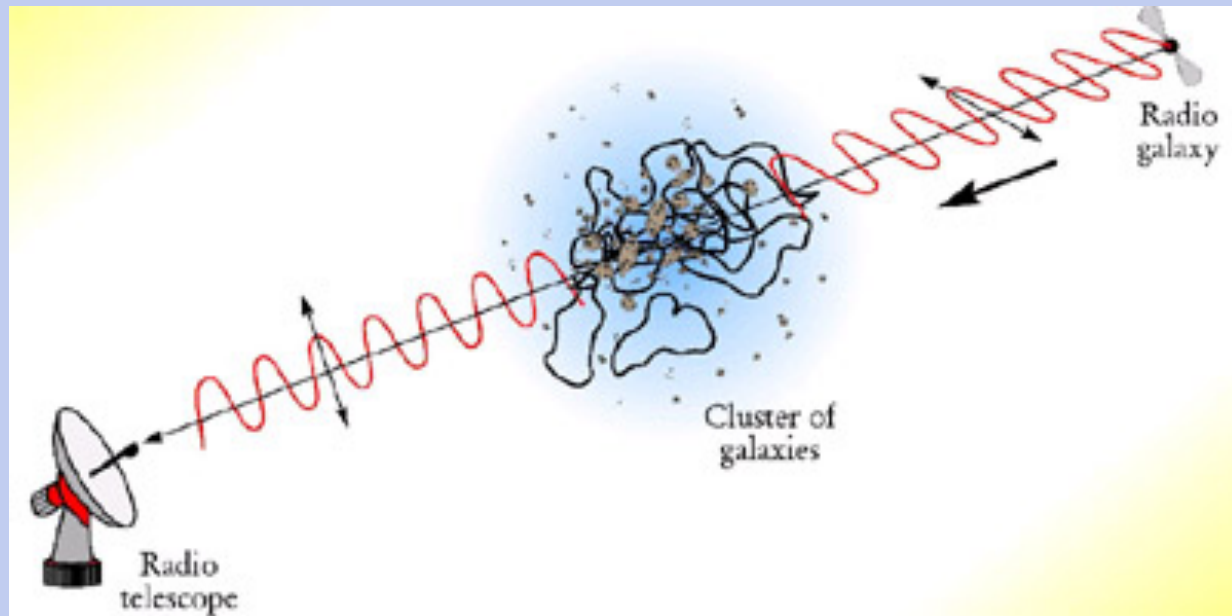
→ from assumptions on  $n_e$  → intensity of magn. field

# Rotation measure





# Rotation measure



Kronberg 2002

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Observ. at different frequencies → rotation measure

→ orientation of electric and magnetic field

→ from assumptions on  $n_e$  → intensity of magn. field

Part 2:

Perseus cluster

# Perseus cluster

- Most X-ray luminous cluster in nearby Universe
- Cavities created by radio galaxy Perseus A (aka 3C 84 and NGC 1275)
- Shocks and ripples in the X-ray image

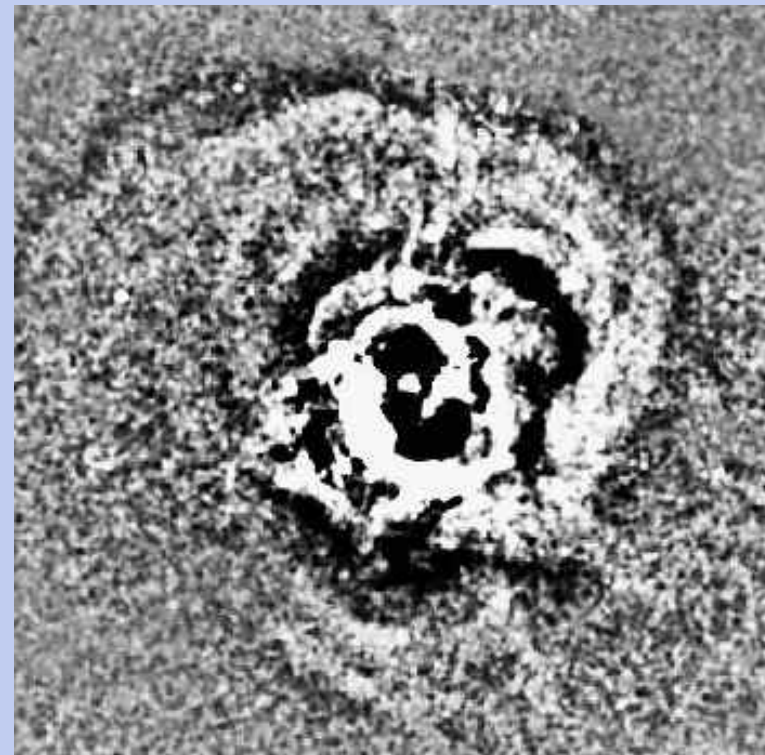
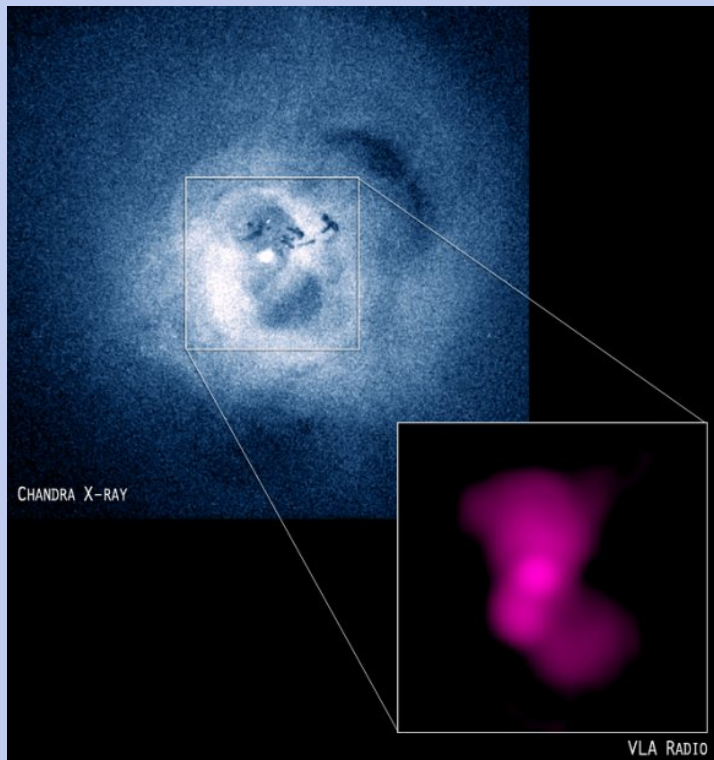
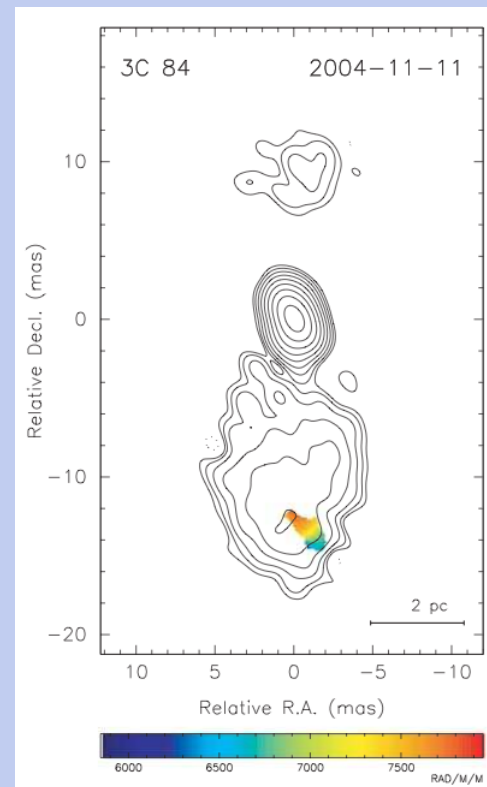
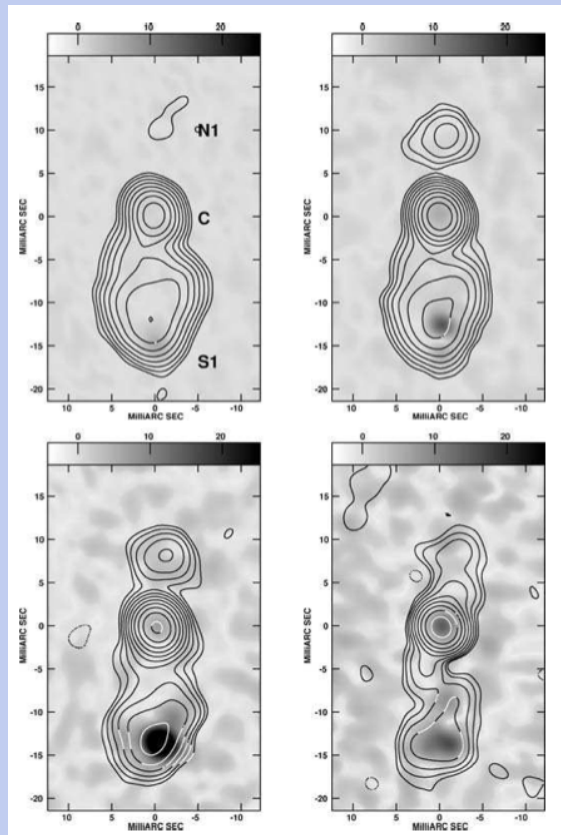


Image courtesy: Chandra

unsharp-masked X-rays

# Perseus cluster

- Taylor et al. (2006):  
Very Large Baseline Array (VLBA) observations at 4 frequencies: 5, 8, 15, 22 GHz  
Including polarisation



Rotation measure  
 $\approx 7000 \text{ rad m}^{-2}$   
(high)

Gradient  $\approx 10\%$   
on scales  $\approx 1 \text{ pc}$

greyscale: lin. pol.; contours: total intensity  
maps:  $\approx 40 \times 25 \text{ mas} \approx 14 \times 9 \text{ pc}$

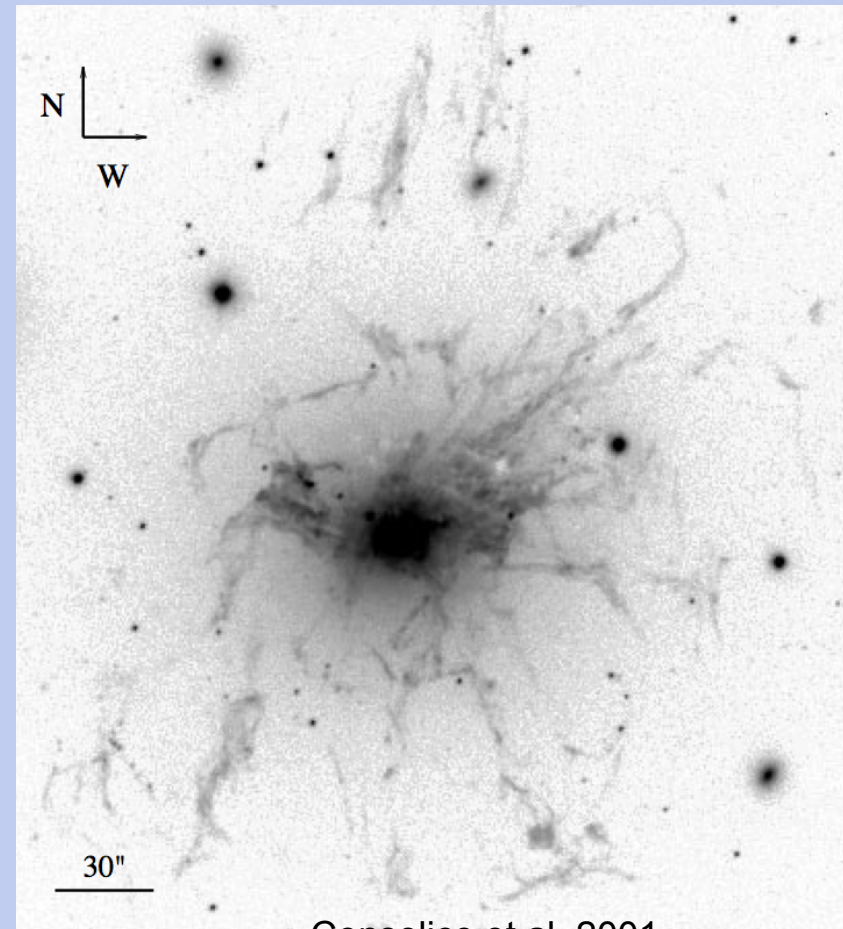
# Perseus cluster

- Taylor et al. (2006):

To explain gradient on such small scales:

Faraday screen: consistent with  
ionized gas filaments

Magnetic fields organised on scales  $< 10$  pc



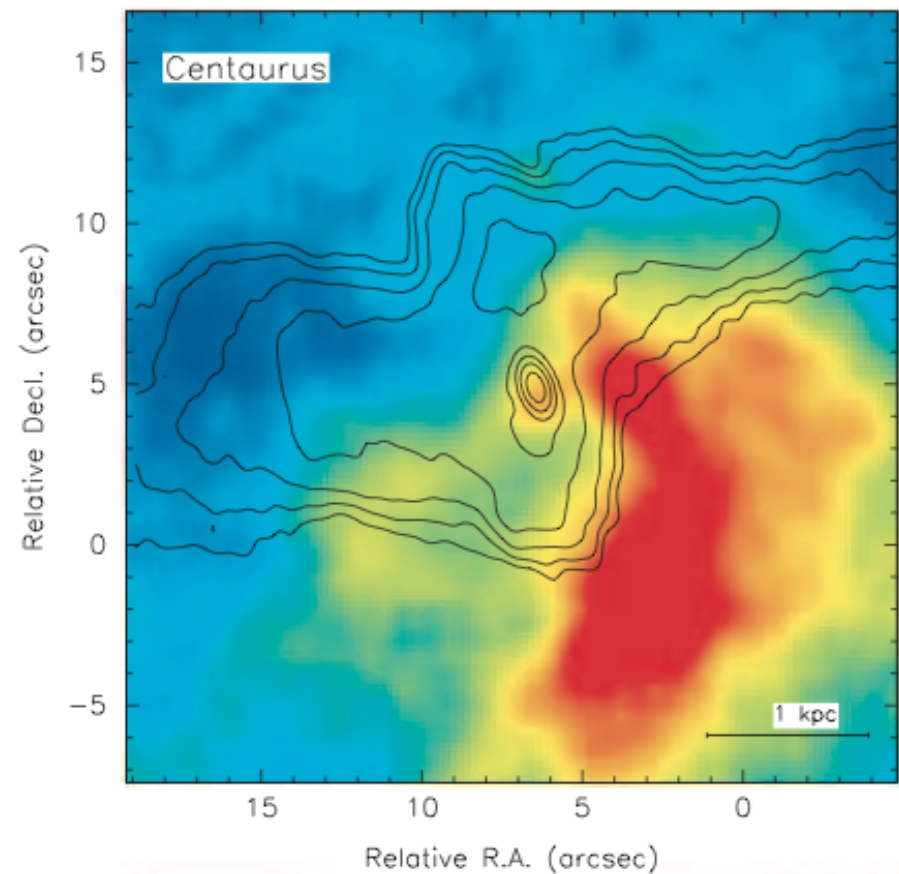
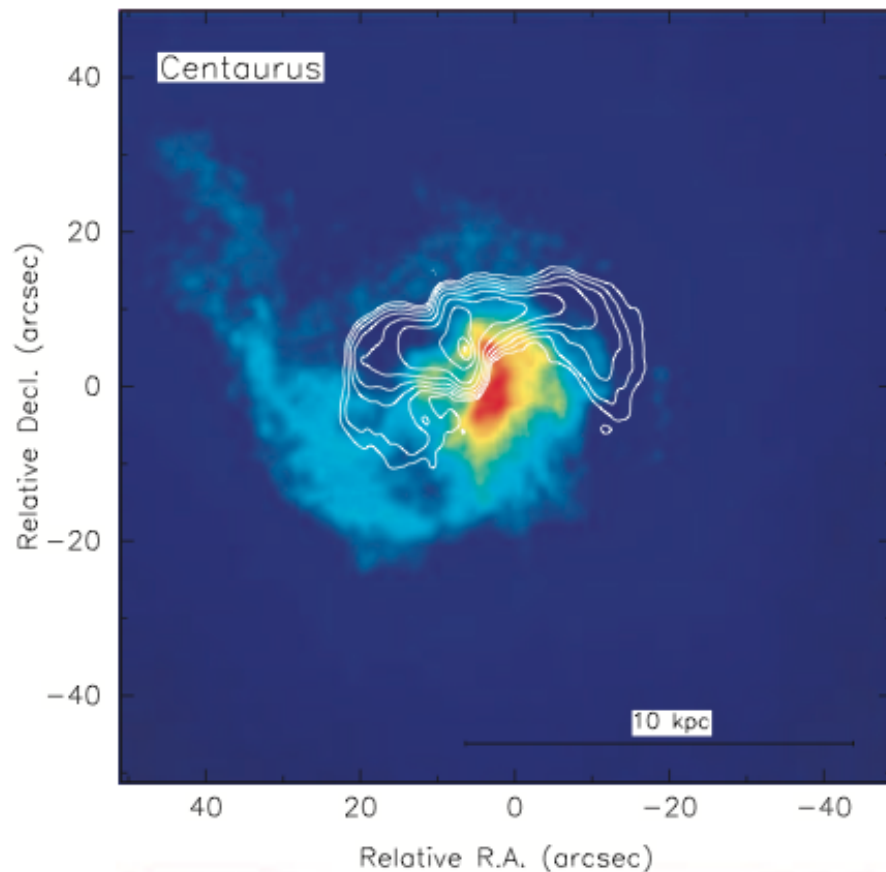
Conselice et al. 2001

Part 3:

Centaurus cluster

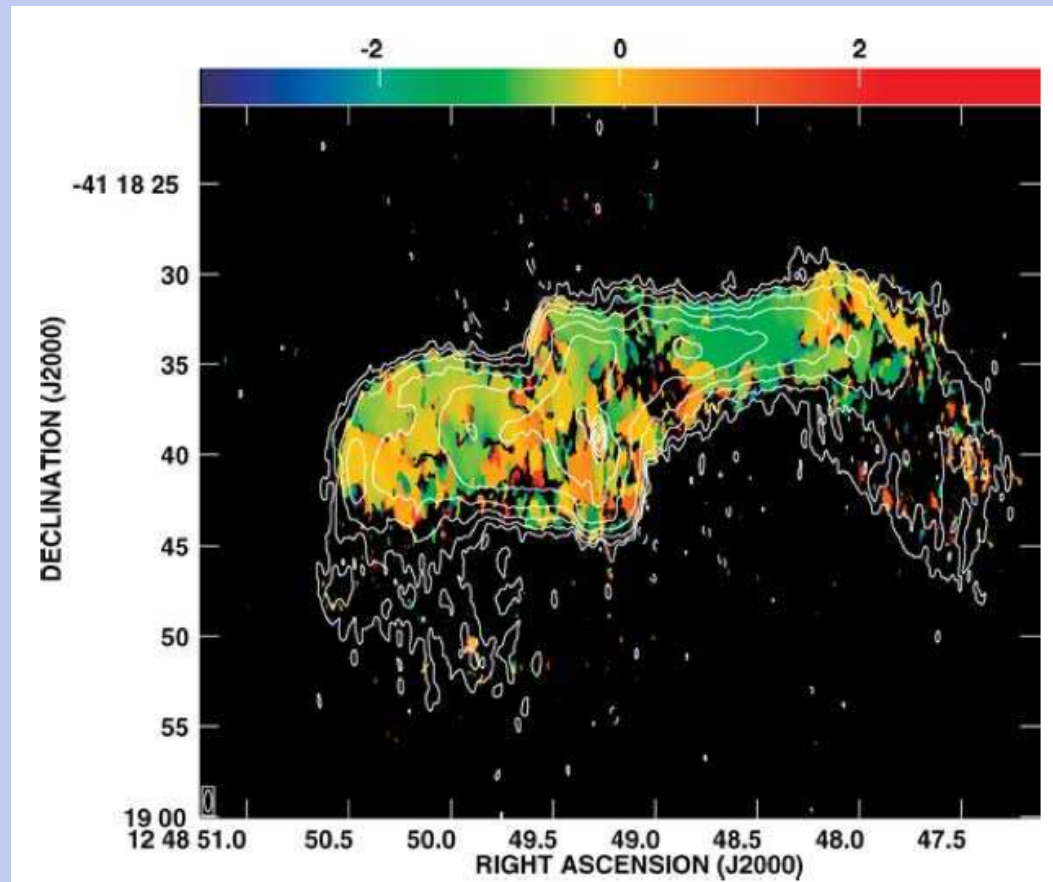
# Centaurus cluster

- Nearby X-ray bright galaxy cluster
- Complex interaction between X-rays and radio galaxy PDS 1246-410 (NGC 4696)



# Centaurus cluster

- Taylor et al. (2007): Very Large Array (VLA) observations at 5 and 8 GHz – A array



beam: 1.2 x 0.4 arcsec (250 x 80 pc)

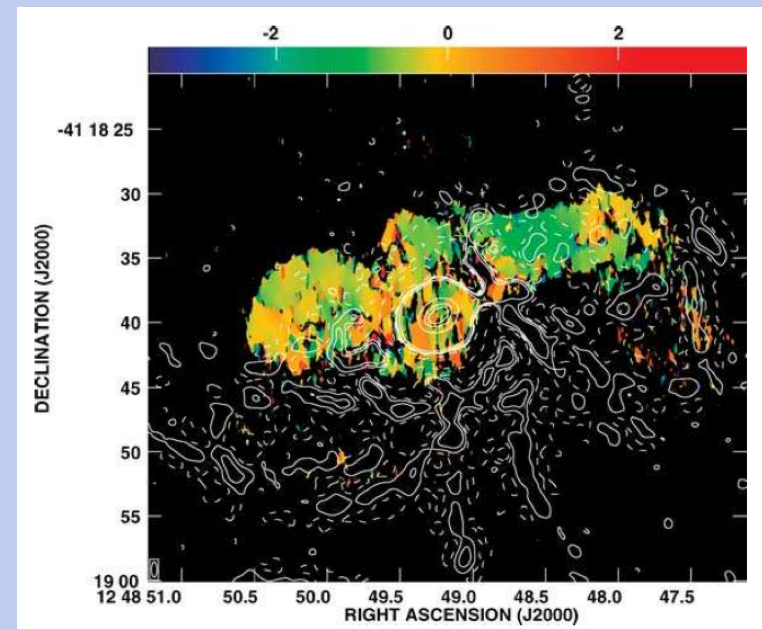
Colours: rotation measure – Contours: total intensity



# Centaurus cluster

- 400 pc: typical size of regions where
  - rotation measure is enhanced
  - rotation measure gradients are enhanced
  - fractional polarization is reduced

Polarized gas filaments not responsible:  
scales too small:  
complete depolarisation would be seen

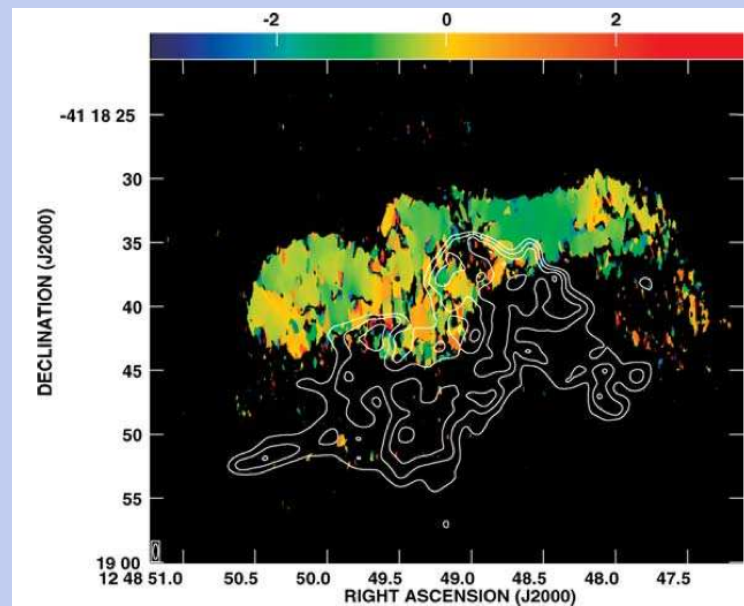


# Centaurus cluster

- 400 pc: typical size of regions where
  - rotation measure is enhanced
  - rotation measure gradients are enhanced
  - fractional polarization is reduced

Soft X-rays: ok

Required magnetic field for enhancement  $\approx 25 \mu\text{G} \approx$  equipartition inside the lobes



Part 4:

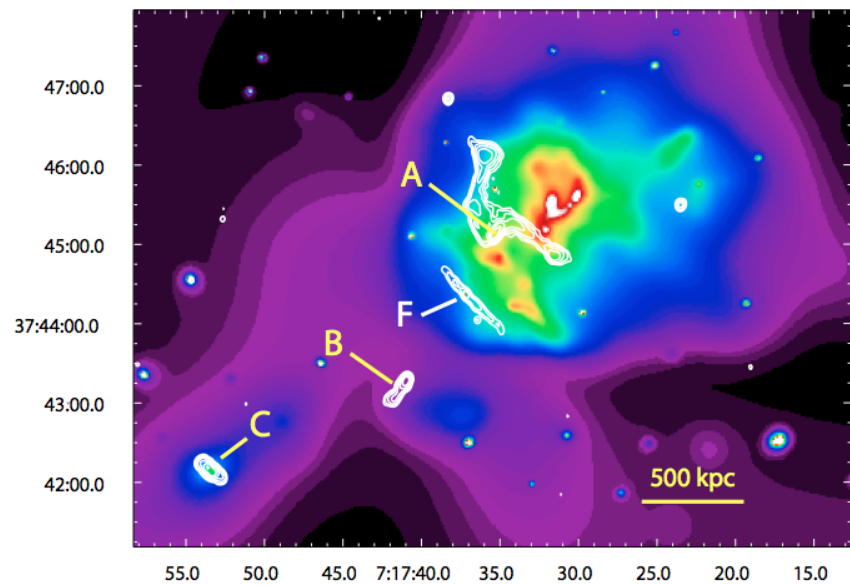
MACS J0717.5+3745

# MACS J0717.5+3745 cluster

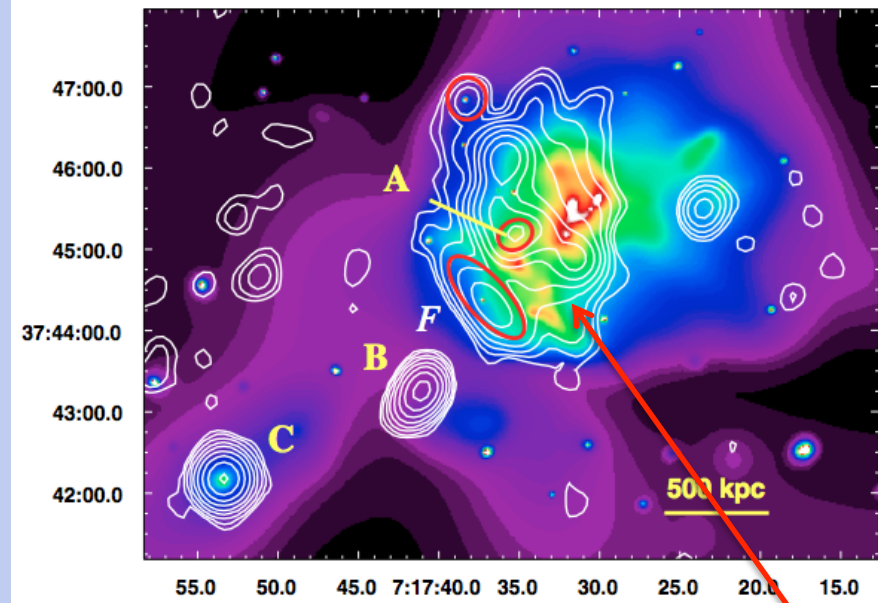
- $z = 0.55$
- Very complex system: one of the most disturbed systems
- New radio data at 1.4 and 5 GHz with the VLA (B, C, and D arrays)

Colours: X-rays

Contours: radio 1.4 GHz (source "F": foreground source)



high resolution radio



low resolution radio (→ diffuse radio halo)

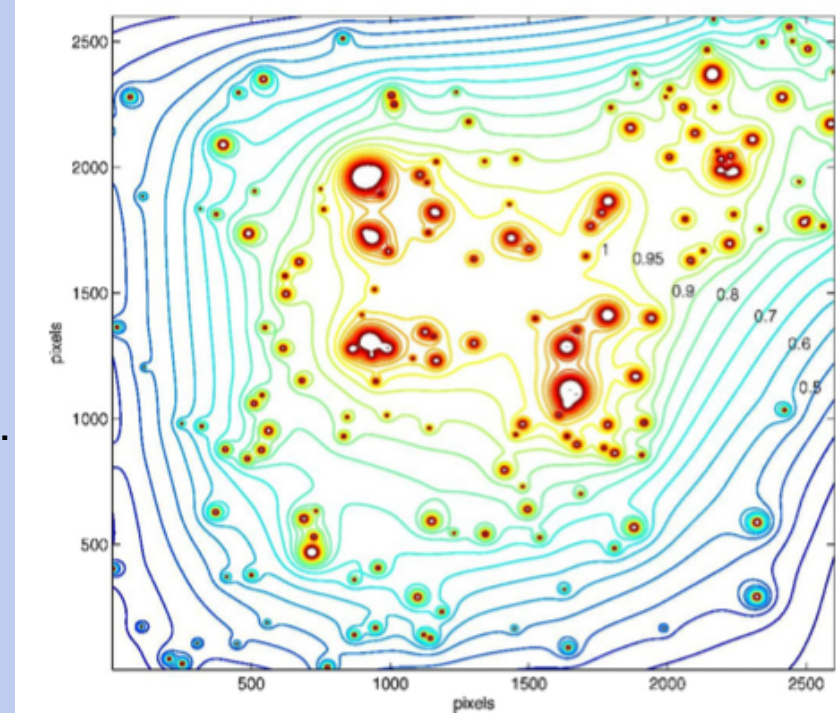
# MACS J0717.5+3745 cluster

- Lensing  $\rightarrow$  mass distribution  $\rightarrow$  Most massive system in  $0.5 < z < 1.0$  range ( $\approx 10^{15} M_{\text{sol}}$ )

- Is such a high mass expected in  $\Lambda$ CDM?

Zitrin et al. (2009): probability  $\approx 10^{-7}$

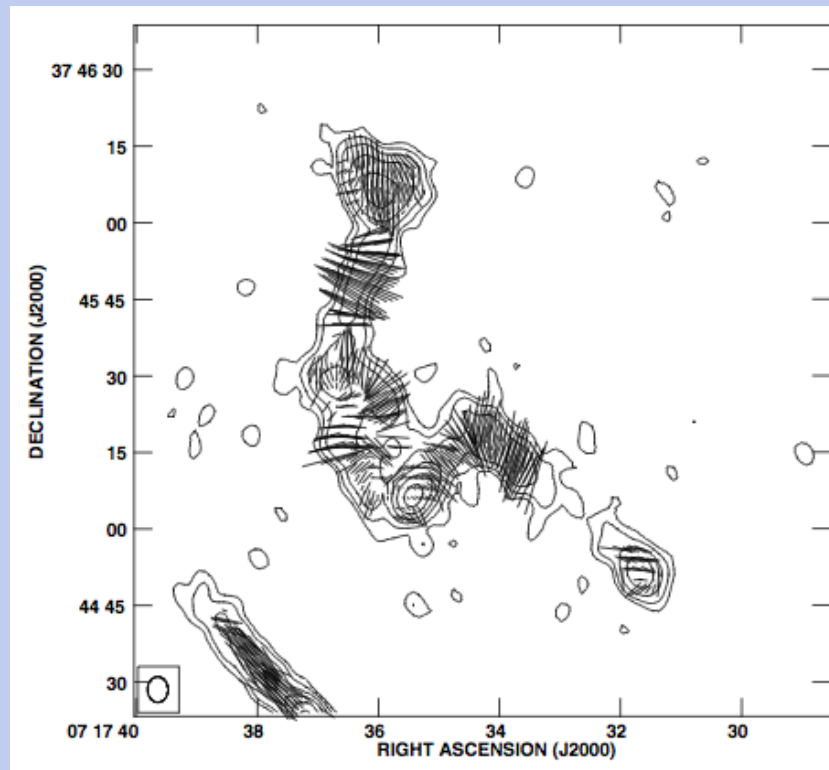
Waizmann et al. (2012): probability  $\approx 0.11$ - $0.42$   
accounting for uncertainties on cosmolog. param.



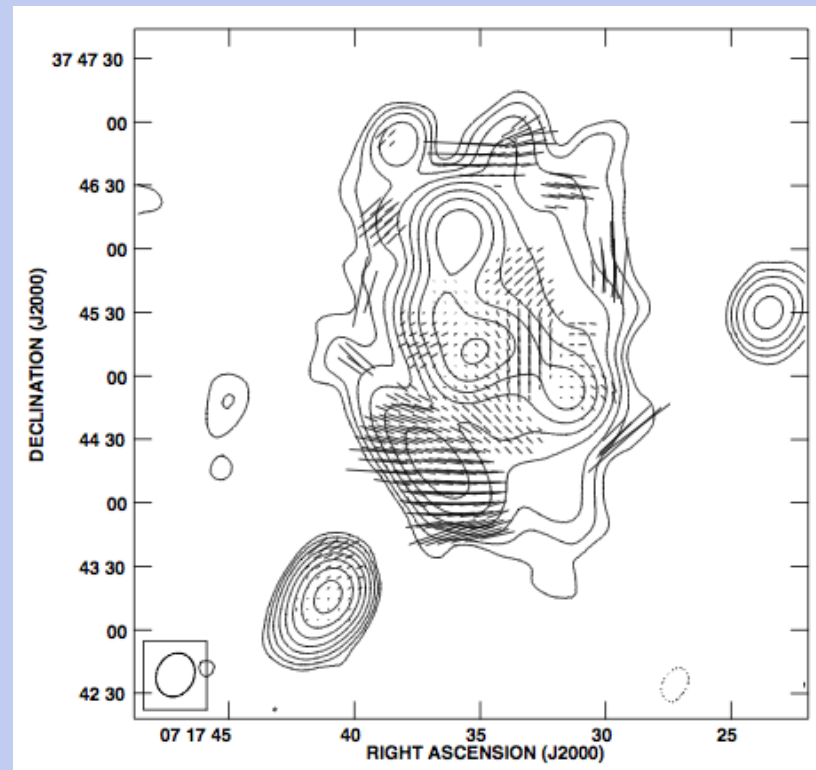
$\approx 150$  kpc  
Zitrin et al. 2009

# MACS J0717.5+3745 cluster

- Radio halo: radio power:  $1.6 \times 10^{26} \text{ W Hz}^{-1}$ : most powerful observed
- Polarised emission from diffuse radio halo  $\rightarrow$  magn. field organised on large scales
- Structure A: filament or relic? Filament: continuity of polarisation emission between structure A and diffuse halo



high resolution



low resolution

# Conclusions

- Perseus cluster: small-scale (10 pc) rotation measure gradients  
→ Faraday screen: ionised gas filaments?
- Centaurus cluster: larger-scale (400 pc) rotation measure structures:  
→ Faraday screen: X-ray gas?
- MACS J0717.5+3745 cluster:
  - one of the most disturbed systems (merger of 4 subclusters?)
  - very powerful radio halo
  - polarised emission from the radio halo → magnetic field fluctuates  
on scales  $\approx 130$  kpc