Occurrence of Radio Halos in galaxy clusters

Insight from a mass-selected sample

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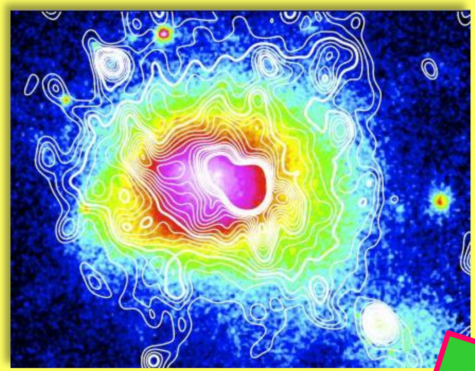
In collaboration with: Gianfranco Brunetti, Rossella Cassano, Daniele Dallacasa…

Radio Halos in galaxy clusters



Coma WSRT radio contours

Radio Halos

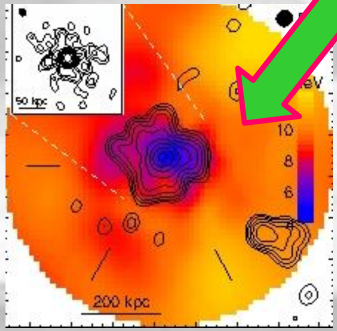
- ~ Mpc scale synchrotron diffuse sources
- Low surface brightness (~ μJy/arcsec^2 at 1.4 GHz)
- Unpolarised
- Steep spectrum ($\alpha \approx 1.2$-1.3, $J(\nu) \propto \nu^{-\alpha}$)

Relativistic (~Gev) e$^-$

+

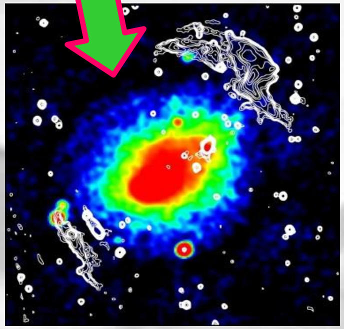
Magnetic field (~μG)

Mini Halos



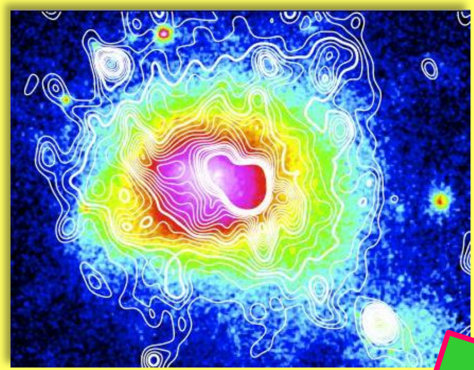
RXC J1504.1-0248 GMRT radio contours

Relics



A3667 ATCA radio contours

Radio Halos in galaxy clusters



Coma WSRT radio contours

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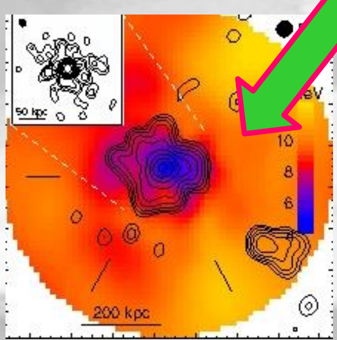
+
Magnetic field (~μG)

Turbulent re-acceleration models

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

Mini Halos



RXC J1504.1-0248 GMRT radio contours

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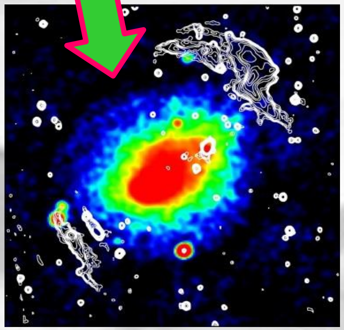
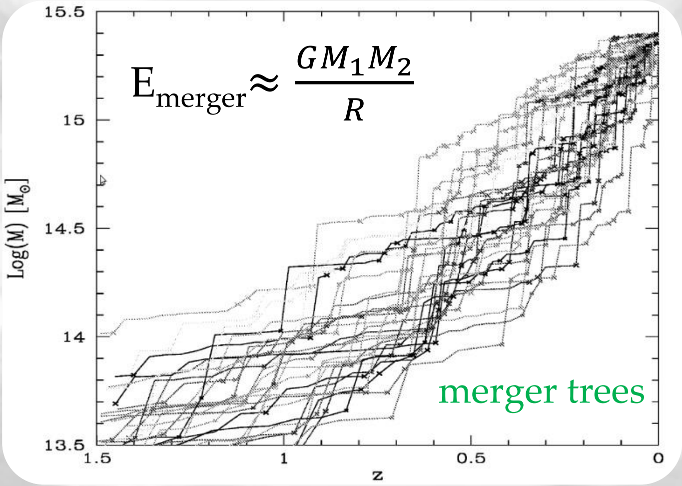


Statistics of RHs from the turbulent re-acceleration model *(Cassano & Brunetti 2005, Cassano et al. 2006)*



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

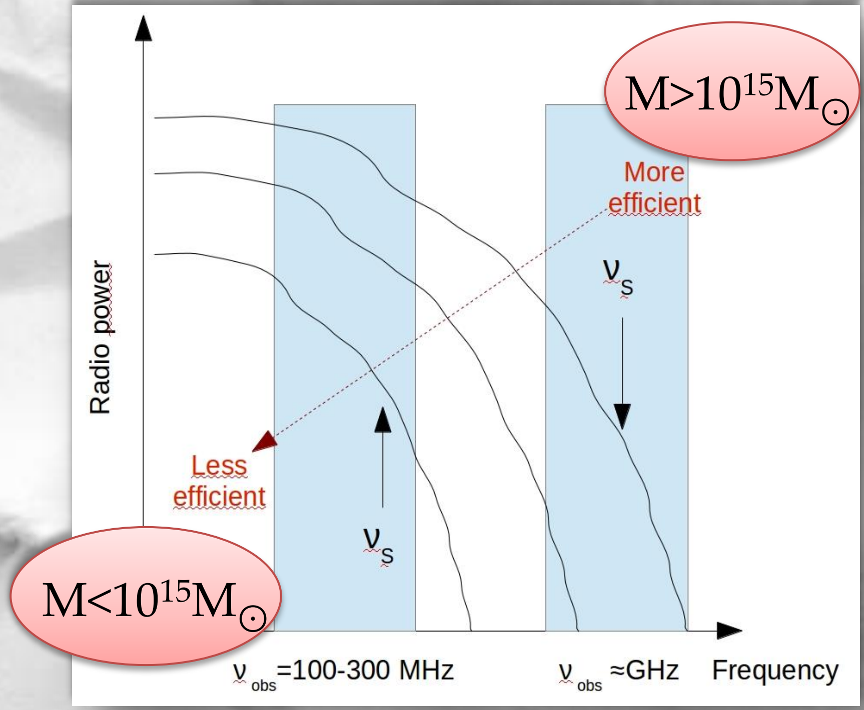
$$\nu_s \propto \langle B \rangle \gamma_b^2 \propto \frac{\langle B \rangle \chi 2}{(\langle B \rangle^2 + B^2_{CMB})^2}$$

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

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

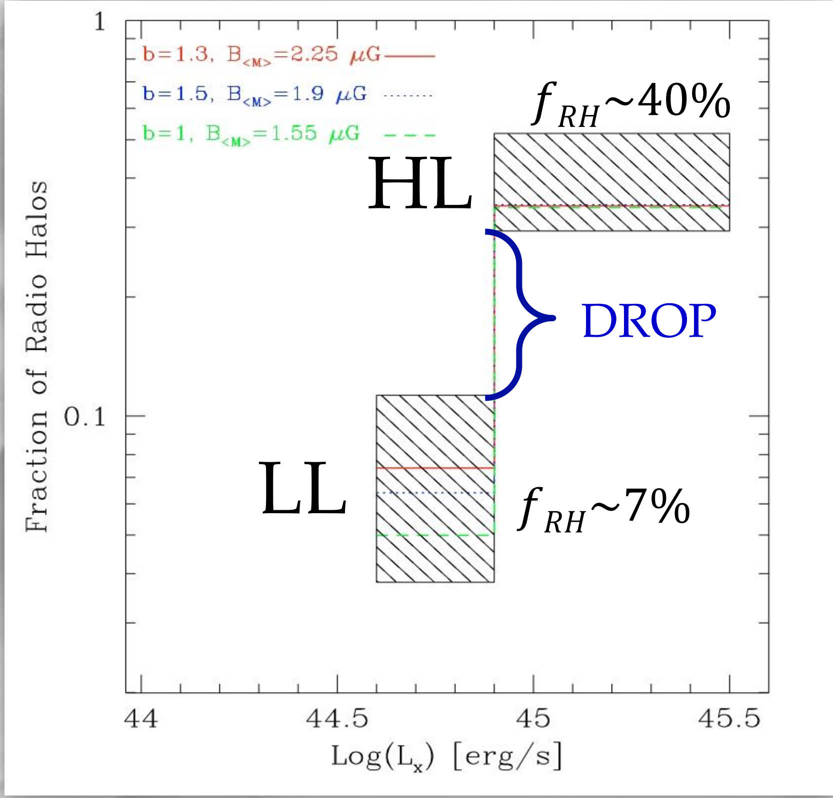
Expectations on the **statistical properties of RHs:**

- f_{RH} increases with M
- Existence of Ultra Steep Spectrum Radio Halos (USSRH)
- f_{RH} increases towards low observational frequencies



Fraction of clusters with RHs (f_{RH}) in the GMRT RH Survey

NVSS-XBAC sample at z<0.2 *(Giovannini et al. 1999)*
+
GRHS at 0.2<z<0.35 *(Venturi et al. 2007, 2008)*



Cassano et al. 2008

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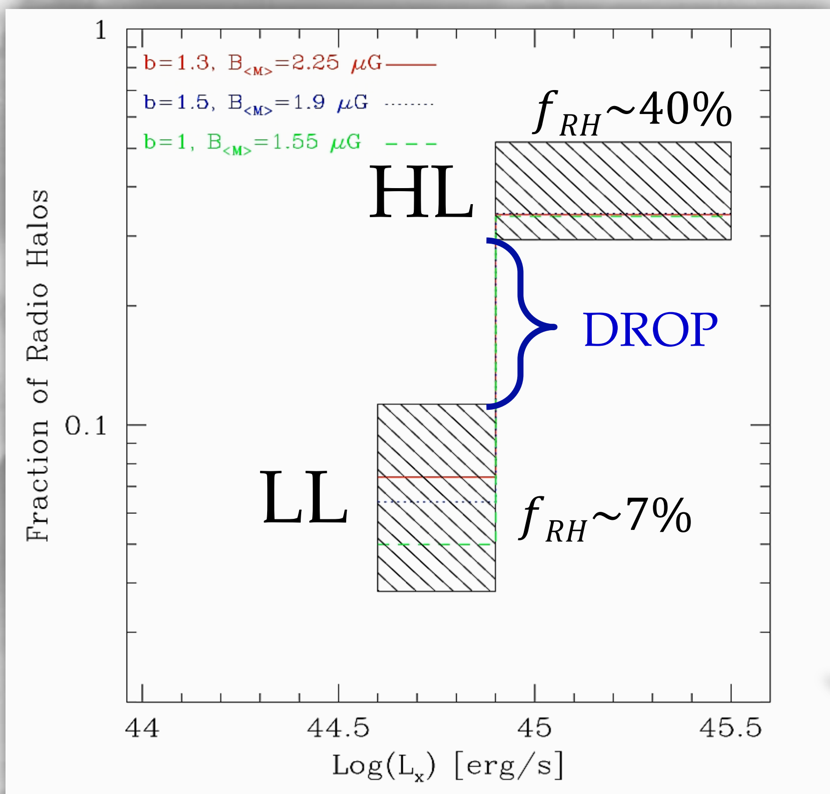
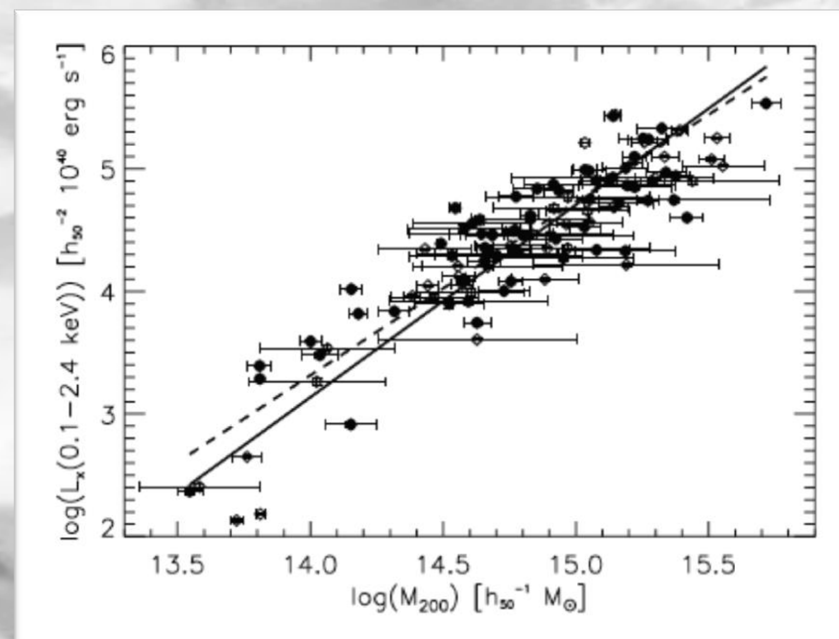
BUT
$L_X \Rightarrow M_V$
possible biases…

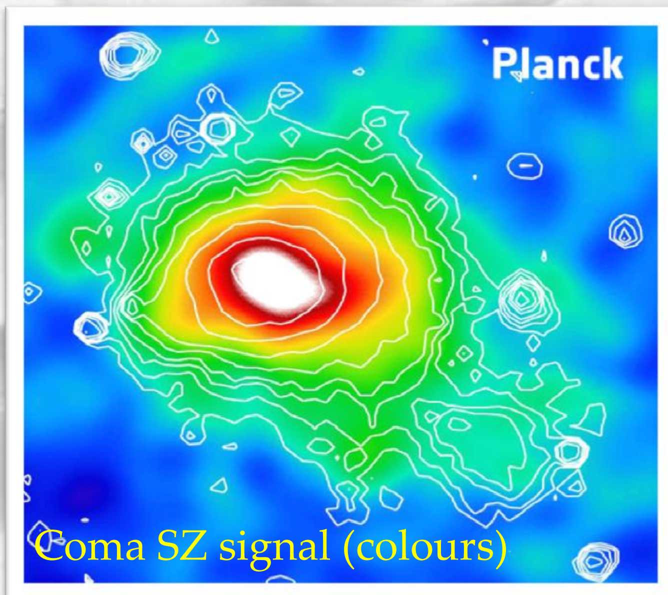


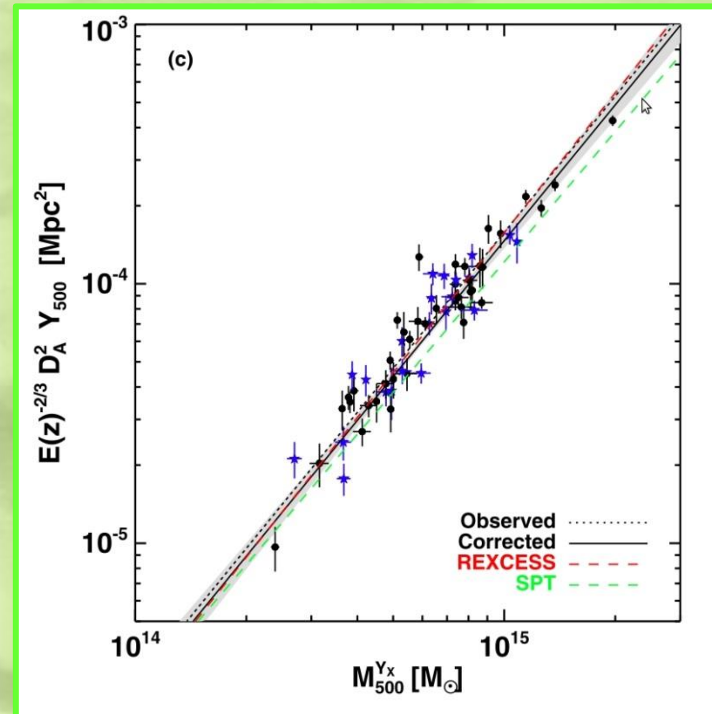
Cassano et al. (2008)



Reiprich & Böhringer (2002)

One possibility to overcome these problems is the **SZ effect**





Compton parameter: $y \propto \int_0^\infty n_e T_e dl$

Y_{500}-M_{500} correlation
(Planck Collaboration 2011)

Integrated Compton parameter:

SZ signal $\propto Y \equiv \int_\Omega y \, d\Omega \propto \frac{1}{D^2_A} \int_0^\infty dl \int_A n_e T_e dA$

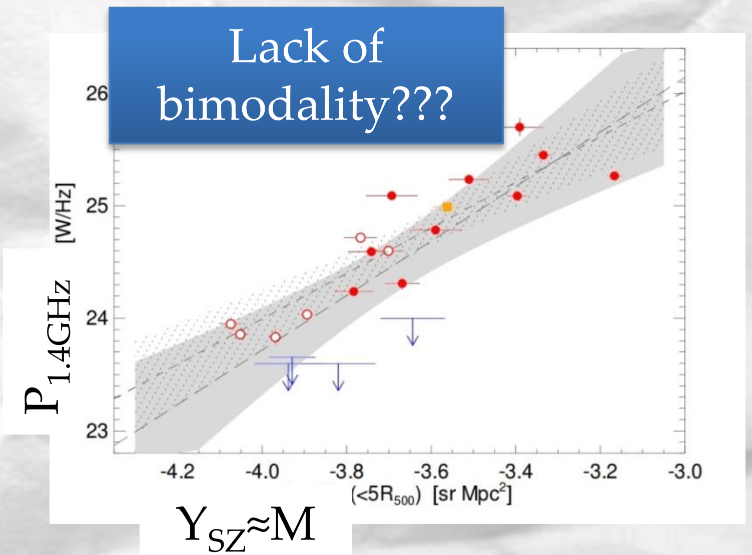
Planck Satellite

$$Y_{500} D^2_A \propto f_{gas} M^{5/3}$$

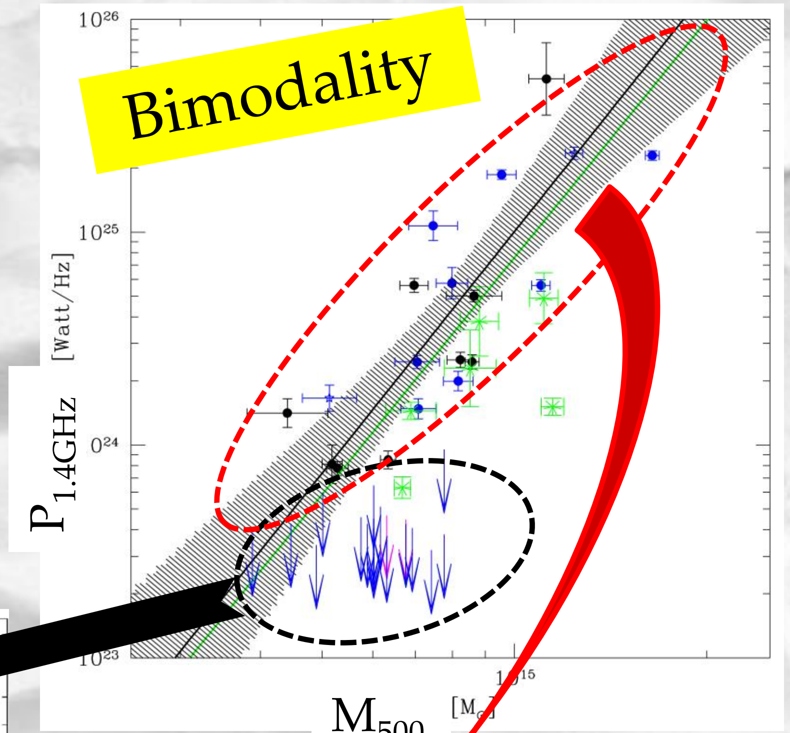
large sample of almost mass-selected galaxy clusters *(Planck Collaboration 2014)*

The SZ effect can be used as a proxy for the cluster mass

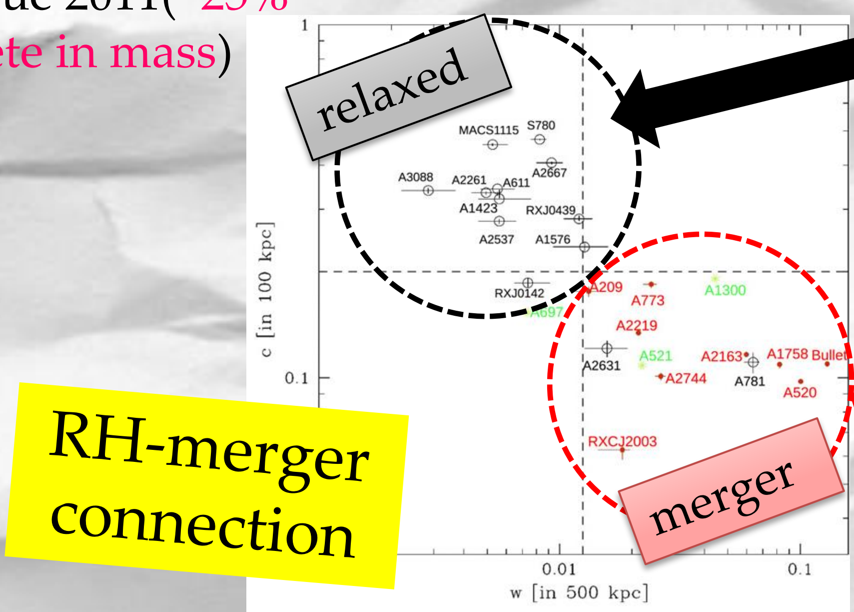
First results on SZ-selected samples



Basu (2012) with Planck catalogue 2011(~25% complete in mass)



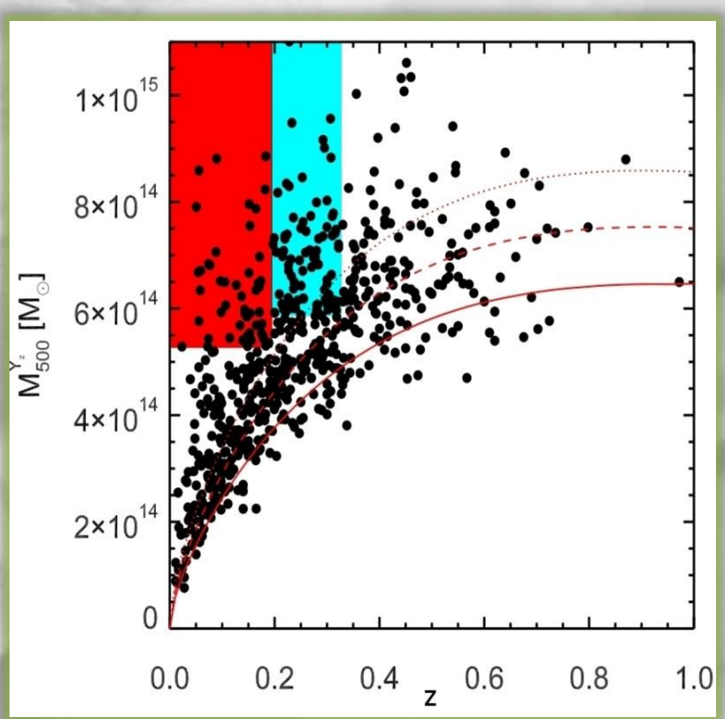
Cassano et al. (2013) with Planck catalogue 2013 (six times the 2011 catalogue and ~80% complete in mass)



However, the incompleteness of the sample did not allow to measure f_{RH} as a function of M

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)

NVSS data reprocessing for clusters without literature information

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

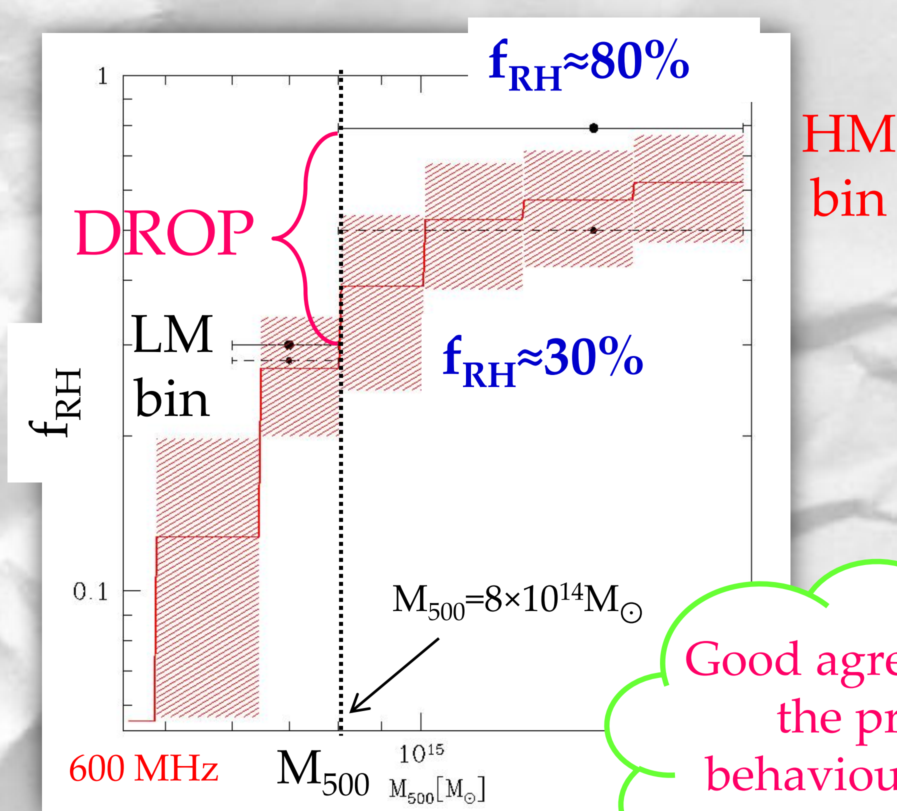
Total sample=75 clusters

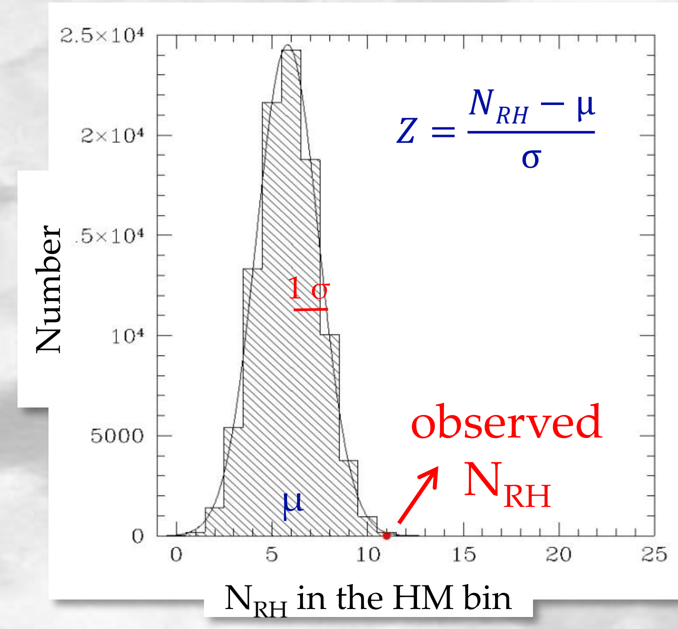
57 of which have information about the presence of RHs (mass completeness≈67%)

- 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

↓

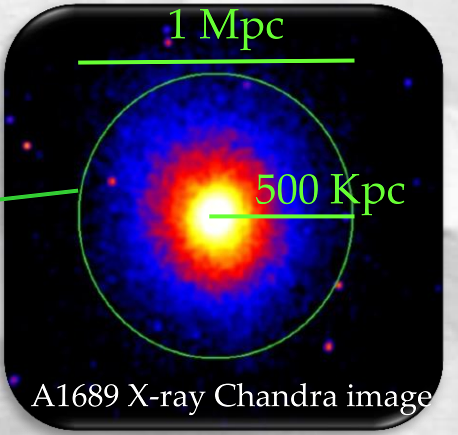
Chance probability < 10^{-4}

Present work:
add the remaining 18 clusters to complete the radio information on the 75 clusters of the sample (≈ 80% mass complete) (GMRT+JVLA 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:

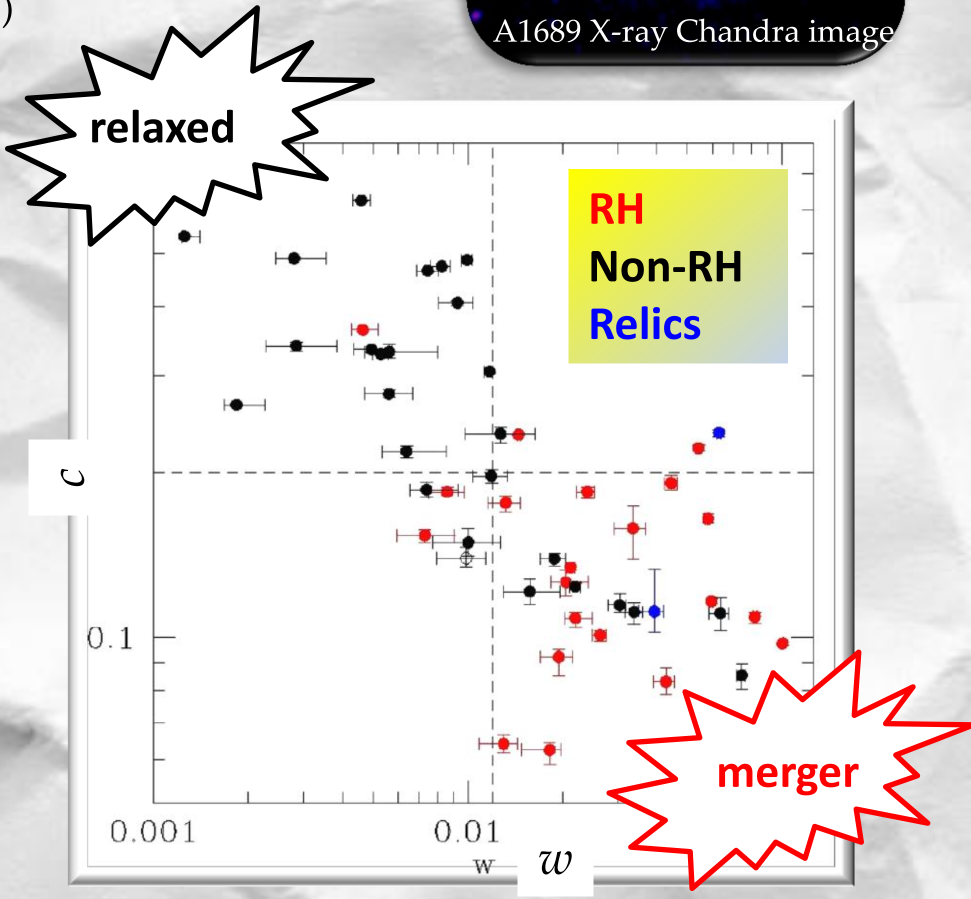
c = concentration parameter (*Santos et al. 2008*)

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

w = centroid shift

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

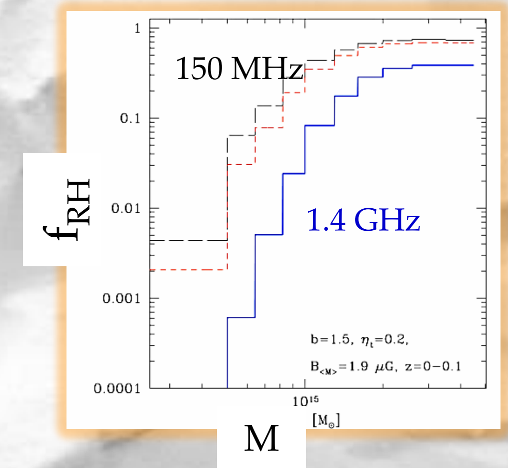
$$w = \left[\frac{1}{N-1}\sum(\Delta_i - \langle\Delta\rangle)^2\right]^{1/2} \times \frac{1}{R_{ap}}$$



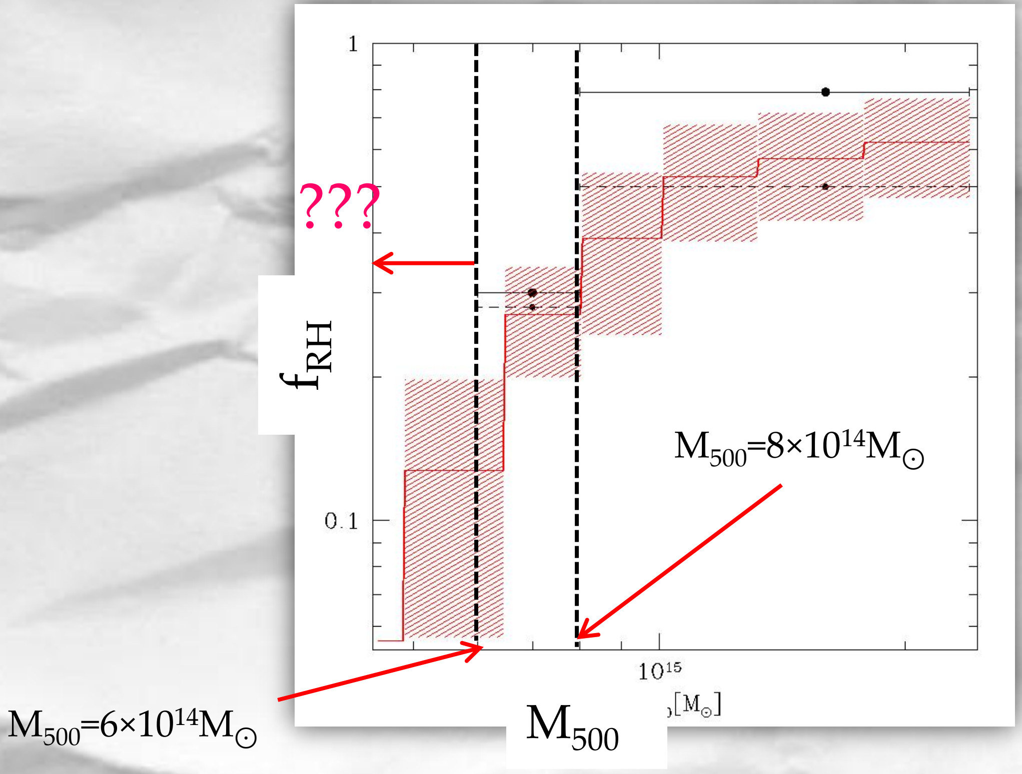
We confirm that RHs are hosted by merging systems, while non-RH clusters are relaxed, although there are some merging clusters without RH…….

Future prospects

- 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 (Gianni Bernardi' s talk).

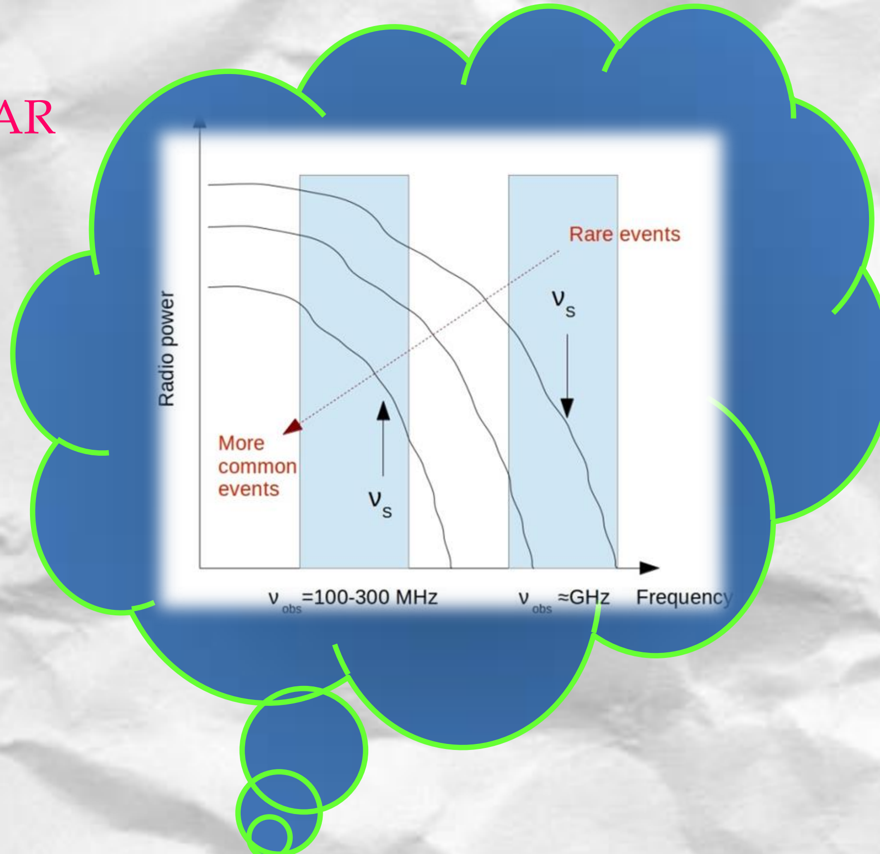


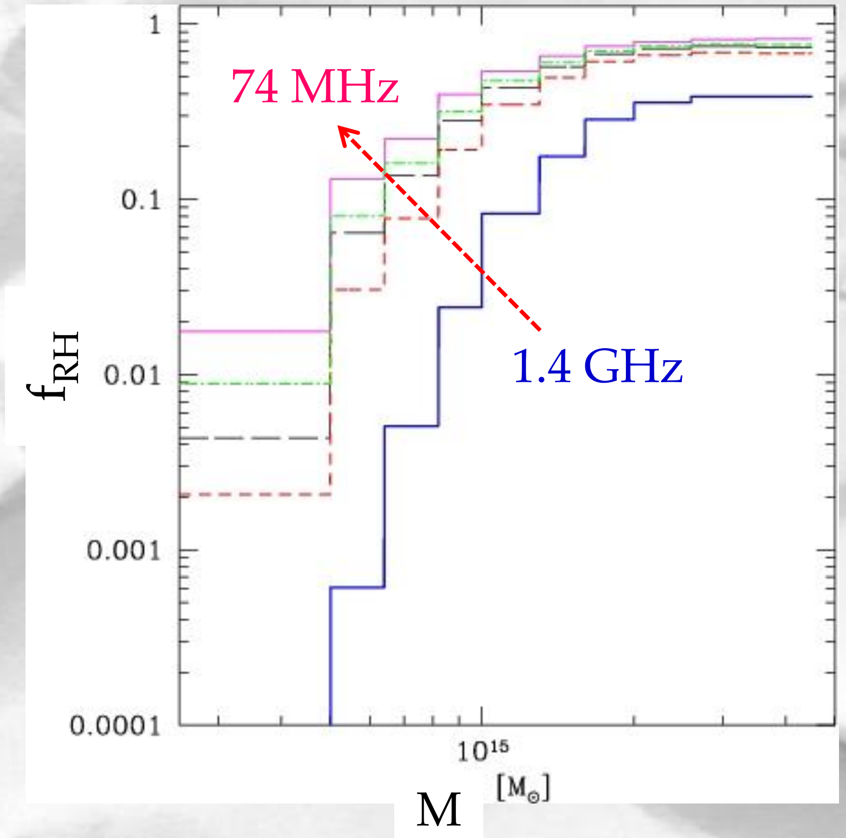
Cassano et al. 2008



- Future observations, with LOFAR and SKA, will allow to measure f_{RH} in very smaller systems, down to $M_{500}\sim10^{14}M_\odot$, where models predict a strong drop of the fraction of clusters with giant RH.

❖ Observe at low frequency with LOFAR





(Cassano et al. 2010)

Models predict:

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

Summary

- We measured for the first time a **drop in the fraction of clusters with RHs**, f_{RH}, at low massive clusters (**3.2 σ result** from Monte Carlo simulations).

- We compared our observational results with the expectations 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 confirmed that **RH** clusters are **merging systems**, while **non-RH** clusters are **relaxed.**

- We are **extending** the analysis **at lower masses** with KAT-7 (Bernardi's talk) and 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)

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

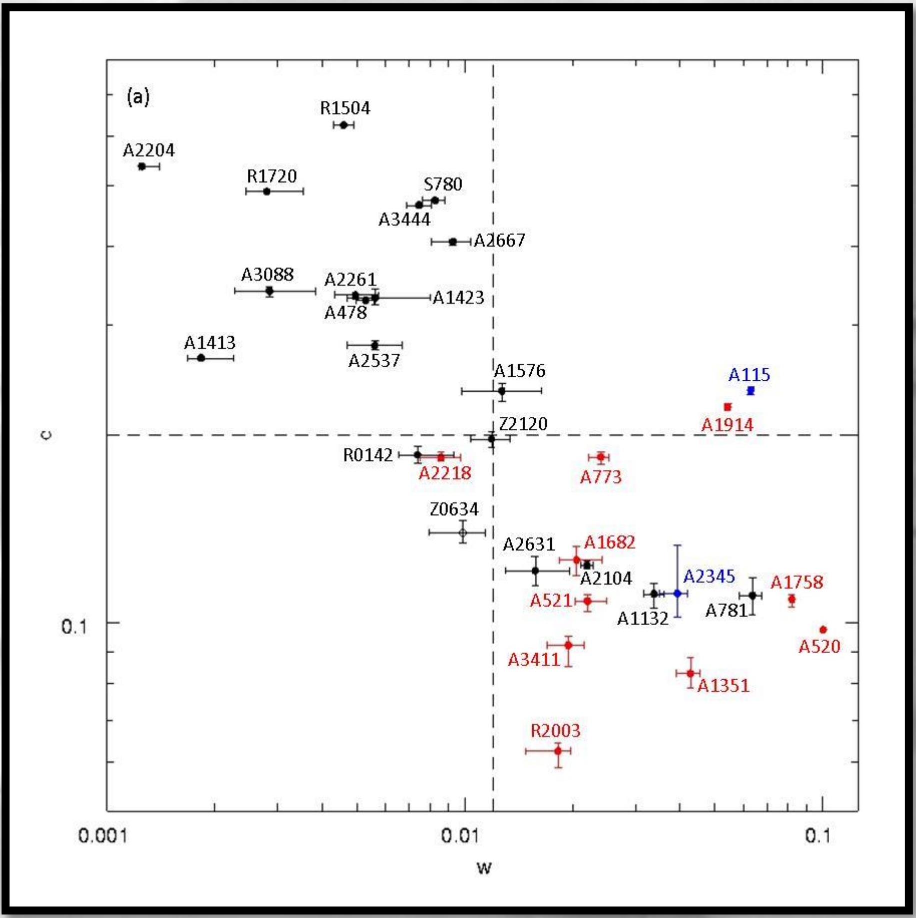
$$\pi^0 \rightarrow \gamma\gamma$$

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

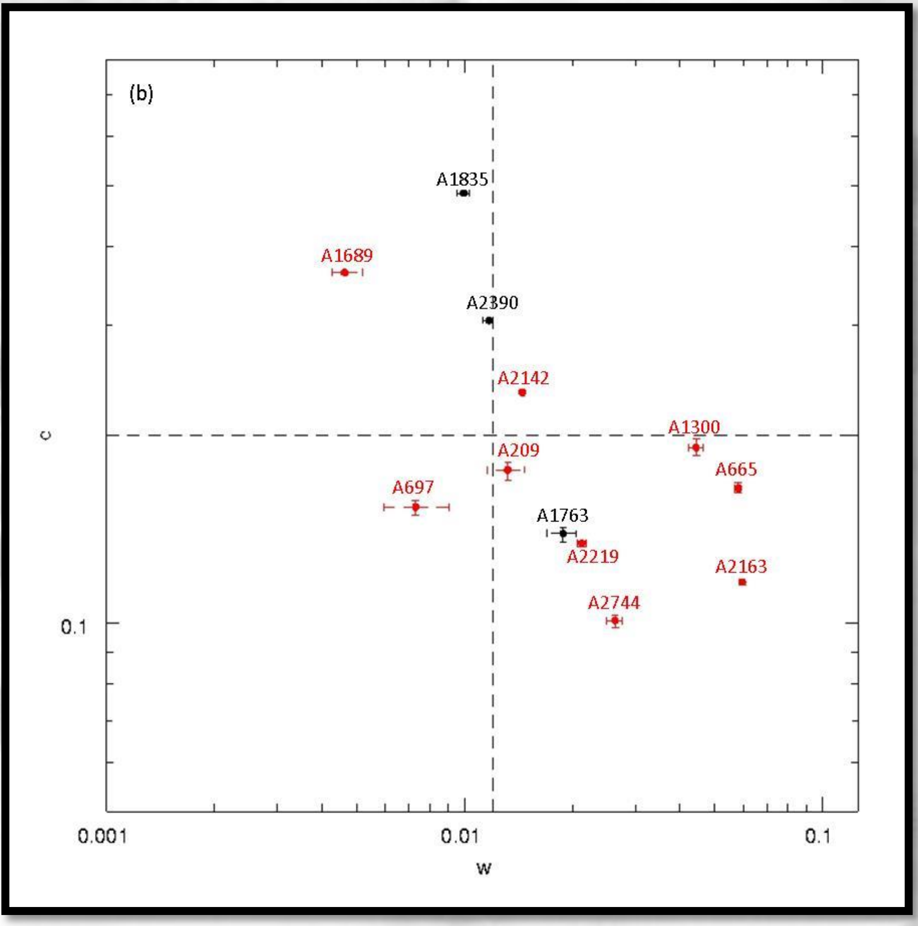
Disfavoured by:

- 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

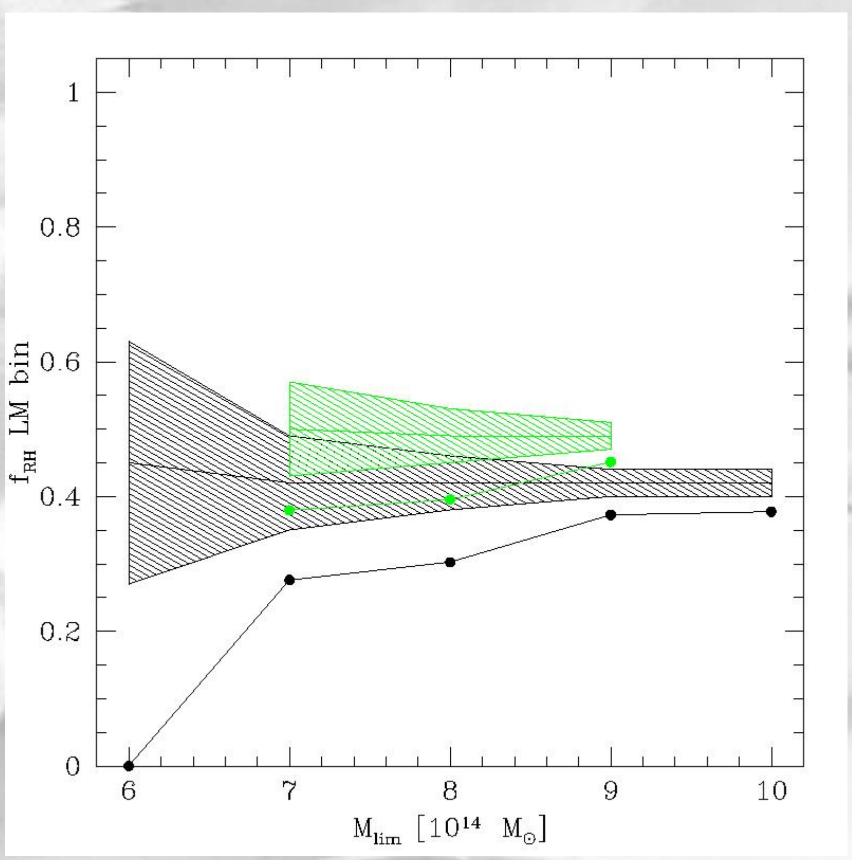
LM bin


(a)
R1504
A2204
R1720
S780
A3444
A2667
A3088
A2261
A1423
A478
A1413
A2537
A1576
A115
A1914
Z2120
R0142
A2218
A773
Z0634
A2631
A1682
A2104
A2345
A1758
A521
A1132
A781
0.1
A520
A3411
A1351
R2003
0.001
0.01
0.1
w
c

HM bin


(b)
A1835
A1689
A2390
A2142
A1300
A209
A665
A697
A1763
A2219
A2163
A2744
0.1
0.001
0.01
0.1
w
c

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



HM bin
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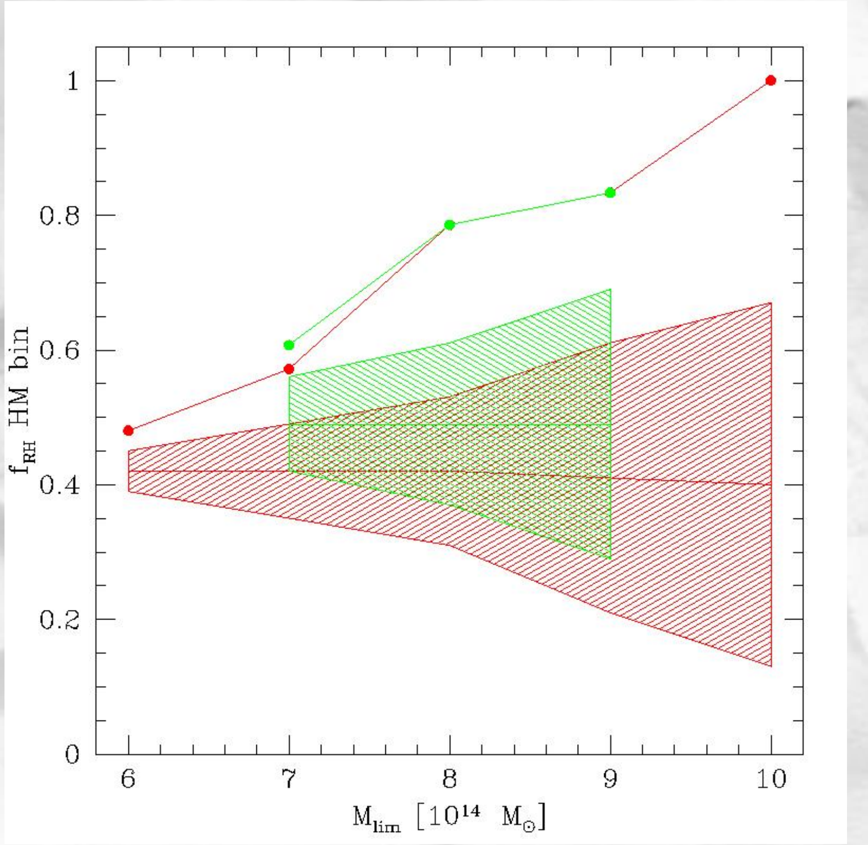

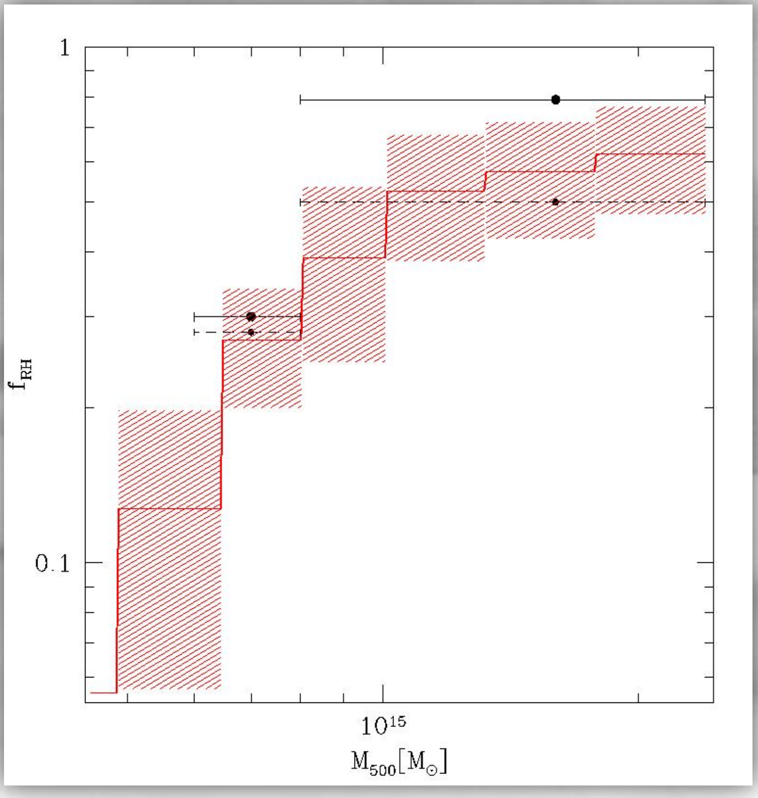

$$B = B_{\langle M \rangle} \left(\frac{M}{\langle M \rangle} \right)^b$$

$B_{\langle M \rangle} = 1.9\ \mu G$ $b = 1.5$

$\langle M \rangle = 1.6 \times 10^{15} M_\odot$ $\boldsymbol{\eta}_t = 0.2$