

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

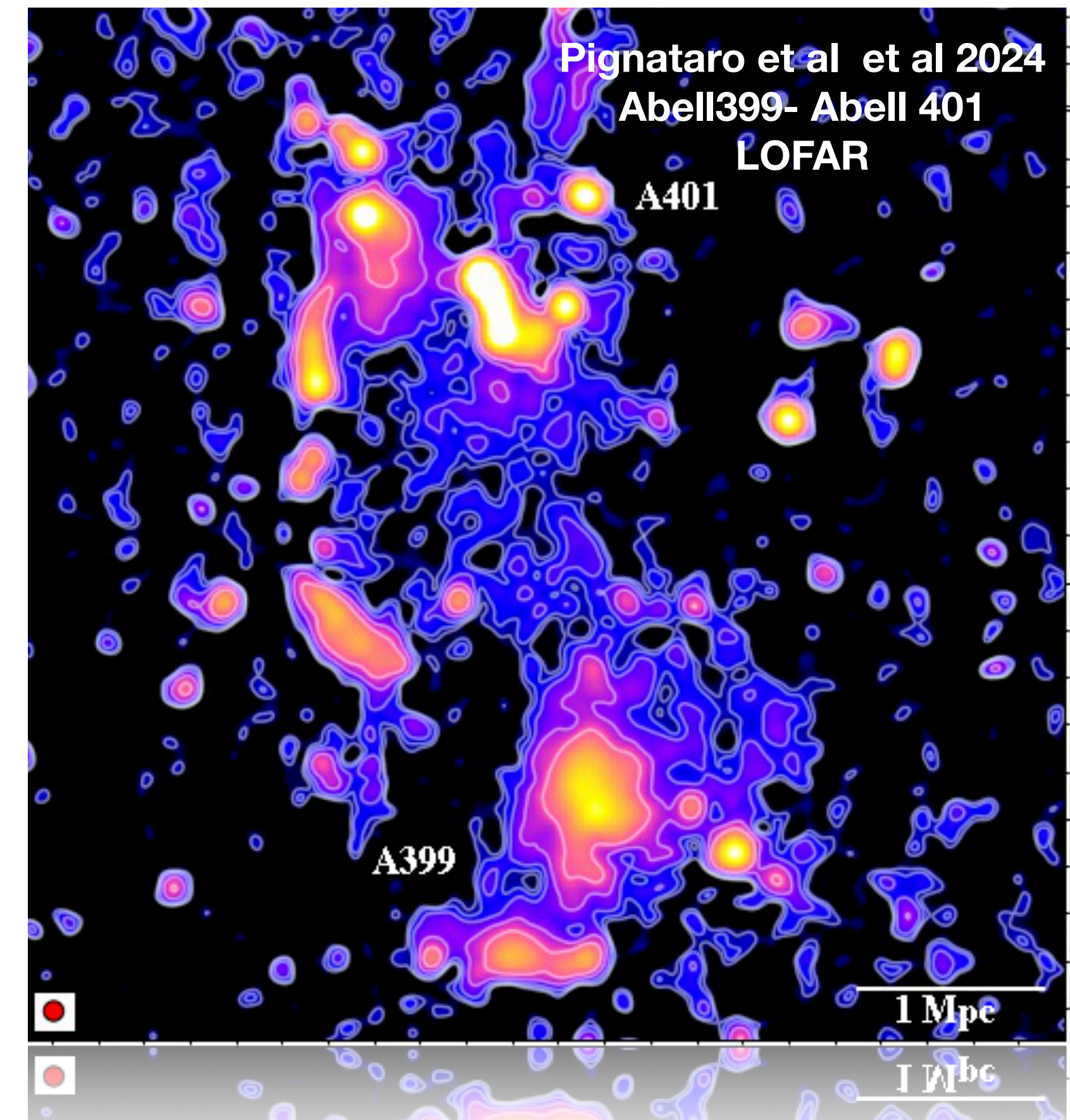
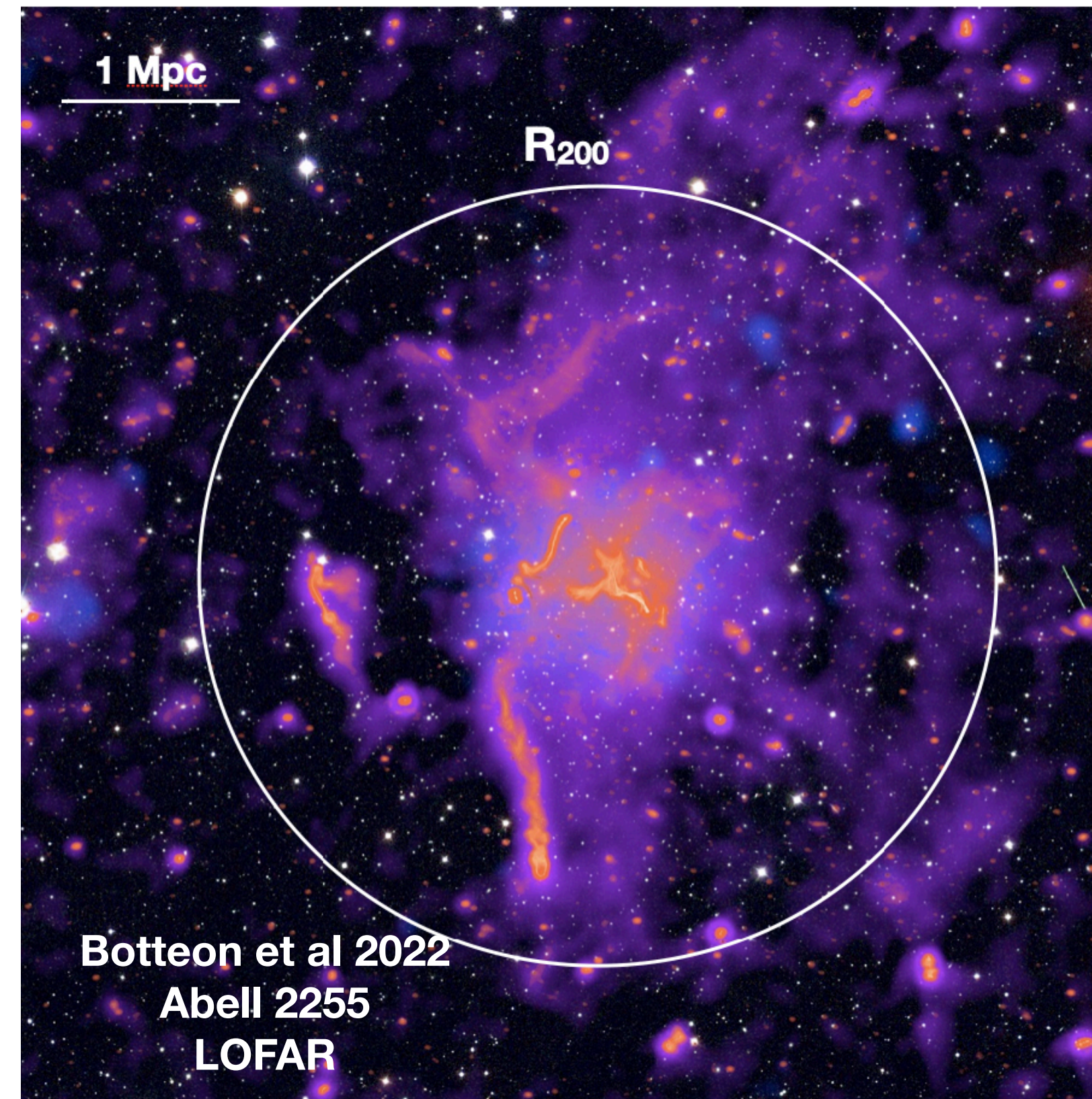
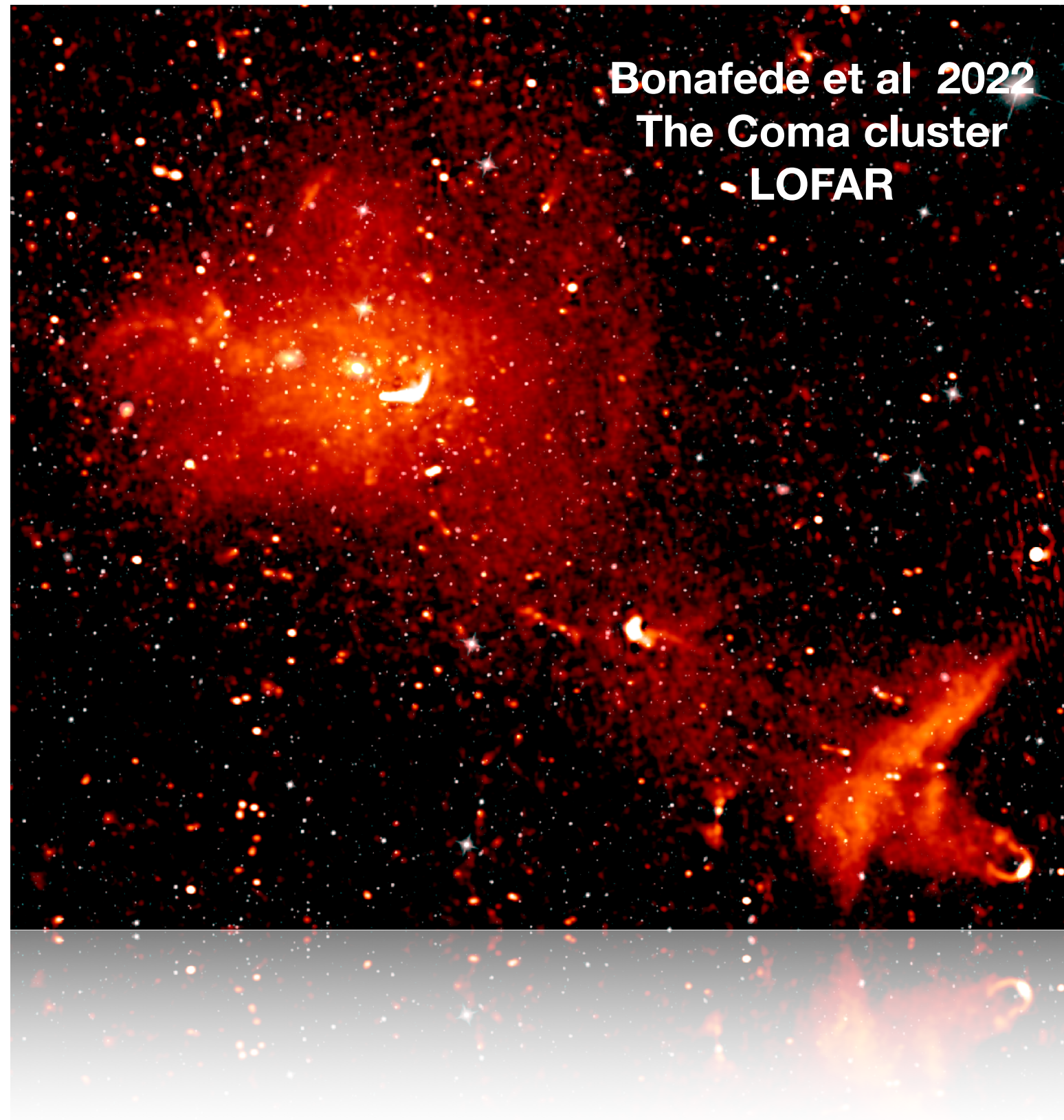


Annalisa Bonafede

**University of Bologna
&
INAF - IRA**



EVIDENCE FOR B IN CLUSTERS AND BEYOND

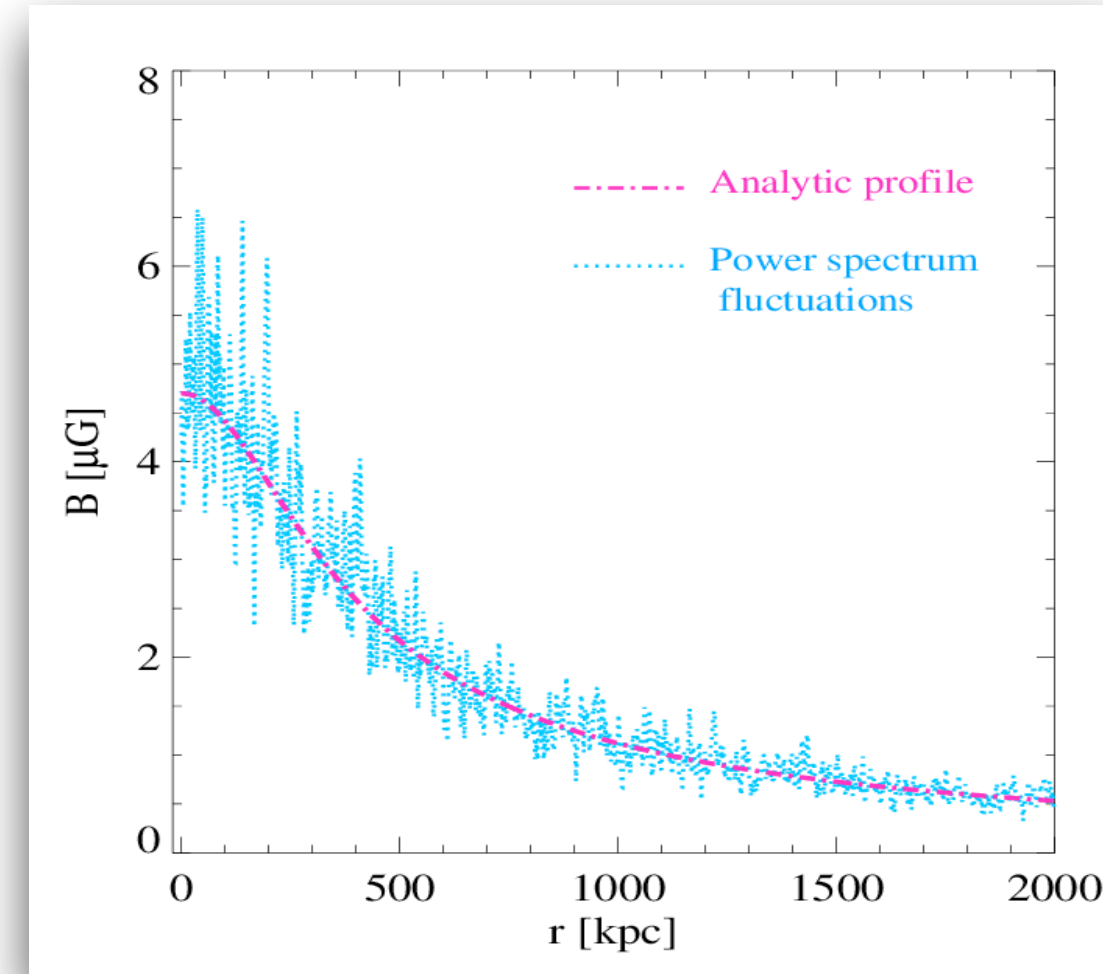


Overall few μG ,

ICM is a high- β plasma

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

MAGNETIC FIELDS IN CLUSTERS: OBSERVATIONS



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

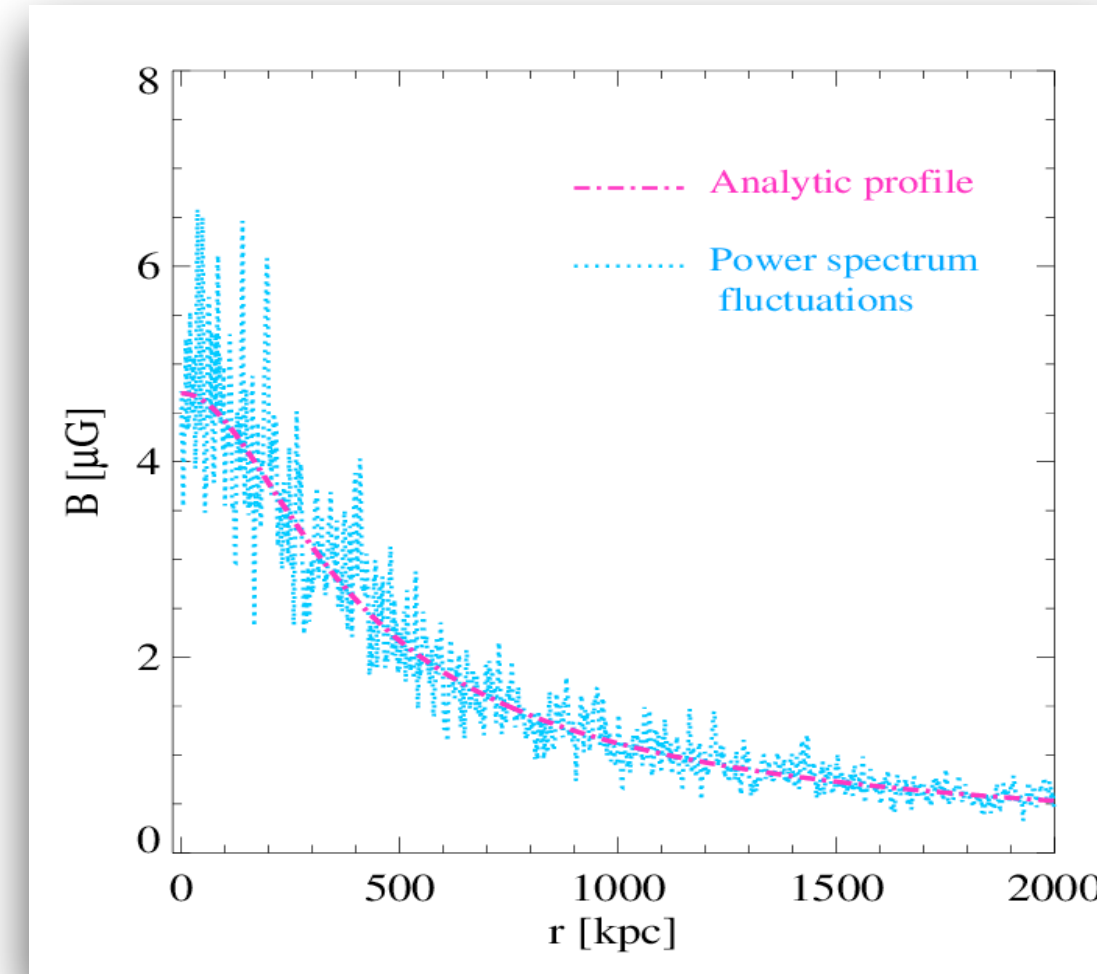
$B \propto n^{0.5}$ (Bonafede et al 2010)

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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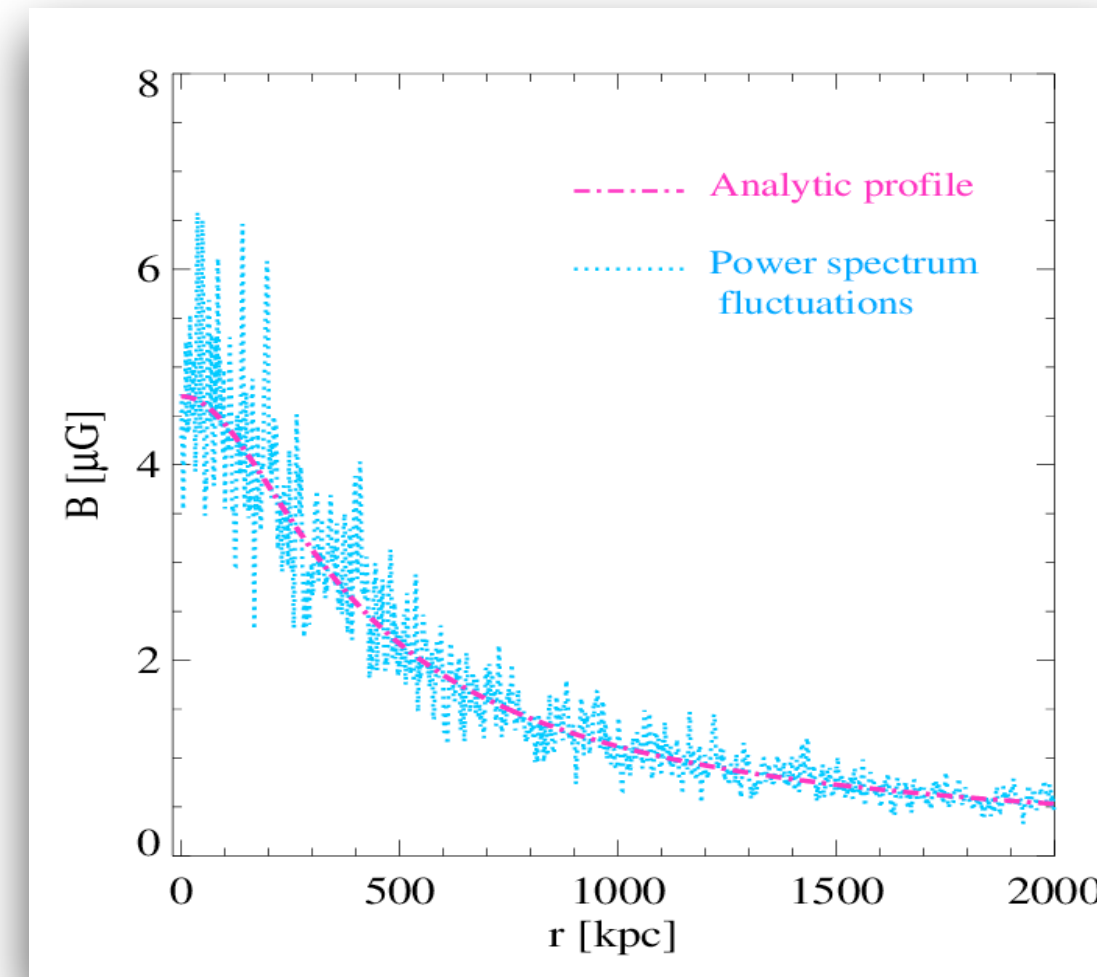
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Galaxy cluster	M_{500} ($10^{14}M_\odot$)	z	$\langle B_0 \rangle$ (μG)	$\langle B_{1Mpc^3} \rangle$ (μG)	η	Ref.
Abell 119	3.4	0.04	5	1.5	0.9	Murgia et al. (2004)
Abell 2255	5.4	0.08	2.5	1.2	0.5*	Govoni et al. (2006)
Abell 2382	2.0	0.06	3.3	1	0.5*	Guidetti et al. (2008)
Coma	7.2	0.02	4.7	2	0.5	Bonafede et al. (2010)
Abell 665	8.9	0.18	1.3	0.75	0.5*	Vacca et al. (2010)
Abell 2199	2.9	0.03	11.7	0.2	0.9	Vacca et al. (2012)
Abell 194	0.3	0.02	1.5	0.3	1.1	Govoni et al. (2017)
Abell 2345	5.9	0.18	2.8	1.2	1.0	Stuardi et al (2021)

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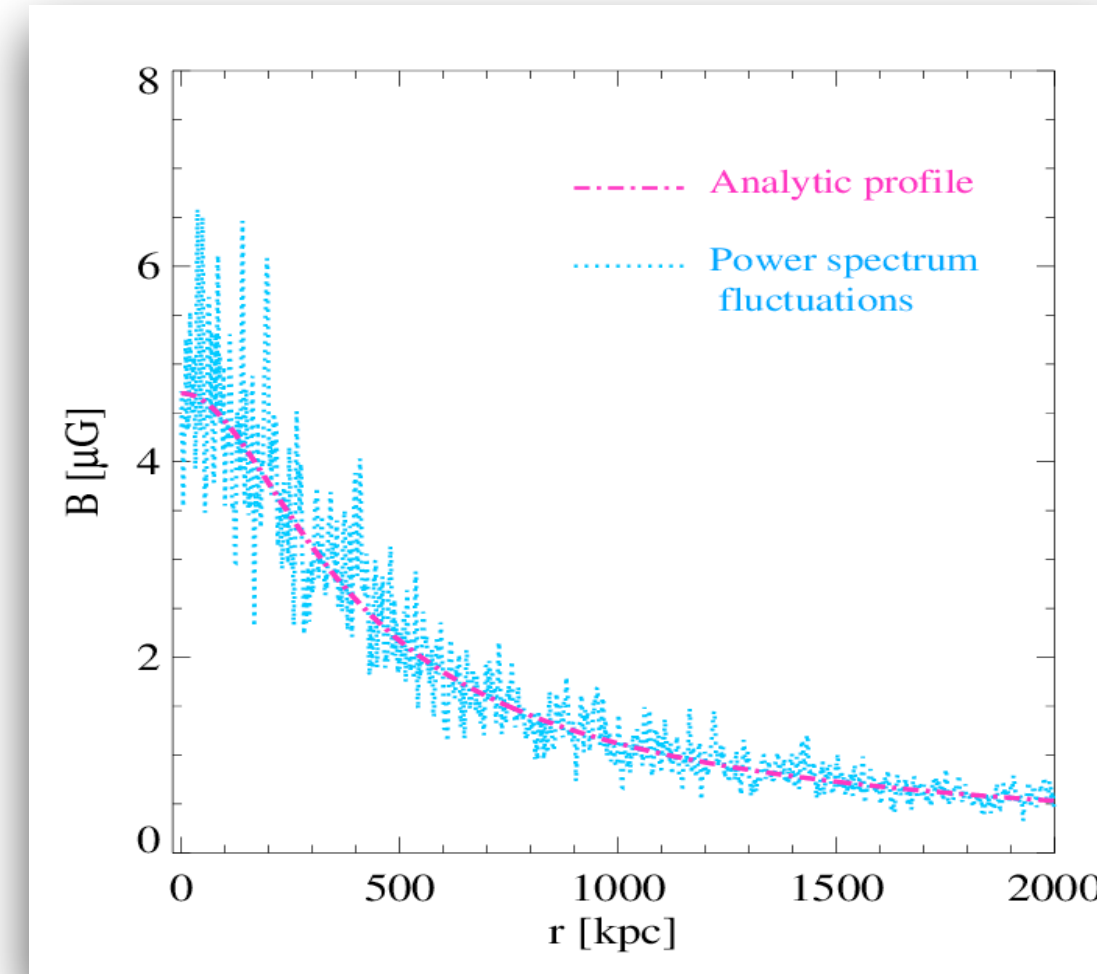
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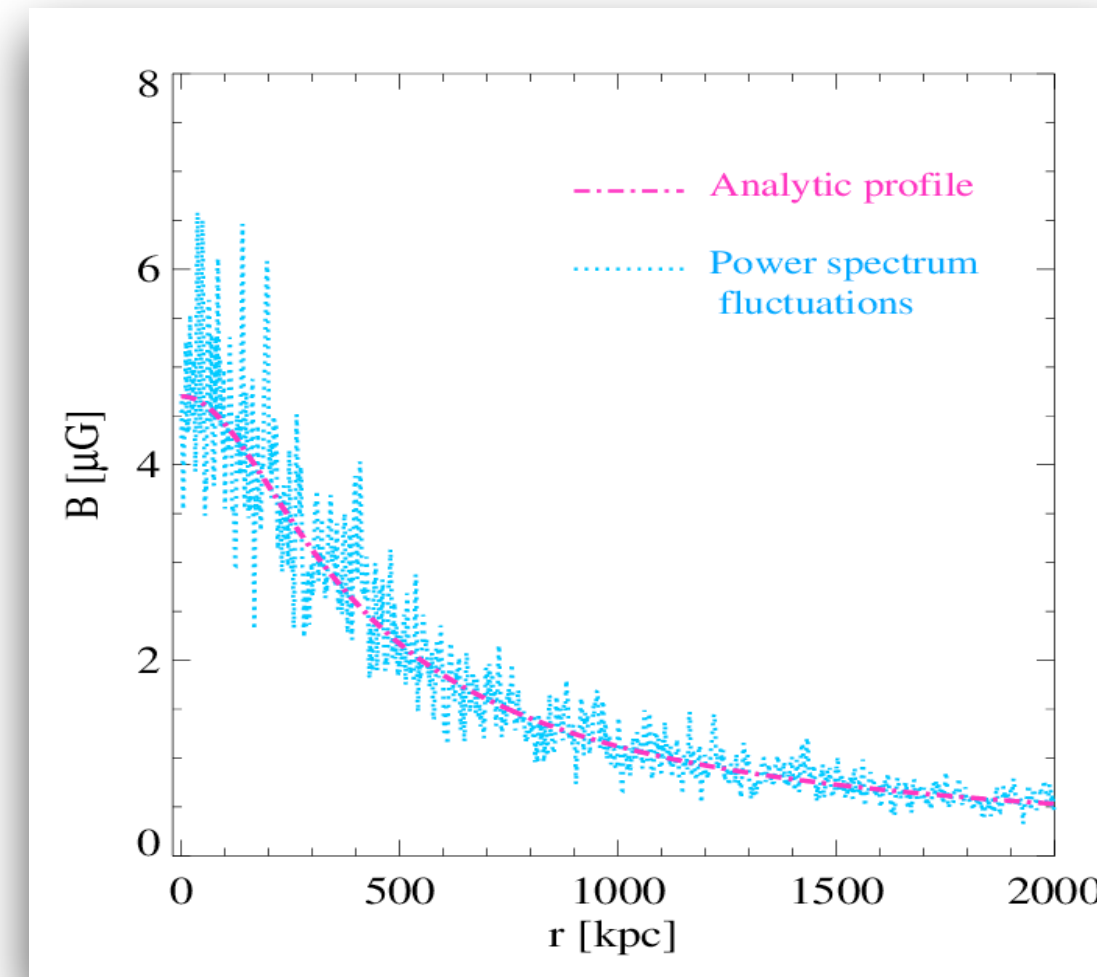
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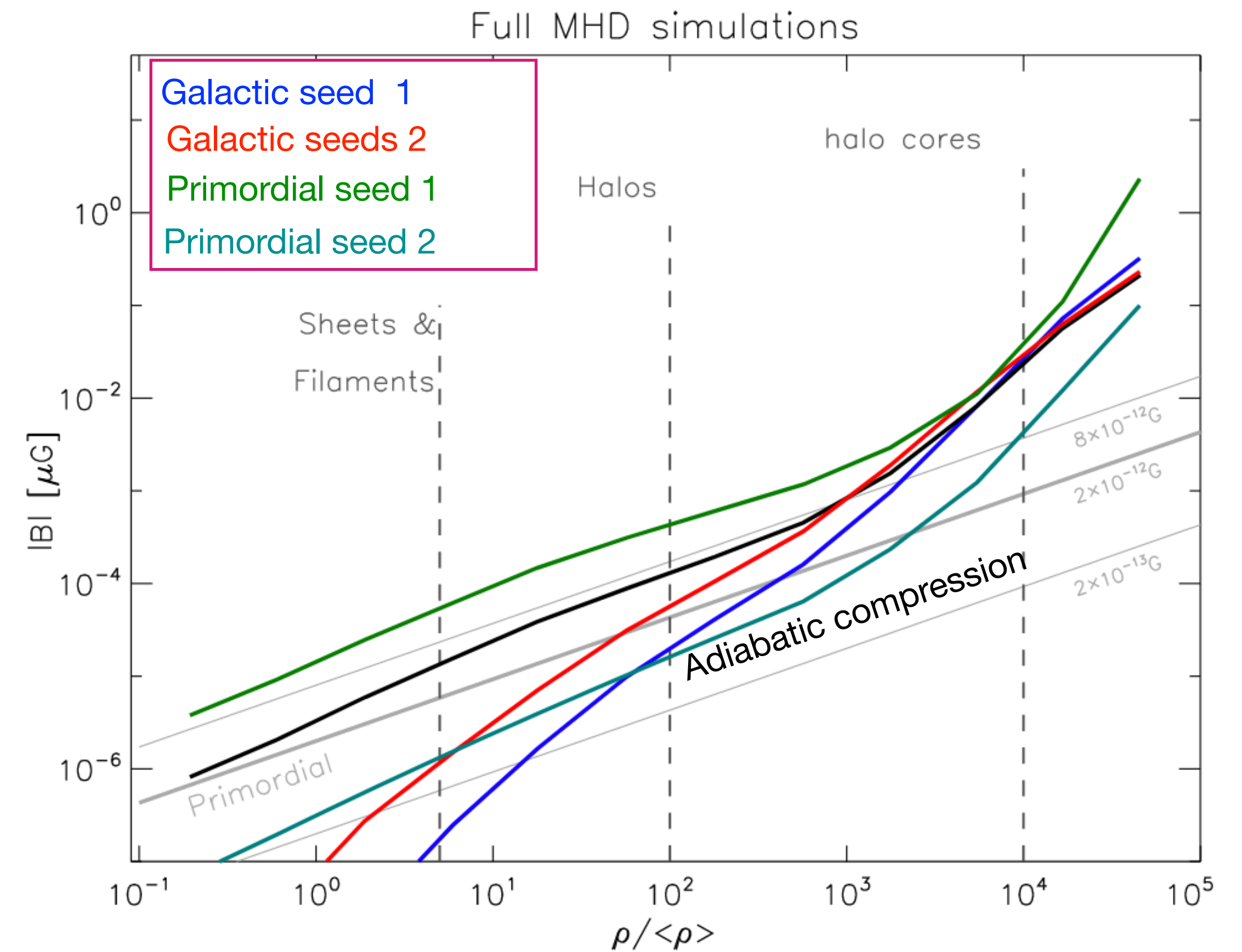
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- $B \sim 5\text{-}10 \mu\text{G}$ magnetic fields at the center of massive local clusters
- Few studies available so far
- Radial profile is difficult to constrain, $B \propto n^{0.5}$ or steeper

MAGNETIC FIELDS IN CLUSTERS: SIMULATIONS

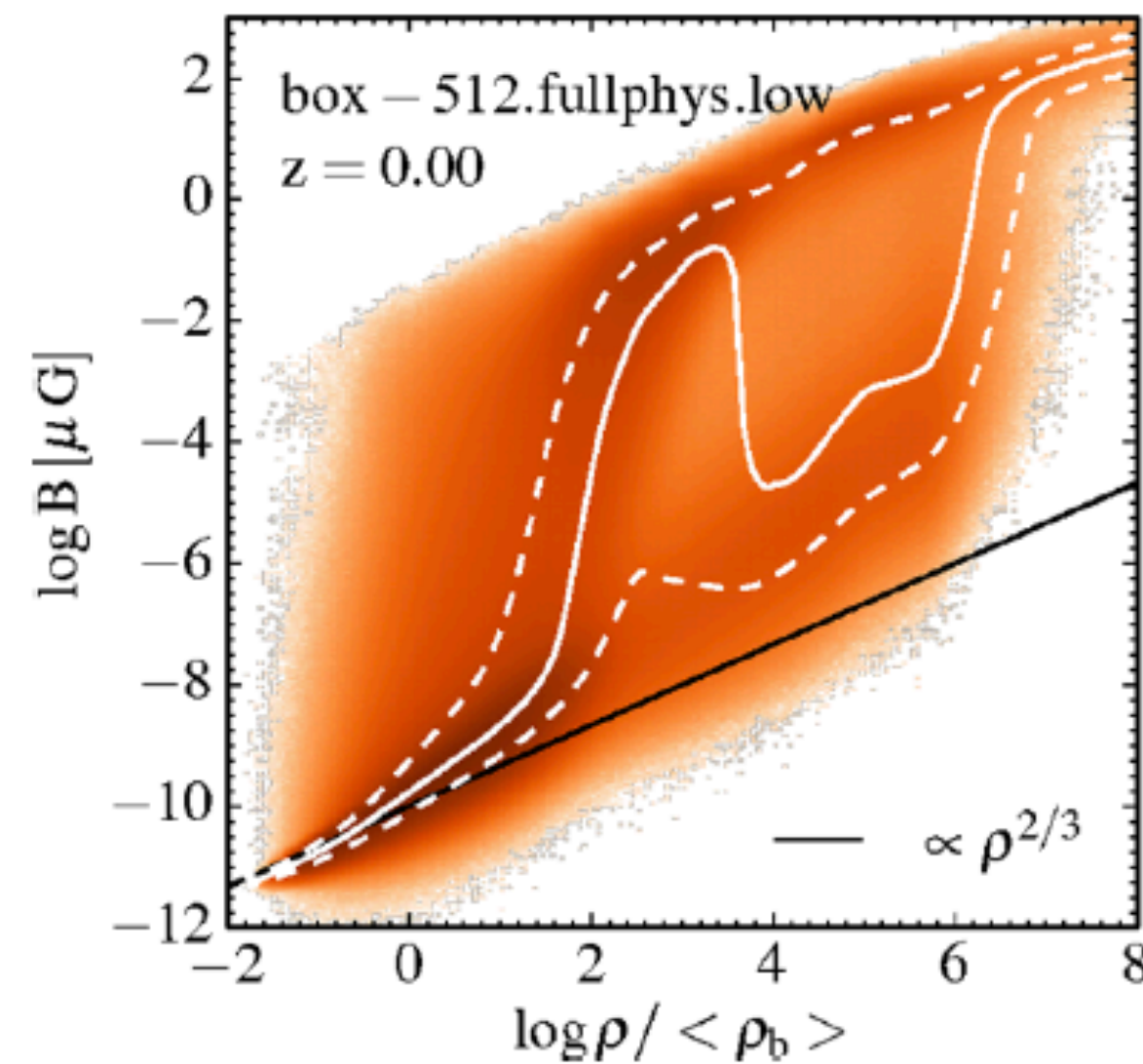
- B results from the amplification of an initial seed/AGN seed
- Adiabatic compression is not enough



Donnert et al (2018)

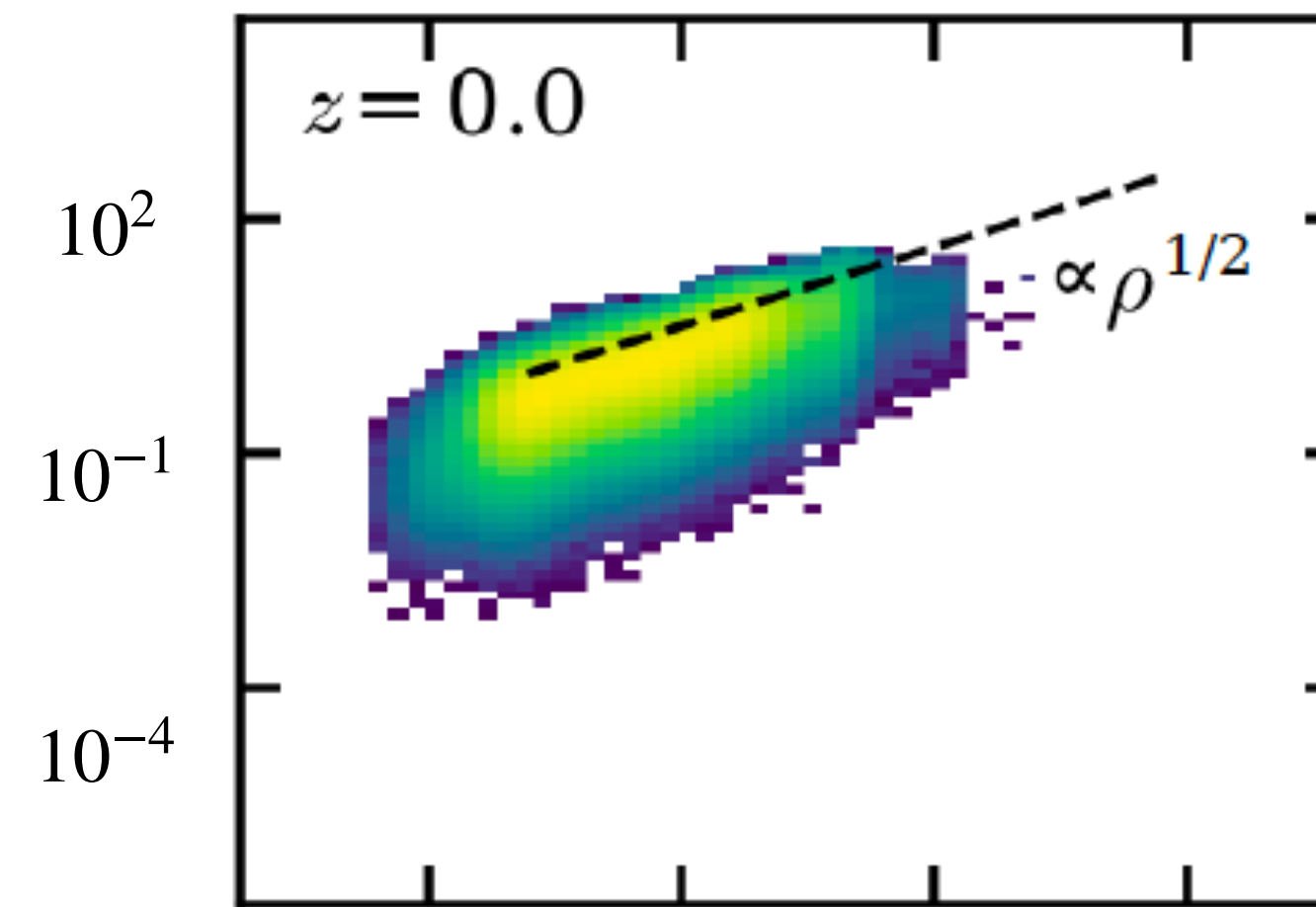
MAGNETIC FIELDS IN CLUSTERS: SIMULATIONS

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



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

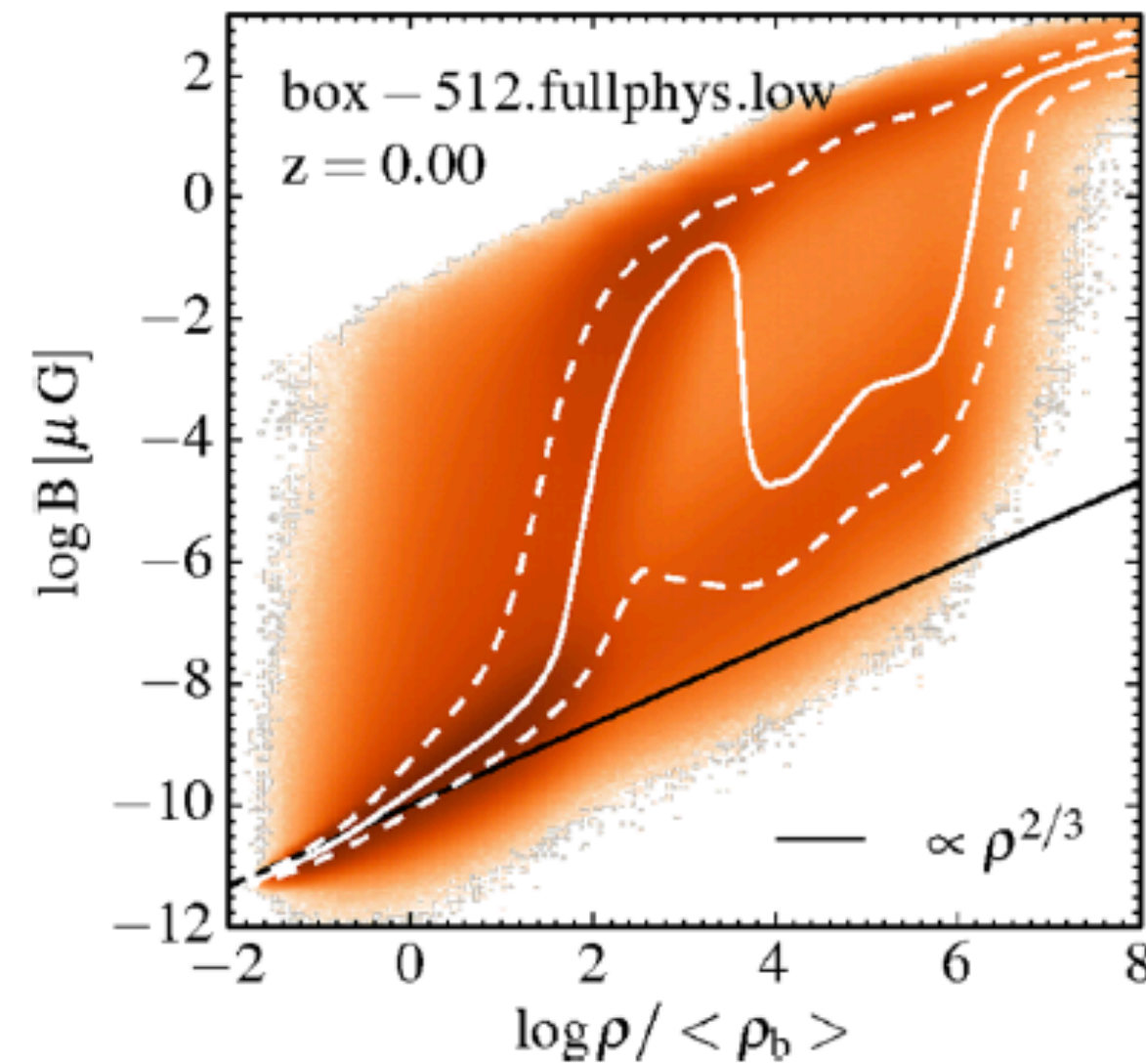
Radiative + galaxy formation



Illustris TNG +galaxy formation
Tevlin et al (2025)

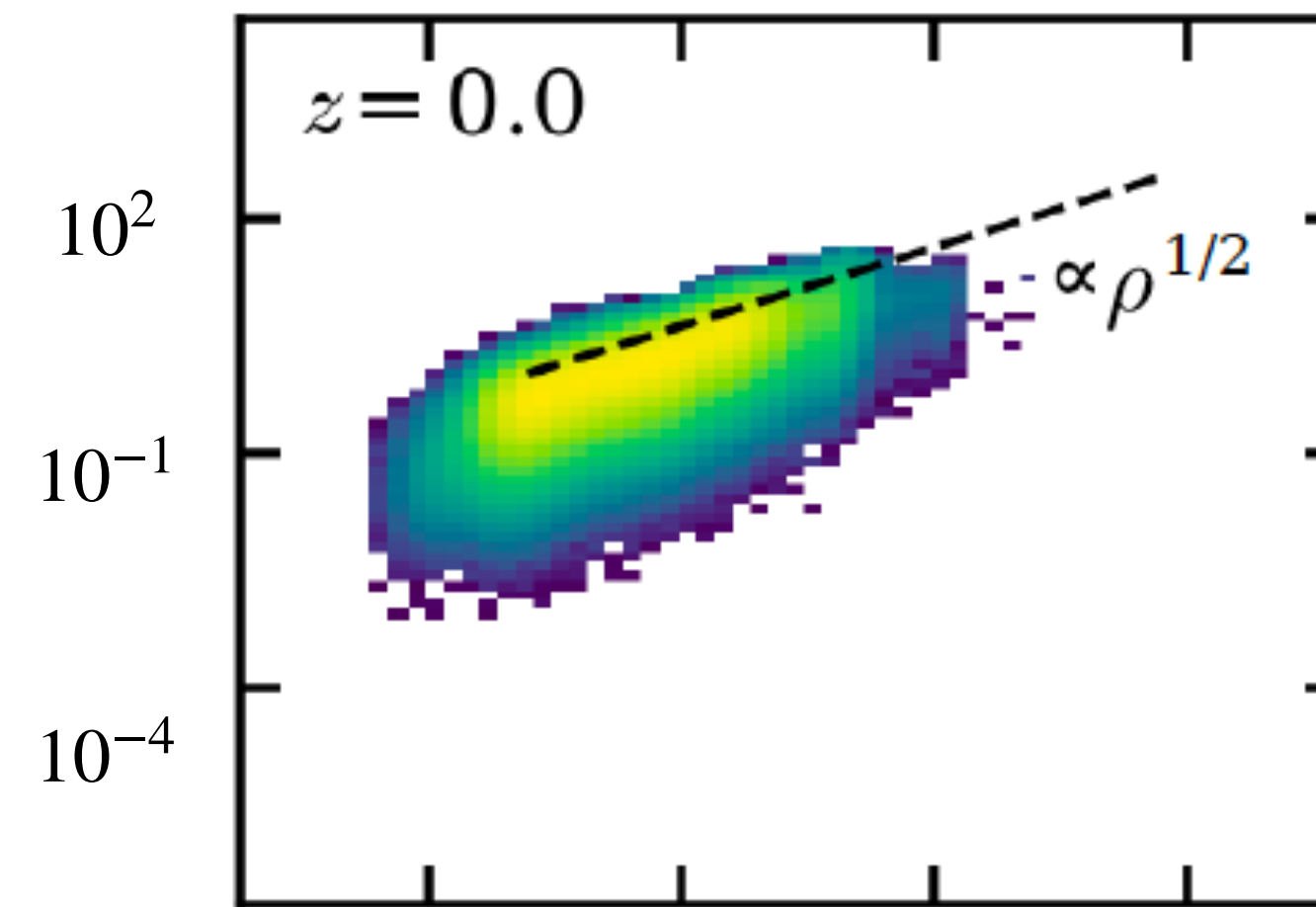
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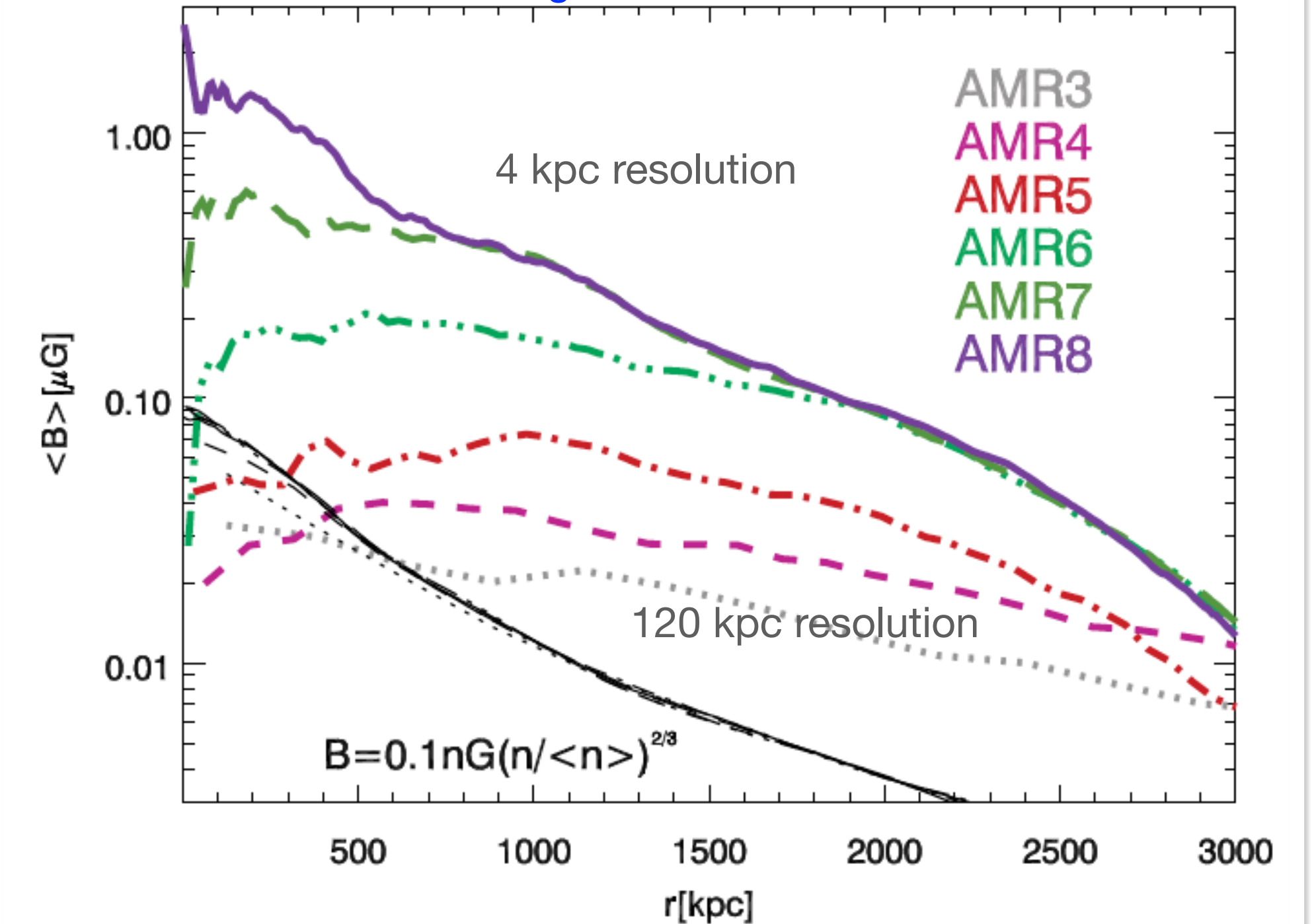
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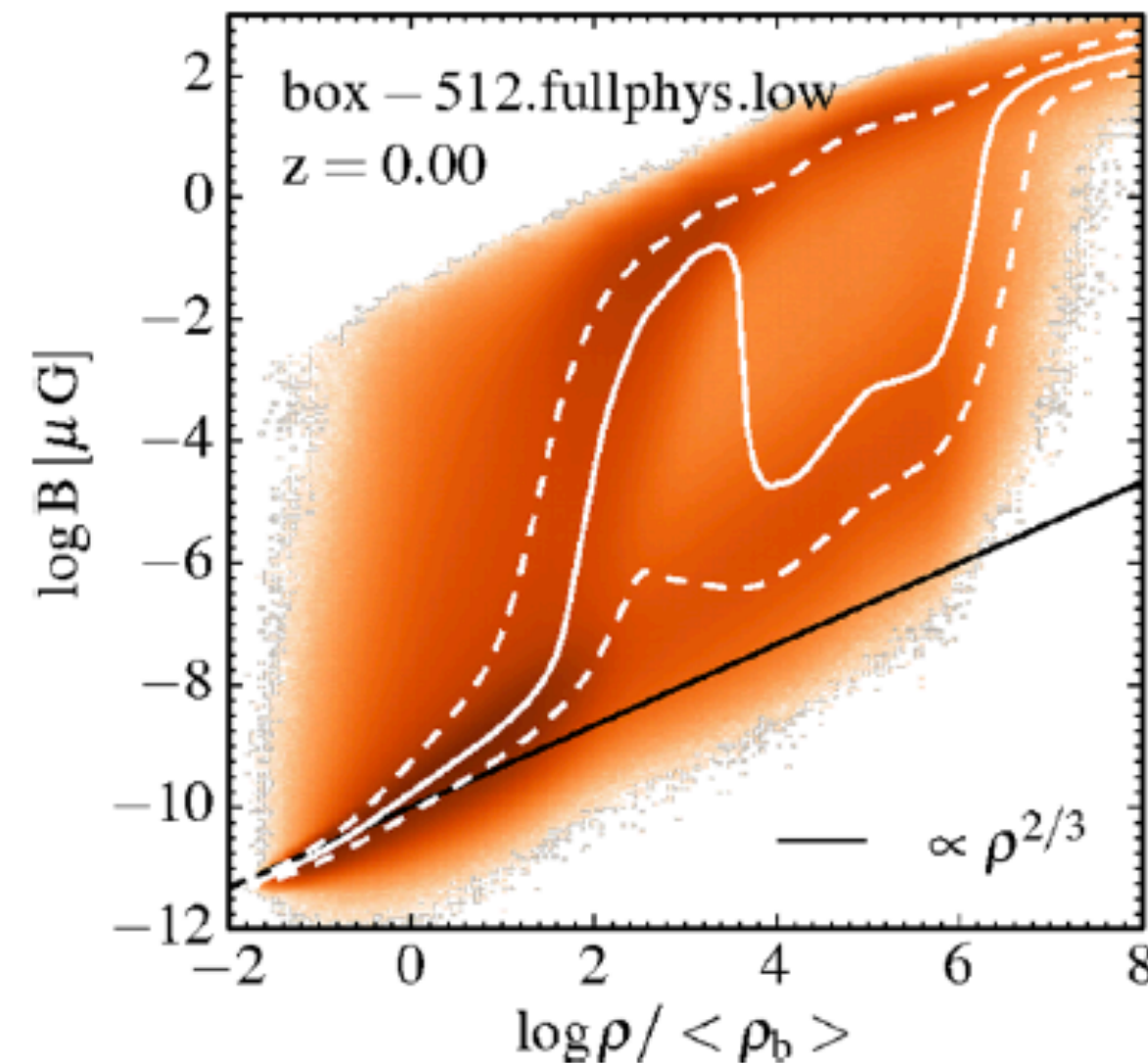
Primordial magnetic field $B_0=0.1$ nG at $z=30$



Vazza et al 2018

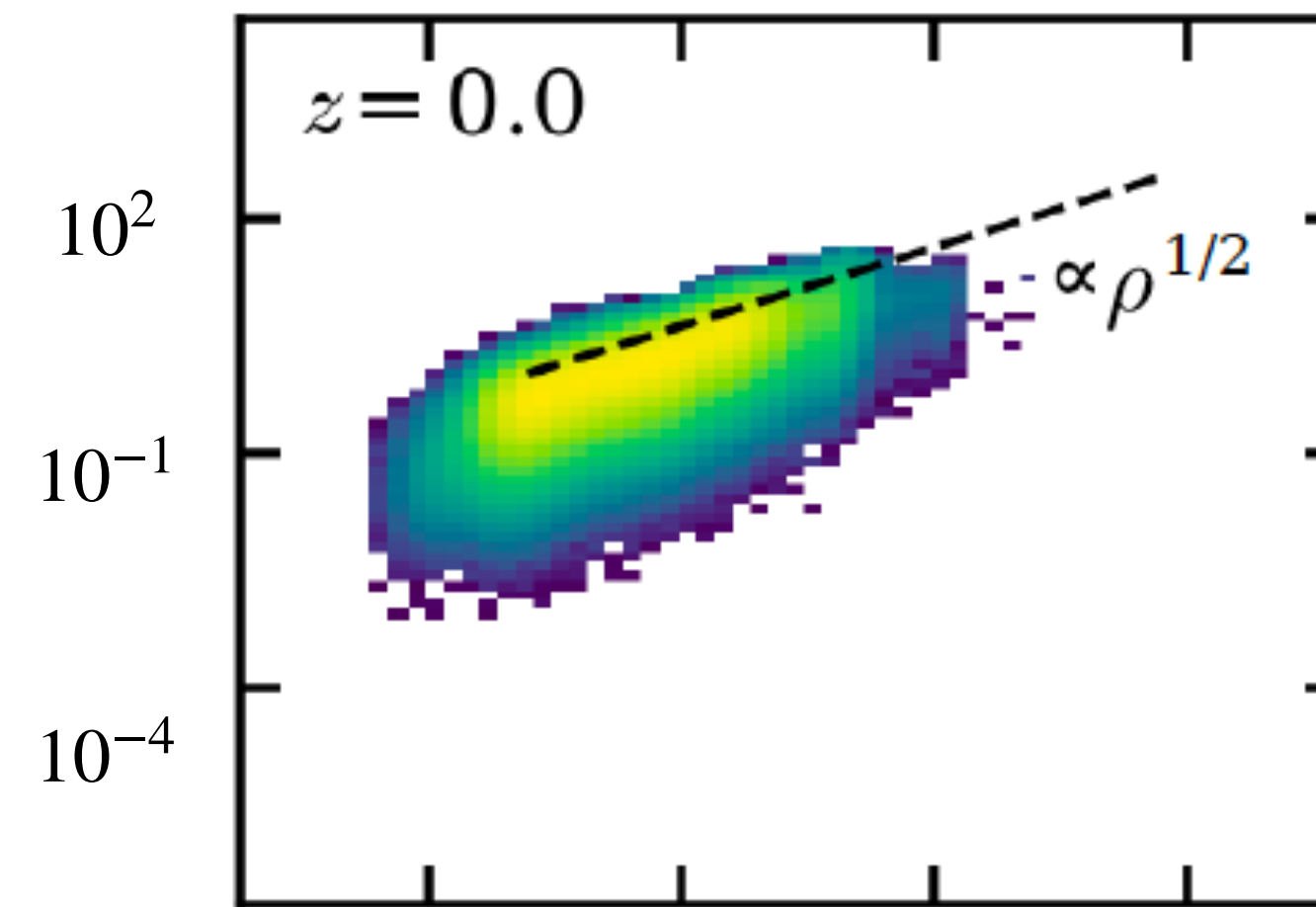
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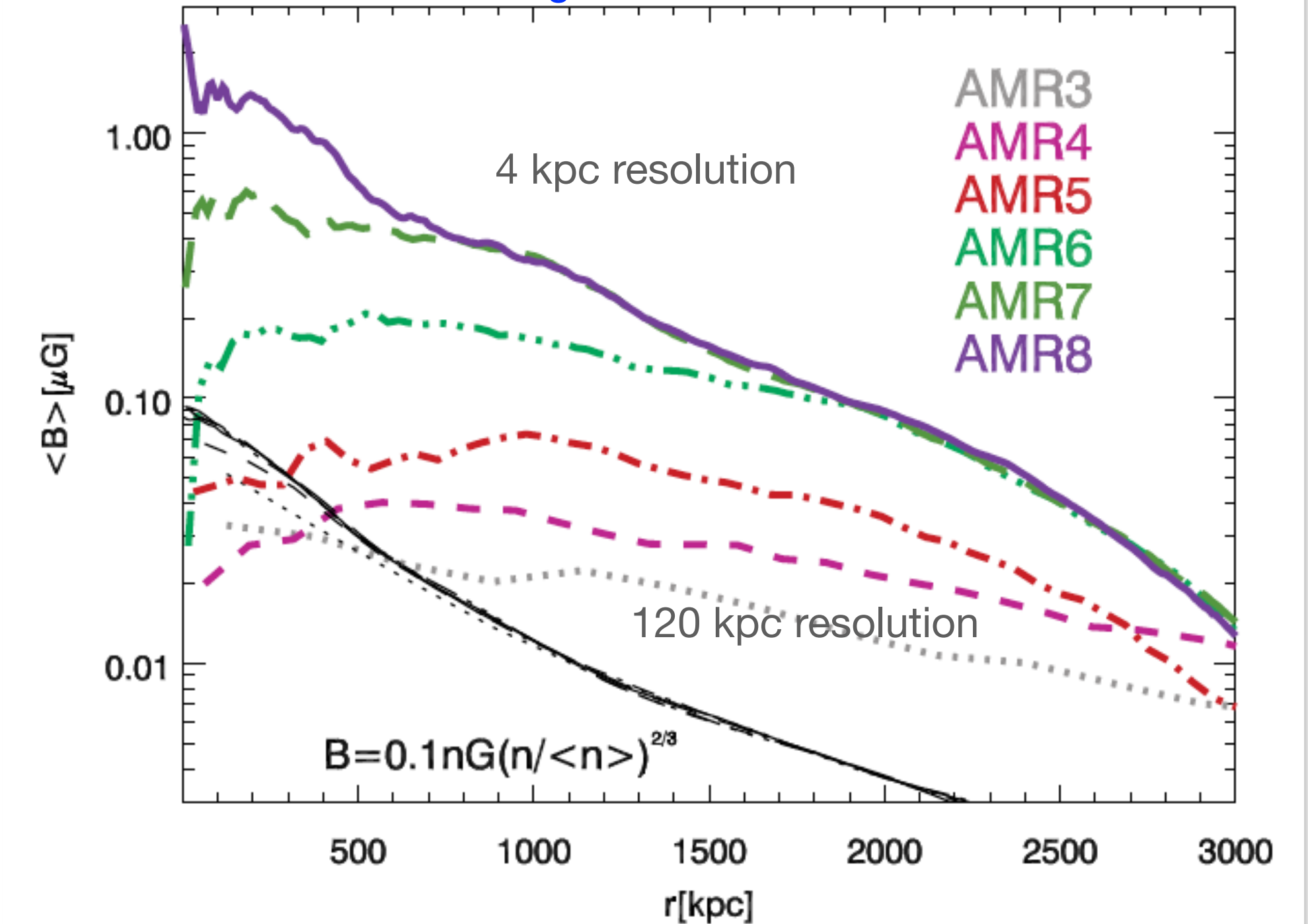
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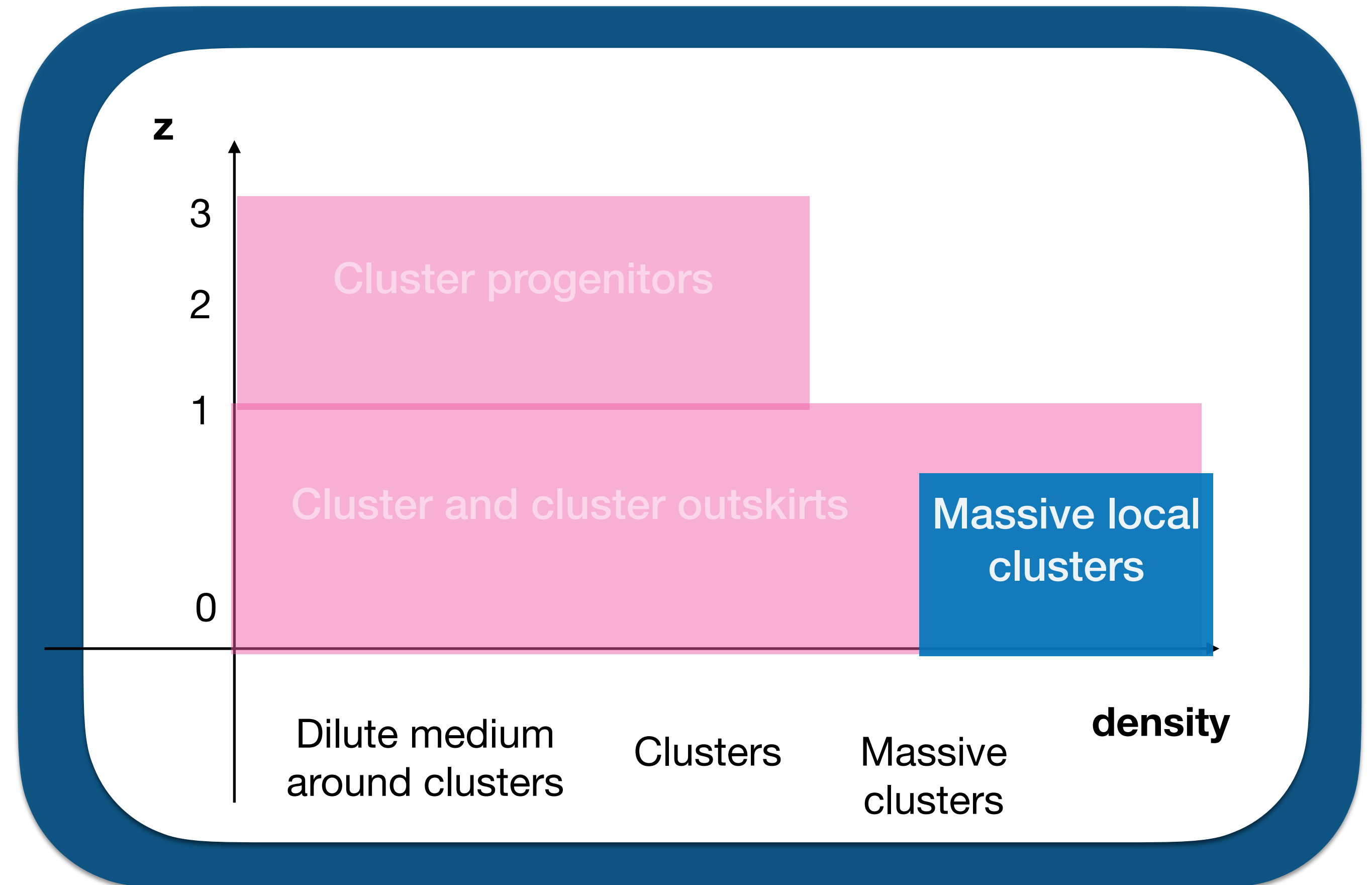


Vazza et al 2018

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

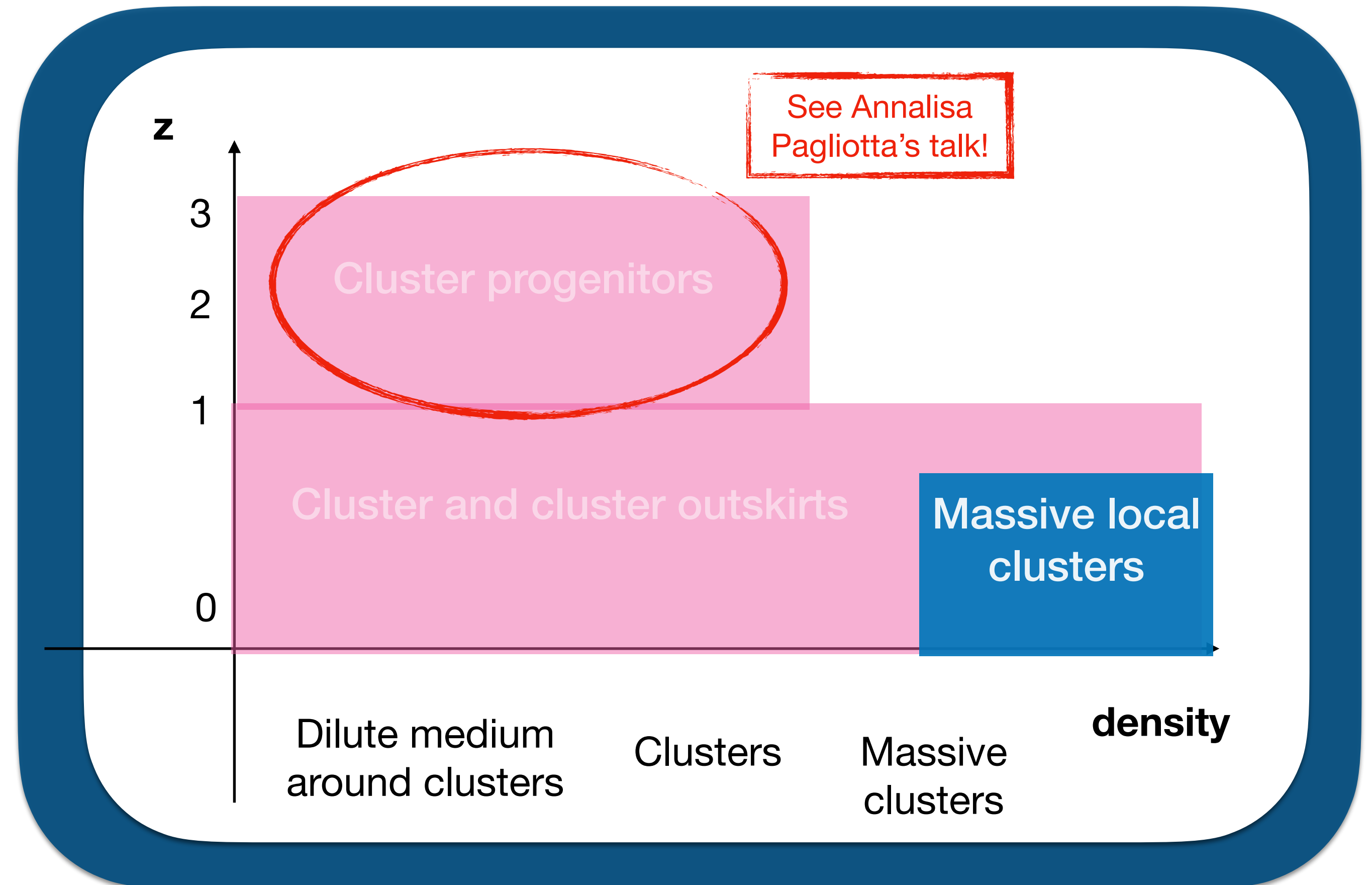
MAGNETIC FIELDS IN CLUSTERS

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



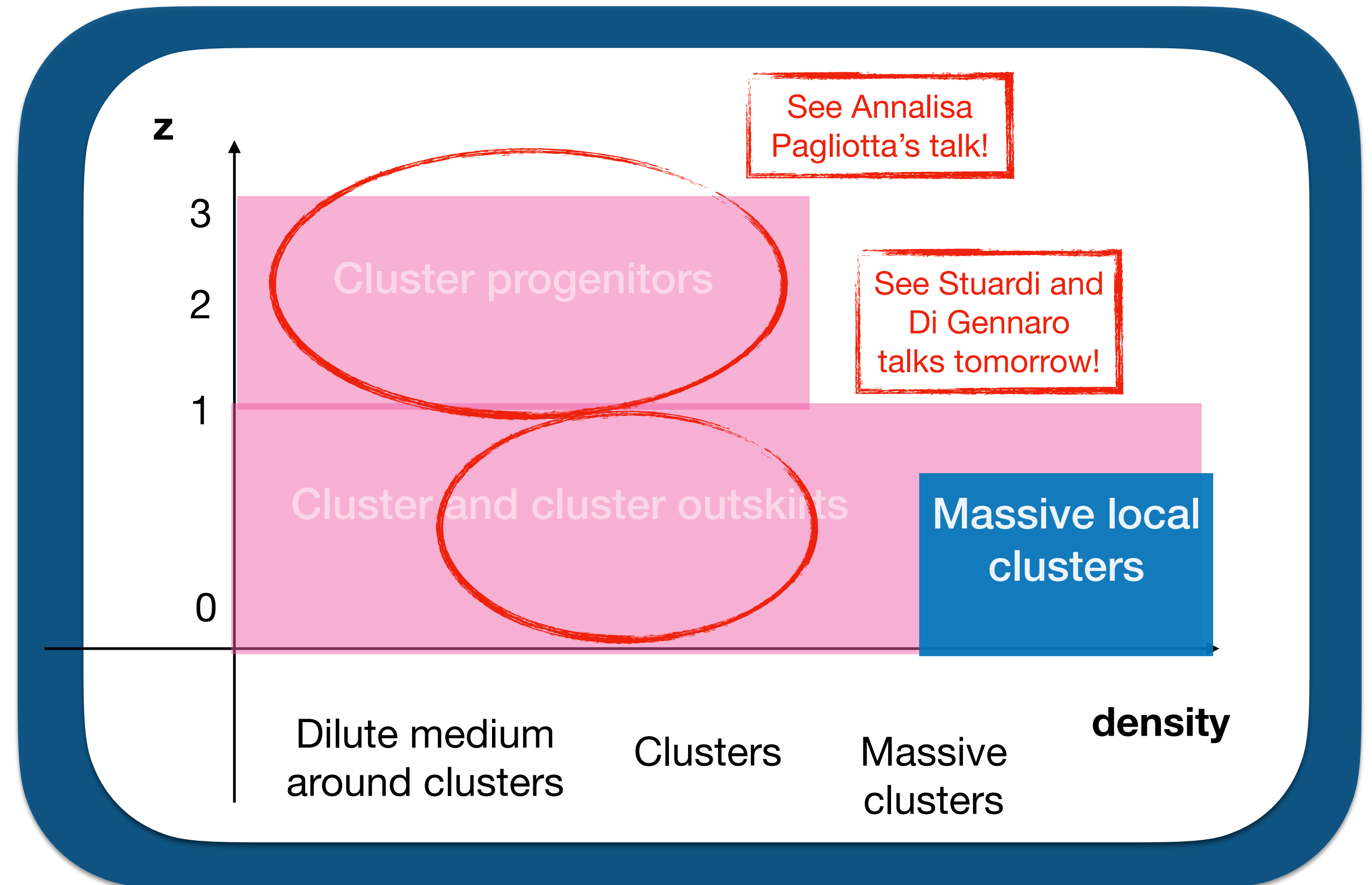
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MAGNETIC FIELDS IN LOCAL CLUSTERS: mass evolution?

MeerKAT XLP Extra Large Project

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

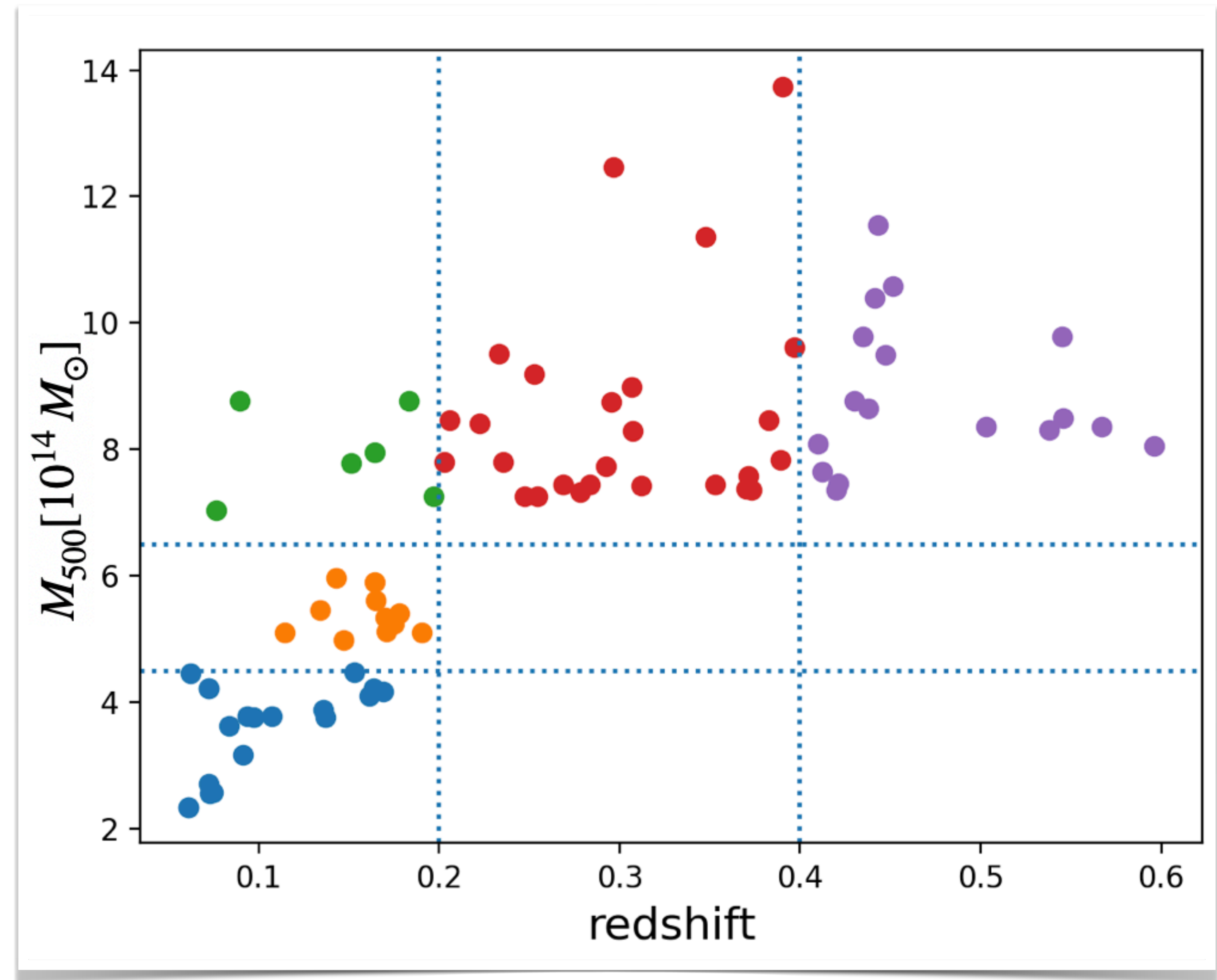


~400h over 4 years
(only year 1 and 2 years allocated at the moment)

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

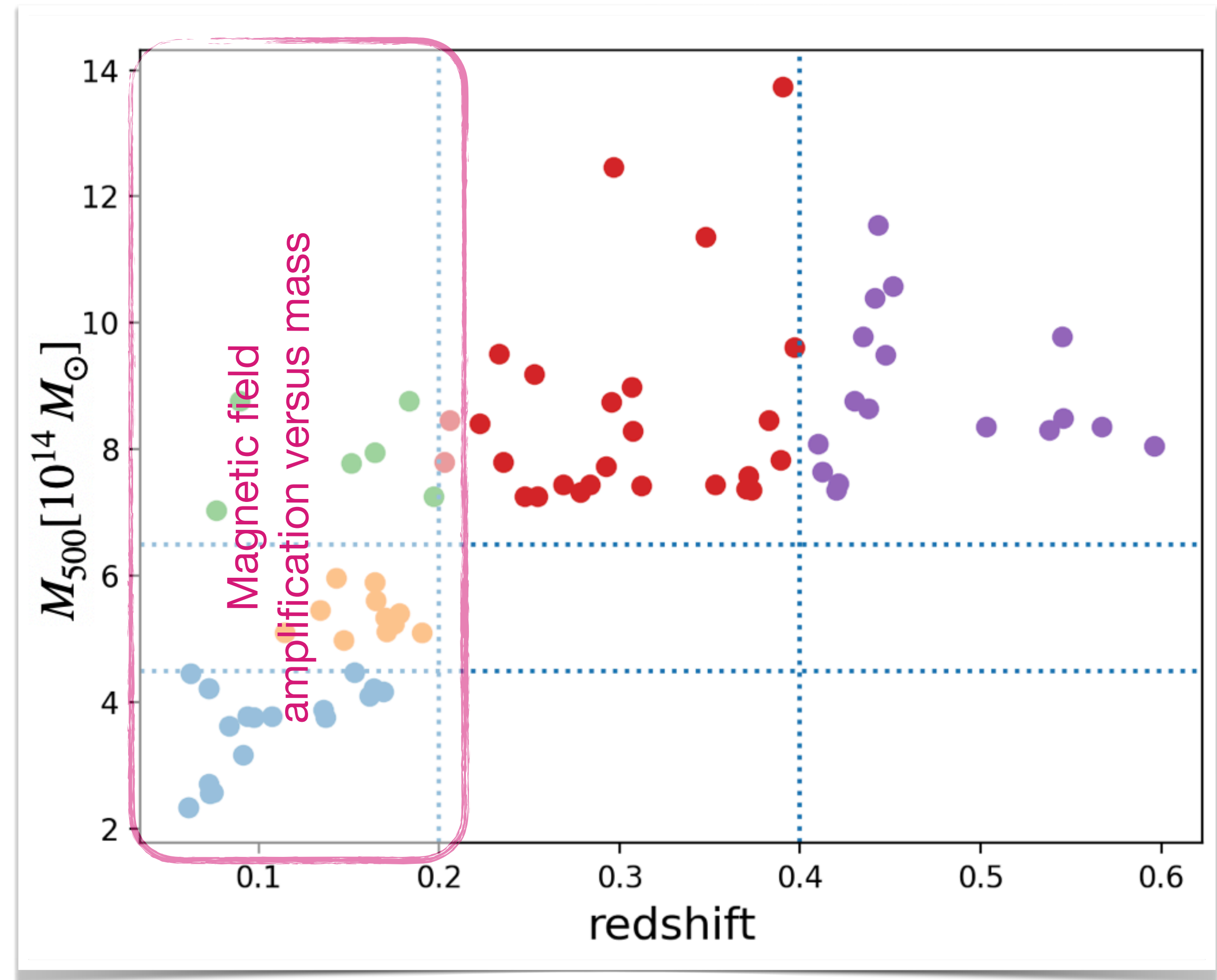
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- Cluster sample: CHEX-MATE
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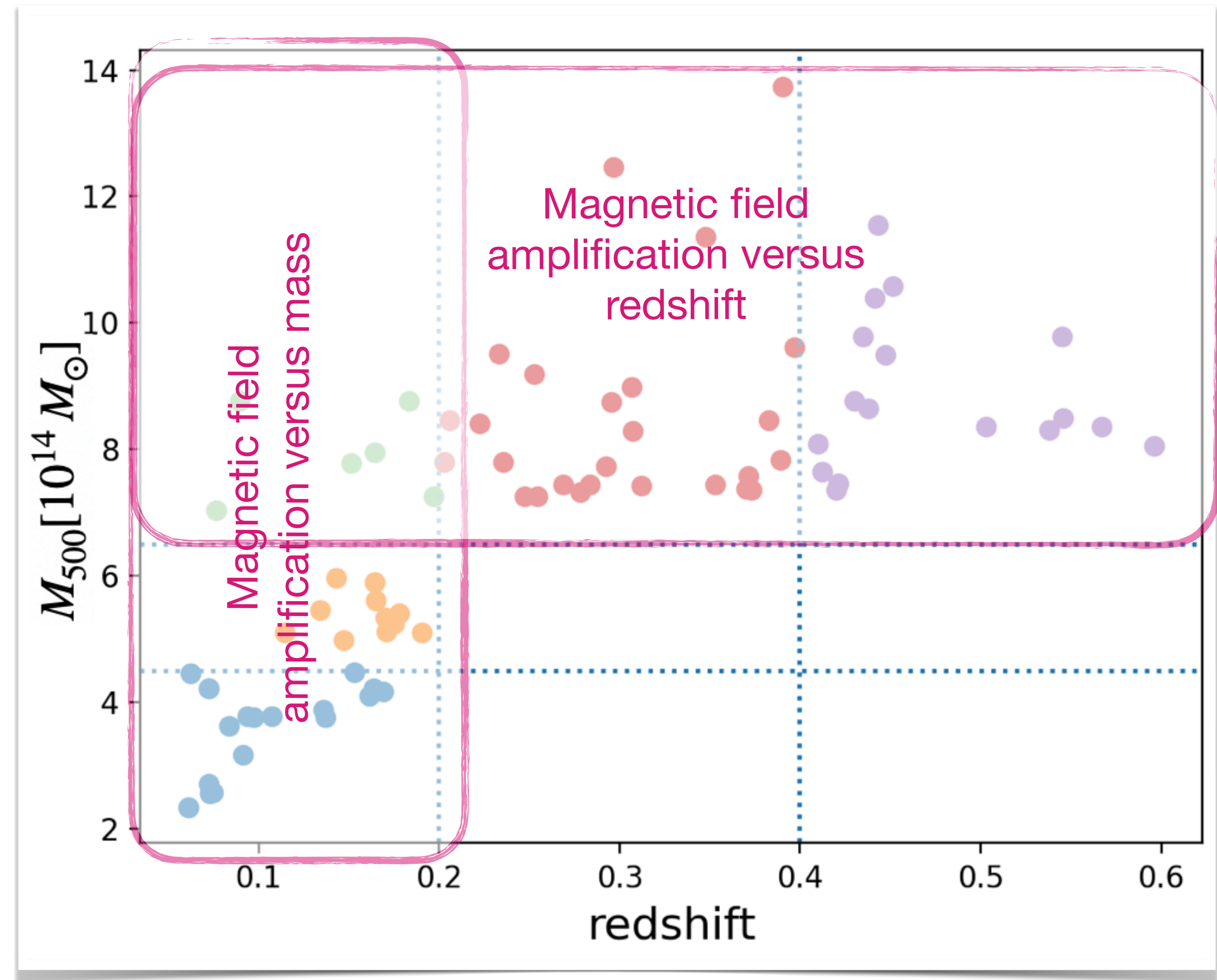
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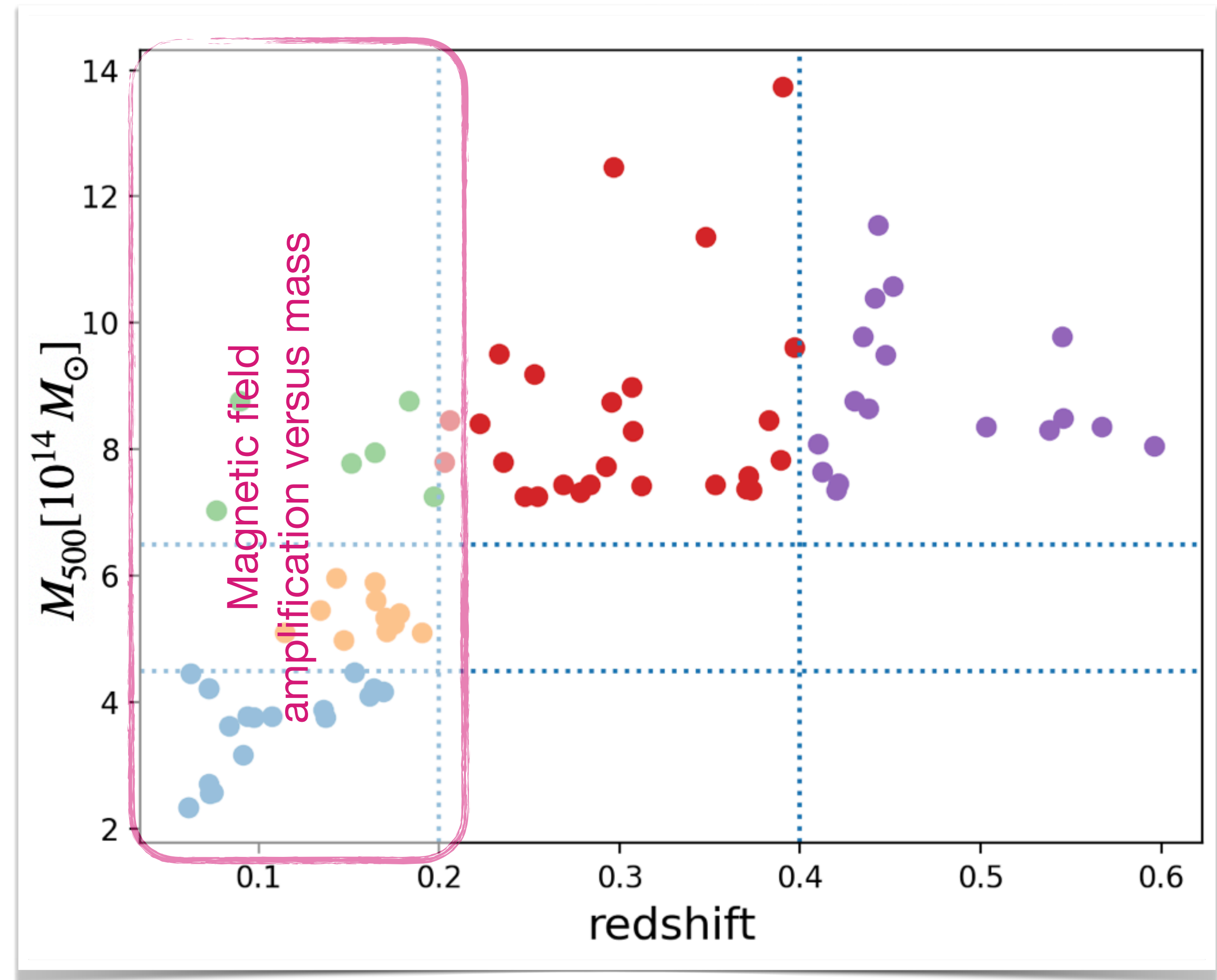
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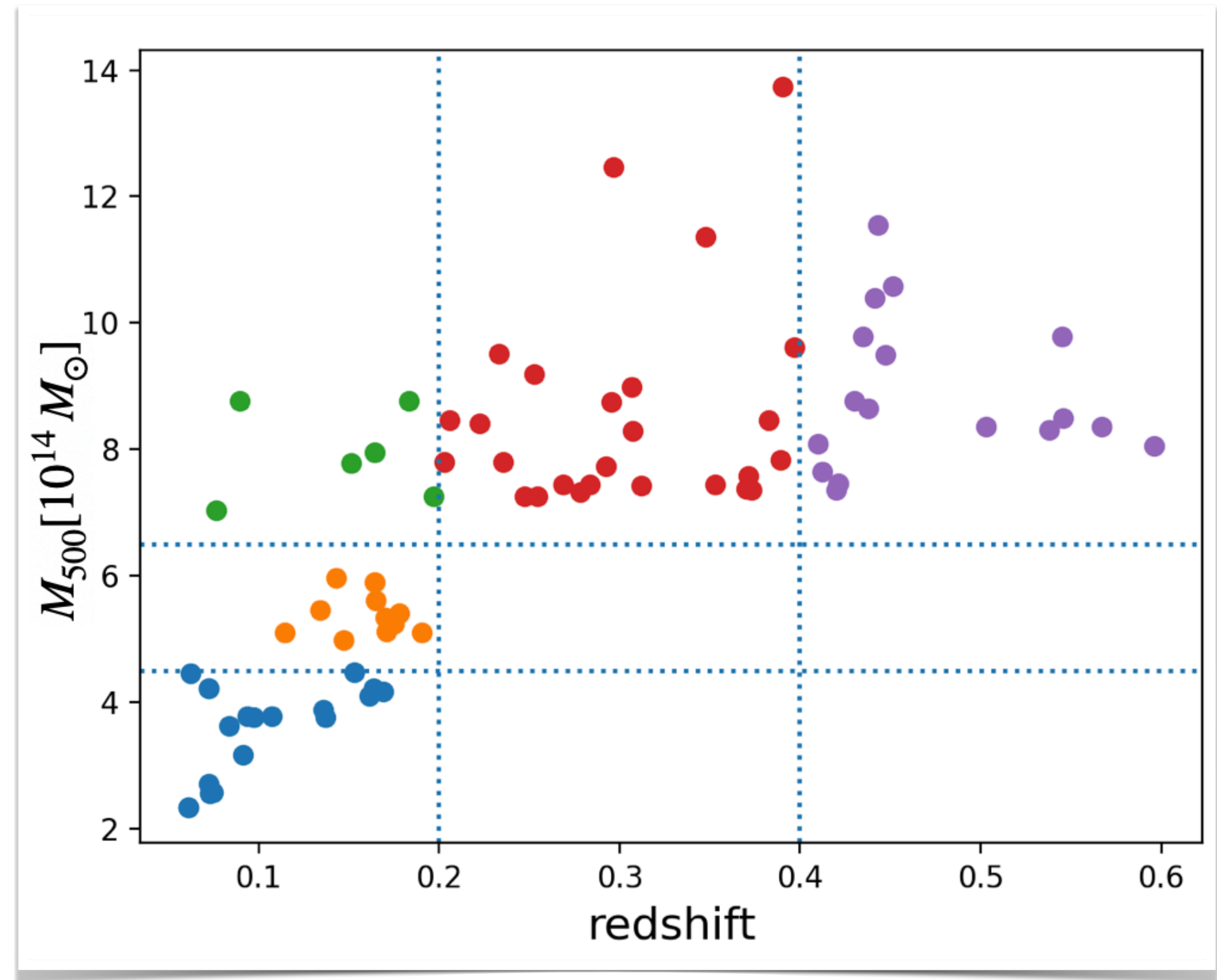
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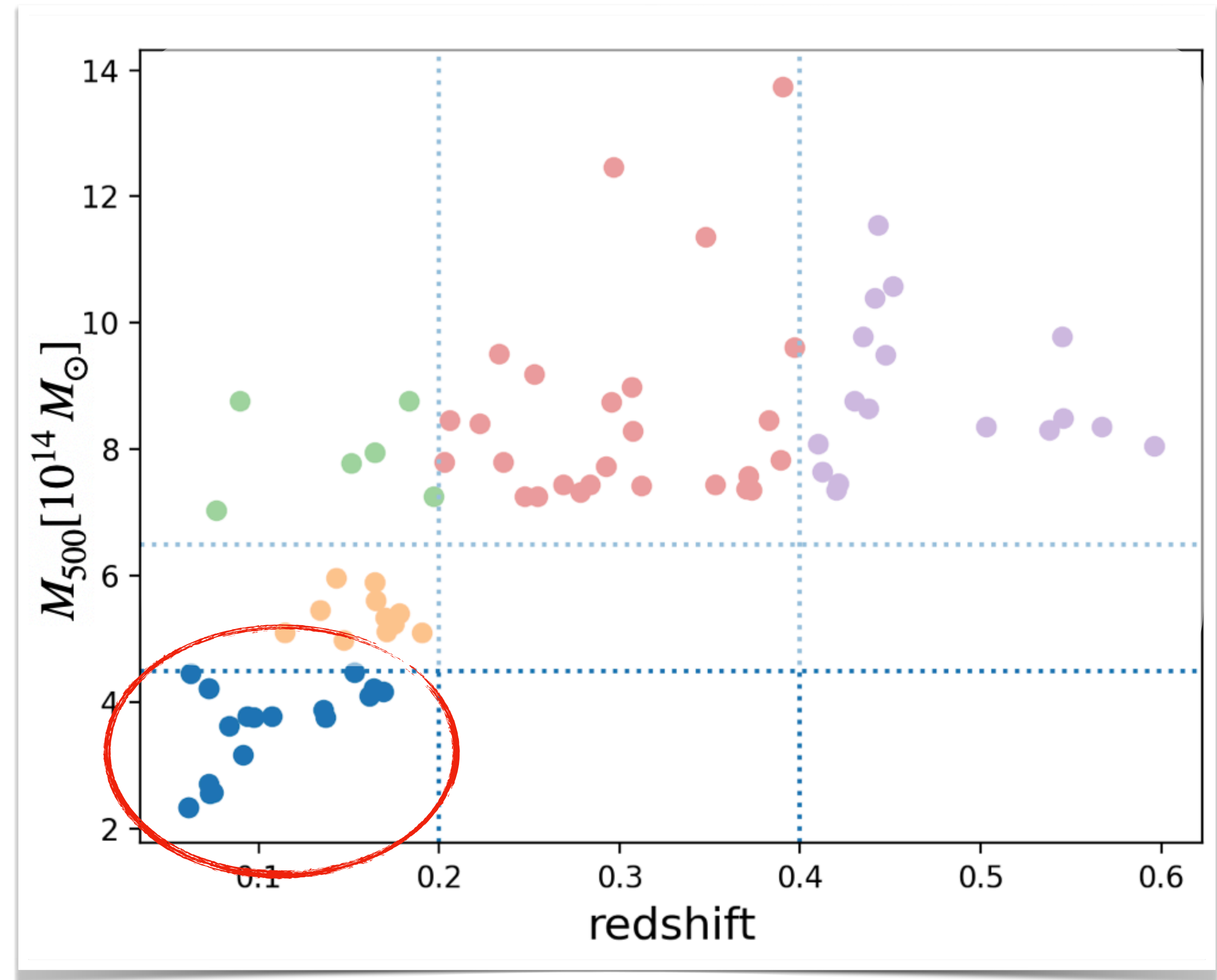
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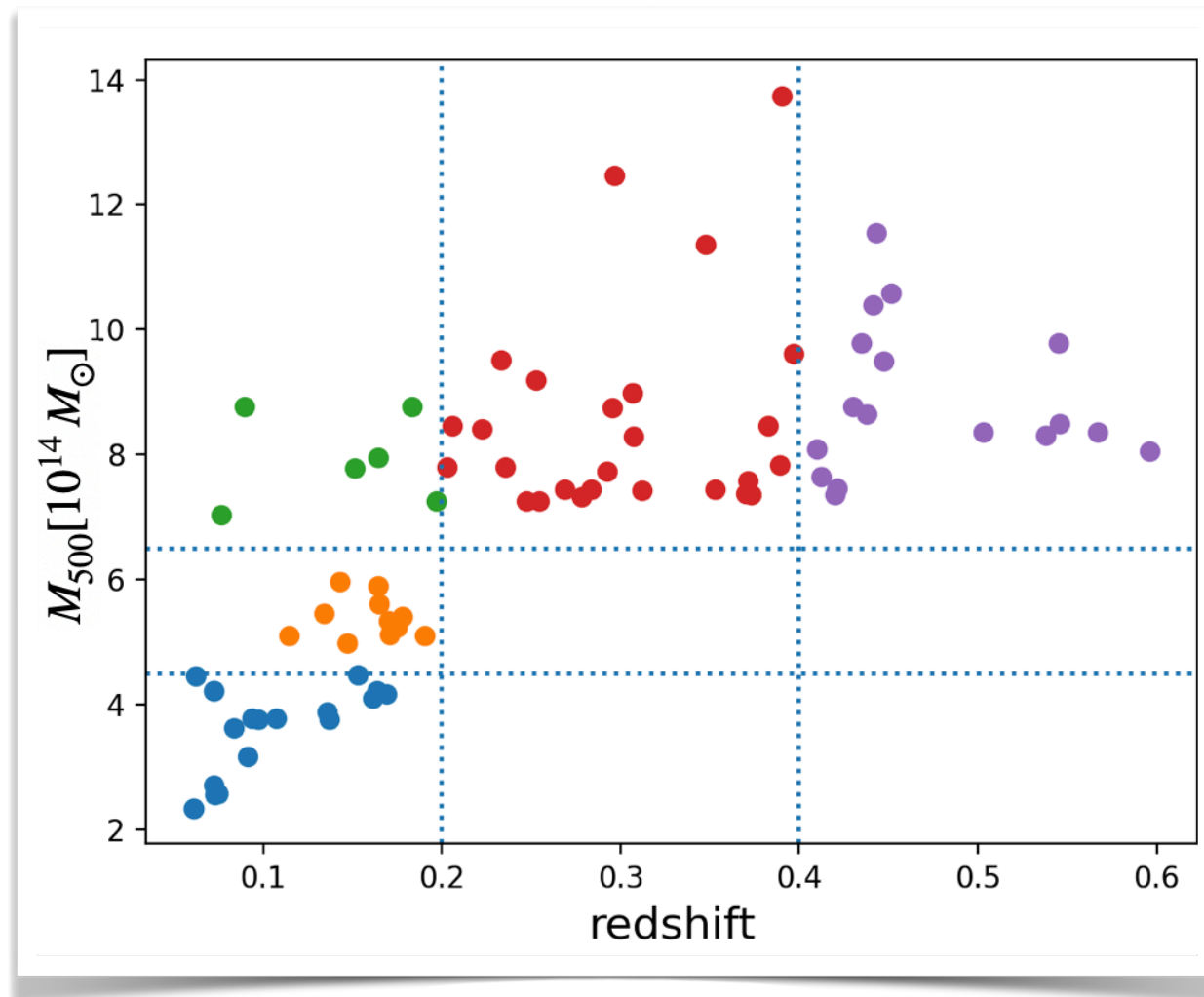


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MeerKAT XLP - Extra Large Project



Sub-sample 1: low mass, low-z clusters

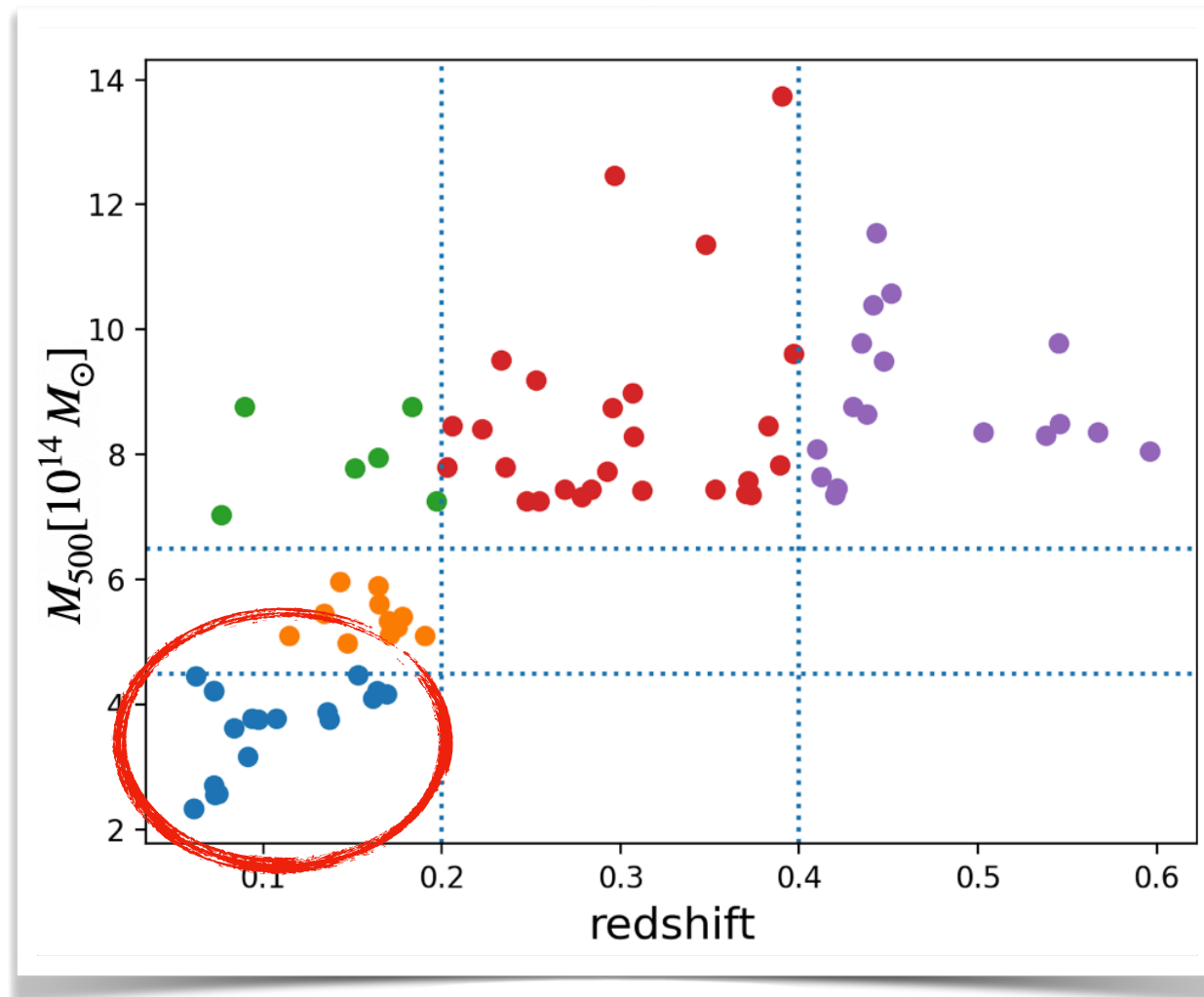
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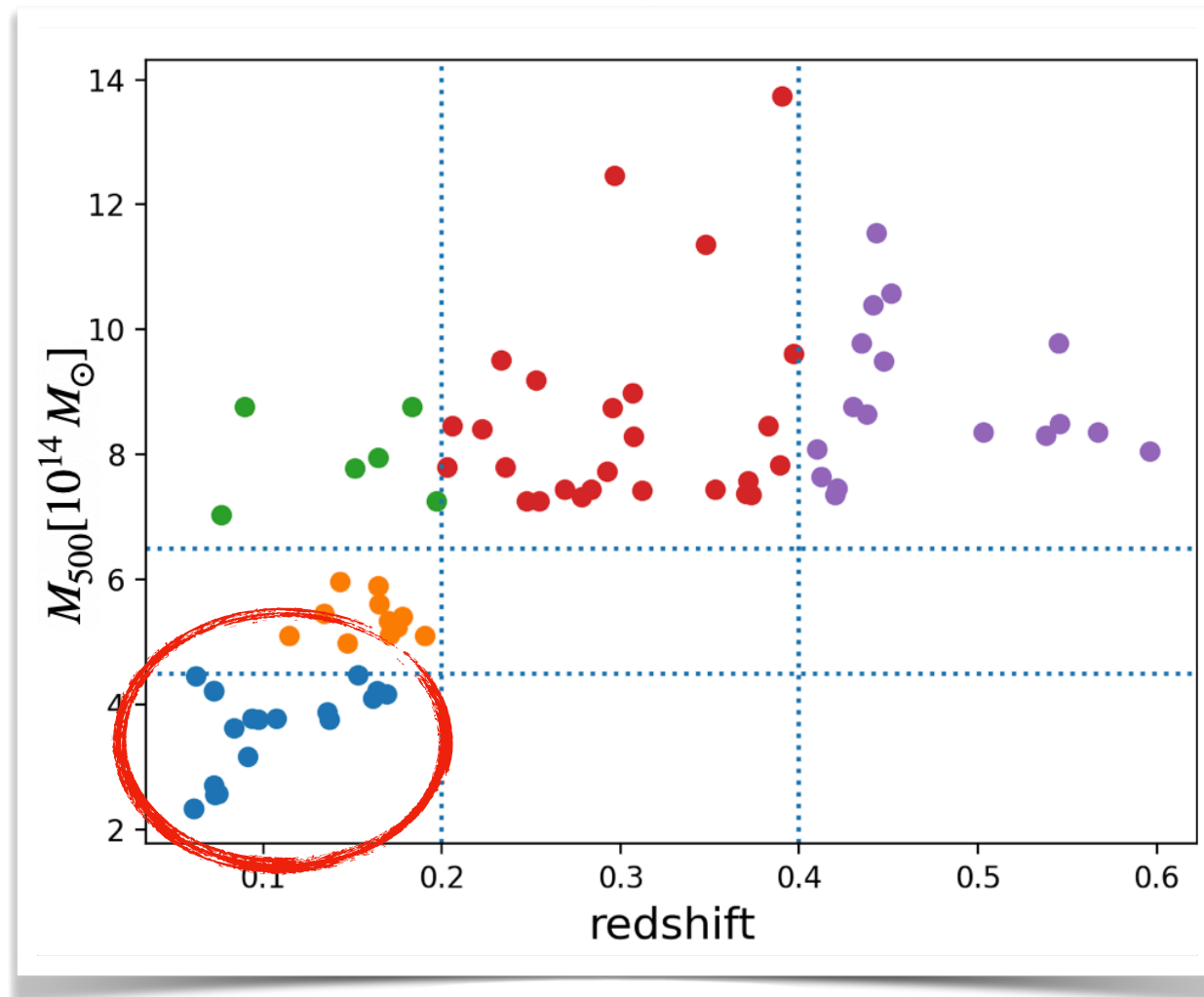
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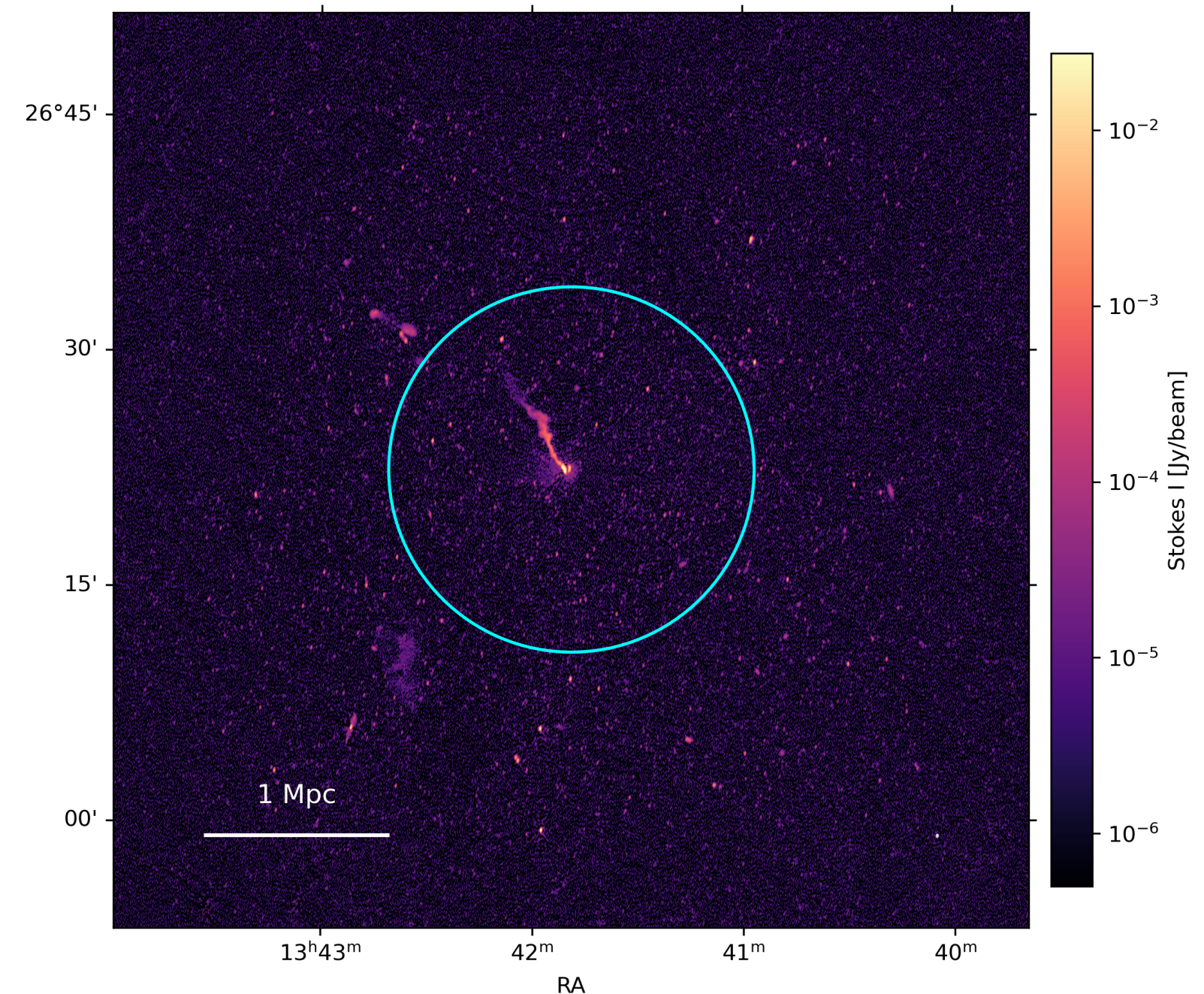
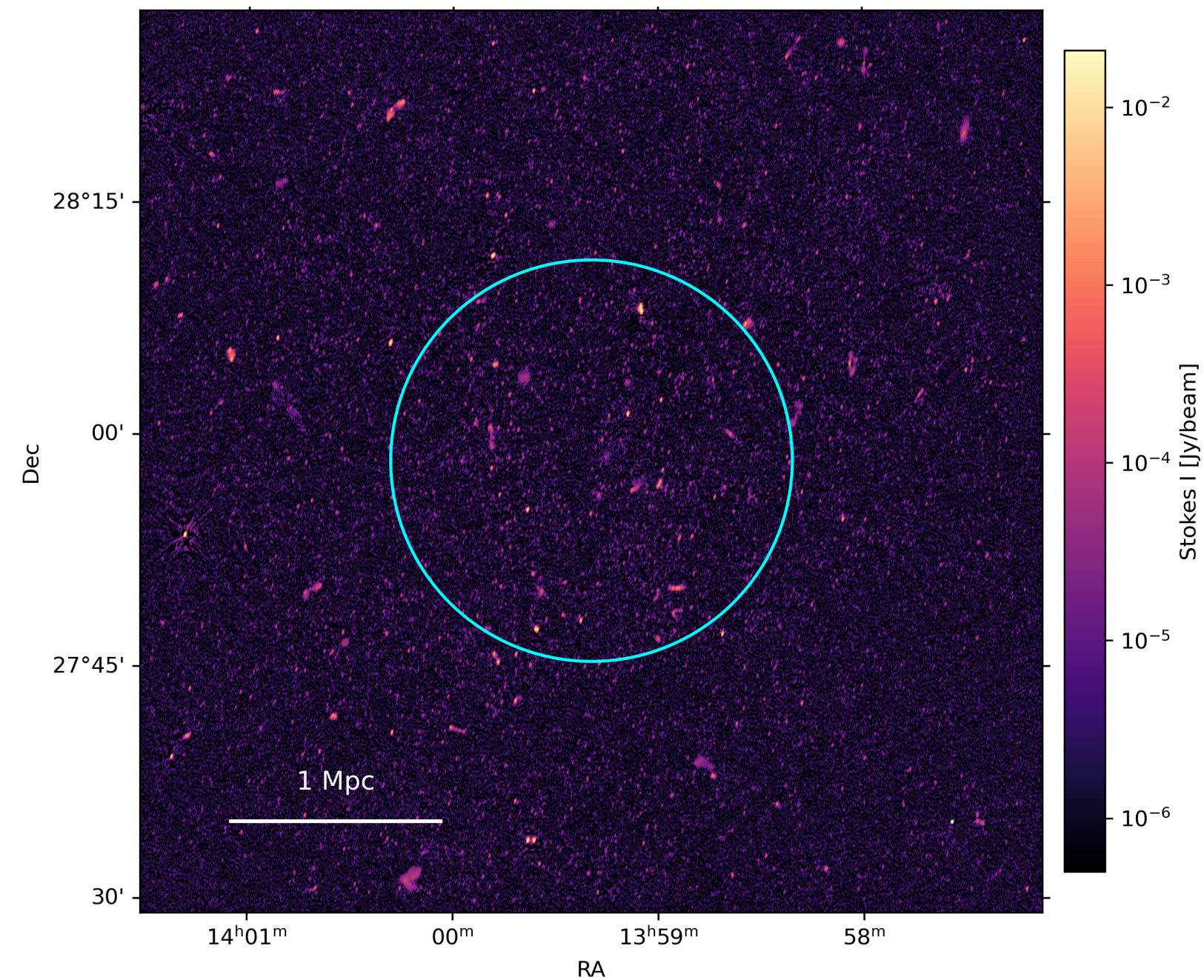
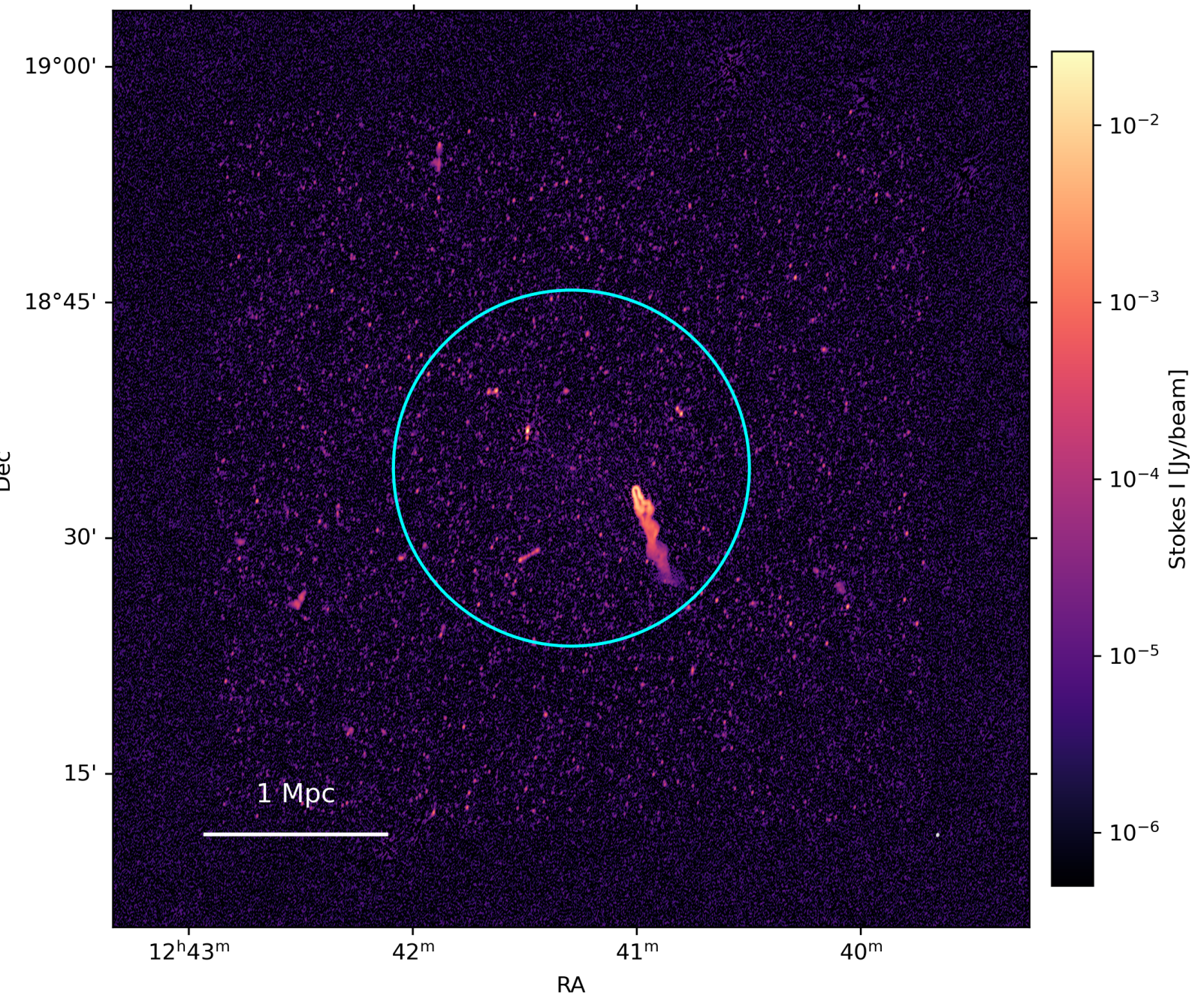
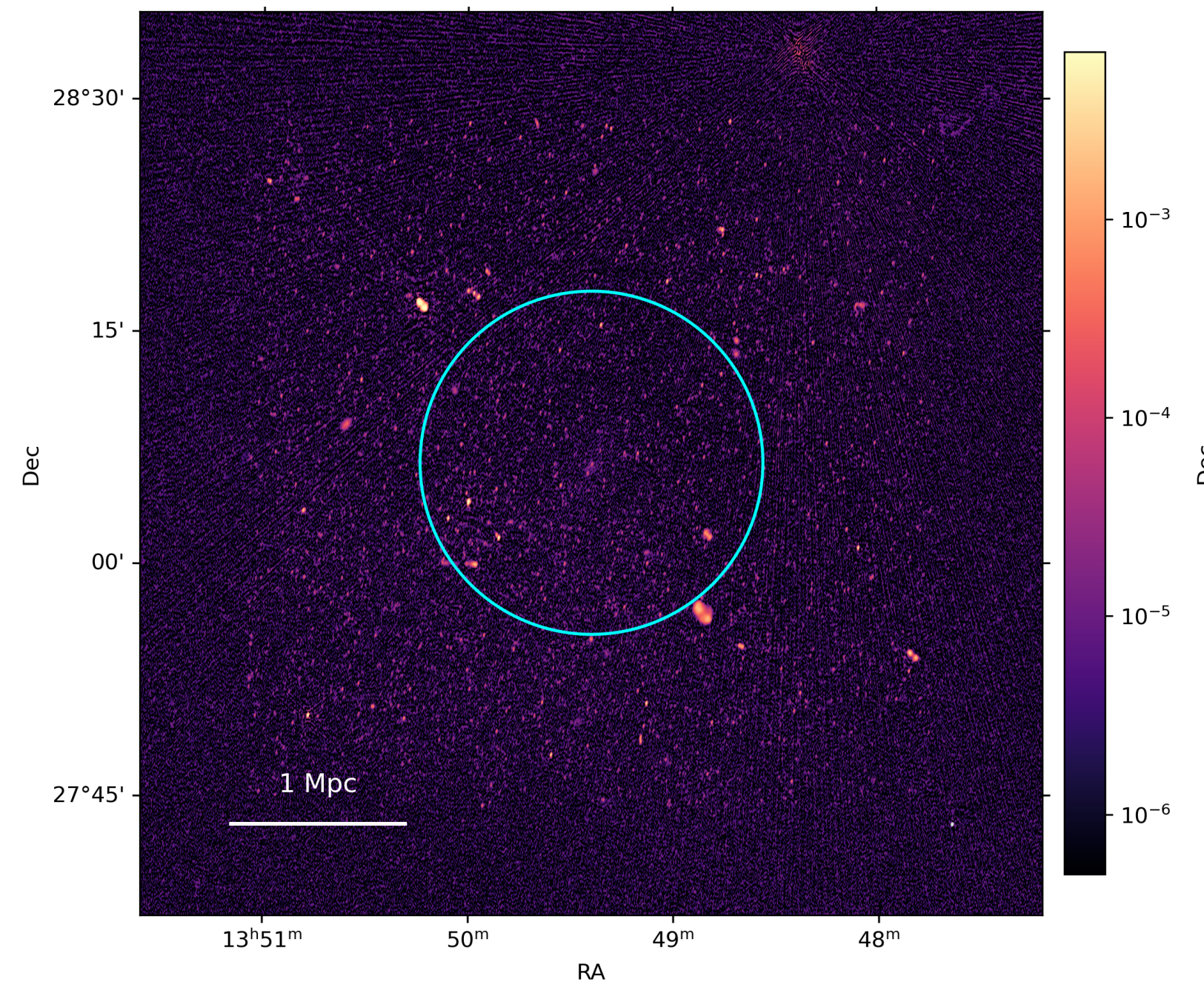
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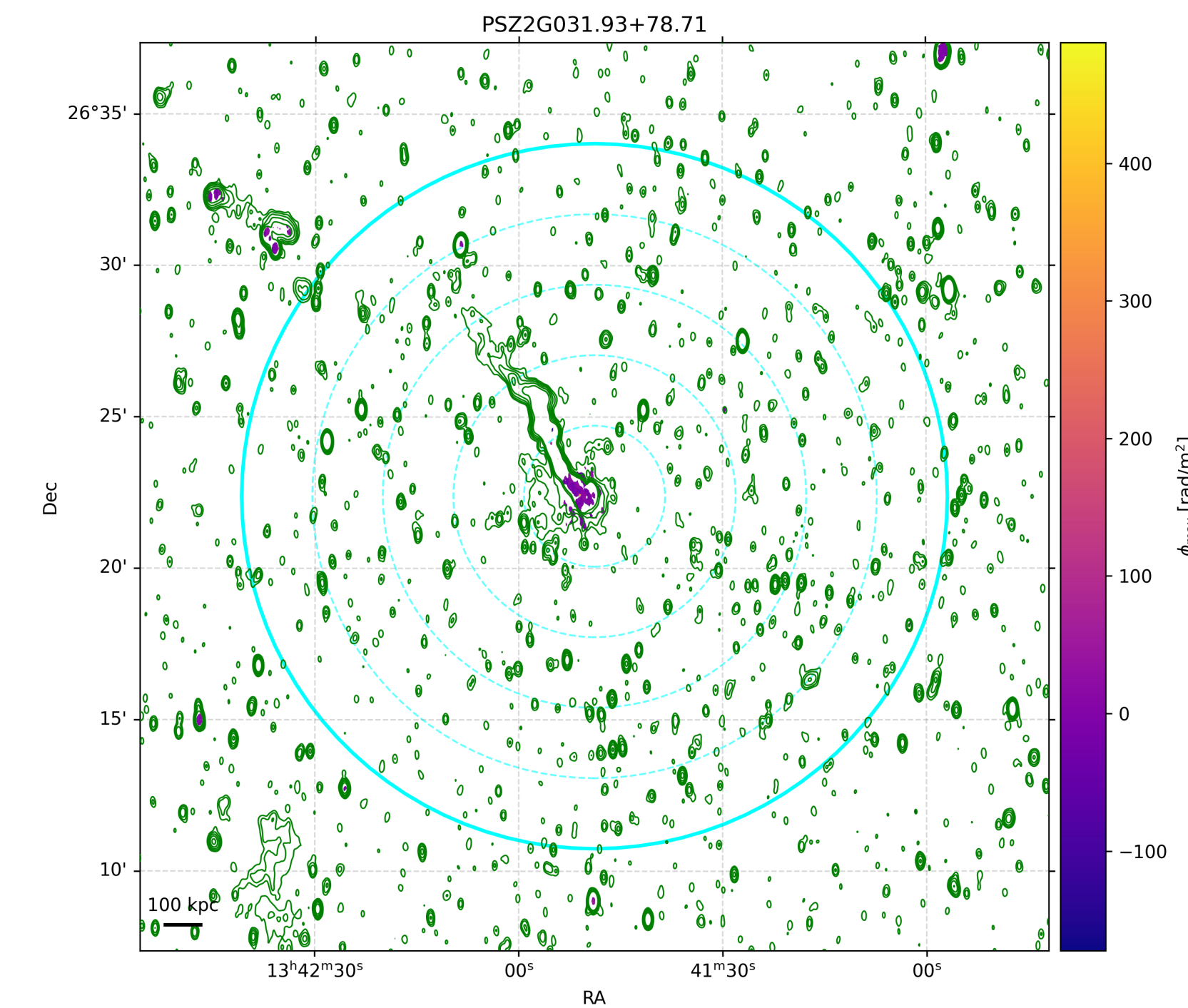
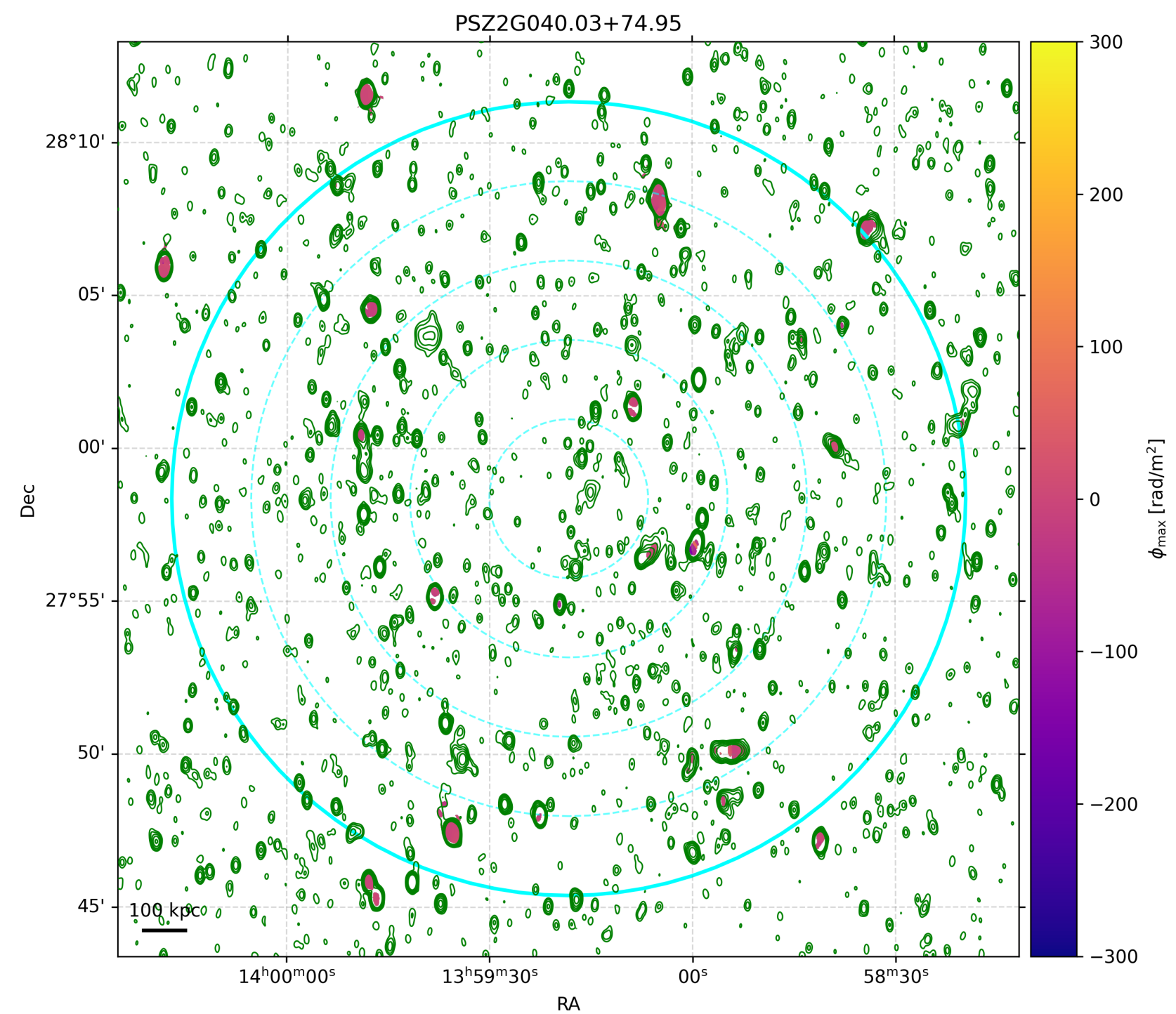
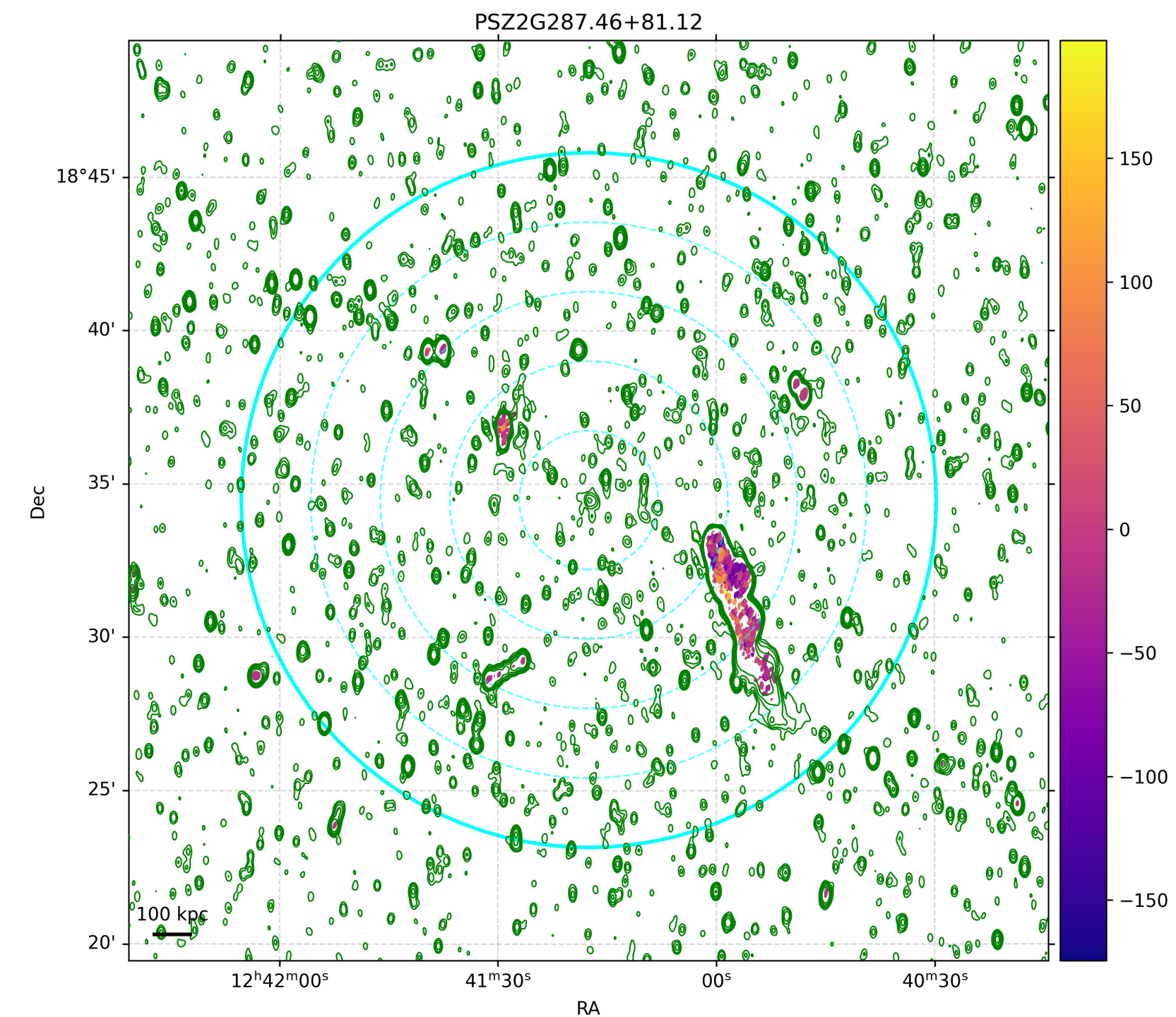
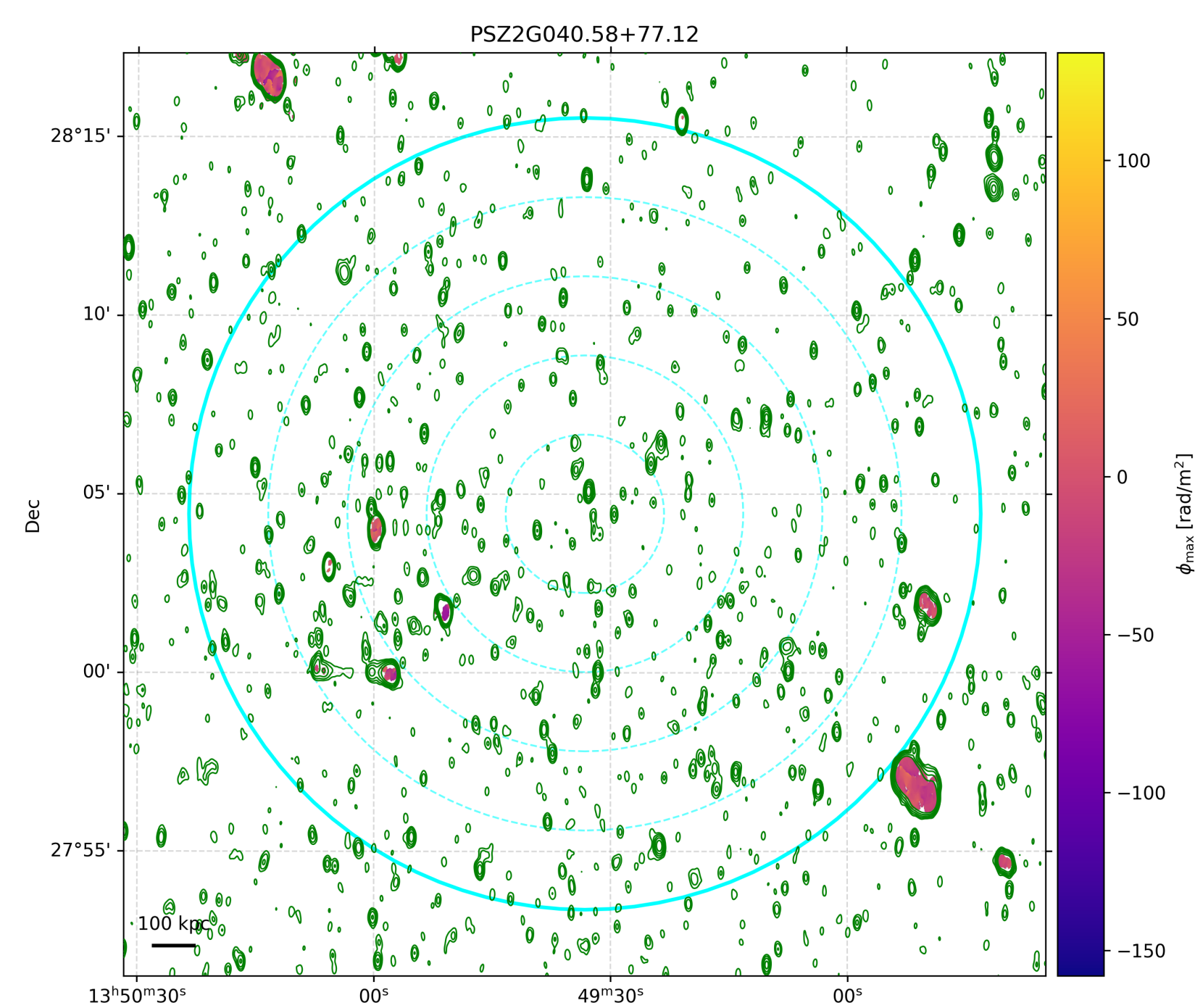
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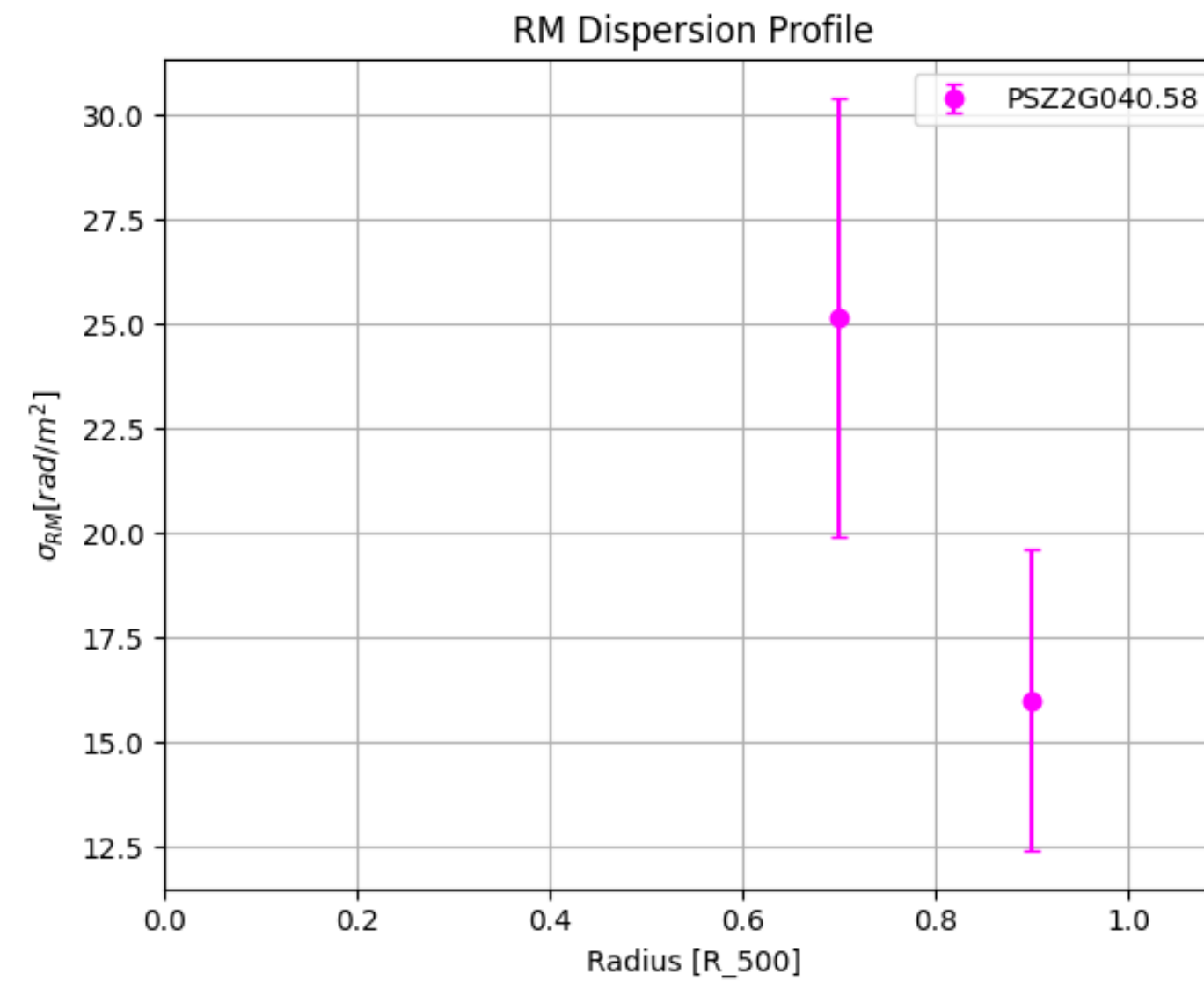
- RM-synthesis with RM Tools including RM clean
- Noise in P $\sim 4\text{e-}6$ Jy/beam
- RM precision (6 sigma) 4 rad/m^2
- Beam ~ 15 arcsec



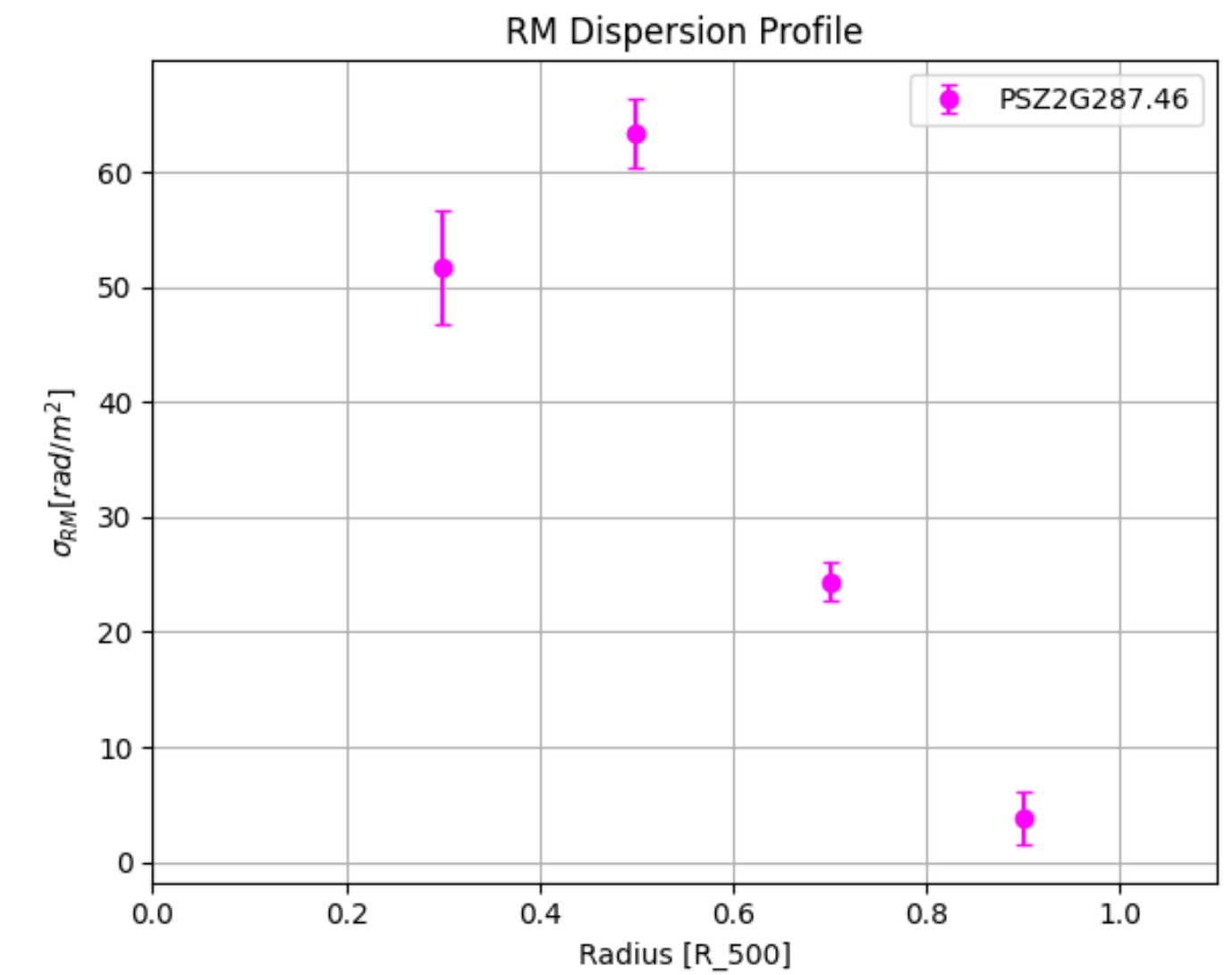
CHEX-MATE-KAT: first observations: low mass, low z sub-sample

- Individual σ_{RM} profiles
 $\sigma_{RM} \propto B_{||}$
- Annuli of 1/5 R_{500} each
- Only annuli with more than 1 equivalent beam

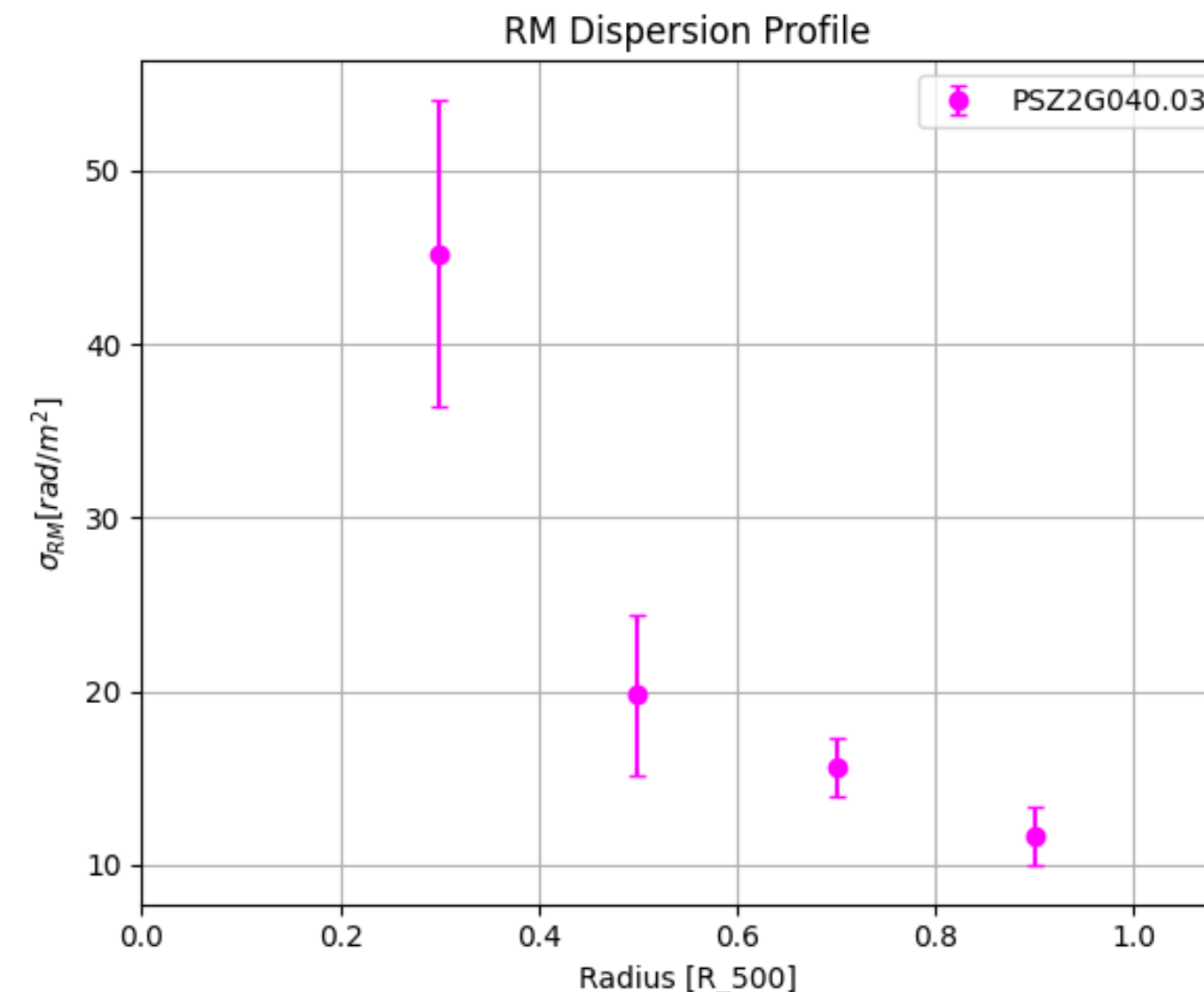
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 $M_{500}=2.57e14$ Msun



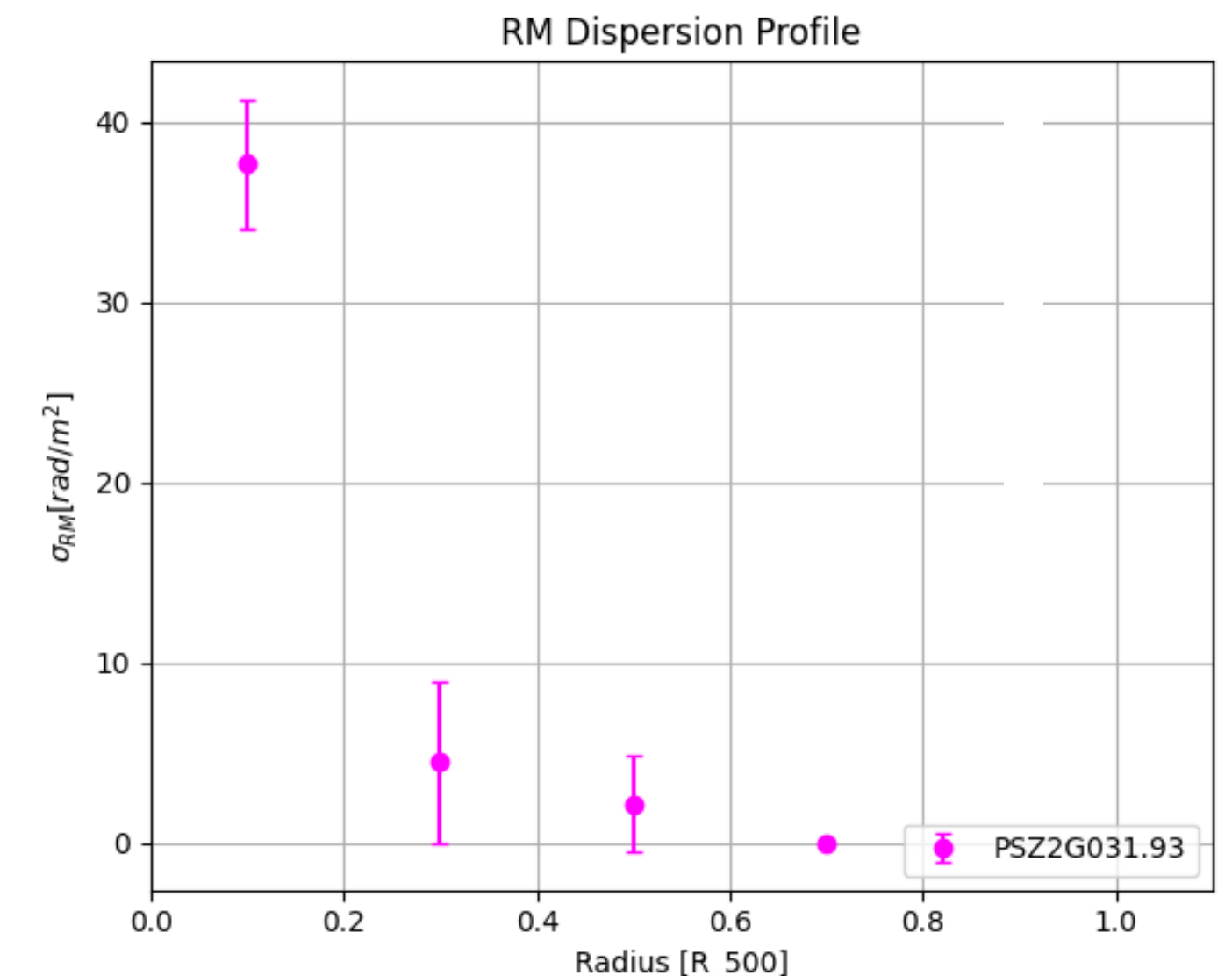
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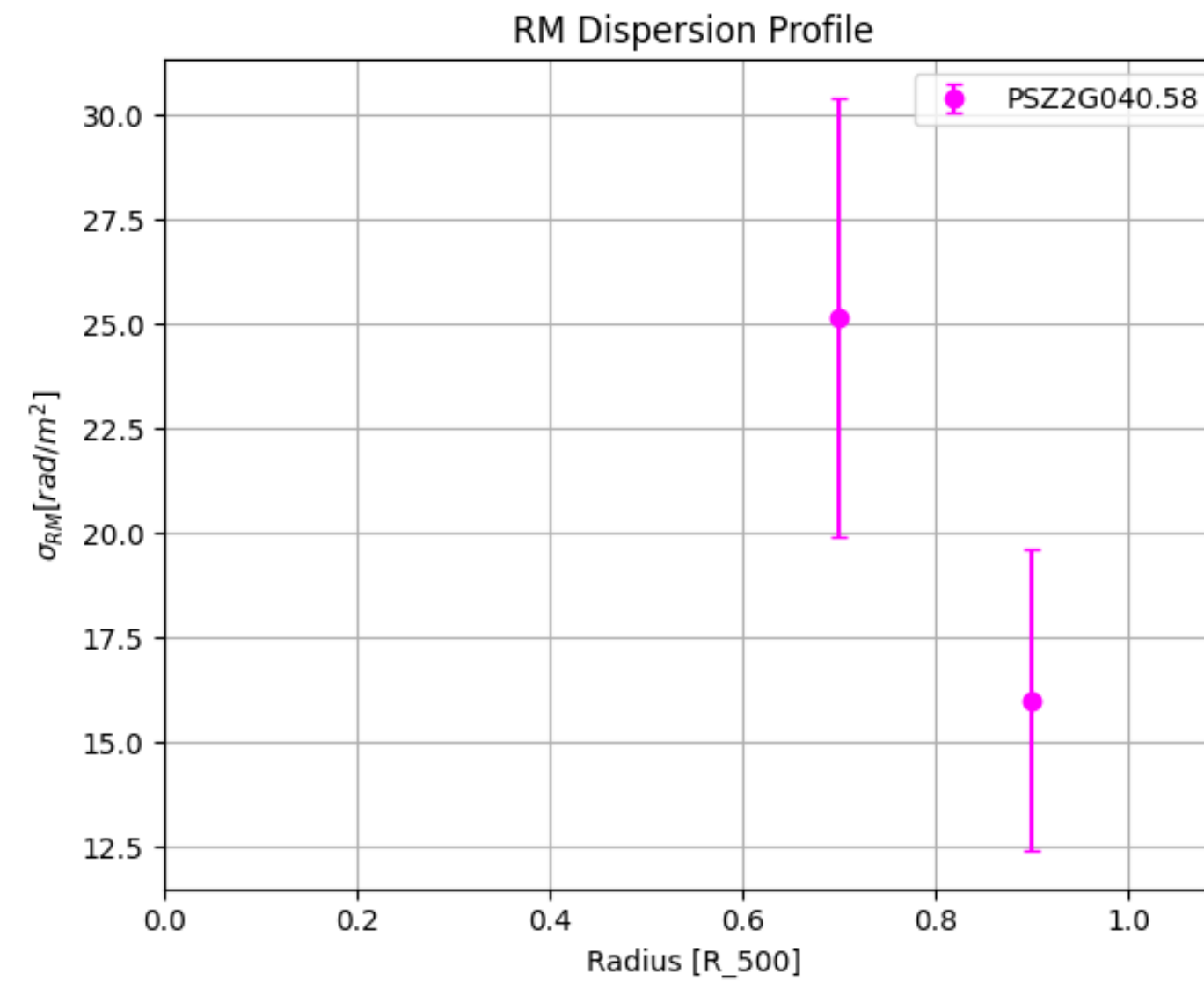
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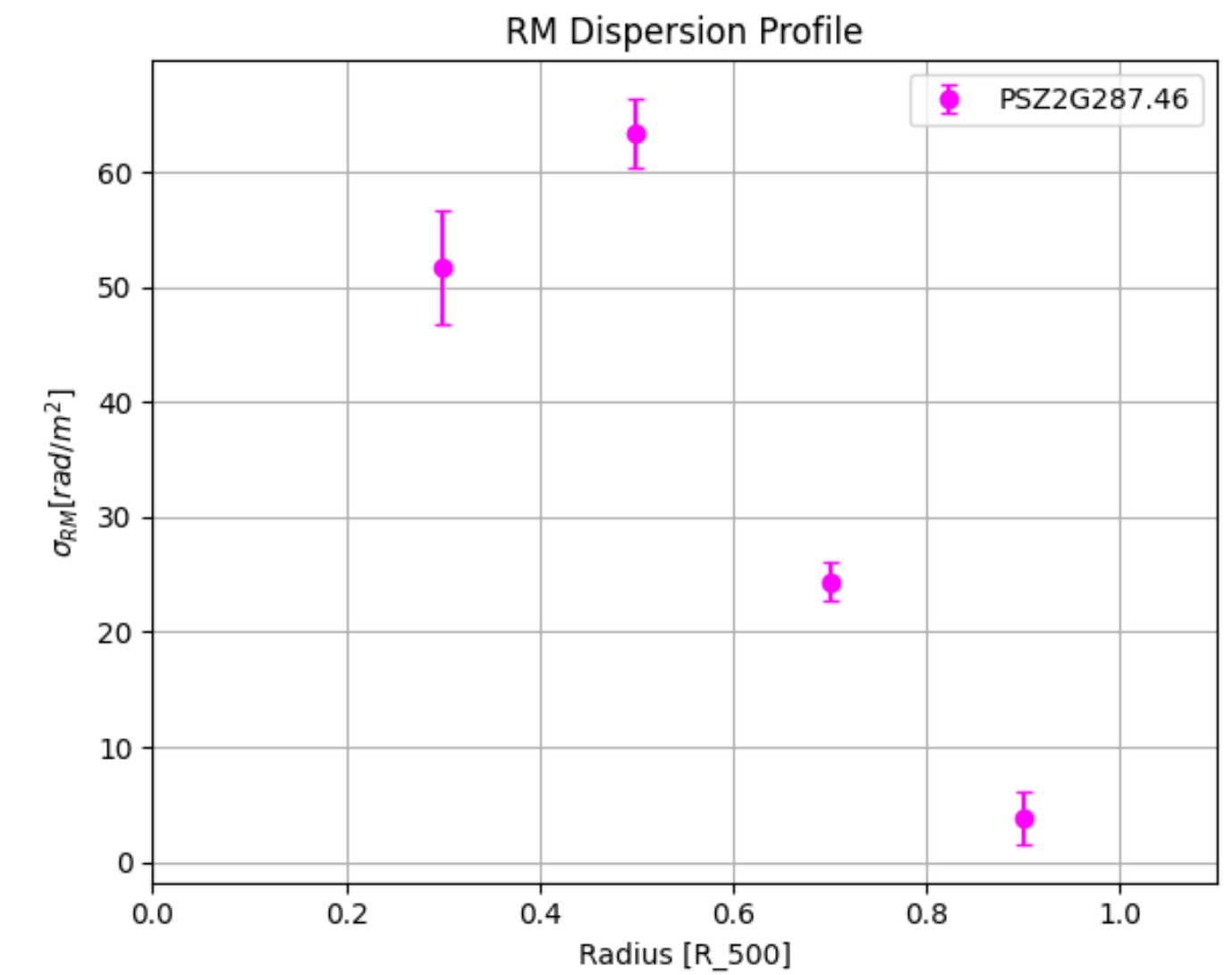
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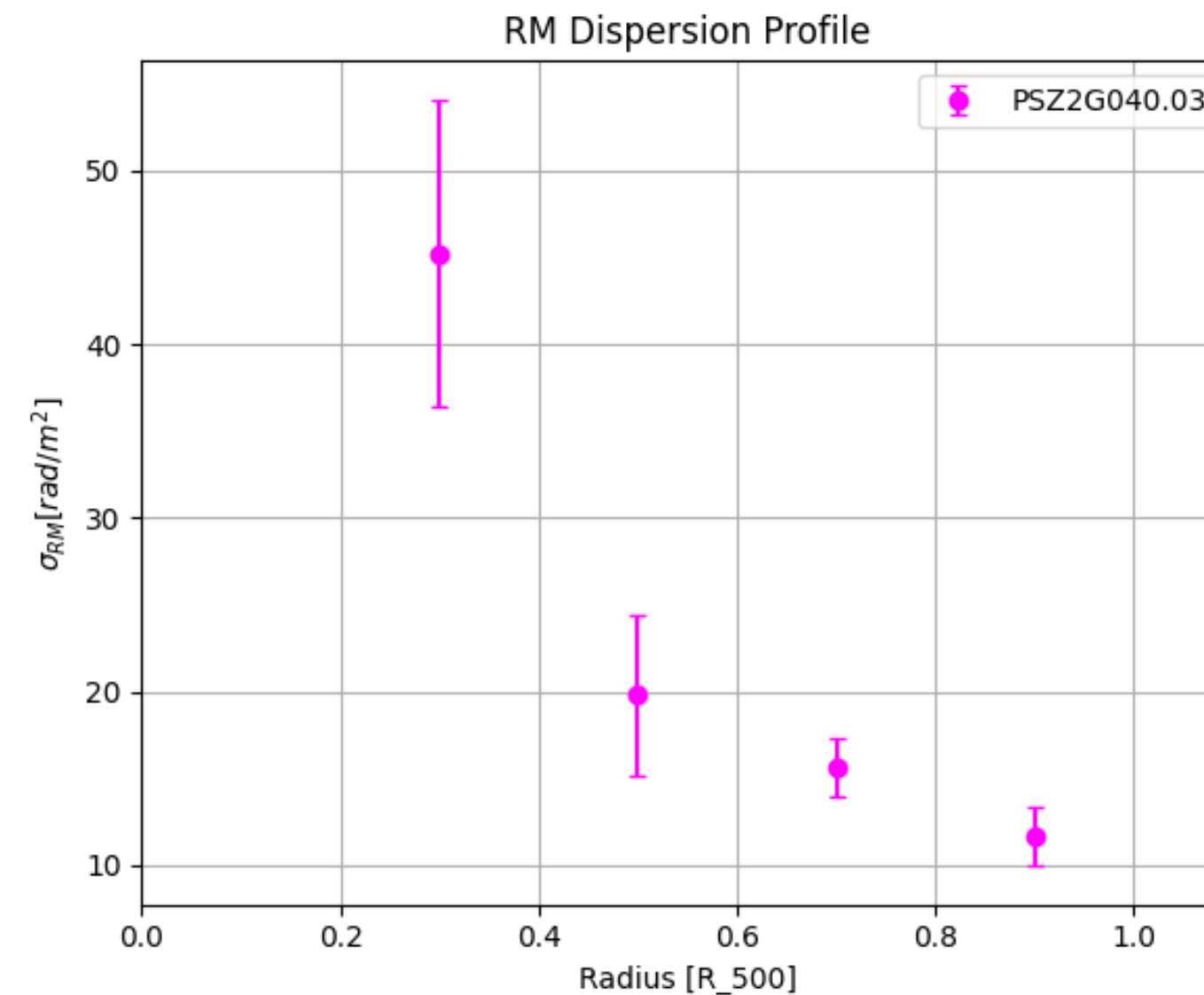
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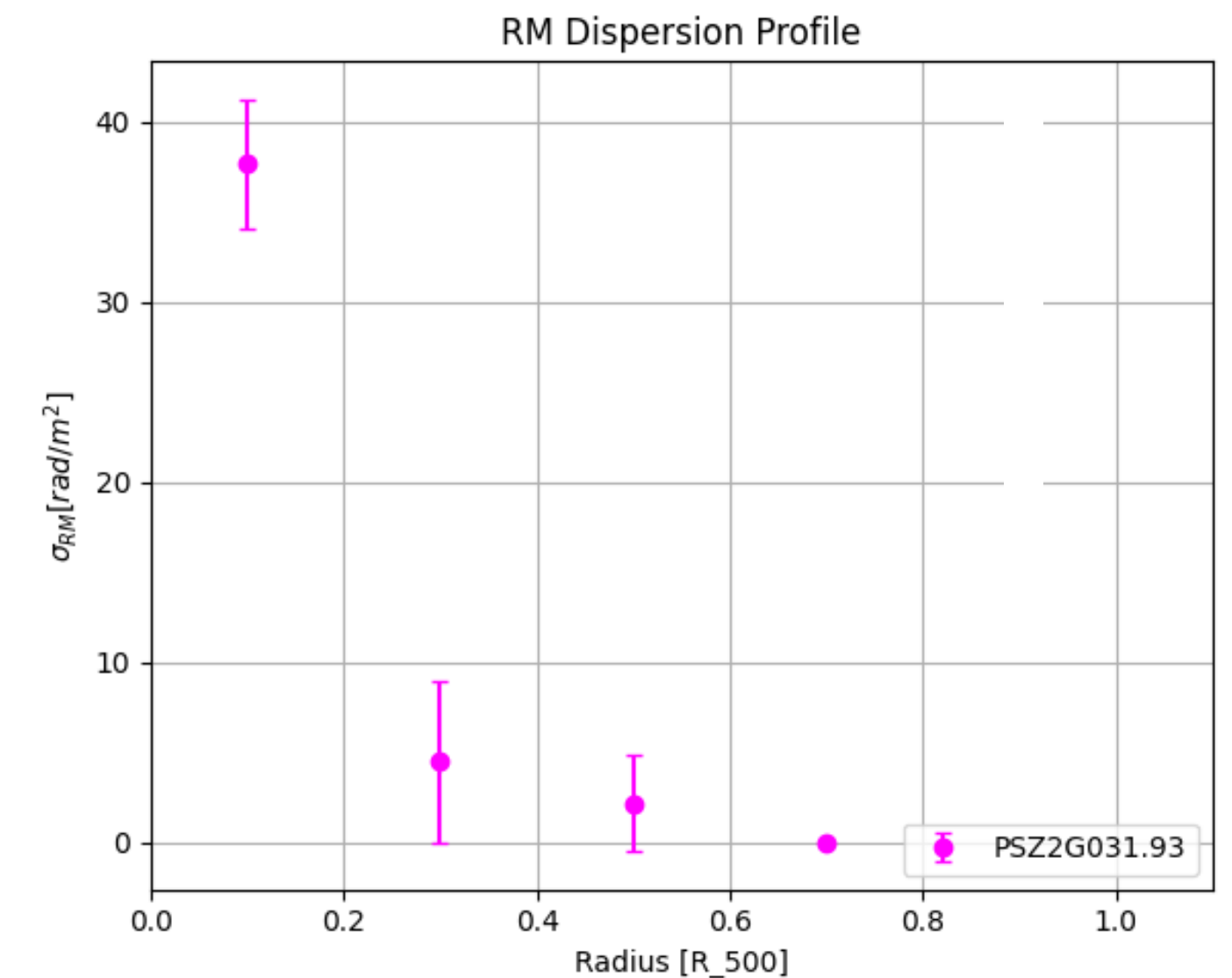
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PSZ2 G031.93+78.71,
 $z=0.0724$, $M_{500}=2.72e14$

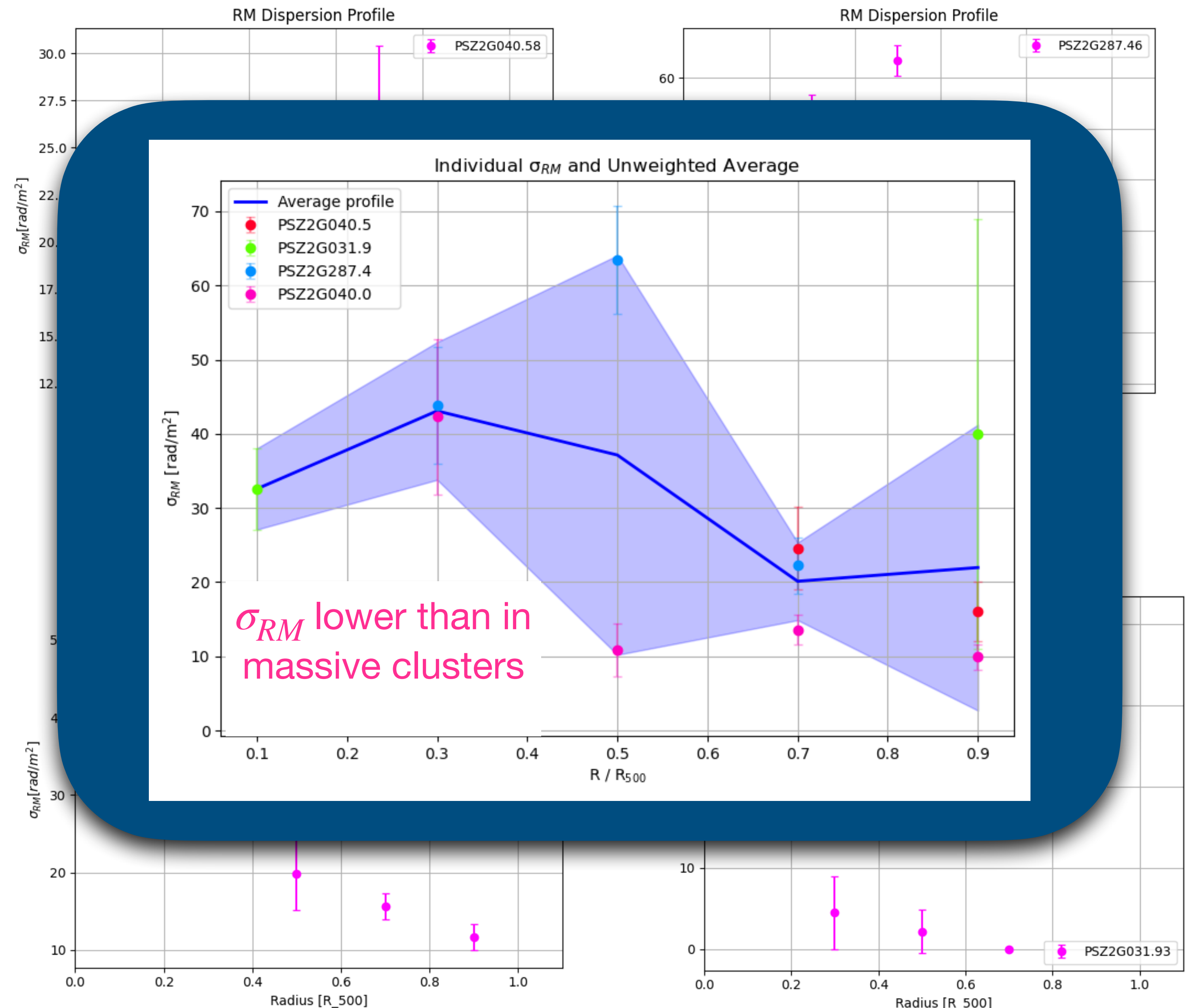


CHEX-MATE-KAT: first observations: low mass, low z sub-sample

- Individual σ_{RM} profiles
- Annuli of $1/5 R_{500}$ each
- Only annuli with 3 equivalent beams or more

PSZ2 G040.58+77.12, $z=0.0748$,
 $M_{500}=2.57e14$ Msun

PSZ2 G287.46+81.12, $z=0.073$,
 $M_{500}=2.56e14$

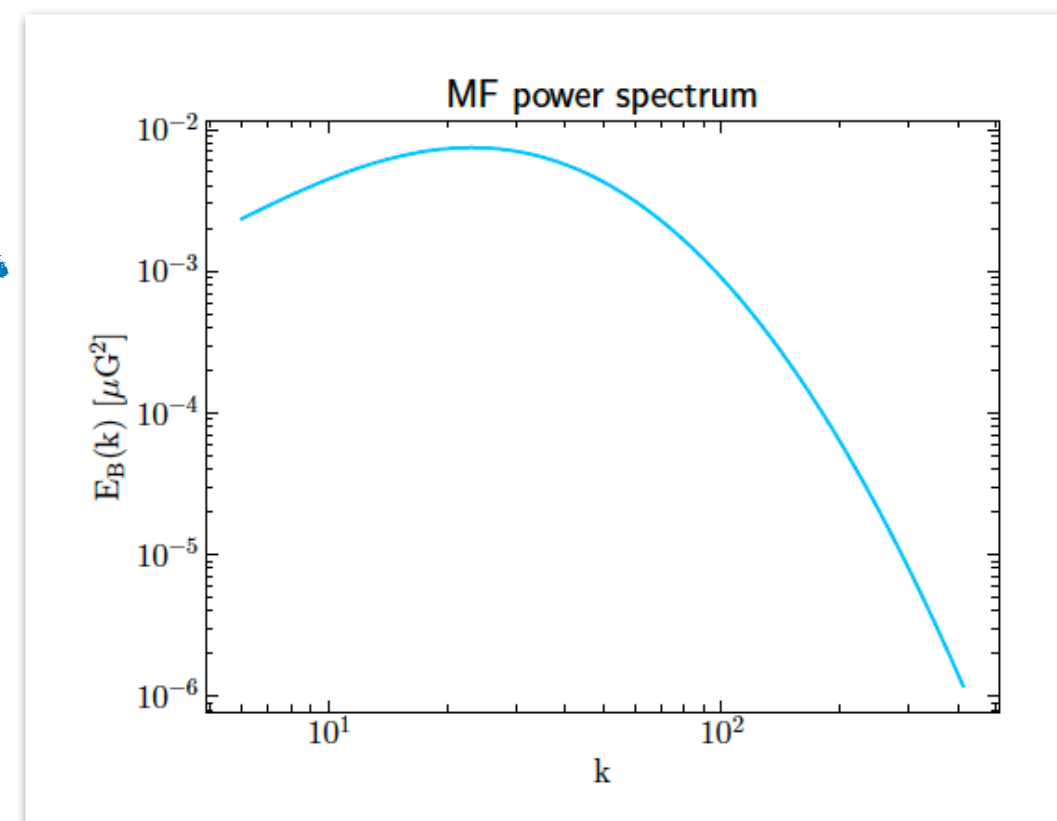
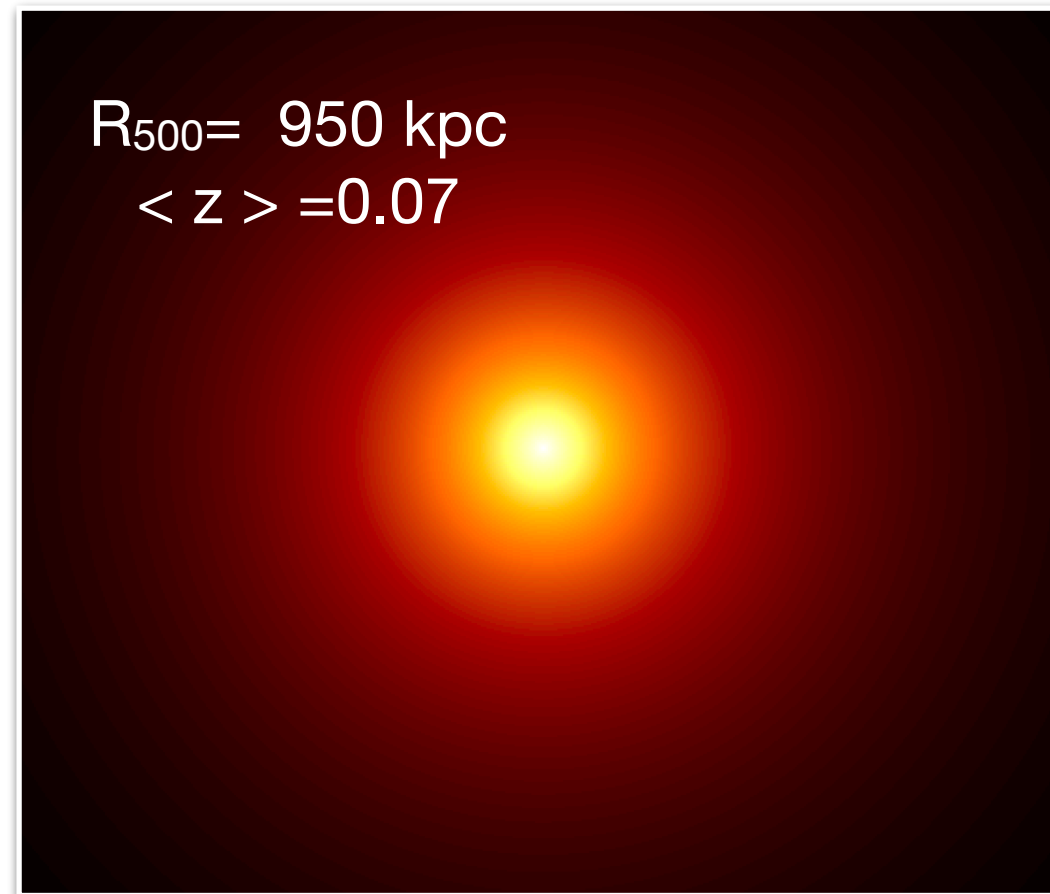


Preliminary

Simulations: MiRo' code

(Bonafede et al 213, Stuardi et al 2021)

- Density: Average cluster profile based on Universal density profiles (Ghirardini et al 2019)
- Numerical model for B:
 - Power spectrum: from Dominguez-Fernandez (2019)
 - B normalised within R_{500}

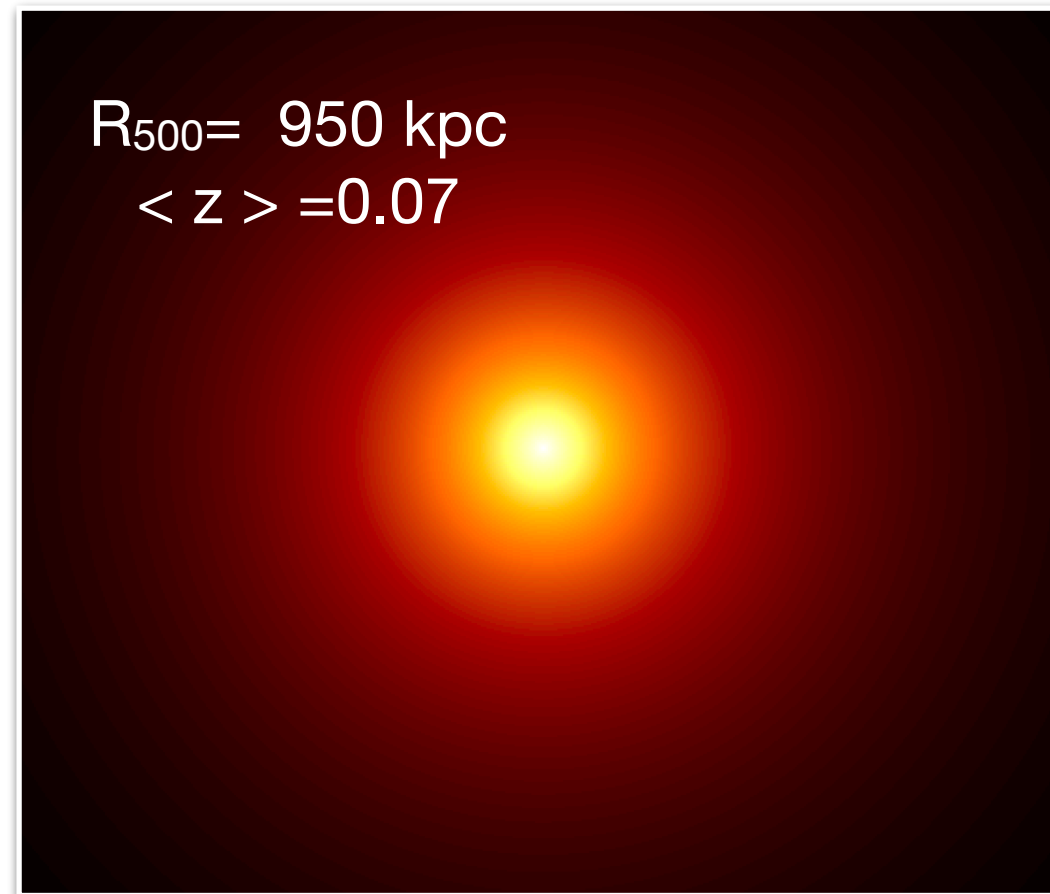


Preliminary

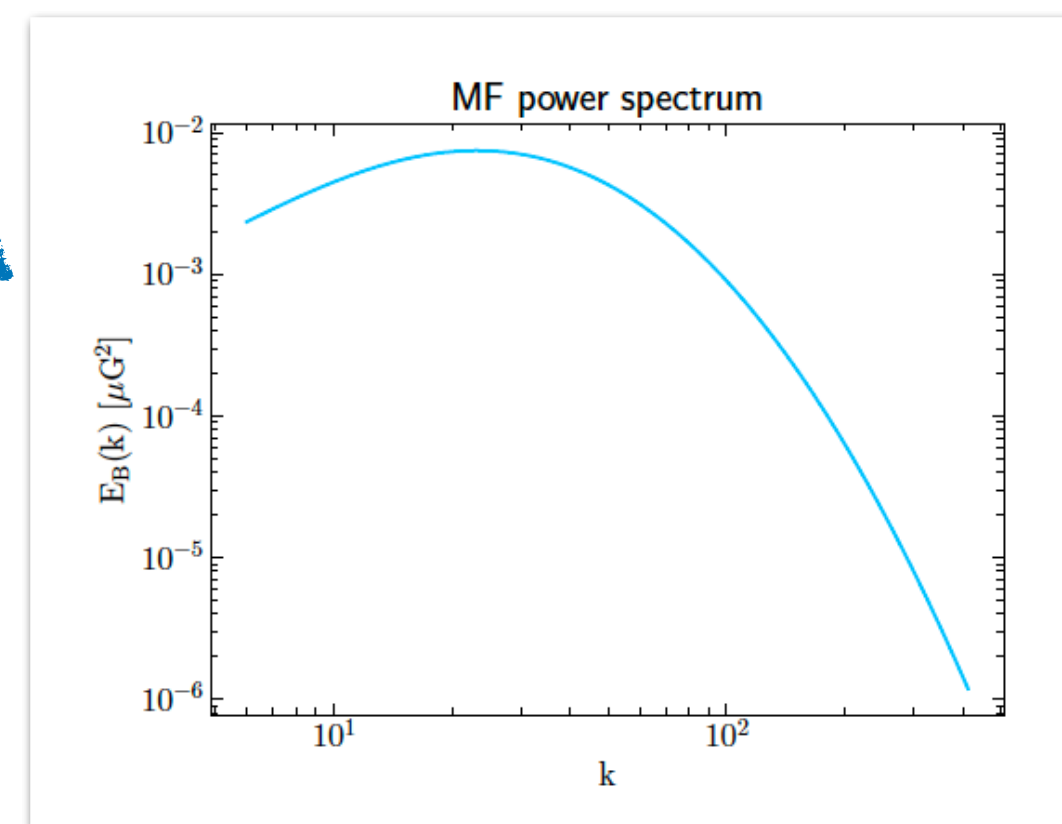
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$$RM \propto \int n_e B_{||} dl$$

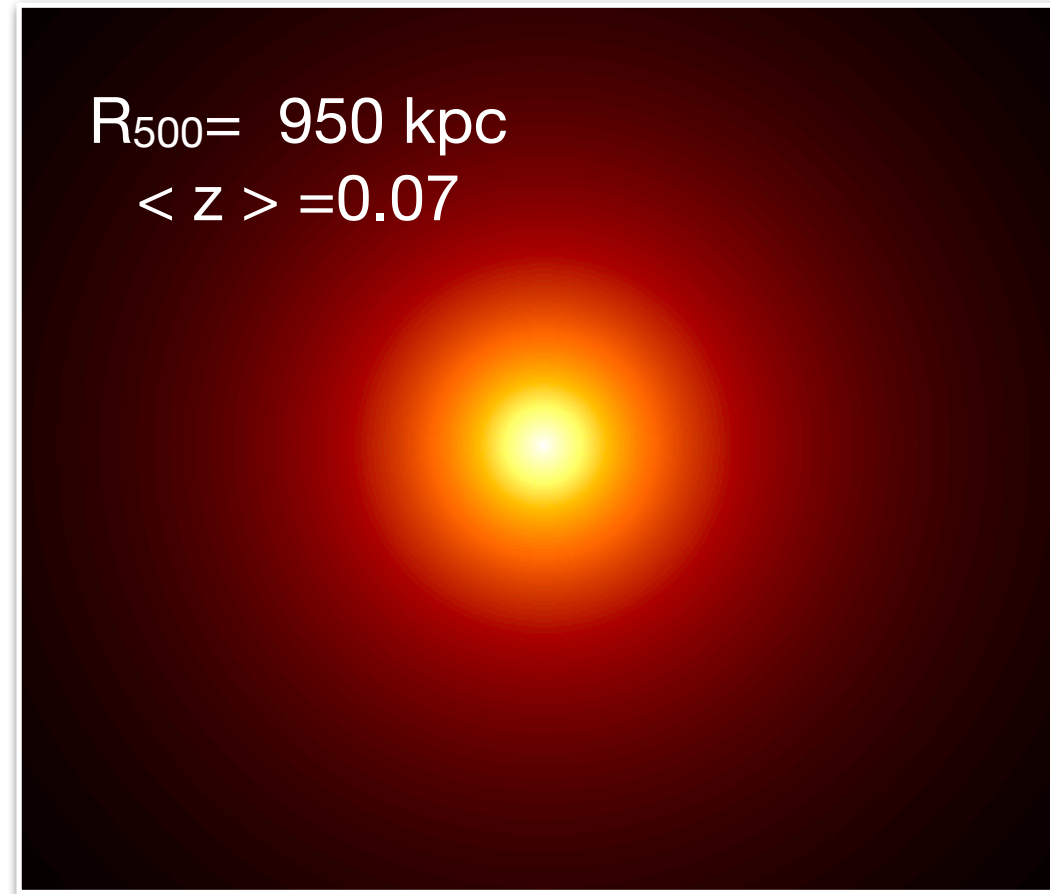


Preliminary

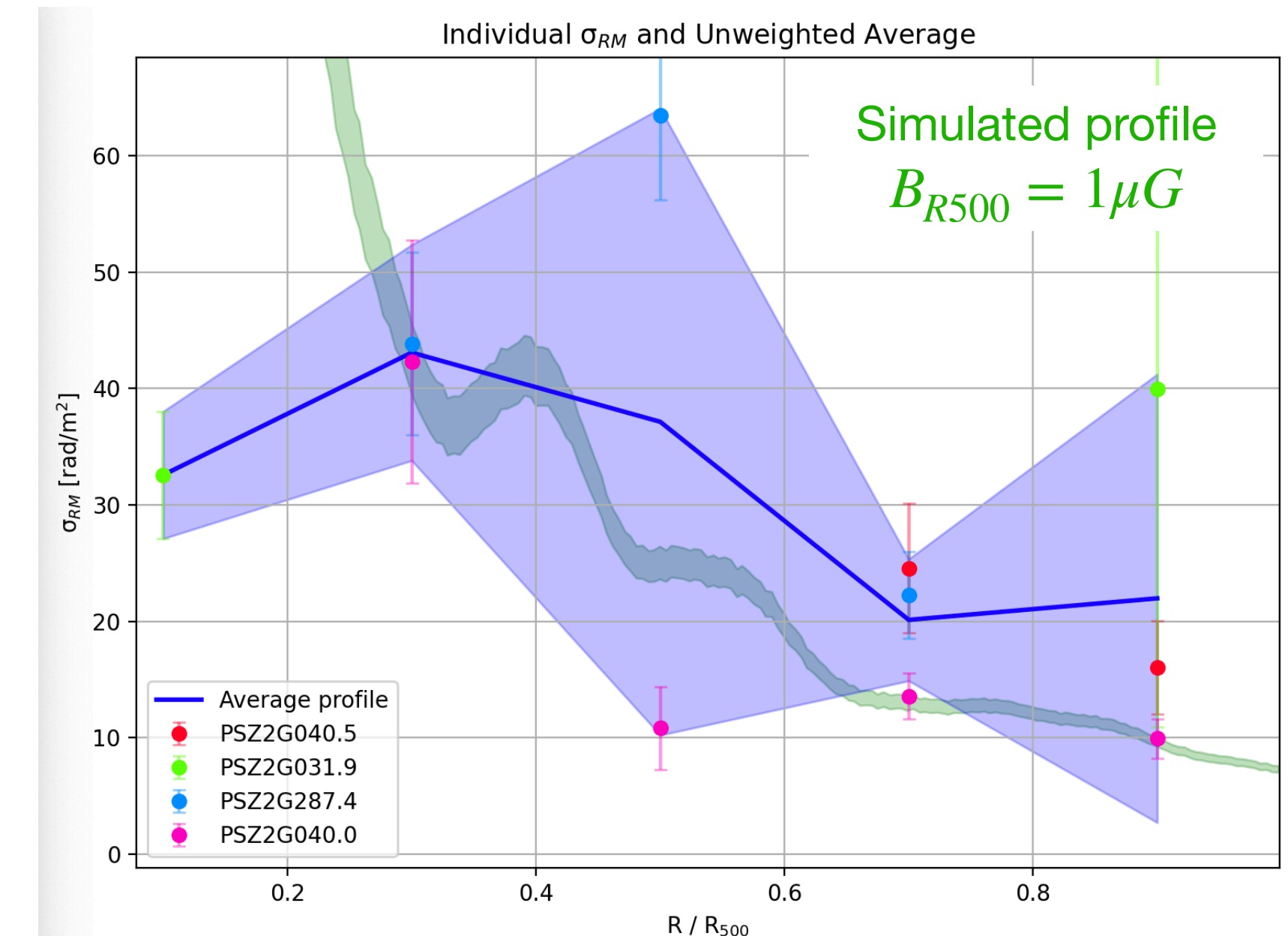
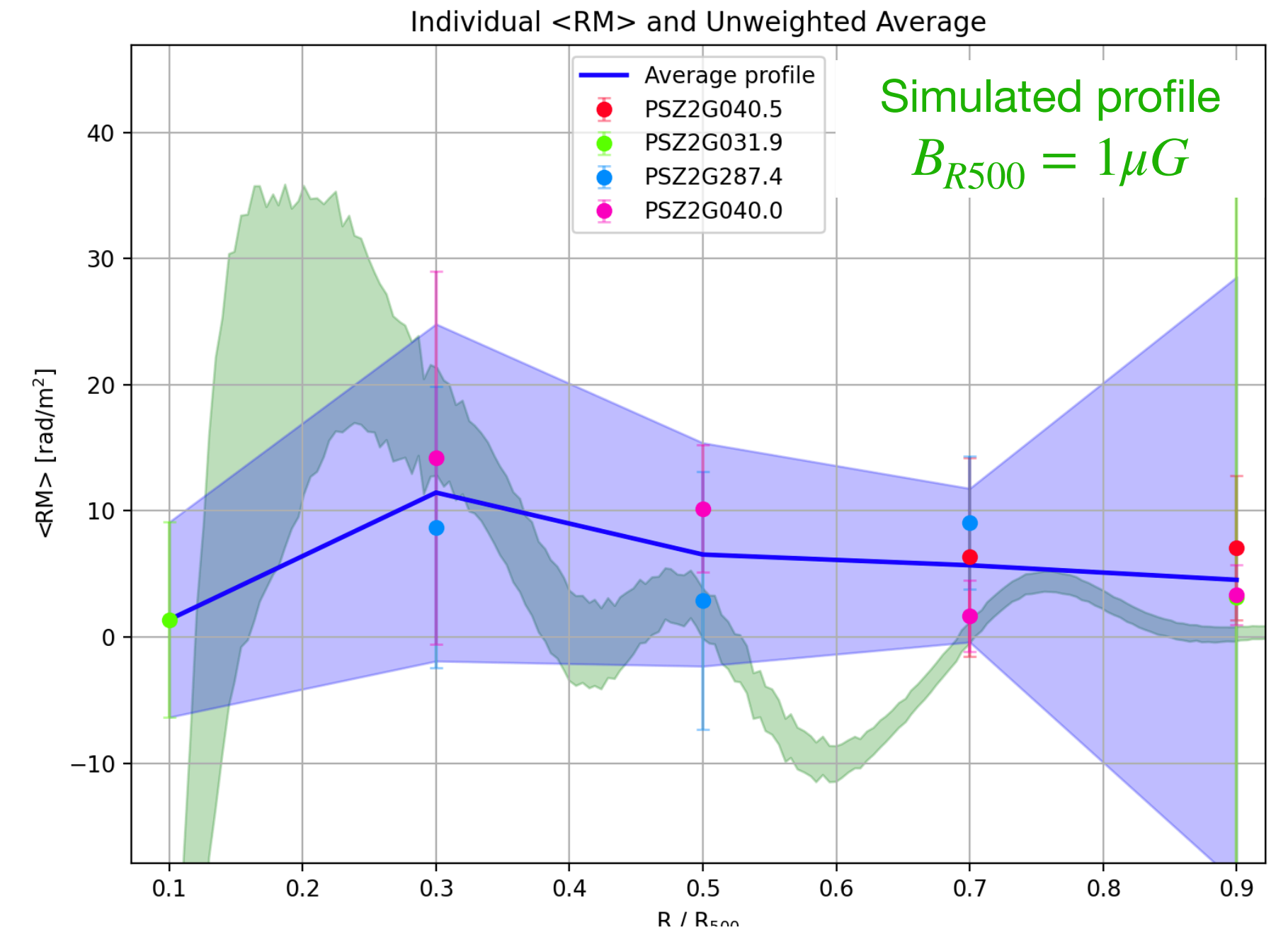
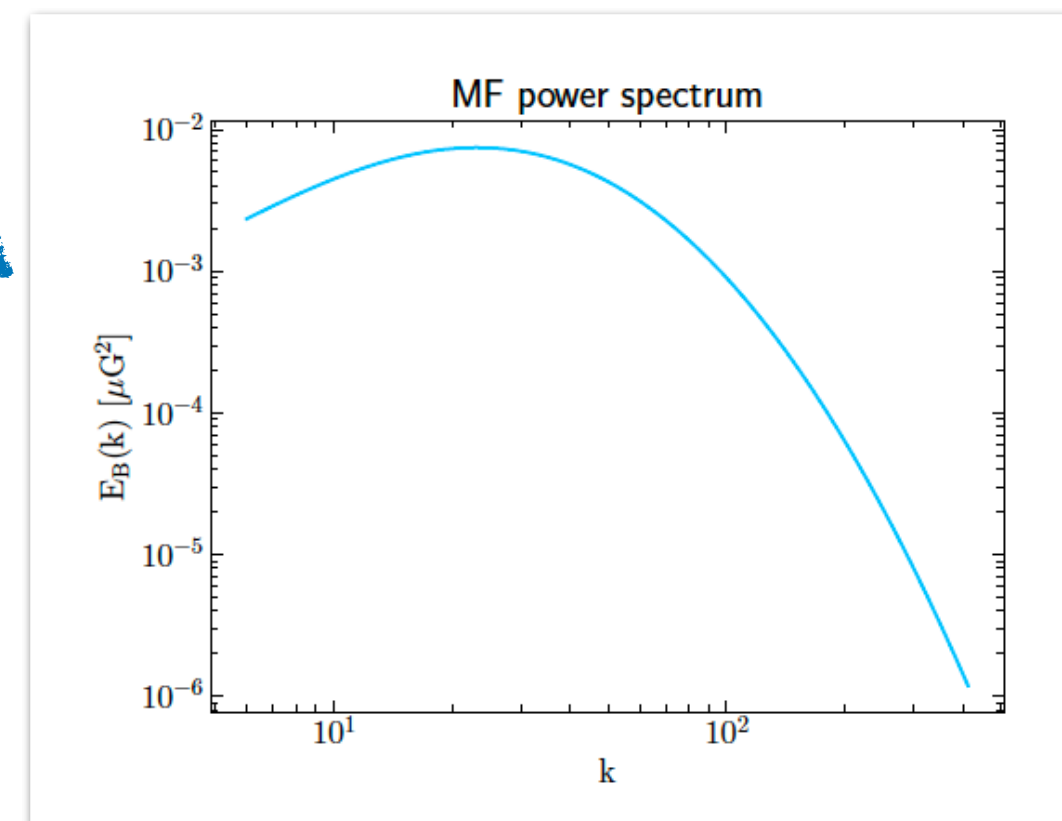
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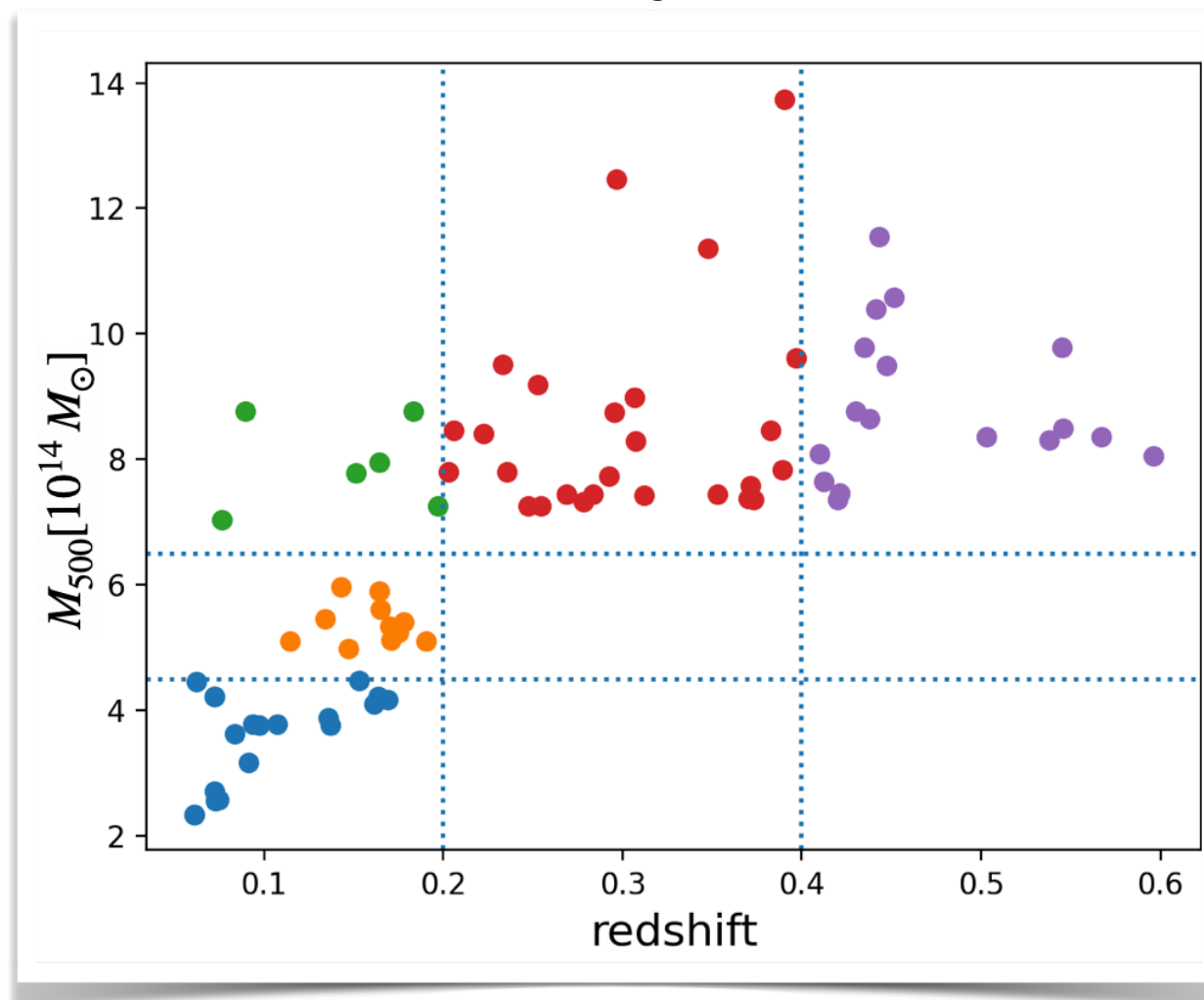


$$RM \propto \int n_e B_{||} dl$$



MeerKAT XLP - Extra Large Project

F. Campolucci
Master thesis



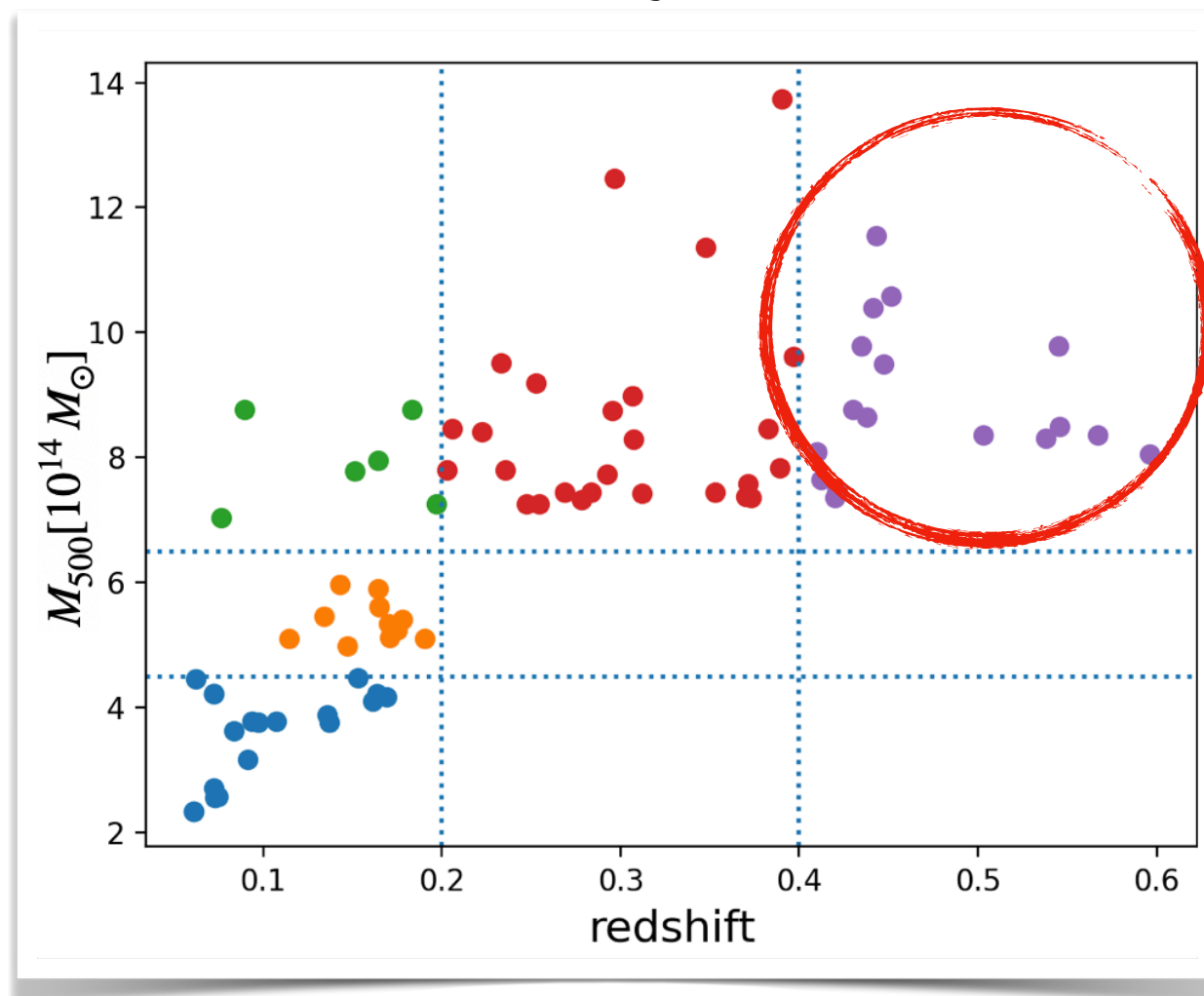
High mass- high z clusters
Time not granted yet, but
observations in the archive
(PI M. Balboni)

not enough sources for RM
studies on single clusters

B constraints based on
depolarisation

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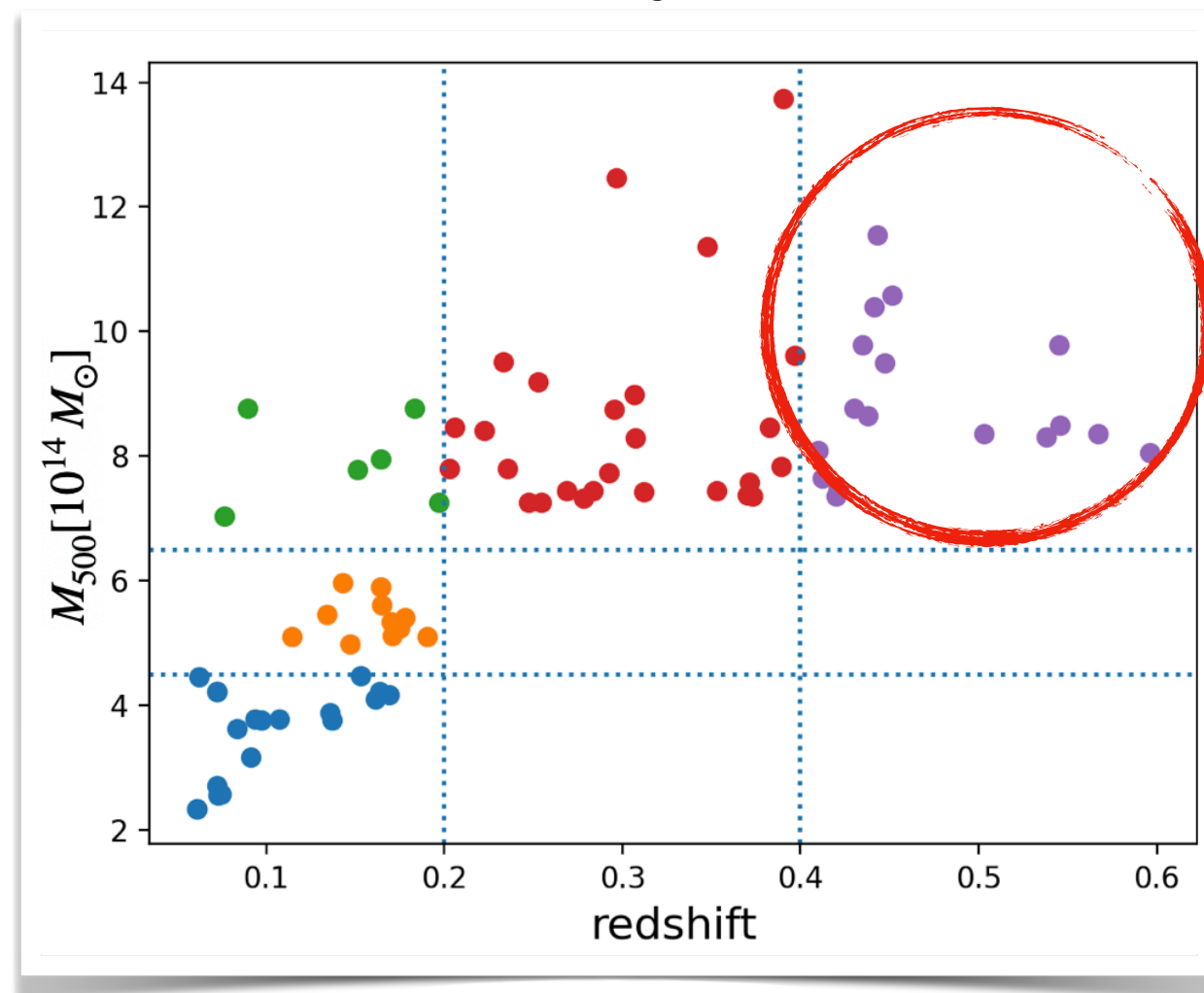
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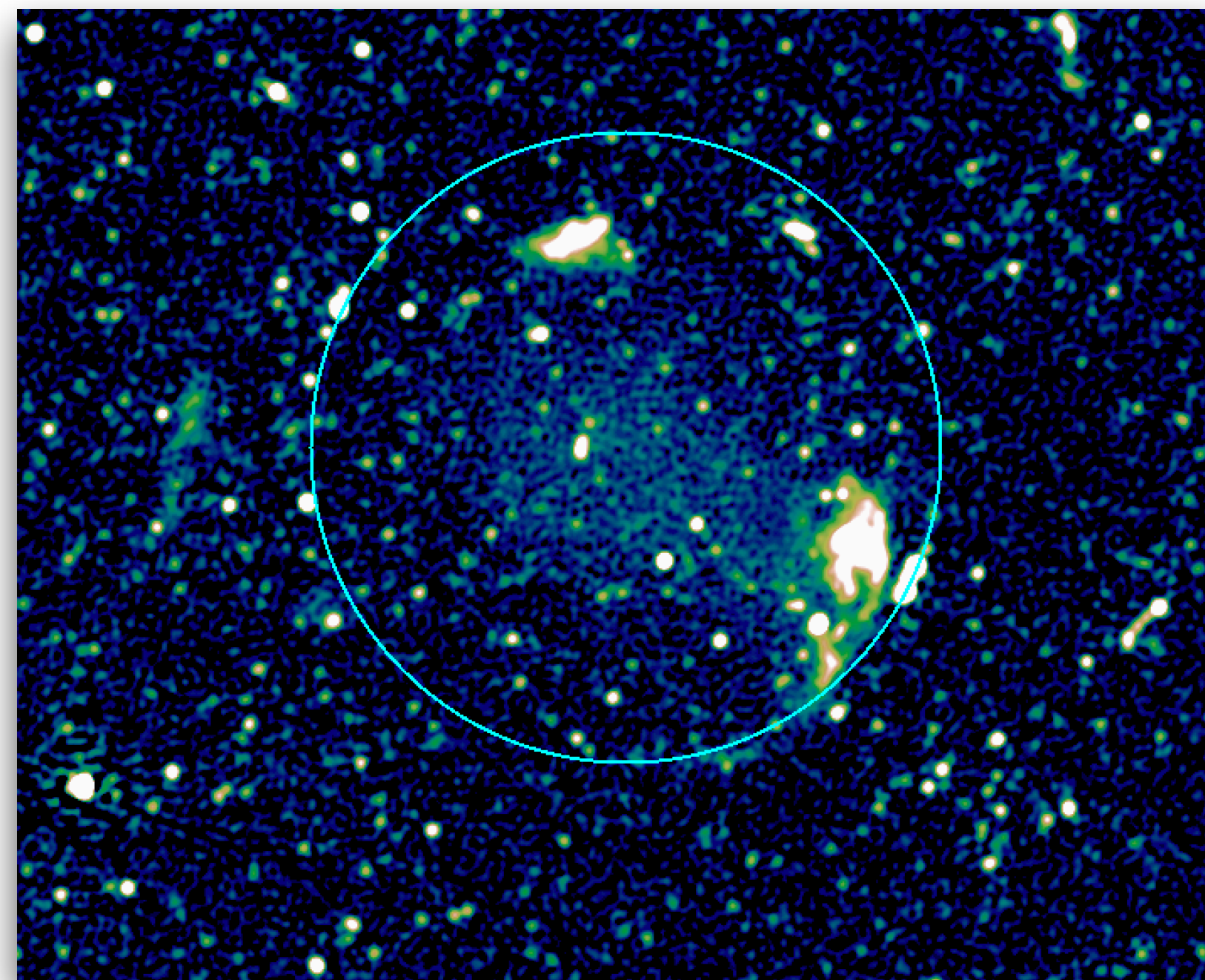
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Master thesis



PSZ2G243.15-73.84

$z = 0.41$

$M_{500} = 8.08 \cdot 10^{14} M_{\text{sun}}$



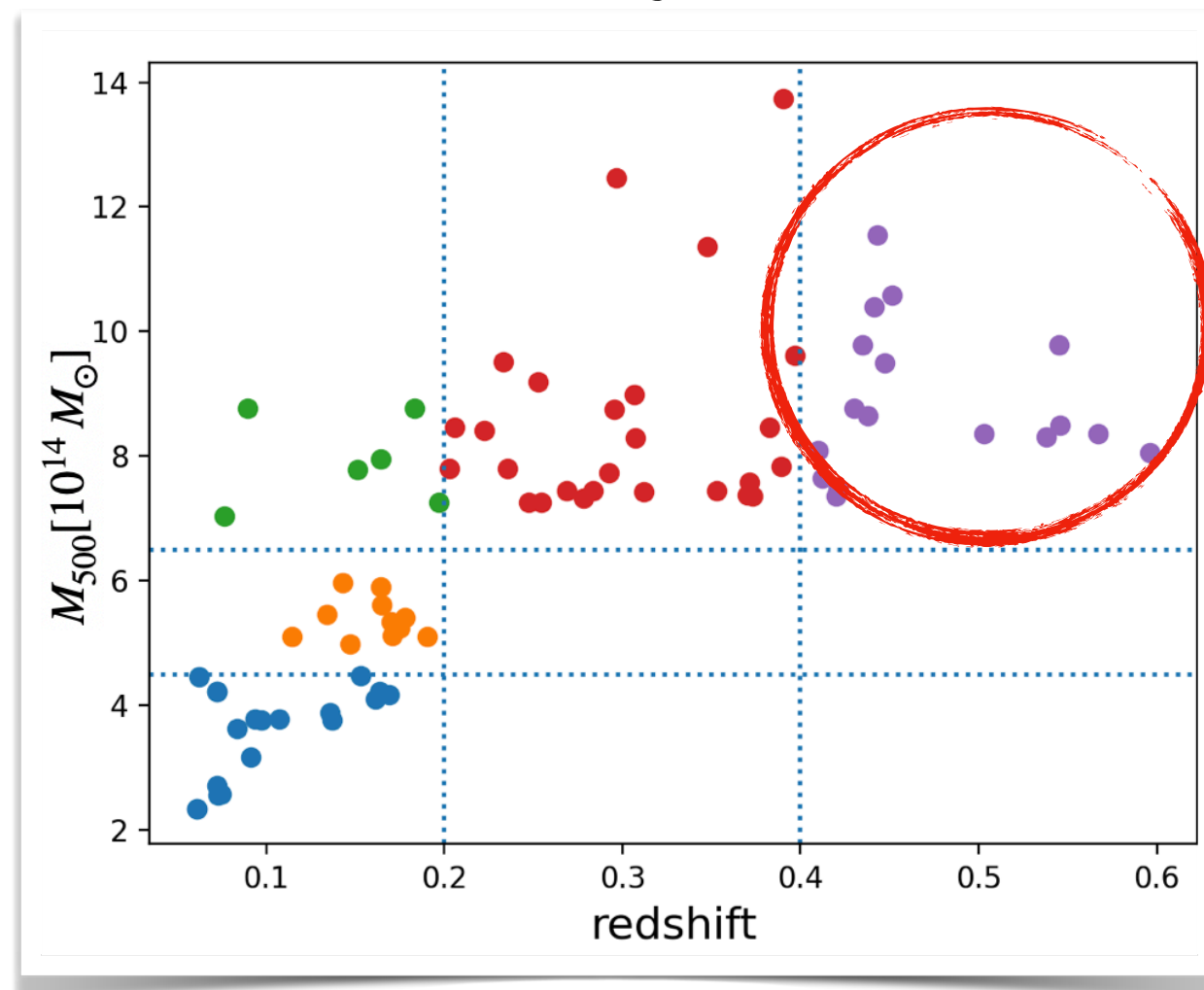
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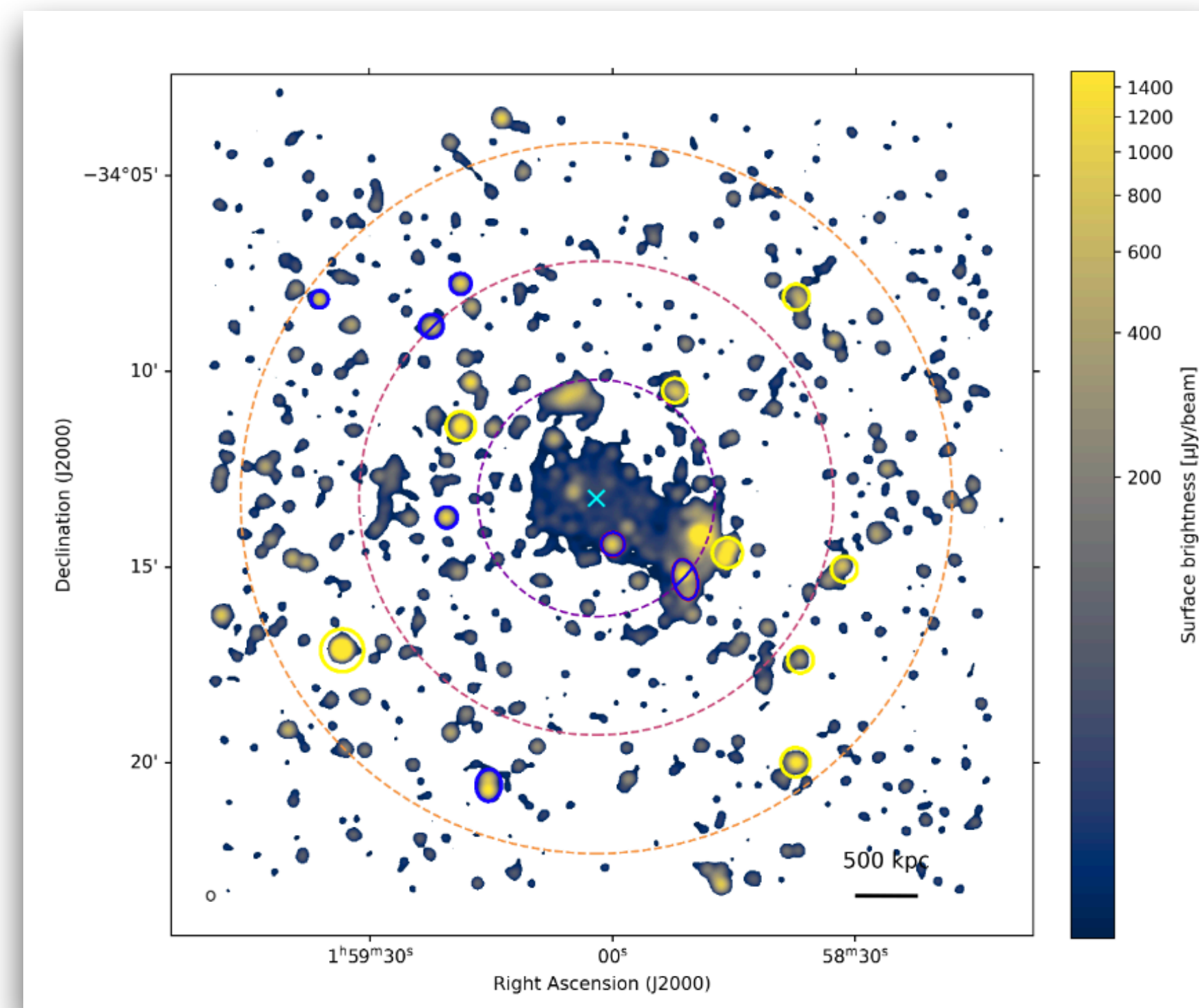
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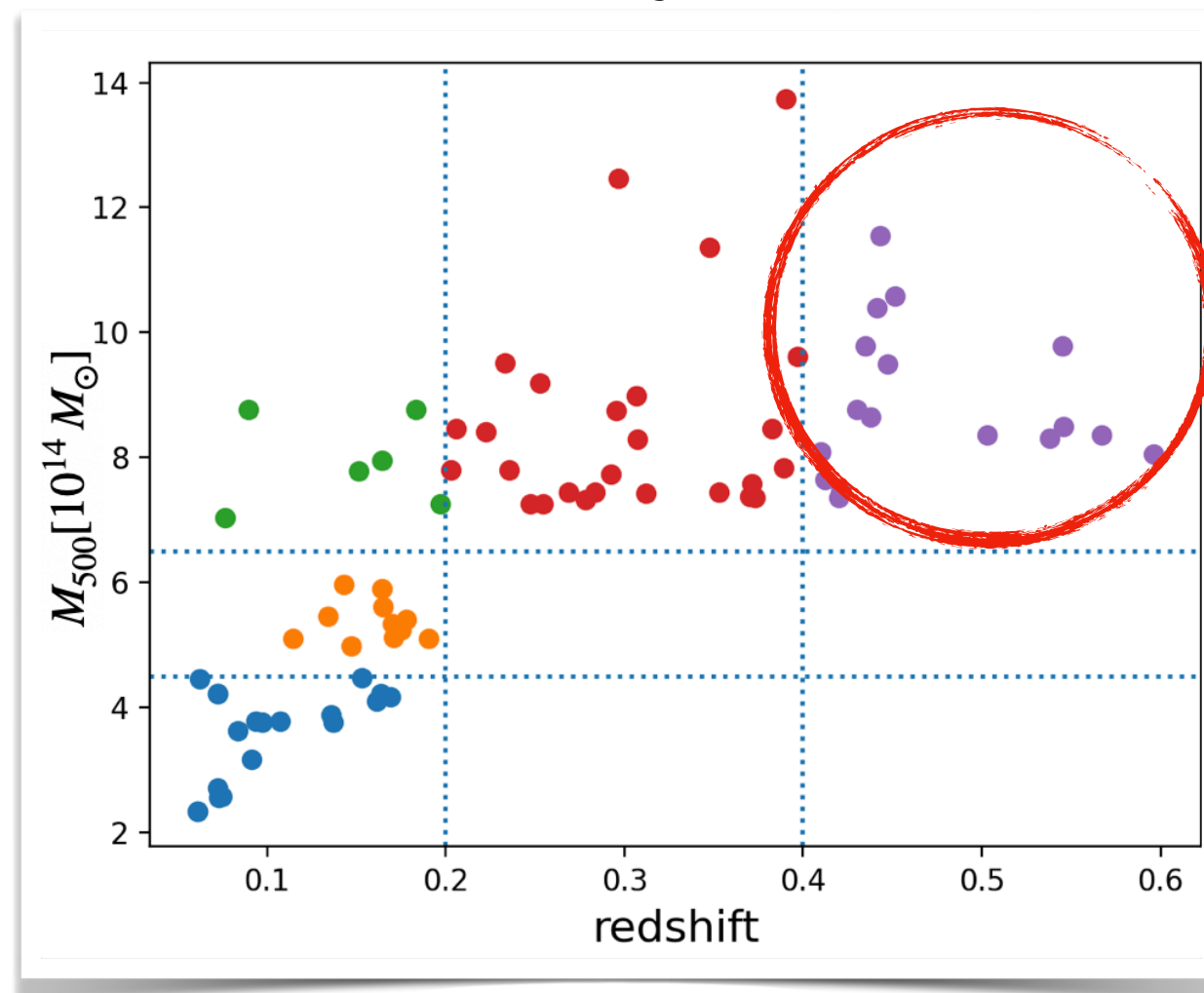
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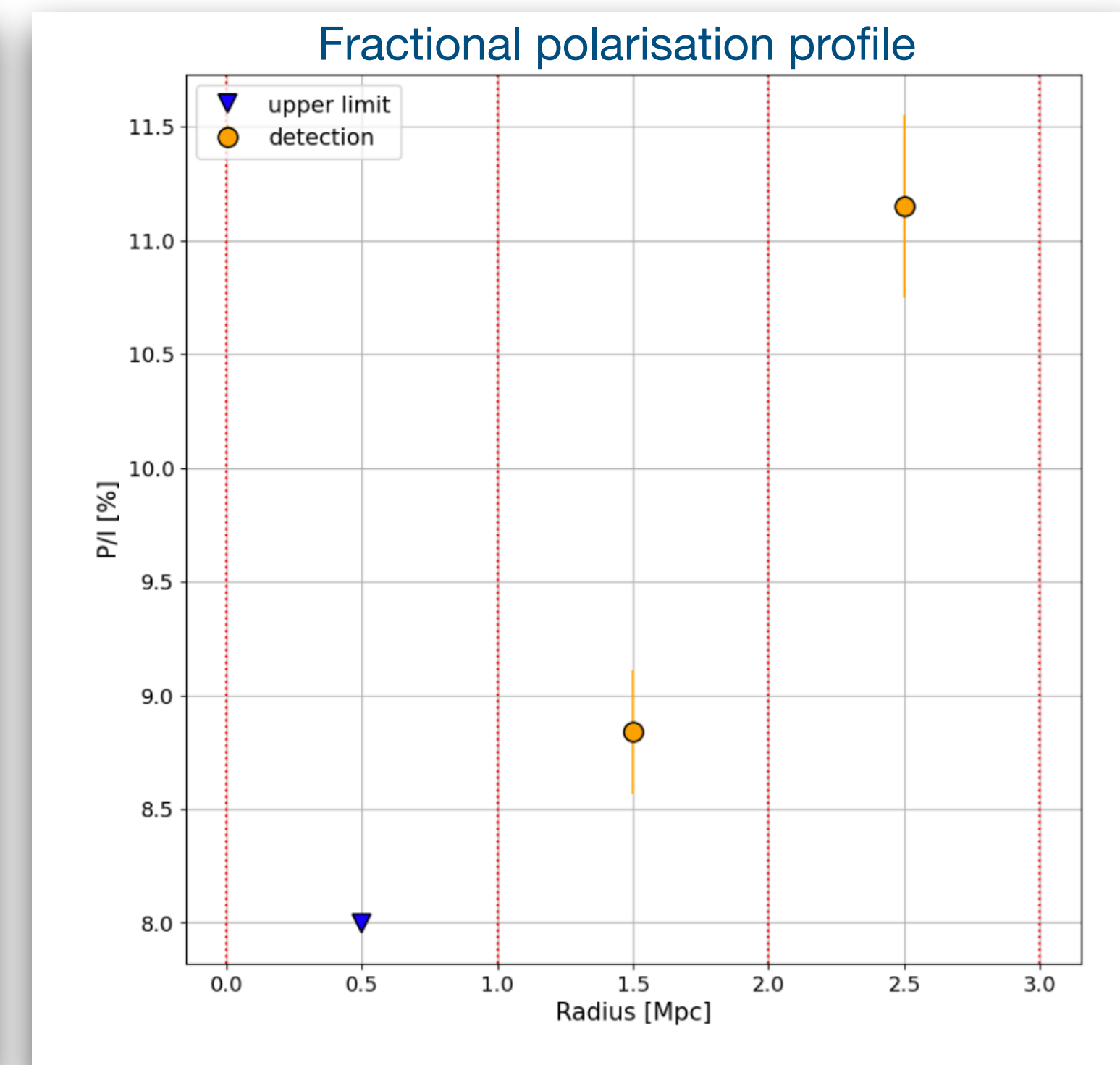
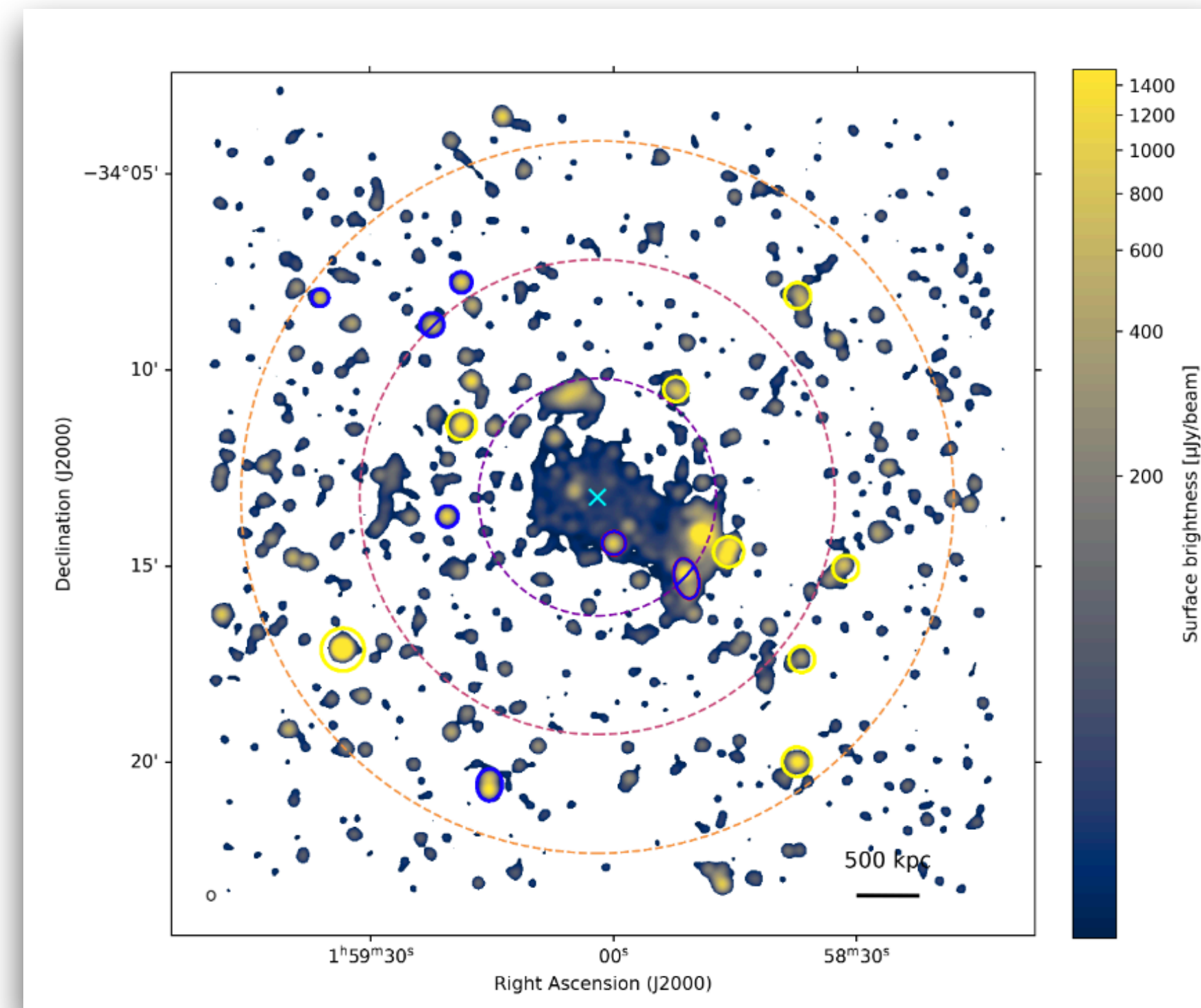
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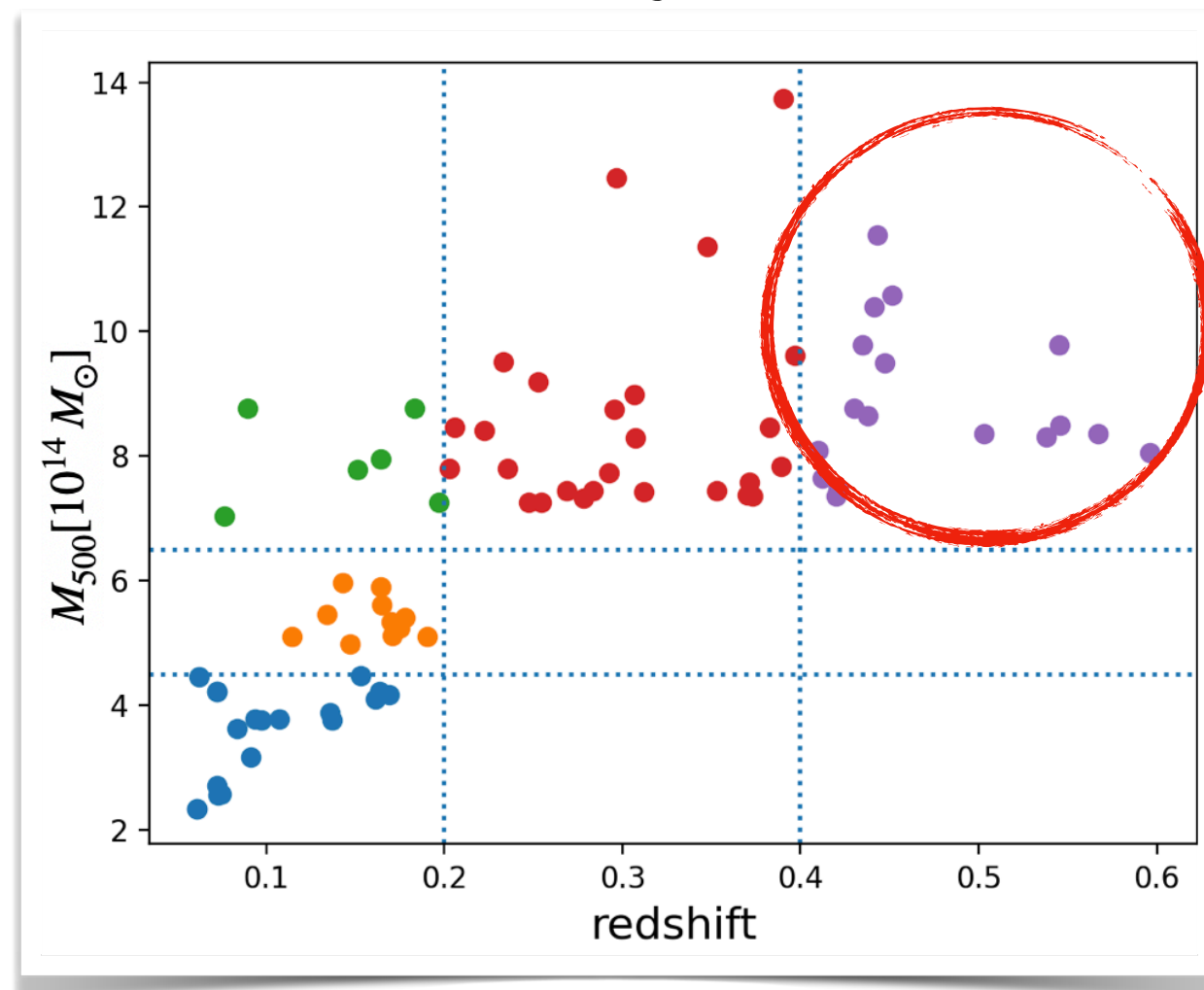
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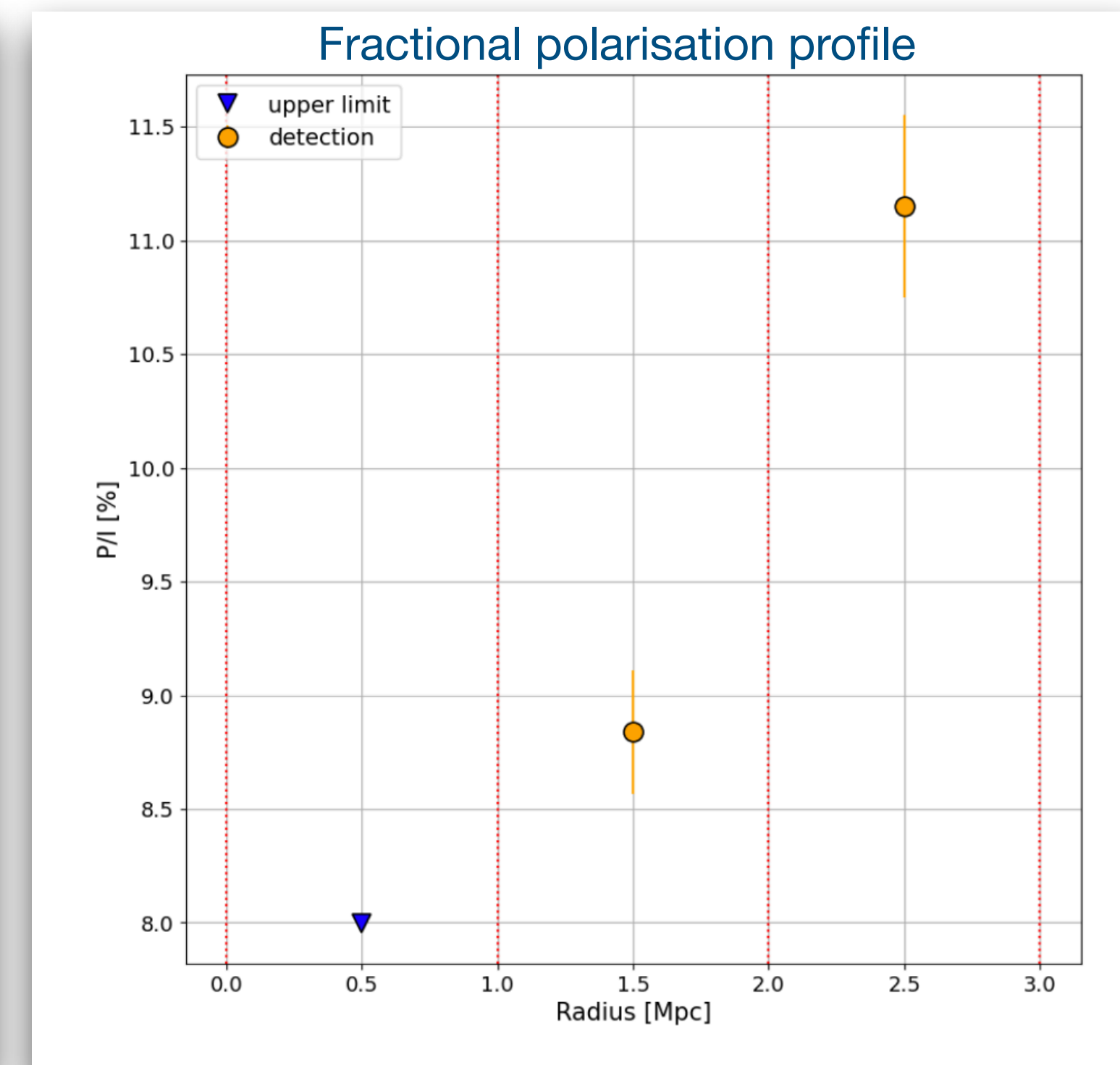
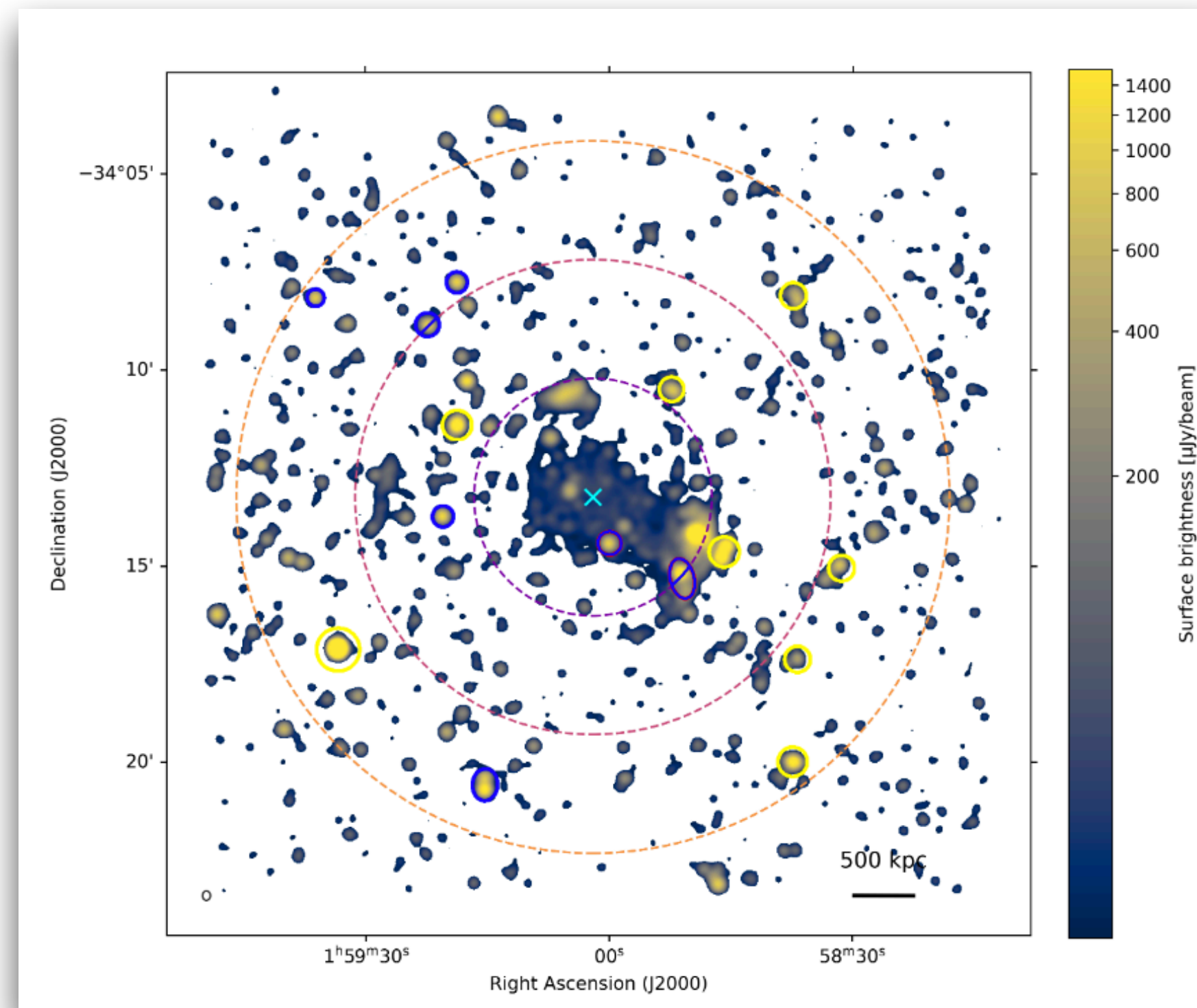
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Preliminary results: $B_{R500} < 3\mu G$

SUMMARY

- Magnetic field in galaxy clusters can be constrained with wide-band polarisation observations
- Stacking of cluster RM can be performed in small mass and z bins
- MeerKAT XLP will provide constraints on B evaluation versus mass and z