FROM X-RAY TO WEAK LENSING: COMPARING CLUSTER MASS PROFILES IN CHEX-MATE

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THE CHALLENGE OF MEASURING GALAXY CLUSTER MASSES

MASS CALIBRATION: X-RAY vs WEAK LENSING



Hydrostatic mass M_{HE}

X-ray gas density and temperature
Assumption: hydrostatic equilibrium

Systematic uncertainties
Non-thermal pressure - turbulence - gas clumping



Weak-lensing mass M_{WL}

Gravitational shear of background galaxies
Assumption: mass profile modeling

Systematic uncertainties
Projection effects - triaxiality - shape noise

The mass calibration problem

$$M_{HE}/M_{WL} \neq 1\,?$$

Key question

To what extent are X-ray mass estimates biased by the hydrostatic equilibrium assumption, and how does this bias depend on the dynamical state of galaxy clusters?

THE CLUSTER HERITAGE PROJECT WITH XMM-NEWTON

Mass Assembly and Thermodynamics at the Endpoint of Structure Formation

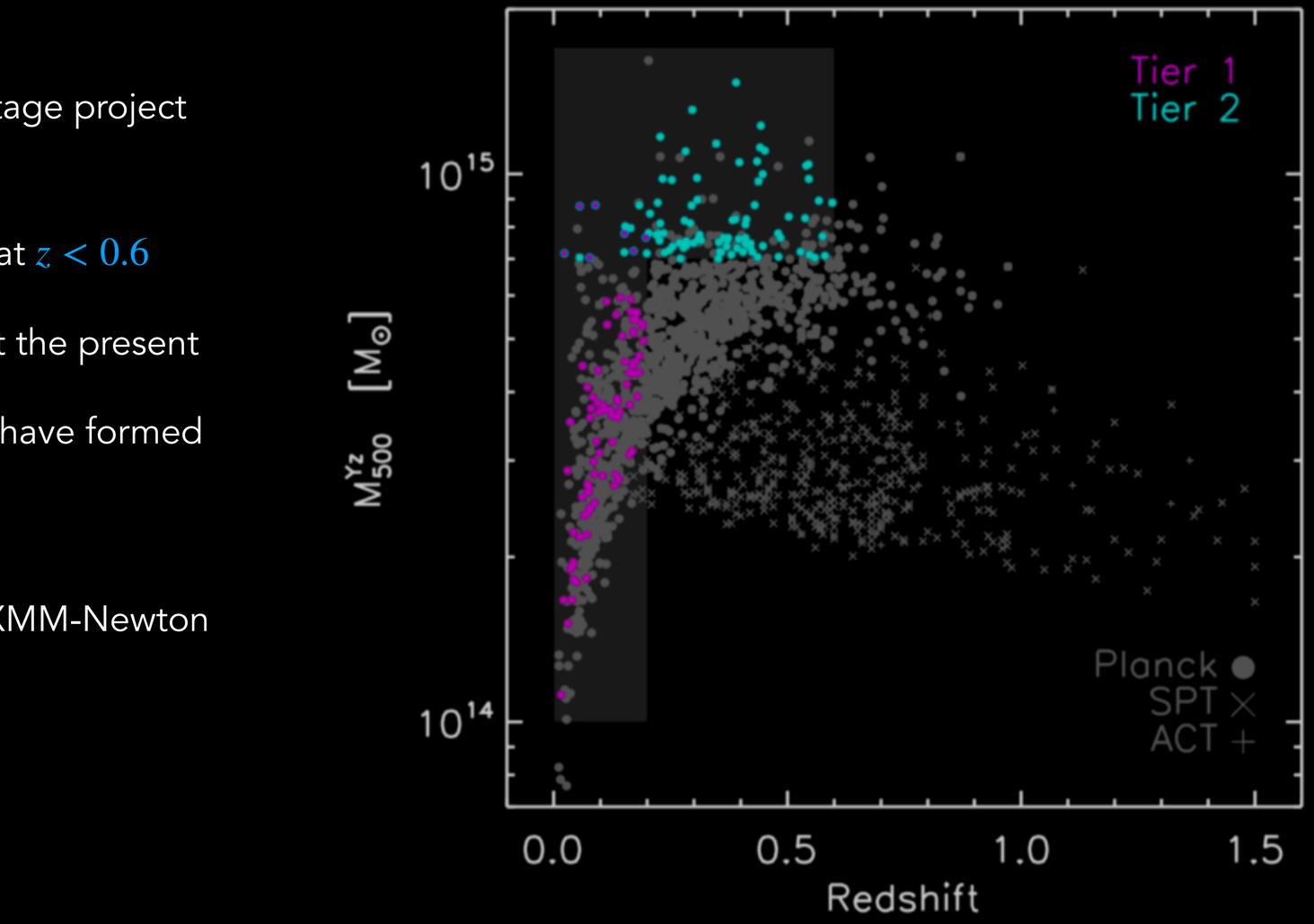
- 3 Ms XMM-Newton Multi-Year Heritage project

- 118 Planck SZE-selected objects at $z < 0.6$

  - **Tier 1**: the population of clusters at the present time
  - **Tier 2**: the most massive objects to have formed thus far

- Homogeneous X-ray coverage with XMM-Newton

Adapted from CHEX-MATE Collaboratio et al., 2021



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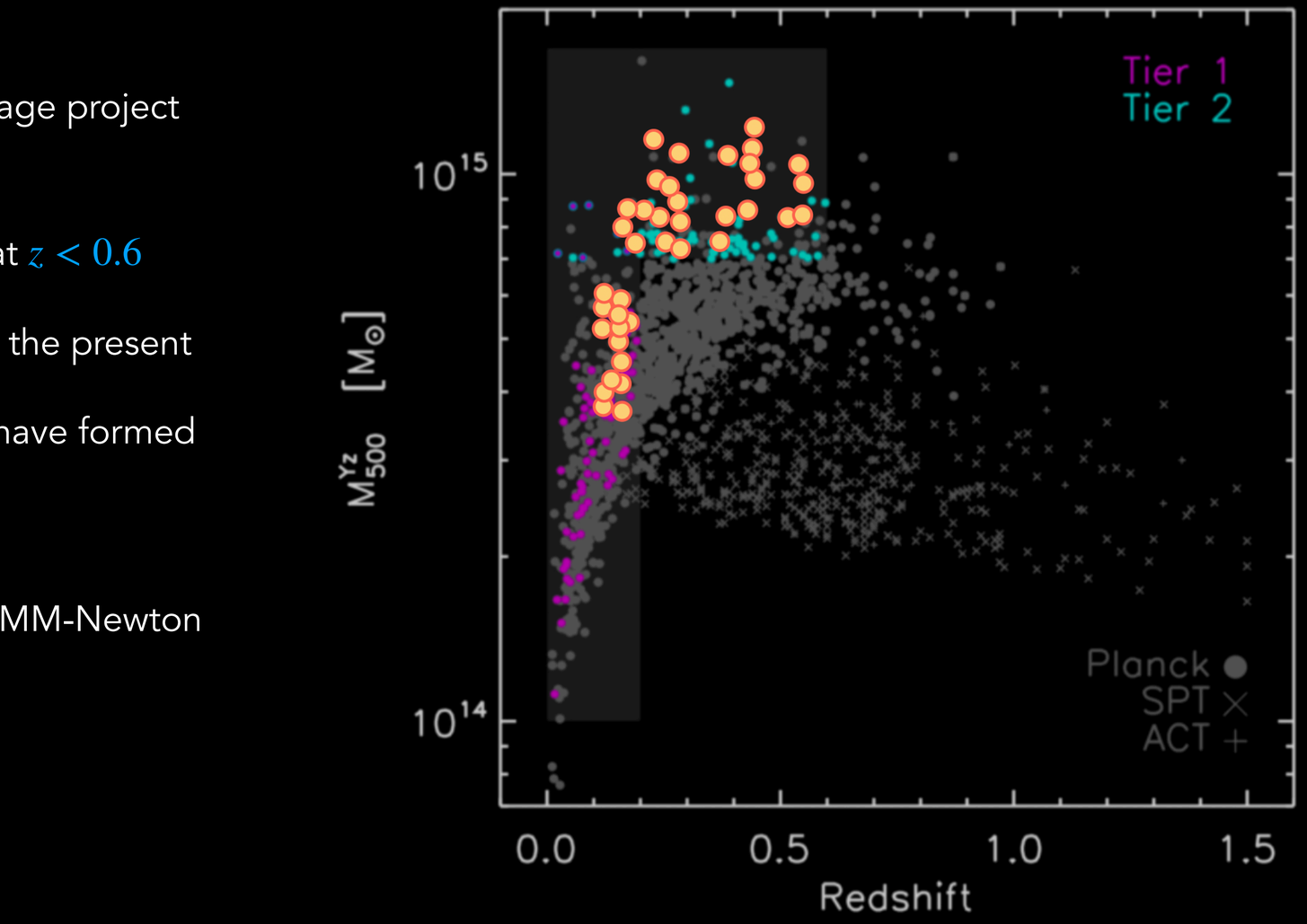

THE CLUSTER HERITAGE PROJECT WITH XMM-NEWTON

Mass Assembly and Thermodynamics at the Endpoint of Structure Formation

- What is the absolute cluster mass scale?
- What is the amount of non-thermal pressure support?
- What is $(1-b)$?
- What are the statistical properties of the 'true' population (selection effects)?
- Can we define a self-consistent evolutionary sequence?

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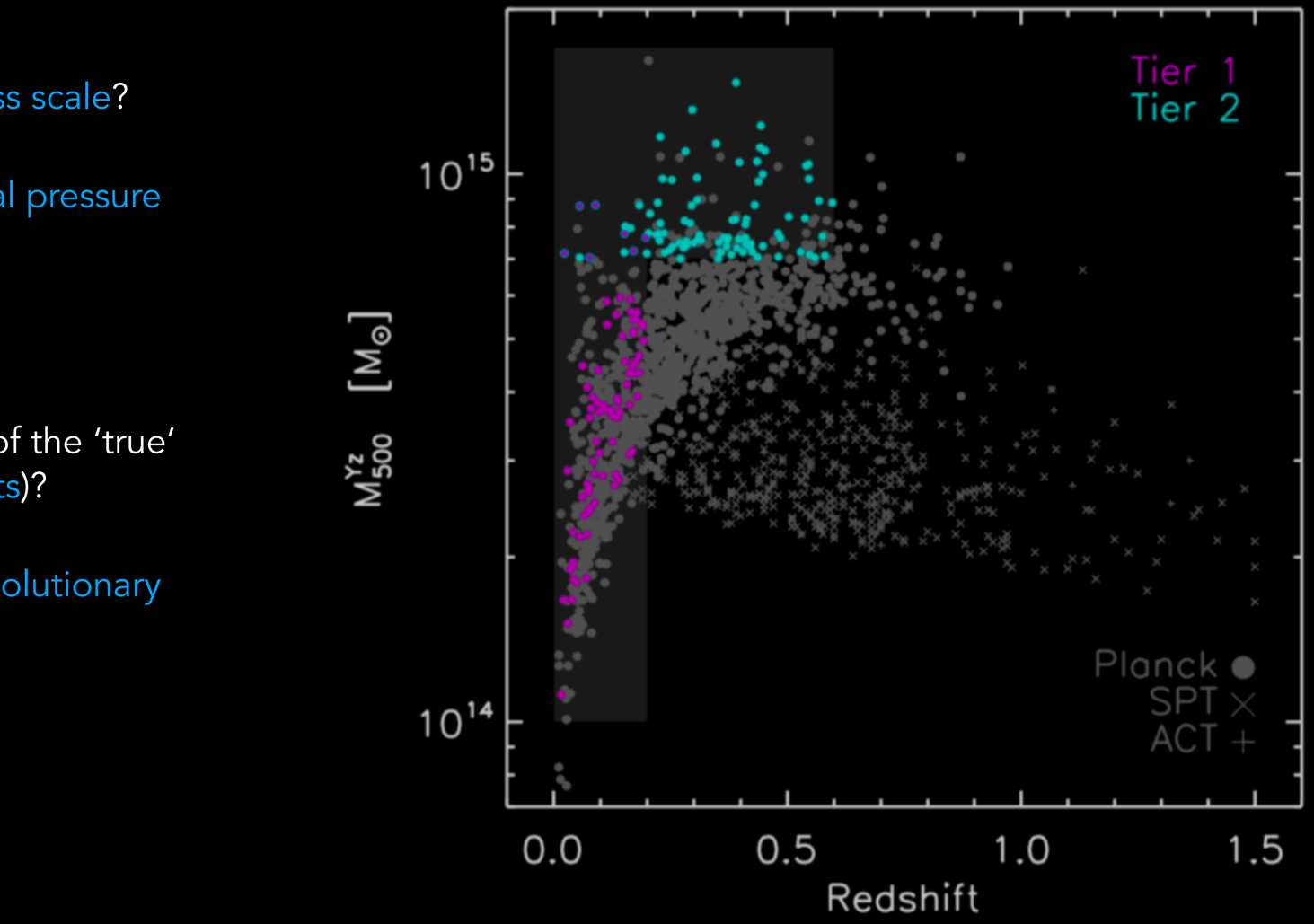

GOALS OF THE OUR ANALYSIS

- Compare X-ray and weak-lensing mass profiles for the sample
- Quantify the hydrostatic-to-lensing mass ratio M_{HE}/M_{WL} as a function of radius
- Investigate whether the mass ratio shows a radial dependences and/or correlations with cluster properties
- Compare the masses at characteristic overdensities R_{500}, R_{1000}, and R_{2500}
- Derive HE–WL scaling relations and constrain their slope, normalization, and intrinsic scatter
- Assess whether an apparent mass dependence of M_{HE}/M_{WL} could be affected by intrinsic scatter or biases
- Radial dependency of gas mass and total mass
- Asses the importance of using mean vs. critical overdensity in scaling relations
- Extend the mass comparison to stellar-mass estimates and investigate their relation with HE and WL masses (?)

AVAILABLE CLUSTERS (SO FAR)

Sample of 39 clusters (for now) based on Umetsu et al., 2026 AMALGAM subsample

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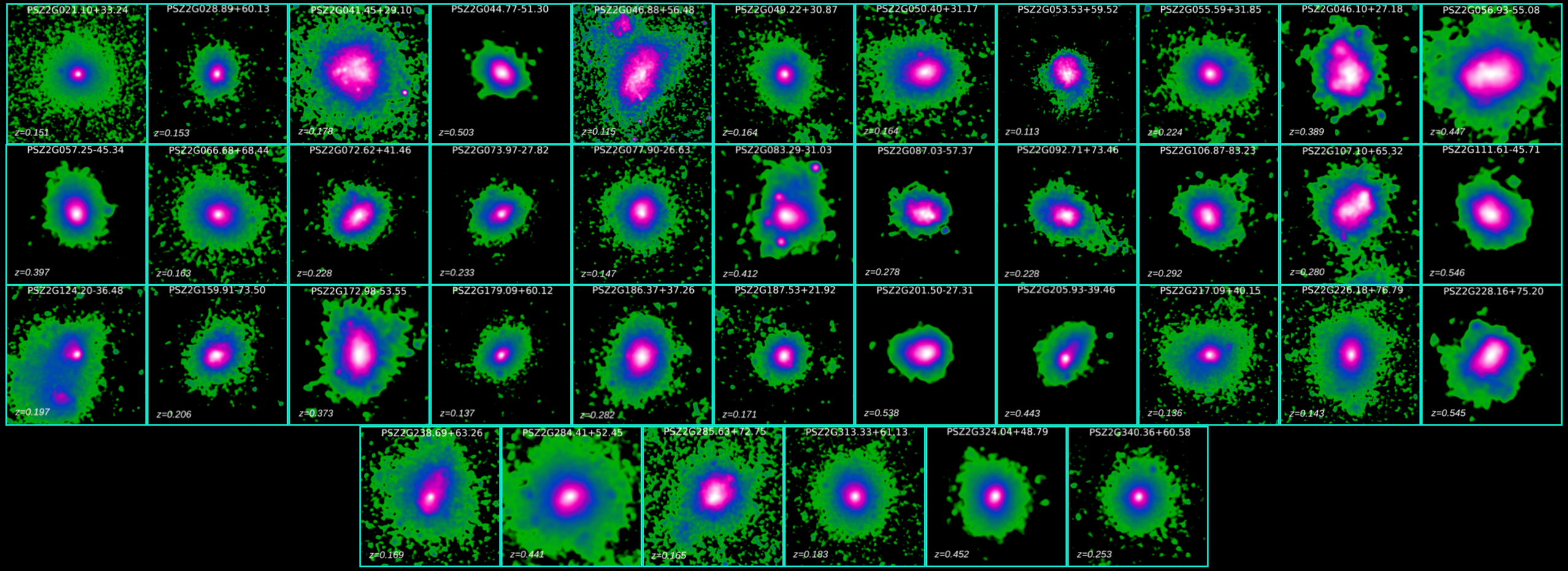

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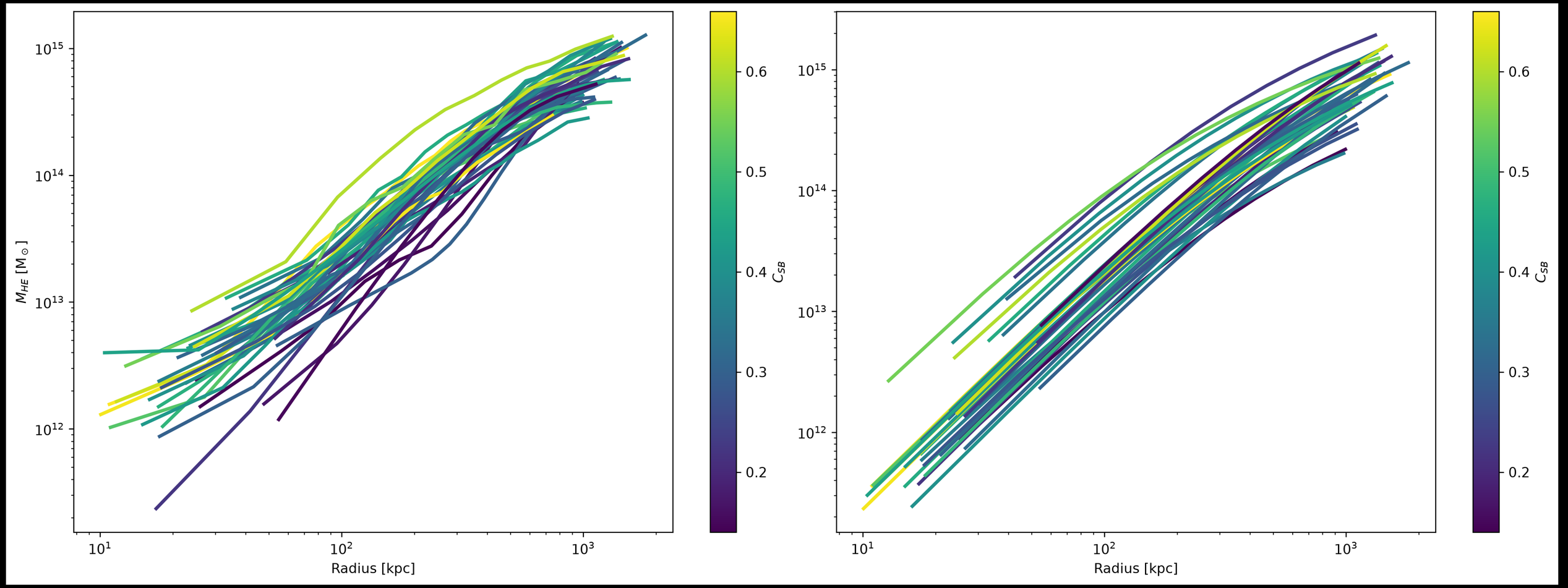

X-ray profiles (integrated)

WL profiles (reconstructed)

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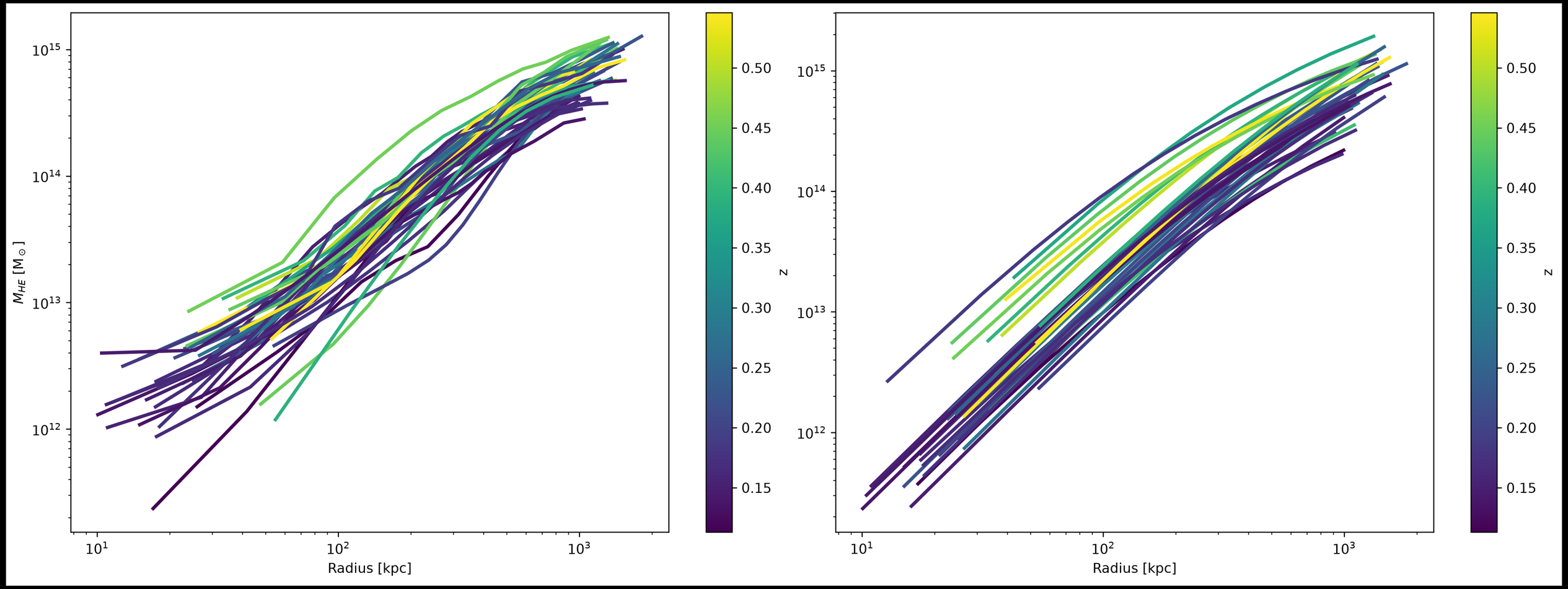

X-ray profiles (integrated)

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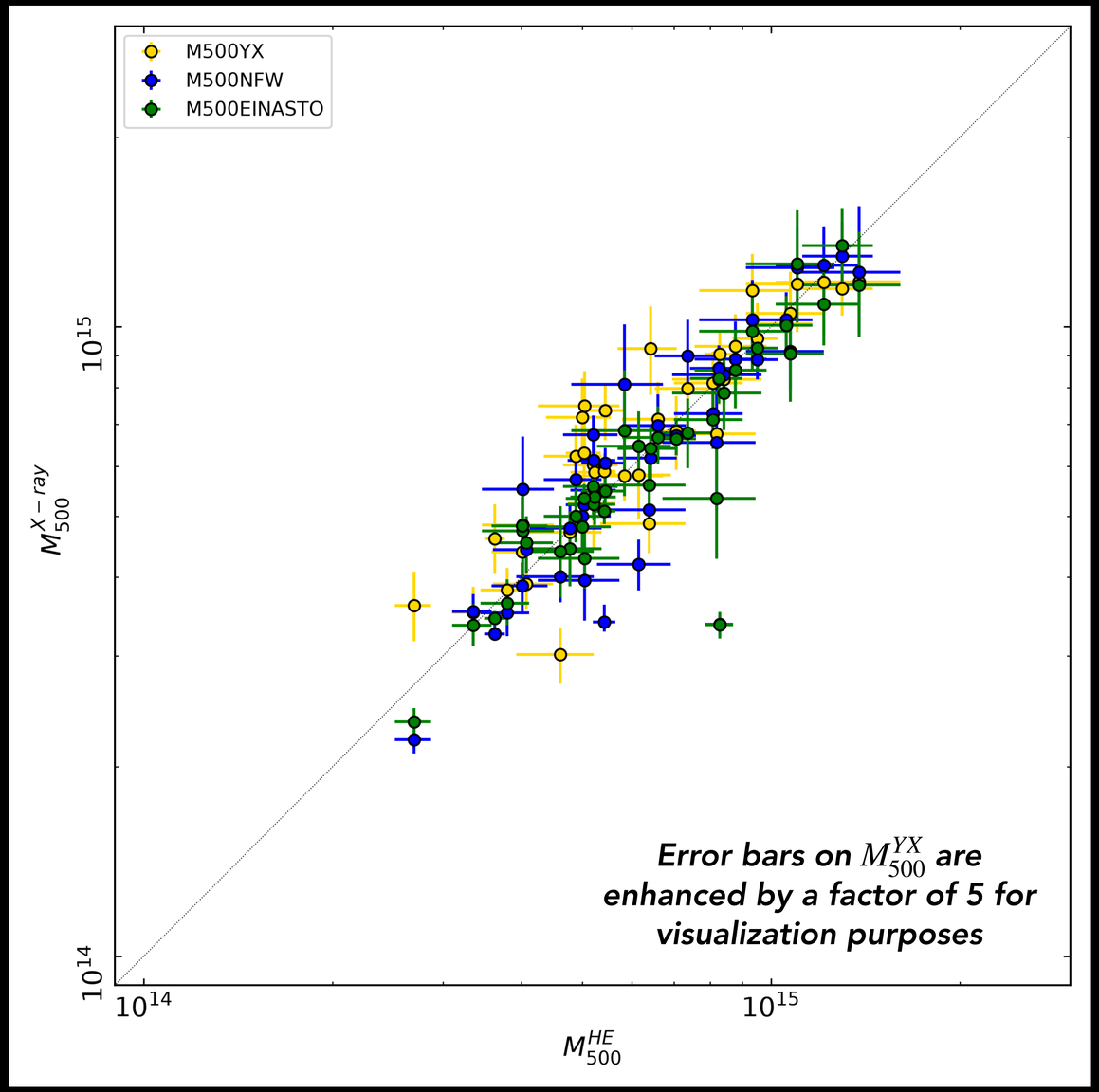
M_{INT}, M_{NFW} & $M_{EINASTO}$ vs M_{YX}



M_{500}^{INT} - Interpolated/extrapolated from total HE mass profile at R_{500} HE

M_{500}^{YX} - Obtained from Arnaud et al., 2010 M-Y_X relation

M_{500}^{NFW} - From NFW fit to HE total mass profile at $R > 0.15R_{500}$

$M_{500}^{EINASTO}$ - From Einasto 1965 fit to HE total mass profile at $R > 0.15R_{500}$

Agreement between X-ray masses

FROM R_{500} TO THE RADIAL MASS-RATIO PROFILES

At R_{500}, HE and WL masses are evaluated at their respective overdensity radii

In the radial analysis, M_{HE} and M_{WL} are compared at the same physical radius [kpc]
→ removing ambiguity from different X-ray and WL overdensity radii

- Does M_{HE}/M_{WL} vary systematically with radius?

- How much does the mass ratio vary among individual clusters?

ANALYSIS PIPELINE

Randomized mass profiles →

X-Ray	***WL***
Mass-profile chains	M_{200} + c_{200} *chains*

↓

Build mass profiles

X-ray: interpolation/extrapolation in log r–log M

WL: NFW profiles

Common physical grid

190–1200 kpc

Posterior sampling

N independent X-ray × WL realizations

↓

Mass ratio in log-space

$ln(M_{HE}/M_{WL})$

+ statistics

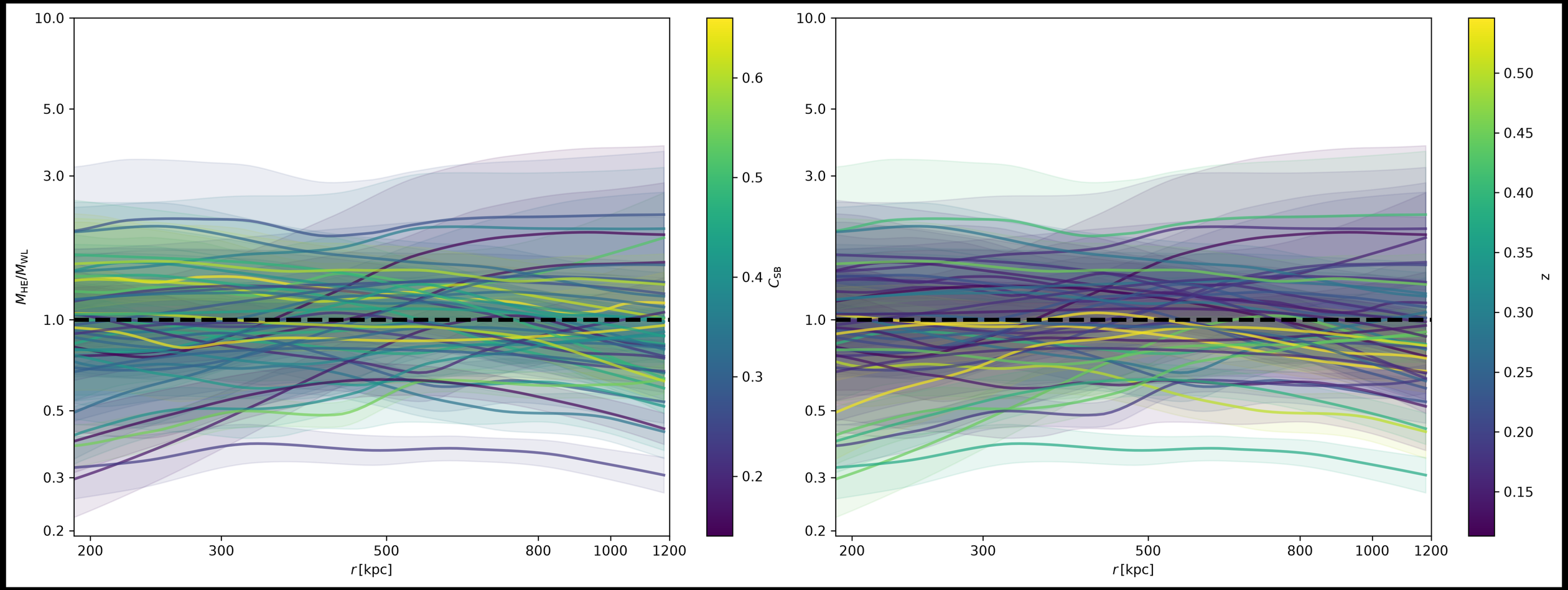
← Physicality checks X-ray:
1 - Finite profile
2 - Positive mass
3 - $M_{r_i+1} > M_{r_i}$
4 - $\Delta(< r) = 3M(< r)/4\pi\rho_c(z)r^3$ finite, positive and decreasing with radius

→ To limit extrapolated points to $\leq 10\,\%$ at both the inner and outer radial boundaries

$\mathrm{N} = \min(\mathrm{N_X}, \mathrm{N_{WL}})$, no replacement →

MASS RATIO: LET'S LOOK AT THE MORPHOLOGY

M_{HE}/M_{WL} from X-ray and WL chains projected onto a grid of physical radii [190-1200 kpc]



- Higher C_{SB} → mass ratios more concentrated around unity
- Higher redshift → some mass ratios tend to be concentrated around unity or fall below unity

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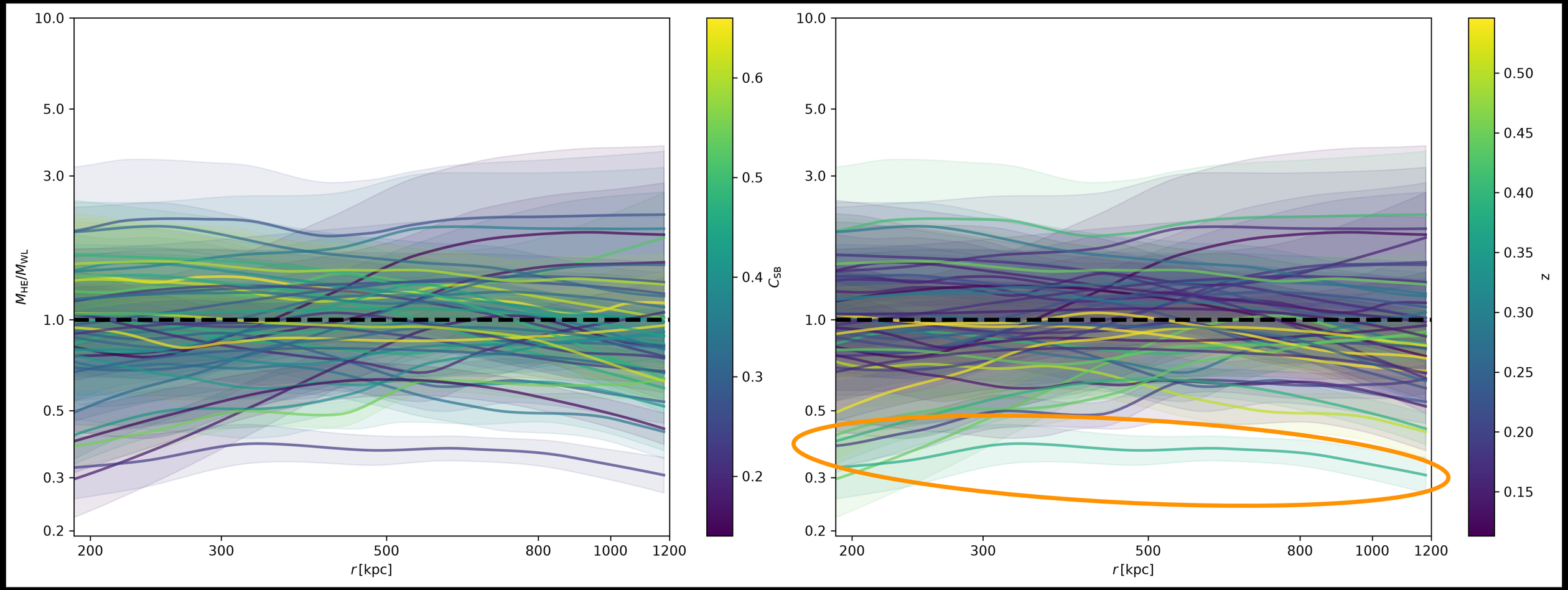

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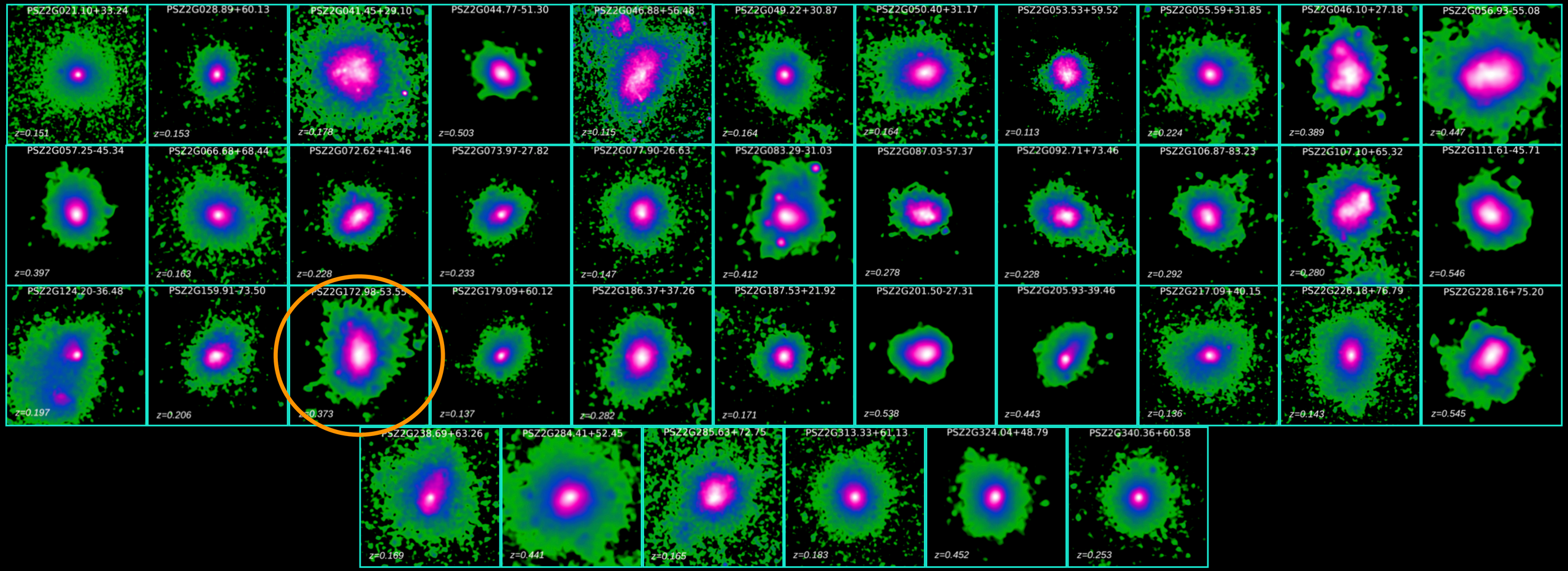
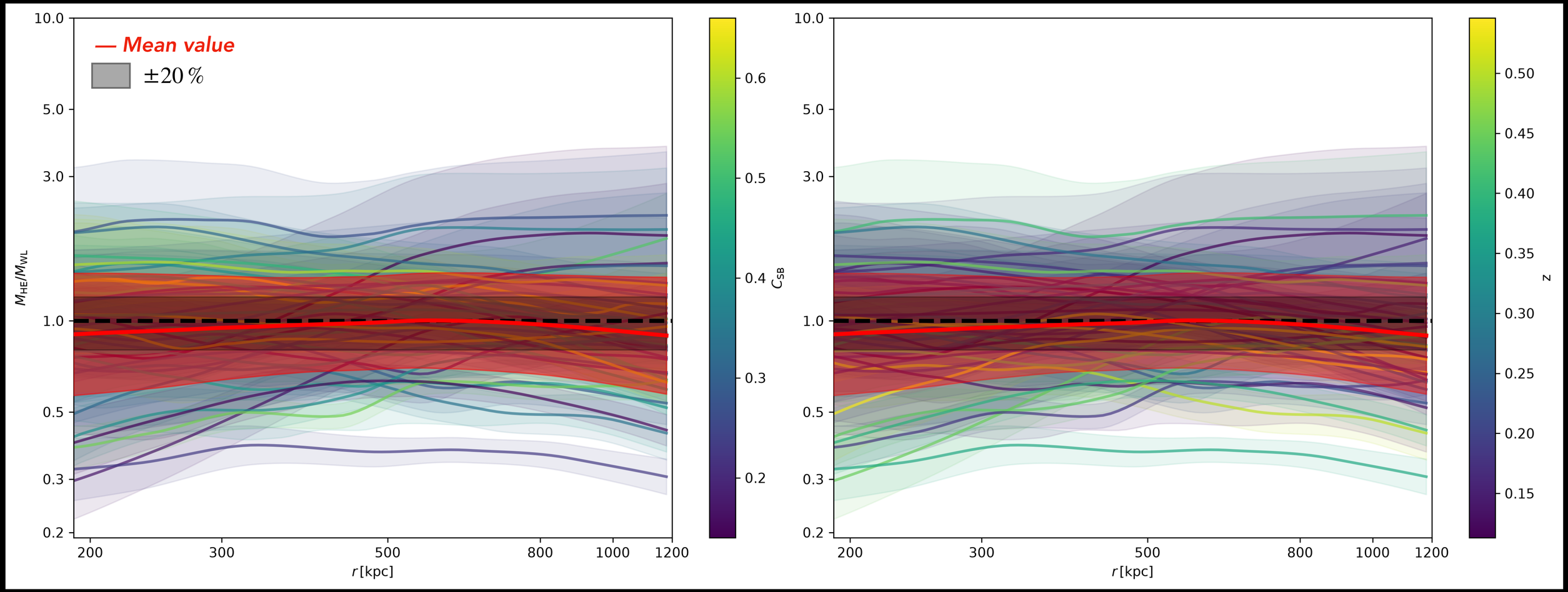


MASS RATIO: MEAN vs MEDIAN VALUE

M_{HE}/M_{WL} from X-ray and WL chains projected onto a grid of physical radii [190-2000 kpc]



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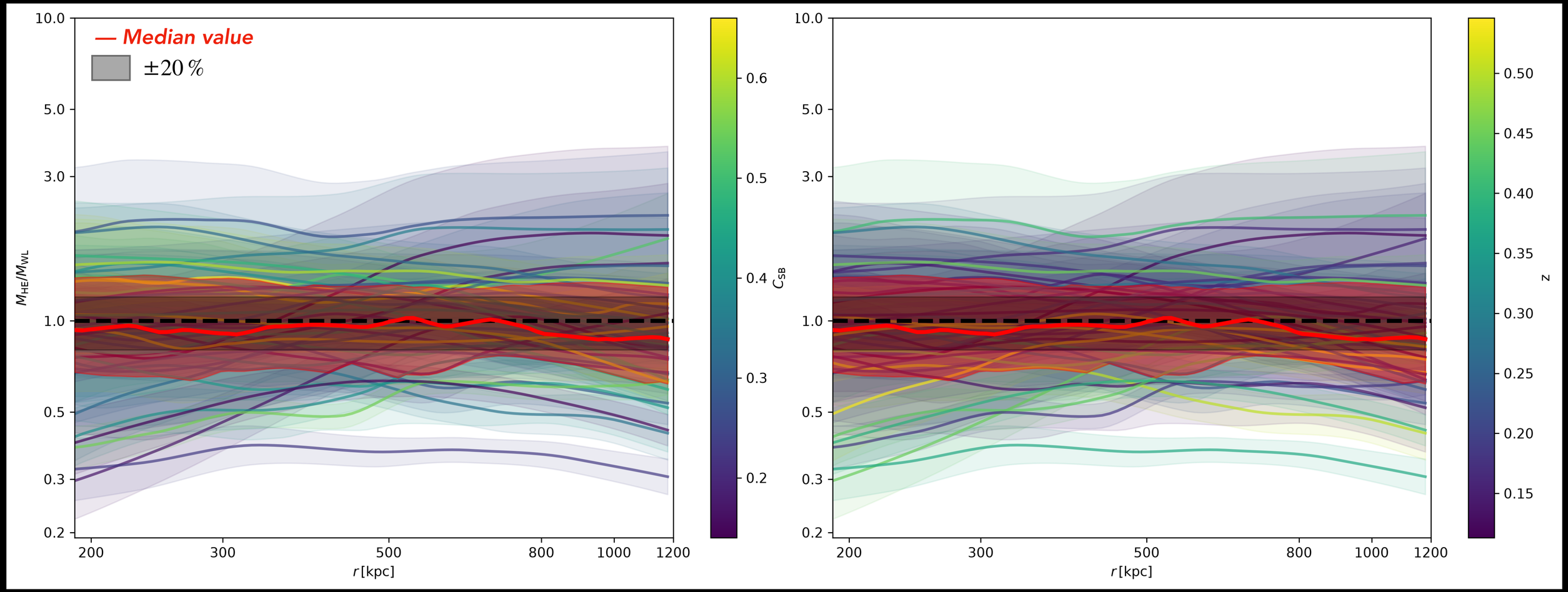

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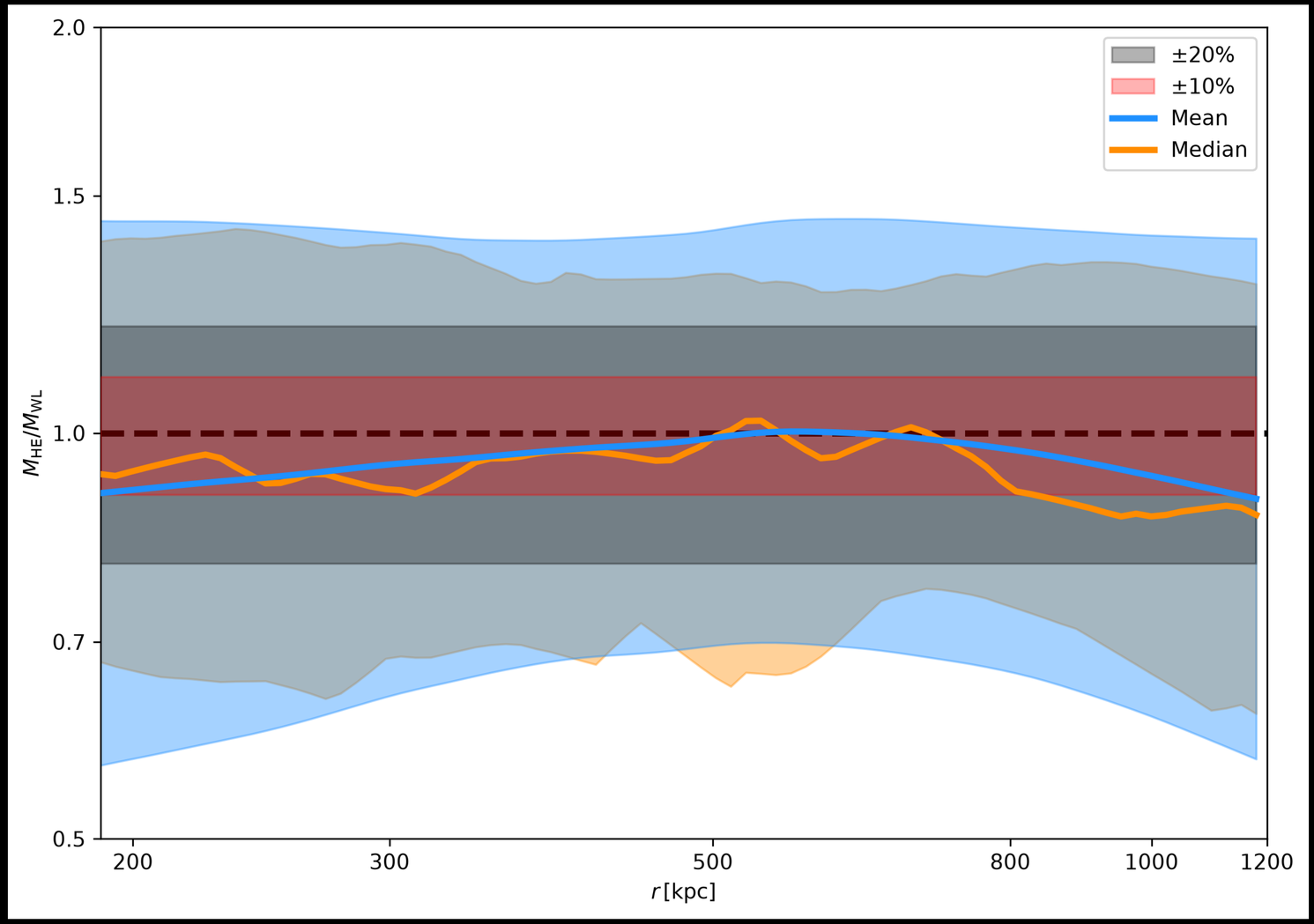

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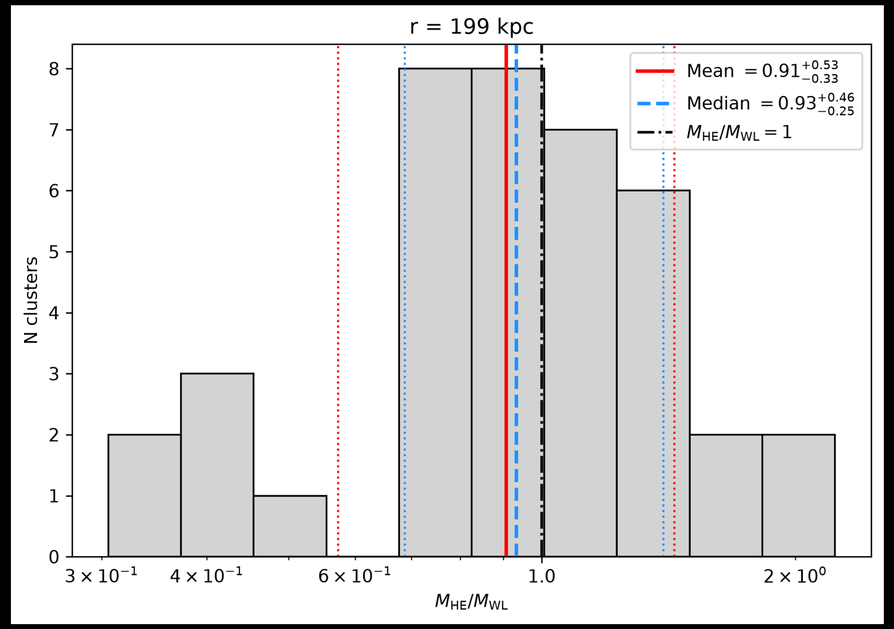
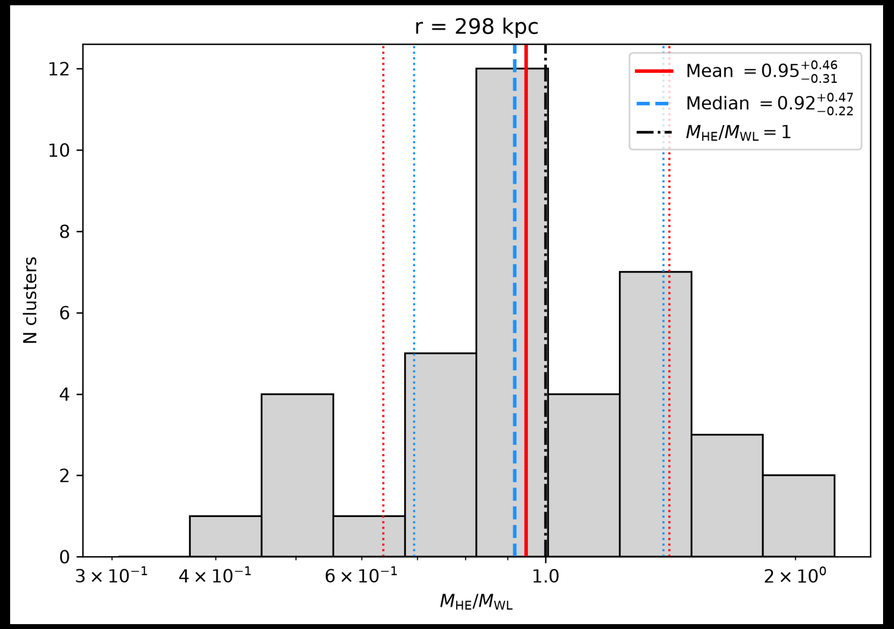
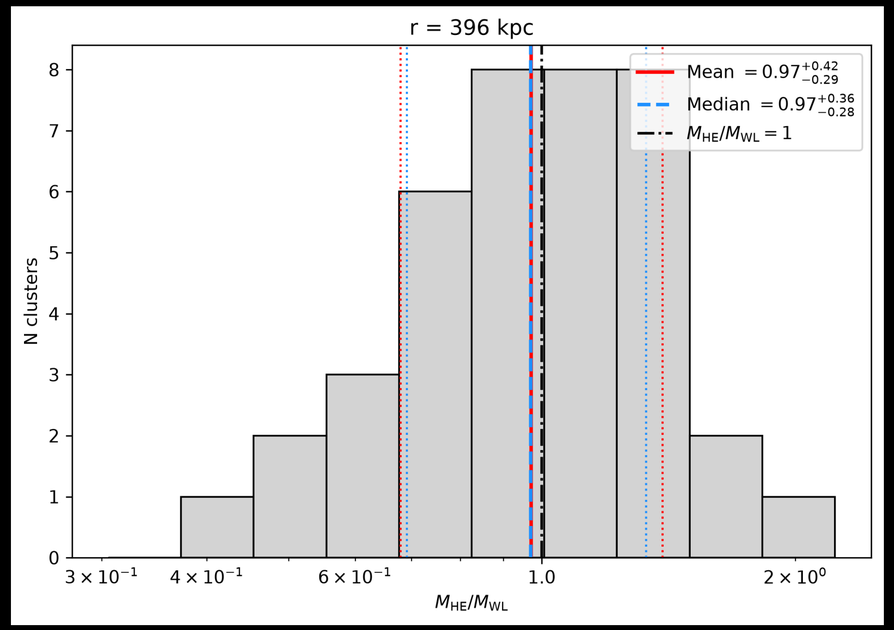
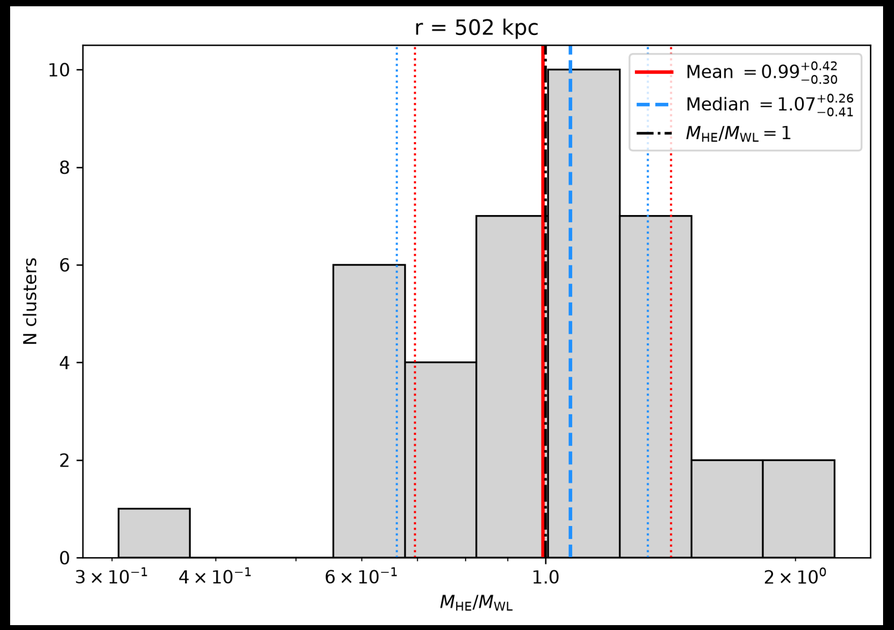
MASS RATIO: MEAN vs MEDIAN VALUE PER RADIAL BIN









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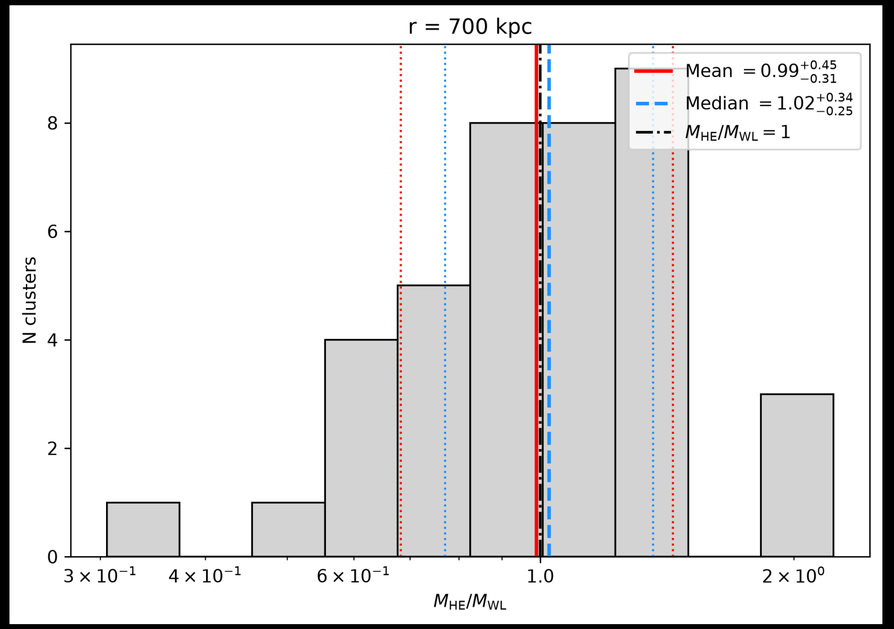
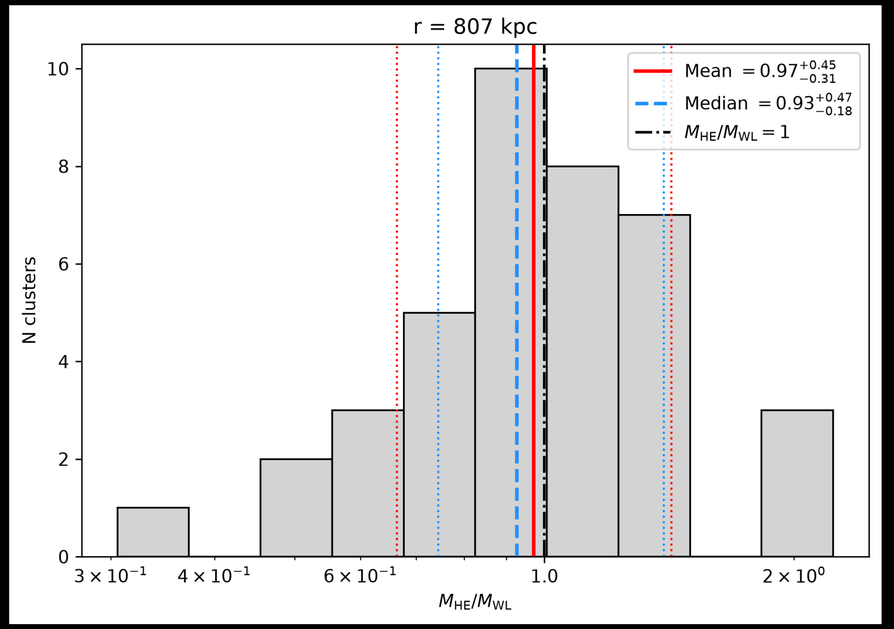
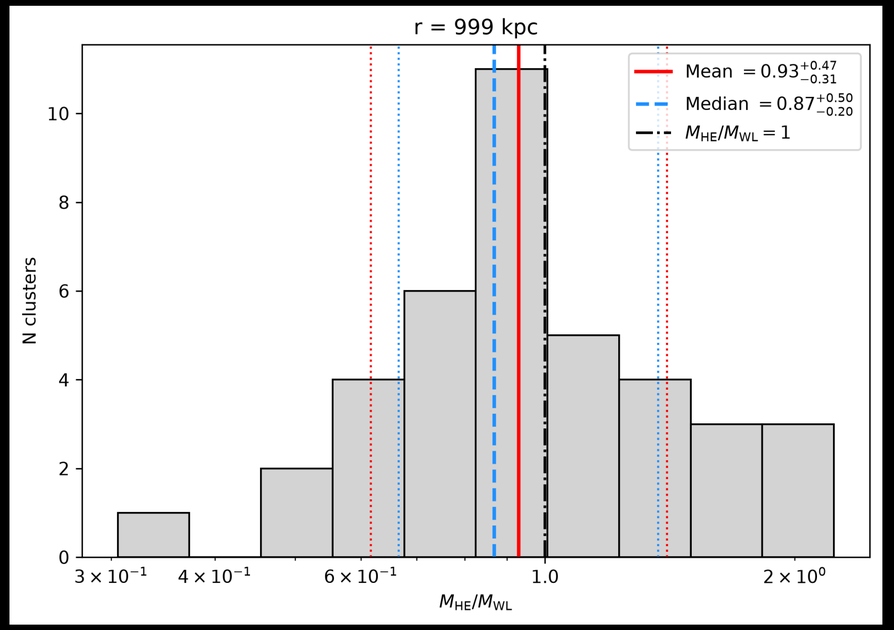
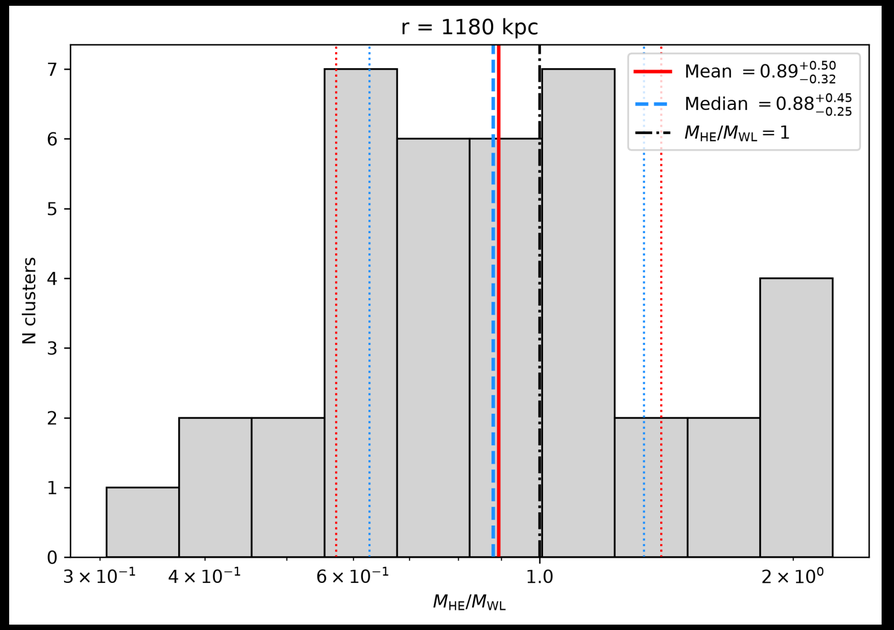
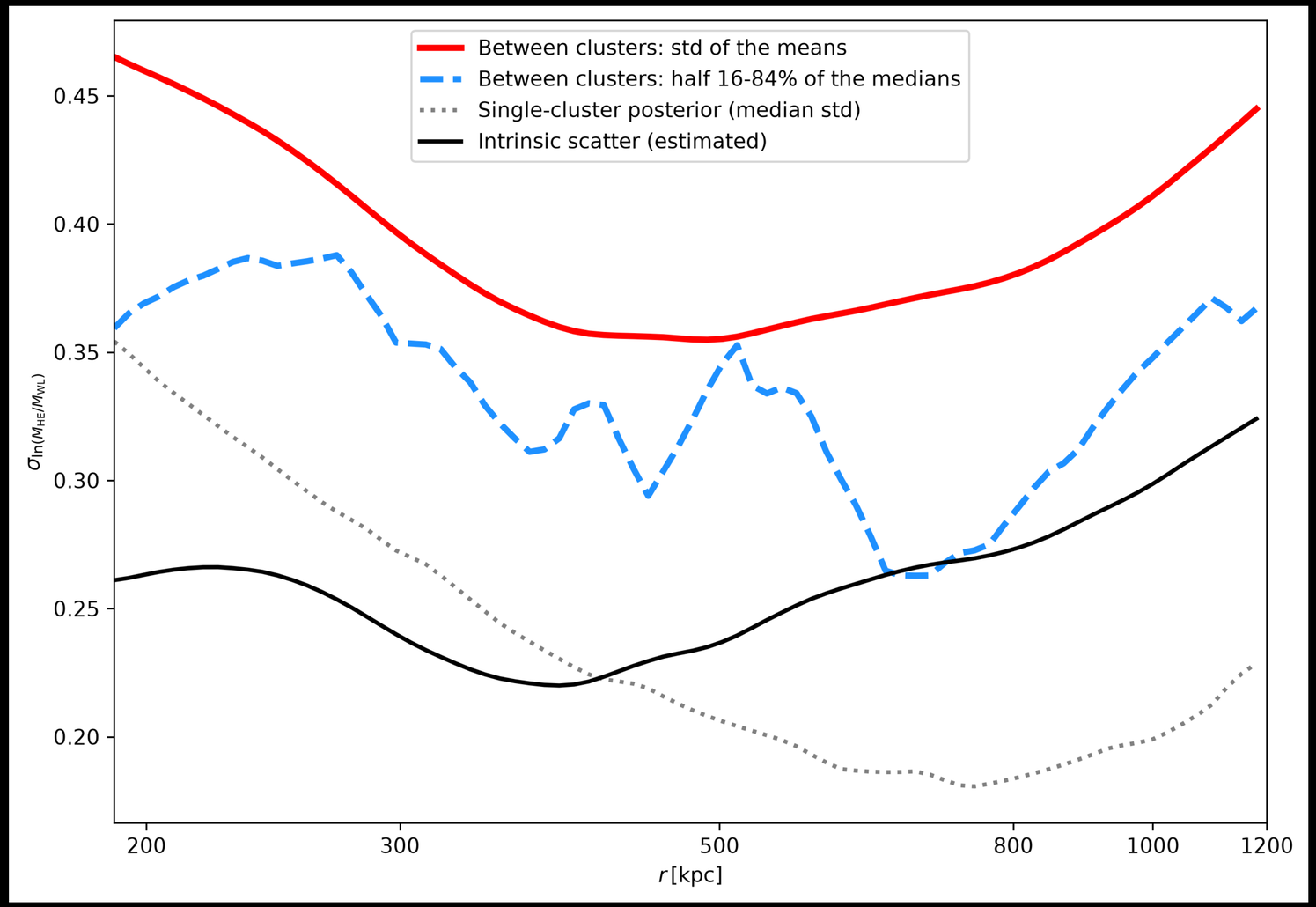








MASS RATIO DISPERSION: HOW DIFFERENT ARE THESE CLUSTERS?



Red curve: standard deviation of cluster mean values of mass ratio

How dispersed are the clusters we observe?

Blue curve: half the 16th and 84th percentile range of the cluster median values

Alternative estimate of the observed between-cluster scatter

Grey curve: median posterior standard deviation of individual clusters

How uncertain are the measurements of individual clusters, typically?

Black curve: estimated intrinsic scatter

$$\sigma_{intr} = \sqrt{\sigma_{obs}^2 - \sigma_{measur}^2}$$

How much scatter remains after accounting for measurement uncertainties?

NEXT STEPS

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⏳ Investigate whether the mass ratio shows a radial dependences and/or correlations with cluster properties

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