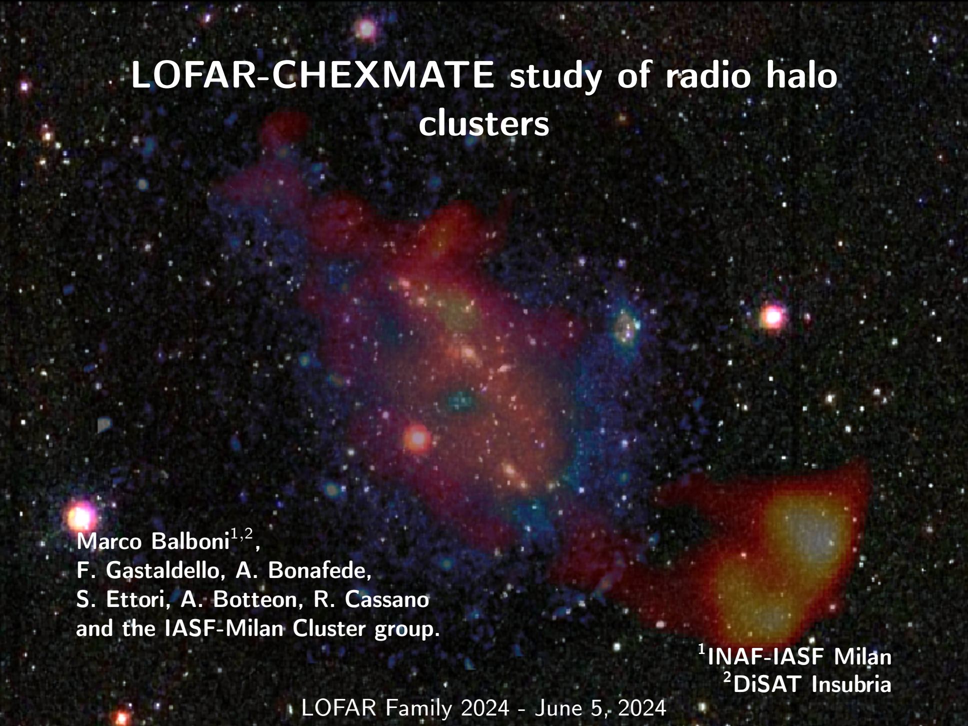
LOFAR-CHEXMATE study of radio halo clusters



Marco Balboni[1,2],
F. Gastaldello, A. Bonafede,
S. Ettori, A. Botteon, R. Cassano
and the IASF-Milan Cluster group.

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[2]DiSAT Insubria

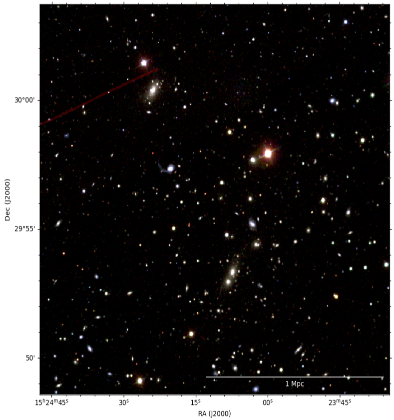
LOFAR Family 2024 - June 5, 2024

Overview

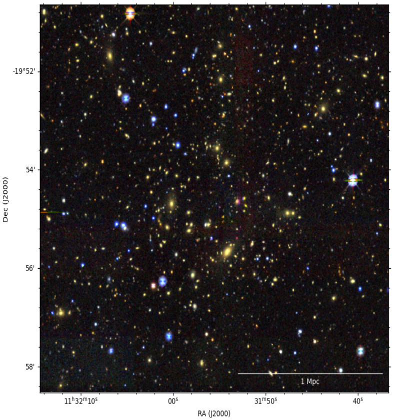
1. Introduction
   - Galaxy cluster at different wavelengths
   - New generation (radio) analyses
   - Datasets
2. Radio-X analysis
   - Point-to-Point correlation
3. Radio profile re-scaling
   - Scaling laws recap
   - Results
4. Summary

1. Introduction

Galaxy cluster multifrequency approach

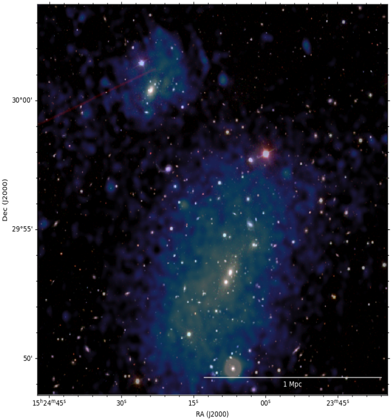


Abell 2069 - PanSTARRS DR1

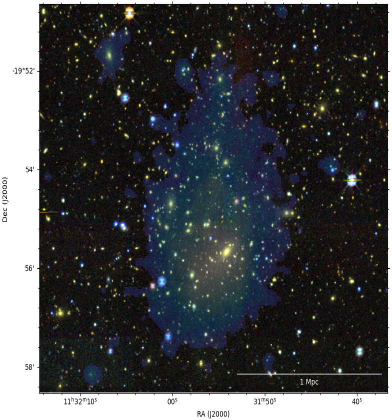


Abell 1300 - DESI DR10

Galaxy cluster multifrequency approach



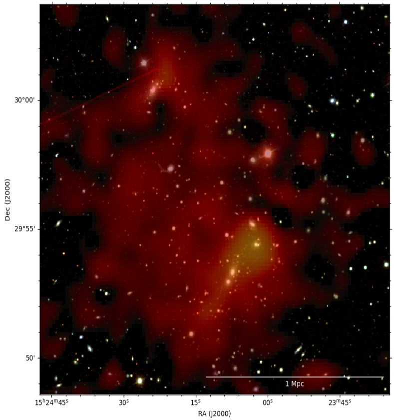
Abell 2069 - XMM Newton (0.7-1.2 keV)



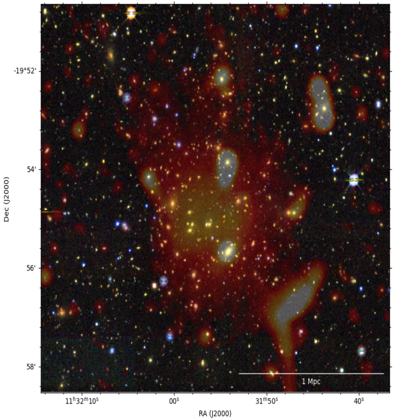
Abell 1300 - XMM Newton (0.7-1.2 keV)

Galaxy cluster multifrequency approach

Merger-induced turbulence scenario (details yet unclear)



Abell 2069 - LOFAR 144 MHz



Abell 1300 - MeerKAT 1.3 GHz

New gen. radio analyses

→ **Merger-induced turbulence scenario** (details yet unclear)

New analyses through spatially resolved studies with recent radio facilities (e.g. LOFAR, MeerKAT, uGMRT, ASKAP, MWA):

- X-ray vs radio brightness studies, but with different instruments, frequency and resolution adopted (e.g. Govoni+01, Cova+19; Xie+20)
  - → link X-ray and radio features (e.g. Botteon+23)
  - → reconstruct clusters' dynamical history (e.g. Biava+24)
- α-index vs thermodynamic quantities, few studies found contrasting results (e.g. Orru'+07, Pearce+17, Botteon+20, Rajpurohit+21)
- Spatially resolved re-scaling

Datasets

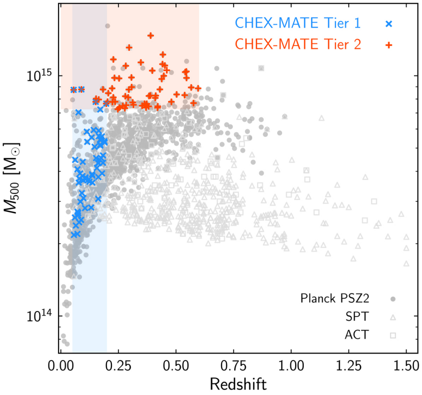
CHEX-MATE

- Representative PSZ sample of 118 GC
- Homogeneous X-ray coverage
- Low and high redshift objects (Tier1 and Tier2)

Aims

- Cluster absolute mass scale
- Cluster statistical properties
- How cluster properties changes over the time

CHEX-MATE Collaboration 2021



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LoTSS

- Deep 120-168 MHz survey of the Northen sky
- High sensitivity (100 $\mu\mathrm{Jy/beam}$)
- Ideal for halos studies

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Same instruments
+
Uniform coverage

Datasets: CHEX-MATE - LoTSS DR2

	Name	Other name	RA	DEC	z	M500
1	PSZ2 G031.93+78.71	A1775	205,47093	26,36844	0,0724	2,71801
2	PSZ2 G040.58+77.12	A1800	207,34932	28,10892	0,0748	2,5692
3	PSZ2 G046.88+56.48	A2069	231,03137	29,888	0,1145	5,10386
4	PSZ2 G048.10+57.16	A2061	230,31609	30,62783	0,0777	3,53963
5	PSZ2 G049.32+44.37	A2175	245,12655	29,89338	0,0972	3,7634
6	PSZ2 G055.59+31.85	A2261	260,61499	32,13541	0,224	7,7238
7	PSZ2 G056.77+36.32	A2244	255,66631	34,05107	0,0953	4,33797
8	PSZ2 G066.41+27.03	PSZ1G066.41+27.03	269,21019	40,13411	0,575	7,69497
9	PSZ2 G077.90-26.63	A2409	330,21881	20,96802	0,147	4,989
10	PSZ2 G083.29-31.03	MCSJ2228.5+2036	337,14043	20,62113	0,412	7,64251
11	PSZ2 G107.10+65.32	A1758	203,17767	50,51829	0,2799	7,79955
12	PSZ2 G111.75+70.37	A1697	198,2768	46,281	0,183	4,34221
13	PSZ2 G113.91-37.01	MCXCJ0019.6+2517	4,9128	25,2908	0,3712	7,58223
14	PSZ2 G143.26+65.24	A1430	179,81181	49,79255	0,3634	7,2567
15	PSZ2 G179.09+60.12	A1068	160,18562	39,95326	0,1372	3,83868
16	PSZ2 G186.37+37.26	A697	130,73818	36,3676	0,282	10,99804
17	PSZ2 G192.18+56.12	A961	154,1	33,62222	0,124	3,62013
18	PSZ2 G053.53+59.52	A2034	227,55461	33,49148	0,113	5,20856

CHEX-MATE: A LOFAR pilot X-ray – radio study on five radio halo clusters

M. Balboni[1,2], F. Gastaldello[1], A. Bonafede[3,4], A. Botteon[4], I. Bartalucci[1], H. Bourdin[10,11], G. Brunetti[4], R. Cassano[4], S. De Grandi[13], F. De Luca[10,11], S. Ettori[6,7], S. Ghizzardi[1], M. Gitti[3,4], A. Iqbal[8], M. Johnston-Hollitt[14], L. Lovisari[1], P. Mazzotta[10,11], S. Molendi[1], E. Pointecouteau[5], G.W. Pratt[8], G. Riva[1,12], M. Rossetti[1], H. Rottgering[9], M. Sereno[6,7], R.J. van Weeren[9], T. Venturi[4], I. Veronesi[1]

- Found (radial) changes of the thermal/non-thermal ratio
- Exploited such analyses to test model predictions

2. Radio-X analysis

X-ray vs radio brightness - LoTSS DR2

- Compute a mesh grid covering the whole radio and X-ray diffuse emission
- Extract the surface brightness values from the images
- Plot I_X and I_R values for all clusters

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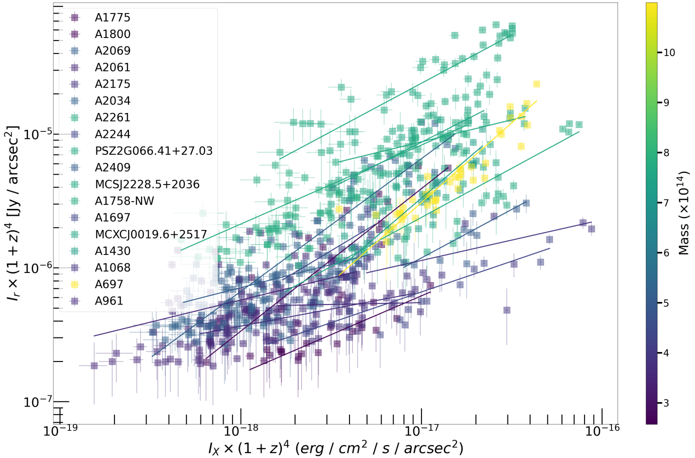

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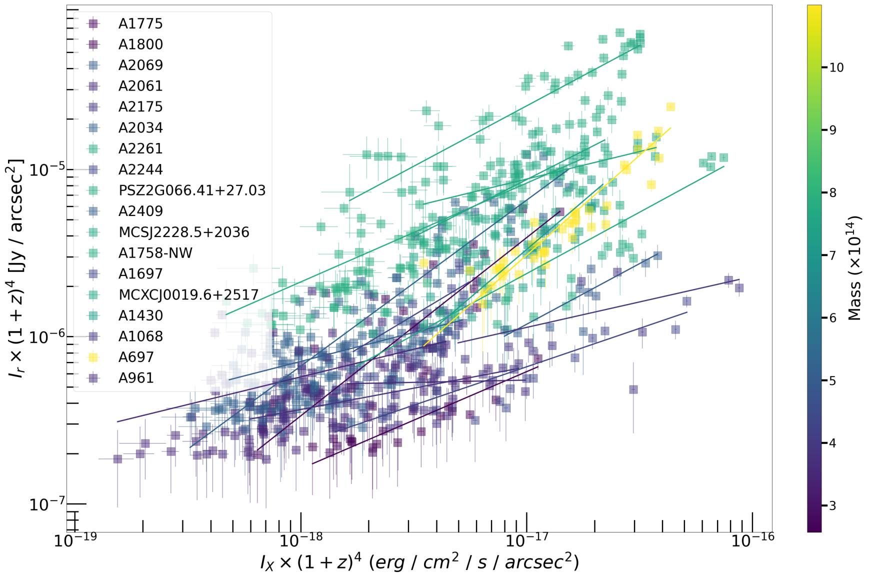
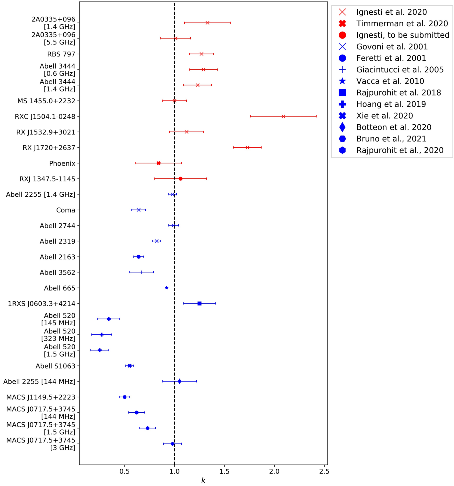


$I_X - I_R$ correlation slope



Ignesti 2021

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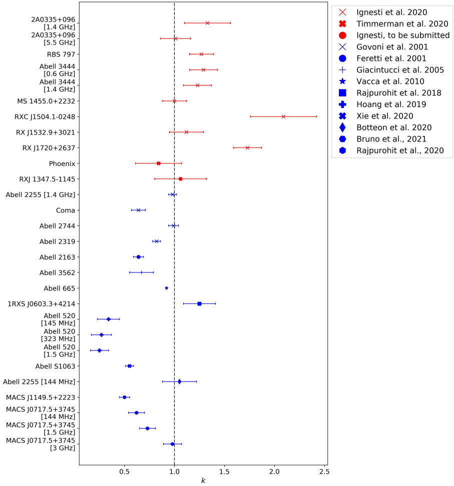

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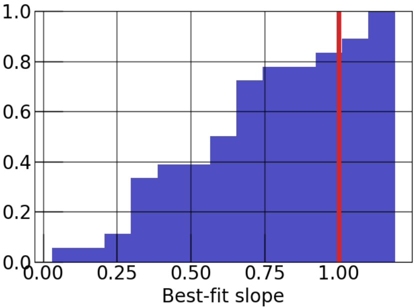

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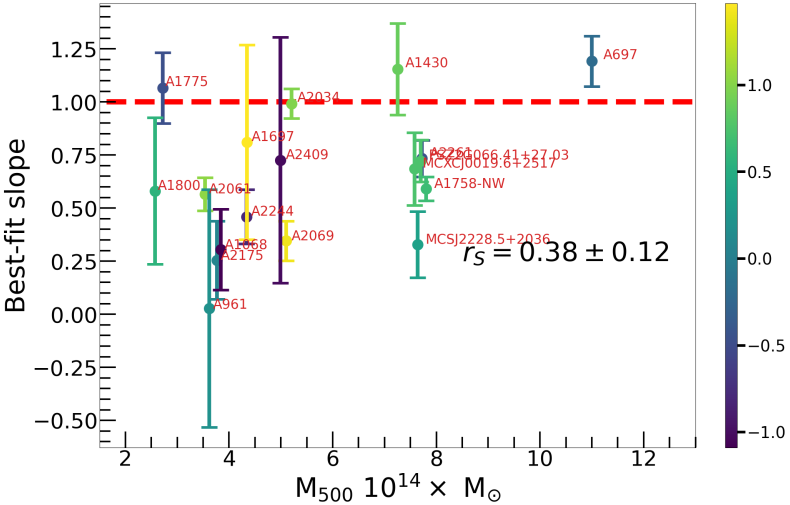

3. Radio profile re-scaling

Self-similar scenario

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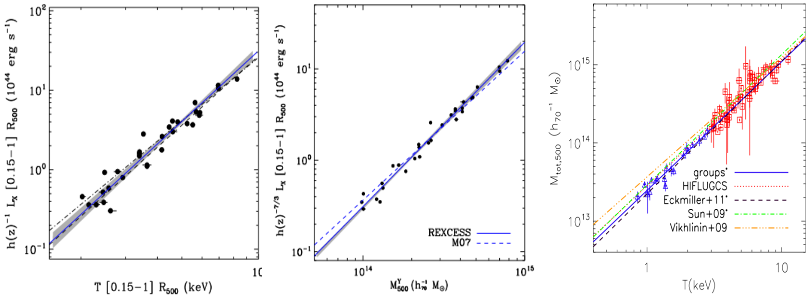
  - Scaling relations among integrated quantities, $L_X - M$, $T - M$, $L_X - T$ (e.g. Pratt+2009, Lovisari+2015)



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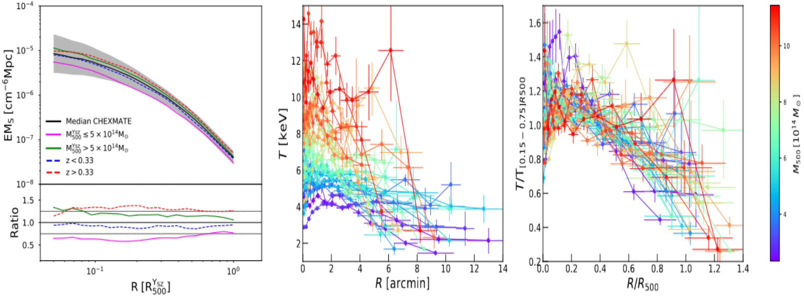

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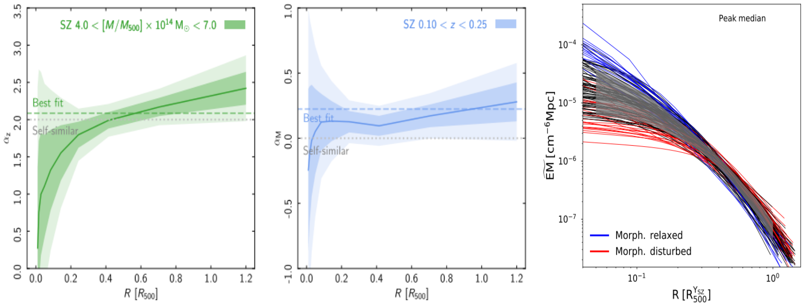
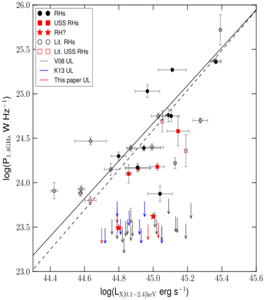
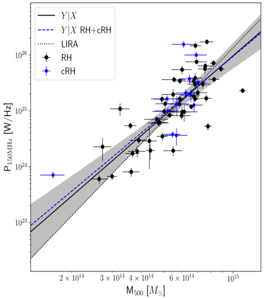
  - (re-)Scaling of resolved properties as density or thermodynamic profiles (e.g. Arnaud+2010, Bartalucci+23, Rossetti+24)
- They found deviations from self-similar predictions and constrained their origin (e.g. Pratt+22, Ettori+23)

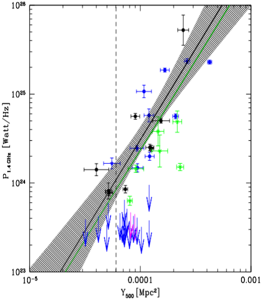


Scaling laws in radio

- Non-thermal component scaling relations have been studied for integrated quantities: $P_{radio} - L_X$, $P_{radio} - M$, $P_{radio} - Y_{SZ,500}$ (e.g Cassano+13, Kale+15, Cuciti+23)
  - $\rightarrow$ finding departures from self-similarity







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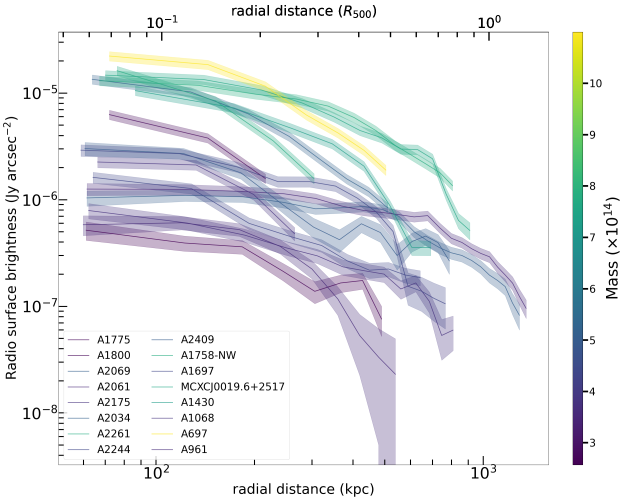
  - $\rightarrow$ finding departures from self-similarity
- No studies have been made on the scaling of spatially resolved properties (but also on the radio halo redshift dependence)

Radio profile re-scaling

- Extracted the radial profiles from the 16 CHEX-MATE – LoTSS DR2 ($z < 0.4$)



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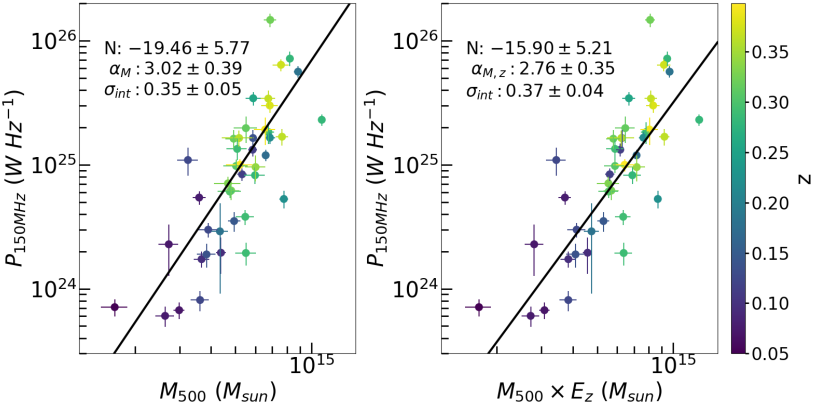

Radio profile re-scaling

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- Derive the expected scaling in mass for the profiles assuming $R_H \sim M^{\beta_M} E_z^{\beta_z}$. Compared the mass expected dependence with the best-fit scaling

$$P_\nu = \frac{4\pi D^2}{(1+z)^{1+\alpha}} S_\nu$$

$$P_\nu \propto (ME_z)^{\alpha_M}$$

$$S_\nu \propto I_\nu R_H^2 \frac{D_L}{D_\theta}^2 \propto I_\nu M^{-2\beta_M} E_z^{-2\beta_z} (1+z)^4$$

$$I_\nu \propto M^{\alpha_M - 2\beta_M} \, E_z^{\alpha_M - 2\beta_z} \, (1+z)^{-(3+\alpha)}$$

Radio profile re-scaling - Results

	γ_M	$\Delta\ \gamma_M$	γ_z (fixed)	$\Delta\ \gamma_z$	σ_{int}	Δ_σ
$I_{150MHz} \propto M^{\gamma_M}$	3.68	0.43	0	/	0.22	0.05
$I_{150MHz} \propto M^{\gamma_M}\ E_z^{4/3}$	3.41	0.38	4/3	/	0.24	0.04
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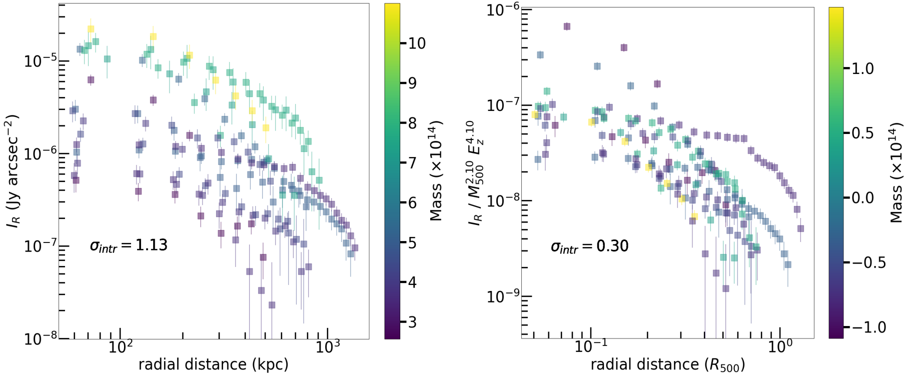

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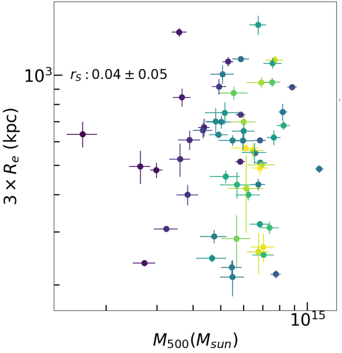
$$R_H \sim M^{\beta_M} E_z^{\beta_z} \sim M^0 E_z^0$$



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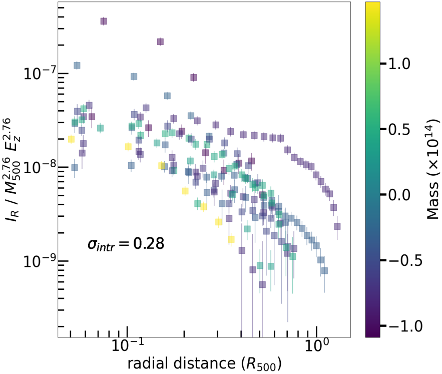

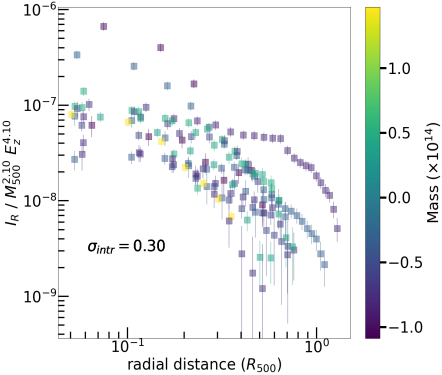

4. Summary

Summary and future prospects

R - **X**

We analysed a cluster sample uniformly observed in radio and X-ray finding:

- A strong, positive correlation among the radio and X-ray surface brightness.
- $I_X - I_R$ sub-linear slopes indicating a flatter distribution of the non-thermal component wrt the thermal one.
- No clear slope – mass/dynamical status relation at 144 MHz (higher freq.?).

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We performed a tentative radio profile re-scaling as usually done for the thermal component:

- by applying "self-similar" scaling we significantly reduced the profile scatter
- found consistency among the best-fit mass scaling of the observed profiles and the expected one.

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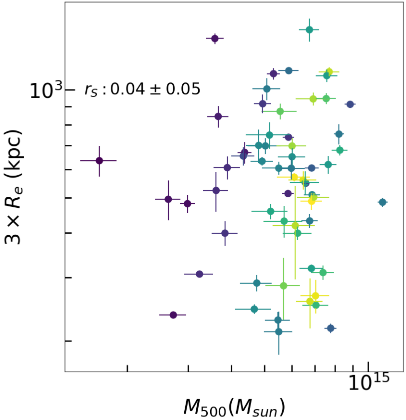
Thank you for the attention!

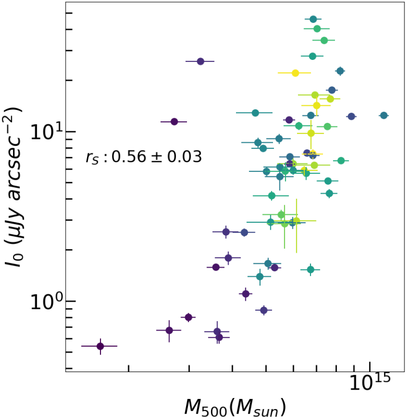
Backup slides

Table: Spearman rank among quantities.

	z	M_{500}	R_{500}	P_{150}	I_0	R_e	σ_{RMS}
z		0.58	-0.01	0.67	0.39	-0.11	-0.08
M_{500}	0.58		0.71	0.78	0.61	0.04	-0.00
R_{500}	-0.01	0.71		0.42	0.38	0.19	0.03
P_{150}	0.67	0.78	0.42		0.60	0.28	-0.02
I_0	0.39	0.61	0.38	0.60		-0.40	-0.08
R_e	-0.11	0.04	0.19	0.28	-0.40		0.08
σ_{RMS}	-0.08	-0.00	0.03	-0.02	-0.08	0.08	

Backup slides





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