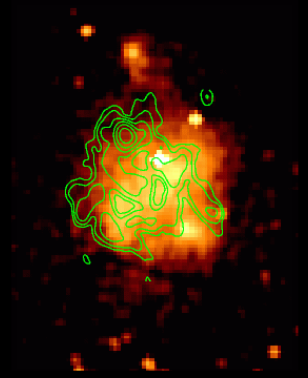
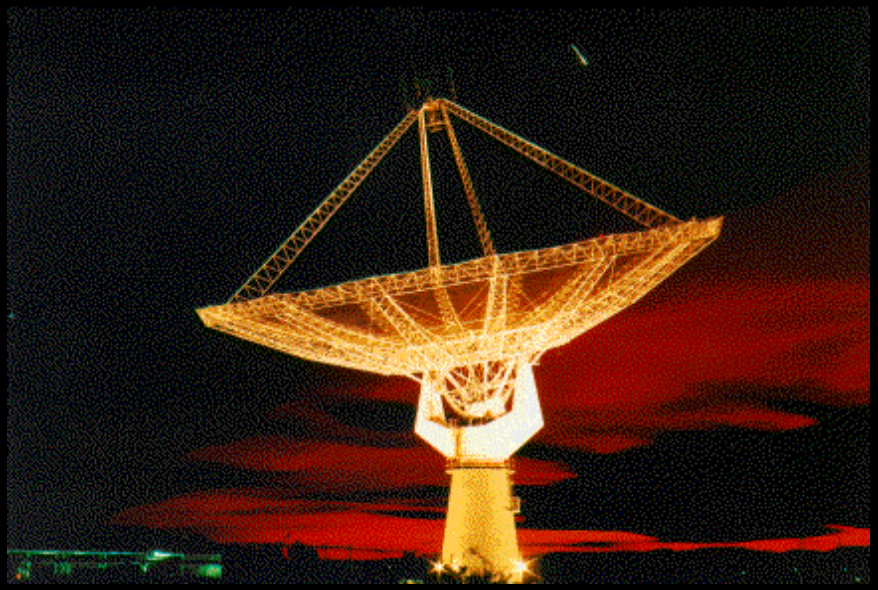
Ten years of GMRT Radio Halo Survey and beyond

Tiziana Venturi
INAF, ORA



&

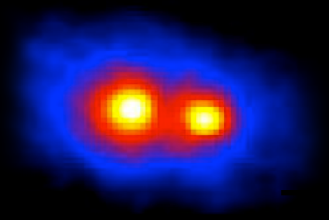
G. Brunetti, R. Cassano,
D. Dallacasa, S.
Giacintucci, R. Kale



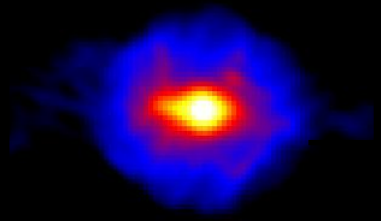
Historical models to account for the origin of halos

Primary models - in-situ re-acceleration of relativistic electrons by MHD turbulence *(e.g., Brunetti et al. 2001, 2004; Petrosian 2001; Fujita et al. 2003; Petrosian & Bykov 2008…)*

Merger



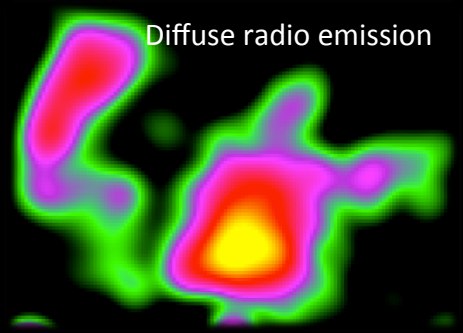
Shocks and turbulence



Vazza et al. 2009

Particle acceleration

Diffuse radio emission



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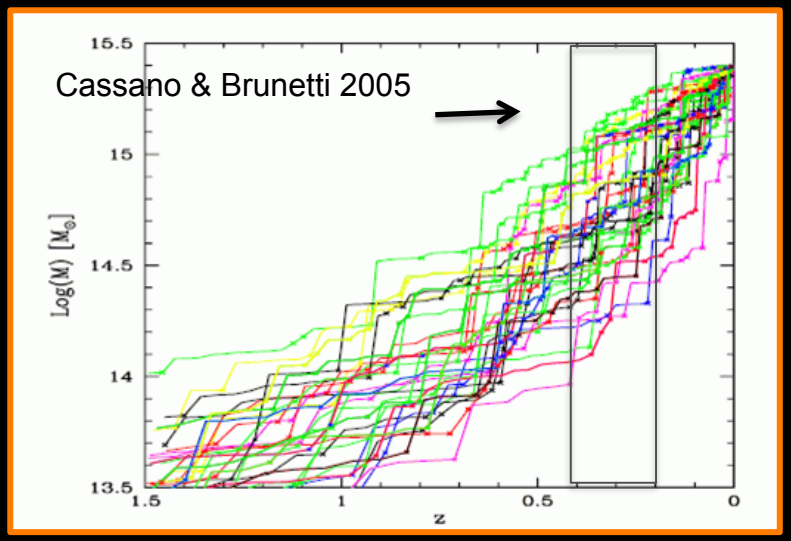

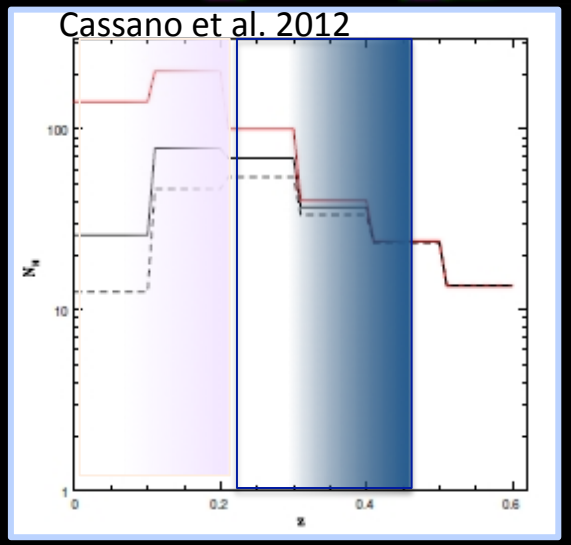

Brief historical background of observations and knowledge of diffuse cluster scale sources

Coma C – Large* 1959;
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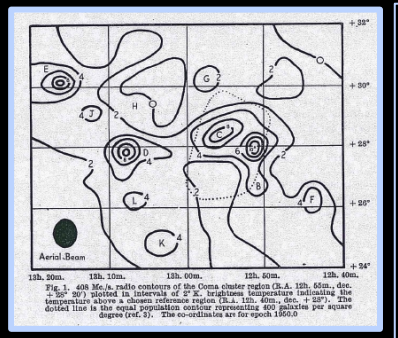

Fig. 1. 408 Mc/s. radio contours of the Coma cluster region (R.A. 12h. 55m., dec. + 28° 30') plotted in intervals of 2° K. brightness temperature indicating the temperature above a chosen reference region (R.A. 12h. 40m., dec. + 23°). The dotted line is the equal population contour representing 400 galaxies per square degree (ref. 3). The co-ordinates are for epoch 1950.0

1959 – Discovery of diffuse emission in the Coma cluster

1959 1995 2001 2005 2015

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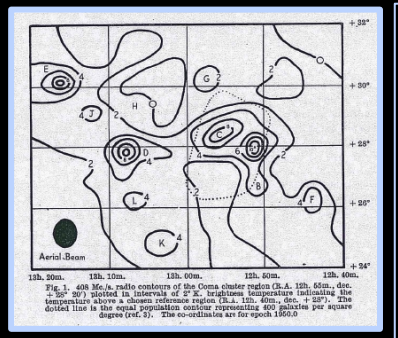

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Clus	Size kpc	$P_{1.4}$ W Hz^{-1}	P_{tot} erg s^{-1}	α	u_{min} erg cm^{-3}	U_{min} erg	H_{eq} μG	Ref
A1656	550	3.2×10^{23}	6.1×10^{40}	1.34	2.4×10^{-14}	5.0×10^{58}	0.5	[3]
A2163	600	-	3×10^{41}	-	5.4×10^{-14}	8.0×10^{58}	0.8	[4]
A2218	550	7.9×10^{22}	9.0×10^{39}	1.1	4.3×10^{-14}	5.3×10^{57}	0.7	[5,2]
A2255	725	2.5×10^{23}	1.6×10^{41}	$\gtrsim$1.5	3.1×10^{-14}	5.3×10^{58}	0.6	[6,2]
A2256	700	1.2×10^{23}	1.6×10^{41}	1.9	1.1×10^{-14}	1.1×10^{58}	0.5	[7,8]
A2319	660	5.1×10^{23}	9.2×10^{40}	1.3	3.7×10^{-14}	7.1×10^{58}	0.6	[2]

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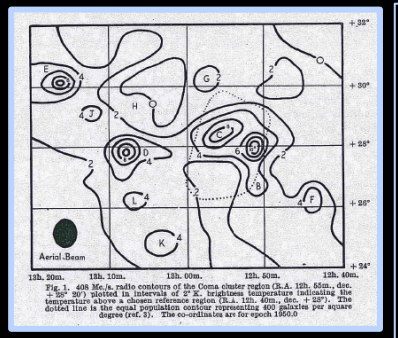

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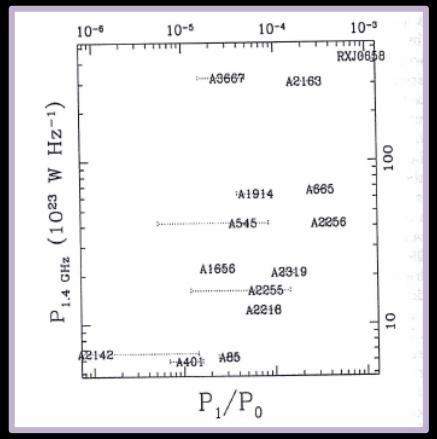
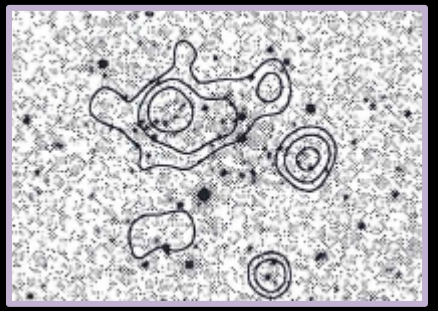


Halo and Relic sources detection rate

L_x(0.1–2.4 keV) 10^{44} erg s^{-1}	Relics %	Halos %	Total %
0–3	1.3(1)	–	1.3
3–5	3.0(1)	3.0(1)	6.0
5–7	4.5(1)	4.5(1)	9.0
7–10	16.1(5)	9.7(3)	25.8
>10	8.3(1)	25.0(3)	33.3



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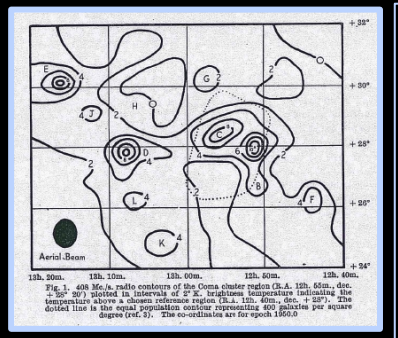

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Turbulent re-acceleration model and start of GMRT RH surveys

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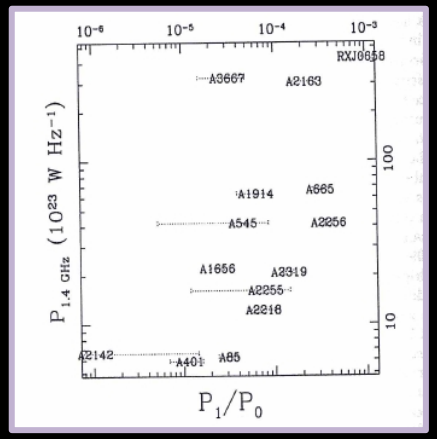

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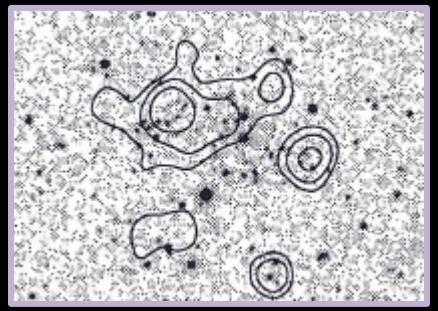

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Initial goals of the GMRT Radio Halo Survey

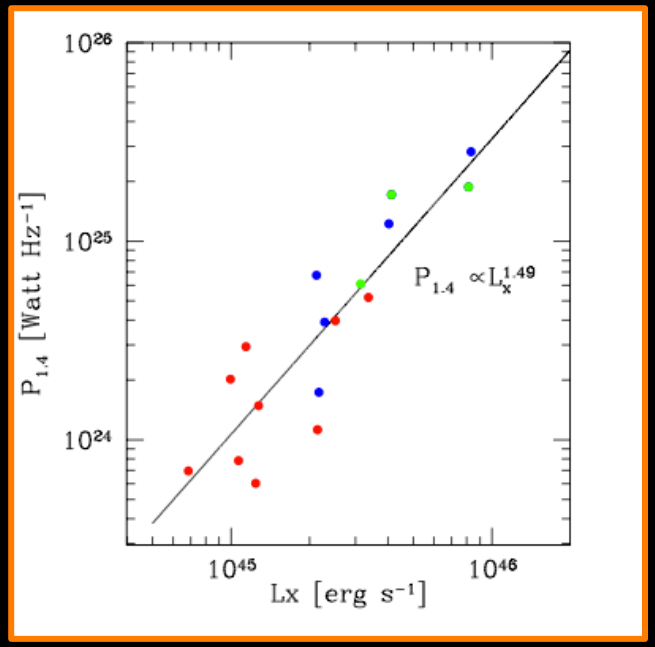
From the original proposals

(1) The discovery of new diffuse radio sources associated with the selected clusters. Increasing the number of radio halos and radio relics is crucial for our understanding of these phenomena.

(2) The measure, for the first time, of the occurrence of radio halos in massive galaxy clusters in the redshift bin $z = 0.2 \div 0.4$.

(3) We will constrain the dependence of their occurrence with cluster mass.

(4) We will combine the statistics of radio halos obtained in the redshift bin z=0 0.2 (from the literature, e.g. Giovannini et al. 1999, New Astronomy 4, 141) with the statistics in the bin z=0.2–0.4 (our project) and test the predictions of our MTM model (e.g. Figs.1 & 2).



State-of-the-art L_x-$P_{1.4GHz}$ correlation as of July 2004 (Cycle 7 GMRT Call for Proposals).

The E-GMRT Radio Halo Cluster Survey 2005 - 2015

1. L_X (0.1-2.4 keV) $> 5 \times 10^{44}$ erg s^{-1};
2. $0.2 < z < 0.4$;
3. $\delta > -30°$ for the REFLEX and eBCS samples.

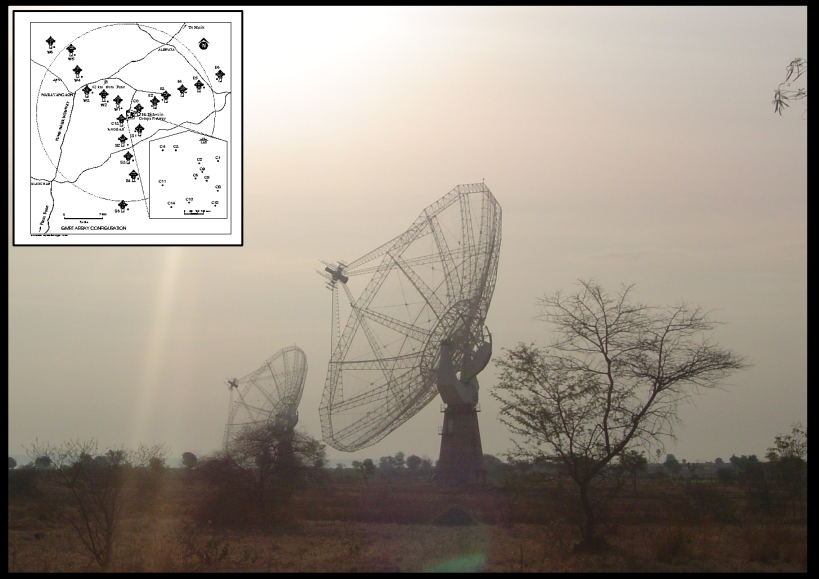
→ 65 clusters in total

The survey was carried out in various steps

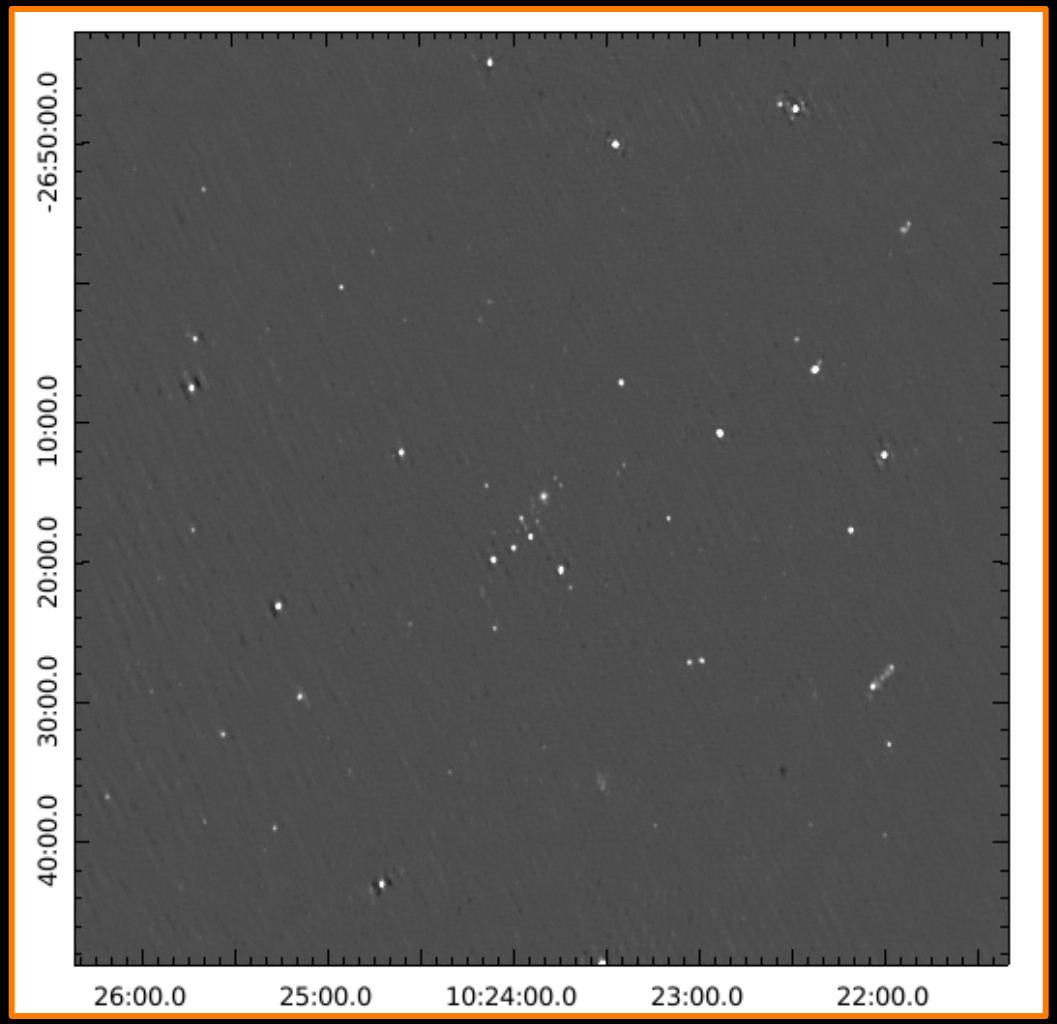
- GMRT RH Survey (observations at 610 MHz, Venturi et al 2007, 2008)
- Extended GMRT RH Survey (observations at 610/240 MHz, Kale et al. 2013 & 2015)

Furthermore

- GMRT 325 & 235 MHz follow up of radio halos (Venturi et al. 2013)
- GMRT 153 MHz follow up of special cases (Macario et al. 2013)
- X-ray imaging from Chandra for the full sample (archive & proprietary data)



Simultaneous sensitivity to large and small angular scales, ideal for the goals of the project



Field of view at 610 MHz ≈ 50’
Average rms ≈ 50 - 70 μJy/b
(from 25 to 100 μJy/b)

Imaging at resolutions from 5-6”arcsec (full res) to 30”-40”

Point source subtraction (in the uv plane) to inspect the central region

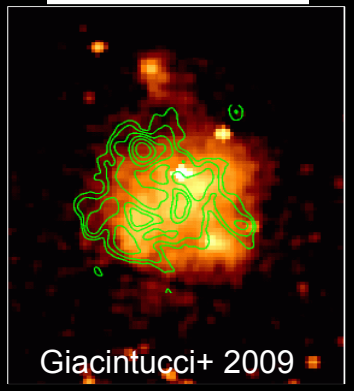
Diffuse emission or
UPPER LIMIT

New giant radio halos, relics and mini-halos

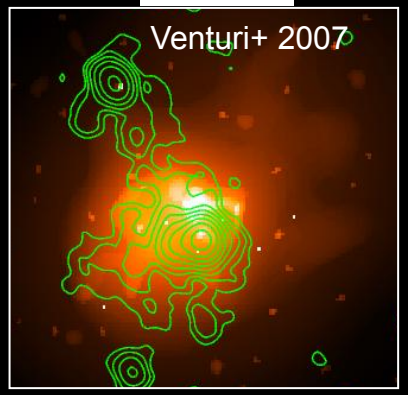
From the E-GMRT Survey

Giant radio halos

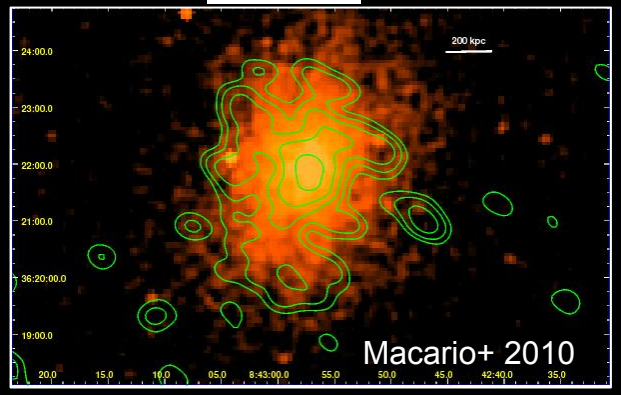
RXCJ2003.5-2323



Abell 209



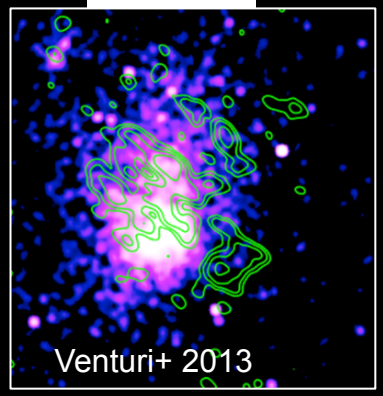
Abell 697



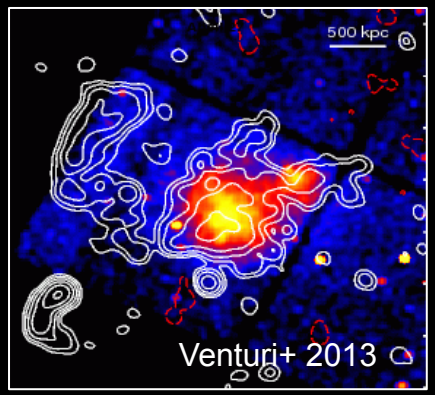
Giant radio halos and one relic

Abell 521

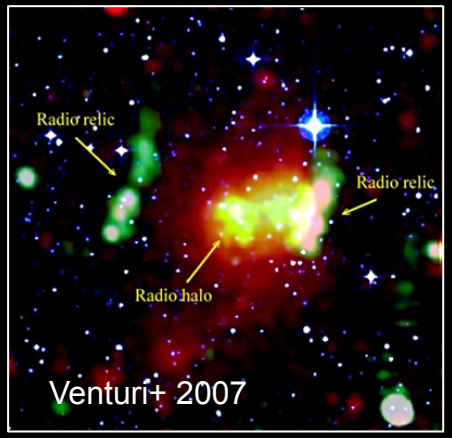
Abell 1300



Abell 2744



Radio halo and two relics



RXCJ 1314.5-2515

The deliverables of the E-GMRT Radio Halo survey

Statistics of giant radio halos

- ✓ Occurrence with cluster mass
- ✓ “Bimodality” & upper limits
- ✓ Radio Halos, Mini-Halos & cluster mergers
- ✓ Ultra steep spectrum halos

New discoveries (halos, relics and mini-halos) and detailed studies of individual clusters in the sample

A521, A697, A781, A1300, A1682, A1758, A3444, RXCJ1314, RXCJ1504, RXCJ1514, RXCJ2003, S780…

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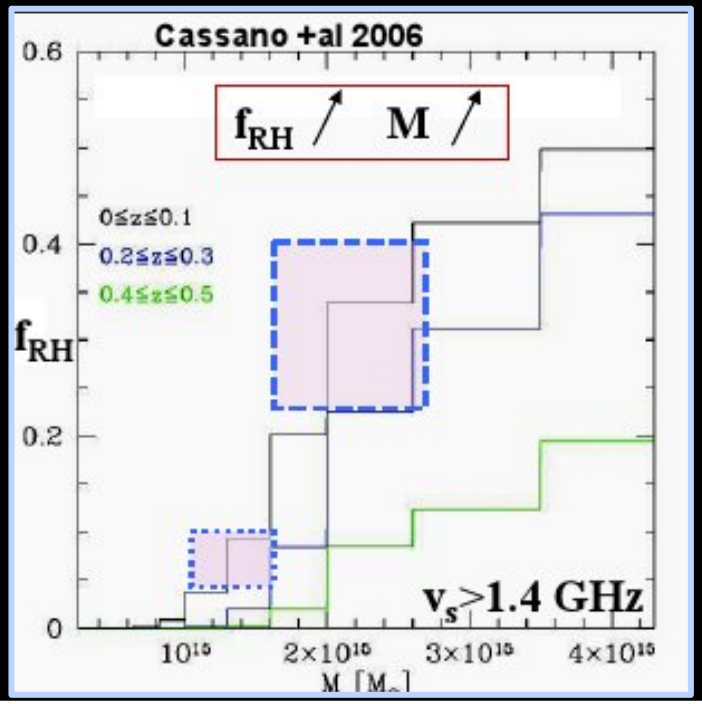
RHs and cluster mass
z=0 – 0.4



The fraction of radio halos is a strong function of mass: only ~ 5% for $M_{cluster}$ <10^{15} M_{Sun}, around 40% for $M_{cluster}$ ≥10^{15} M_{sun} (z ≤ 0.4; NVSS+GMRT radio halo cluster samples, *Cassano+ 2008*). E-GMRT RHS confirms this result *(Kale et al. 2013 & 2015)*

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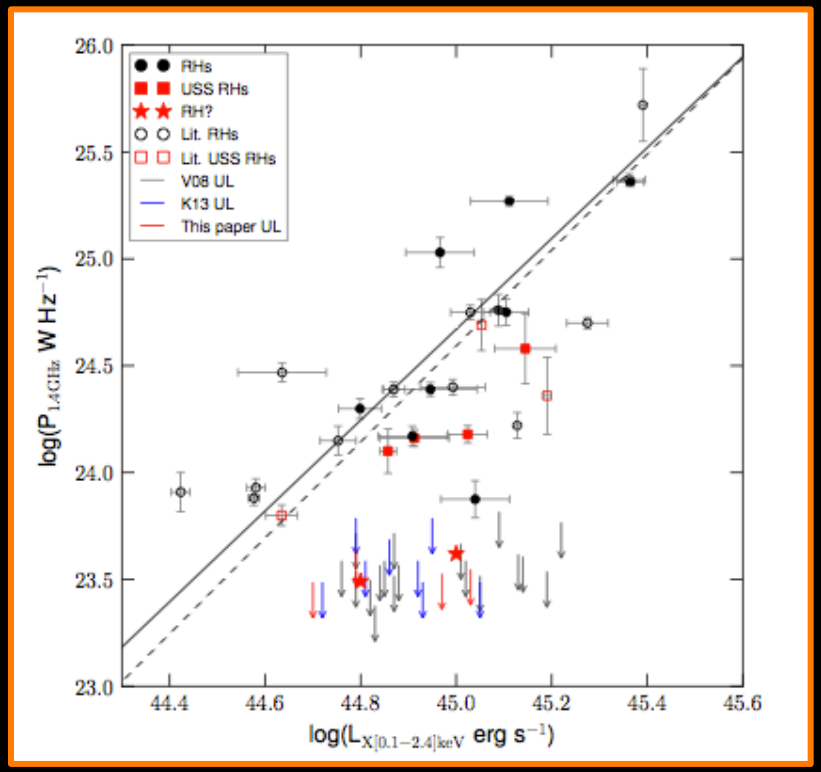

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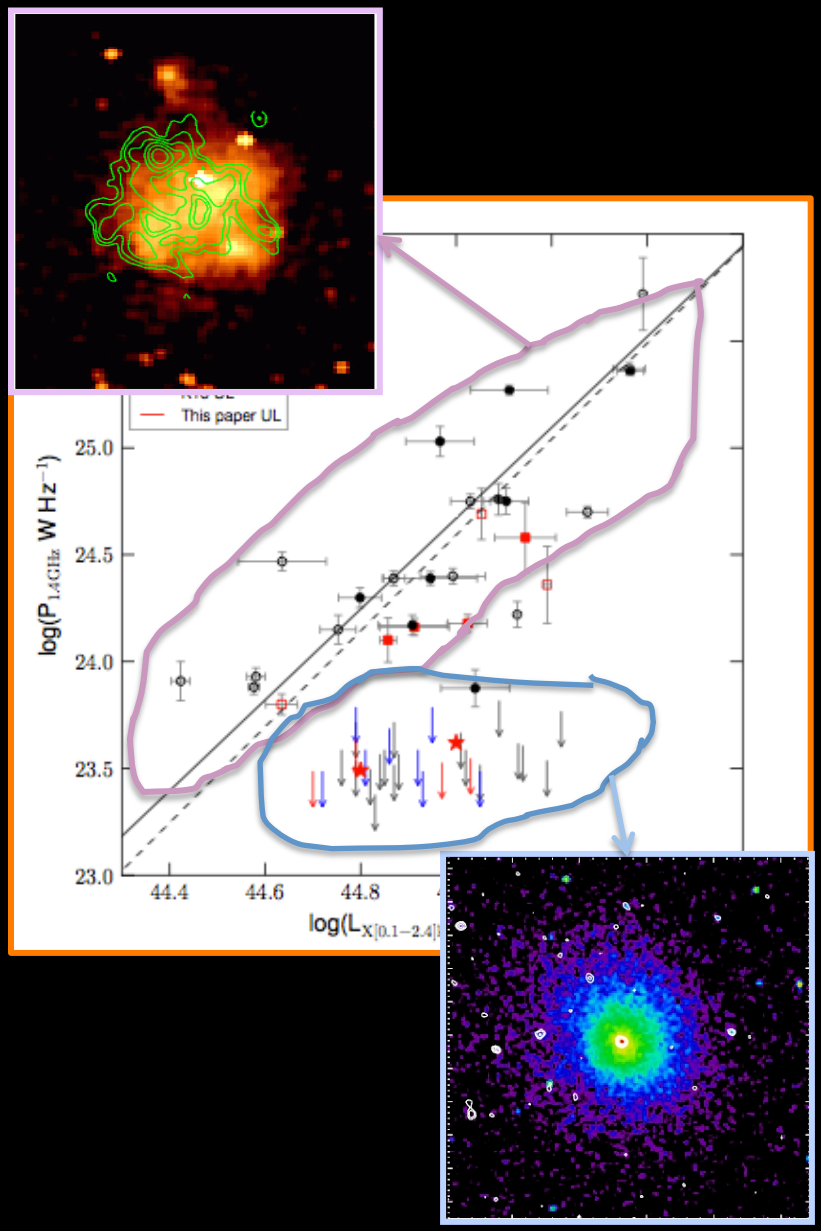

The deliverables of the E-GMRT Radio Halo survey

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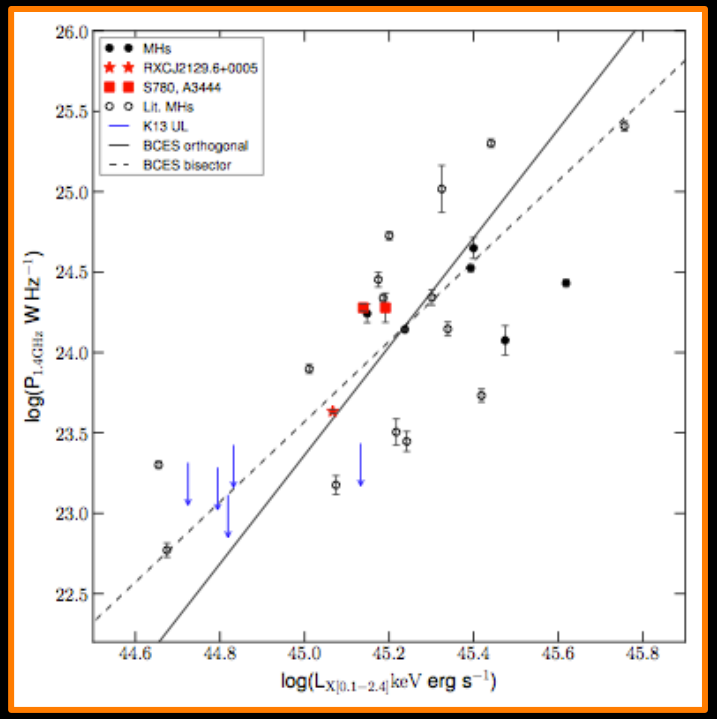
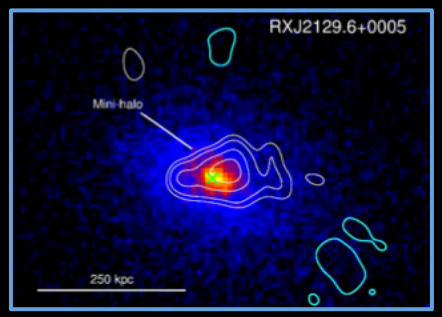
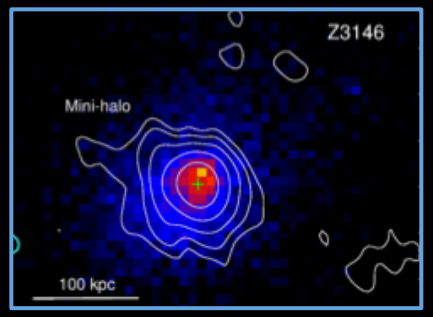
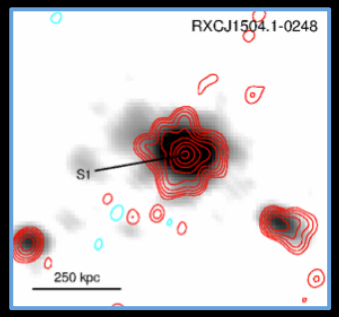
Though not among the starting motivations, the survey considerably improved our knowledge on mini-halos

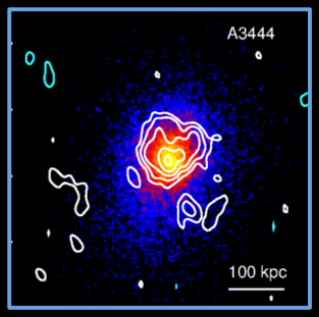


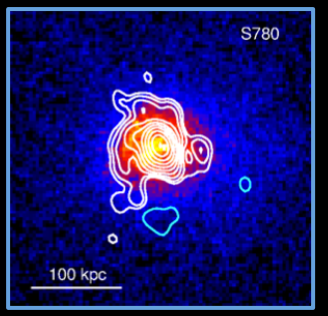
Kale et al. 2015











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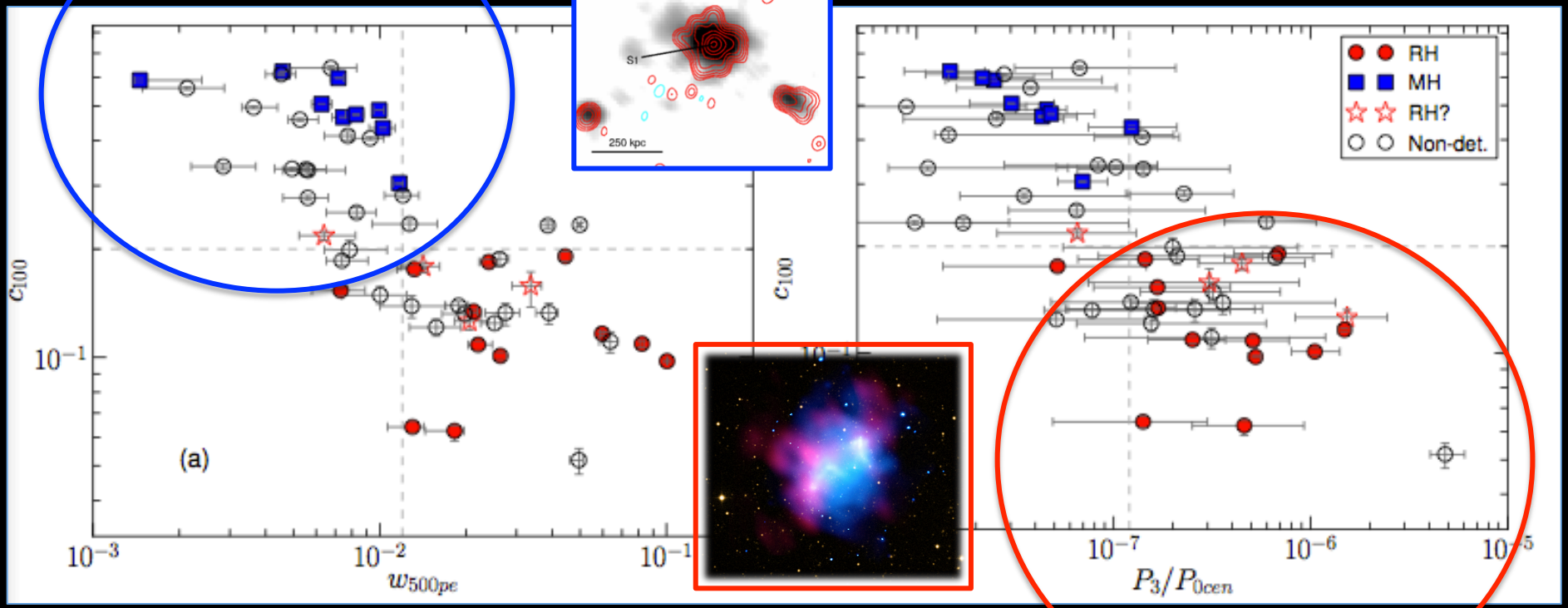


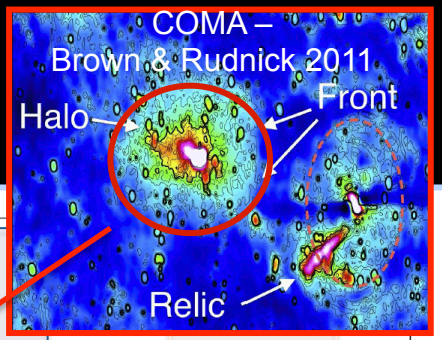
Cassano et al. 2010, Kale et al. 2015

The deliverables of the E-GMRT Radio Halo survey

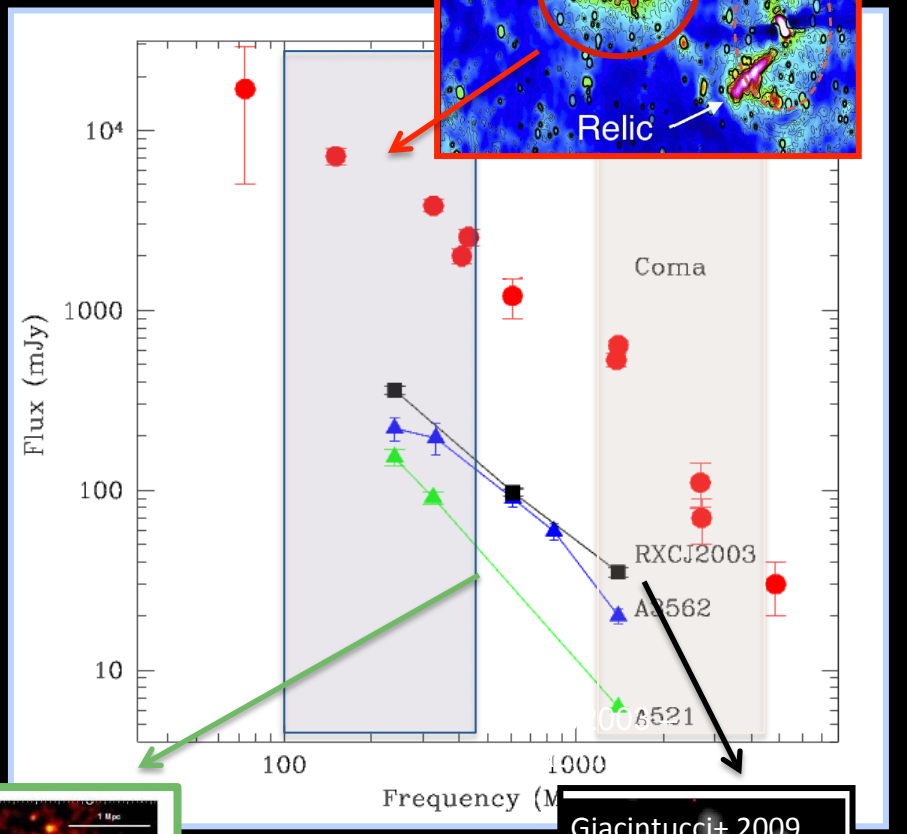
Statistics of giant radio halos

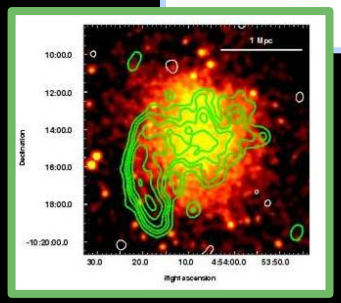
- ✓ Occurrence with cluster mass
- ✓ "Bimodality" & upper limits
- ✓ Radio Halos, Mini-Halos & cluster mergers
- ✓ Ultra steep spectrum halos

Wide range of values for α, from ≈ 1.2 to 2

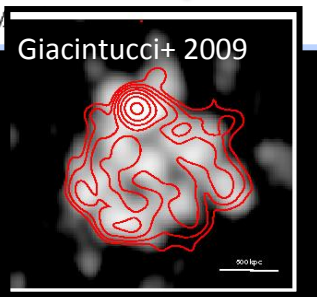


Venturi et al. 2013





Brunetti+ 2008



The deliverables of the E-GMRT Radio Halo survey

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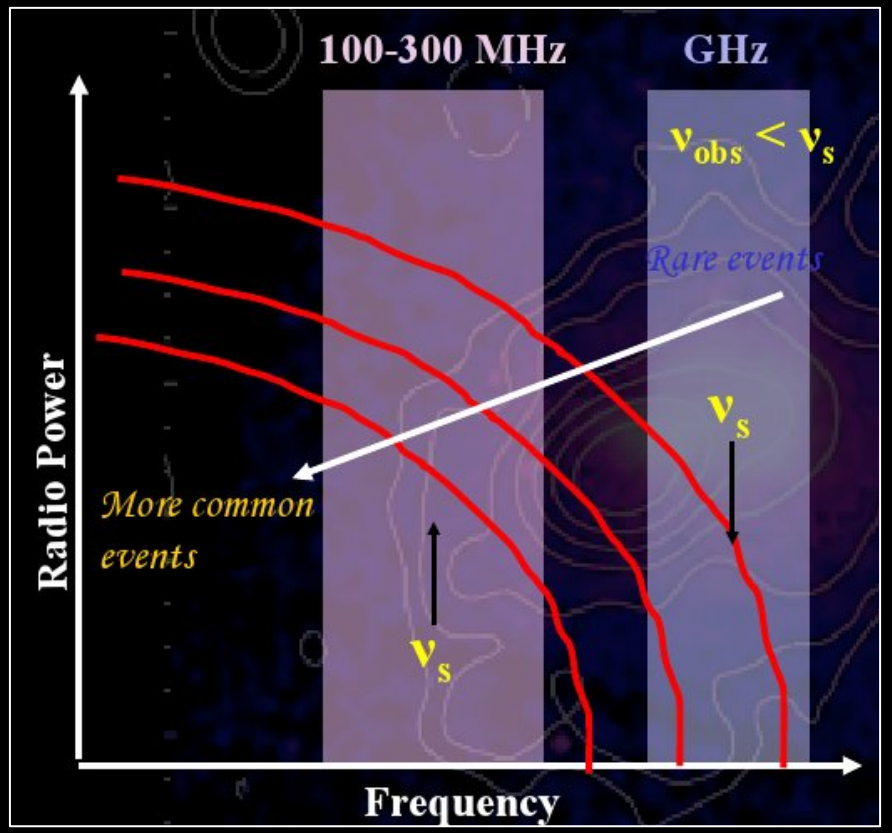
Ultra steep spectrum radio halos, best detectable at frequencies below 610 MHz as due to less energetic/ minor mergers/accretion of smaller systems

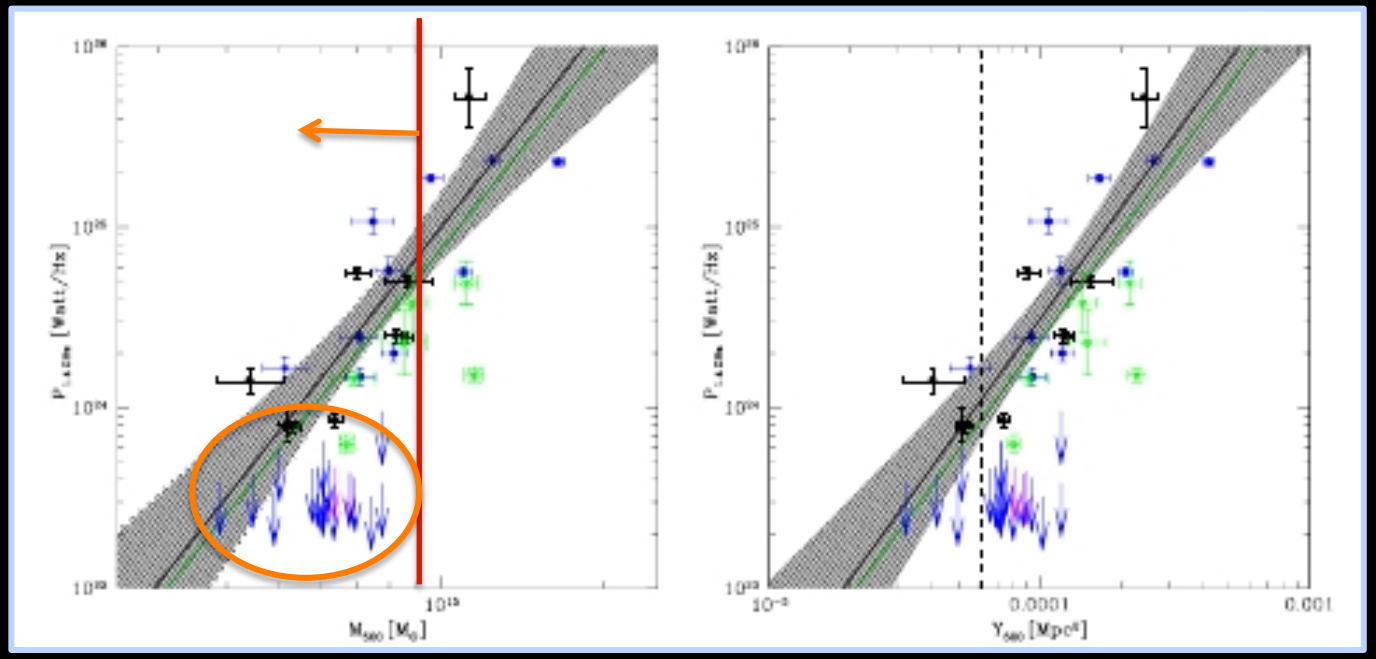
Predictions from turbulent re-acceleration: "GHz" radio halos and ultra steep spectrum RHs



From Cassano

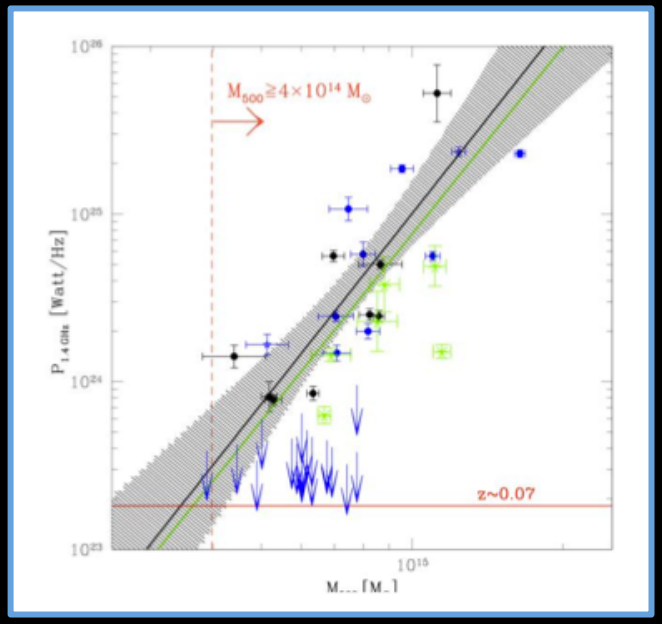
Where are we now…

- From X-ray luminosity selected samples to mass selected samples – see talk by V. Cuciti
- From intermediate-high to intermediate-low cluster masses



Bimodality in the $P_{1.4\ GHz}$ – Mass plane

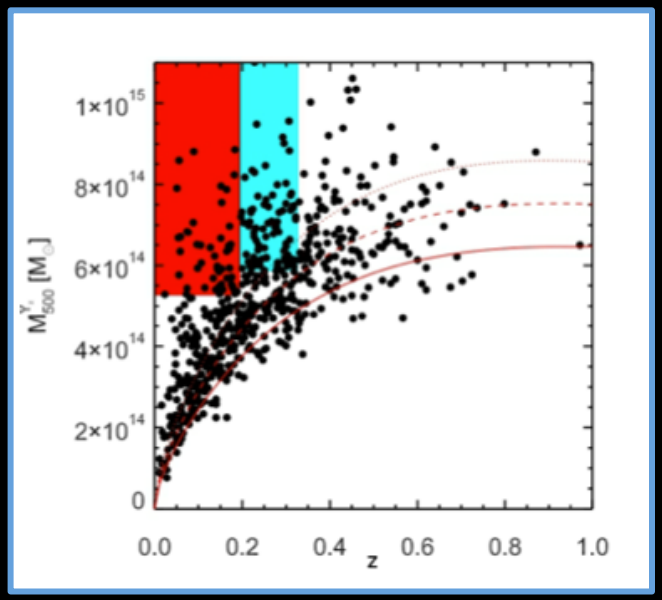
Cassano et al. 2013



- ✓ Mass & distance limited sample ($M>4x10^{14}\ M_{Sun}$, $0.05<z<0.1$) of Southern Clusters observed with KAT 7 at 1.86 GHz and MWA

Bernardi, Venturi, Cassano et al. MNRAS in press

See talk by G. Bernardi



- ✓ Mass & distance limited sample observed with GMRT and JVLA

PhD thesis, V. Cuciti

Final considerations

The Extended GMRT Radio Halo Survey:

- has given a major contribution to our current knowledge and understanding of the origin of radio halos in galaxy clusters
- has proved the importance of a statistical approach in the study of diffuse radio sources in galaxy clusters (many surveys have been initiated by many groups)
- has been a milestone for the study of diffuse cluster scale emission in less energetic/less massive mergers
- has been a milestone for the statistical predictions on the radio halo population with the next generation radio interferometers

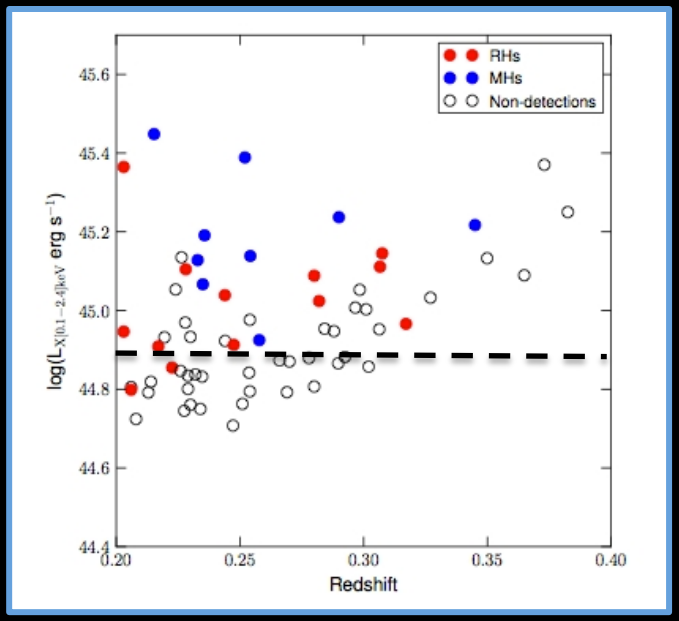
Thanks to my collaborators… it has been (and still is) great fun!

THANK YOU FOR YOUR ATTENTION

13 radio halos (22%)
2 relics & 1 double relic
9 mini-halos (16%)

43% of clusters host diffuse emission of some kind
3 candidate radio halos

Upper limits



Kale+ 2015