Magnetic fields in galaxy clusters in the SKA and its precursors era

Annalisa Bonafede

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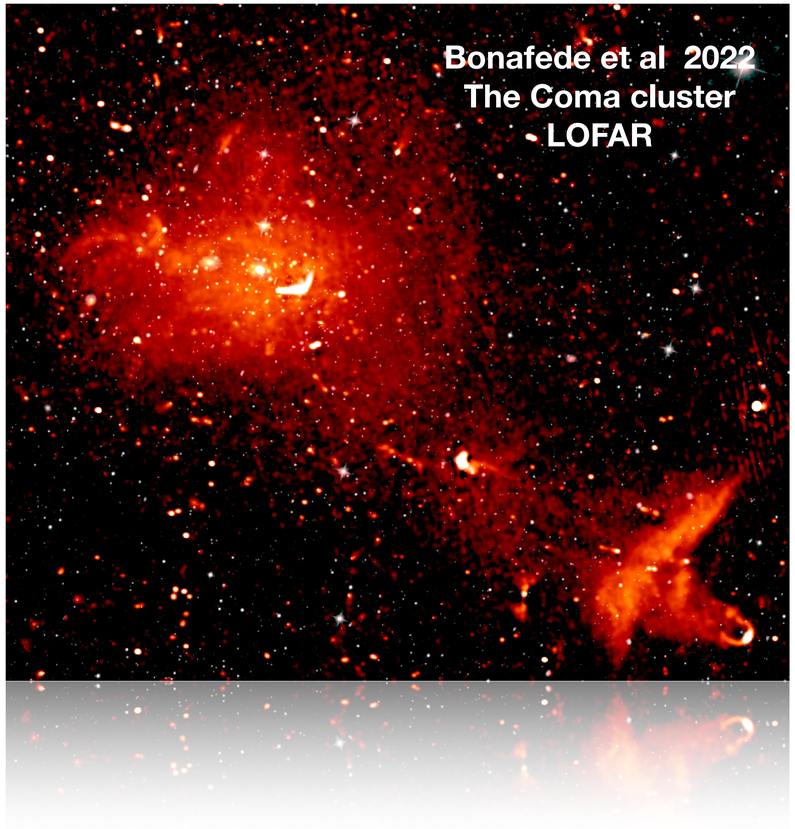
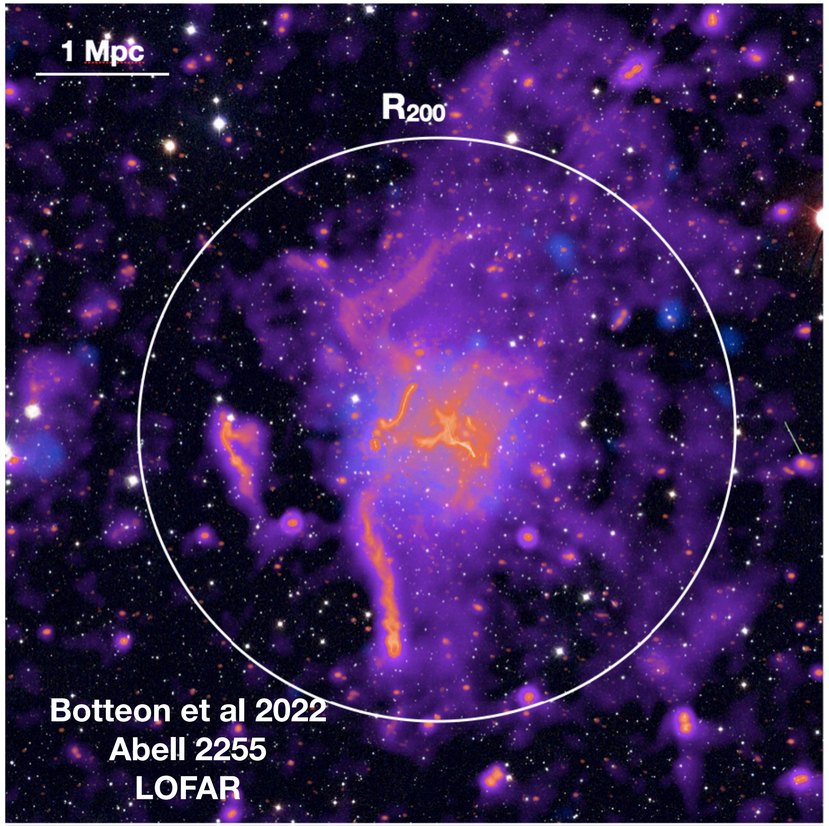
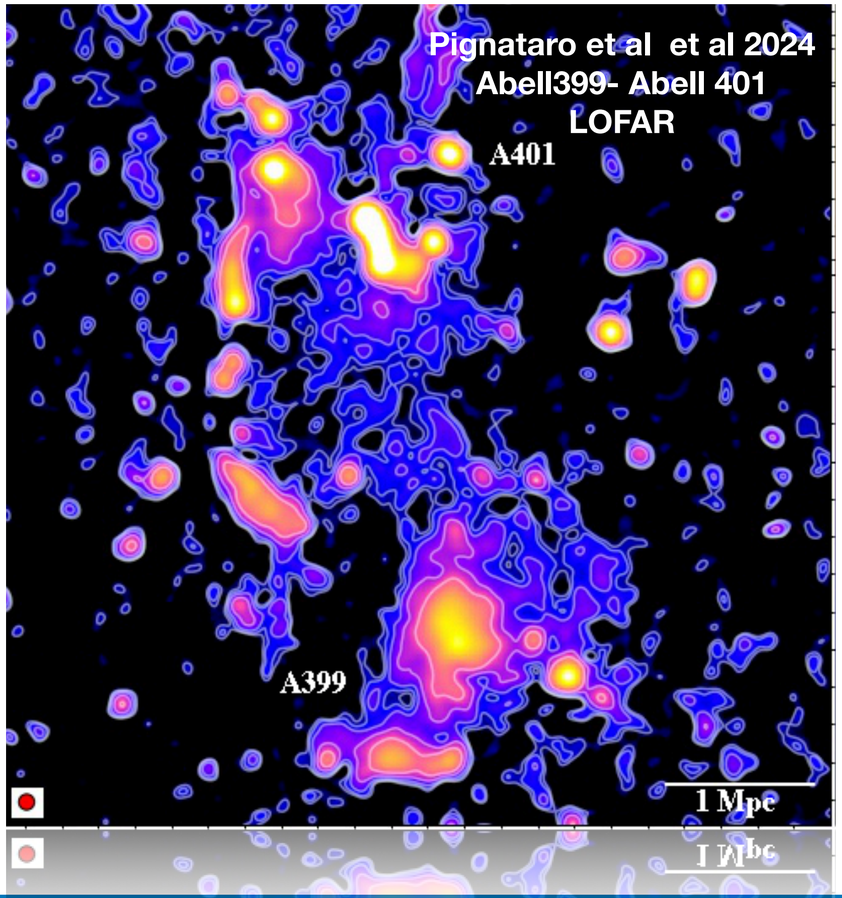
&
INAF - IRA

EVIDENCE FOR B IN CLUSTERS AND BEYOND





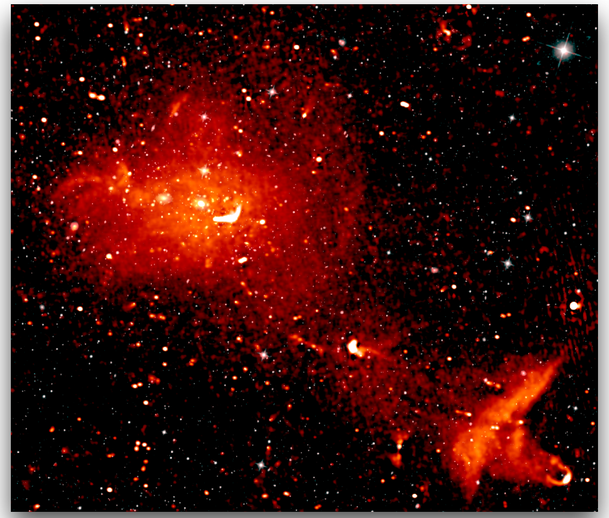


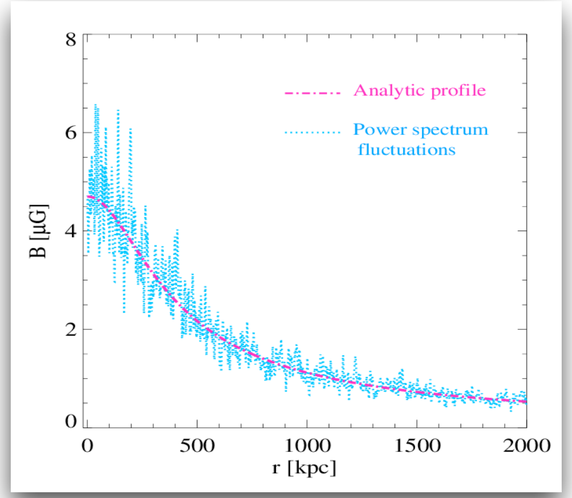
Overall few muG,

ICM is a high-β plasma

—> B Not dynamically dominant, but shape the ICM microphysics

MAGNETIC FIELDS IN CLUSTERS: OBSERVATIONS





COMA: $B_0 = 5\mu G$, z=0.02

$B \propto n^{0.5}$ (Bonafede et al 2010)

13 sources in total

each one observed separately and in different narrow band

$$B(r) = B_0 \left(\frac{n(r)}{n_0} \right)^{\eta}$$

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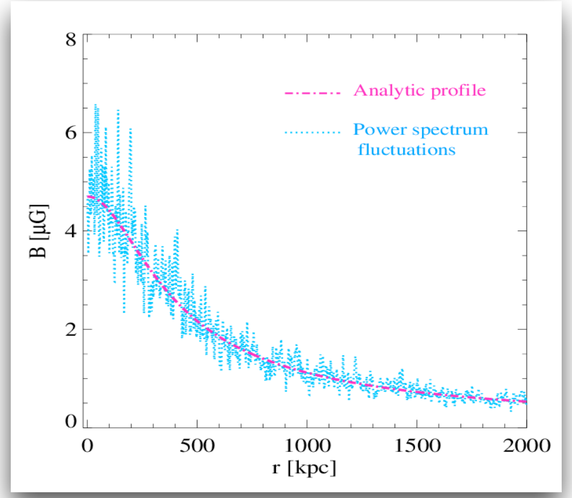

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Galaxy cluster	M_{500} ($10^{14} M_\odot$)	z	$\langle B_0 \rangle$ (μG)	$\langle B_{1\mathrm{Mpc}^3} \rangle$ (μG)	η	Ref.
Abell 119	3.4	0.04	5	1.5	0.9	Murgia et al. (2004)
Abell 2255	5.4	0.08	2.5	1.2	0.5*	Govoni et al. (2006)
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Abell 2345	5.9	0.18	2.8	1.2	1.0	Stuardi et al (2021)

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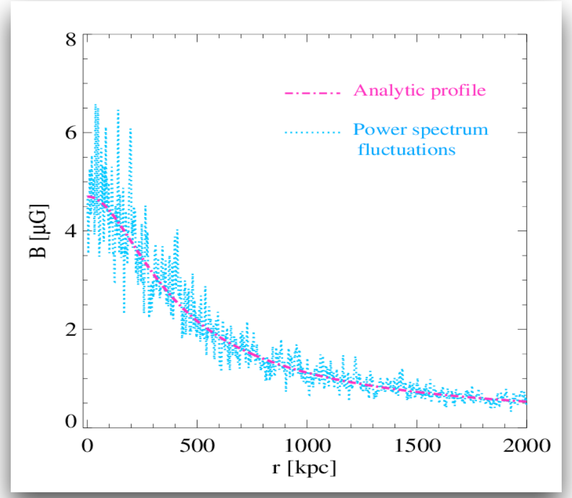

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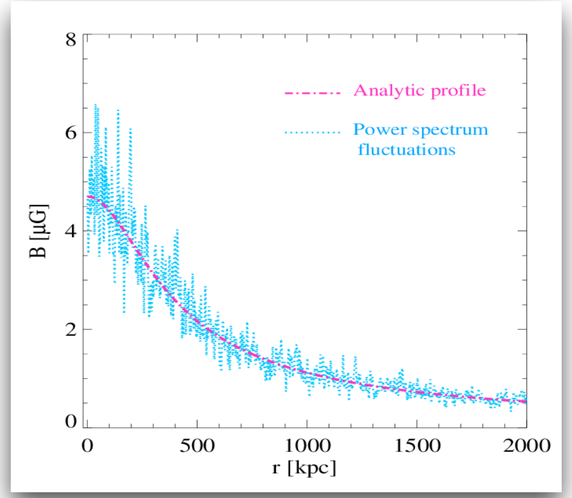

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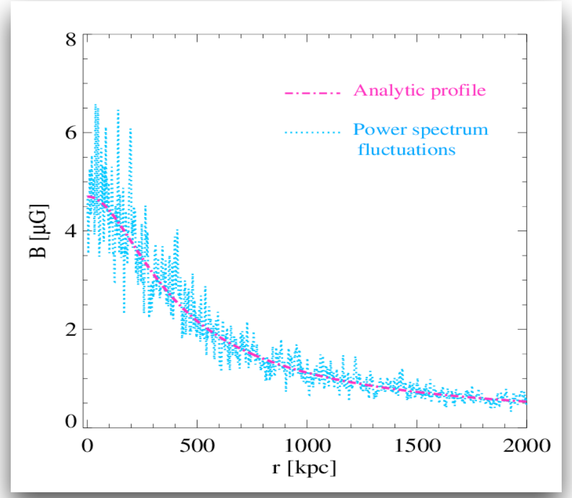

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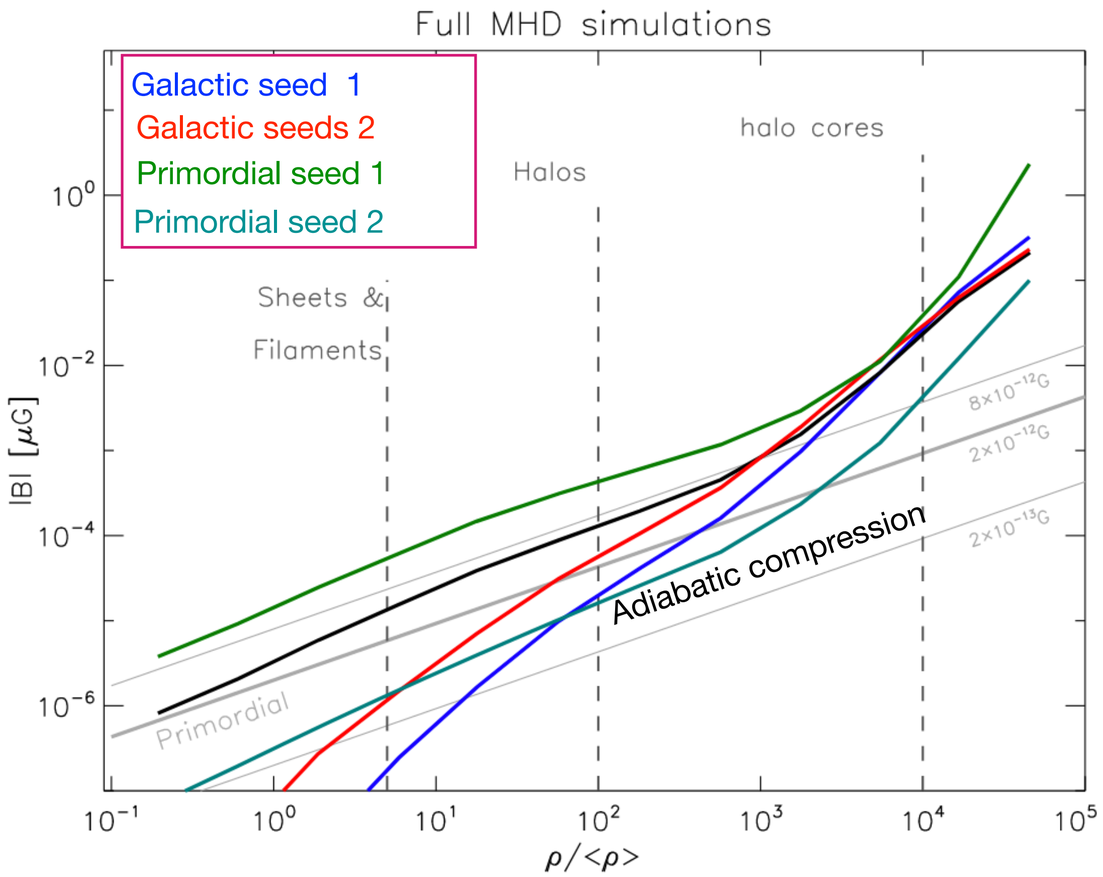
Stuardi et al (2021)

- B ~ 5-10 μG magnetic fields at the center of massive local clusters
- Few studies available so far
- Radial profile is difficult to constrain, $B \propto n^{0.5}$ or steeper

MAGNETIC FIELDS IN CLUSTERS: SIMULATIONS

- B results from the amplification of an initial seed/AGN seed

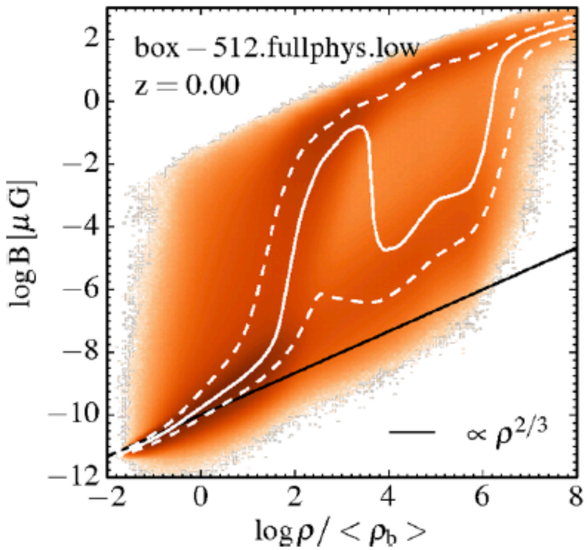
- Adiabatic compression is not enough



Donnert et al (2018)

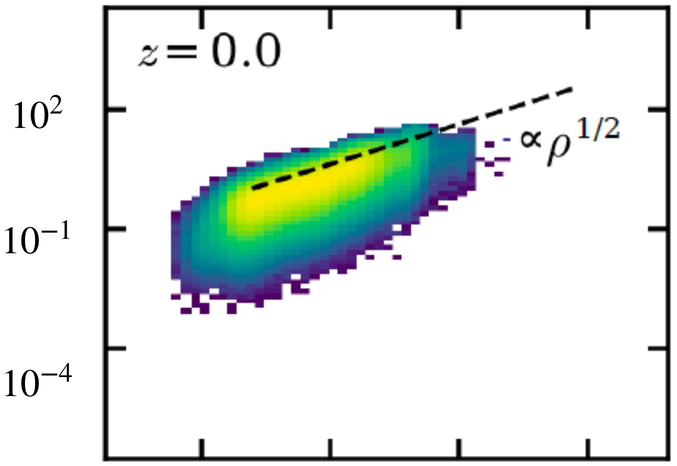
MAGNETIC FIELDS IN CLUSTERS: SIMULATIONS

Full Physics Runs, with different seeds
(1e-14 G at z=100)



Illustris (Marinacci et al 2015)
Illustris TNG (Nelson et al 2024)

Radiative + galaxy formation



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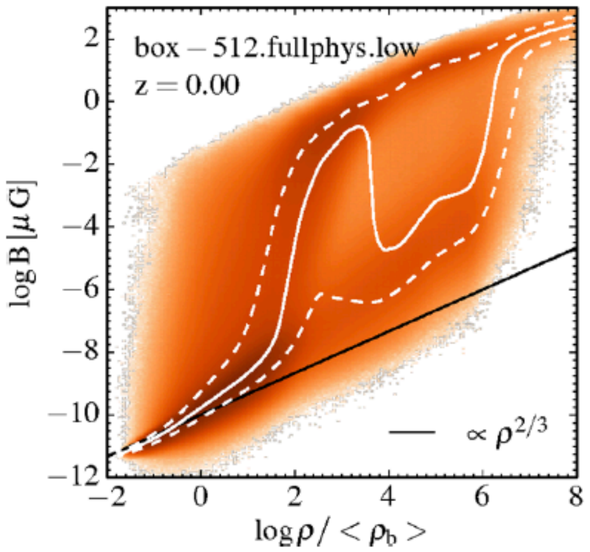

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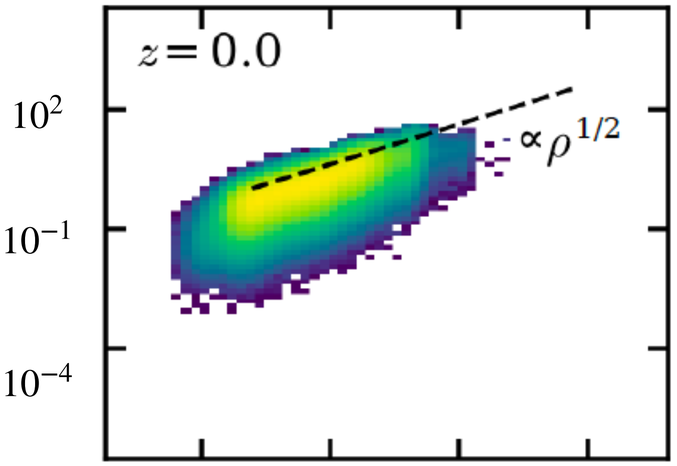

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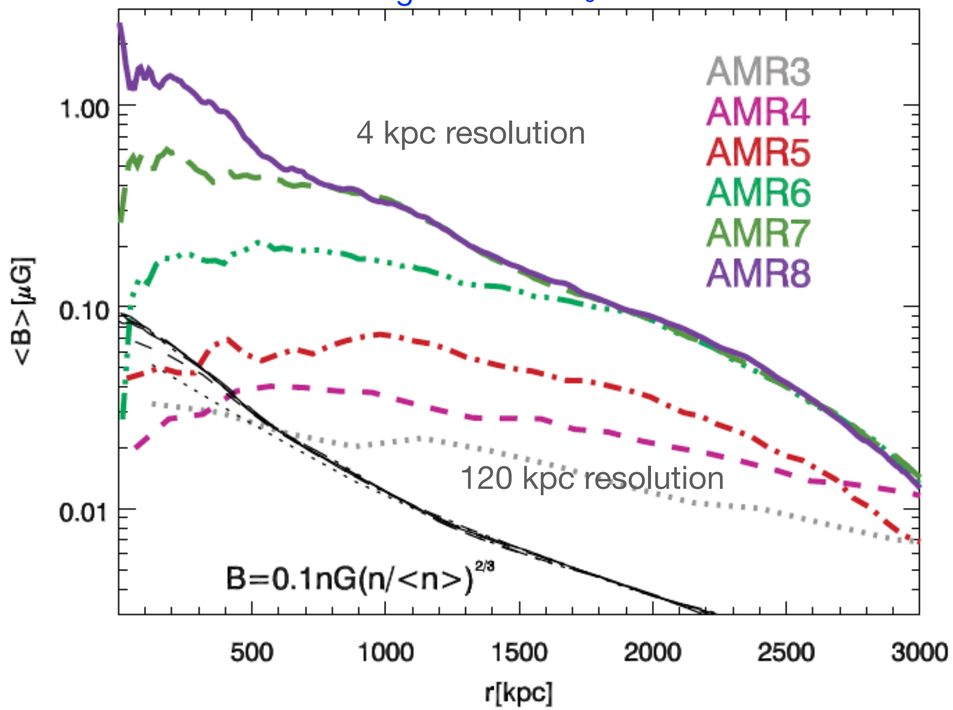
Primordial magnetic field B_0=0.1nG at z=30



Vazza et al 2018

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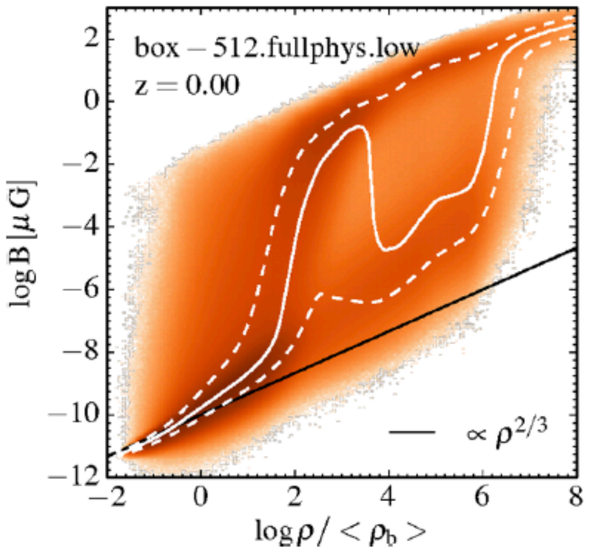

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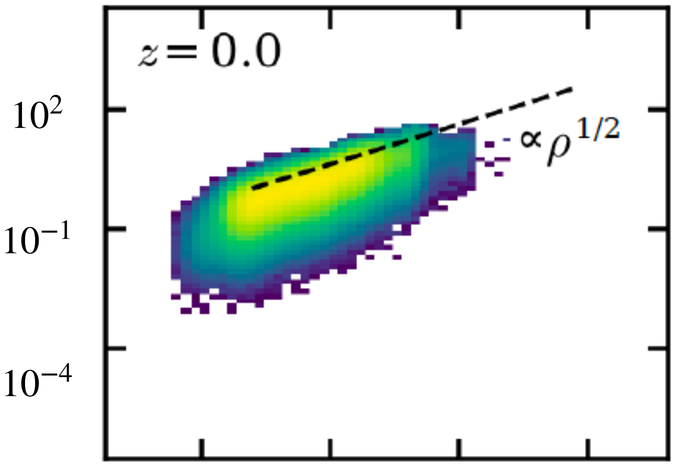

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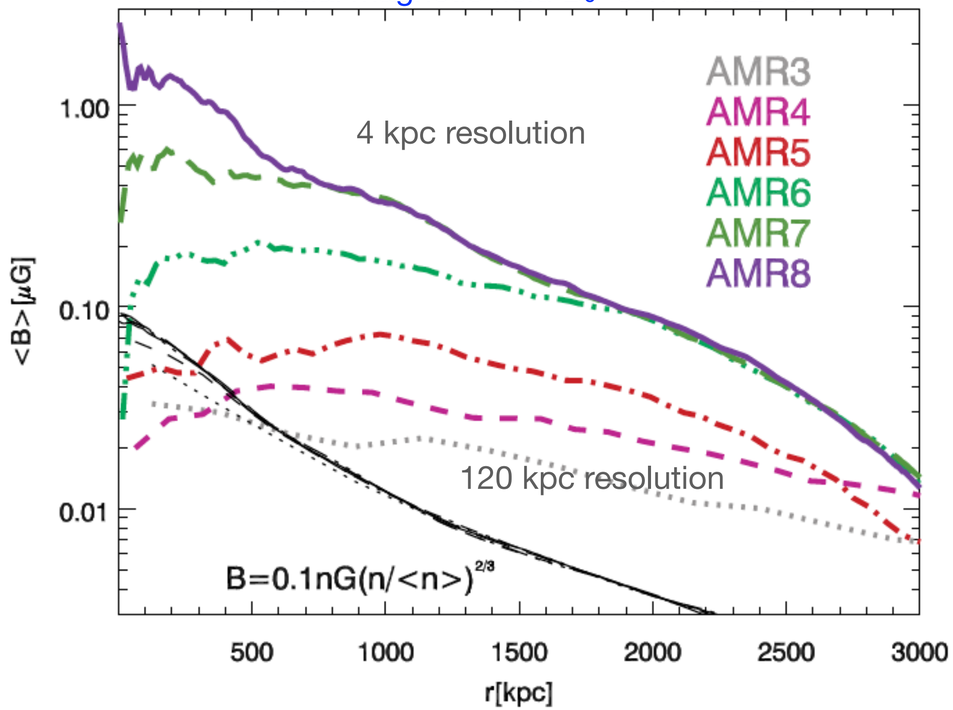
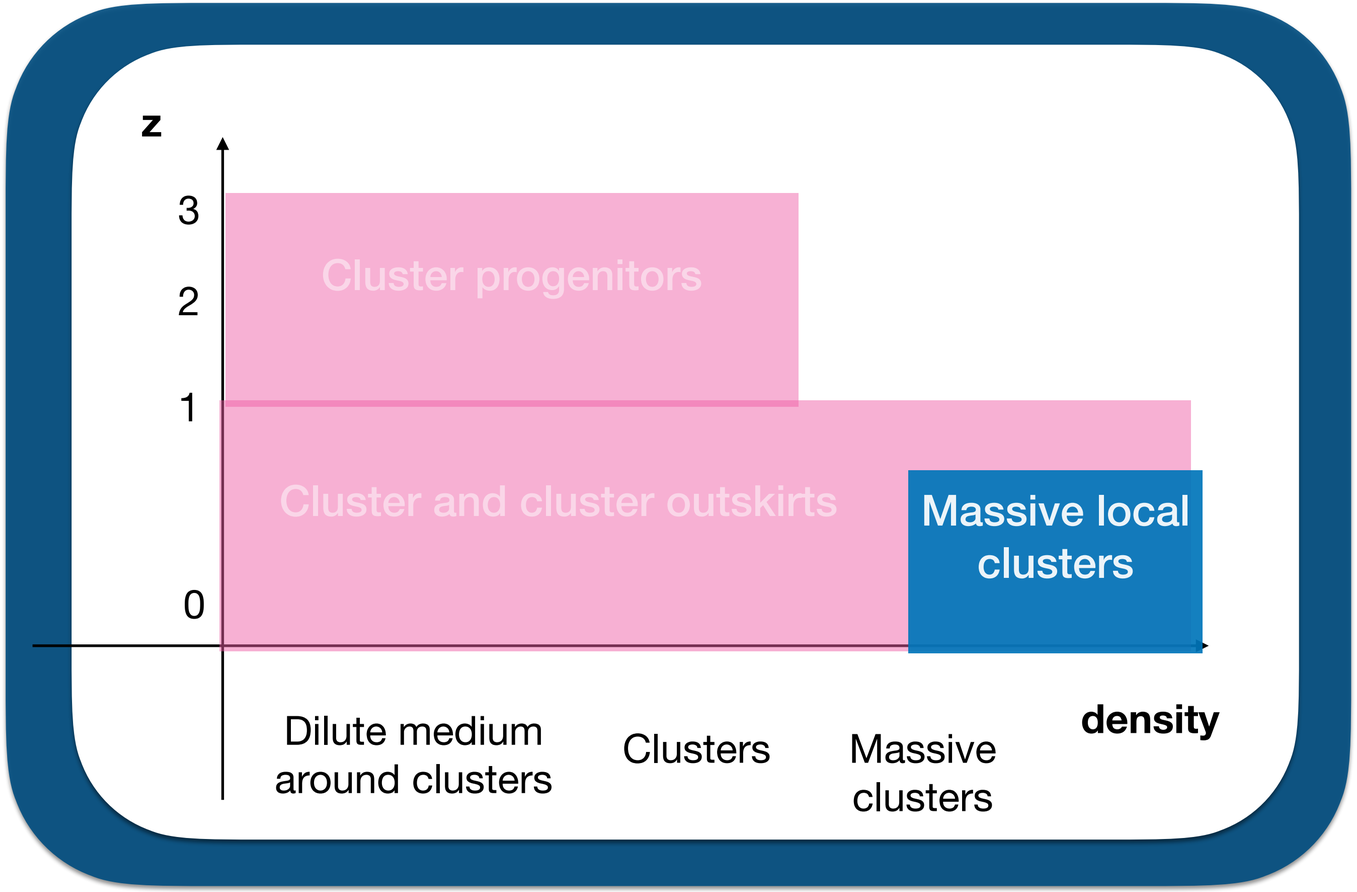


Vazza et al 2018

- Evidence for dynamo amplification
- Simulations (MHD) can over predict the magnetic field at the center of clusters

MAGNETIC FIELDS IN CLUSTERS

- To understand the magnetic field amplification in clusters, we need:
  - Constraints on magnetic fields in local clusters
  - Constraints over mass and redshift



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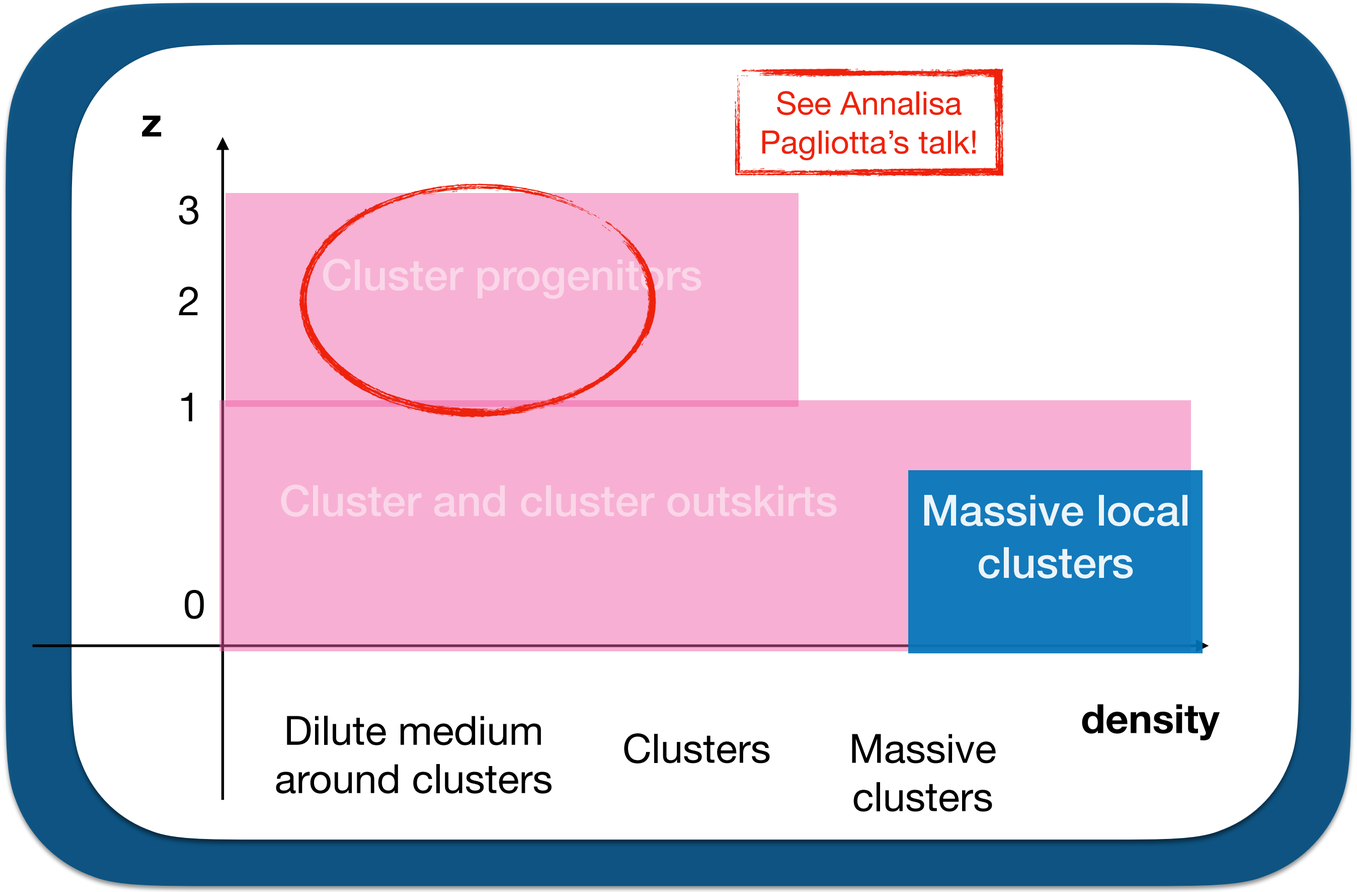

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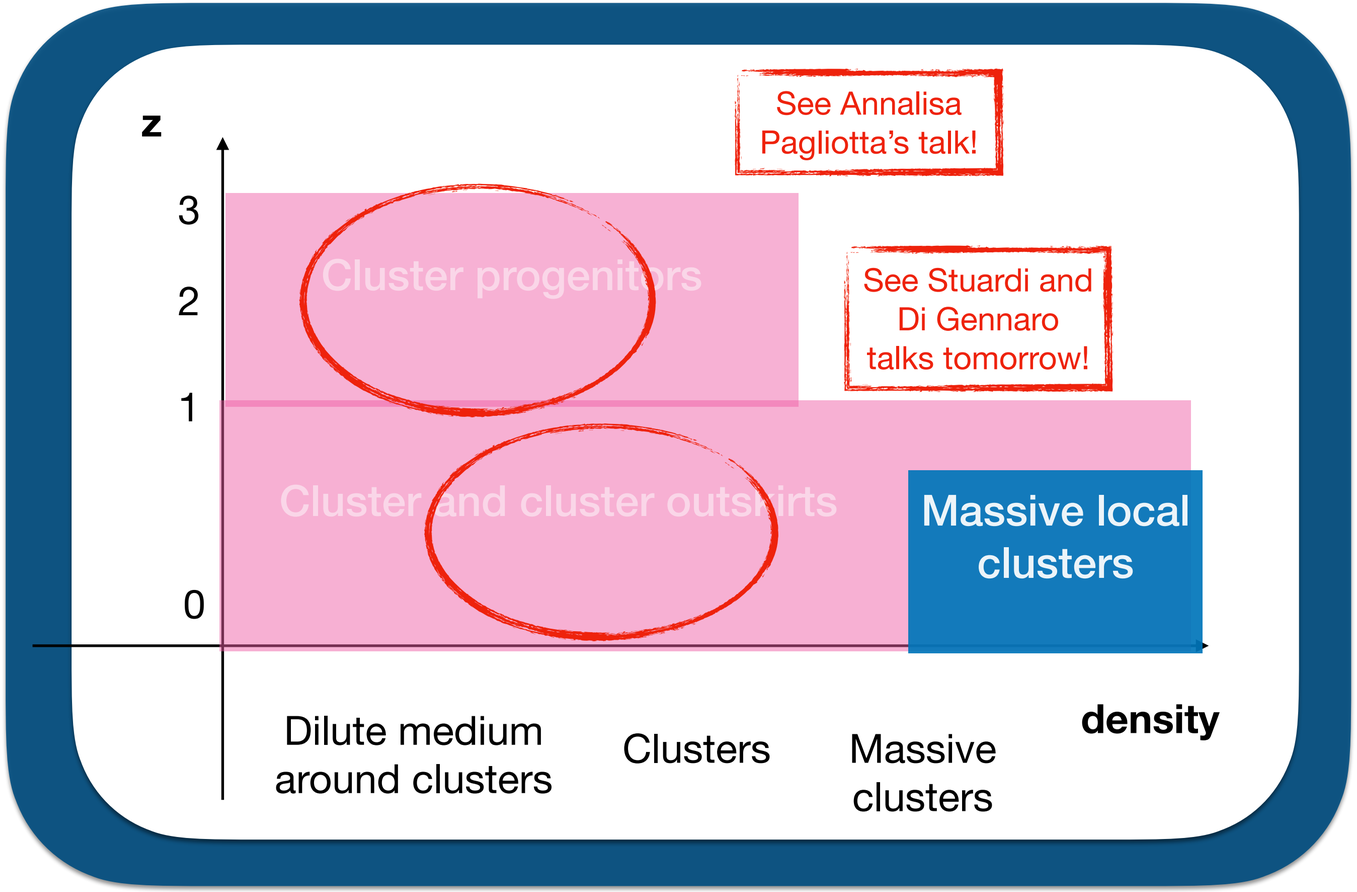

MAGNETIC FIELDS IN LOCAL CLUSTERS: mass evolution?

MeerKAT XLP
Extra Large Project

“Tracing magnetic field amplification in galaxy clusters during the process of structure formation”

~400h over 4 years
(only year 1 and 2 years allocated at the moment)

MeerKAT L band observations
PI AB + M. Balboni, F. Gastaldello, R. Cassano, C. Stuardi, F. Loi

“Tracing magnetic field amplification in galaxy clusters during the process of structure formation”

- Cluster sample: CHEX-MATE
  - thermal component mapped uniformly out to R_{500} with XMM-Newton observations

- Selection criteria:
  - Outside the Galactic plane (|b| < 20)
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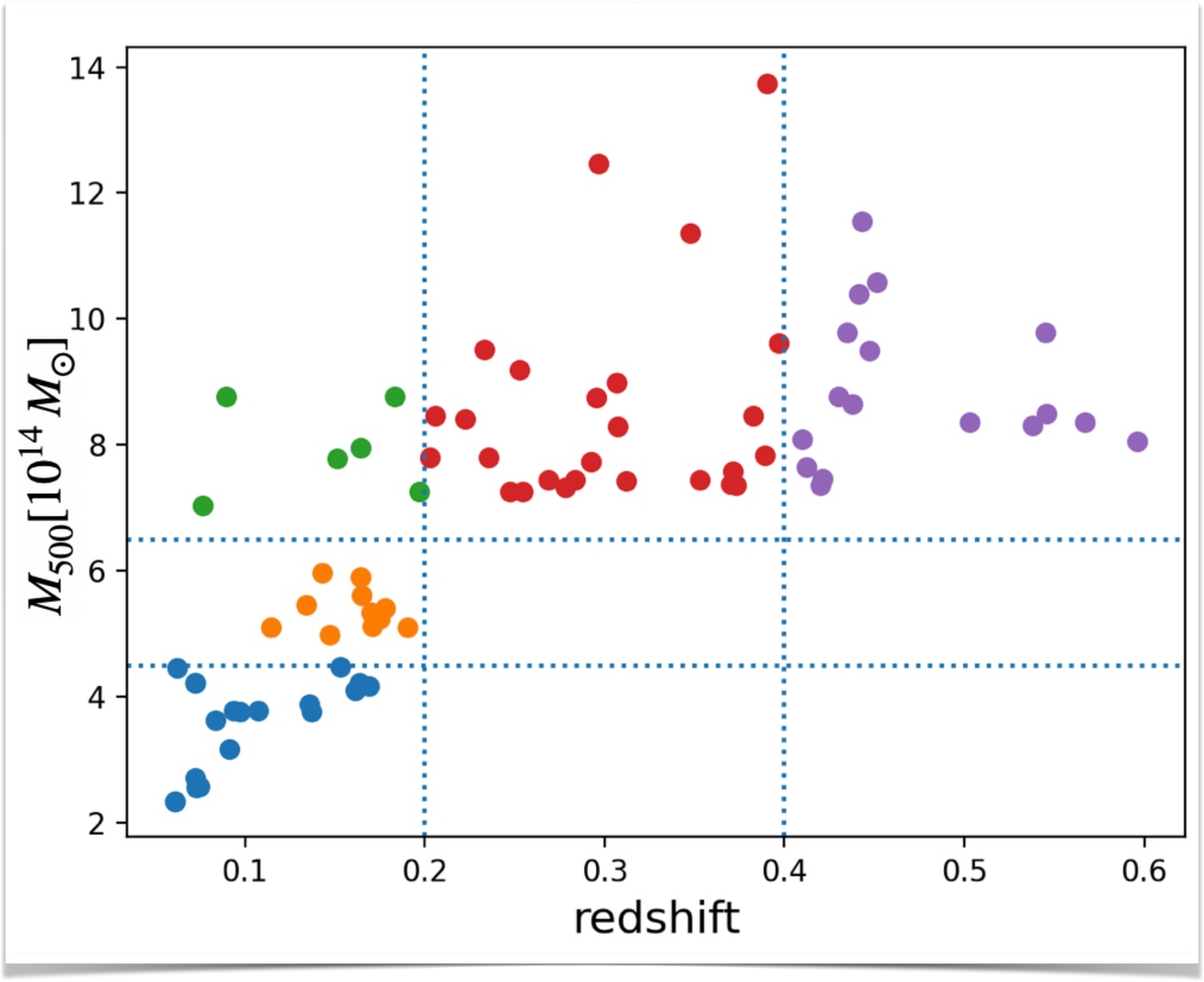
- 5hours/cluster observing time to have enough sources per mass and redshift bin



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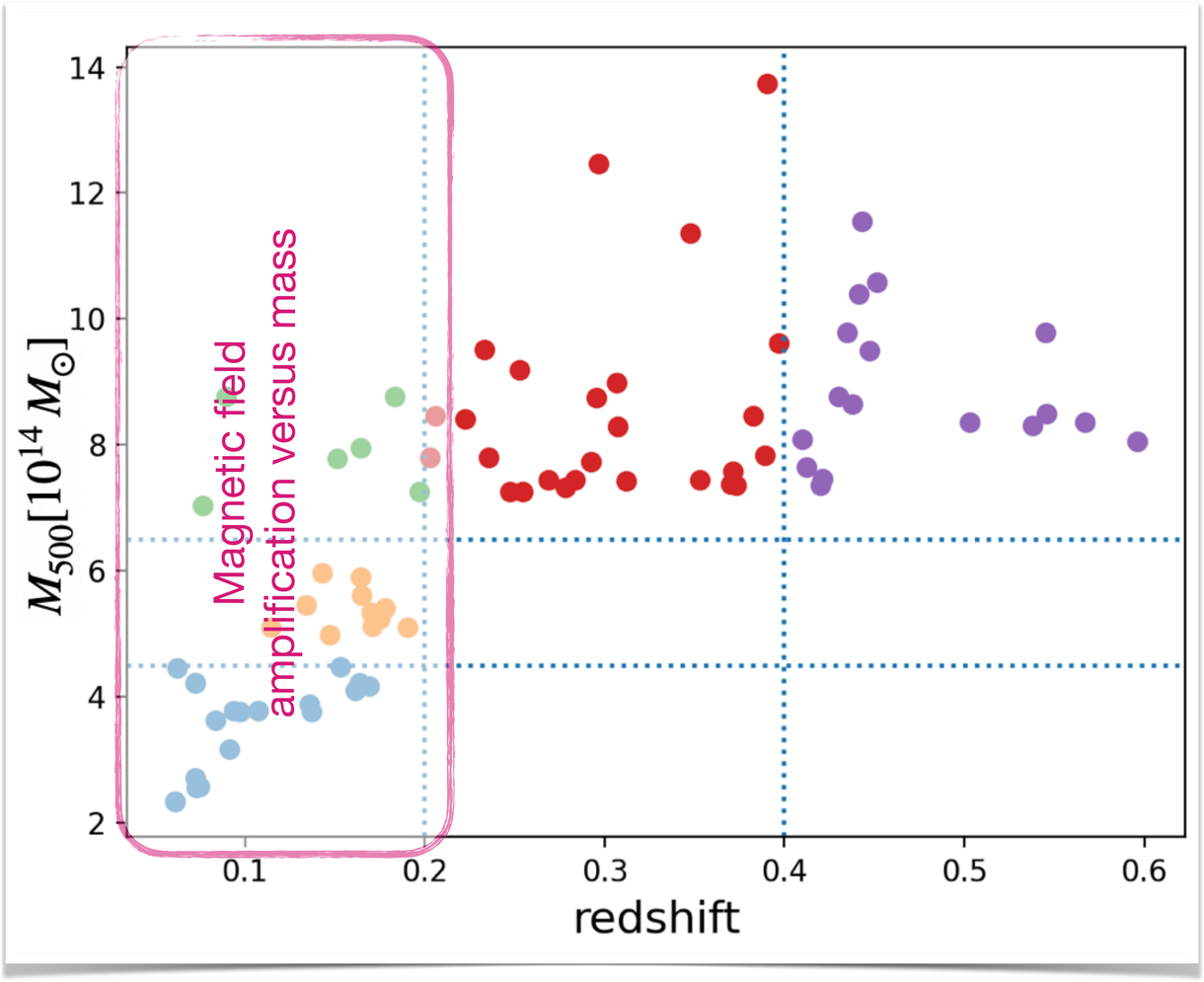

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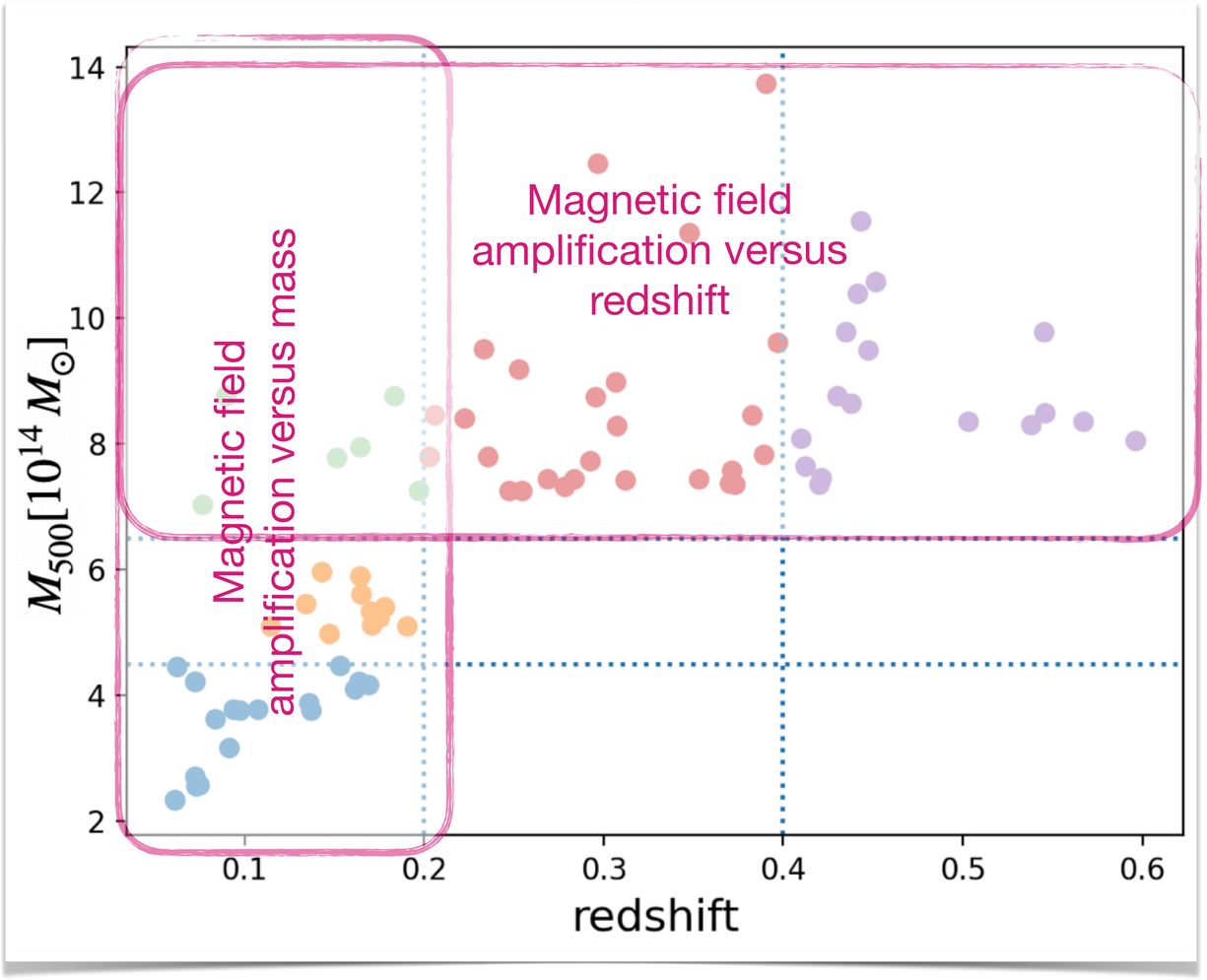

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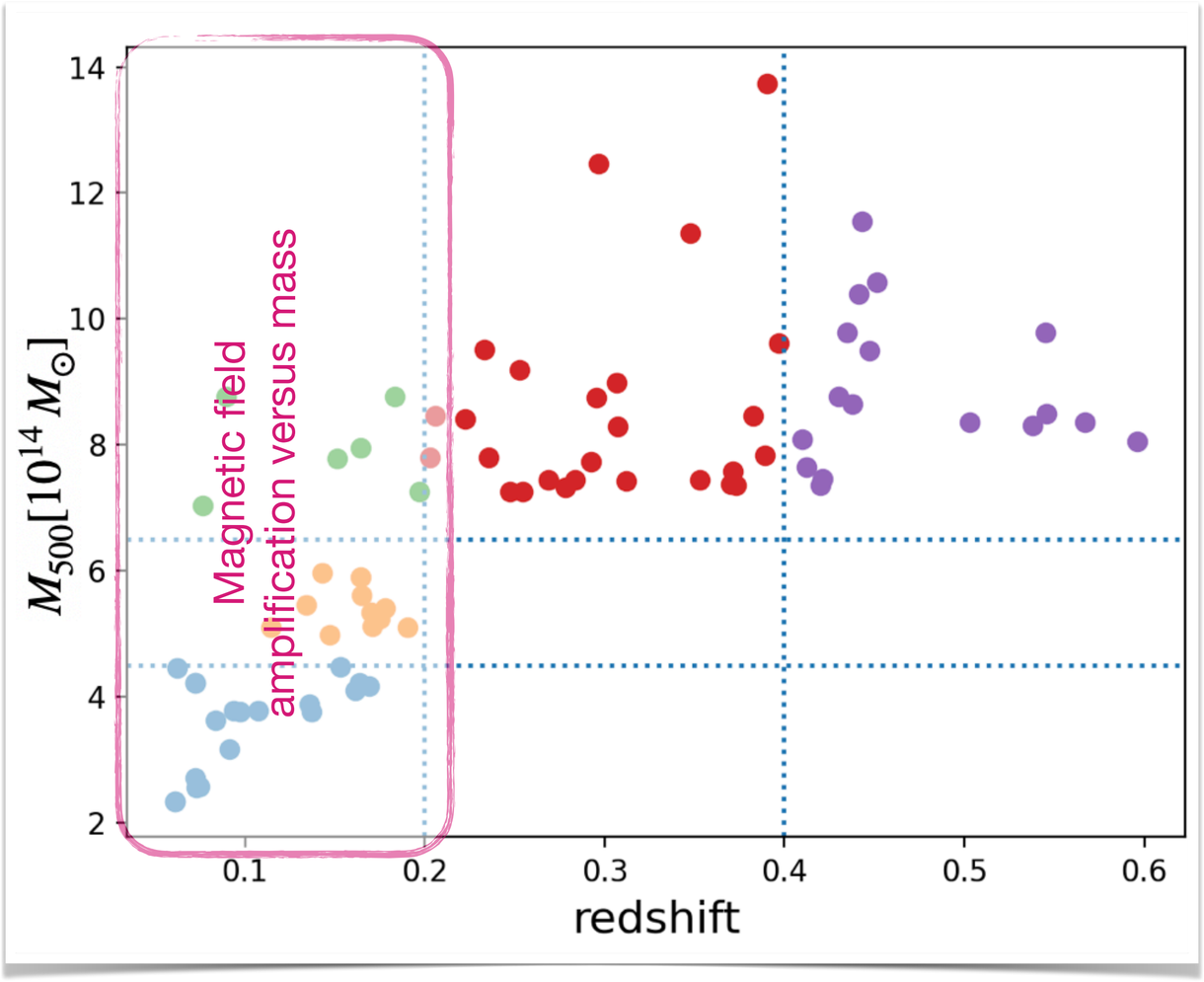

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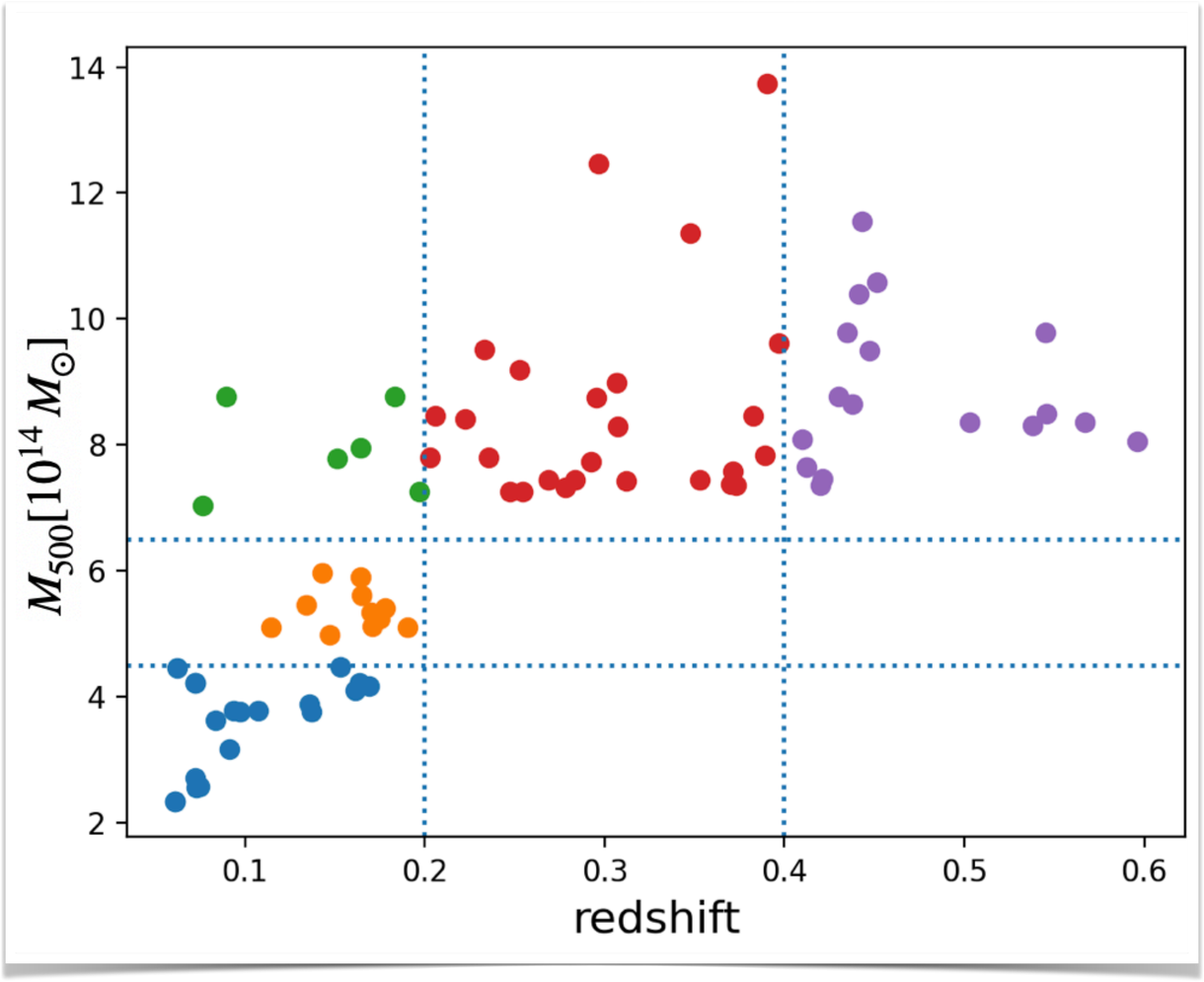

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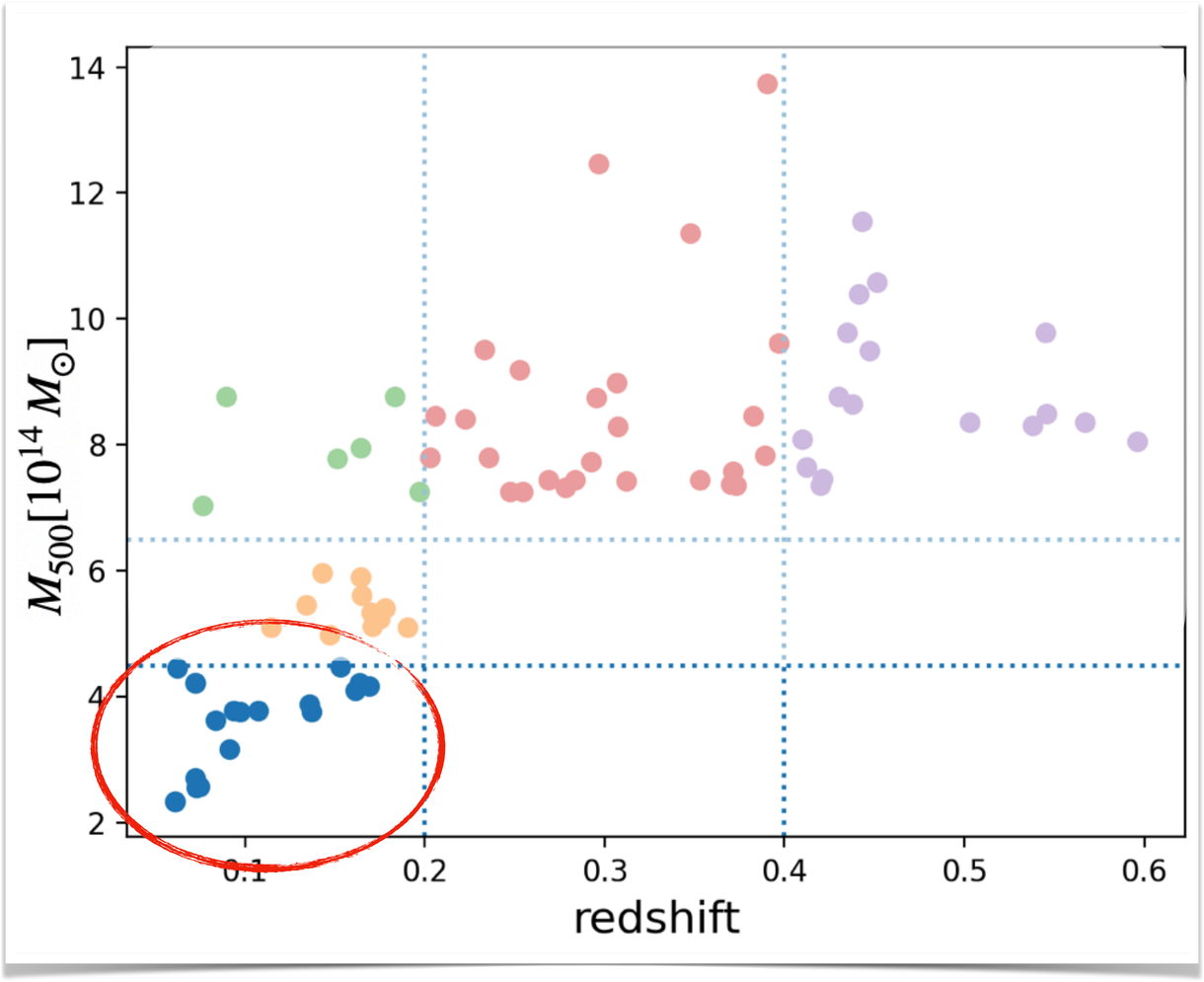
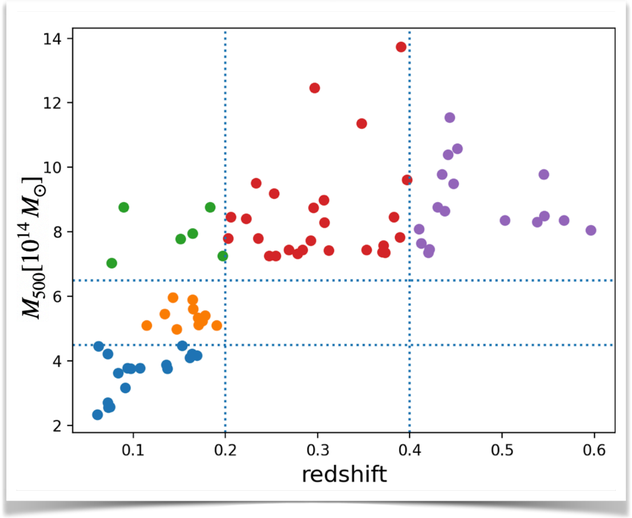


MeerKAT XLP - Extra Large Project



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low mass, low-z clusters

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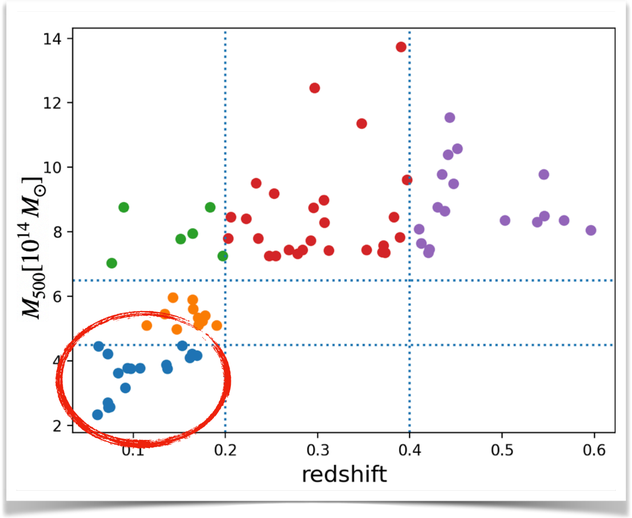

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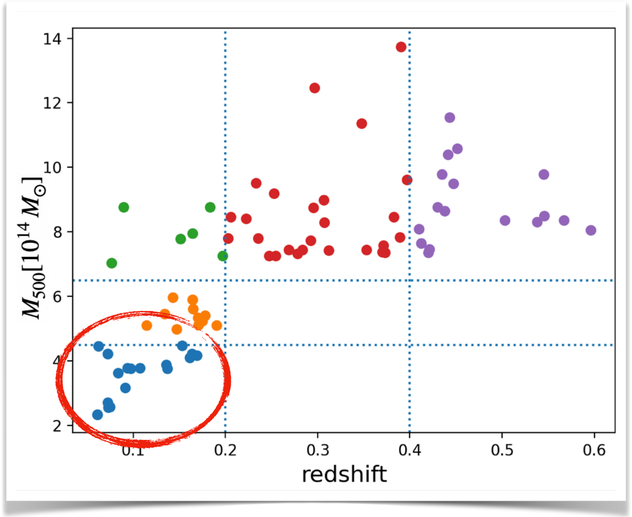

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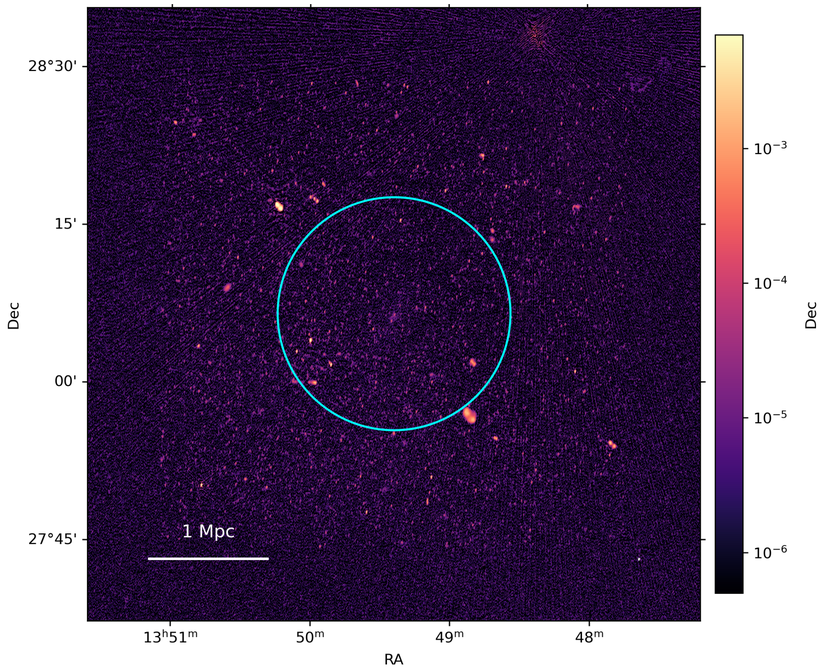
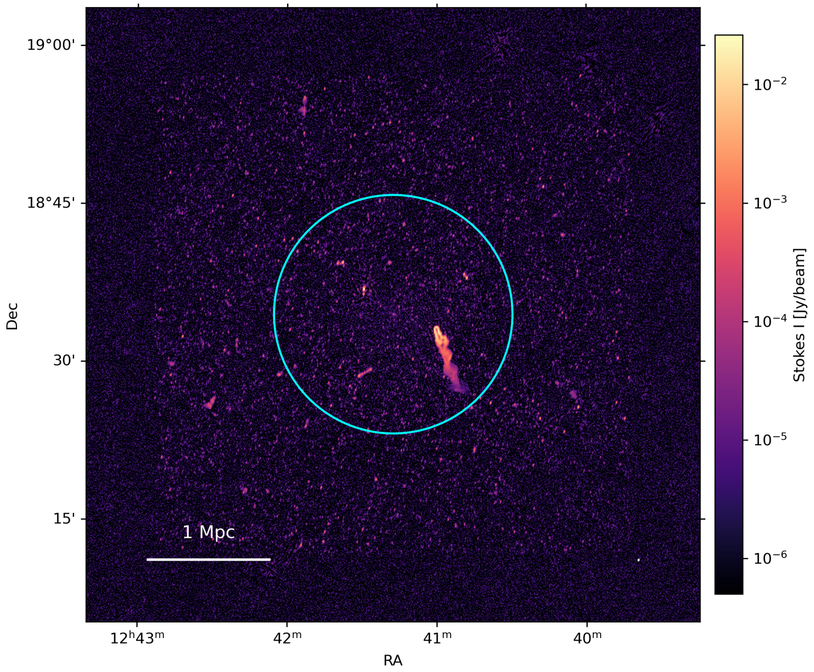
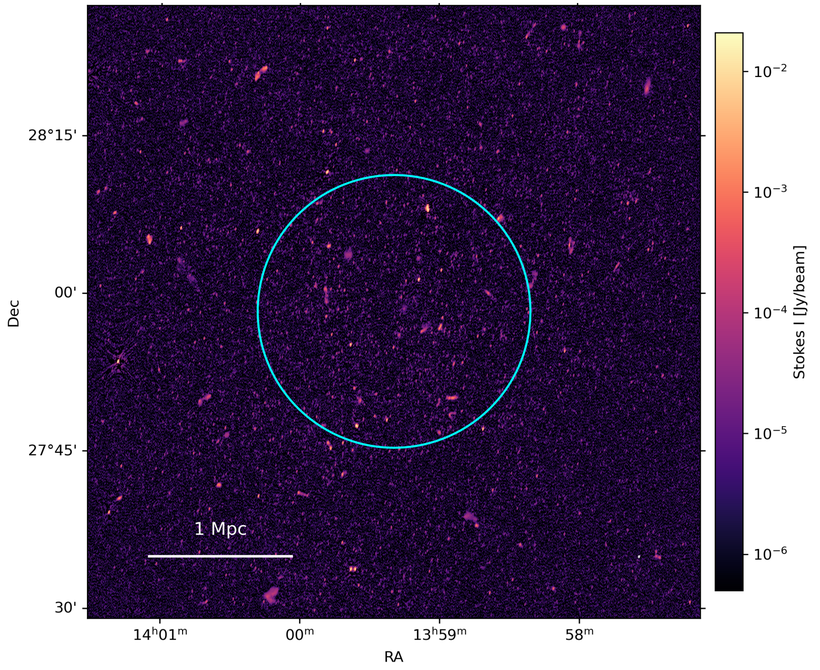
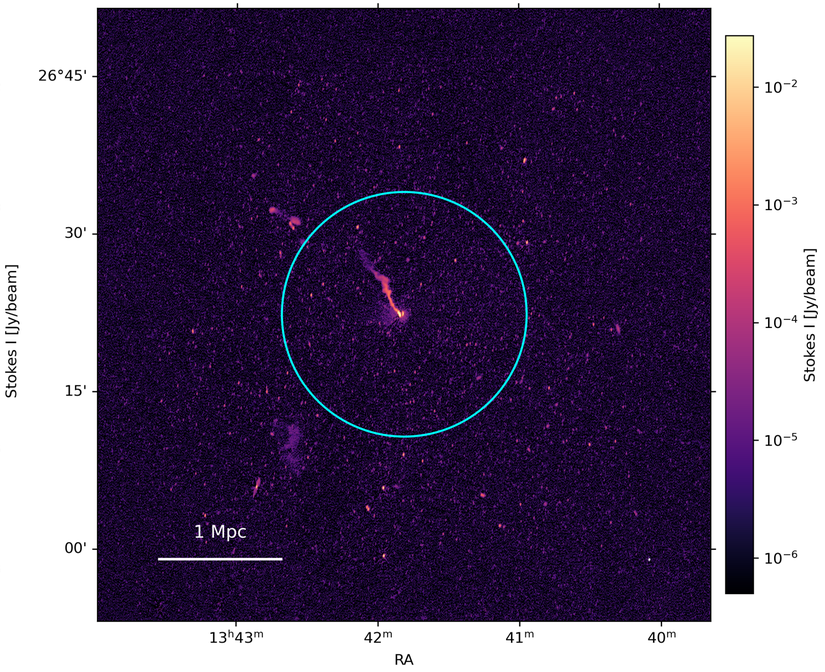


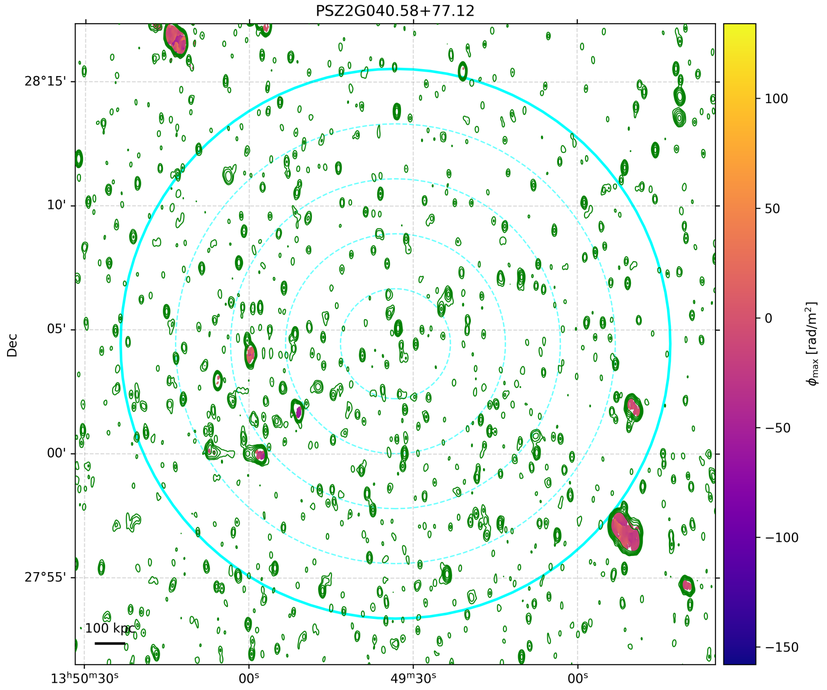


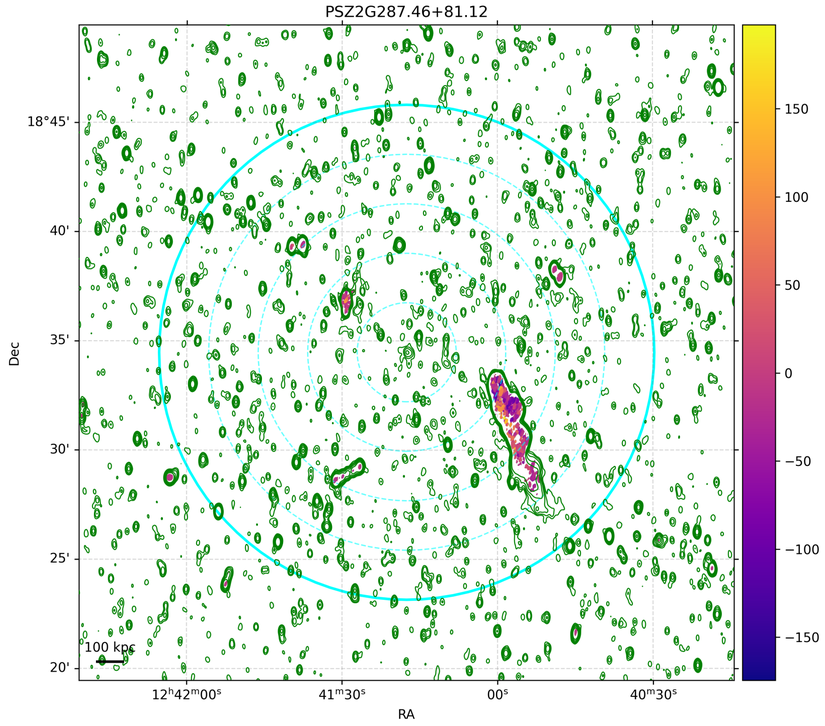


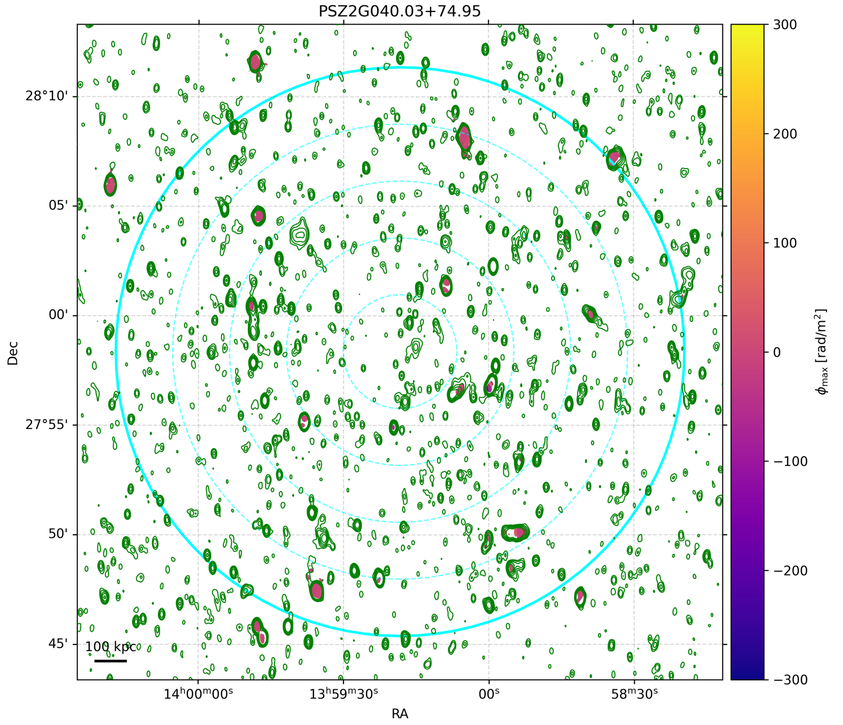


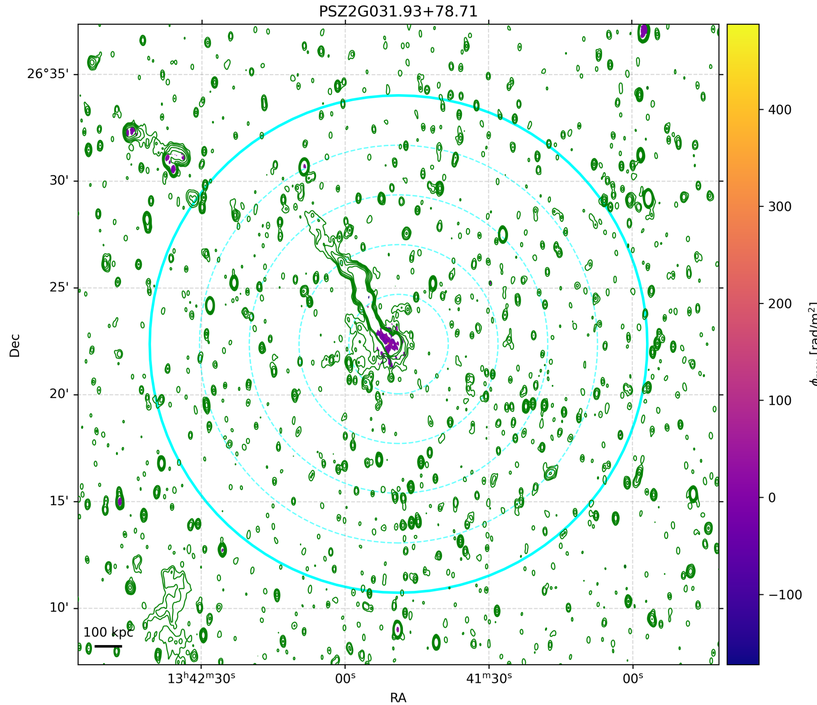
MeerKAT XLP - Extra Large Project

- RM-synthesis with RM Tools including RM clean
- Noise in P ~4e-6 Jy/ beam
- RM precision (6 sigma) 4 rad/m^2
- Beam ~15 arcsec









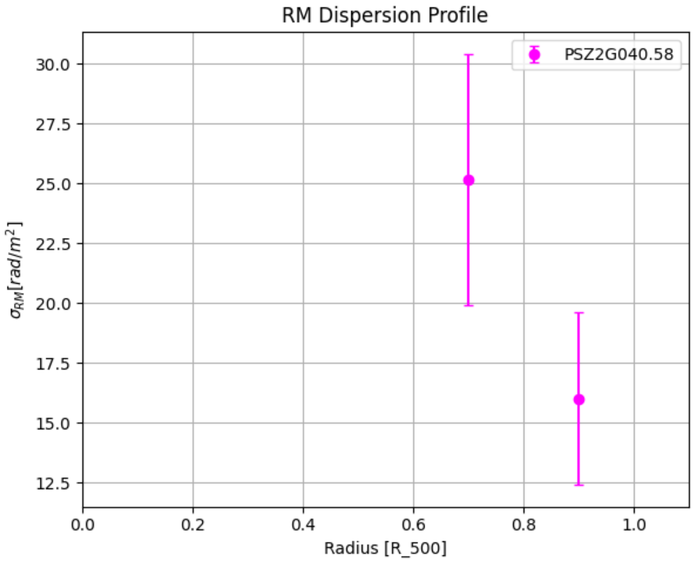
CHEX-MATE-KAT: first observations: low mass, low z sub-sample

- Individual σ_{RM} profiles

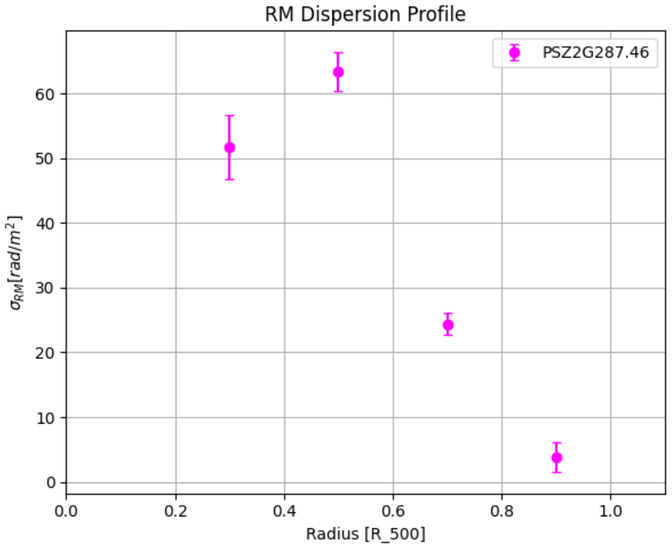
$$\sigma_{RM} \propto B_{//}$$

- Annuli of 1/5 R_{500} each
- Only annuli with more than1 equivalent beam

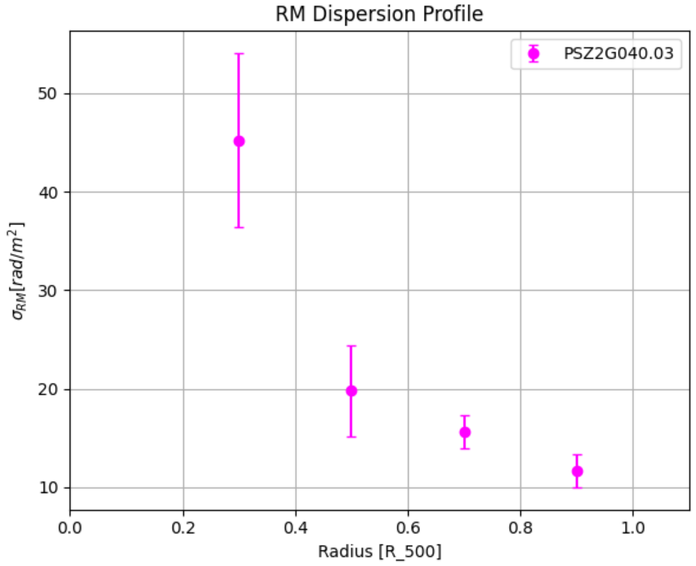
PSZ2 G040.58+77.12, z=0.0748, M500= 2.57e14 Msun



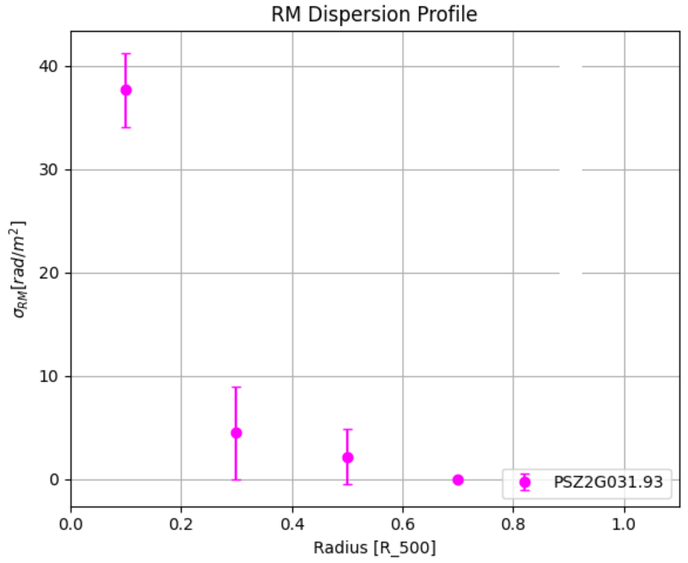
PSZ2 G287.46+81.12, z=0,073, M500=2.56e14



PSZ2 G040.03+74.95 , z=0,0612, M500=2.34e14



PSZ2 G031.93+78.71, z=0,0724, M500= 2.72e14



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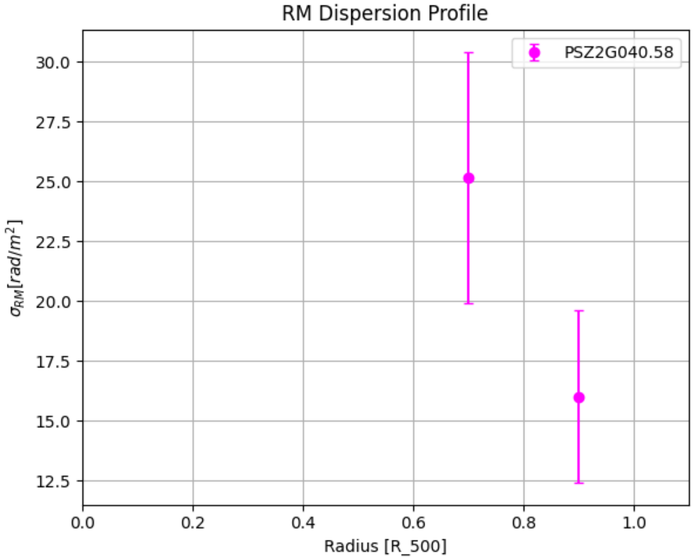

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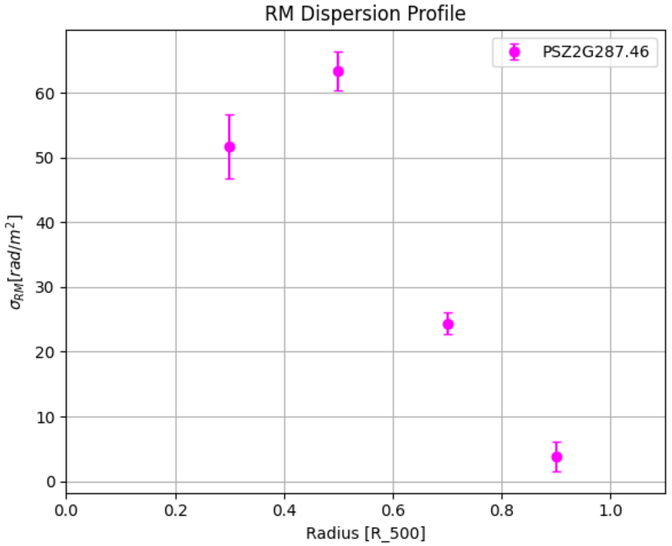

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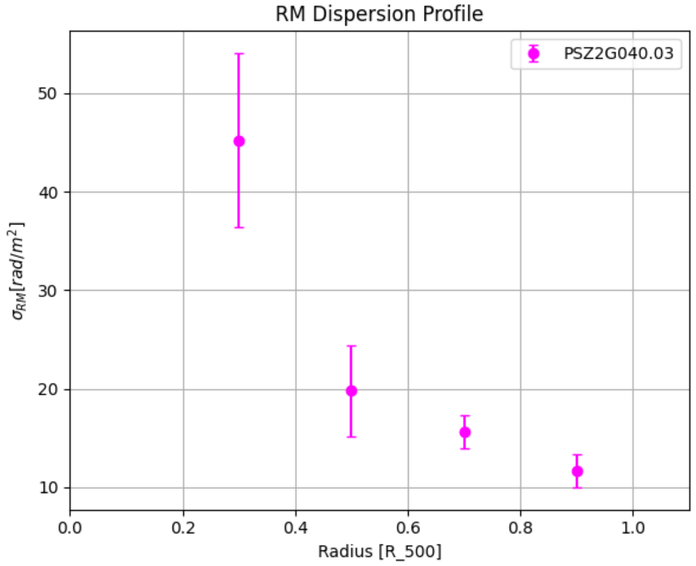

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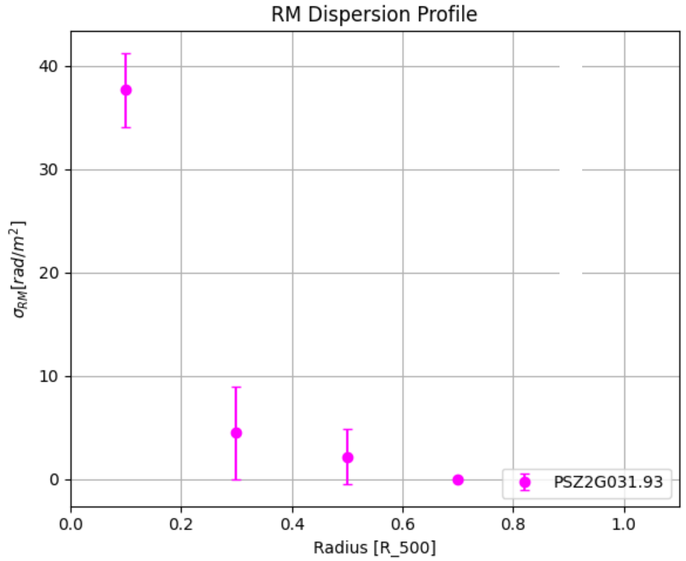

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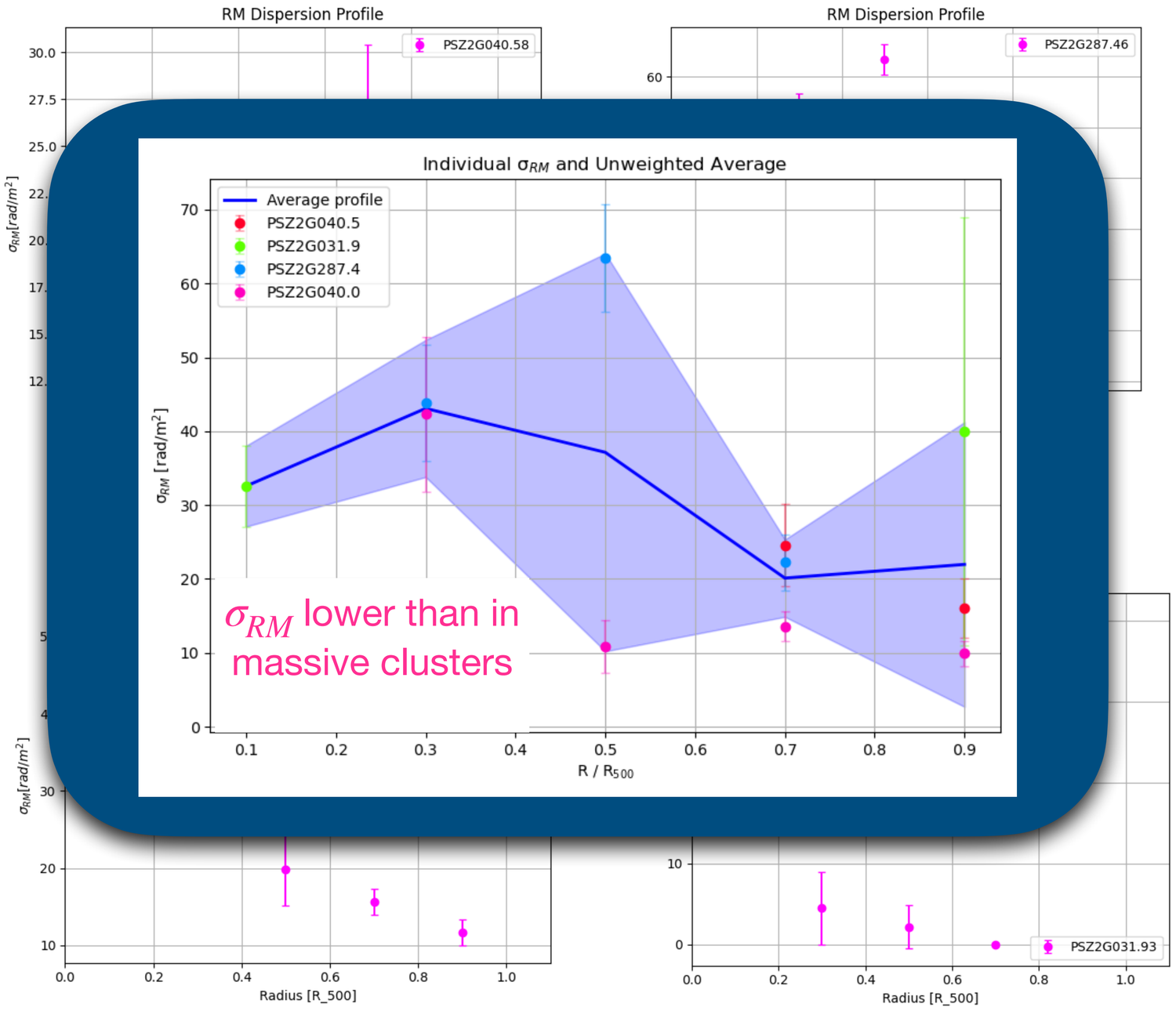

Preliminary

Simulations: MiRo' code

(Bonafede et al 213, Stuardi et al 2021)

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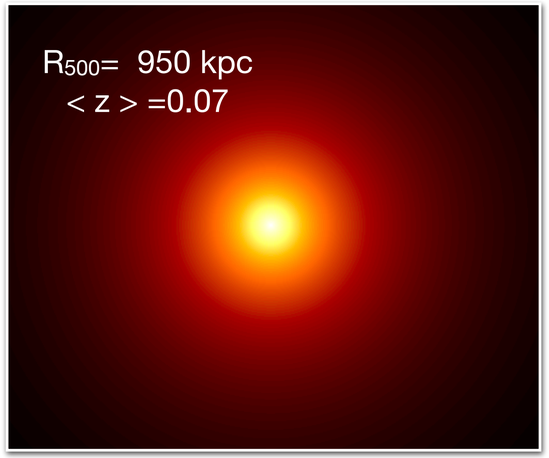

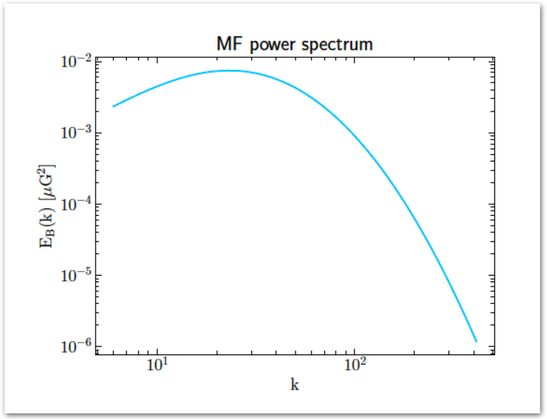

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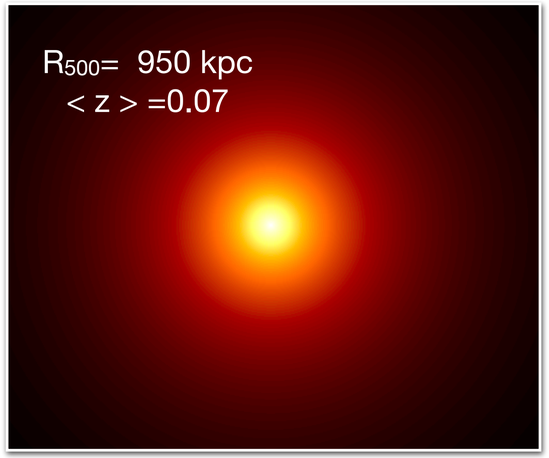
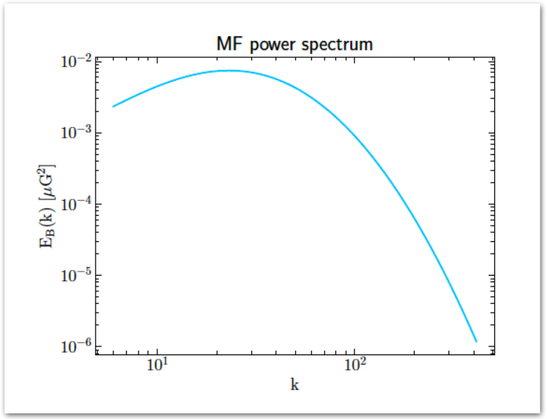


$$RM \propto \int n_e \, B_{||} \, dl$$



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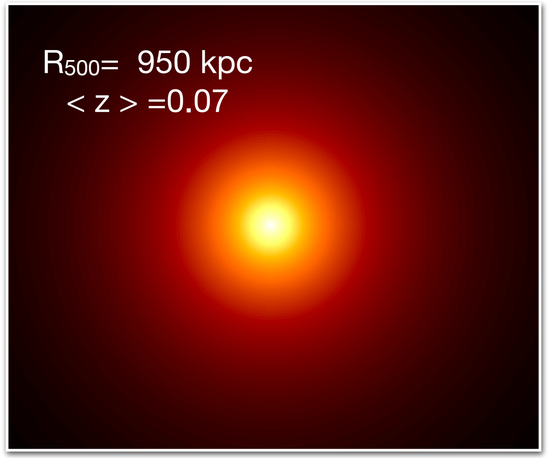

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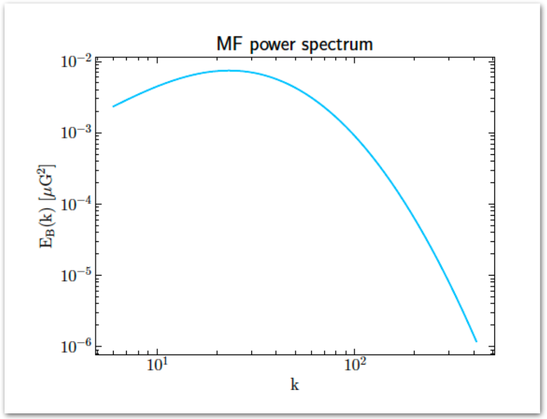
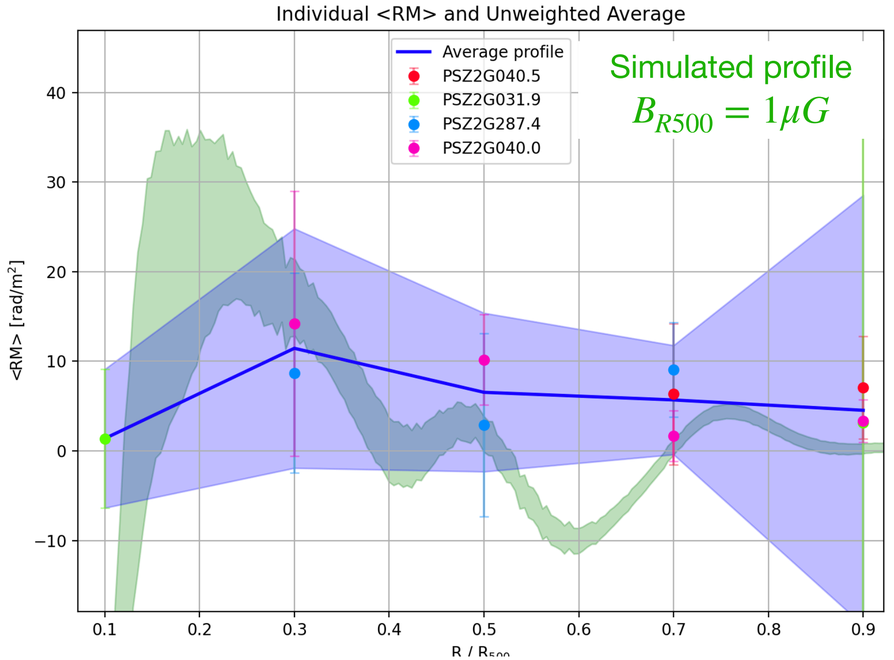
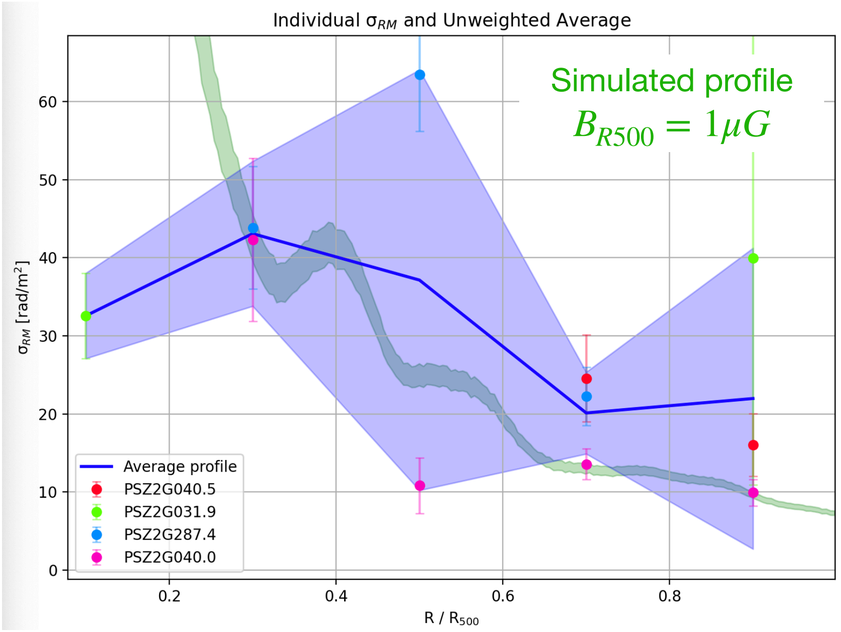
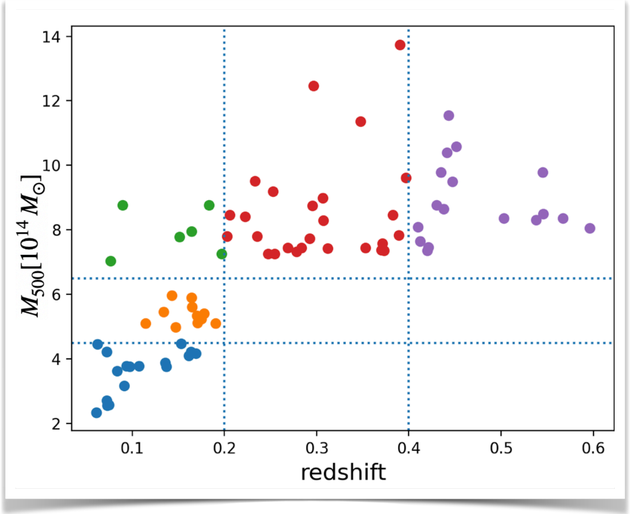






MeerKAT XLP - Extra Large Project

F. Campolucci
Master thesis



High mass- high z clusters
Time not granted yet, but observations in the archive (PI M. Balboni)

not enough sources for RM studies on single clusters

B constraints based on depolarisation

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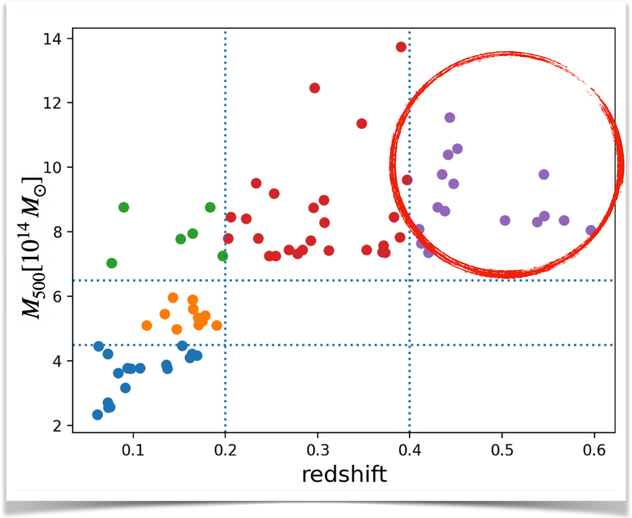

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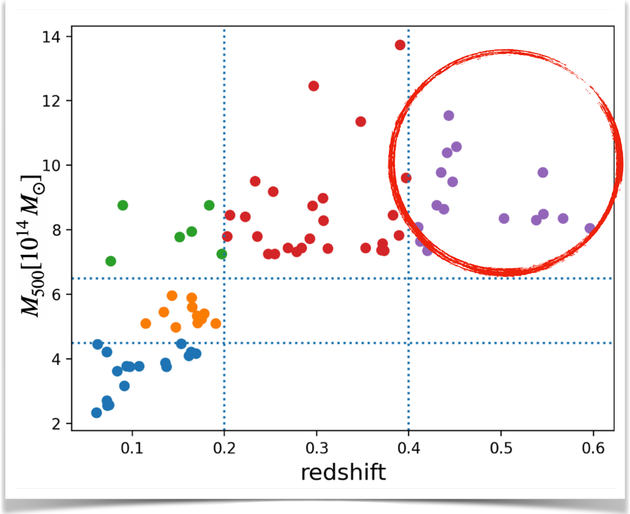
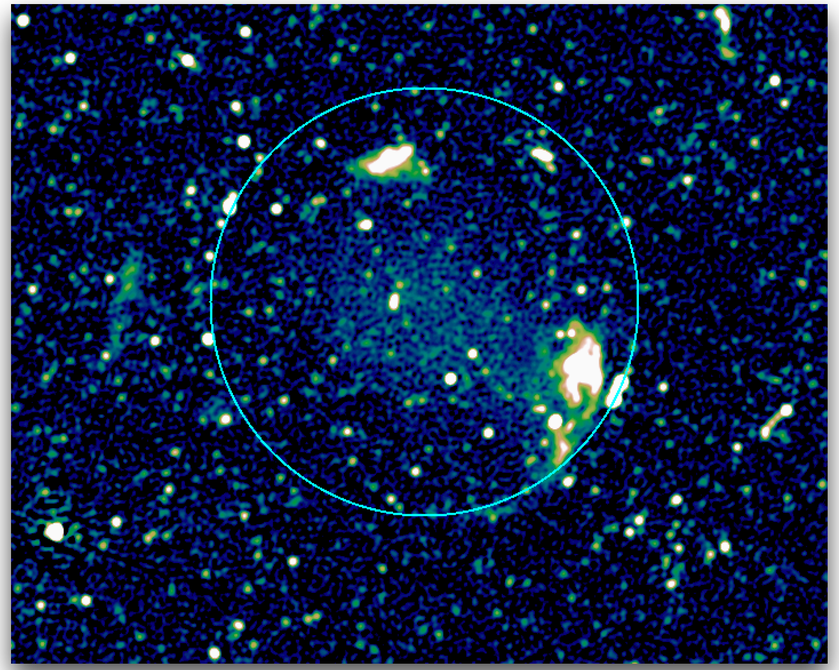


PSZ2G243.15-73.84
z = 0.41
$M_{500} = 8.08\ 10^{14}\ M_{sun}$



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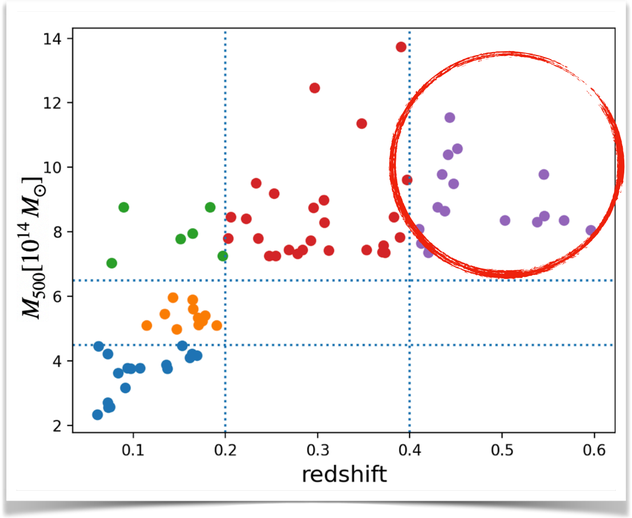

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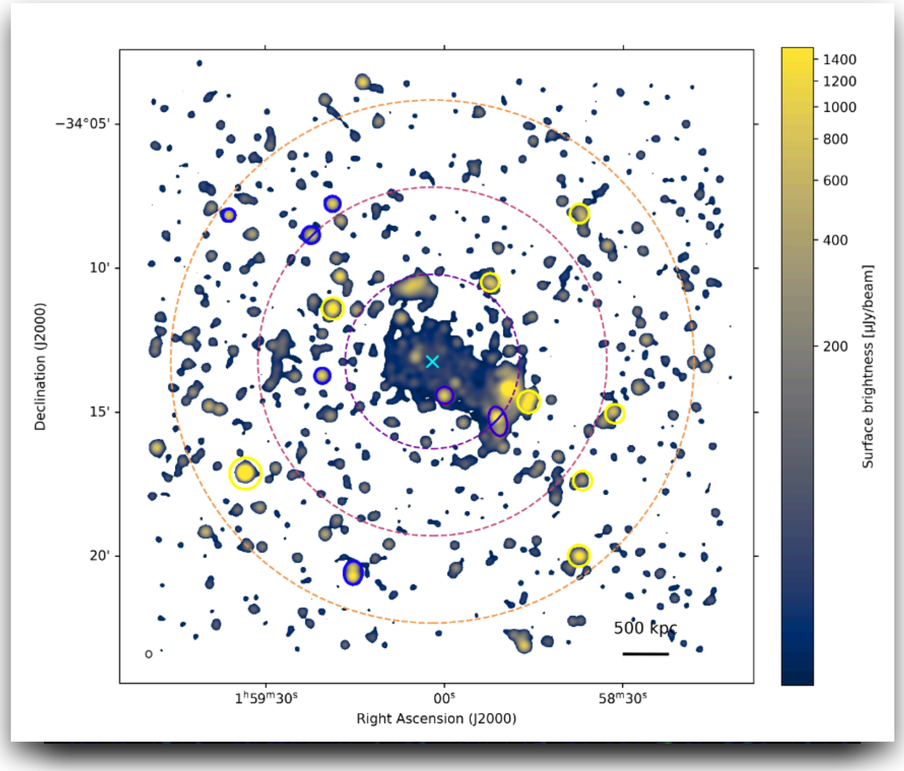

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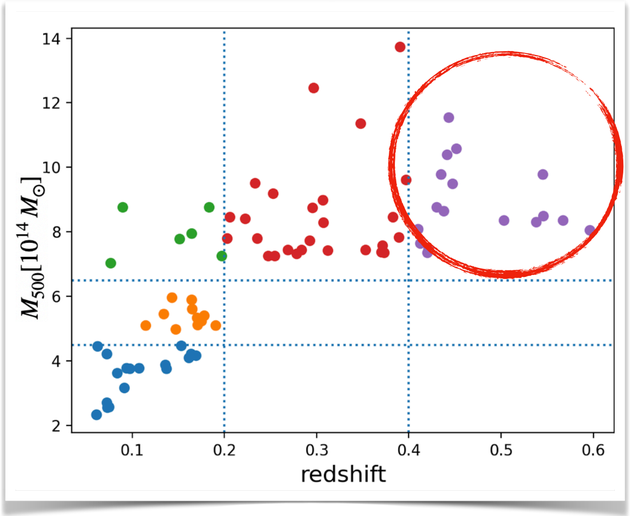

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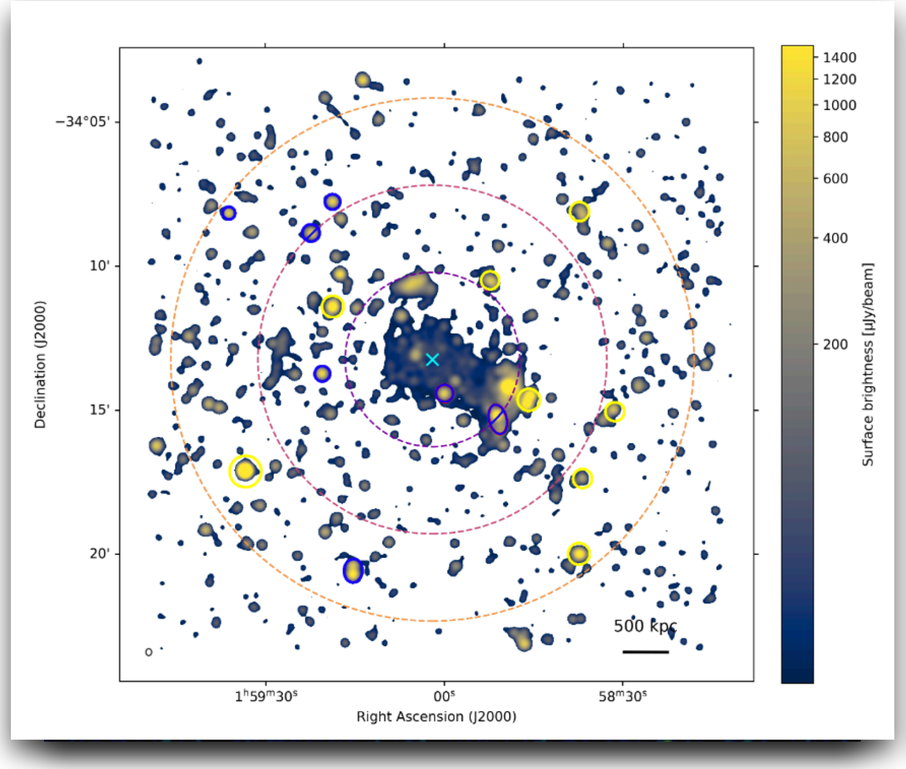

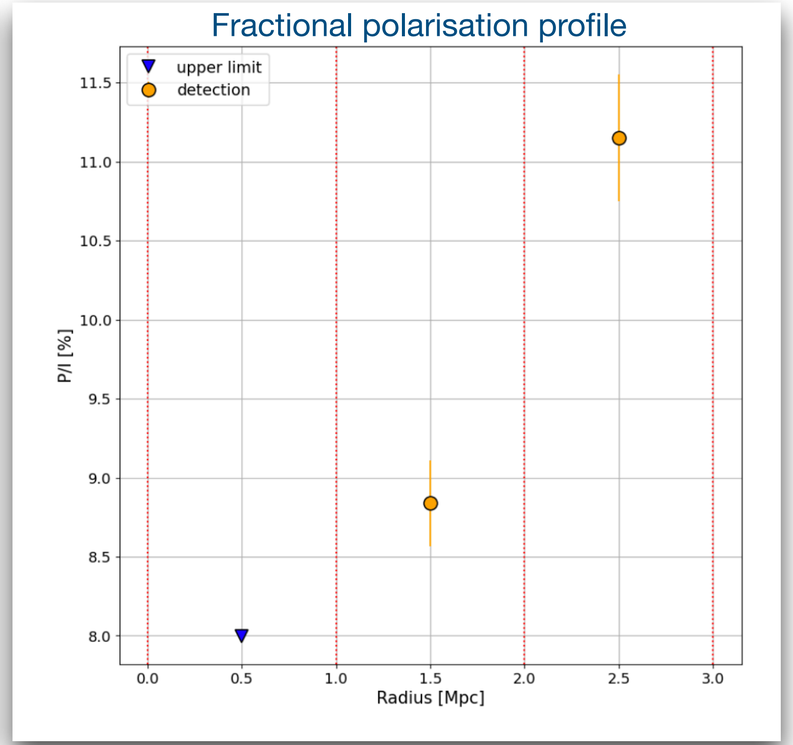

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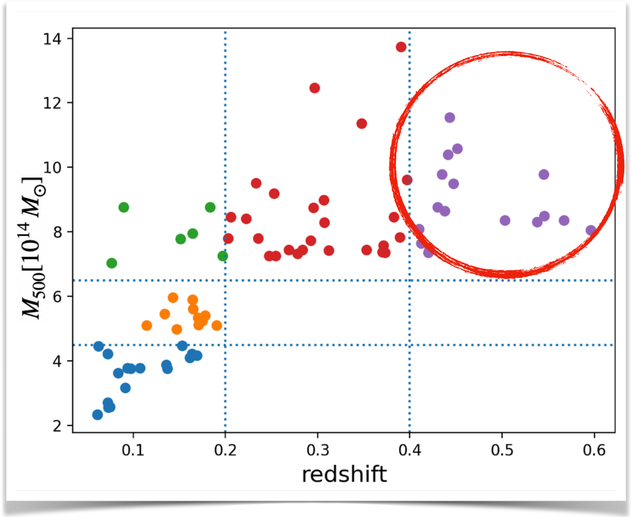

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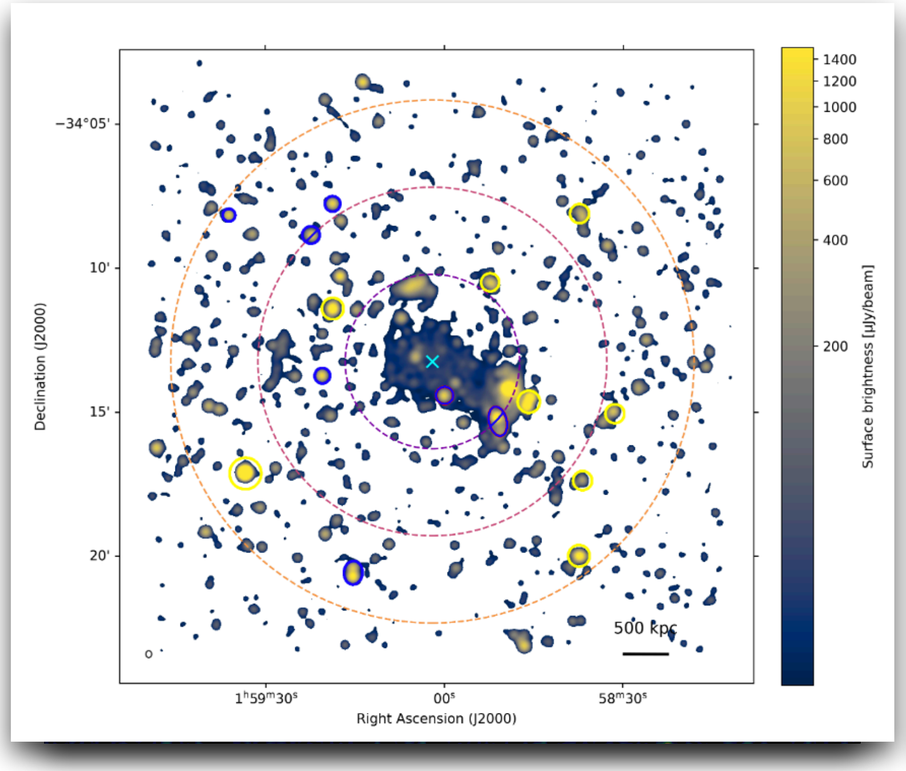

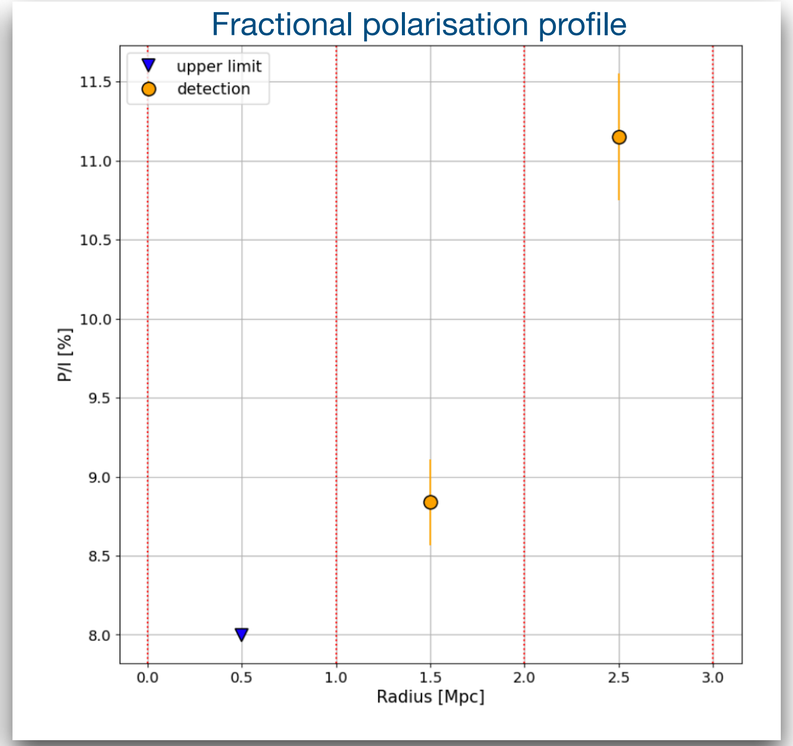

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B constraints based on depolarisation

Preliminary results: $B_{R500} < 3\mu G$

SUMMARY

- Magnetic field in galaxy clusters can be constrained with wide-band polarisation observations in the pre-SKA era

- Stacking of cluster RM in small mass and z bins will allow to trace the evolution of B

- Likely many systematics need to be accounted for