

Clusters of galaxies

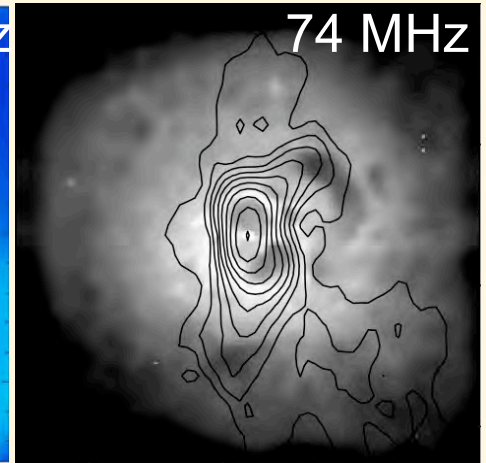
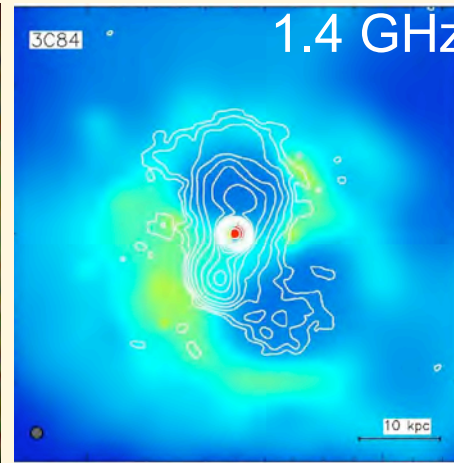
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Some focus on the X-ray/radio connection
not exhaustive

X-ray / radio connection : cluster thermo-dynamical history

Information on

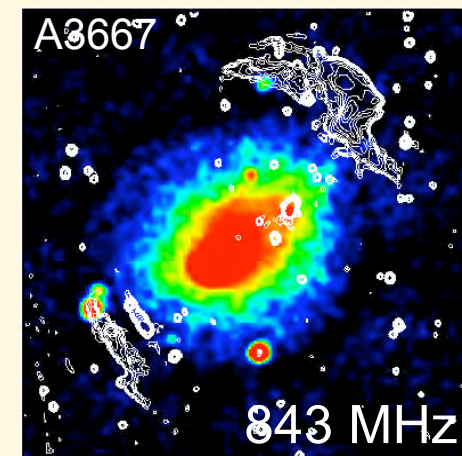
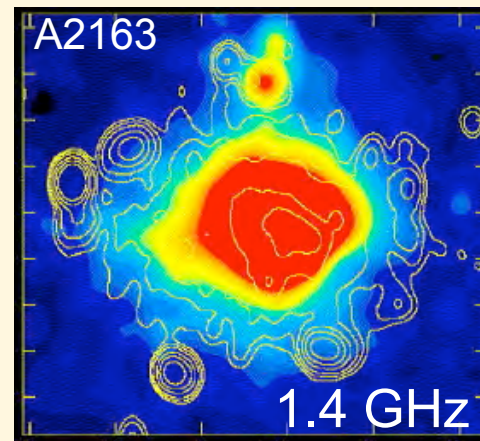
- AGN feedback
 - in center
the CF pb
 - at large scale ?
the entropy excess



Fabian et al, 00, 02

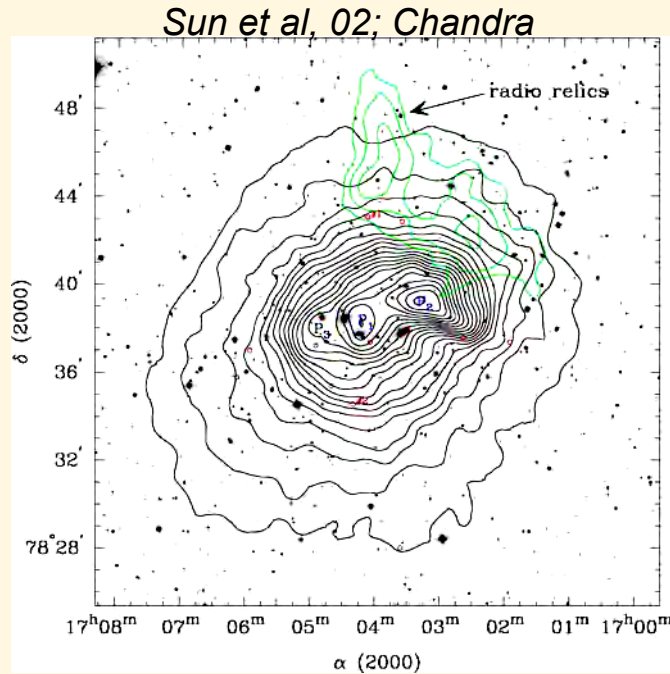
- The dynamics of cluster
(hierarchical) formation
(this presentation)

see e.g. reviews by L. Feretti, 04,05



Feretti, 05 adapted from Feretti et al, 01 ; Röttgering et al, 97

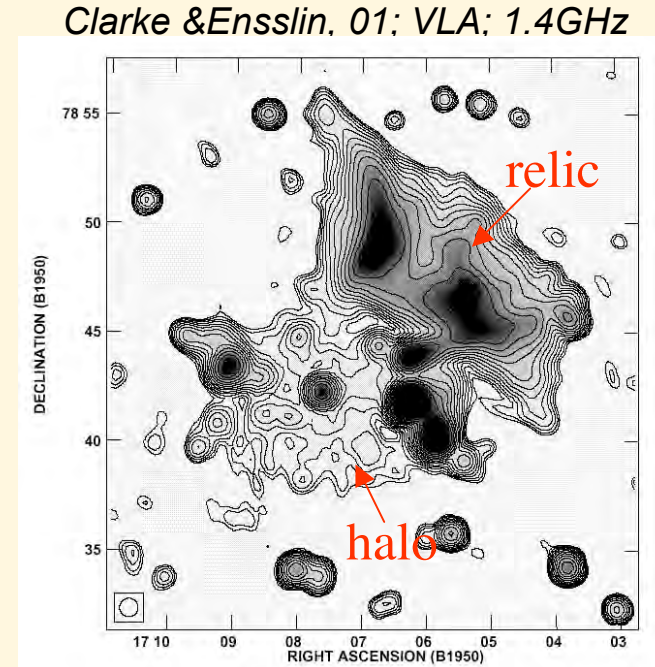
LS X-ray/radio emission: Thermal and non-thermal components



X-ray thermal - diffuse

- Hot plasma ($T \sim 2-10$ keV)

main baryonic component
[80% DM, 20% ICM, 5% stars]

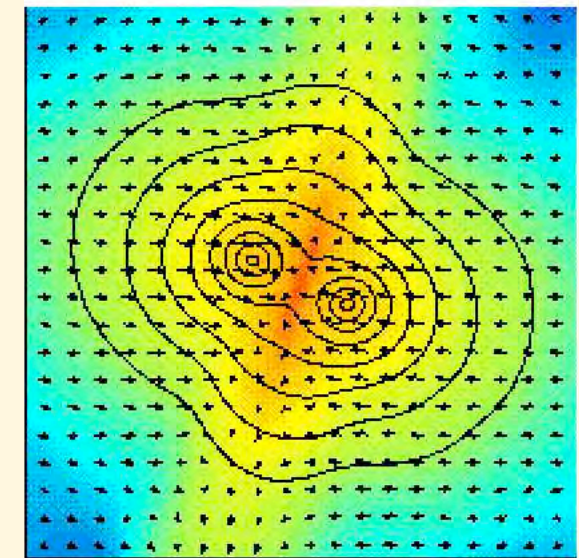
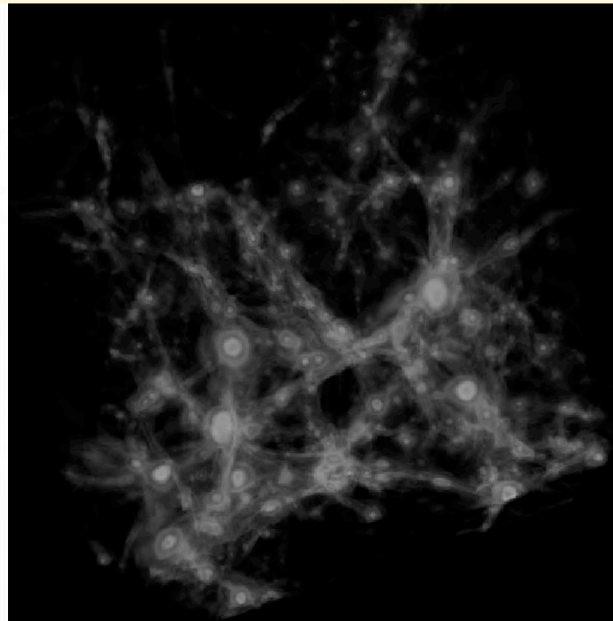
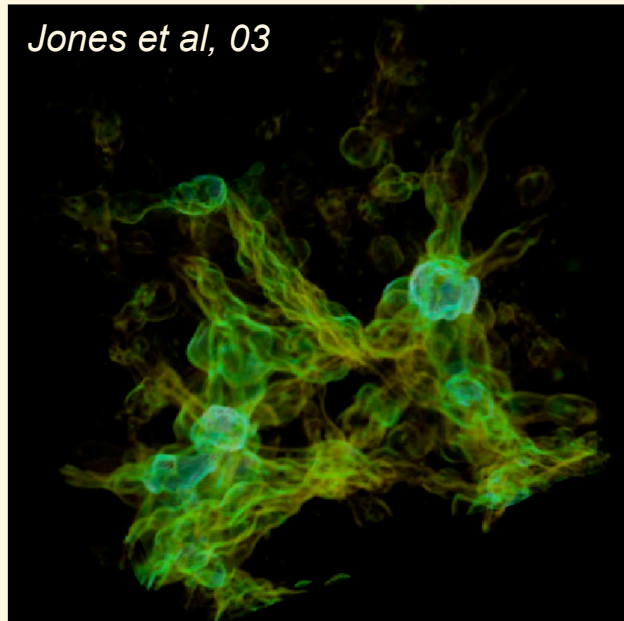


Radio synchrotron - diffuse - steep ($\alpha > 1$)

- Relativistic electrons ($\sim 1-100$ GeV)
- Magnetic Field ($0.1 - 1 \mu\text{G}$)

IC e- on CMB \Rightarrow NT X-ray (pwl)

Origin and acceleration of the relativistic electrons?



Ritchie & Thomas, 02

Cluster hierarchical formation => Shocks (heat the gas at T_{virial})

- Clusters are good reservoir of $E < 10^6$ Gev particles
- Problem: $\sim \text{Mpc}$ size but $t_{\text{life}} \sim 10^7 - 10^8$ years $\ll t_{\text{diffusion}}$
=> **Recent creation or (re) acceleration by a mechanism at cluster scale**
- Radio halos/relics detected in unrelaxed (merger) clusters only

Several Models:

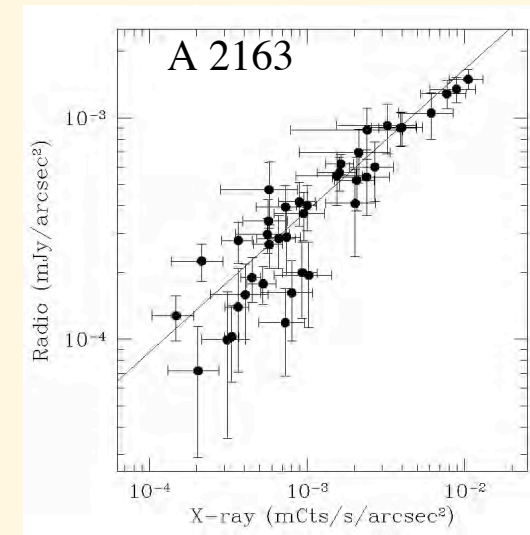
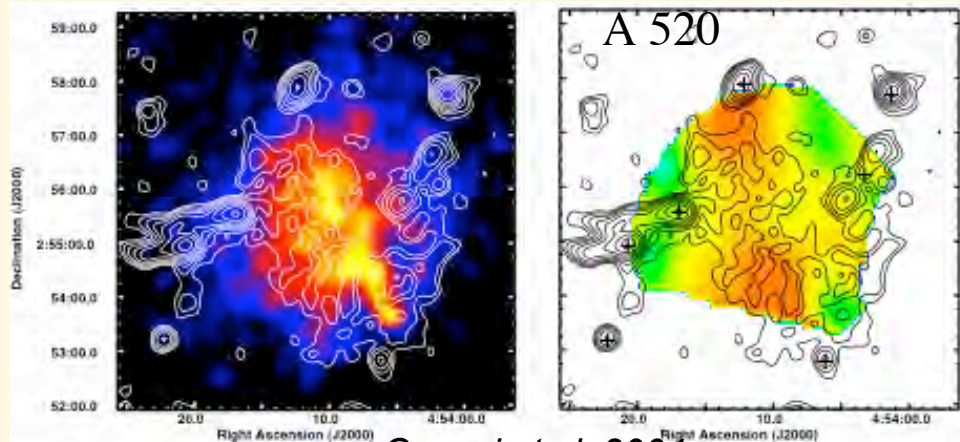
- Thermal electrons accelerated by shocks (high M) /turbulence
- Non thermal electrons (from above or from AGN/Winds) re-accelerated
- Secondary electrons from inelastic collisions of NT protons with ICM

Importance of studying the NT cluster component ?

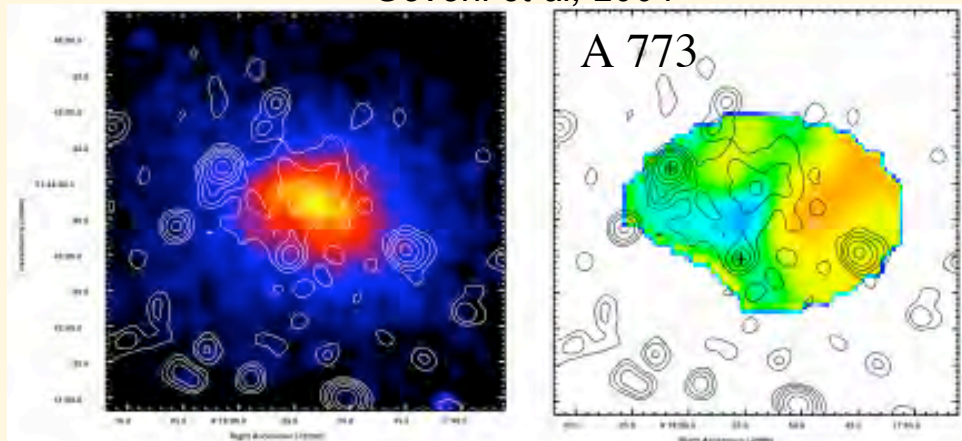
- Understand NT e- creation and acceleration mechanism!
- Diagnostic information on the hierarchical formation process
 - probe of physics of merger events (shocks, turbulence..)
 - probe of ICM magnetic field
 - tracer of merger history
- May influence the thermo-dynamical evolution of the thermal ICM
- May contribute to the overall pressure
 - => Mass higher than estimated from the HE equation and P_{therm} only
 - => Possible impact on cosmological parameters estimated from $N(M)$ or f_{gas}

Need (new) radio observations combined with X-ray information

Radio- thermal X-ray comparison in individual clusters (I)



Feretti et al, 01



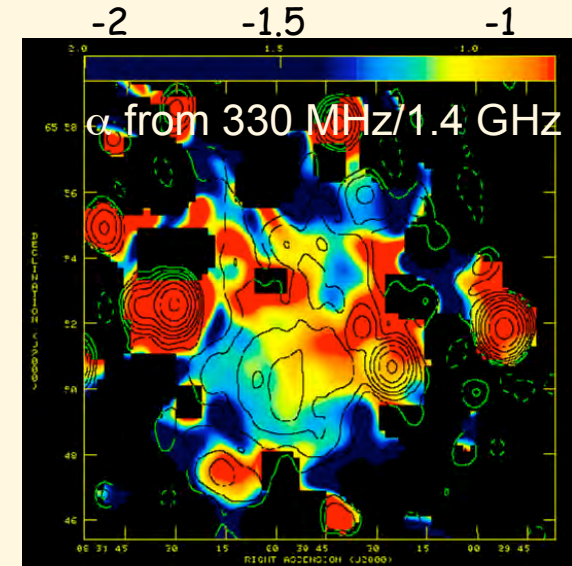
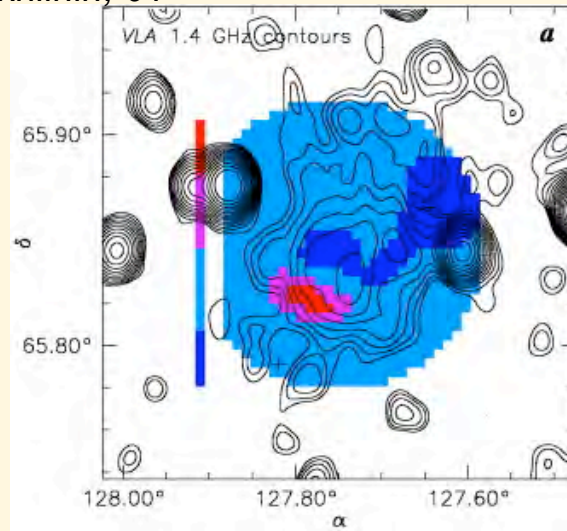
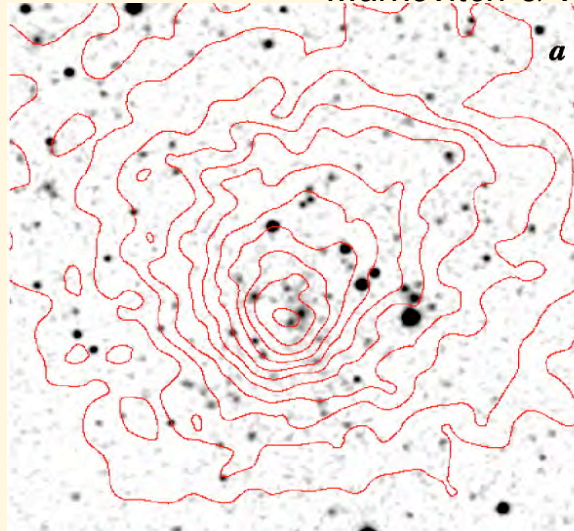
Radio versus kT map →

- Radio halos connected to thermal gas
- constraints for models:
Radio versus X-ray map/profiles

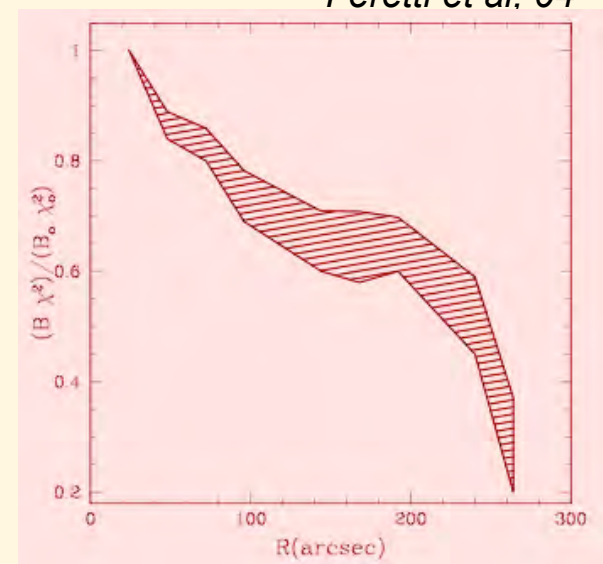
Probably mostly acceleration by turbulence

Radio- thermal X-ray comparison in individual clusters (II)

Markevitch & Vikhlinin, 01



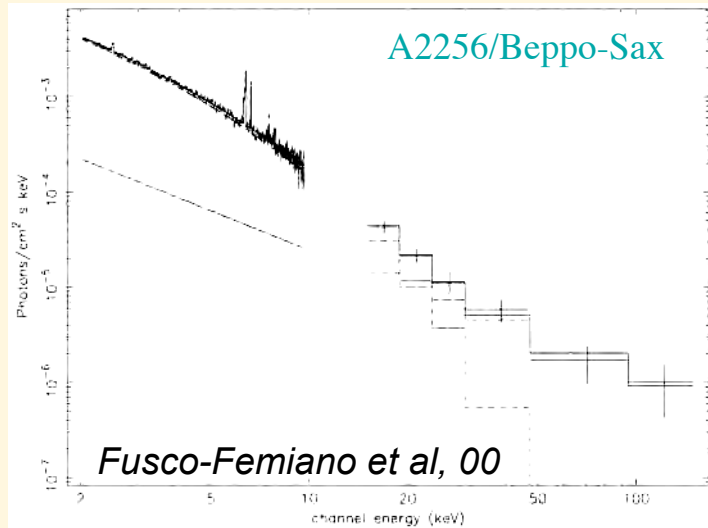
Feretti et al. 04



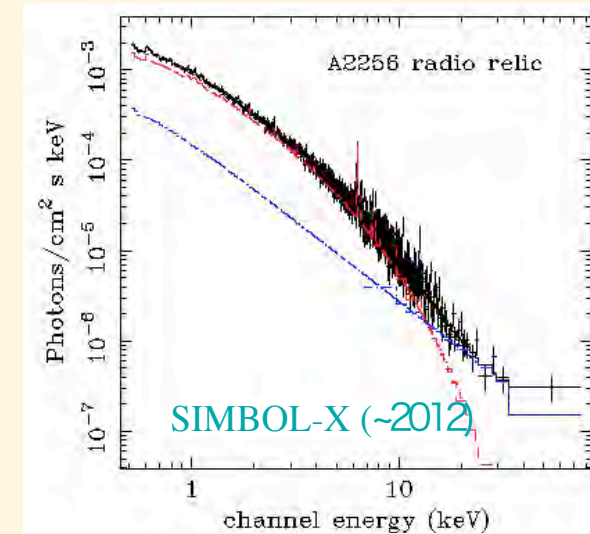
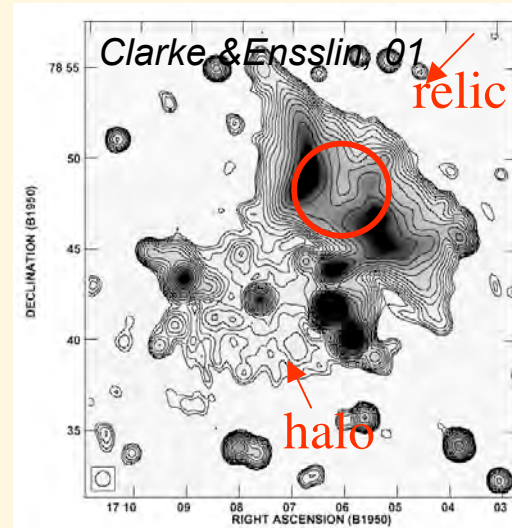
Clumpiness; flattening in the region affected by merger
 no connection to the (weak $M \sim 2$) shock
 Radial steepening
 favor re-acceleration by turbulence

Need to extend to much larger cluster samples:
 Radio map (α / S_{rad}) versus X-ray map ($ne/kT / P/S$)
 XMM/Chandra

Radio- NT X-ray comparison in individual clusters



Global spectrum => ambiguous



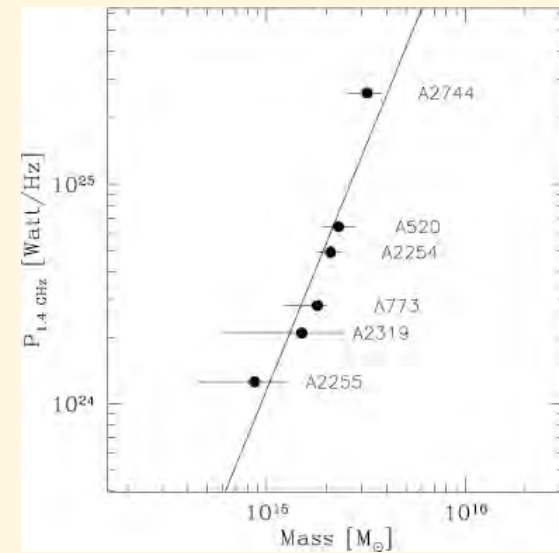
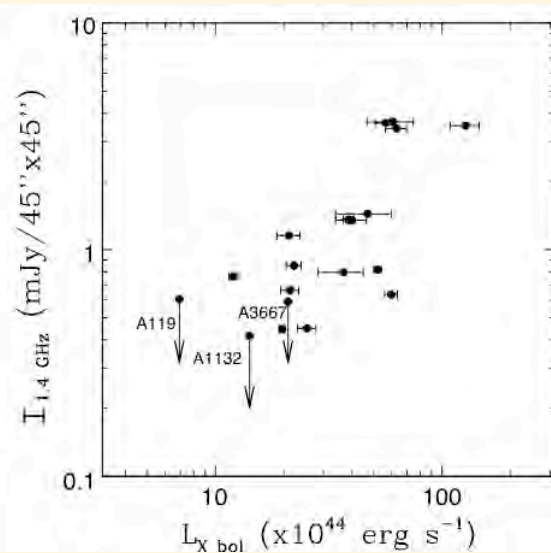
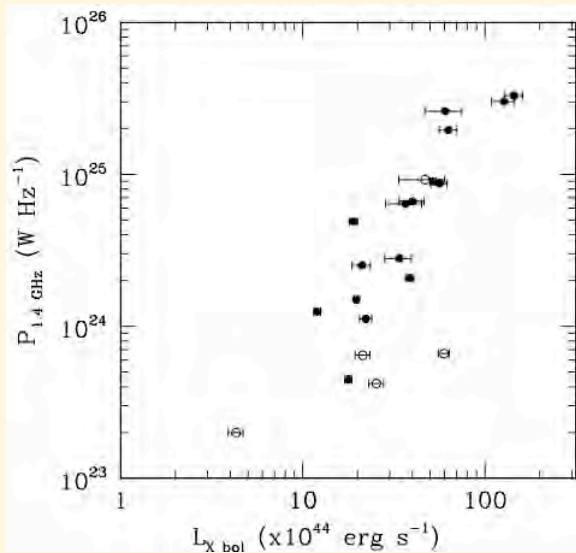
Spatially resolved spectroscopy

Radio: degenerate information on B, NT e-
+ Faraday Rotation (B, Te-) => B in few directions (LOFAR?)
+ **hard X-ray** : IC (NT e-) => **break the degeneracy**

LOFAR + SIMBOL-X (luminous clusters)

LOFAR + XMM ? (low mass systems where IC/thermal higher)

Radio/Xray connection (I): correlations with global properties



Feretti , 05 and ref therein; Bacchi et al, 03 Giovannini et al, 06

Govoni et al, 01

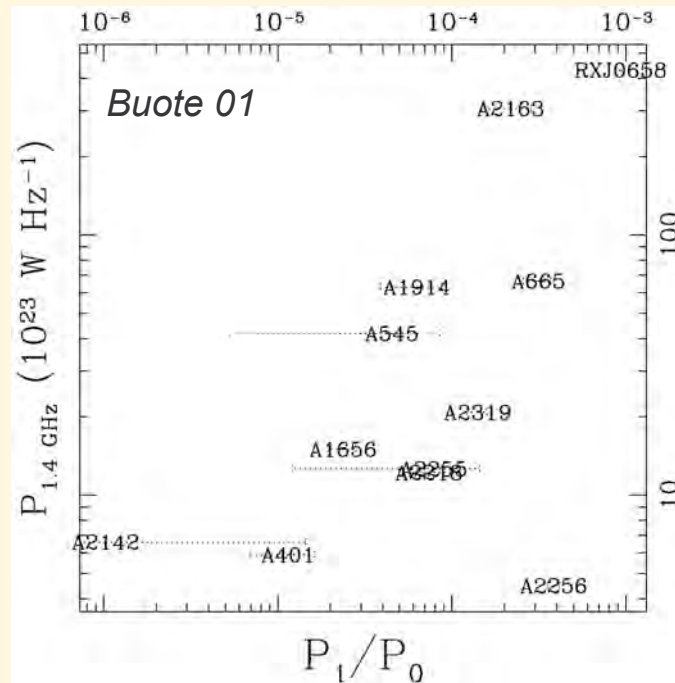
Open questions:

- Do all clusters with a recent merger have halos/relic?
- Do ALL clusters have a radio halo ?
- What is the most relevant X-ray quantity and what is the slope/dispersion/evolution of the correlations => quantitative test of models

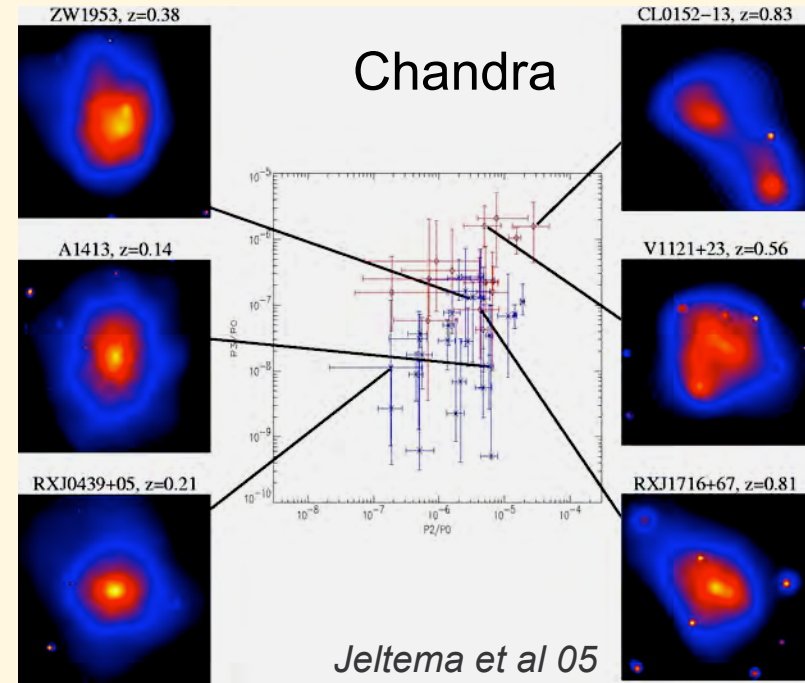
We need:

- X-ray data: exist (XMM/chandra follow-up of ROSAT samples; XMM serendipitous surveys)
- much higher sensitivity radio survey/ follow-up : **LOFAR**

Radio/Xray connection (II) : correlations with dynamical state



Correlation with departure from relaxation



High z clusters are dynamically younger
(as expected in hierarchical scenario)

The frequency/properties of radio halos is expected to evolve with z
... a test of structure formation and merger physics

also combination with SZ (Planck) data

Conclusion

- Detailed **combined X-ray/radio spectro imagery**
⇒ Physics of hierarchical cluster formation
(shocks, turbulence, particles acceleration,
B amplification etc...)

Lofar: adapted to steep spectrum
well matched spatial resolution

Q: Higher flux at low ν but older e population
Lofar sensitivity for diffuse emission ?
capability for 'spectro-imagery' on specific targets

NB: combining with hard X-ray (e.g. SIMBOL-X) part. interesting..

- **Discovery of new relics/halos and statistical properties (correlation with X-ray/SZ) and evolution with z**
⇒ again constraints on model PLUS tracer of cluster formation

Lofar: 'survey' capability !

Q: expected radio sample versus existing/planned X/SZ samples

