Radio halos in a mass-selected sample of galaxy clusters

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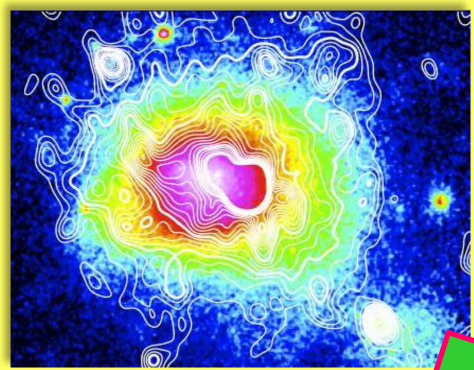
In collaboration with: Gianfranco Brunetti, Rossella Cassano, Daniele Dallacasa…

Radio Halos in galaxy clusters



Coma WSRT radio contours

Radio Halos

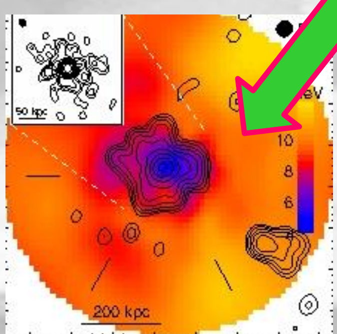
- ~ Mpc scale synchrotron diffuse sources
- Low surface brightness (~ μJy/arcsec^2 at 1.4 GHz)
- Unpolarised
- Steep spectrum ($\alpha \approx 1.2$-1.3, $J(\nu) \propto \nu^{-\alpha}$)

Relativistic (~Gev) e^-

+

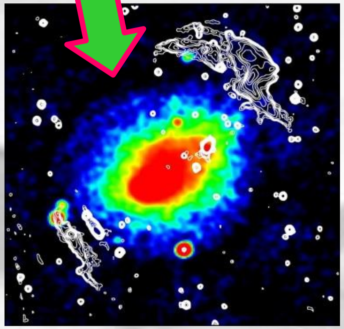
Magnetic field (~μG)

Mini Halos



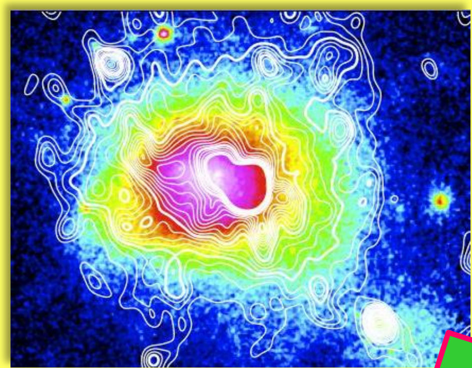
RXC J1504.1-0248 GMRT radio contours

Relics



A3667 ATCA radio contours

Radio Halos in galaxy clusters



Coma WSRT radio contours

Radio Halos

- ~ Mpc scale synchrotron diffuse sources
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Turbulent re-acceleration models

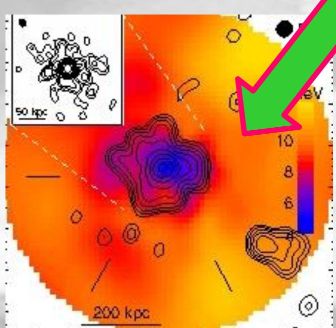
e^- are re-accelerated by turbulence injected during merger events (*Brunetti & Jones 2014 for a review*)

Relativistic (~Gev) e^-

+

Magnetic field (~μG)

Mini Halos



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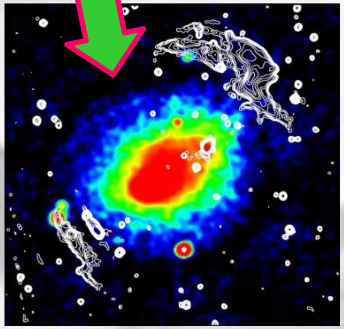
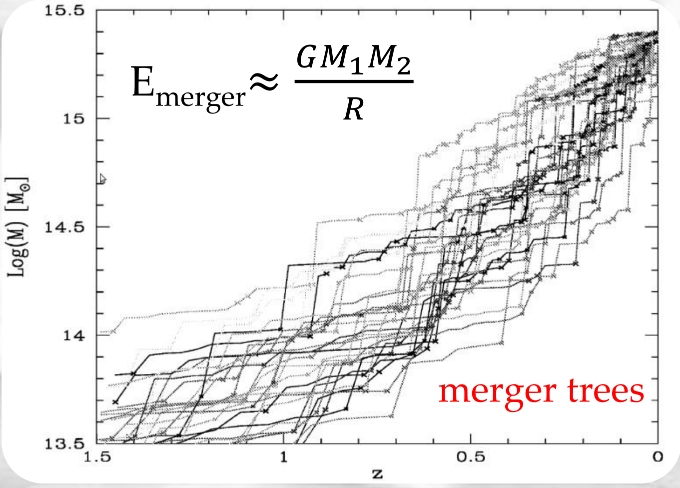




RHs provide information on the magnetic field in galaxy clusters

(Cassano & Brunetti 2005, Cassano et al. 2006)

- $P_{1.4GHz}$-M correlation

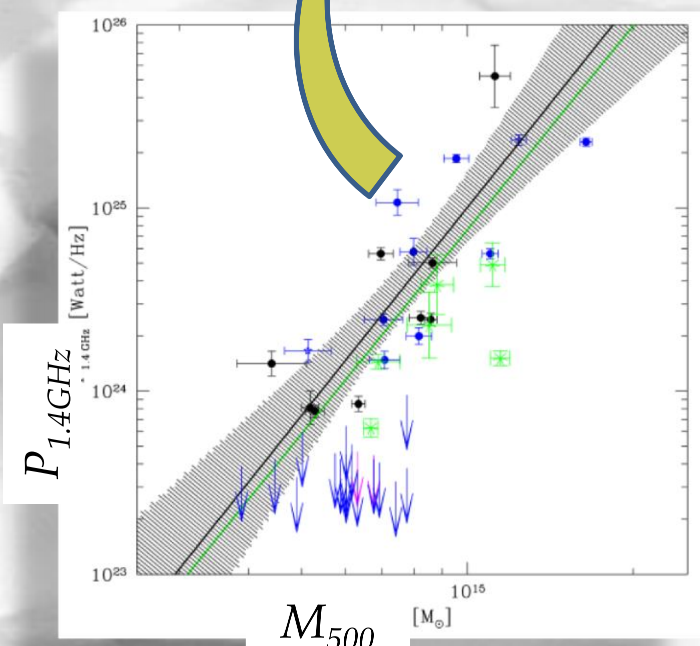
syncrothron emission
$e^- + B$

$$\langle B \rangle = B_{\langle M \rangle} \left(\frac{M}{\langle M \rangle} \right)^b$$

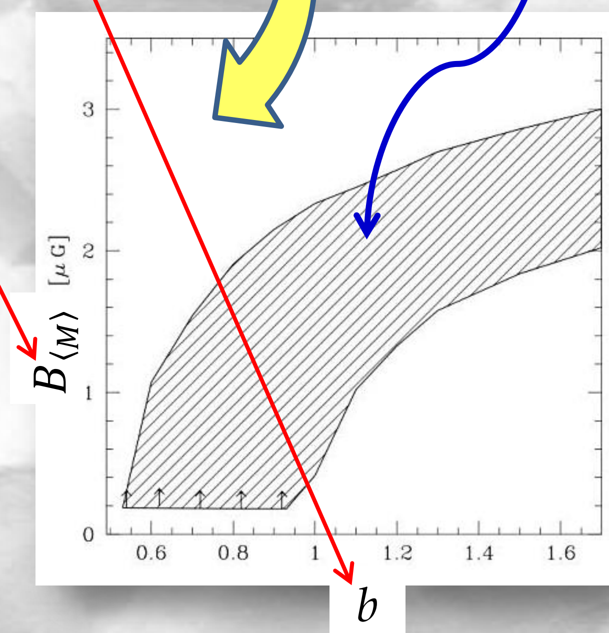
$$P_R \propto \frac{M^{2-\Gamma} \langle B \rangle^2}{(\langle B \rangle^2 + B_{CMB}{}^2)^2}$$

$T \propto M^{\Gamma}$
$\Gamma = 2/3$

Allowed region to reproduce the observed $P_{1.4GHz}$-M correlation

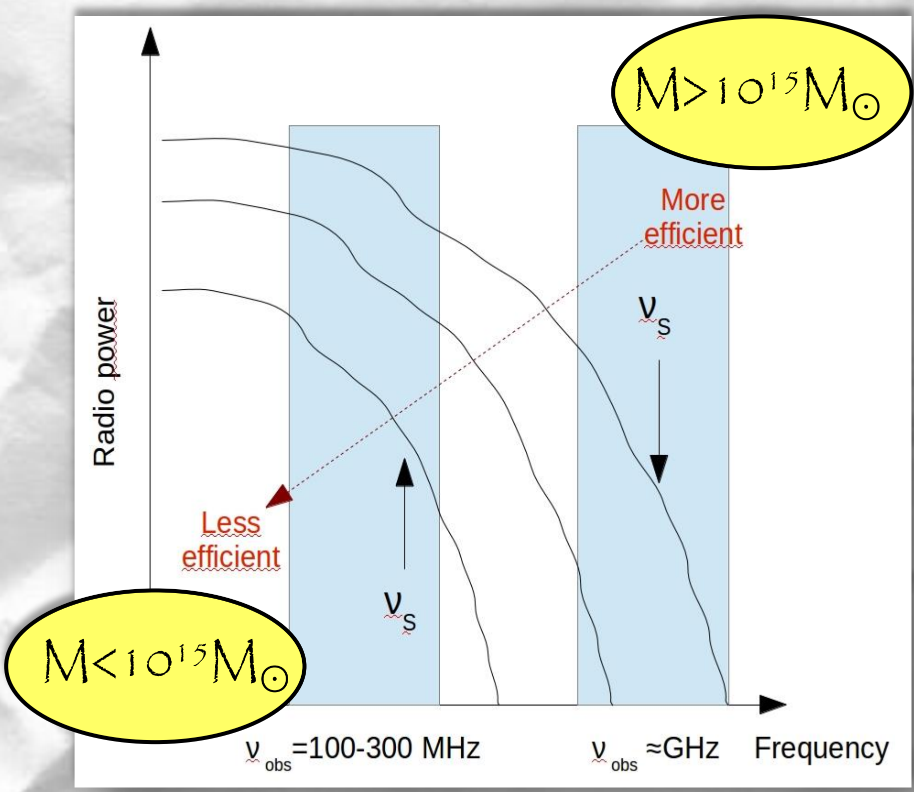


Cassano et al. 2013



Cassano et al. 2006

- Fraction of clusters with RHs: f_{RH}



RH spectra are characterized by a **break frequency**:

$$\nu_s \propto \langle B \rangle \, \gamma_b^{\,2} \propto \frac{\langle B \rangle \chi 2}{(\langle B \rangle^2 + B^2{}_{CMB})^2}$$

B_{CMB}=equivalent magnetic field of the CMB

$\tau^{-1} = \chi$: **electron acceleration coefficient**

$\chi = \chi(z, M, \Delta M)$

Main expectations:

- f_{RH} increases with M (more energetic merging events)
- f_{RH} increases towards low observational frequencies (less energetic merging events are more common)

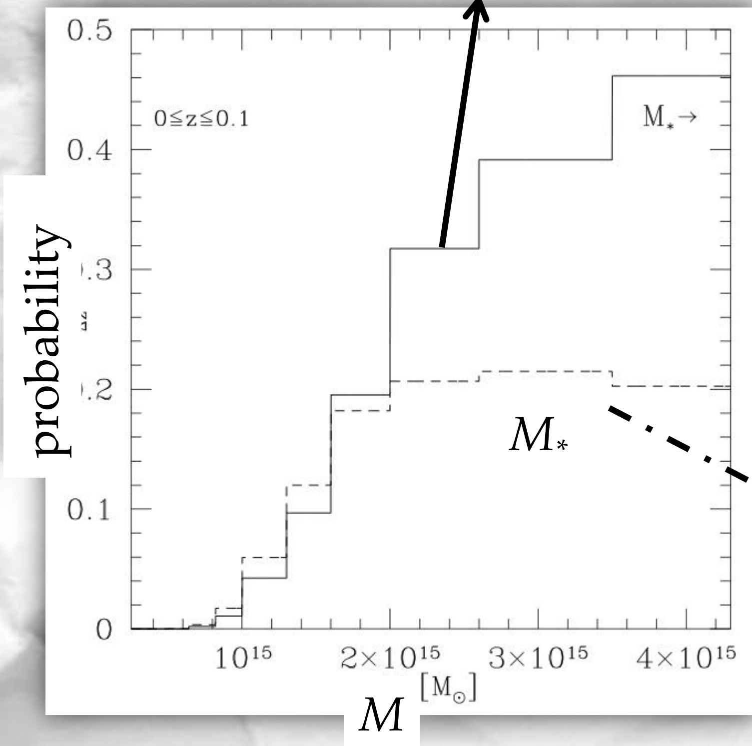
- Fraction of clusters with RHs: f_{RH}

Sub-linear regime: $b<1$

$B<<B_{CMB}$

$$\langle B\rangle = B_{\langle M\rangle}\left(\frac{M}{\langle M\rangle}\right)^{b}$$

$$\nu_s \propto \langle B\rangle\, \gamma_b{}^2 \propto \frac{\langle B\rangle \chi 2}{(\langle B\rangle^2 + B^2{}_{CMB})^2}$$



Cassano et al. 2006

$B_{CMB} \propto (1+z)^2$ → The probability to form RHs is expected to decrease with redshift

Super-linear regime $b>1$

$M>M_* \longrightarrow B>B_{CMB}$

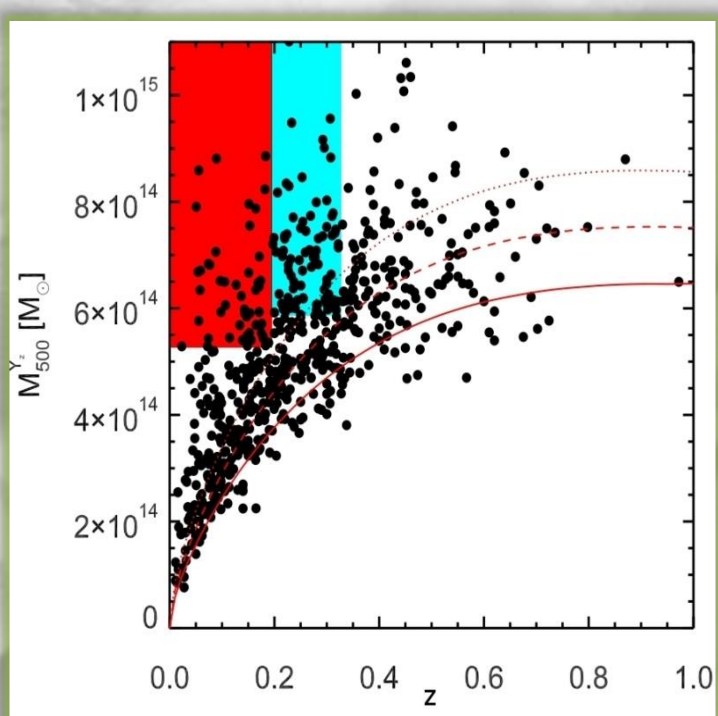
$$M_*(z) \propto \langle M\rangle \left[\frac{(1+z)^2}{B_{\langle M\rangle}}\right]^{1/b}$$

I will compare observational results on f_{RH} with the expectations of the turbulent re-acceleration model:

- $\langle B\rangle \propto M^b$, B constant with z….what if B decreases with z???
- $b=1.5$

Main goals

- Measure **the fraction of cluster with RHs**, f_{RH}, and its dependence on the cluster mass in a mass-selected sample of galaxy clusters



Planck Collaboration 2014

From the Planck SZ cluster catalogue *(Planck Collaboration 2014):*

- $M_{500} \gtrsim 6\times10^{14} M_\odot$
- $0.08<z<0.33$

Low-z sample (0.08<z<0.2) NVSS
(Condon et al. 1998)

High-z sample (0.2<z<0.33) EGRHS
(Venturi et al. 2007, 2008; Kale et al. 2013,2015)

NVSS data reprocessing for clusters without literature information

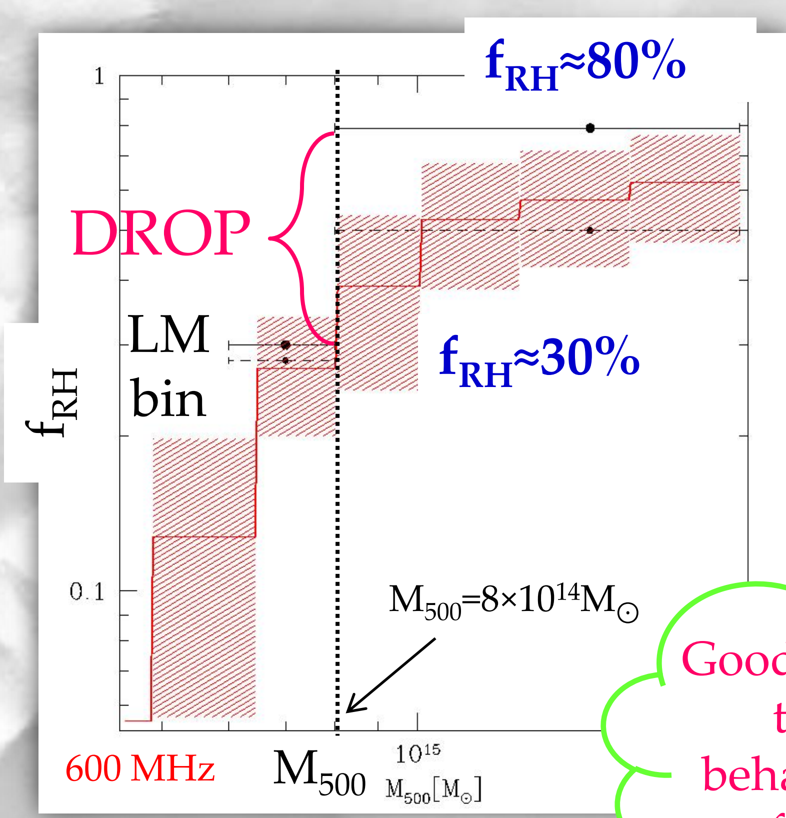
Total sample=75 clusters

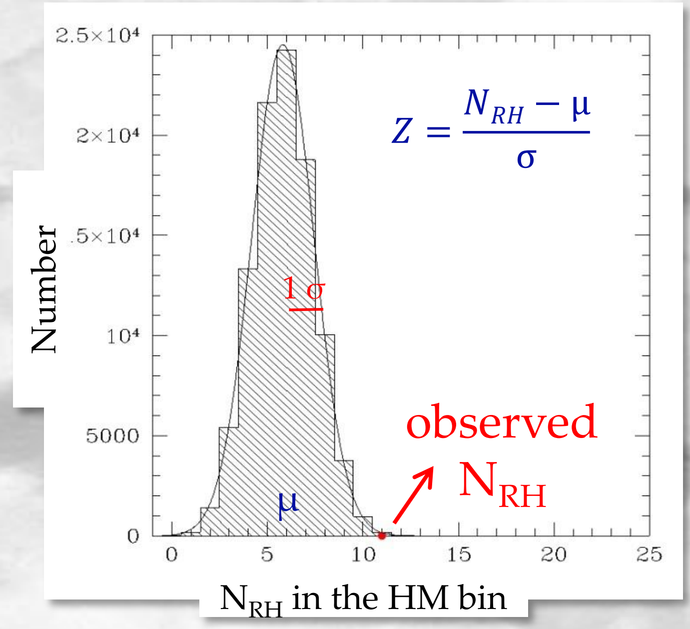
57 of which have information about the presence of RHs (mass completeness≈67%)

- Study the connection between the presence of RH and the cluster dynamical status (Chandra X-ray data)

Results: occurrence of RHs *(Cuciti et al. 2015)*

57 clusters , 24 host a RH





Distribution of the number of RHs in the HM bin after 10^5 Monte Carlo trials

Good agreement with the predicted behaviour o f_{RH} as a function of M

Monte Carlo analysis

↓

3.2 σ result

↓

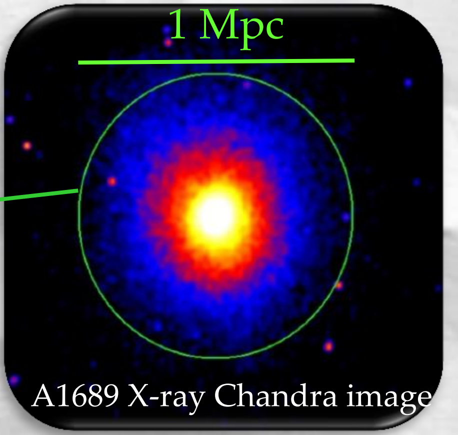
Chance probability < 10^{-4}

Present work:
add the remaining 18 clusters to complete the radio information on the 75 clusters of the sample (≈ 80% mass complete) (GMRT+VLA proprietary data analysis in progress).

Results: RH-merger connection

(*Cuciti et al. 2015*)

50 clusters out of 57 have available Chandra X-ray data



MORPHOLOGICAL PARAMETERS:

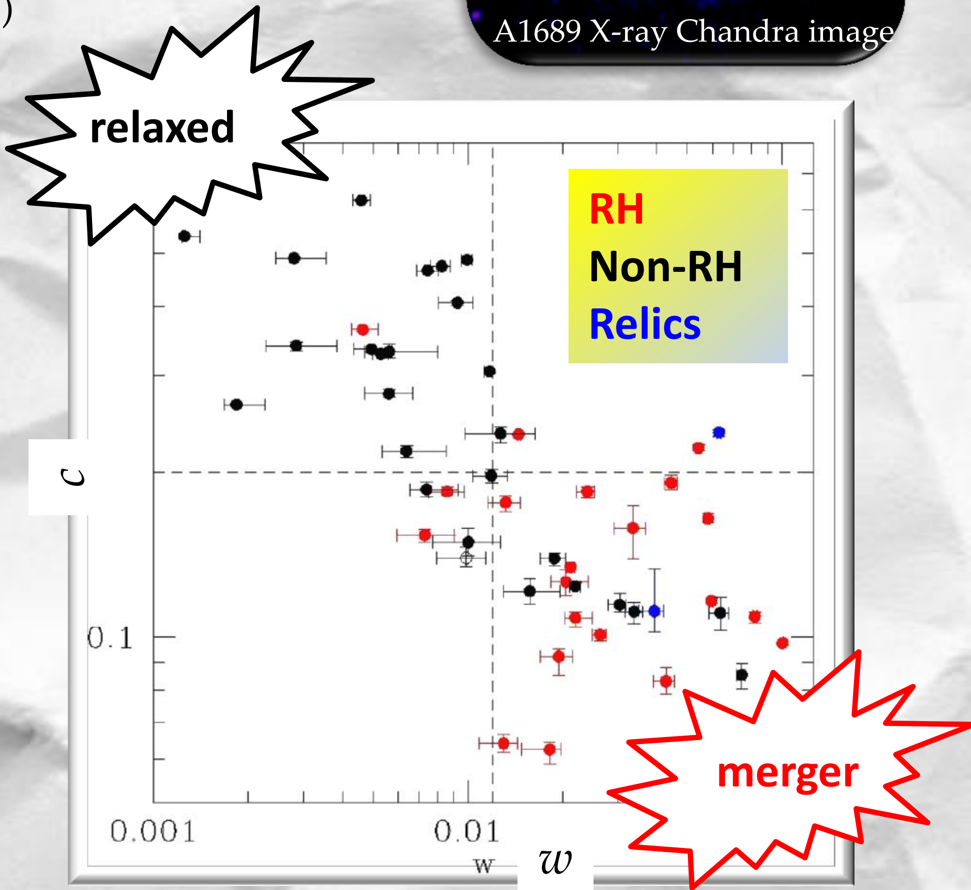
c = **concentration parameter** (*Santos et al. 2008*)

$$c = \frac{S(r < 100\ kpc)}{S(r < 500\ kpc)}$$

w = **centroid shift**

(*Poole et al. 2006; Maughan et al. 2008*)

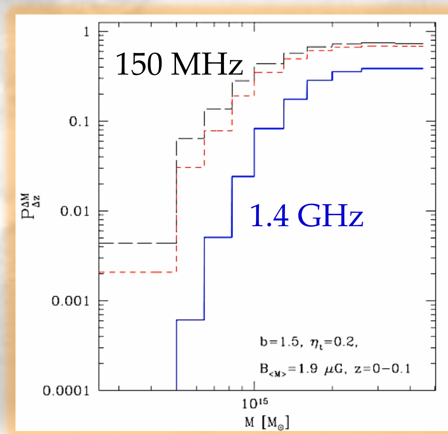
$$w = \left[\frac{1}{N-1}\sum(\Delta_i - \langle\Delta\rangle)^2\right]^{1/2} \times \frac{1}{R_{ap}}$$



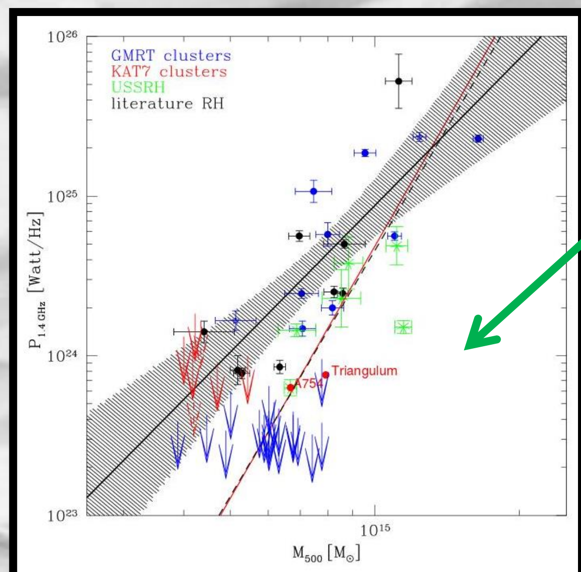
We confirm that RHs are hosted by merging systems, while non-RH clusters are relaxed, although there are some merging clusters without RH…….

First attempts to extend the analysis at lower masses

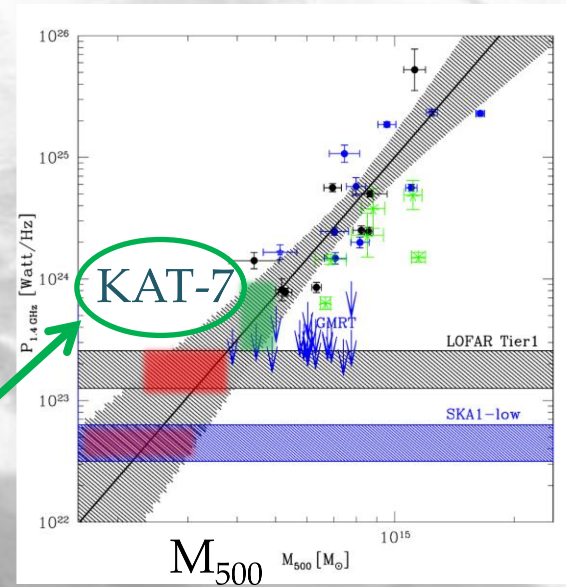
- Test the drop of f_{RH} in smaller systems ($M<6\times10^{14}M_{\odot}$): with SKA precursors KAT-7 (1.9 GHz) , MWA (90-200 MHz) observations of clusters with $M_{500}>4\times10^{14}M_{\odot}$ in z<0.1 clusters.



Cassano et al. 2008



Bernardi et al. 2015, submitted



Increase the statistics at low masses and confirm the existence of a steep correlation between P_R and M

- Future observations, with LOFAR and SKA, will allow to measure f_{RH} in very smaller systems, down to M_{500}~$10^{14}M_{\odot}$, where models predict a strong drop of the fraction of clusters with giant RH.

Summary

- We measured for the first time a **drop in the fraction of clusters with RHs**, f_{RH}, at low massive clusters.

- We tested the statistical significance of this result by running Monte Carlo simulations ⟶ **3.2 σ result.**

- We compared our observational results with the expectation of the turbulent re-acceleration model ⟶ good agreement between theory and observations.

- We are **adding the clusters without radio information** to the sample, this will allow us to finally test the existence of such a drop in a mass-selected sample of galaxy clusters (>80% mass completeness).

- We confirm that **RH** clusters are **merging systems**, while **non-RH** clusters are **relaxed.**

- We are **extending** the analysis **at lower masses** (KAT-7, MWA observations).

- We need future observations (**LOFAR**, **SKA**) to test the expectations of the turbulent re-accelration model in **very low massive clusters** and at **low observational frequencies.**

Secondary models

(e.g. Dennison et al. 1980)

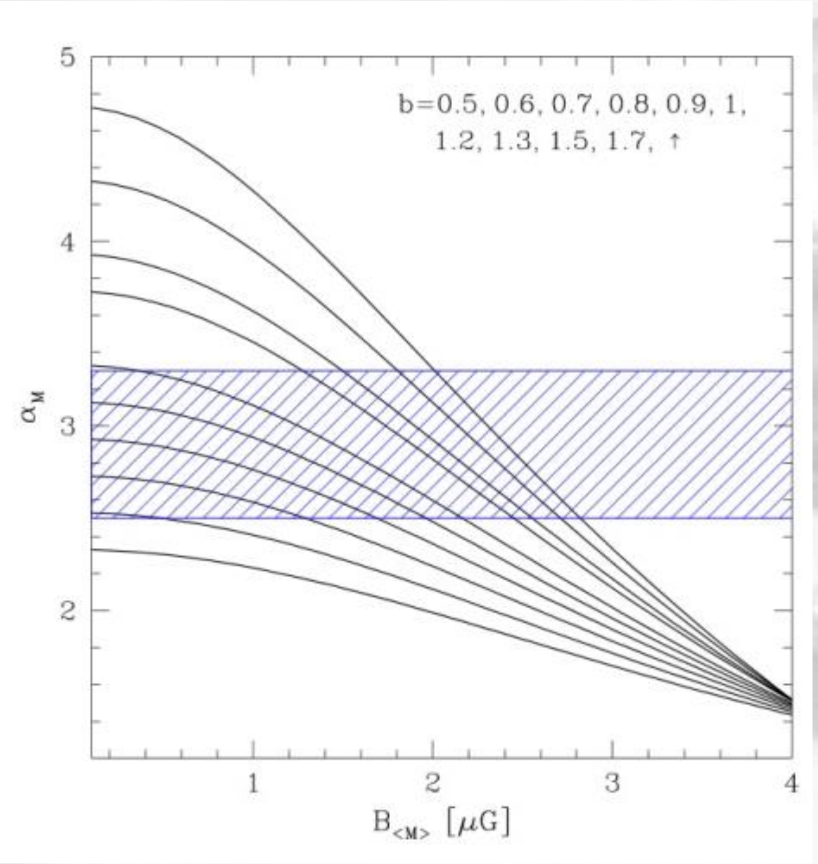
$$p + p \rightarrow \pi^0 + \pi^+ + \pi^-$$

$$\pi^0 \rightarrow \gamma\gamma$$

$$\pi^\pm \rightarrow \mu^\pm + \nu_\mu \quad \mu^\pm \rightarrow e^\pm \nu_\mu \nu_e$$

Disfavoured by:

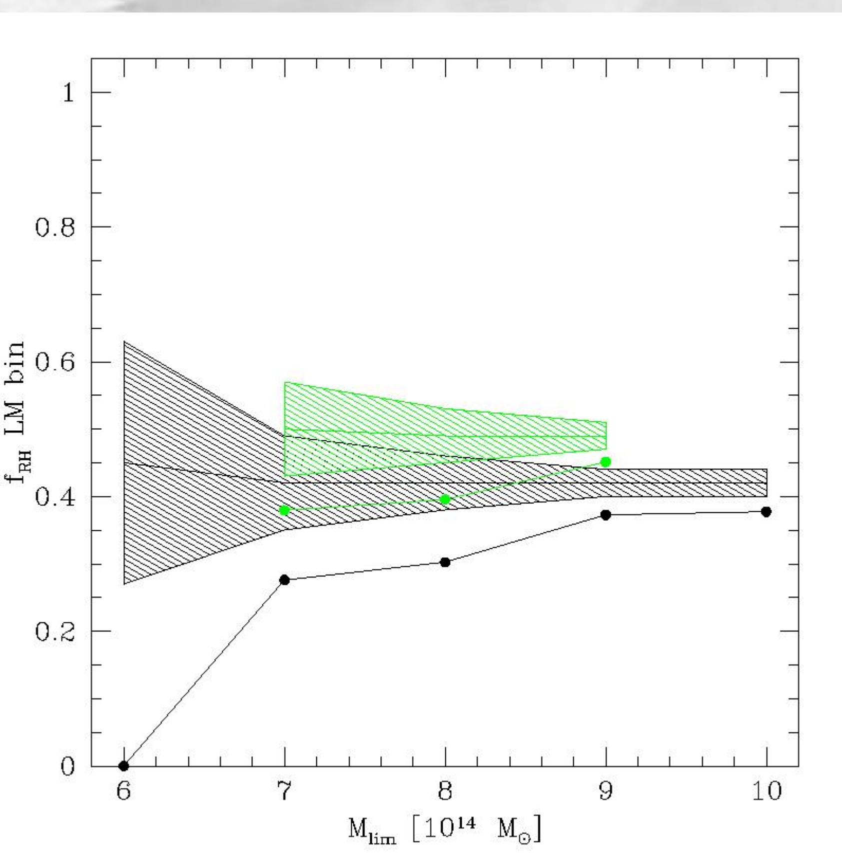
- non detection in γ-ray (*FERMI-LAT Collaboration*)
- RH with $\boldsymbol{\alpha}$>1.5 *(e.g. Brunetti et al. 2008, Dallacasa et al. 2009)*
- RH-merger connection

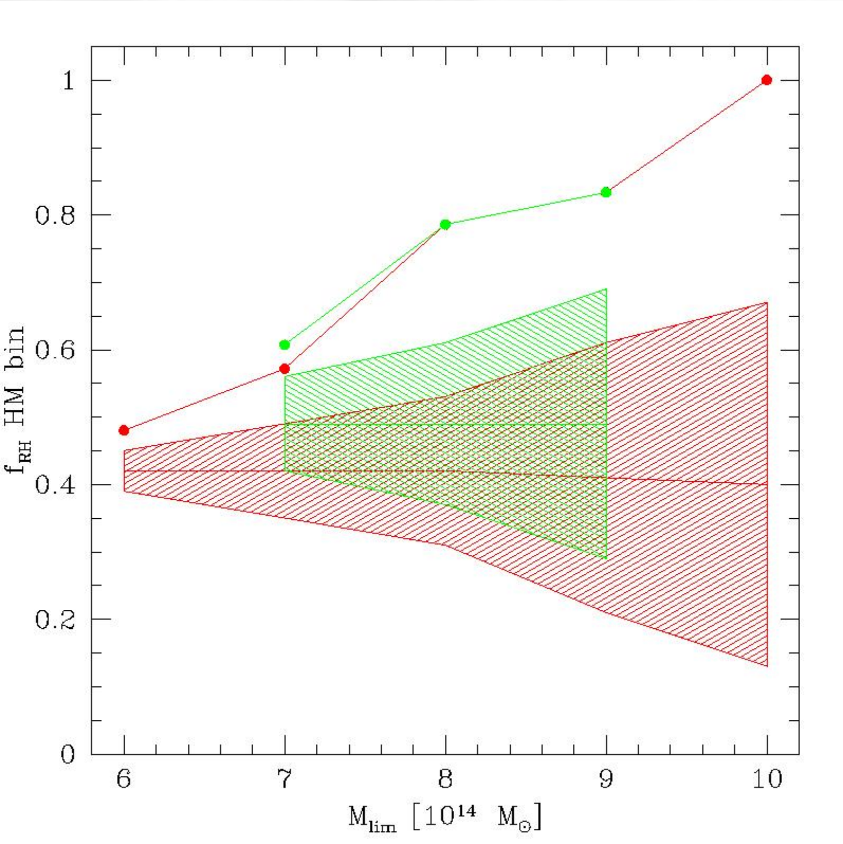


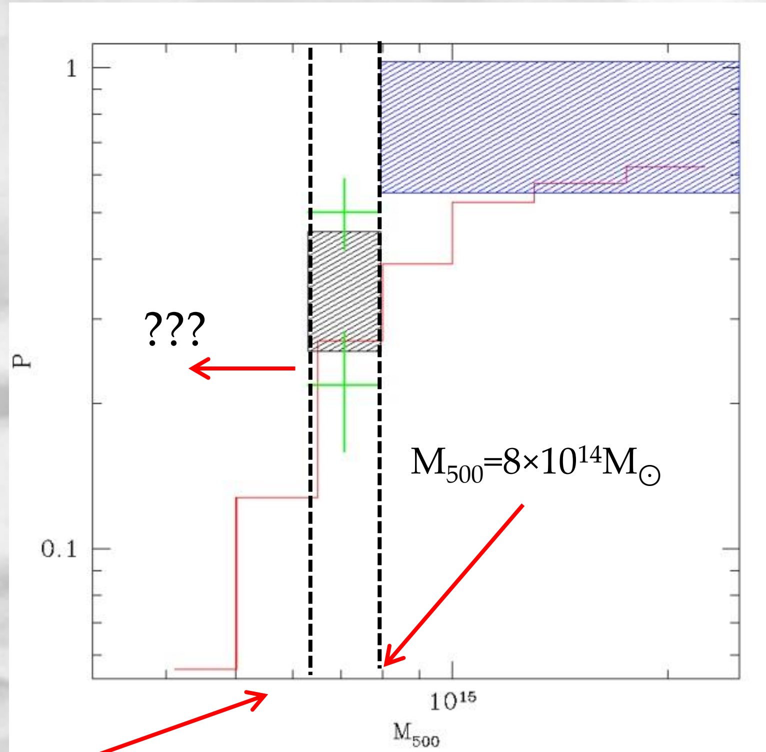
b=0.5, 0.6, 0.7, 0.8, 0.9, 1,
1.2, 1.3, 1.5, 1.7, ↑
α_M
$B_{<M>}$ [μG]

LM bin
$M_{500}<8\times10^{14}M_{\odot}$

HM bin
$M_{500}>8\times10^{14}M_{\odot}$



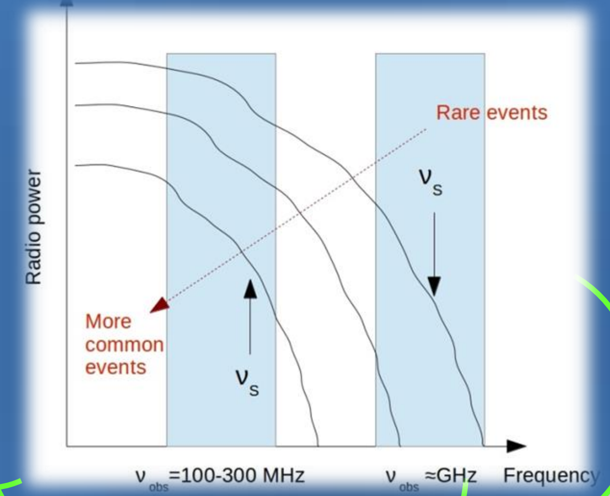


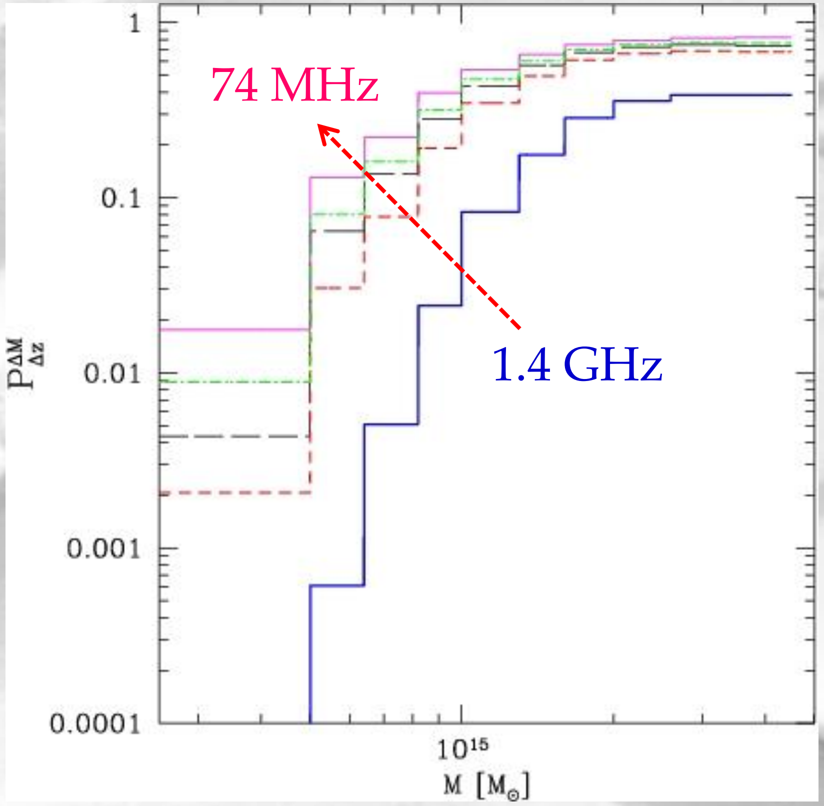


M_{500}=6×10^{14}M$_\odot$

$$B = B_{\langle M\rangle}\left(\frac{M}{\langle M\rangle}\right)^b \quad B_{\langle M\rangle}= 1.9\ \mu\text{G} \quad b=1.5 \quad \langle M\rangle = 1.6\times10^{15}\text{M}_\odot \quad \boldsymbol{\eta}_t=0.2$$

- Observe at low frequency with LOFAR





(Cassano et al. 2010)

Models predict:

- f_{RH} increases towards lower frequencies
- Less pronounced drop of f_{RH}