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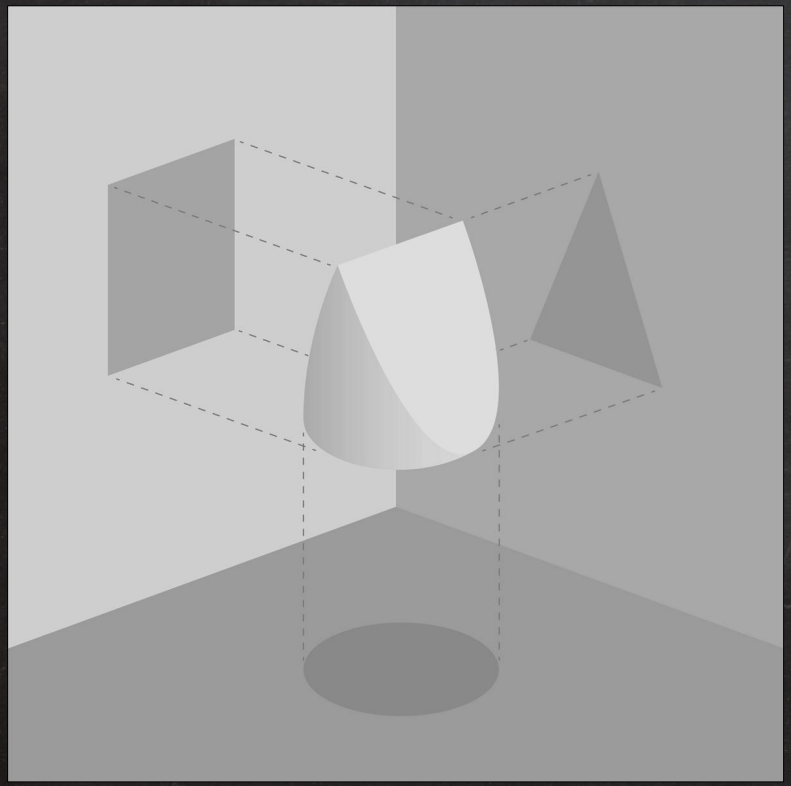


CHEX-MATE: Factors influencing density profile reconstruction in galaxy clusters

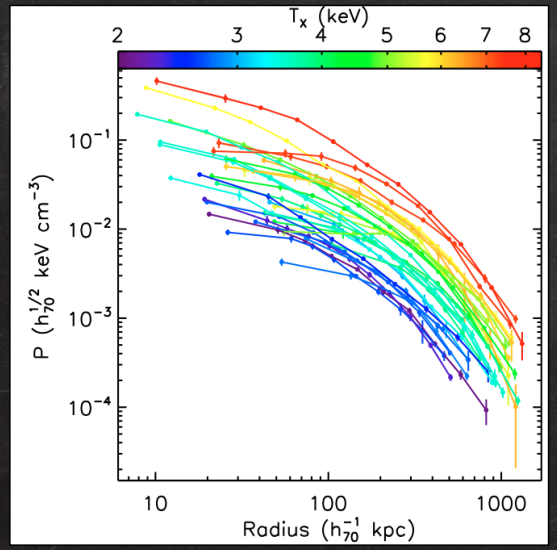
Iacopo Bartalucci, G.W. Pratt, E. Rasia, R. Duffy
and CHEXMATE collaborators

mm Universe 2025

1. Introduction: n_e profiles

Galaxy cluster density profiles are a key ingredient:

Astrophysics:
basic ingredient of thermodynamic profiles and integrated quantities

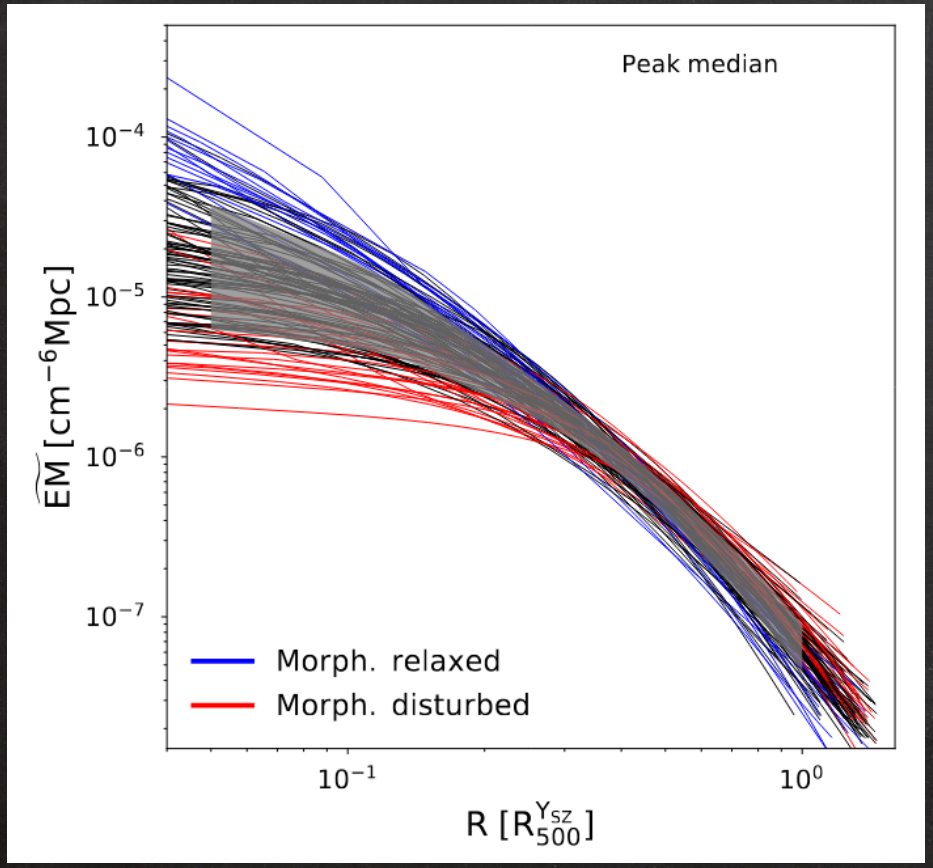


Arnaud et al. 2010

Cosmology:
Ingredient to derive the hydrostatic mass

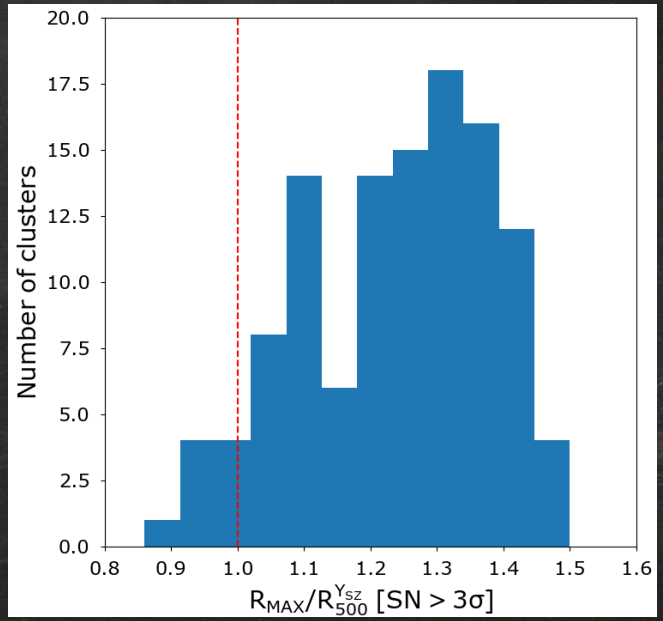
$$M(\leq R) = -\frac{kT(r)\,r}{G\mu m_p}\left[\frac{\mathrm{d}\ln n_e(r)}{\mathrm{d}\ln r} + \frac{\mathrm{d}\ln T(r)}{\mathrm{d}\ln r}\right]$$

1. Introduction: CHEX-MATE n_e profiles



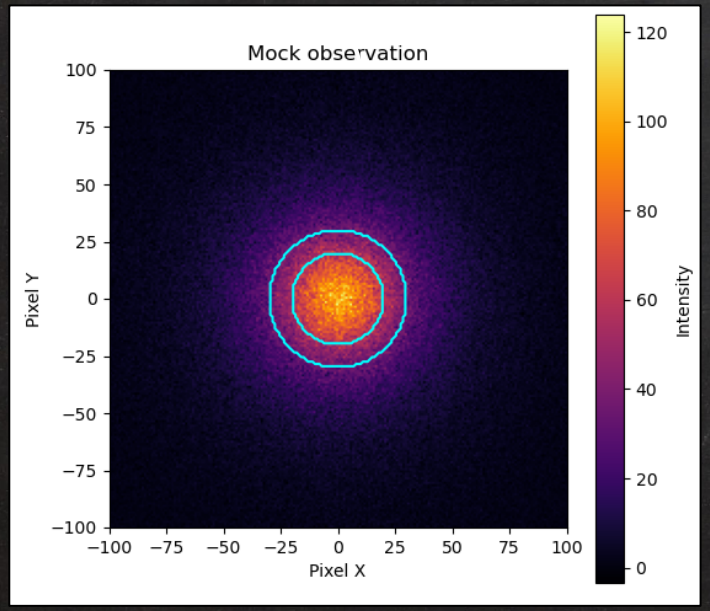
Bartalucci et al 2023

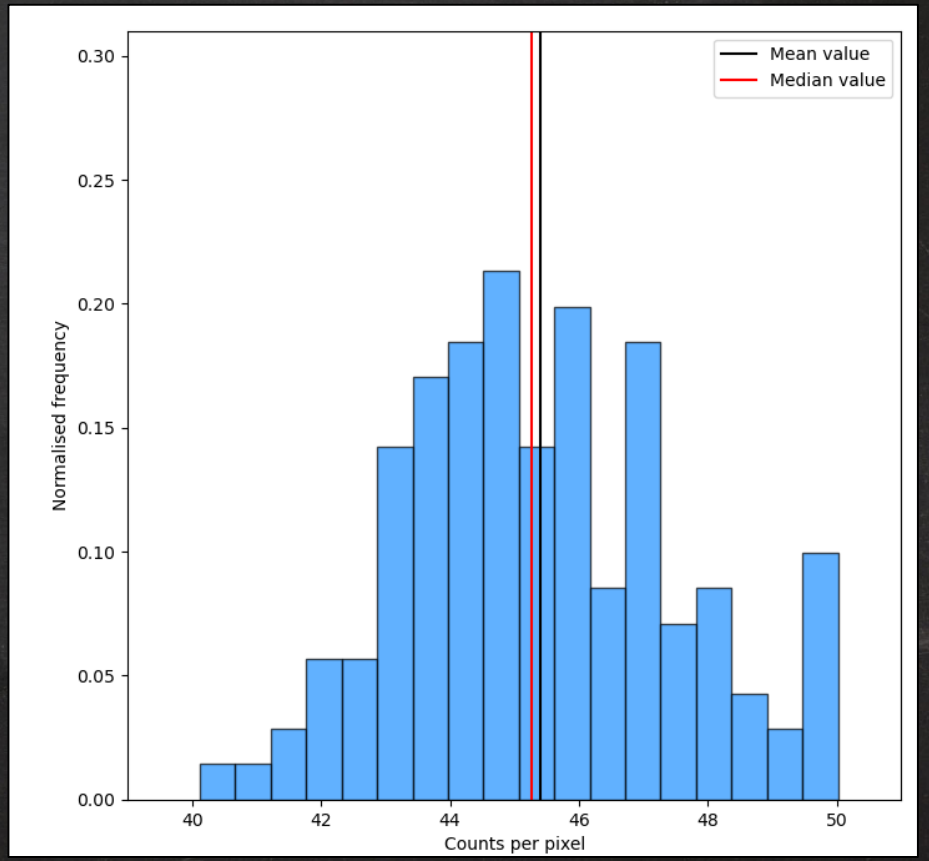
CHEXMATE n_e profiles:
high statistical quality & homogeneus for a large minimally biased sample



1. Introduction: some nomenclature

mean vs median profiles
(Zhuravleva et al. 2013, Eckert et al. 2015)





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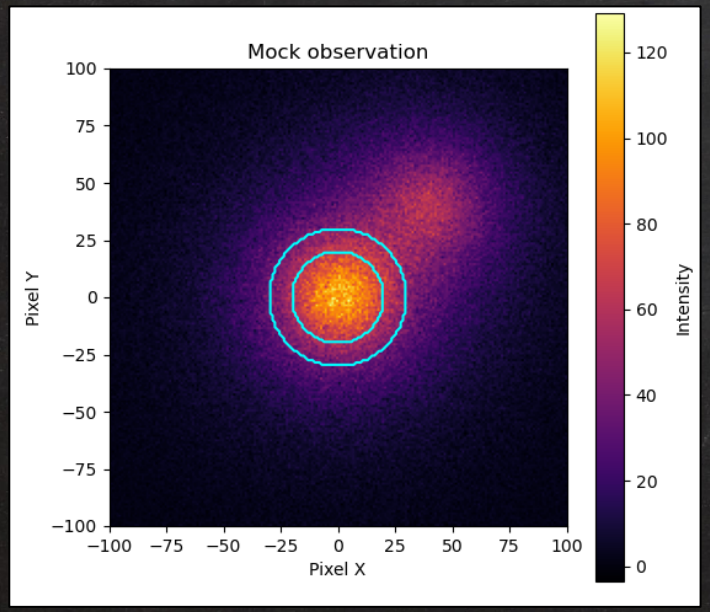
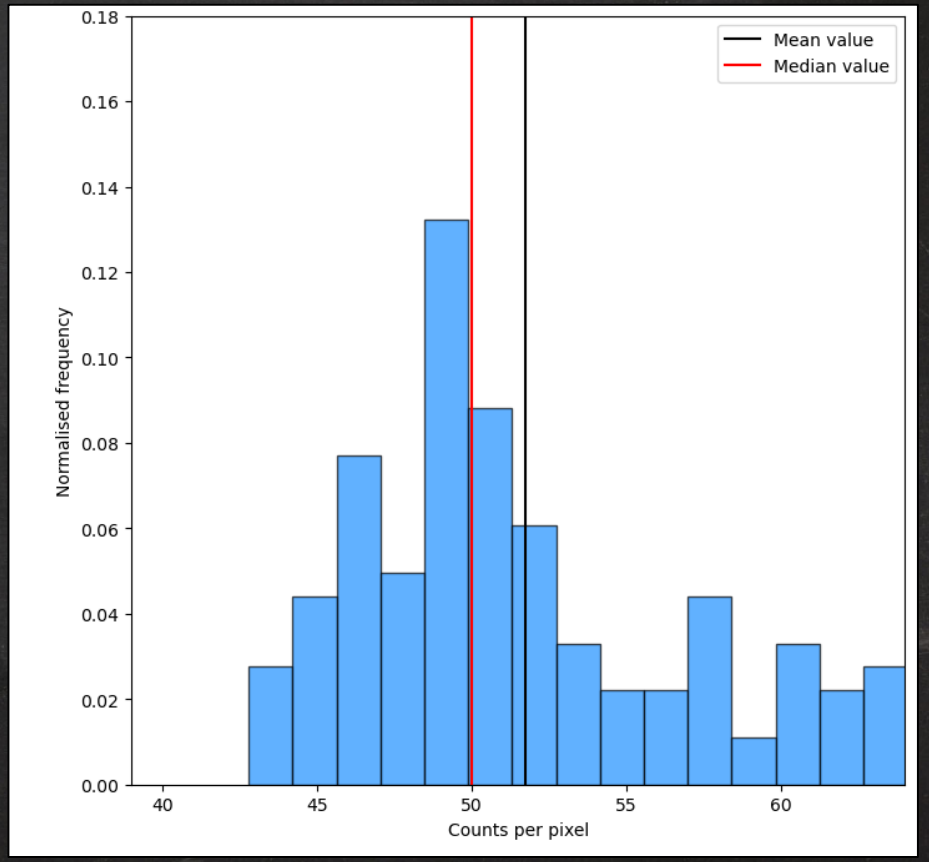
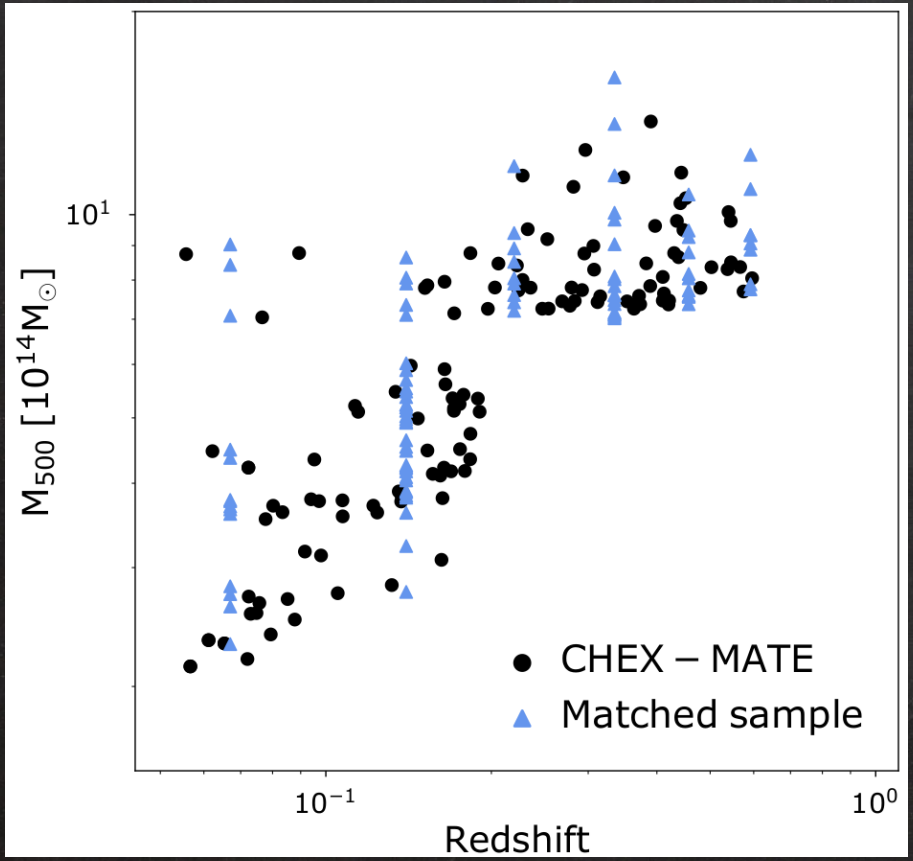




2.Sample: 93 clusters



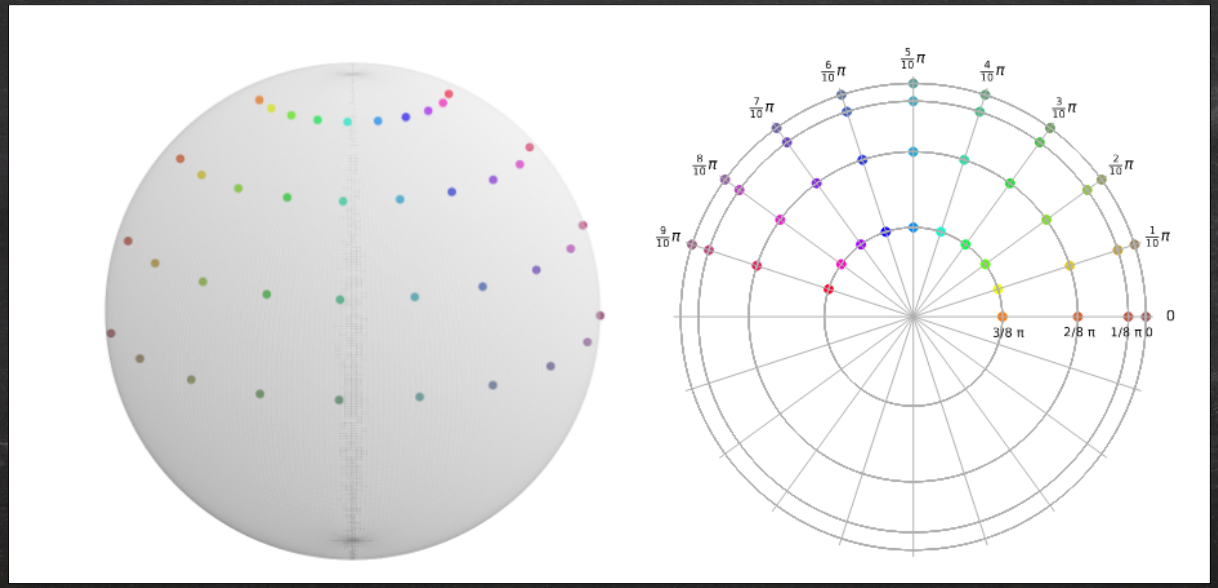
We used the “Matched sample” of Bartalucci et al. 2024 drawn from the 300 cosmological simulation (Cui et al. 2018)
(Elena’s talk)

Same mass (folding the 20% bias!), redshift distribution and matching the morphology

2.Sample: 40 lines of sight

For each simulated cluster we have access to the 3D data and its emission has been projected along 40 lines of sight (I.e 40 emission measure map)!

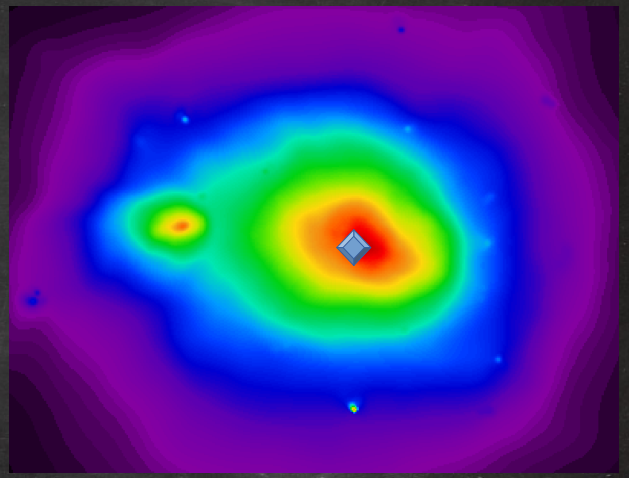
Unique dataset to investigate our deprojection capability



Veronesi et al. 2024

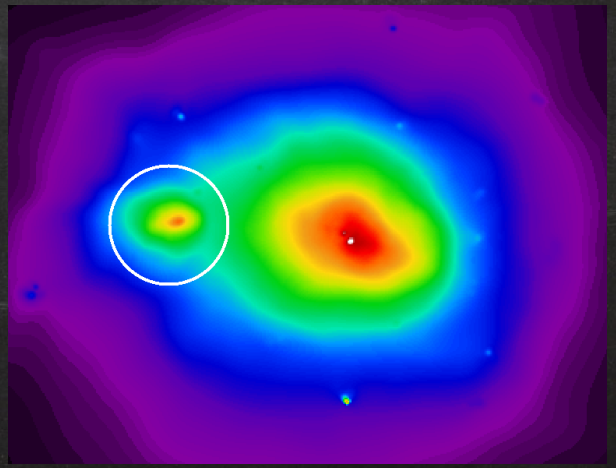
3. Methodology: stick to CHEXMATE

We identify the X-ray peak on each map



We stick as close as possible to real X-ray analysis

We exclude substructures by eye (for a limited smaple)



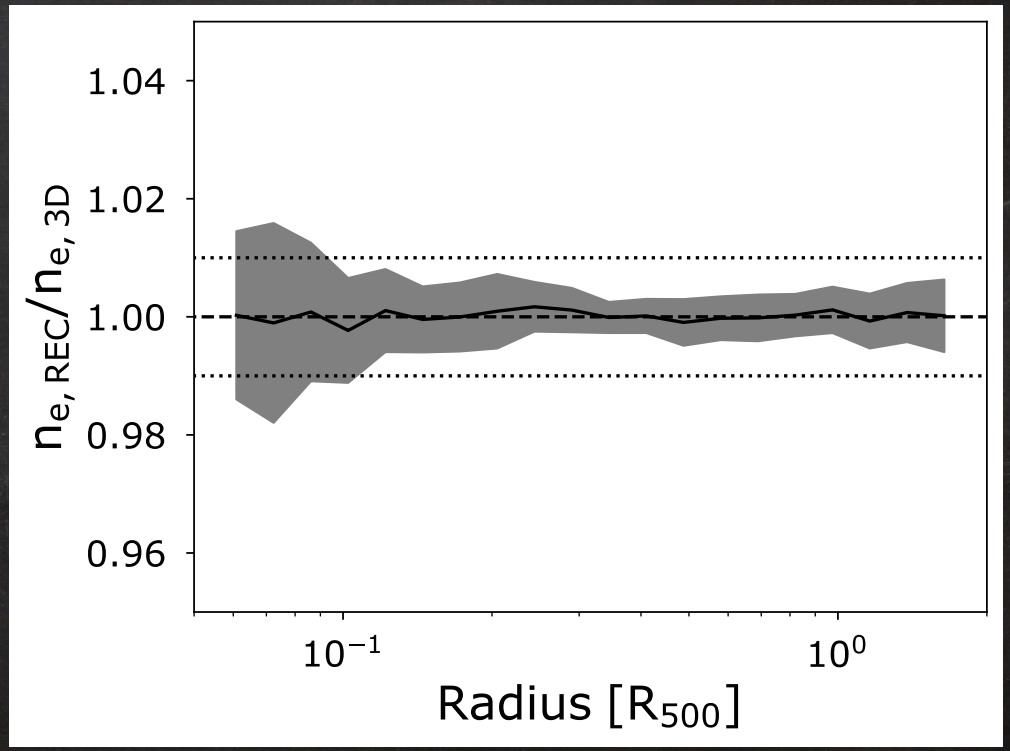
3. Methodology: first test

The density profiles are obtained via:
- non-parametric deprojection with regularization (Croston et al 2006, 2009)
- parametric deproection (Vikhlinin et al 2006)

within [0.05-1.3] R_{500}

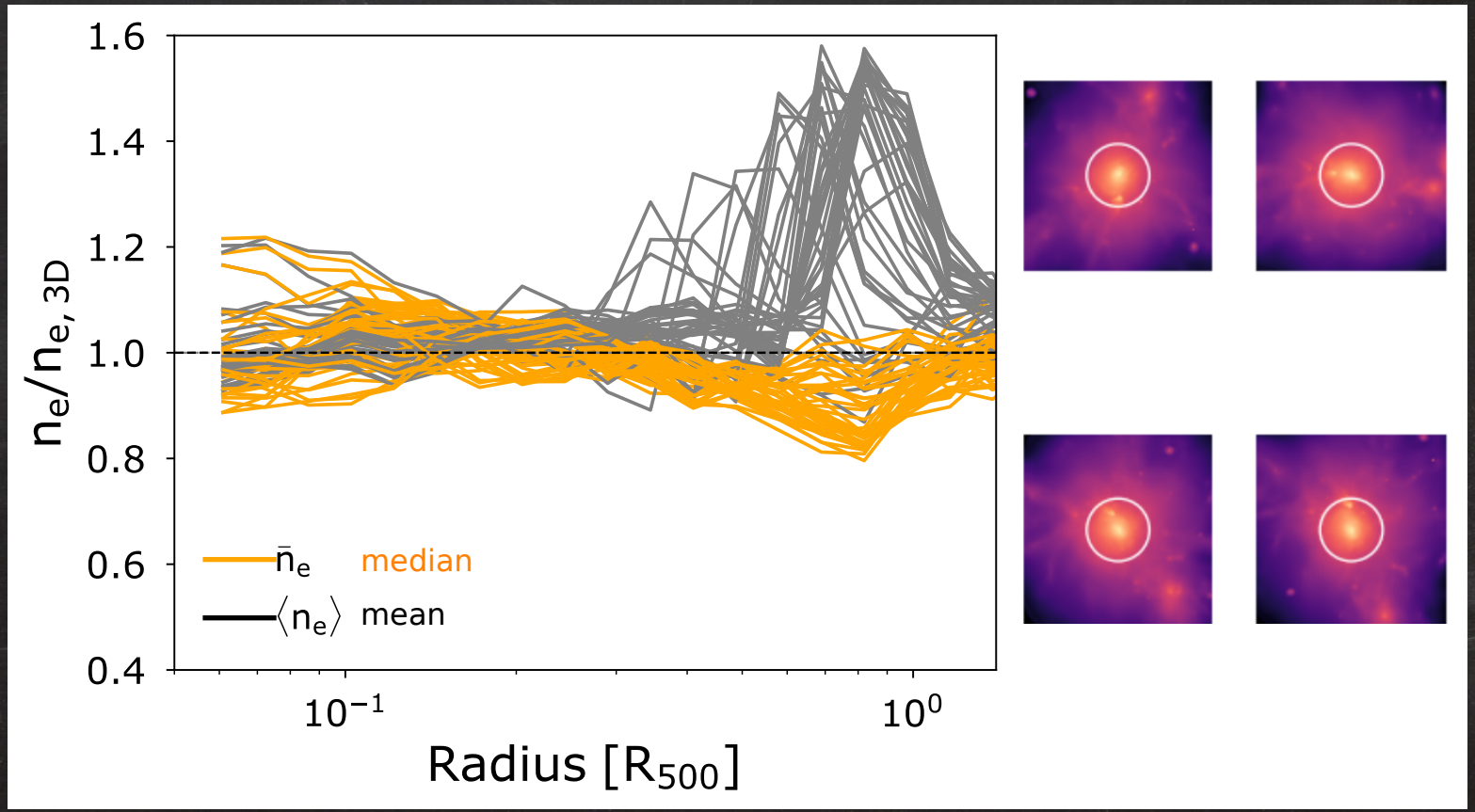
First test: projecting the 3D profile and NP deprojection

Same codes we use in the CHEXMATE pipeline



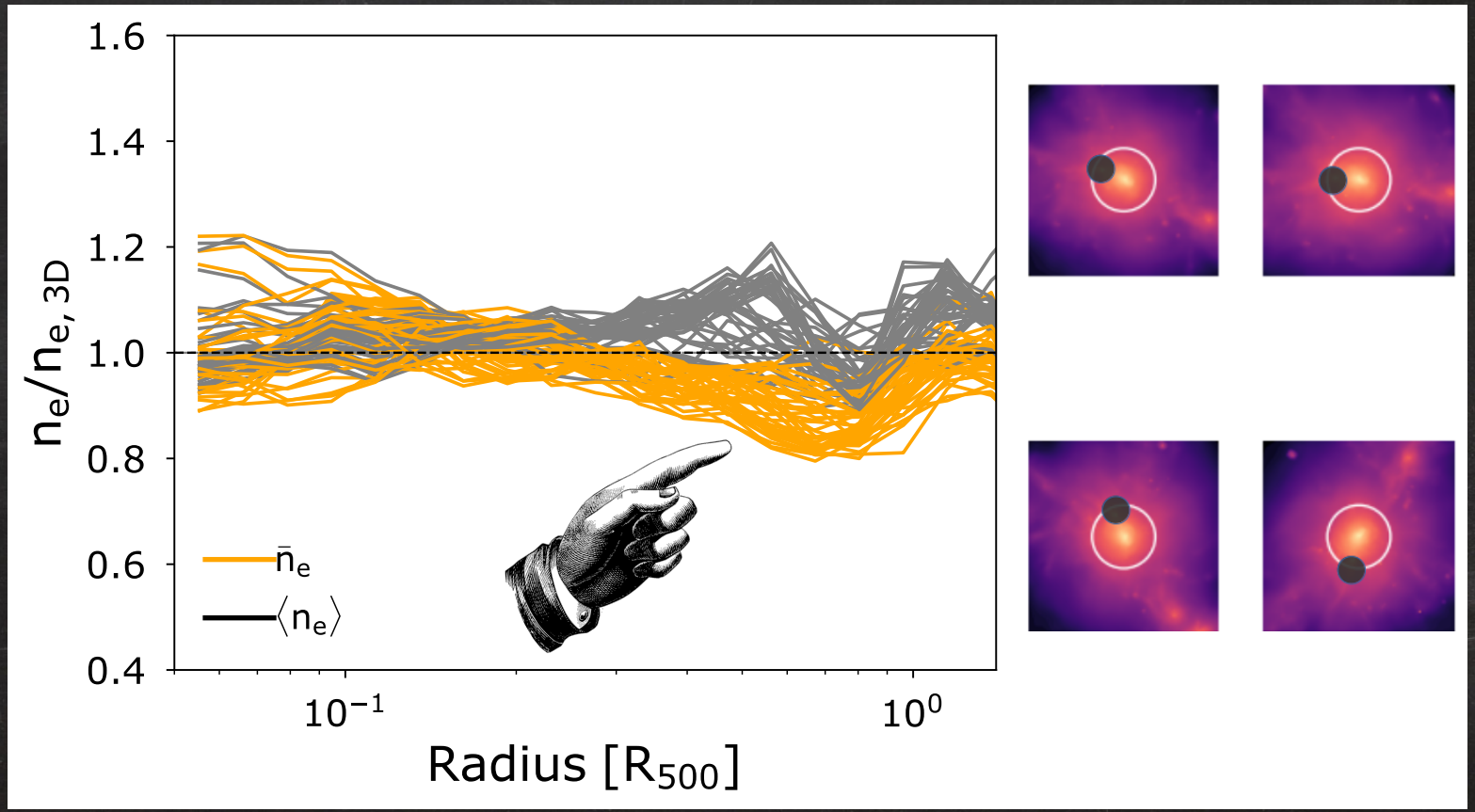
3. Results 40 lines – 1 cluster

The most average cluster (M_{500}, z, χ)



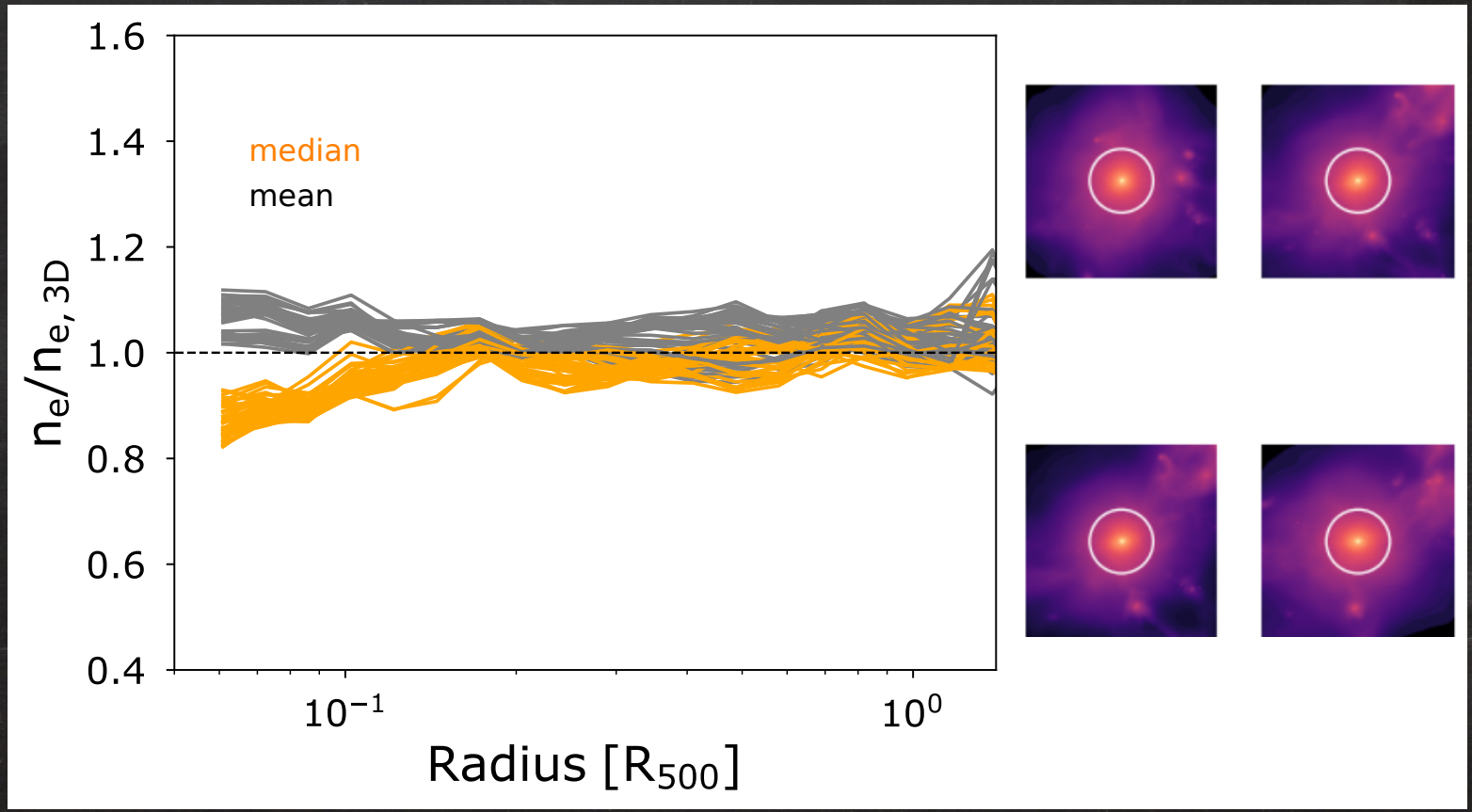
3. Results 40 lines – 1 cluster

Masking the substructure as in realistic analysis



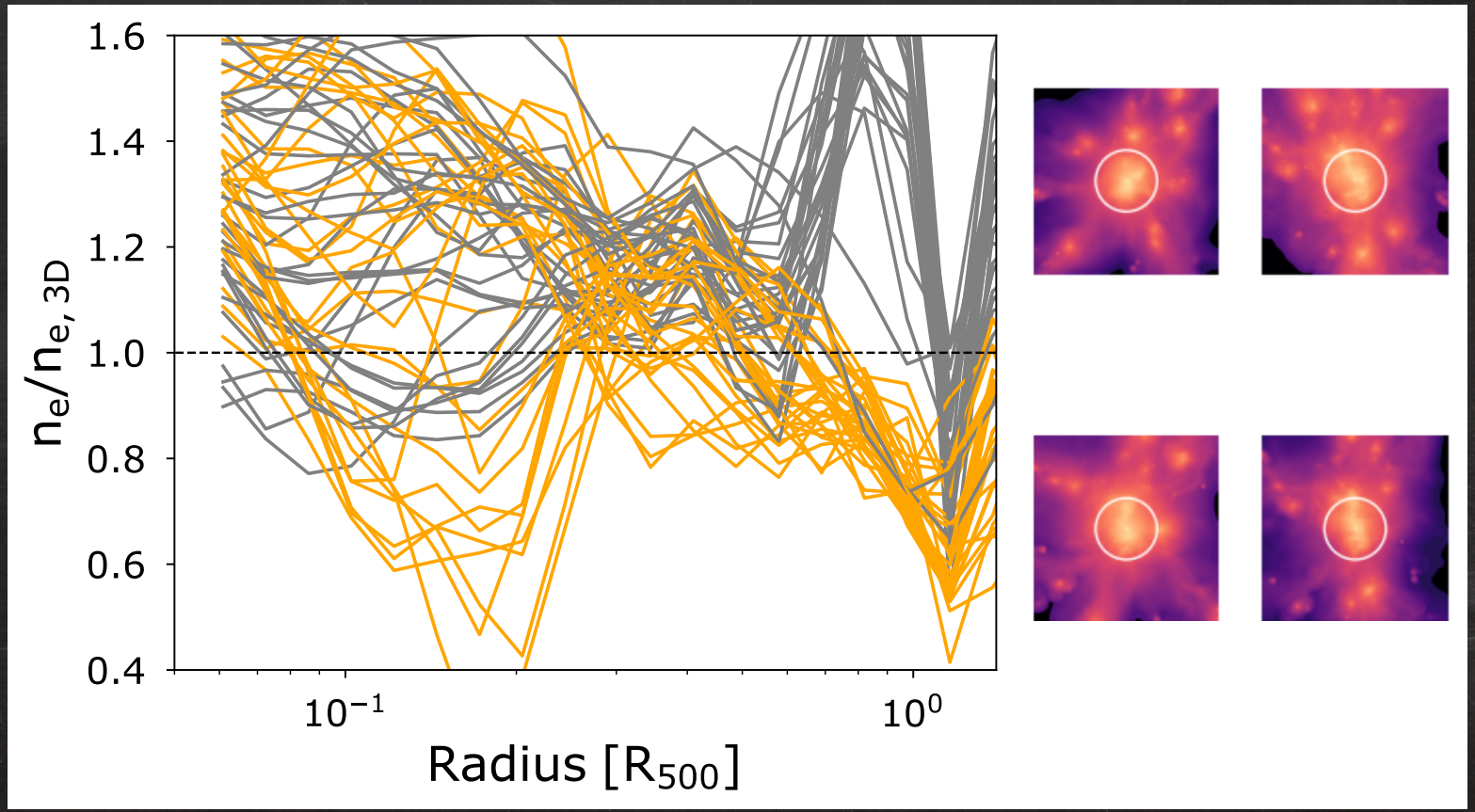
3. Results 40 lines – 1 cluster

The most relaxed



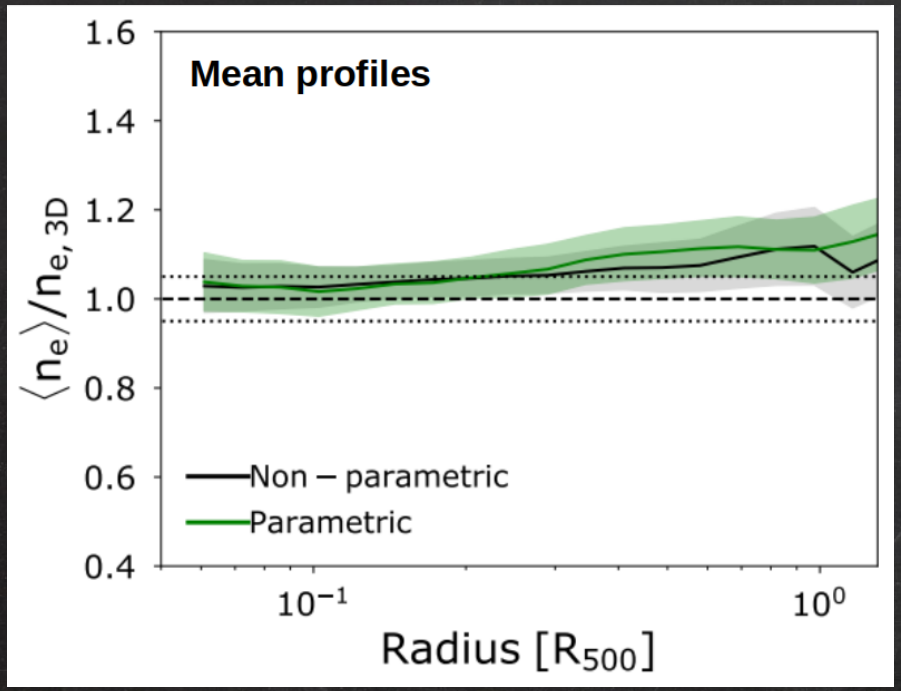
3. Results 40 lines – 1 cluster

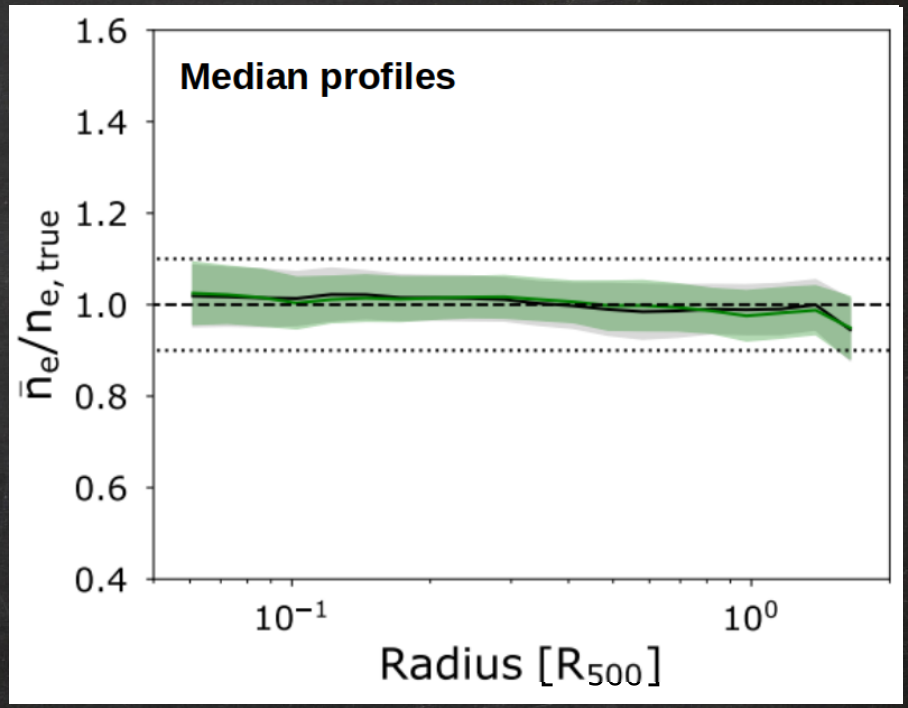
The most disturbed



3. Results: full sample, median of median 40 lines

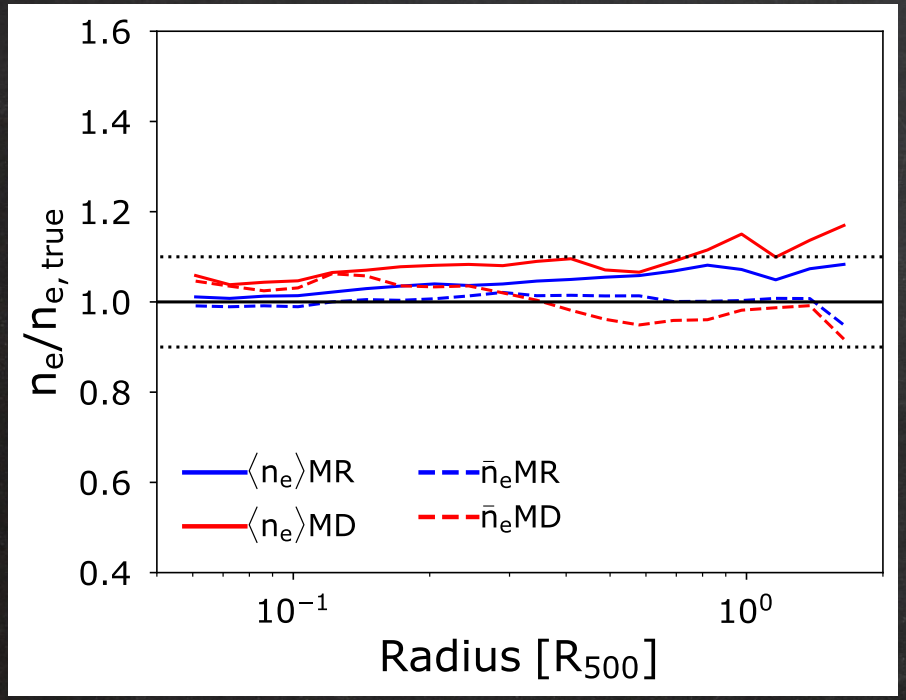
Whole sample





P vs NP → NP better for mean, same for median
Mean vs Median → Bias of the order of 10% for mean, few for median

3. Results: dynamical status correlation



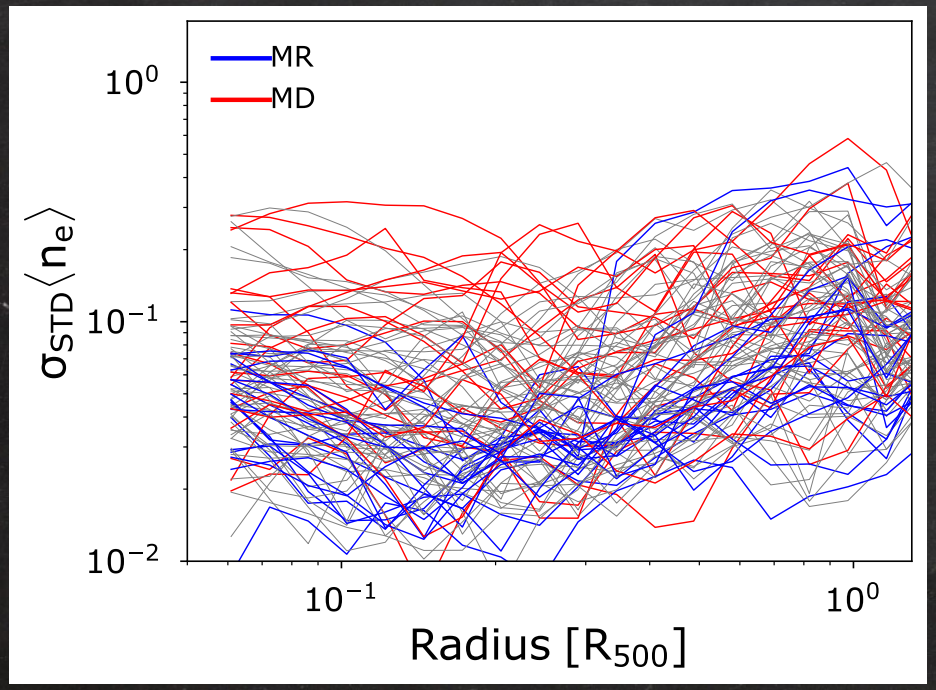
Our limits on the deprojection is driven by the intrinsic dynamical status → departure from spherical symmetry (Veronesi et al. 2024)

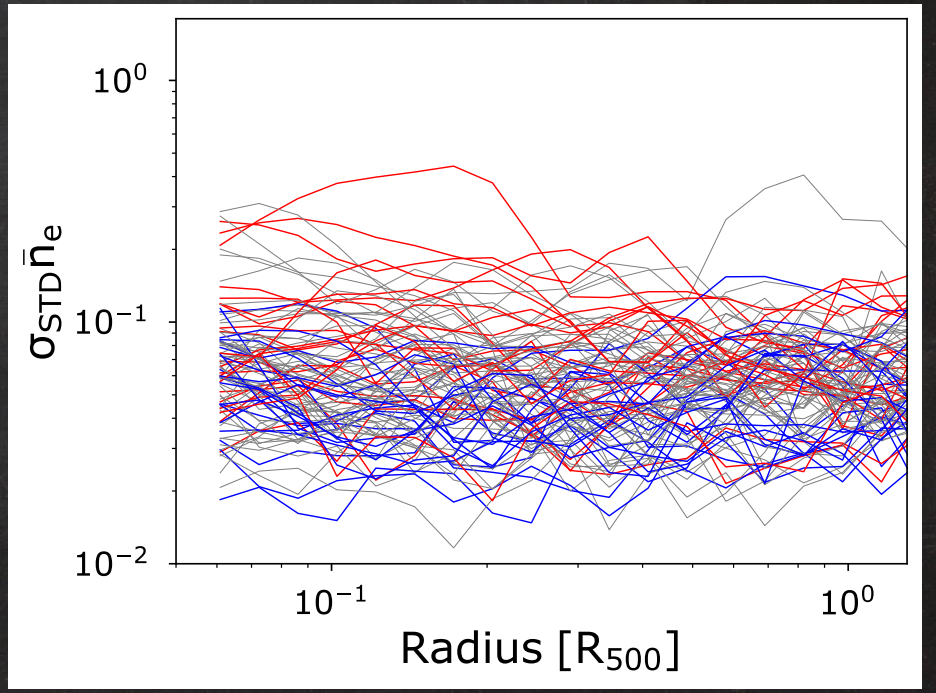
Median profiles are less prone and have little to no bias

Mean profiles @R_{500} 5% bias for relaxed objects, up to 15% for disturbed and 10% on average

3. Results: reconstruction stability

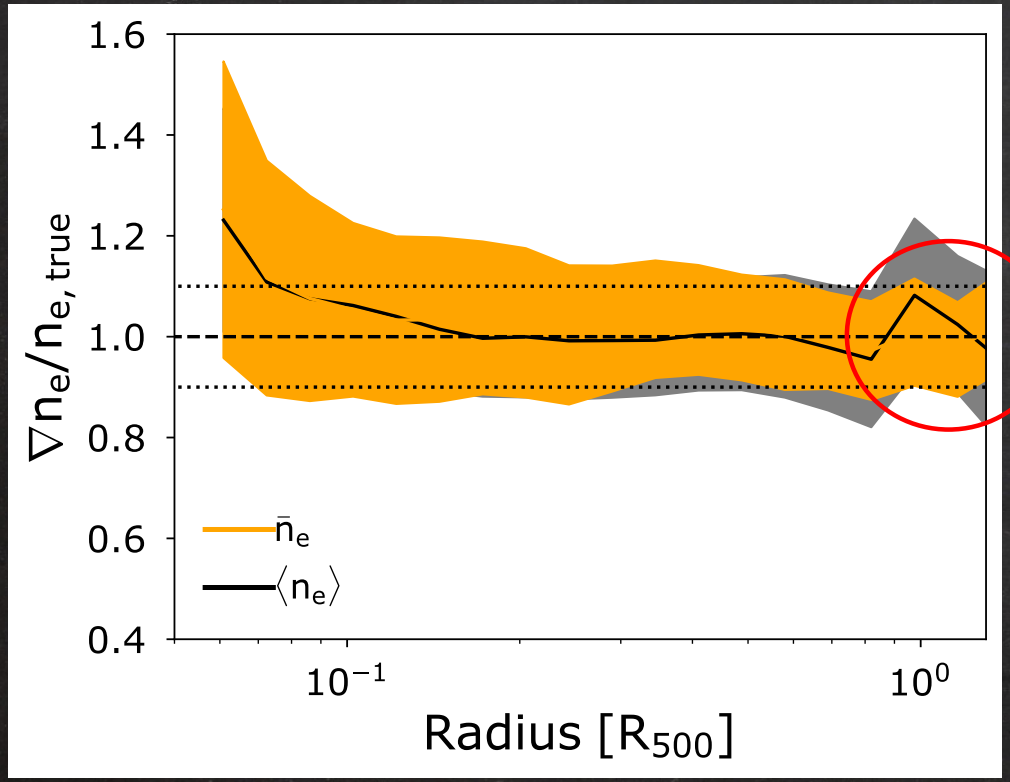
Dependency on the line of sight → Scatter between the reconstructed profiles is quite stable and constant!





Most relaxed → 5%
Most disturbed → 10%

3. Results: ∇n_e

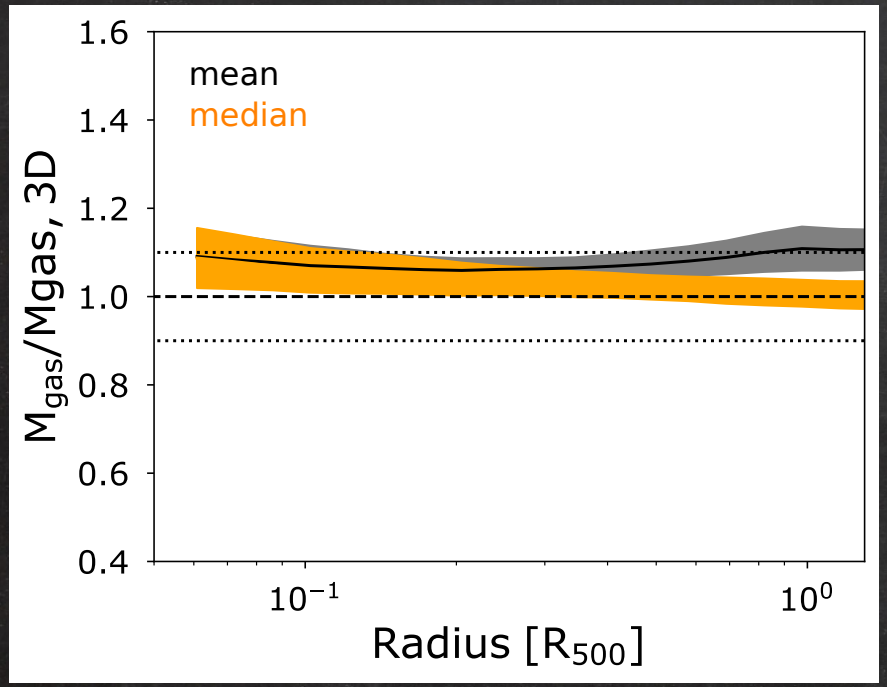


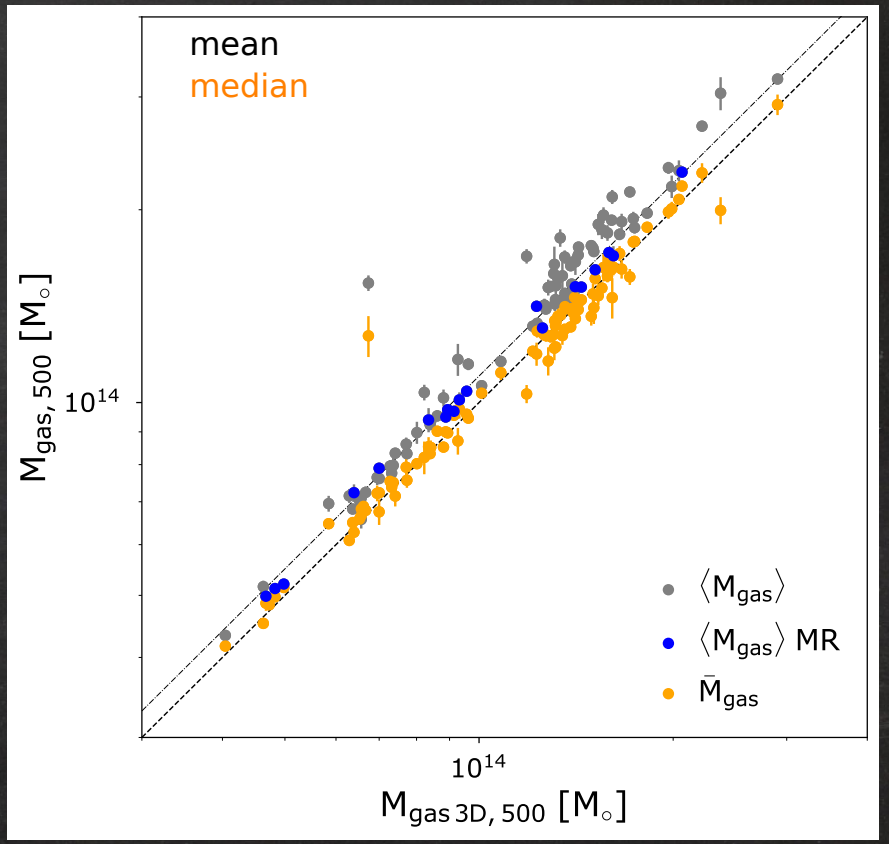
No impact on the shape of the profiles!

Reconstruction of the total mass profiles via HE can be done with both techniques

Still to be investigated

3. Results: gas mass profiles





Mass profiles → few % bias for the median; bias for the mean depends from dynamical status: few % relaxed, 5-10% on average

3. Conclusion

We have inevstigated our capacity in reconstructing the 3D density profile from X-ray data and found

- separating contributions: no bias introduced by NP deprojection, sub-structures is significant but can be removed, dynamical status contributes the most → **ICM spatial distribution**

- on average the mean profile yields a bias of ~5% (<10%@R_{500}); median few % → CHEX-MATE will provide both → **mean for central parts, median for outer**

- reconstruction is solid! On average the scatter between the profiles of the 40 lines of sight is constant and of the order of ~5%

- **no impact** on derivative of density!