The Three Hundred Project Modeling Galaxy Clusters and Their Environment

https://www.nottingham.ac.uk/astronomy/The300/index.php

Elena Rasia (on behalf of The300 Collaboration)
INAF - Astronomical Observatory of Trieste, University of Michigan

The300 Institutes

>100 scientists with active projects

90 published papers
9 submitted
~50 active projects

Cross collaborations
WEAVE, CHEX-MATE,
NIKA2, Euclid, ACT,
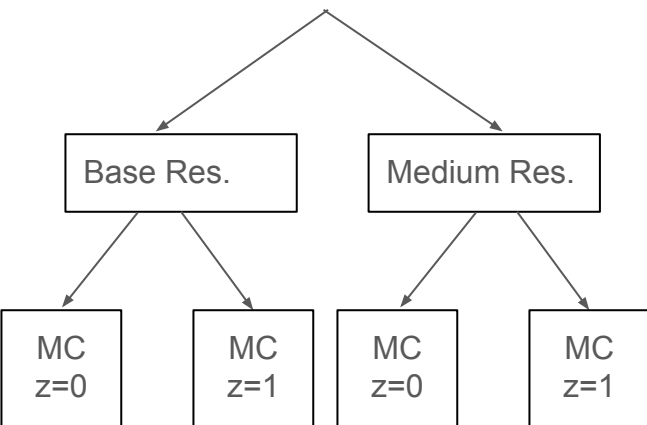CLUMP-3D

see Adriana
Gavidia's talk-
Mon. (PM)

GADGET-X

Base Res.
Medium Res.

MC z=0 MC z=1 MC z=0 MC z=1

The300 (392 Lagrangian regions)

Mass Complete @ z=0: 324 regions (R~15 Mpc/h) around the most massive clusters identified at z=0 in 1 Gpc/h DM-only cosmological box
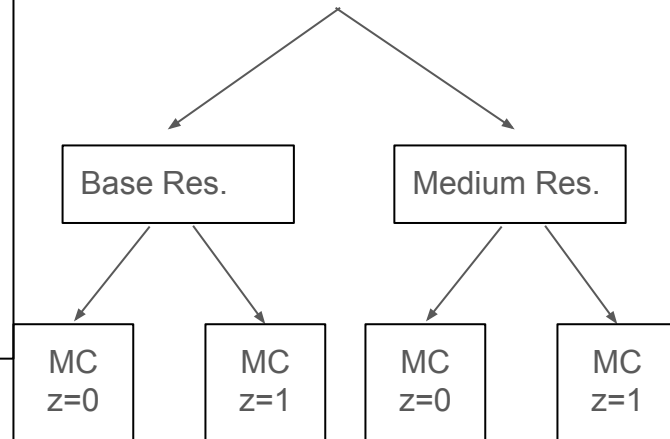
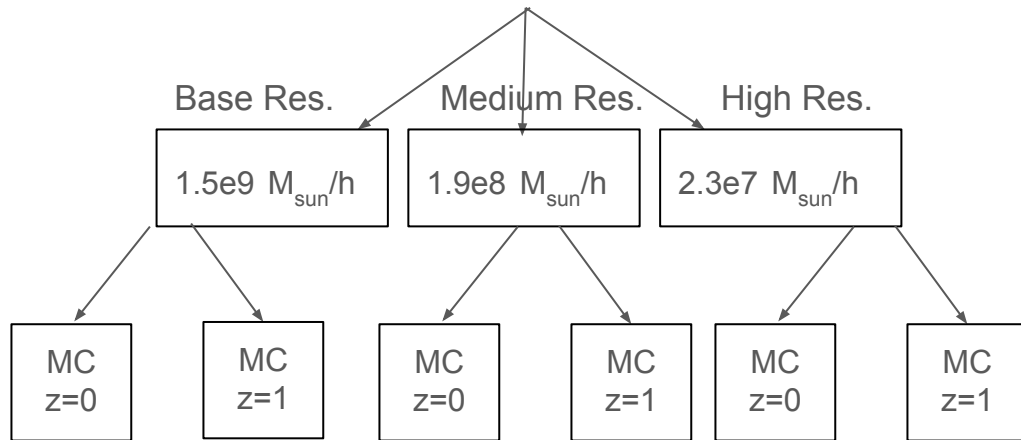Mass Complete @z=1: +68 regions

Resimulated with baryonic physics

GIZMO-SIMBA

Base Res.
Medium Res.

MC z=0 MC z=1 MC z=0 MC z=1

Dark Matter

Base Res.
Medium Res.
High Res.

$1.5e9 \ M_{sun}/h$ $1.9e8 \ M_{sun}/h$ $2.3e7 \ M_{sun}/h$

MC z=0 MC z=1 MC z=0 MC z=1 MC z=0 MC z=1

Some of the available products (Elena's)

TABLES	PROFILES	MAPS
- Masses - Temperatures - M_HE - M_WL - Coll.: Filaments definition (from gal and gas) - DisPerSE - Coll.: Dynamical state parameters	- Total mass - Gas density (stellar/DM density) - Temperatures (MW and SL) - Pressure - Entropy - Clumpiness 2D & 3D	- MW temperature - SL temperature - SZ - EM - Grav Potential/ convergence/ Shear maps

Steering Committee

Alexander Knebe

Chris Power

Elena Rasia

Frazer Pearce

Gustavo Yepes

Meghan Gray

Romeel Dave

Weiguang Cui

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To request membership or propose a project

Current Working Groups

- Filaments/Bridges (galaxies & gas)
- Inter Cluster Light/BCG
- Weak Lensing
- Intra Cluster Medium
- TBD: Observations/Maps (Optical, X-ray, SZ)
- CHEX-MATE (The300 reference: E. Rasia)
- NIKA2 (The300 reference: M. De Petris)
- Machine Learning
- Semi-Analytic Model Comparison
- New Sims

see Stefano Ettori's talk- Thu. (AM)

see Frederic Mayet's talk- Thu. (AM)

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"The Atacama Cosmology Telescope: A census of bridges between galaxy clusters" (Isopi et al., 2025, arXiv:2410.14404)
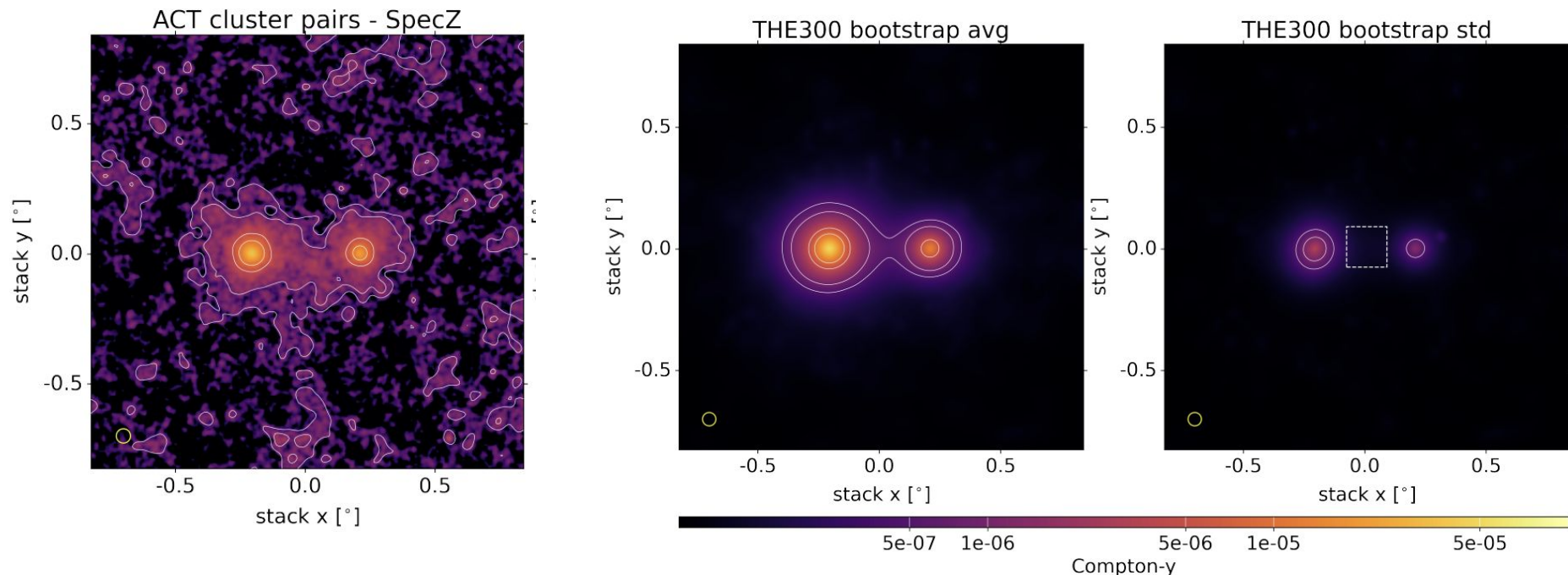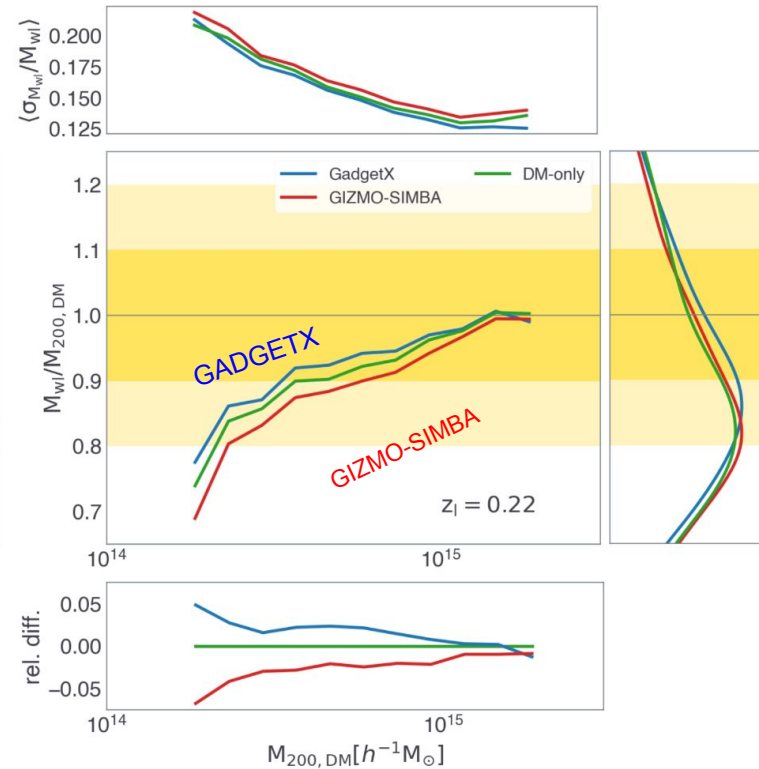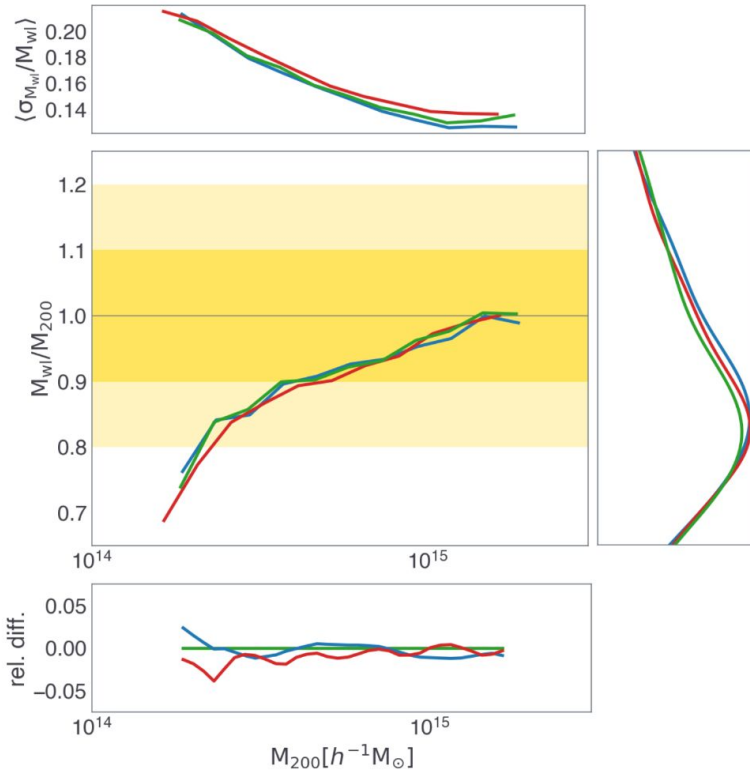
The Y signal of stacked cluster bridges in sim. and obs. is consistent.

"*The Three Hundred Project Hydrodynamical Simulations: WL Mass Bias and Richness using different hydro model*" (Giocoli+ 2025, A&A, 697 184)
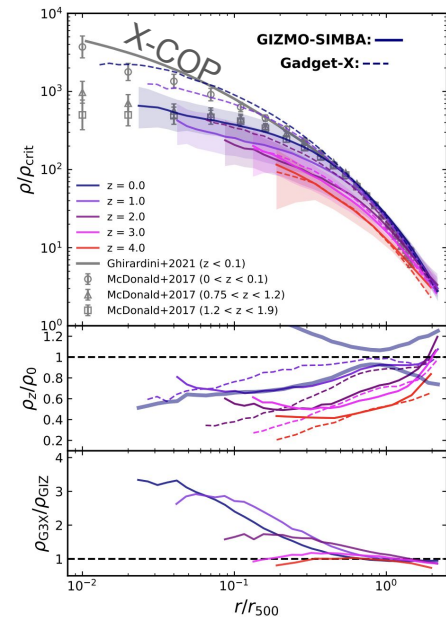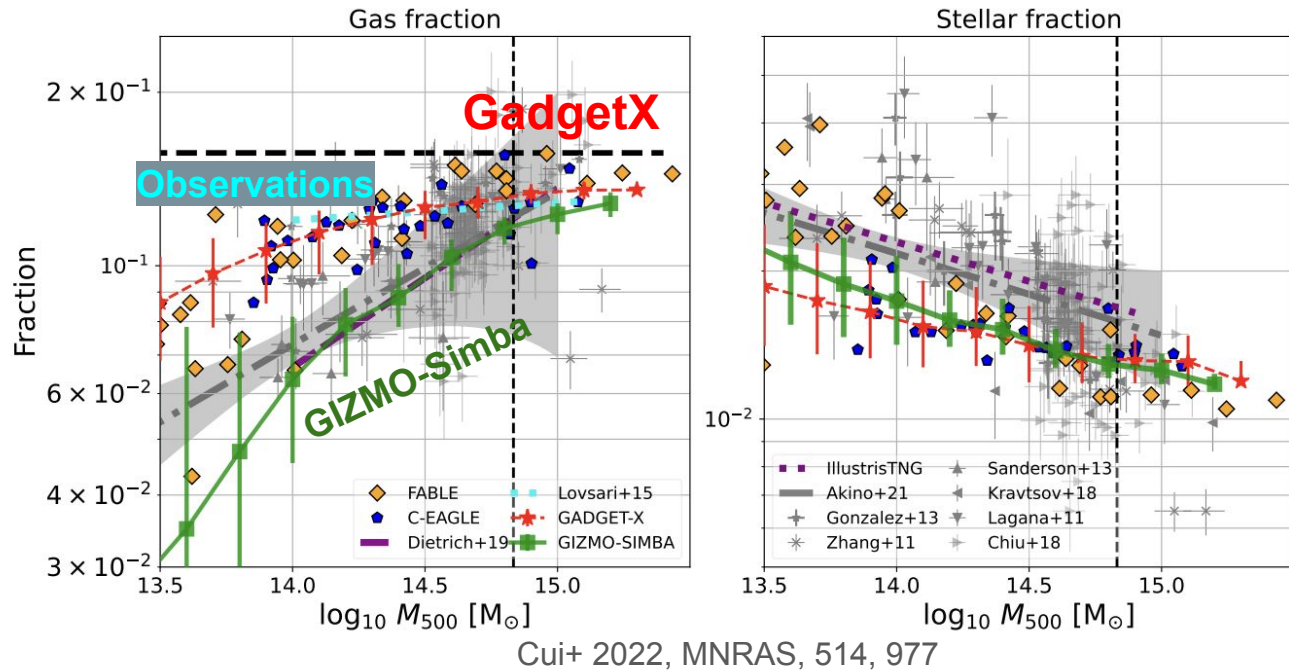
WL mass bias does not the depend on the hydro recipe.

However, the ratio $(M_{HYDRO} - M_{DM})/M_{DM}$ depends on the variation of the Mass Function due to baryons.

see also, Euclid, Giocoli+ 2024

The300: GadgetX - GIZMO-SIMBA comparison
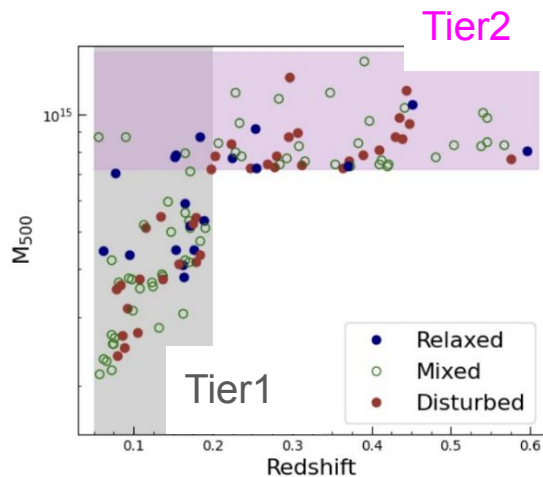

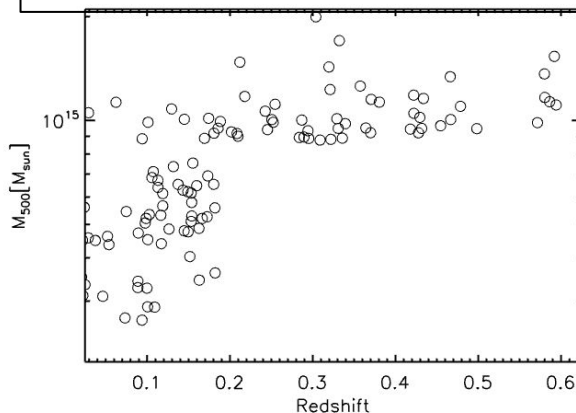Cui+ 2022, MNRAS, 514, 977

Li+2023, MNRAS, 523, 1228

GadgetX has higher f_{gas} and more gas in the cluster center than GIZMO-SIMBA
(in better agreement with data of massive clusters)
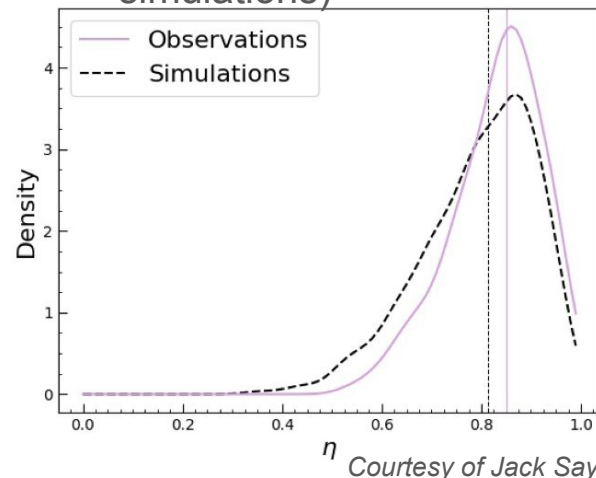
The300 - CHEX-MATE comparisons

- Test techniques
- Evaluate biases
- Provide hints for selection bias (though this has been evaluated with other numerical and analytical simulations)

The CHEX-MATE sample

Campitiello+, 2022, A&A, 665, 117

see talks - early today/ Wed. (PM) Thu. (AM+PM)

The300 matched sample CHEX-MATE-like sample

The observed ellipticity of the CHEX-MATE clusters tend to be rounder suggesting systems are oriented along the line of sight

Courtesy of Jack Sayers

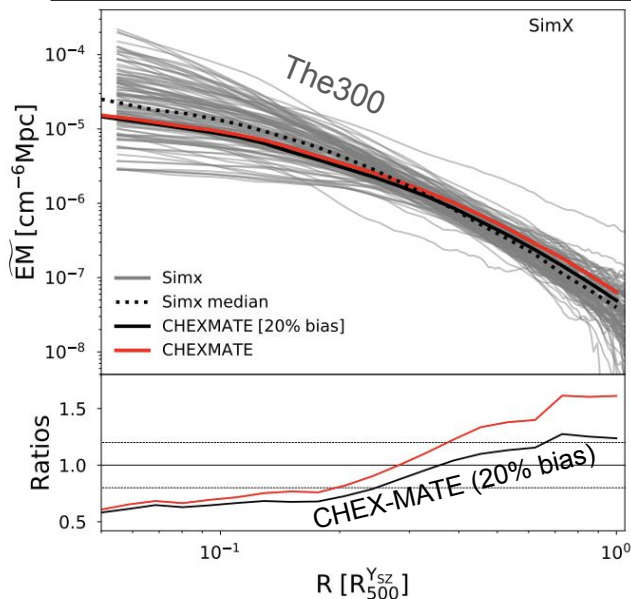**see Harsda Saxena's talk - Wed. (PM)**

"*CHEX-MATE:Morphological Analysis of the Sample*"
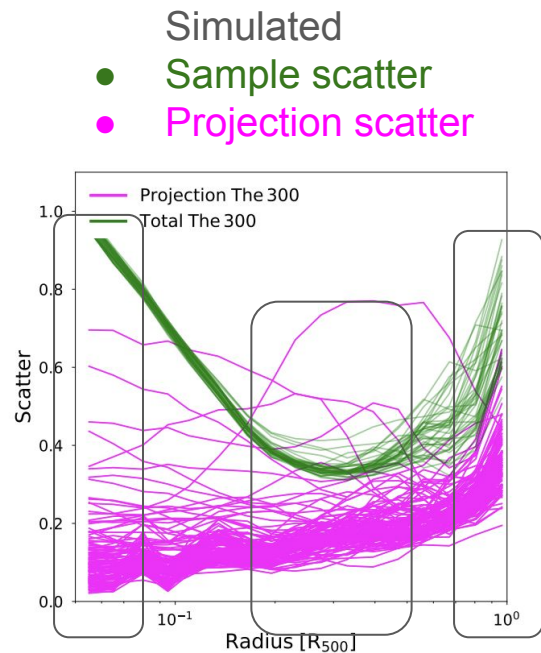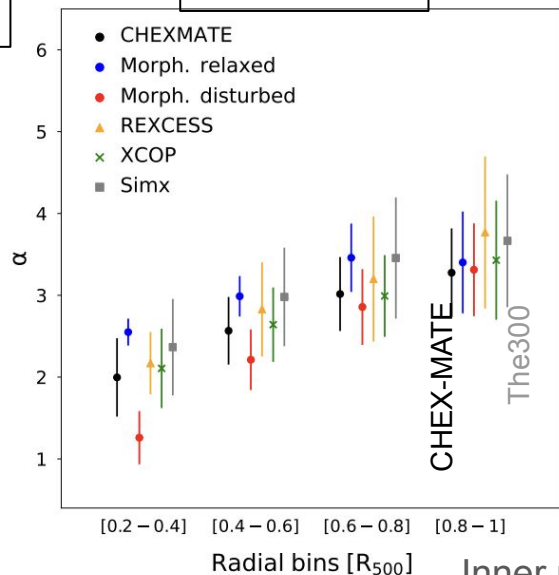## Campitiello et al. 2022, A&A, 665, 117
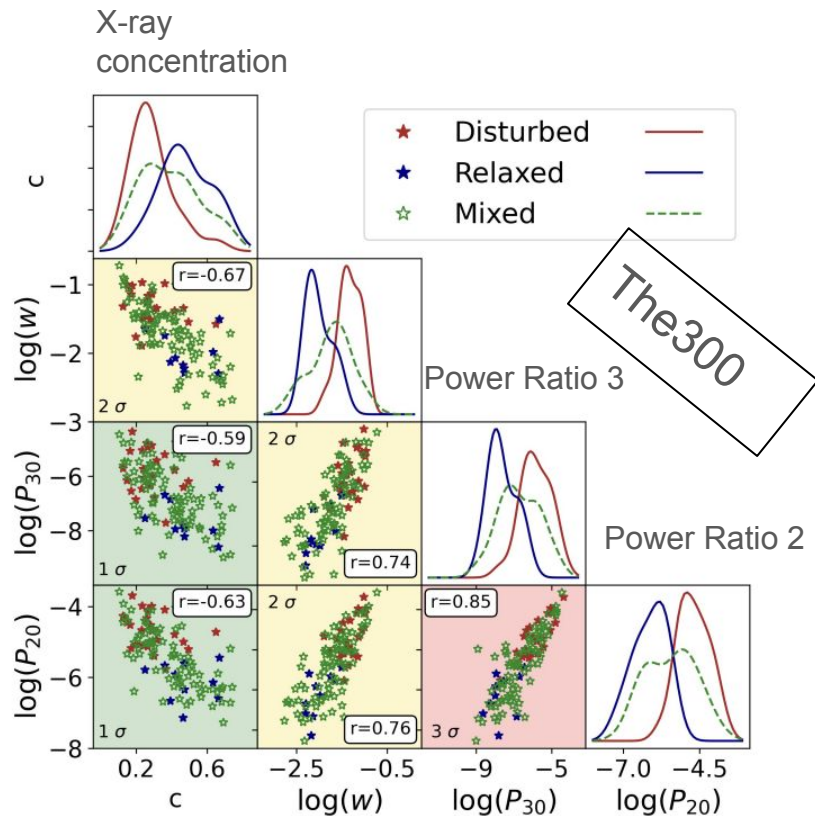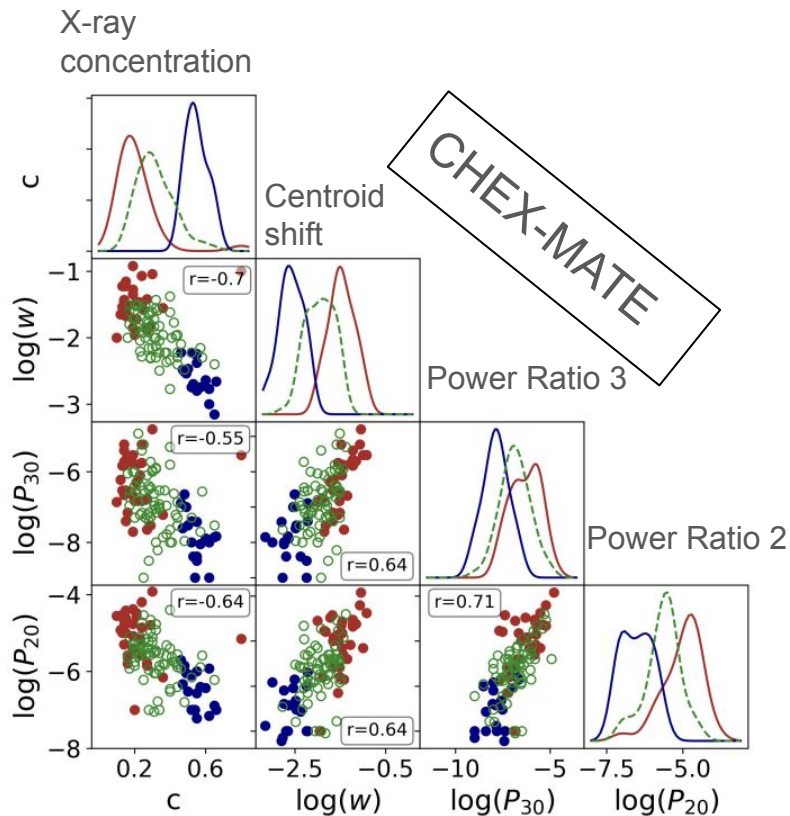
"CHEX-MATE: Constraining the origin of the scatter in galaxy cluster radial X-ray surface brightness profiles" (Bartalucci et al., A&A, 674, 179)


Emission Measure profiles

EM Slope

Simulated
- Sample scatter
- Projection scatter

see Iacopo Bartalucci's talk - Thu. (PM)

Inner region: large difference due to cluster-to-cluster variation in the core
Med region ~20% difference
External region: both scatter grow, growth due to clumps/substructures/local inhomogeneities

"*CHEX-MATE: Robust reconstruction of temperature profiles in galaxy clusters with XMM-Newton*" (Rossetti et al., 2024, A&A, 686,68)
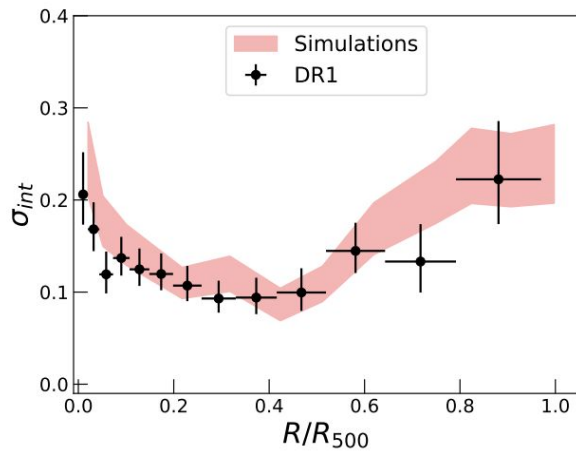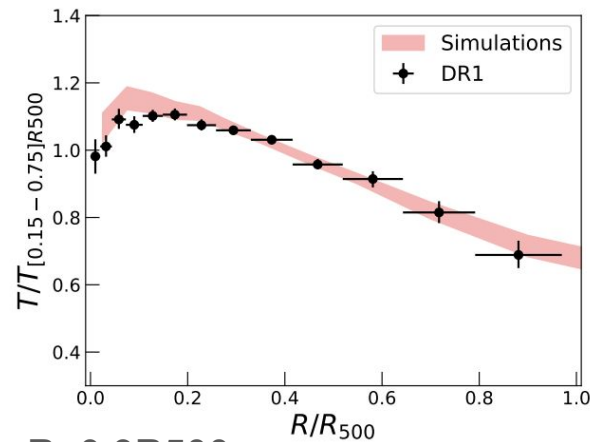
Weighted Mean Temp.
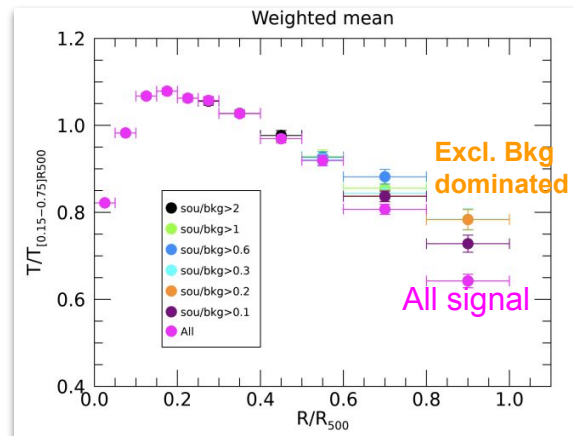
For R>0.3R500
• Simulations have a slope ~0.34
• CHEX-MATE's excluding the Source/Background<0.2: slope ~0.4 supporting the choice to exclude background dominated regions

See also Sayers+2023 for the Pressure intrinsic scatter and the comparison between The300 & Planck+Chandra)

For Pressure intrinsic scatter profile of CHEX-MATE

see Miren Muños-Echeverría's talk - Tue. (PM)

Entropy

Temperature

Gas Density

K/K_{500}

T/T_{500}

$n_e\, E(z)^{-2}\ [cm^{-3}]$

MACSIS
The300
HIGHMz $(1 - b = 0.8)$

Ratio

σ_{int}

R/R_{500}

"CHEX-MATE: The intracluster medium entropy distribution in the gravity-dominated regime" Riva+, 2024, A&A, 691, 340
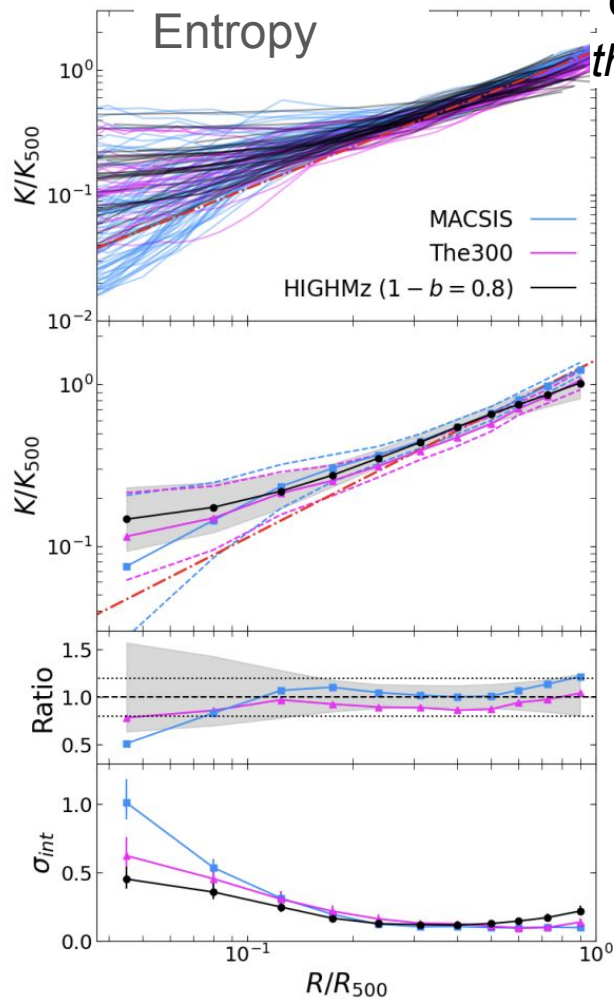
HighMz sample

The300 slightly underestimates the median entropy profile, but it reproduces well the range of the core entropy (artificial conduction)
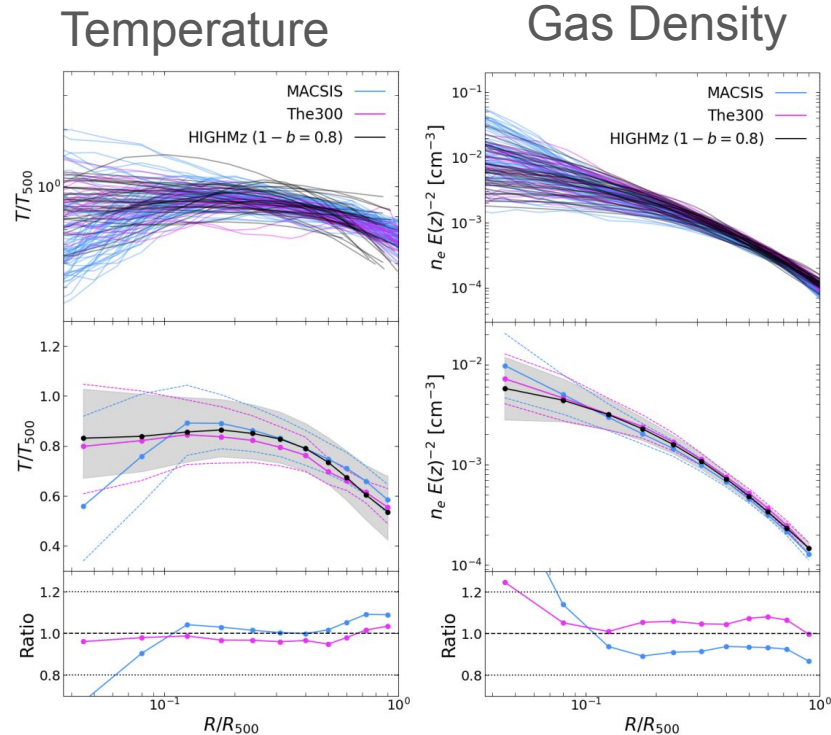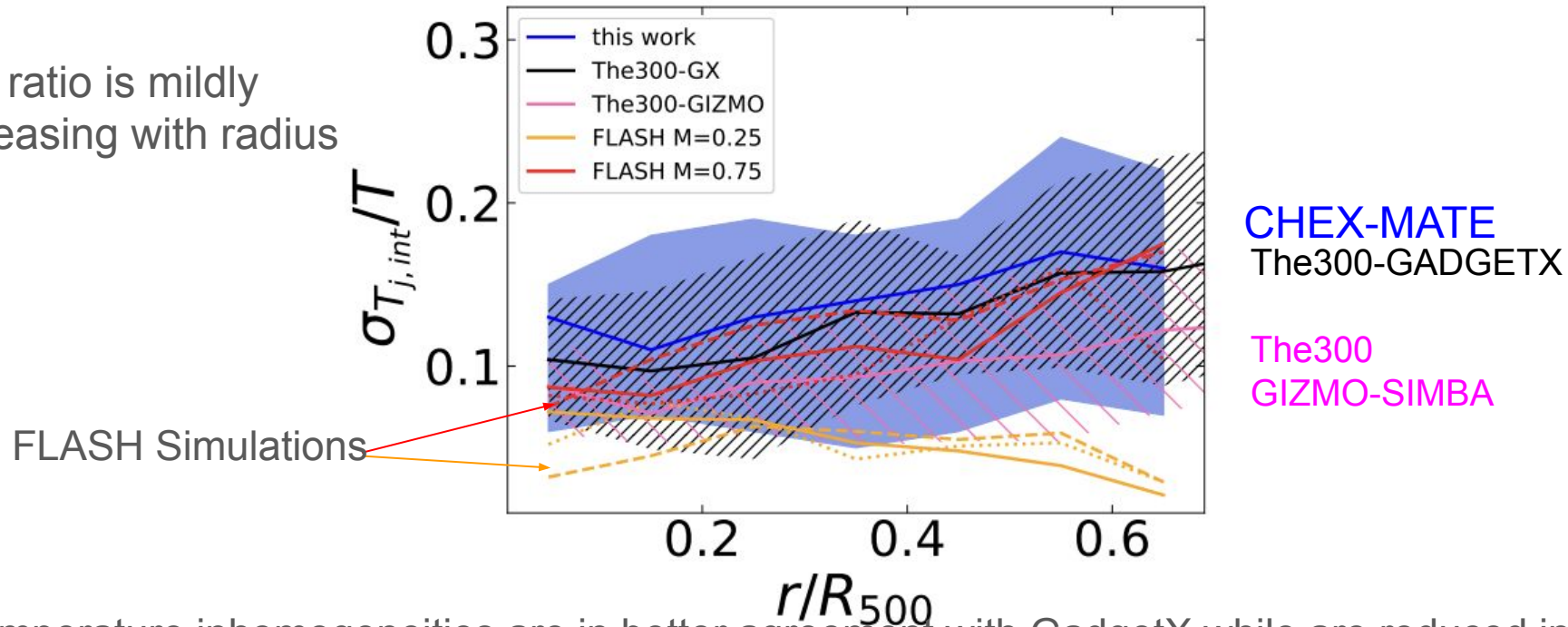
"*CHEX-MATE: Characterization of the intra-cluster medium temperature distribution*"
Lovisari et al., 2024, A&A, 682, 45

Ratio between the intrinsic dispersion and the median value of the ICM temperature

The ratio is mildly increasing with radius

FLASH Simulations

CHEX-MATE
The300-GADGETX

The300
GIZMO-SIMBA

The temperature inhomogeneities are in better agreement with GadgetX while are reduced in the GIZMO version. In constrained simulations a high level of turbulence is required to match the data.

The300-NIKA2 #1: Gas pressure profiles in the NIKA2 LPSZ redshift range (0.5-0.9): recovery from mock maps (Aishwarya Paliwal et al.)
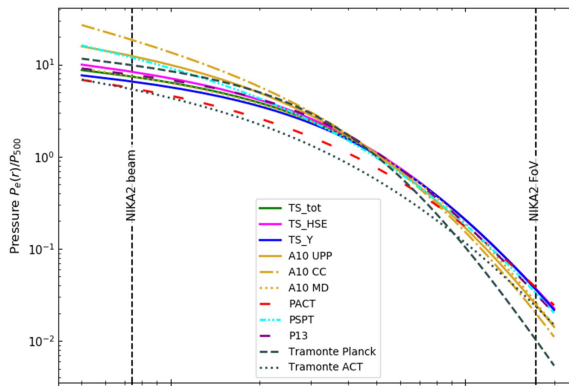
- Aim: to **recover 3D pressure profiles** from mock SZ maps of The300-NIKA2 TSs, verify the **recovery bias** and to compare the **UPP to existing literature**
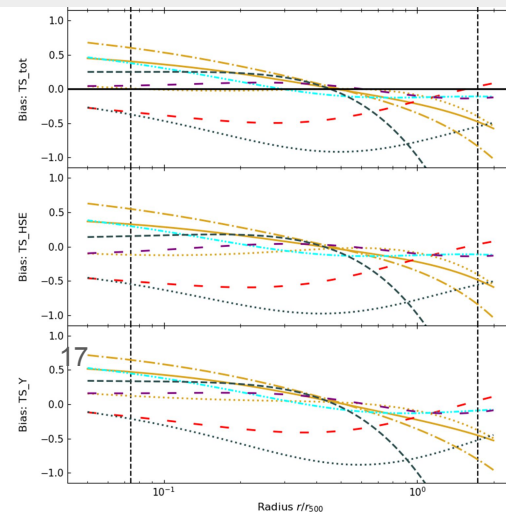- Results:

Recovery bias
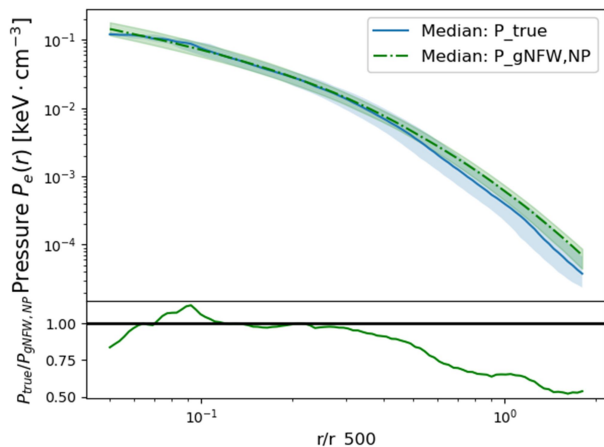
Bias consistent with zero up to ~0.5 R_500 (~ Δ=1000)

UPP

TS UPP compared to literature, we define the bias between the two as:

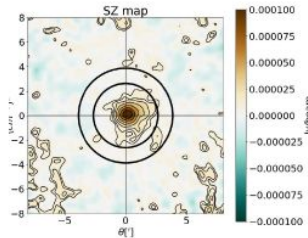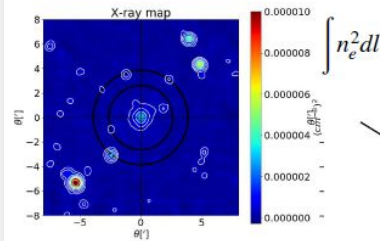$$b_P = \frac{P_{\text{true}} - P_{\text{gNFW,NP}}}{P_{\text{true}}}$$
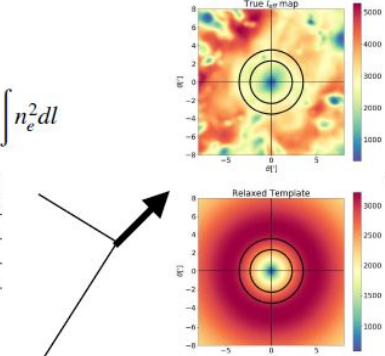
17

Consistent with Planck 2013

Courtesy of Marco De Petris

The300-NIKA2 #2 & #3:

Temperature maps inference from joint X-ray and SZ observations

(Wicker et al.)

X-ray map $\int n_e^2 dl$

SZ map $\frac{\sigma_T}{m_e c^2} \int P_e dl$

Simulated X-ray and SZ images

True l_{eff} map

Relaxed Template

Simulated or modeled « effective length » map

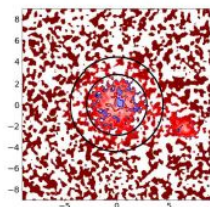T_{SZX} map, obtained using true l_{eff}
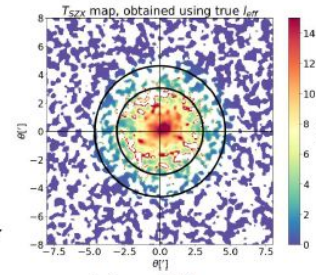
Inferred T_{SZX} map
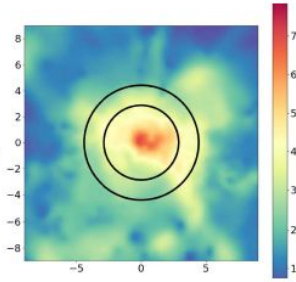
Compare to a theoretical simulated T_{mw} map

Theoretical X-ray and SZ maps : infer temperatures within 10%
Paper 1 of 2 in preparation

T_{SZX}

$(T_{mw} - T_{SZ})/T_{mw}$
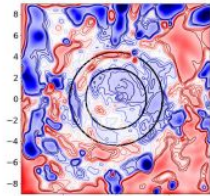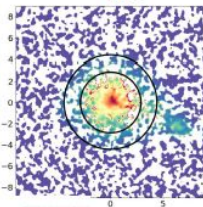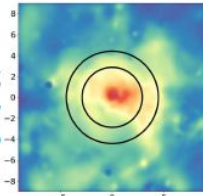
Realistic mock XMM-like and NIKA2-like maps : **Investigation still needed**, strong offsets observed in the center, **issues with the SZ transfer function**
Paper 2 of 2 to be written at the end of the analysis

Courtesy of Marco De Petris

The300-NIKA2 #4: Dynamical state inference by Zernike Polynomials applied on NIKA2 tSZ mock and real maps (Elia Pappalardo et al.)

1. Validation of ZP indicator on mock NIKA2 The300 SZ-maps, i.e. NIKA2 Twin Samples
2. Application on real NIKA2 LPSZ maps (35 clusters observed with NIKA2 at 150 and 260 GHz 0.5<z<0.9)
3. Ranking of LPSZ clusters for cosmological applications: e.g. by pressure profiles and Y-M scaling law
4. Comparison with other morphological «classical» indicators

ZP indicator
V. Capalbo et al. 2021

$$\mathcal{C} = \sum_{n,\, m \neq 0} |c_{nm}|^{1/2}$$

Morpho ⟷ Dyn State
calibration

Relaxation parameter
F. De Luca et al. 2021

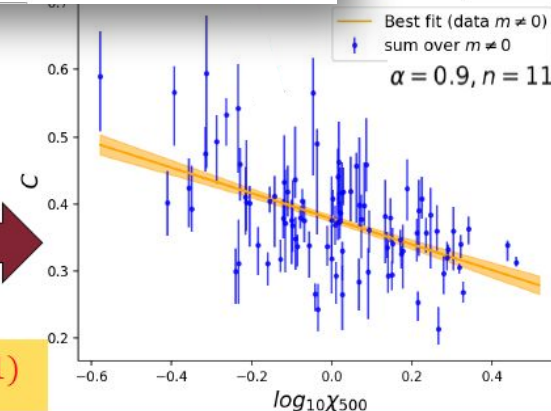$$\chi = \sqrt{\frac{2}{\left(\frac{f_s}{0.1}\right)^2 + \left(\frac{\Delta_r}{0.1}\right)^2}}$$

- **Final best $\mathcal{C}$ recipe** → $[\alpha = 0.9, n = 11]$
- Final best correlation and $\mathcal{C}$ dispersion decrease
  → $<r> = -0.46 \pm 0.05$ and $<RMSE> = -0.20 \pm 0.01$

$$C = \sum_{n<11, m \neq 0} |C_{nm}|^{0.9}$$

$$C = (-0.19 \pm 0.03)\, log_{10}\chi_{500} + (0.38 \pm 0.01)$$

Best fit (data $m \neq 0$)
sum over $m \neq 0$
$\alpha = 0.9, n = 11$
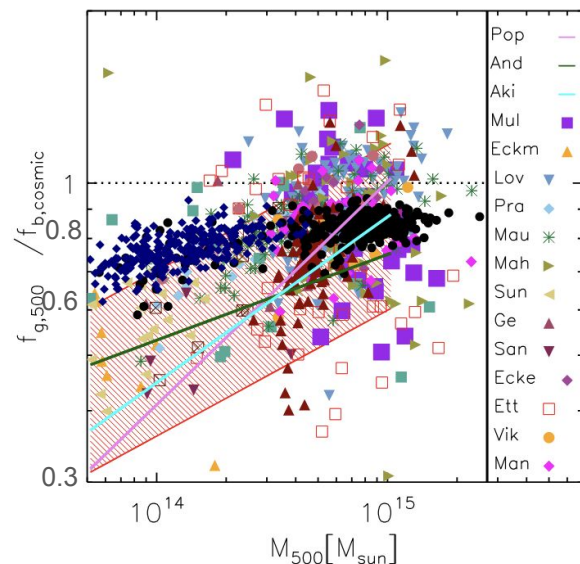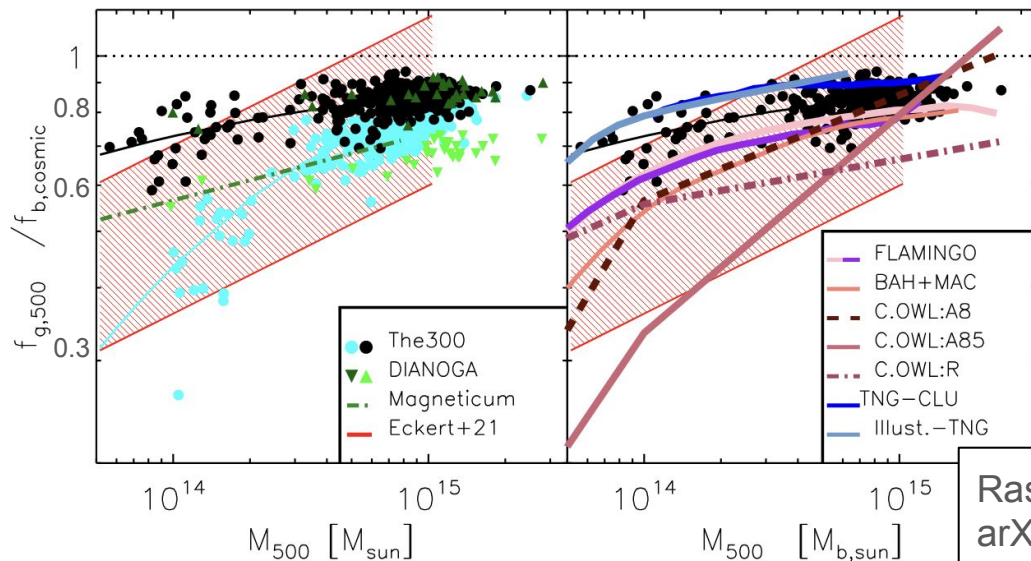
C vs $log_{10}\chi_{500}$

Limitations

As all other cosmological hydrodynamical simulations, The300 also have some limitations:
both GadgetX and GIZMO-SIMBA have difficulty to simultaneously reproduce the properties of both clusters and groups in terms of f_{gas}/gas profiles

The300 vs observations

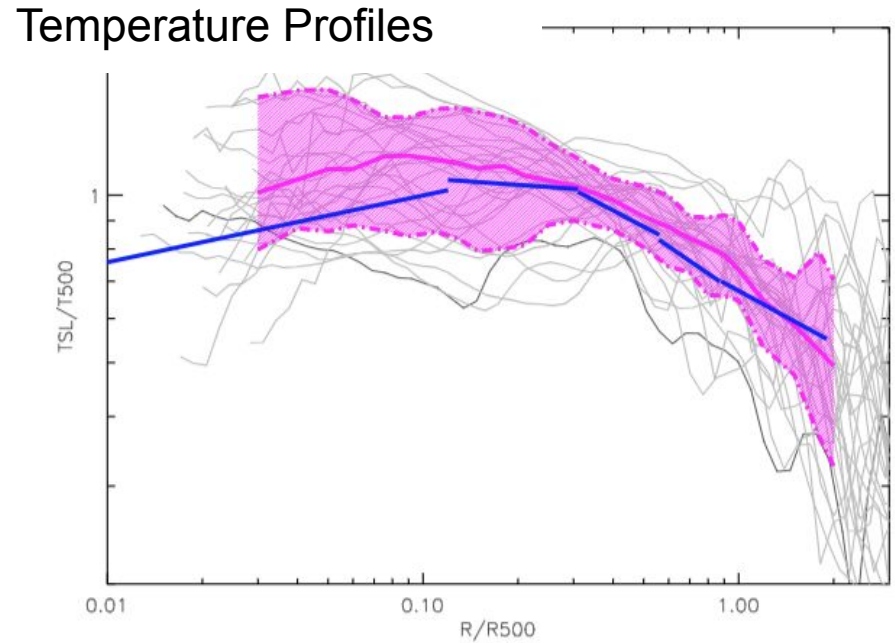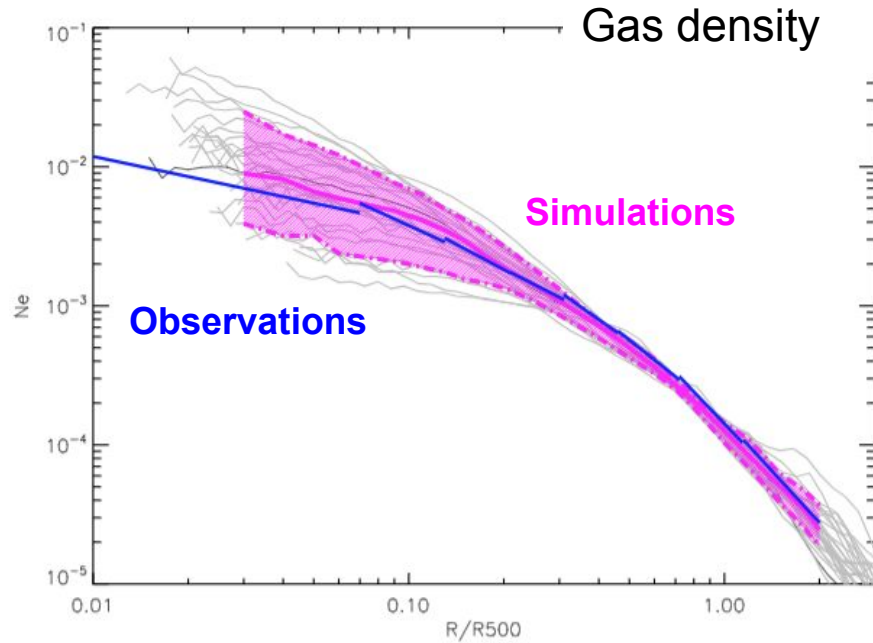The300 vs other simulations

Rasia+2025, arXiv

Conclusions

• The300 are built to follow the evolution of massive systems whose characteristics in terms of ICM properties are well reproduced (thermodynamic profiles median and scatter and T inhomogeneities in 2D maps)

• Provide theoretical framework to the interpretation of data

• Useful for testing techniques (via intrinsic or mock observations analyses)

New members/ projects are always welcome !

elena.rasia@inaf.it

https://docs.google.com/forms/d/e/1FAIpQLScVzmojD6VA2RsX8n-PeRc8Bd1zdGZ5QrxW1RgDFct1sRjIVQ/viewform

Comparison with XCOP (blue) & The300 (magenta) same Mass and Redshift

Gas density

Temperature Profiles

Simulations

Observations

X-COP from Ghirardini+2019

"The Three Hundred Project Hydrodynamical Simulations: WL Mass Bias and Richness using different hydro model" (Giocoli+ 2025, A&A, 697 184)
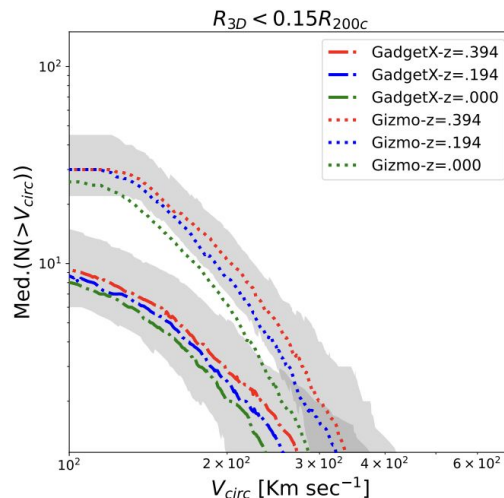
GIZMO-SIMBA has
- similar number of members(galaxies)
- Denser Galaxies
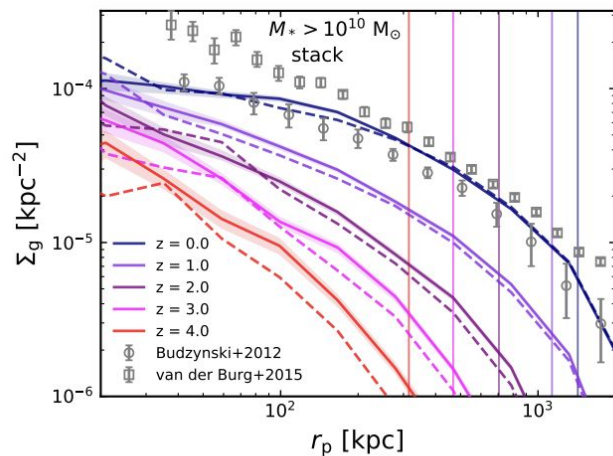
Solid G-S
Dashed GX

z=0

Li+2023

Srivastava+24, Meneghetti+23

Evolution/Mass dependence of the WL mass bias (2 bins in mass)

DM

Gadget X

Gizmo-SIMBA

With respect to the DM universe

With respect to the the hydro universes

GadgetX
GIZMO-SIBMA
GadgetX/$M_{200, GX}$
GIZMO-SIBMA/$M_{200, G-S}$
DM-only

$\langle M_{wl}/M_{200, DM} \rangle$

z

log($M_{200, DM}$)

Giocoli+2025