Radio emission in clusters of galaxies

An observational perspective

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Overview

- What are galaxy clusters
- Radio emission from elliptical galaxies
- Interaction between cluster radio galaxies and external medium
  - morphologies and statistical properties
  - central radio galaxies
  - restarted and dying radio sources
- Diffuse cluster scale radio emission
  - morphologies and observational properties of halos and relics
  - statistical properties of radio halos

What are galaxy clusters

Largest gravitationally bound systems in the Universe

Galaxy cluster constituents

Galaxies: ~5%

($\sim 10^{13} - 10^{15}$ M_{Sun})

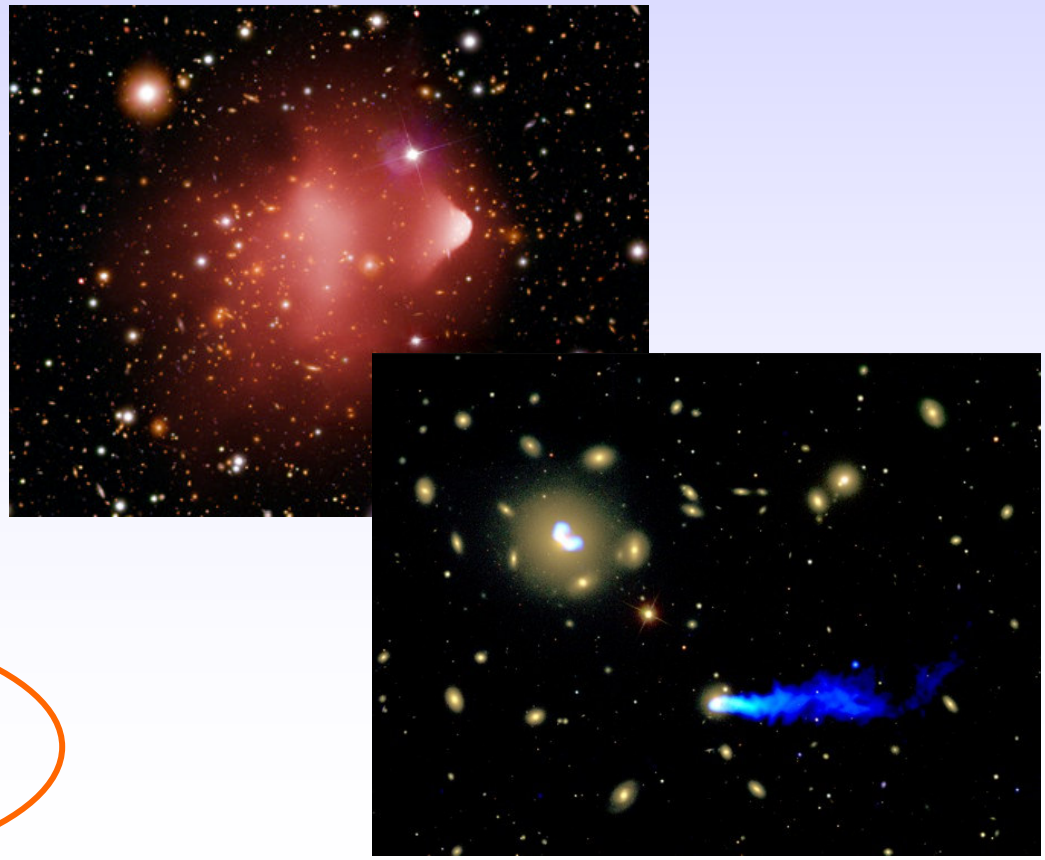
Dense and hot gas: ~ 15%

- $\rho_0 \sim 10^{-3}$ part/cm^3
- $T \sim 5 - 8 \times 10^7$ K
- $L_x \sim 10^{44} - 10^{45}$ erg/s
- $M_{gas} \sim 10^{14} - 10^{15}$ M_{Sun}

Dark matter ~80%

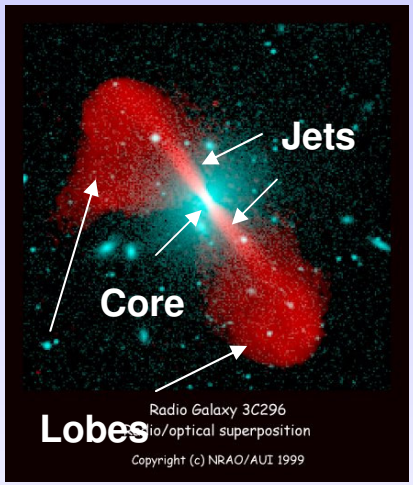
Non-thermal radio emission

- radio galaxies
- diffuse cluster sources



Radio emission from elliptical galaxies

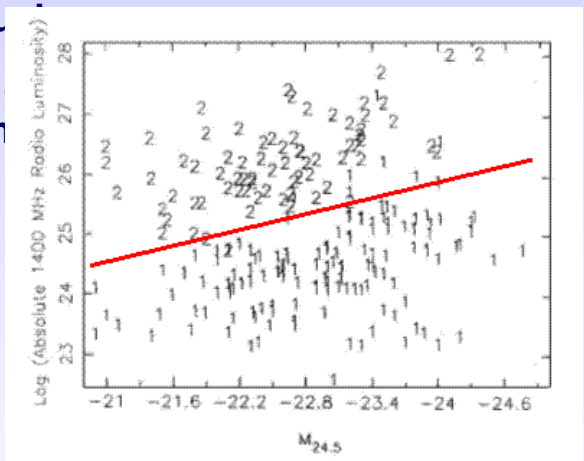
Active Galactic Nuclei

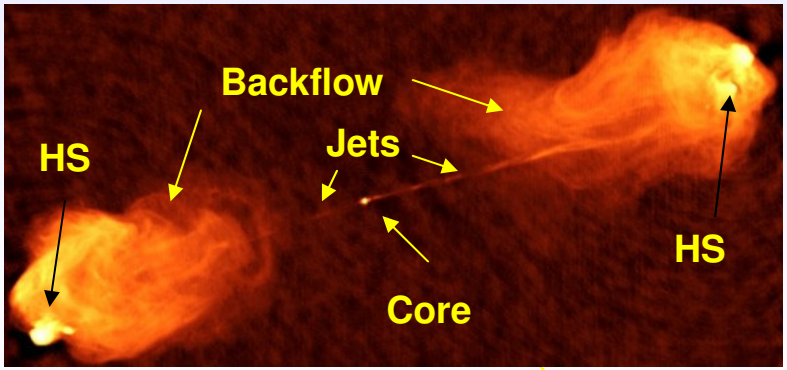


FRI: $\log P_{1.4GHz} \leq 24.5$ W/Hz

Central core coincident with optical nu

Visible straight symmetric jets, which
lose collimation and expand to form th





FRII: $\log P_{1.4GHz} \geq 24.5$ W/Hz

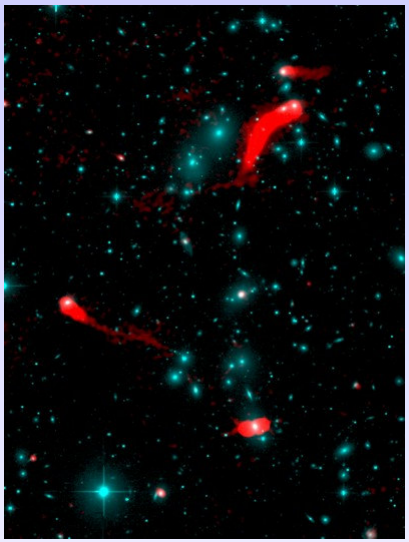
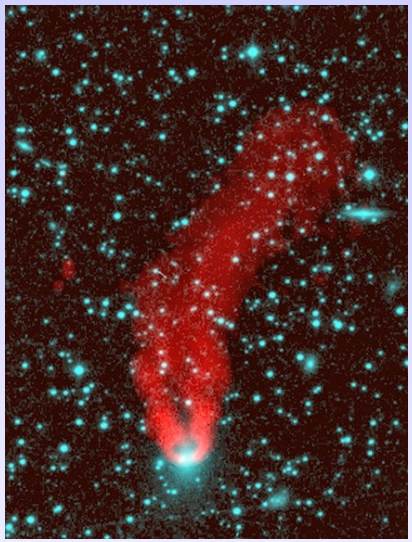
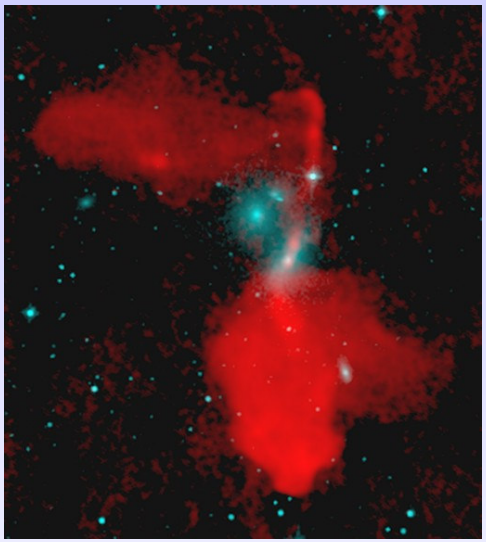
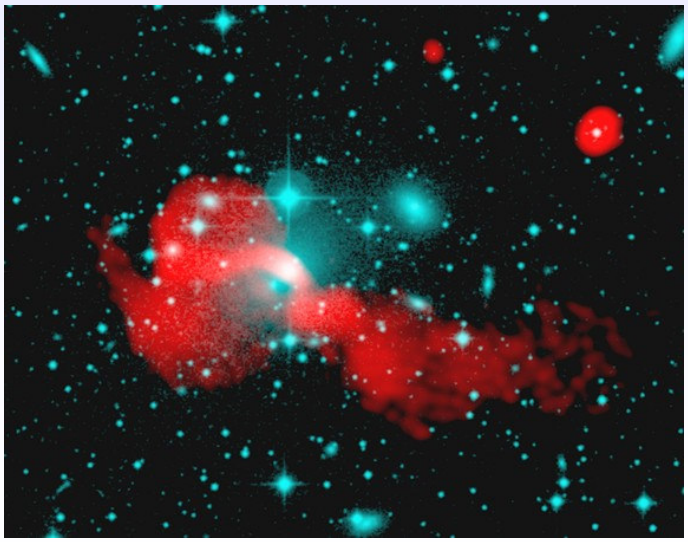
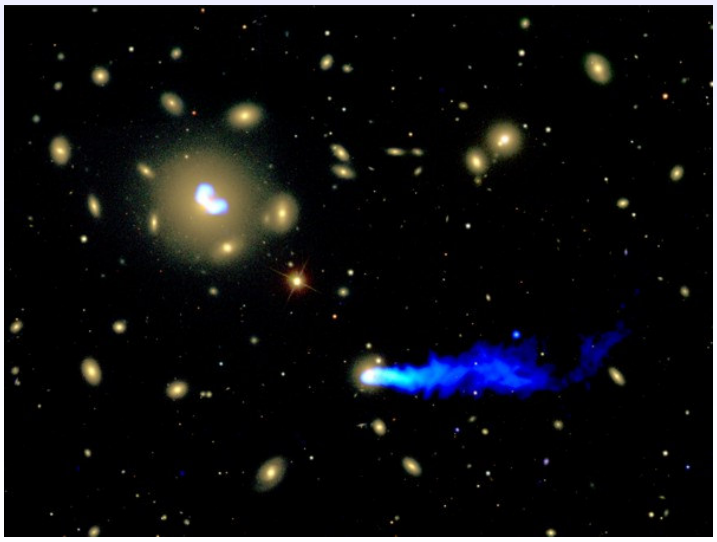
Central core coincident with optical nucleus

Straight asymmetric jets which culminate in compact high surface brightness regions (hot spots) and extended backflow lobes

Radio Galaxies and Cluster Environment

- Morphology
- Statistical properties
- Confinement of extended emission and steep spectrum sources
- AGN – ICM feedback in the central cluster regions and restarted radio galaxies

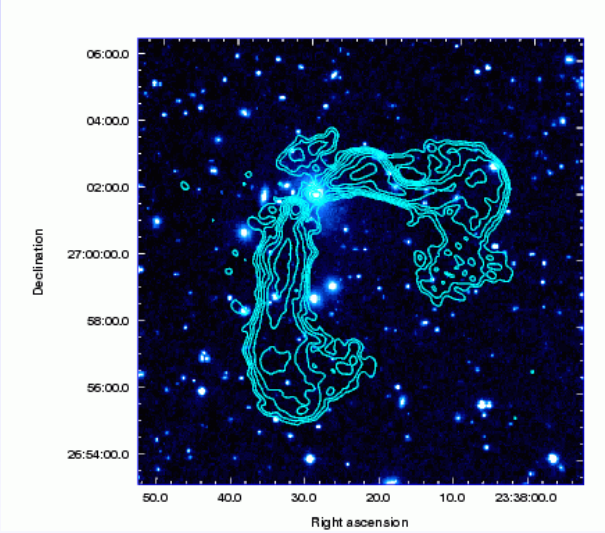
Morphologies of radio galaxies in clusters. I.

Morphologies of radio galaxies in clusters. II.

Deviation from jet straightness

Wide Angle Tail sources



Associated with BCG

Radio power close to the FRI/FRII divide

Slow galaxy motion + “cluster weather”

Narrow Angle Tail sources

Associated with less massive galaxies

FRI radio powers

Optical counterparts with high dispersion velocities

Statistical properties of radio galaxies

Cluster environment:

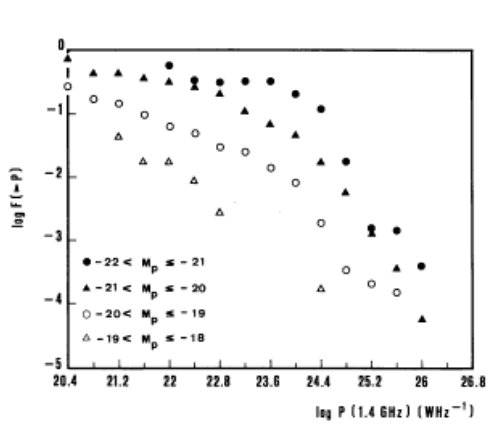
High galaxy density in clusters compared to the field

galaxy-galaxy interaction

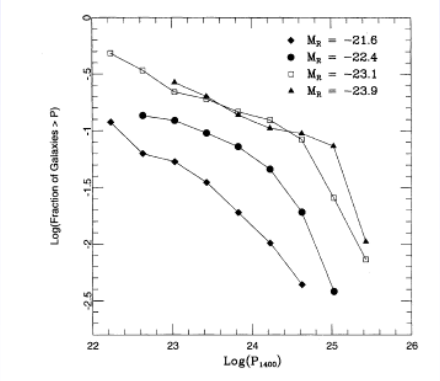
Large scale interaction (cluster merger)

Does this affect the AGN radio luminosity function in ellipticals?

Field galaxies



Auriemma et al. 1977

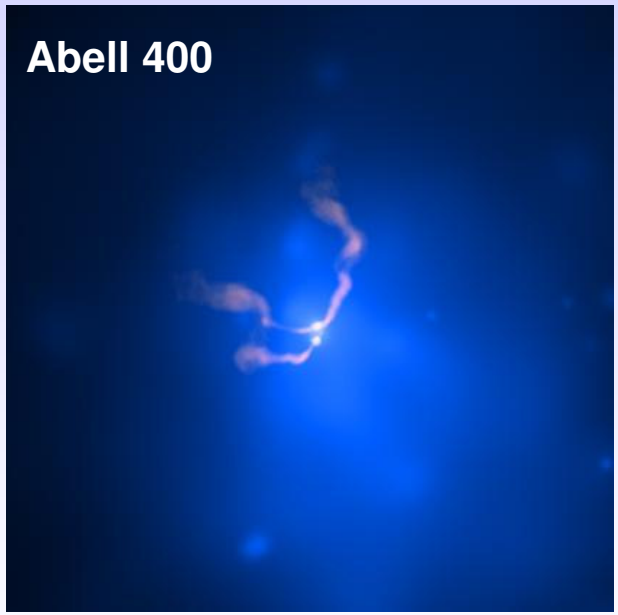


Ledlow & Owen 1996

Cluster galaxies

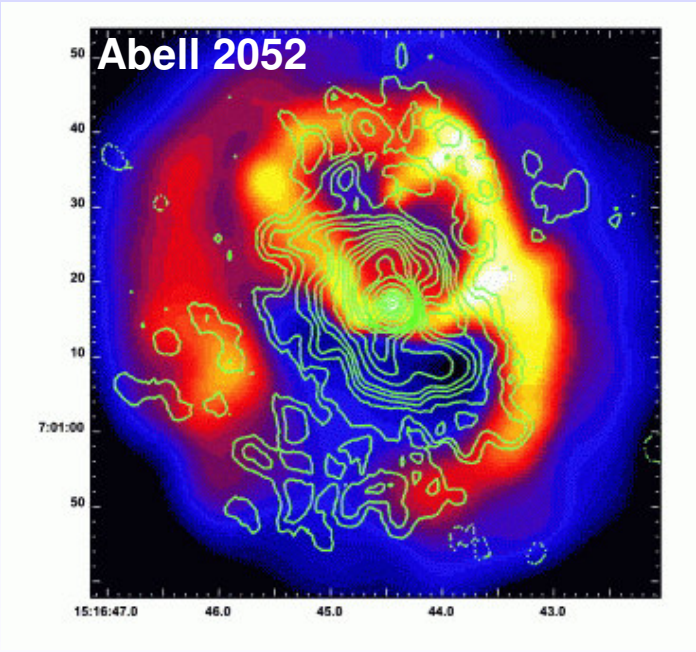
Radio galaxies at the cluster centres

A large fraction of brightest cluster members (BCG) is radio loud (~60%) – Their radio morphology can be broadly divided into two classes:



WATs and extended

Both in cooling and non cooling clusters



Core-Halo radio galaxies

Only in cooling clusters

Radio emission and ICM at the cluster centres know of each other

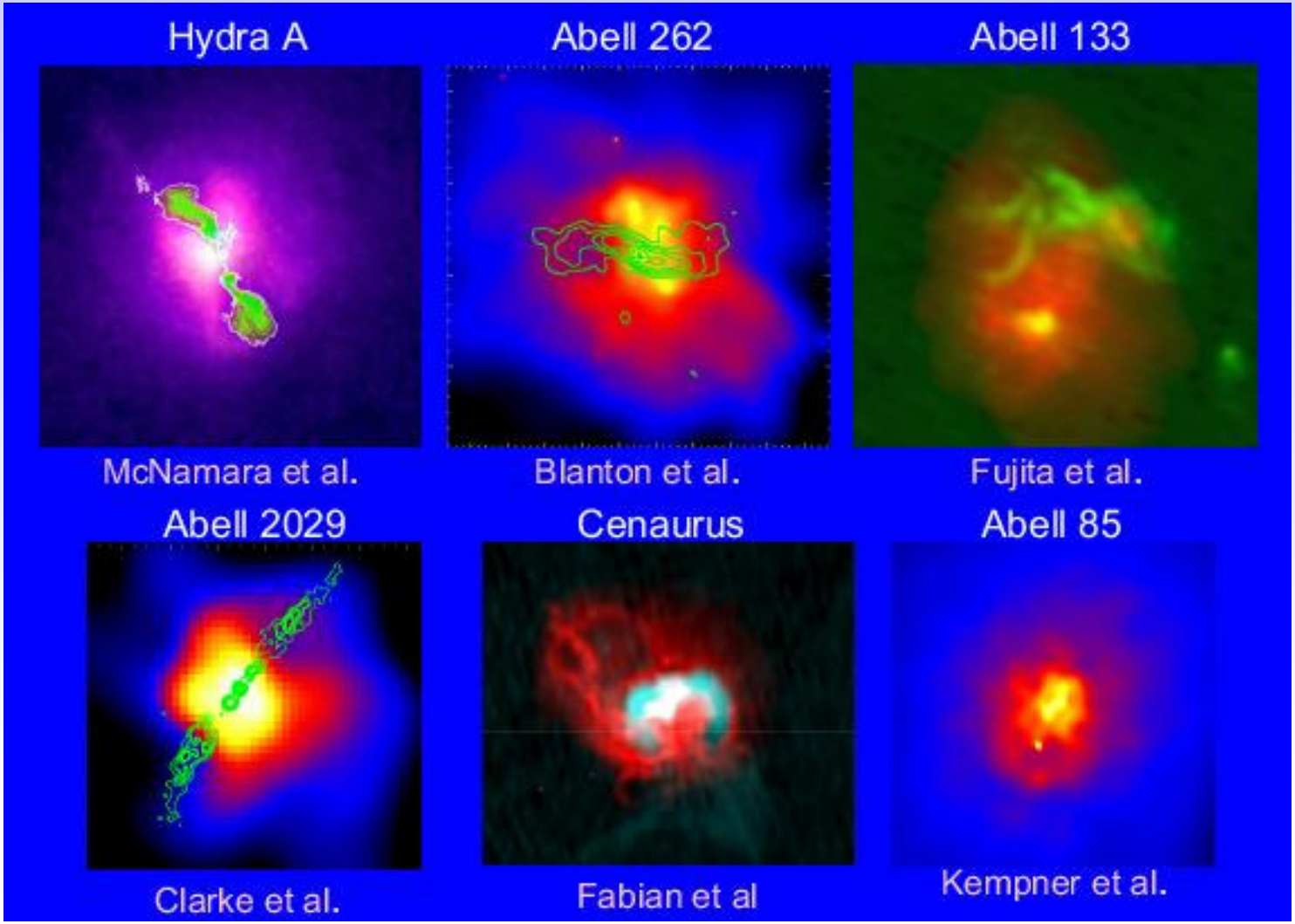


Image from Sararzin et al. 2006

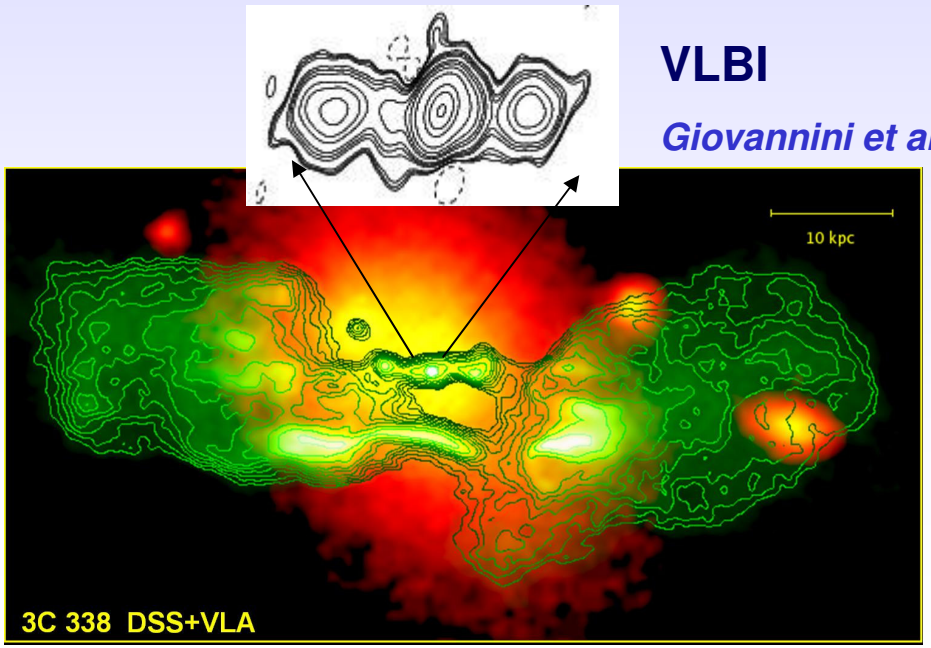
Cycles of AGN radio activity

The detection of cavities in the ICM of a numer of clusters by Chandra, and the following finding that some of these cavities are filled with old (steep spectrum) radio plasma, has triggered the study of a possible connection between cycles of radio activity in the cluster BCG and substructure in the ICM

3C338 in A2199

Multiple

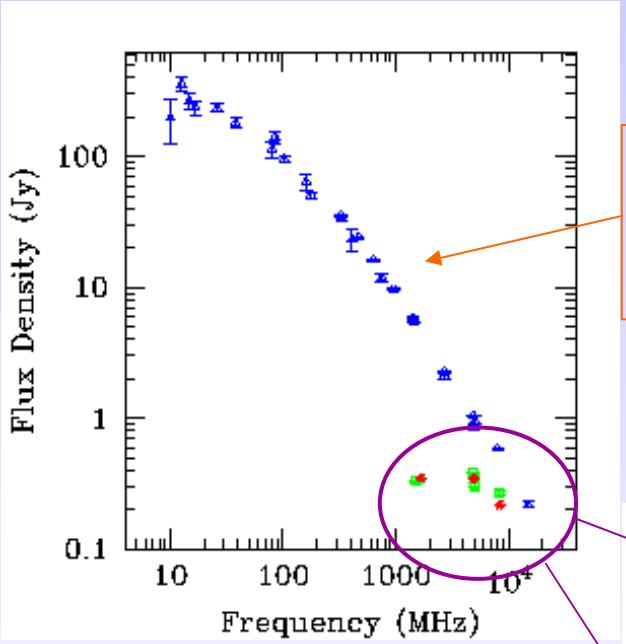
BCG



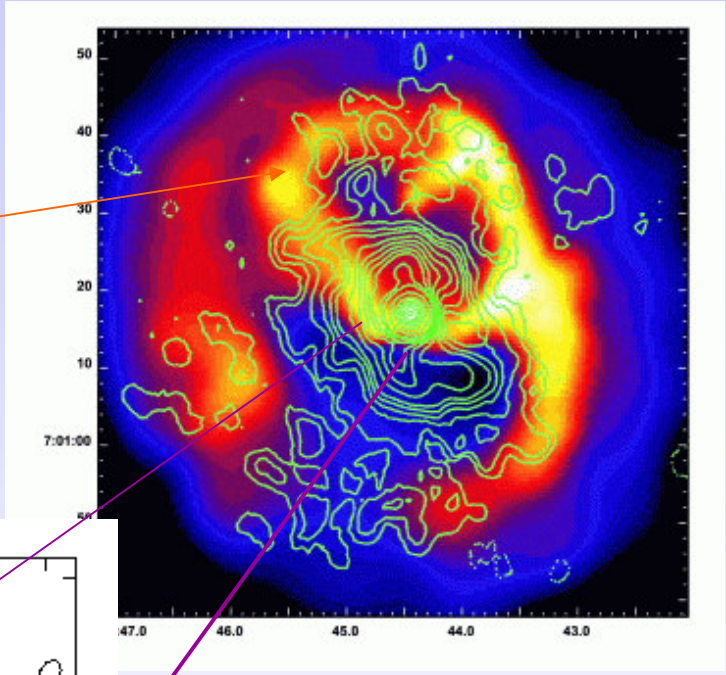
VLBI

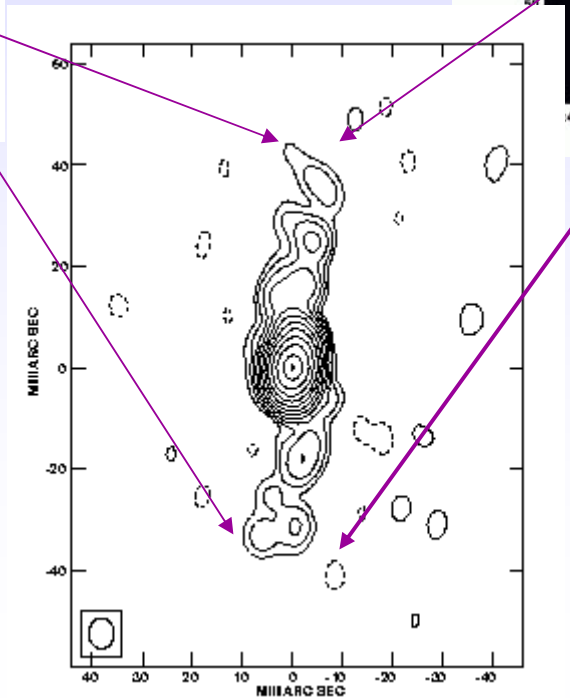
Giovannini et al. 1998

3C317 in A2052



Steep spectrum dominated by the diffuse emission



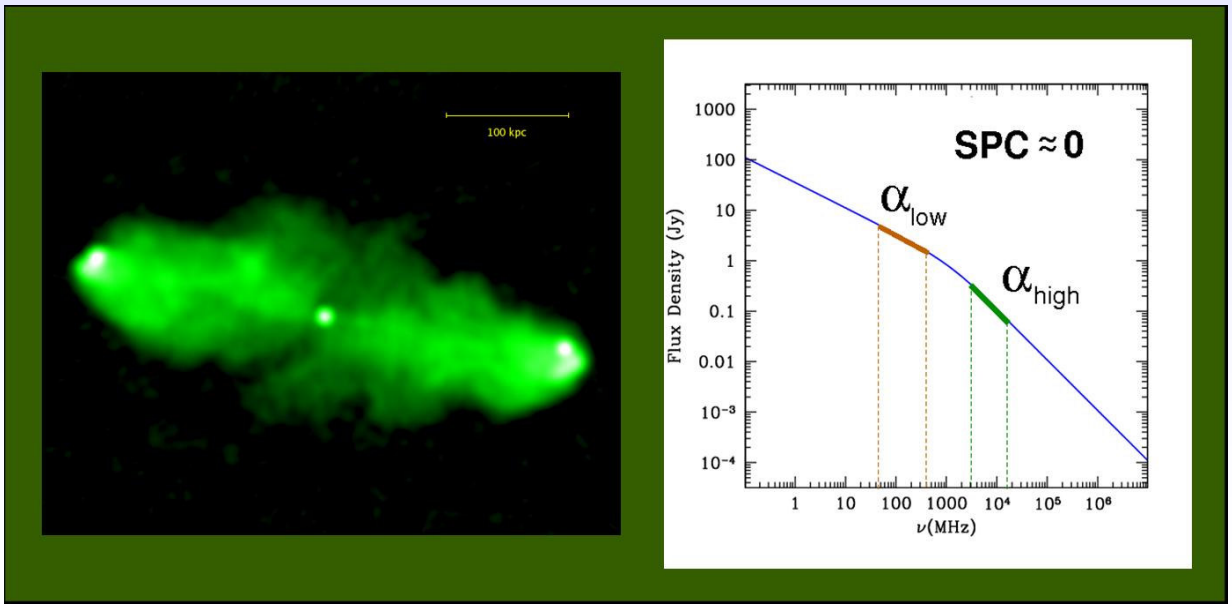


VLBI Active nucleus

Venturi et al. 2004

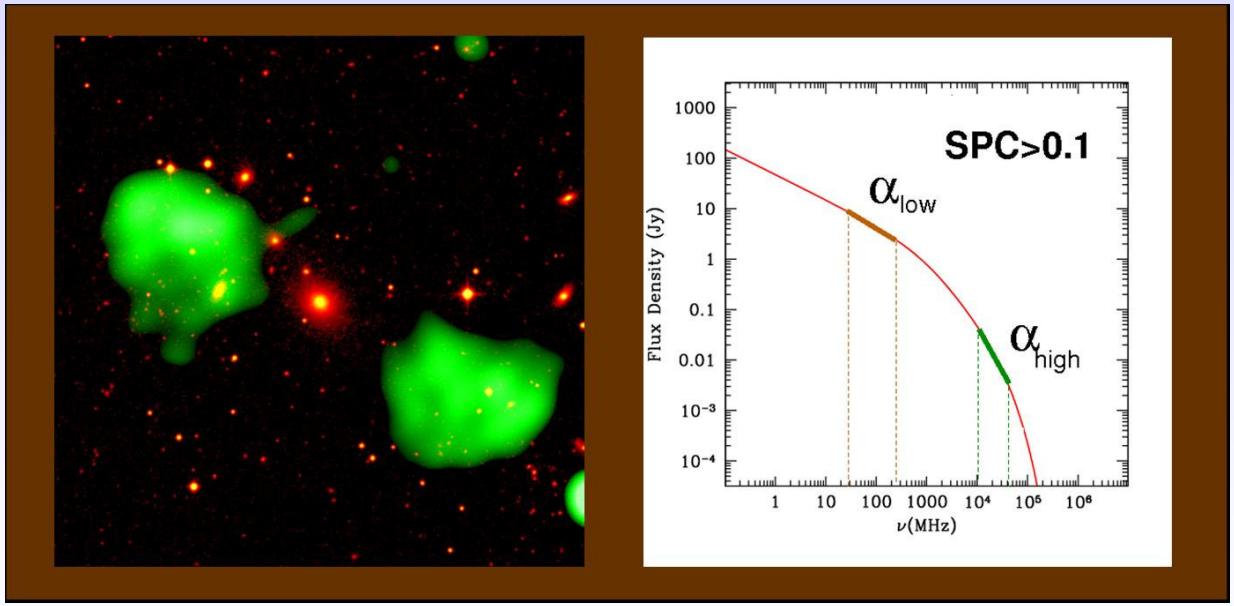
Galaxy cluster environment and late stages in the life of radio galaxies

When the activity in the nucleus stops or decreases to such a low level that the plasma outflow can no longer be sustained, the radio source is expected to undergo a period of fading (the dying phase) before disappearing completely.



Active Galaxy

In the dying phase, the radio core, the jets and the hot spots quicky fade away. On the other hand, the radio lobes may remain detectable for a long time if they are subject only to radiative losses.



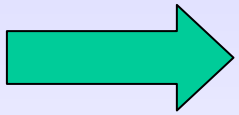
Dying

Radio Source

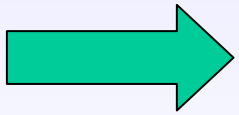
Only few sources in the dying phase are known so far

Steep spectrum: best detected at low frequencies

It has long been known that the radio spectra of radio galaxies in the central regions of galaxy clusters are on average steeper than those in other environments *(i.e. Roland 1985; Slee et al. 2001).* This has always been interpreted in terms of confinement of the external gas, which prevents adiabatic expansion of the radio lobes and aging of their synchrotron spectrum



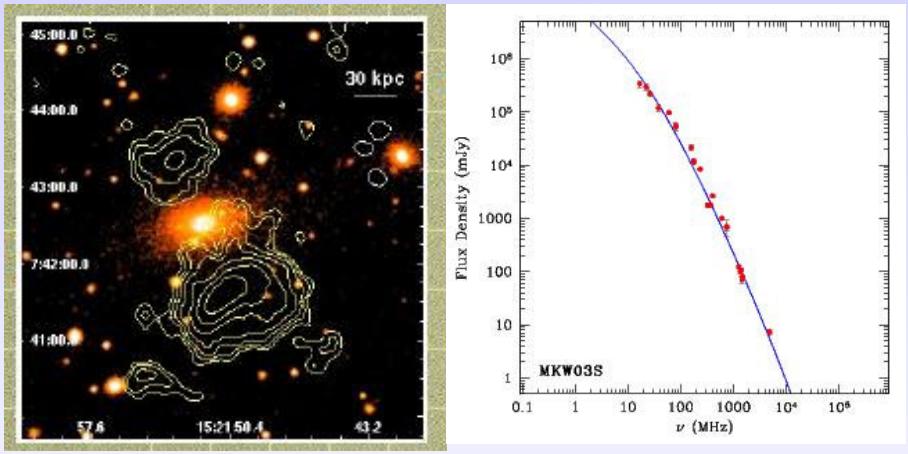
Galaxy clusters seem an appropriate place to search for radio galaxies in the final stages of their evolution



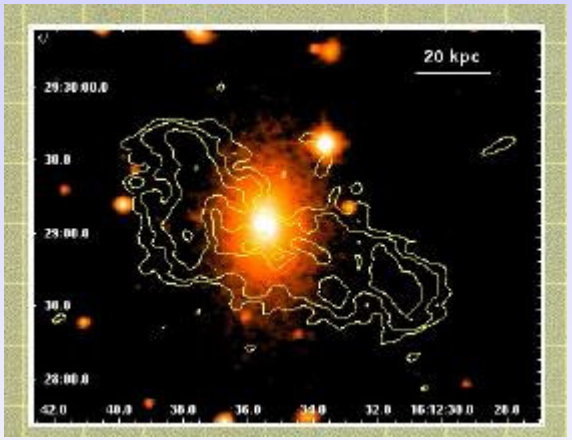
It is expected that dense gas is surrounding dying radio galaxies

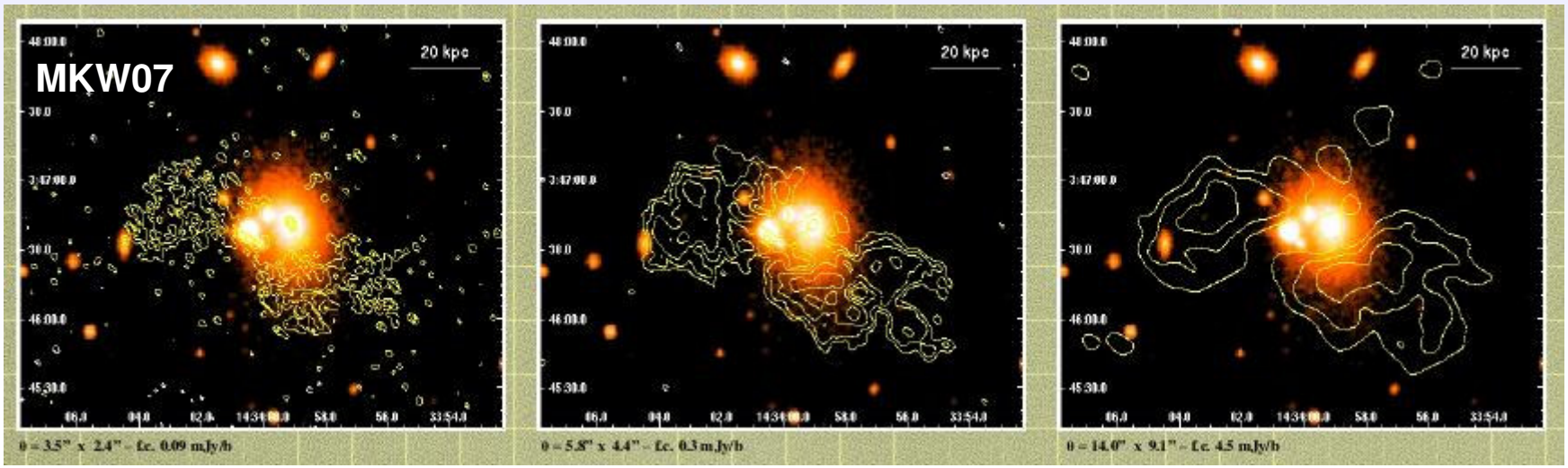
A recent study of the radio properties of cD galaxies in a sample of poor clusters led to the unexpected finding of a number of radio galaxies in their final evolutionary stage *(Giacintucci et al. 2007)*

MKW03s

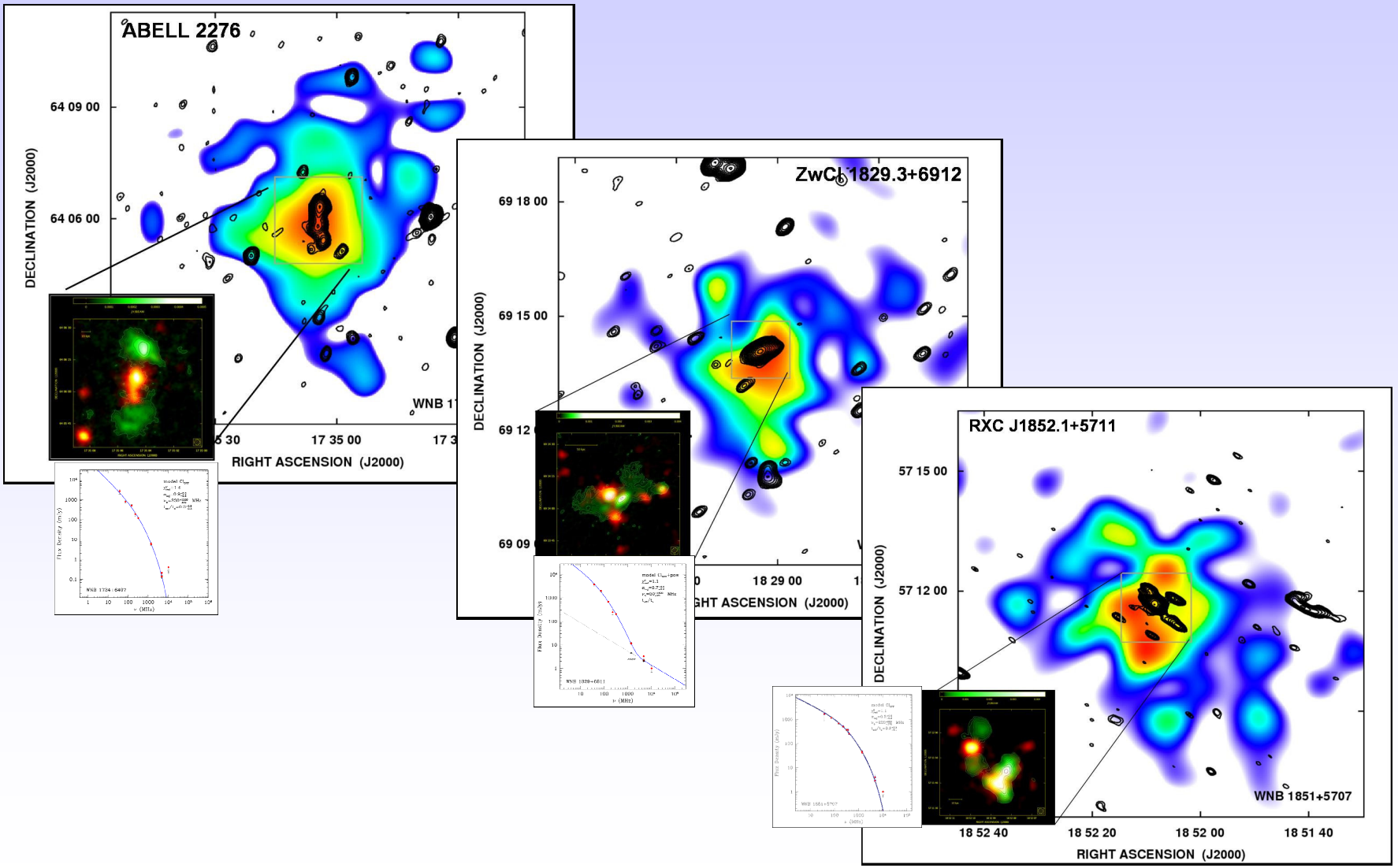


A2162



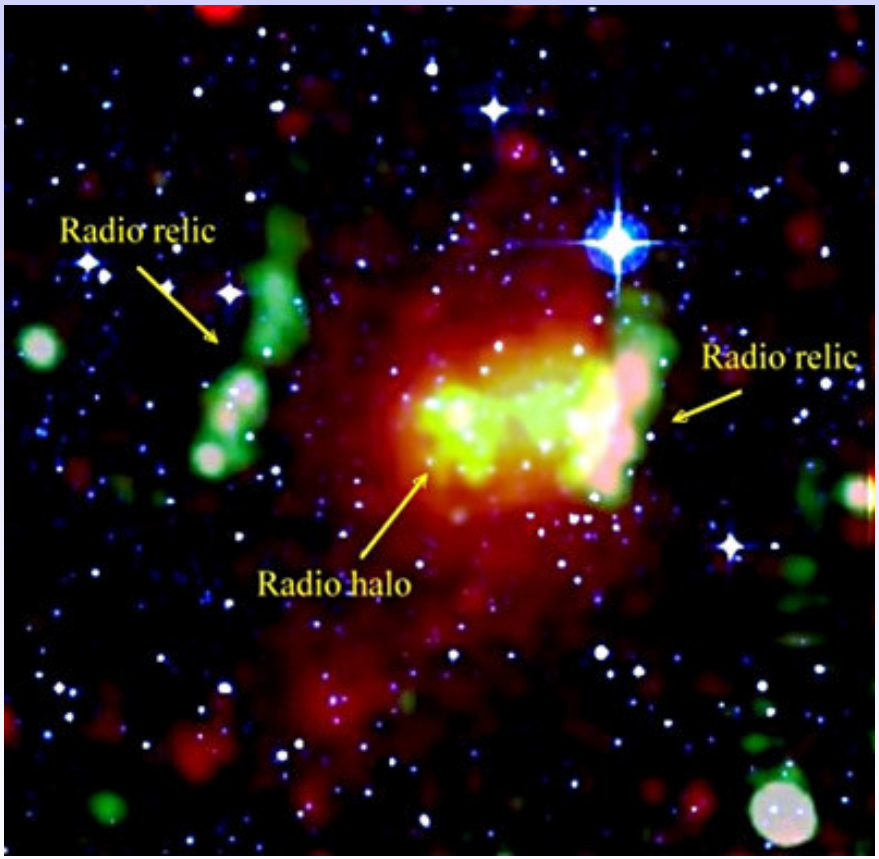


A study of the environment around dying radio galaxies selected from the WENSS shows that they are all located in high gas density regions *(Parma et al. 2007; Murgia et al.2008)*



Diffuse cluster sources

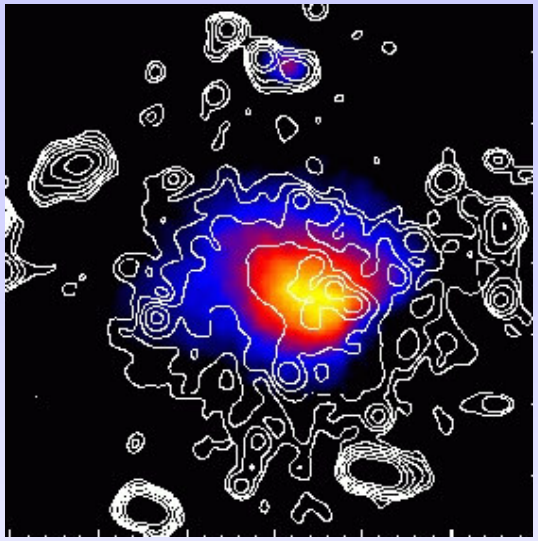
Radio halos and relics



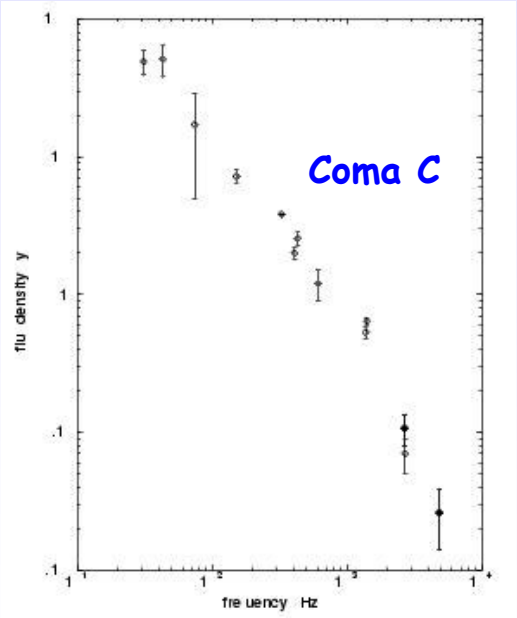
Very large radio sources, not associated with individual galaxies, not a blend of radio sources either, but rather "connected" with the intracluster gas

Cluster radio halos

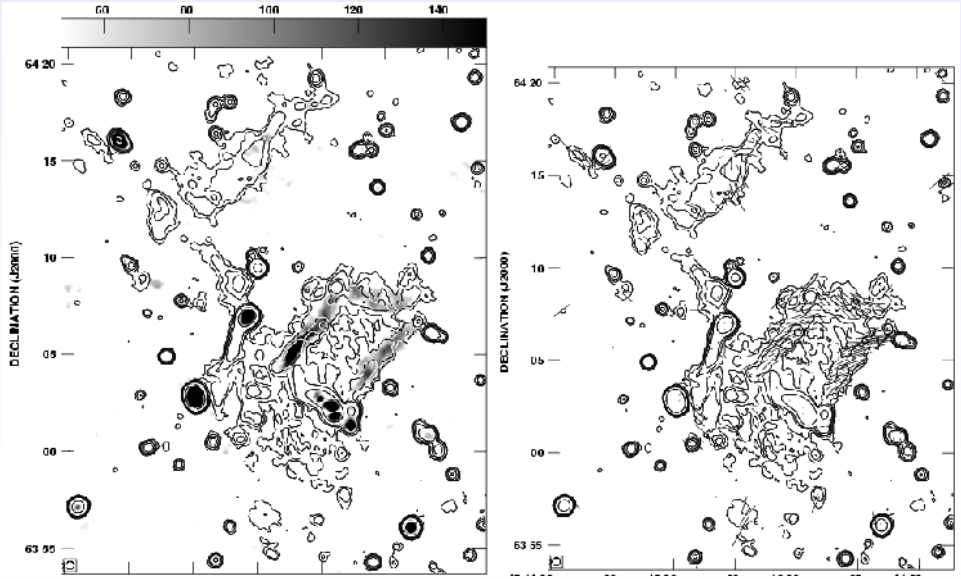
Very extended radio sources (up and beyond Mpc size)
Low surface brightness
Located at the centres of a fraction of rich clusters
Synchrotron steep radio spectrum: α~1.2 – 1.4
"Regular" morphology, similar to the X-ray brightness
Unpolarized, except A2255 (*Govoni et al. 2005*)



Govoni et al. 2004

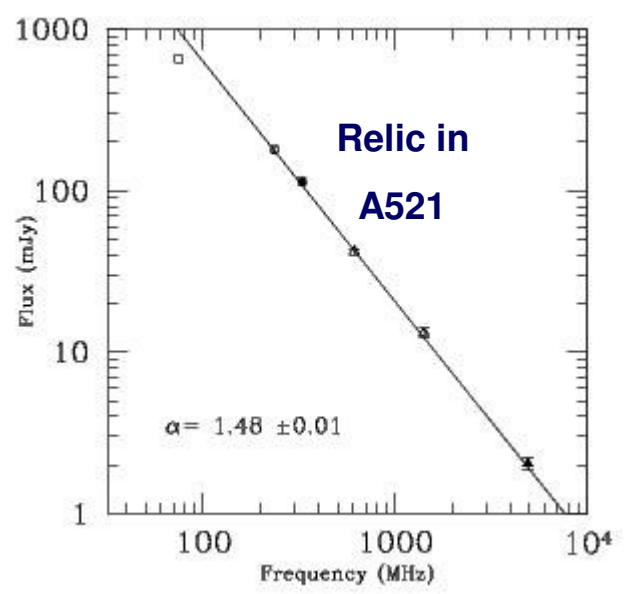


Thierbach et al. 2003



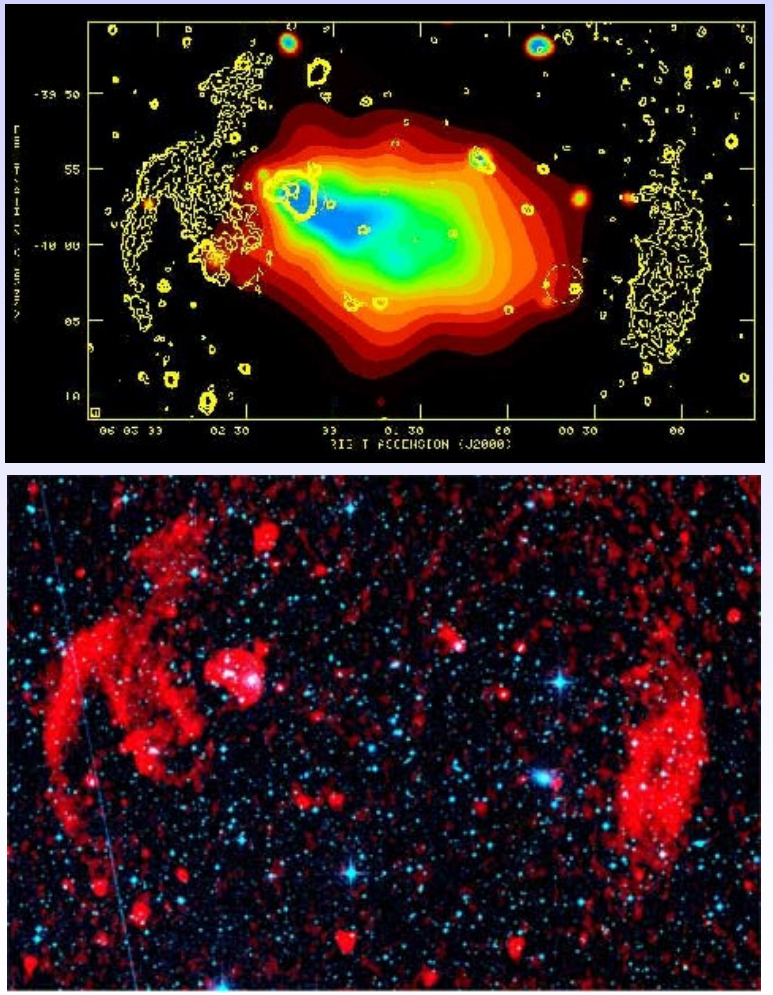
Cluster relics

Large linear size (Mpc)
Low surface brightness
Steep synchrotron spectrum: α~1.2 – 1.4
Range of morphologies (elongated, arcs, toroids)
Located in peripheral cluster regions
Highly polarized (up and beyond 30%)
Double relics in 5 clusters



Giacintucci et al. 2008

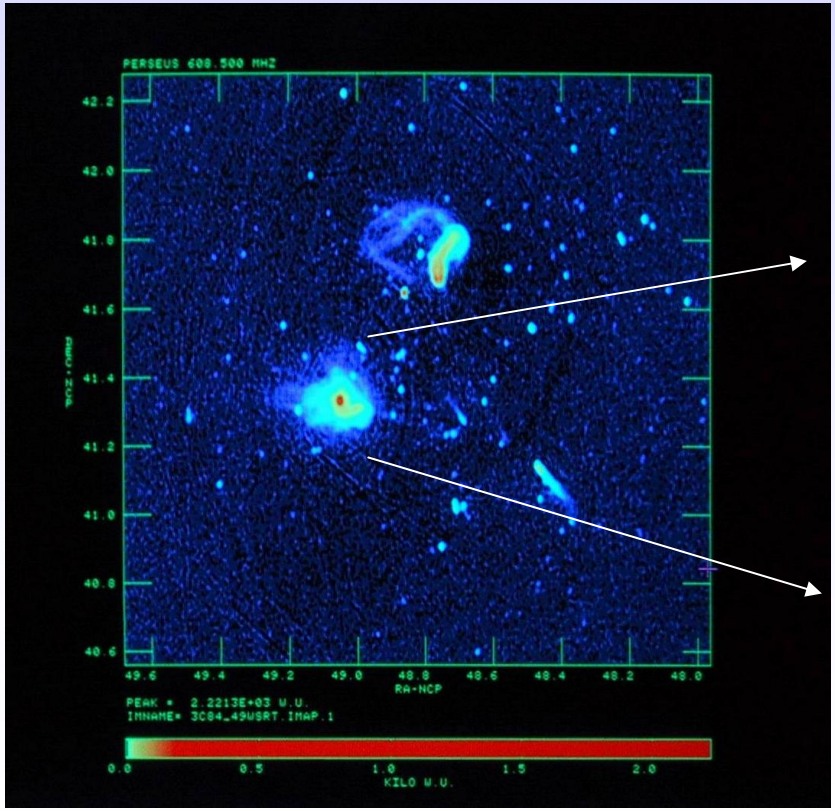
A3376 *(Bagchi et al. 2006)*

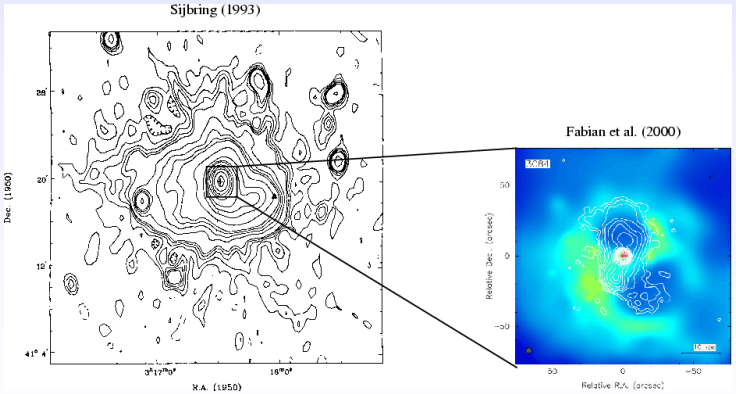


Mini-halos

Extended (few hundred kpc) emission at the centres of cool core clusters, surrounding the BCG, which is radio loud

Perseus, prototypical mini halo



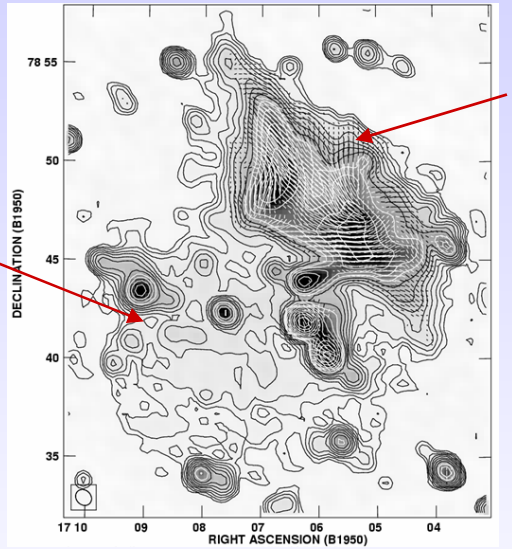


Radio halos and relics probe the existence of magnetic fields and relativistic particles spread over volumes as large as the extent of galaxy clusters

Magnetic field strengths of the order of the μG from equipartition arguments

Giant halo

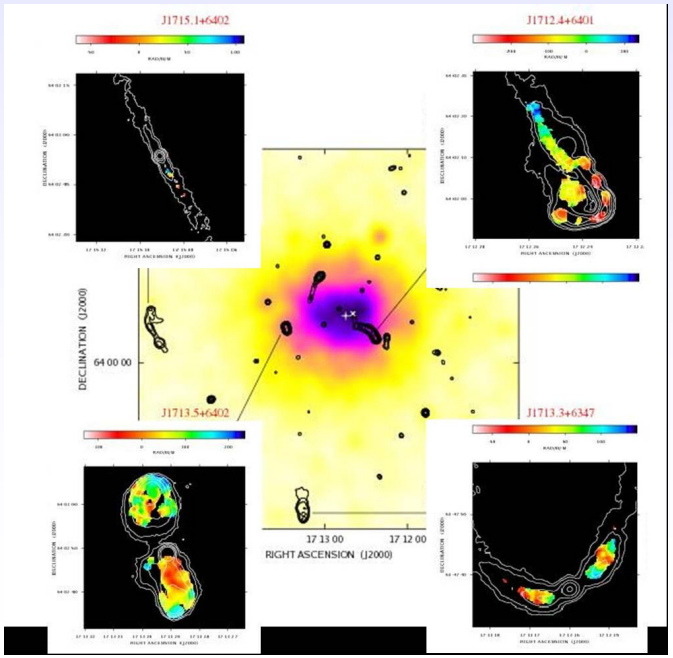
Clarke et al. (2004)



Relic

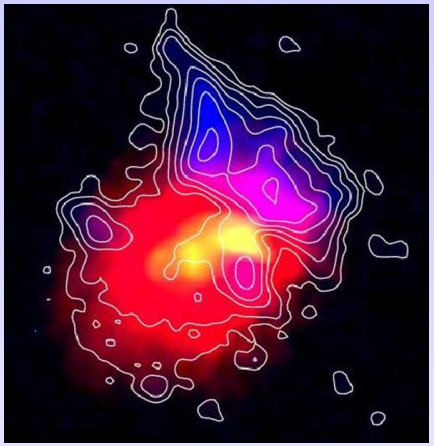
Polarised 20-40% ordered B on large scale

And large regions with uniform B



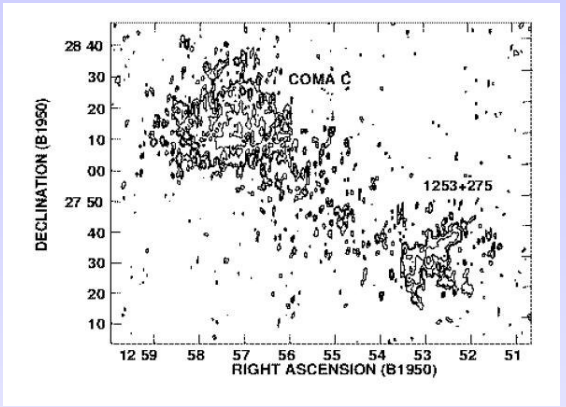
Magnetic fields exist in all galaxy clusters – RM in radio galaxies

Problem of the origin of halos and relics



Their Mpc size imply that

$t_{diff} >> t_{synchr}$



Some for ation is needed

Next presentation by Brunetti

Primary electron models: in situ reacceleration, first proposed by Jaffe (1977)

Secondary electron models: in situ production of relativistic electrons via proton-proton collisions, first proposed by Dennison (1980)

~25 radio halos and ~20 relics known to date

Candidates from the NVSS (VLA-D, 1.4 GHz) *(Giovannini, Feretti, Tordi, 1999)* **and pointed follow up studies** *(Govoni et al. 2001, 2004, …; Bacchi et al. 2003)*

Studies of individual objects

Candidates from WENSS (WSRT, 327 MHz) *& Sarazin, 2001)*

GMRT Radio Halo Survey (GMRT *l. 2007 & 2008)*

Radio halos are f **of galaxy clusters, depending on the** **uminosity**

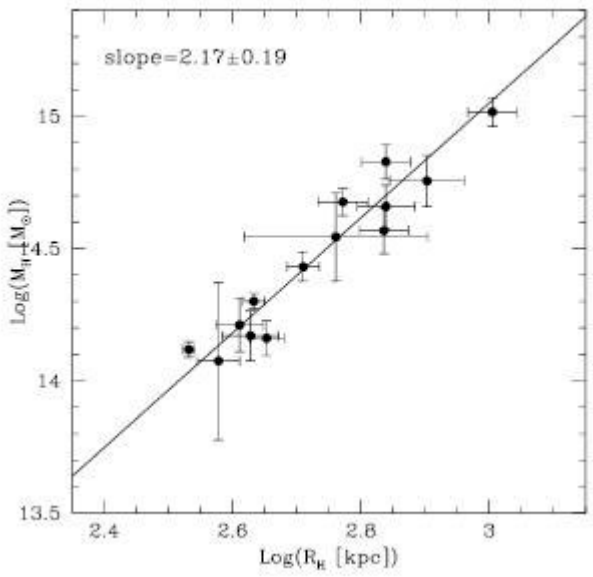
Radio radio halos and relics are RARE

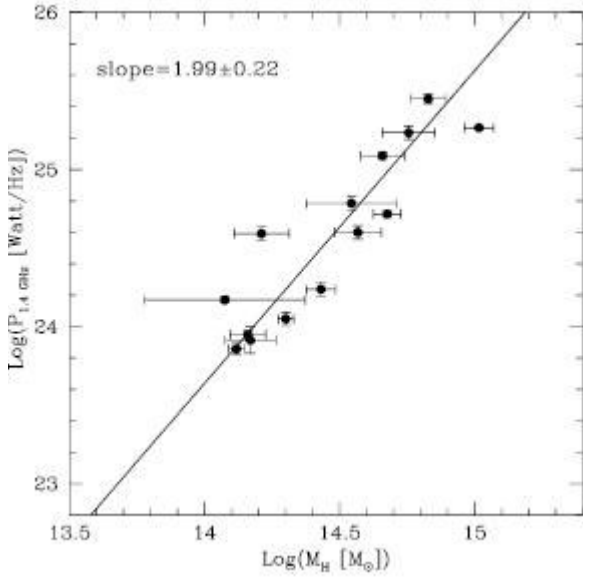
Radio Halos and Cluster X-ray properties

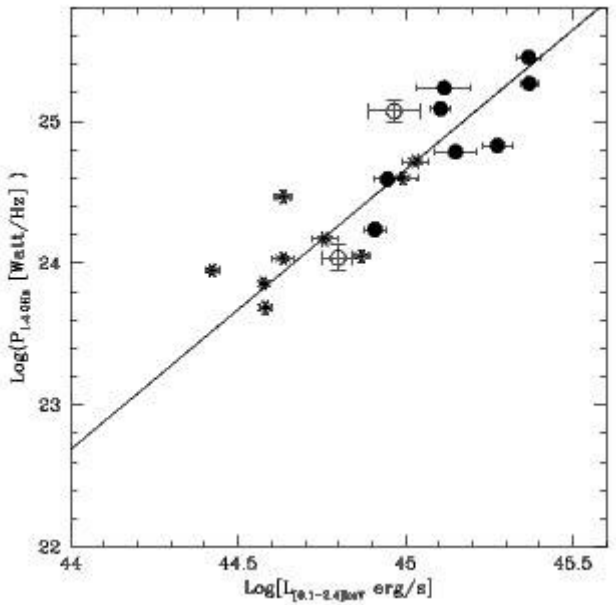
Radio halos are more frequently found in clusters with high X-ray luminosity (i.e. more massive)

More massive clusters host larger radio halos

The radio power of radio halos correlates with the cluster X-ray luminosity



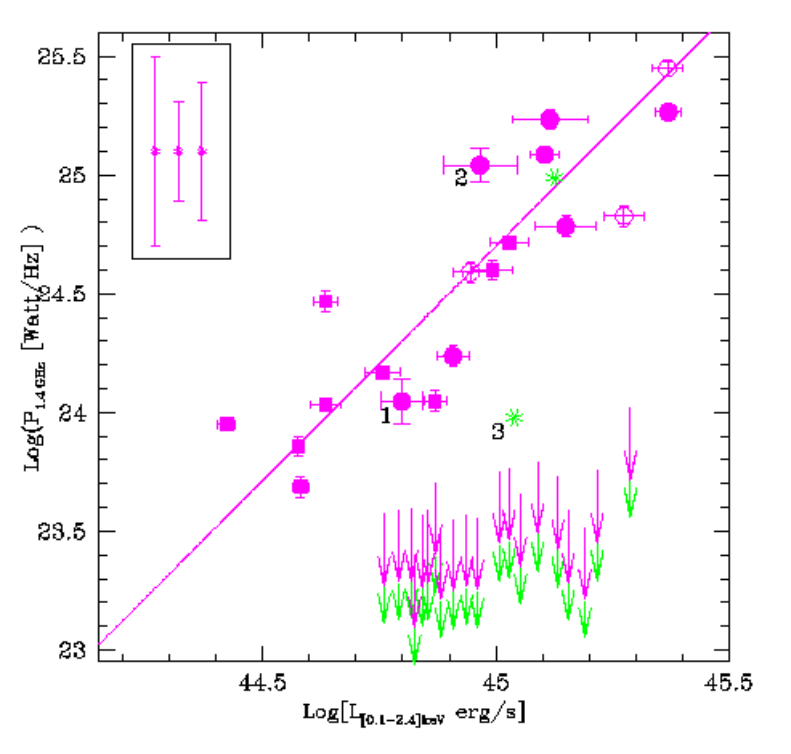




More on radio halos and cluster X-ray properties

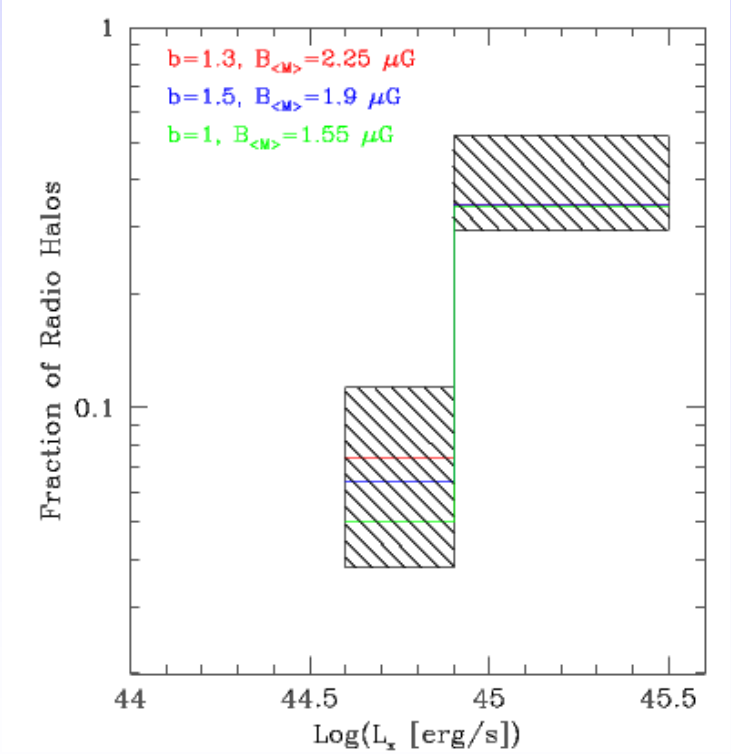
(0< z <0.4)

Bimodal distribution of clusters with and without radio halos



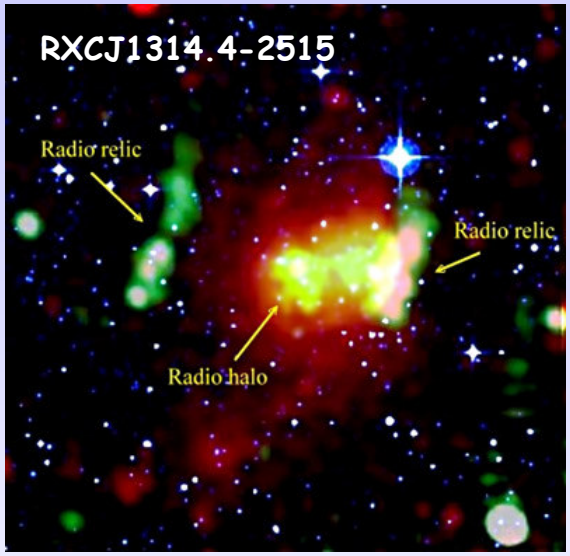
Brunetti et al. 2007, ApJ 670L, 5

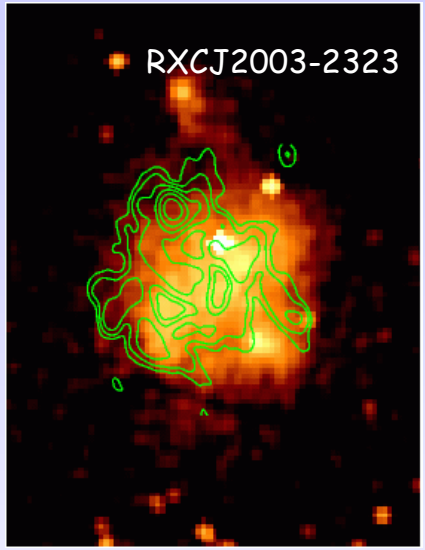
Fraction of clusters with radio halos as function of cluster mass

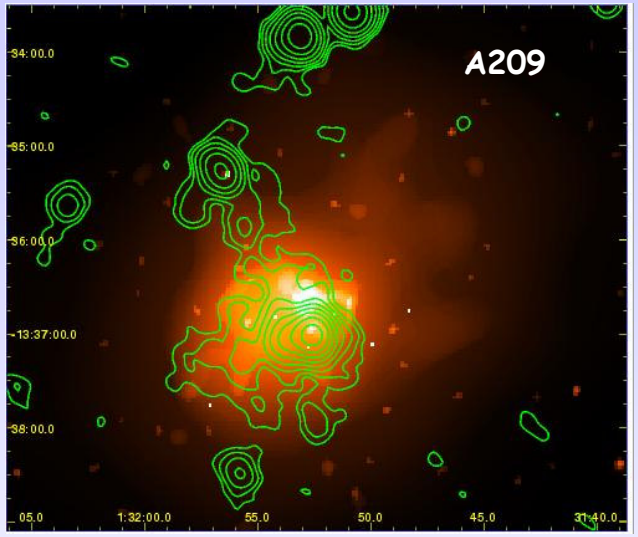


Cassano et al., 2008, A&A, 480, 327

Radio halos relics and major cluster mergers

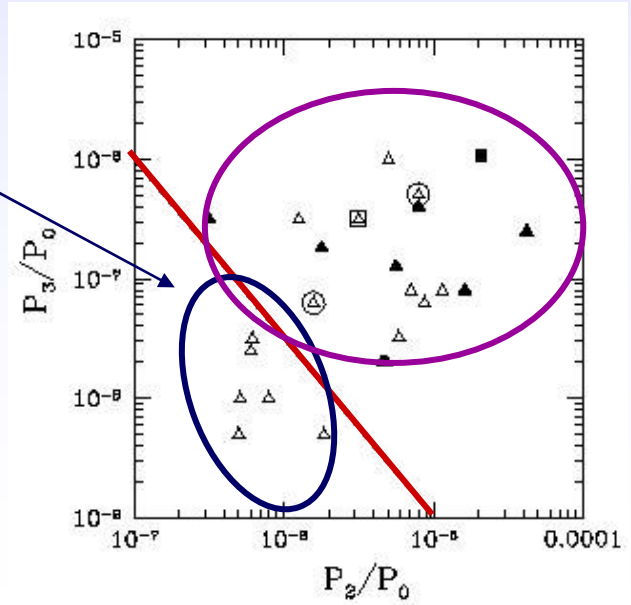






GMRT @ 610 MHz over Chandra

Relaxed clusters: never host diffuse cluster galaxies
Merging clusters: sometimes do, sometimes don't

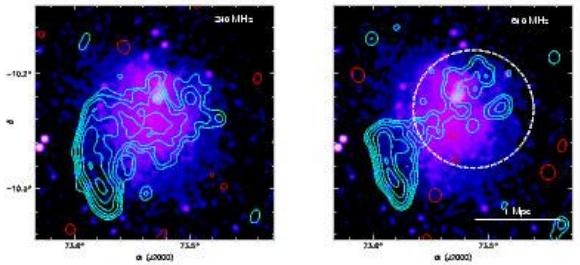


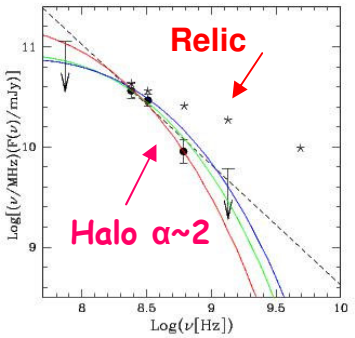
Cluster dynamical state and presence of halos and relics, or lack thereof

Venturi et al., 2007 & 2008

Classical and ultra steep radio halos

235 MHz - GMRT - 610 MHz





VLA

1.4 GHz

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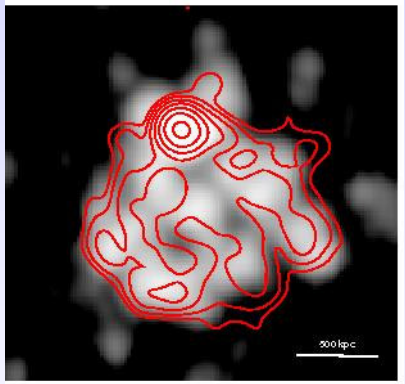
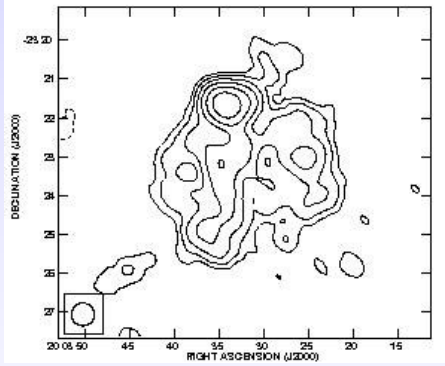
Brunetti et al. 2008

Expected in the re-acceleration model: less energetic merger events

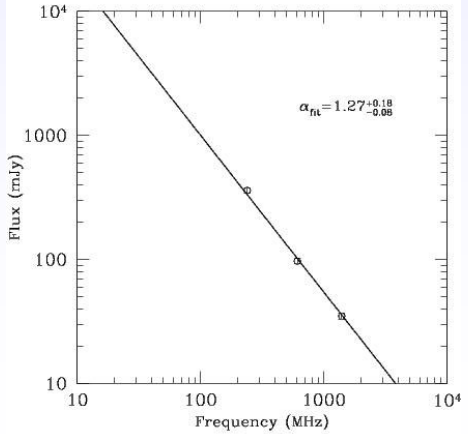
RXCJ2003.5-2323

240 MHz - GMRT





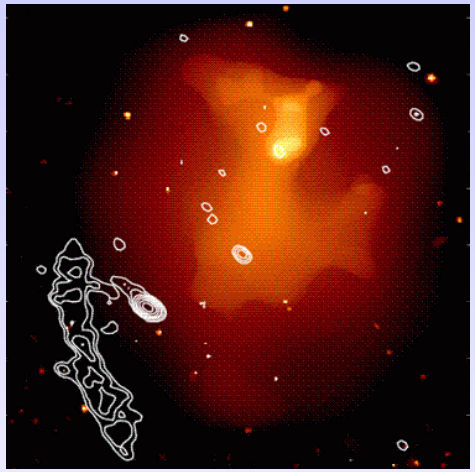
1.4 GHZ VLA overlaid on 610 MHz GMRT

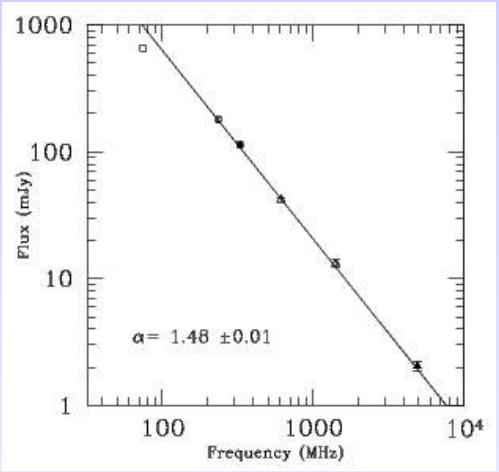


Giacintucci et al. To be submitted

Cluster relics: connection with merger shocks?

A521

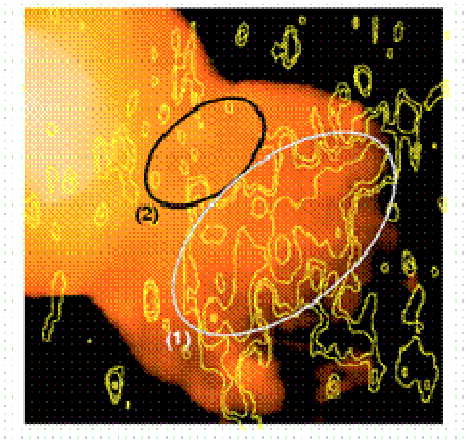




Electron acceleration by a shock with Mach number ~ 2.2

Giacintucci et al. 2008

Relic in the Coma cluster



No indication of shock at the relic location

Feretti et al. 2005

… to summarize…

The radio emission in galaxy clusters takes a variety of forms, which can be broadly divided into two main flavours:

1) Radio emission associated with individual galaxies

2) Diffuse extended emission on the cluster scale, in the form of halos and relics

1) The interaction between the intergalactic medium and the cluster radio galaxies allows us to study the late stages in the radio galaxy evolution and the cycles of activity in AGNs

2) Halos and relics witness the existence of magnetic fields and relativistic particles over cluster scale volumes. The origin of such sources may be related to the formation of clusters (and large scale structures) in the Universe