

## ***Euclid* preparation**

**LXVI. Impact of line-of-sight projections on the covariance between galaxy cluster multi-wavelength observable properties: insights from hydrodynamic simulations**

# MAGNETICUM

## Overview

Magneticum Pathfinder aims to follow the formation of cosmological structures in a hitherto unaccomplished level of detail by performing a set of large scale and high resolution simulations, taking into account many physical processes to allow detailed comparison to a variety of multi-wavelength observational data. Such simulations need to incorporate a detailed description of various complex, non-gravitational, physical processes, which determine the evolution of the cosmic baryons and have an impact on their observational properties.

## Simulations

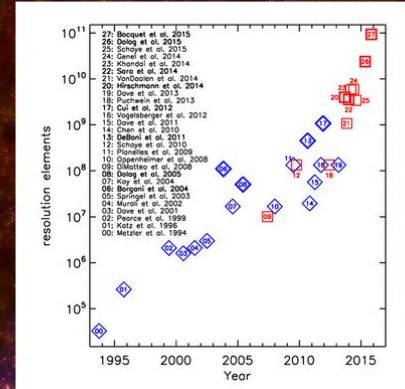
### Magneticum Pathfinder & Magneticum

	Box0	Box1a	Box2b	Box2	Box3	Box4	Box5
[Mpc/h]	2688	896	640	352	128	48	18
mr	$2*4536^3$	$2*1512^3$	$2*2880^3$	$2*594^3$	$2*216^3$	$2*81^3$	$2*81^3$
hr				$2*1584^3$	$2*576^3$	$2*216^3$	$2*81^3$
uhr					$2*1536^3$	$2*576^3$	$2*216^3$
xhr						$2*1536^3$	$2*576^3$

Table 1: Number of particles used in the *Magneticum Pathfinder* and *Magneticum* simulations for the different resolution levels *mr*, *hr*, *uhr* and *xhr*. The blue entries mark simulations which have been stopped before reaching  $z=0$ . *Box2b/hr* has been stopped very close to  $z=0$  (e.g.  $z \sim 0.2$ ). The gray entries mark future, planned simulations.

	$m_{dm}$	$m_{gas}$	$eps_{dm}$	$eps_{gas}$	$eps_{stars}$
mr	1.3e10	2.6e9	10	10	5
hr	6.9e8	1.4e8	3.75	3.75	2
uhr	3.6e7	7.3e6	1.4	1.4	0.7
xhr	1.9e6	3.9e5	0.45	0.45	0.25

Table 2: Mass of dm and gas particles (in  $M_{sol}/h$ ) at the different resolution levels and the according softenings (in kpc/h) used.



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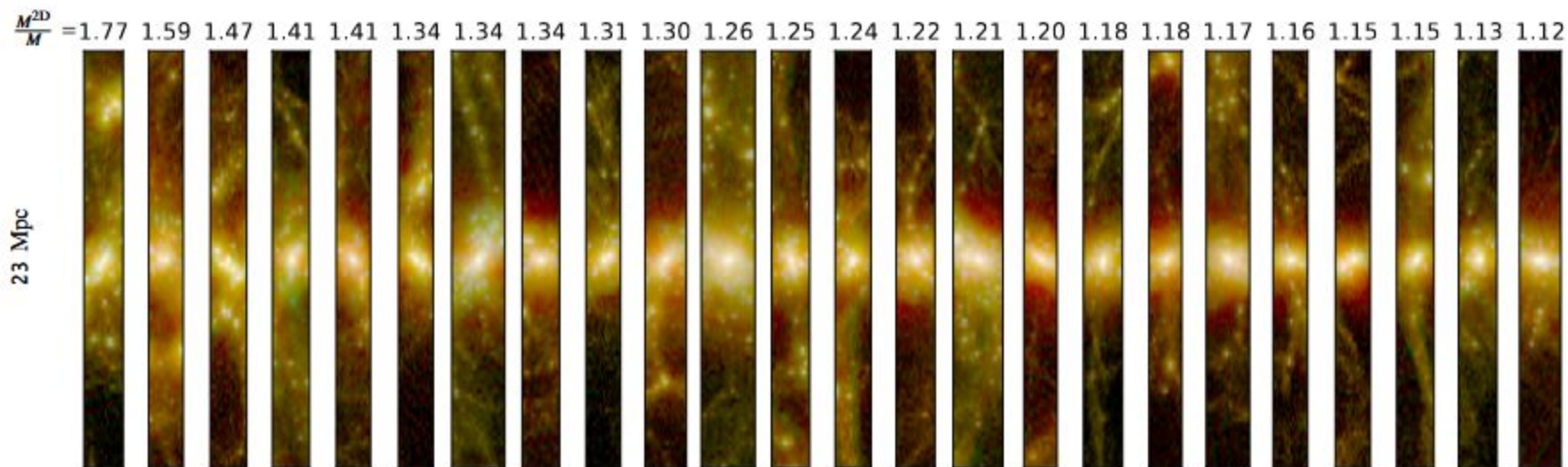


Fig. 6: Projected maps along a cylinder of length 23 Mpc, with radius  $r_{200c}$  and centred on a random sample of our galaxy clusters, ordered by their  $M^{2D}/M$  (over-plotted above each map) values decreasing from left to right. The pixel red, green, and blue channels are used as follows: the red channel maps the gas projected mass, the green channel maps the dark matter projected mass, and the blue channel maps the stellar projected mass. Columns widths are proportional to the cluster radii.

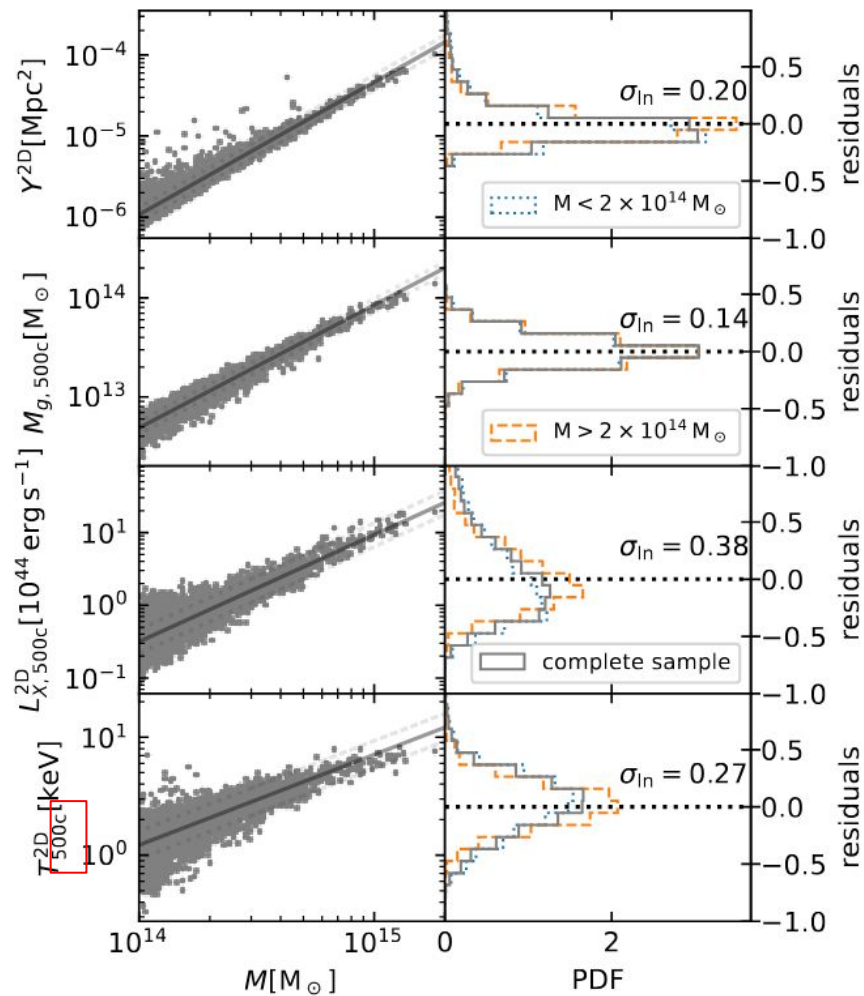
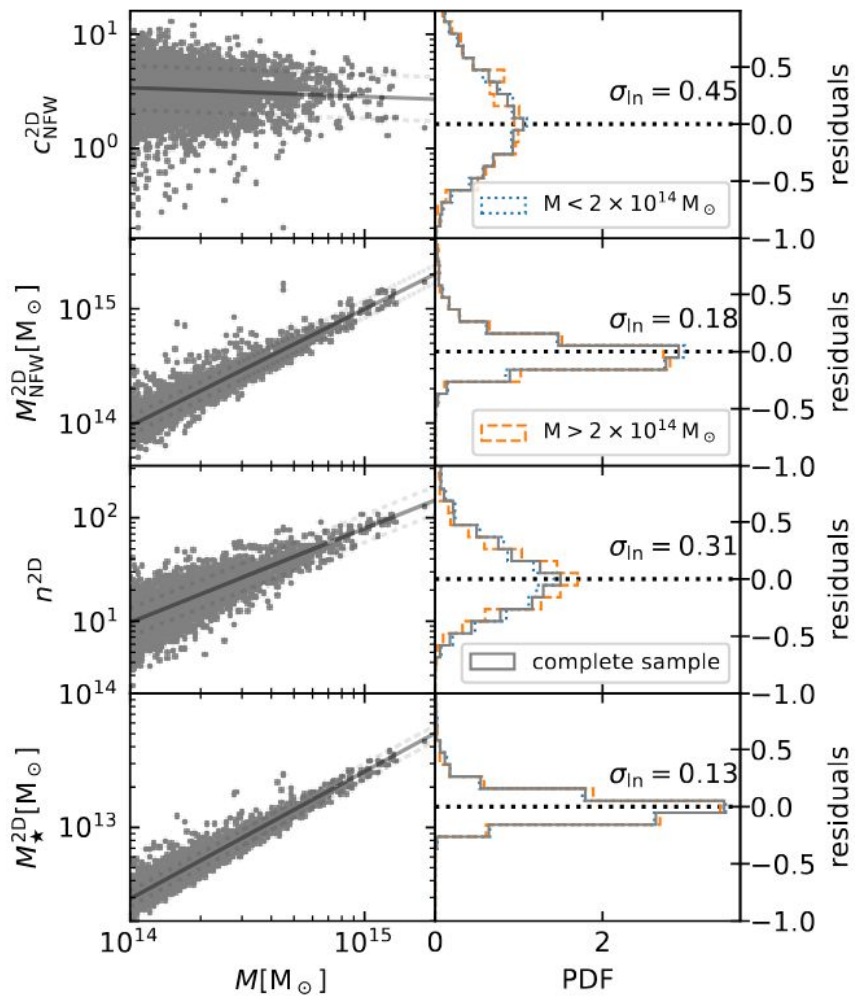
Quantity	Notation	Comments
Stellar mass	$M_\star$	
Temperature	$T$	Weighted by X-ray emissivity
Richness	$n$	Satellites with $\log_{10}(M_\star/M_\odot) > 10.65$ , and background subtraction as in <a href="#">Andreon et al. (2016)</a>
X-ray luminosity	$L_X$	In [0.5, 2] keV band
Gas mass	$M_g$	
Thermal SZ parameter	$Y$	See Eqs. (2) and (3)
NFW profile fit parameters	$M_{\text{NFW}}, c_{\text{NFW}}$	In 3D: 100 log-spaced bins with $60 \text{ ckpc} < r < r_{200c}$ , in 2D: reduced shear fit as in Eq. (4), and uncertainty as in Eq. (6), on 12 log-spaced bins with $300 \text{ kpc} < R < 3000 \text{ kpc}$ , a cylinder depth of 20 cMpc, and a source distribution in redshift as in <a href="#">Euclid Collaboration (2024)</a>

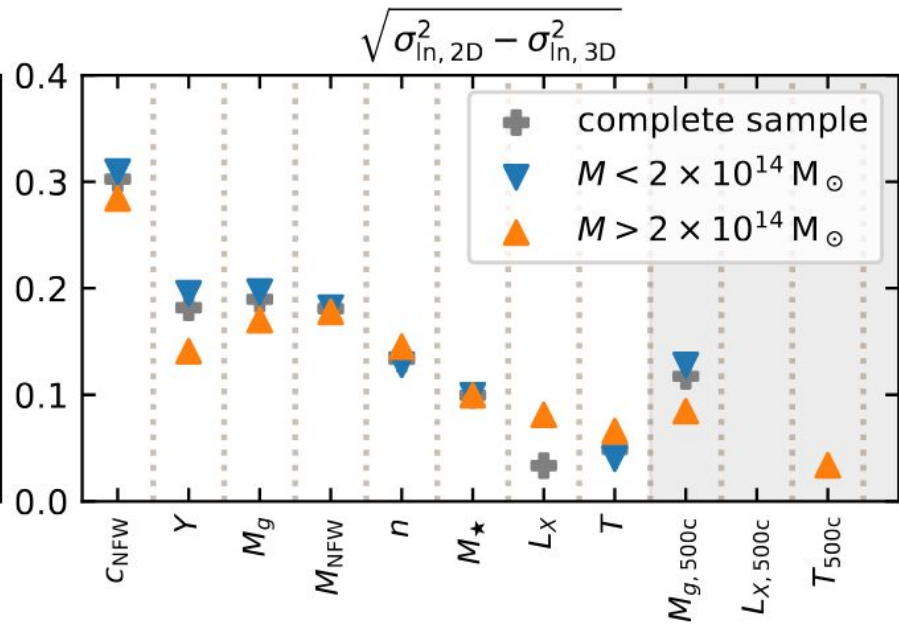
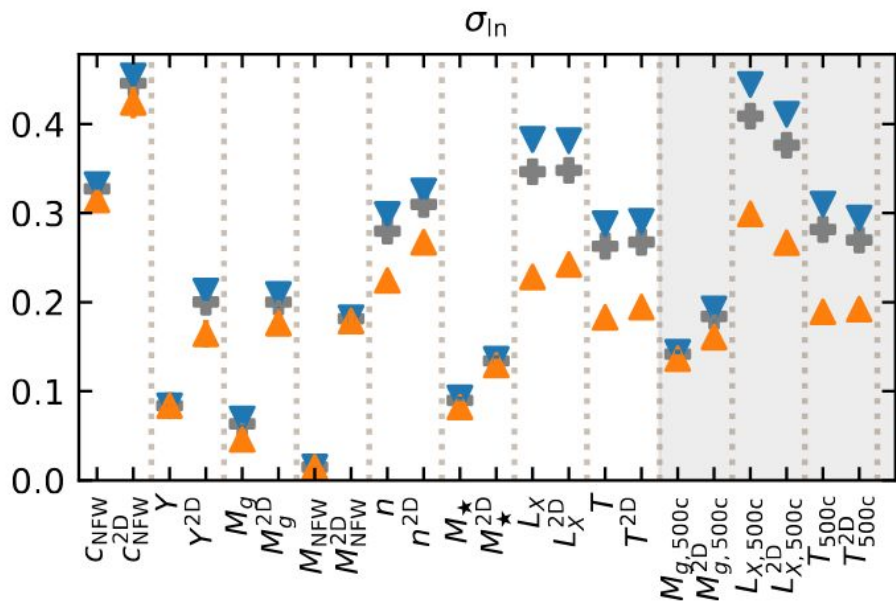
w APEC similar to Biffi+18

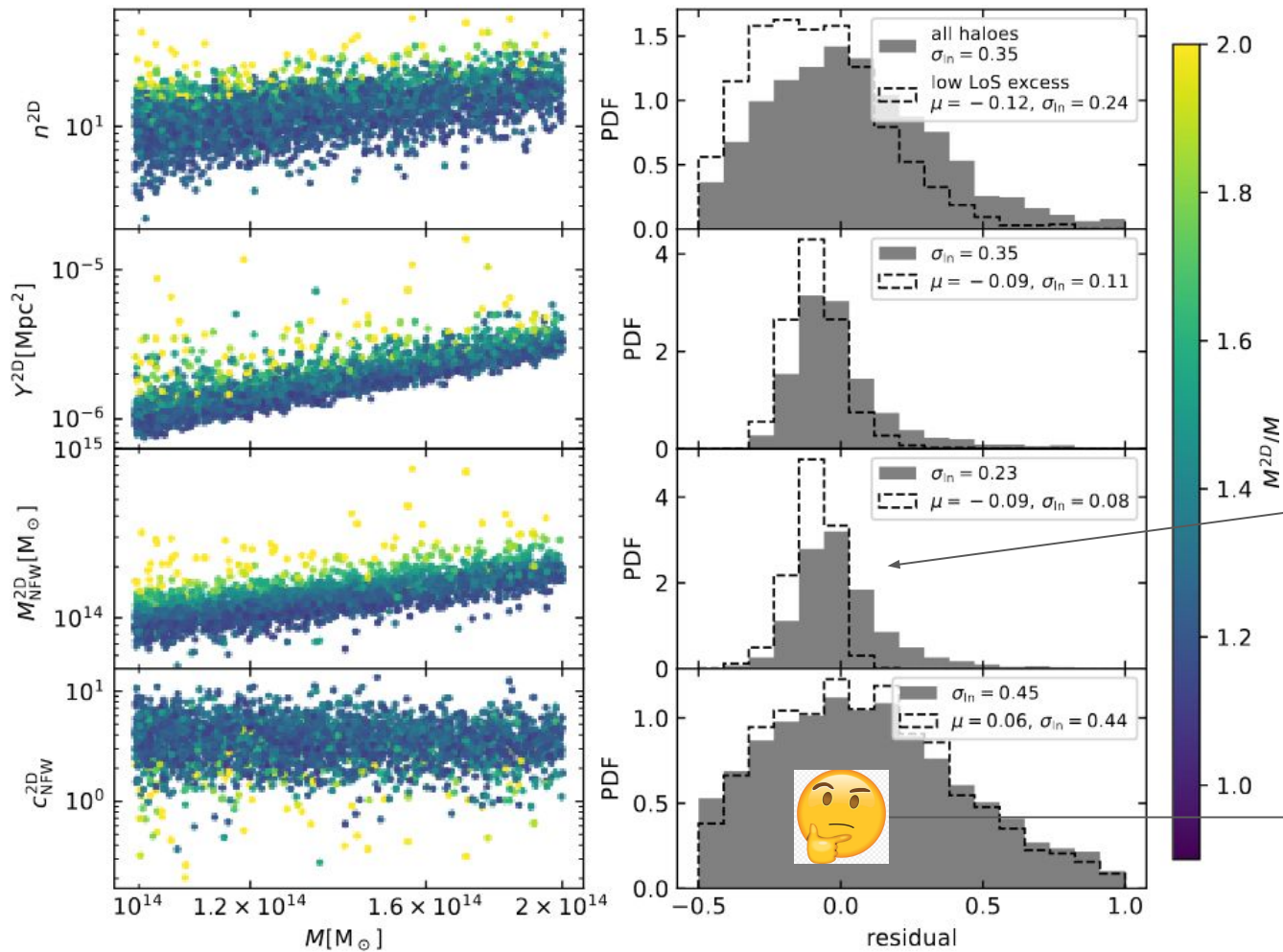
$$y = \frac{k_B \sigma_T}{m_e c^2} \int T n_e dl,$$

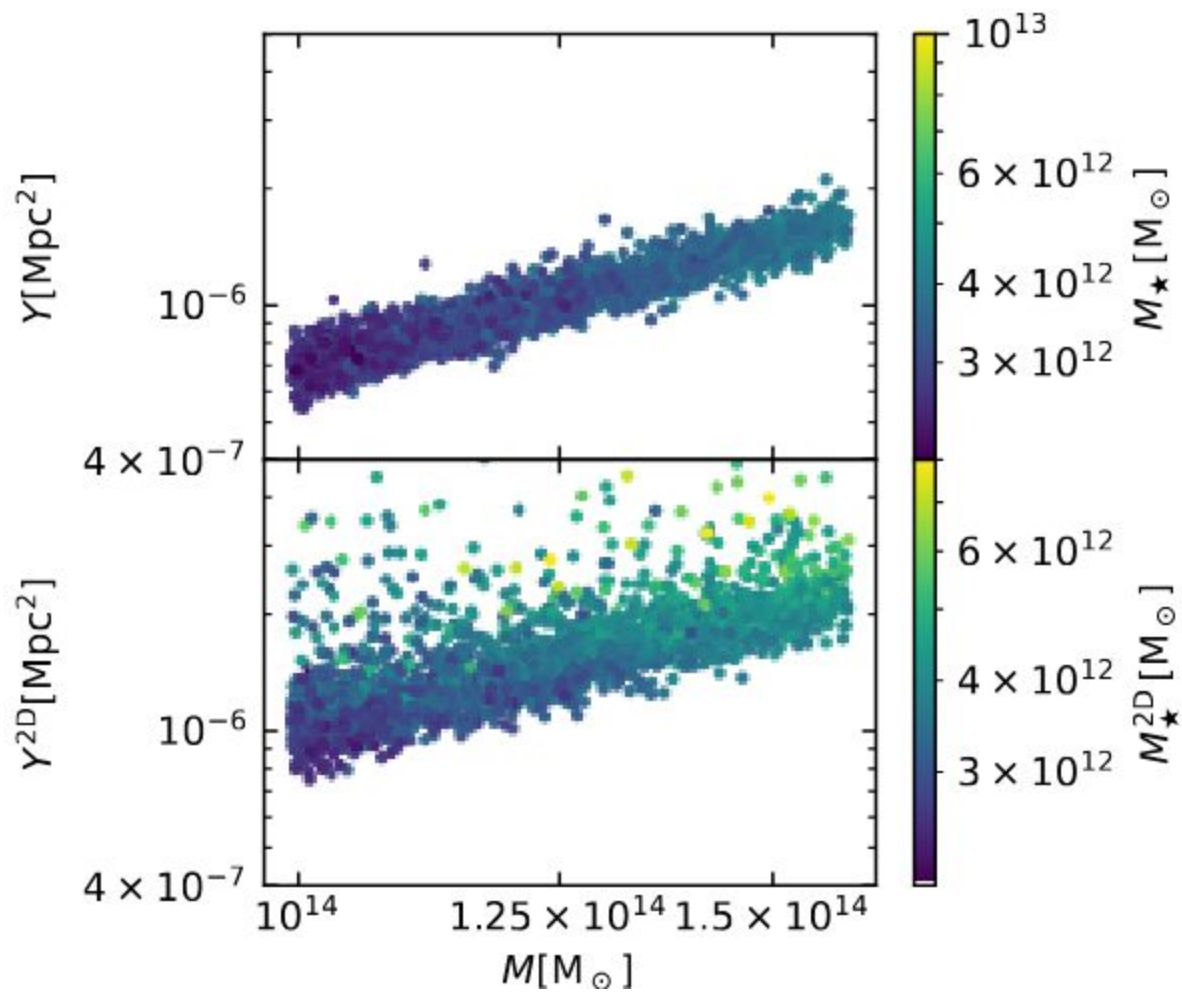
$$\langle \Delta \Sigma_{\text{gt}} \rangle (R) \simeq \frac{\langle \Delta \Sigma_t \rangle (R)}{1 - \langle \Sigma_{\text{cr}}^{-1} \rangle \langle \Sigma \rangle (R)}.$$

First: let's check how observables correlate with projection effects









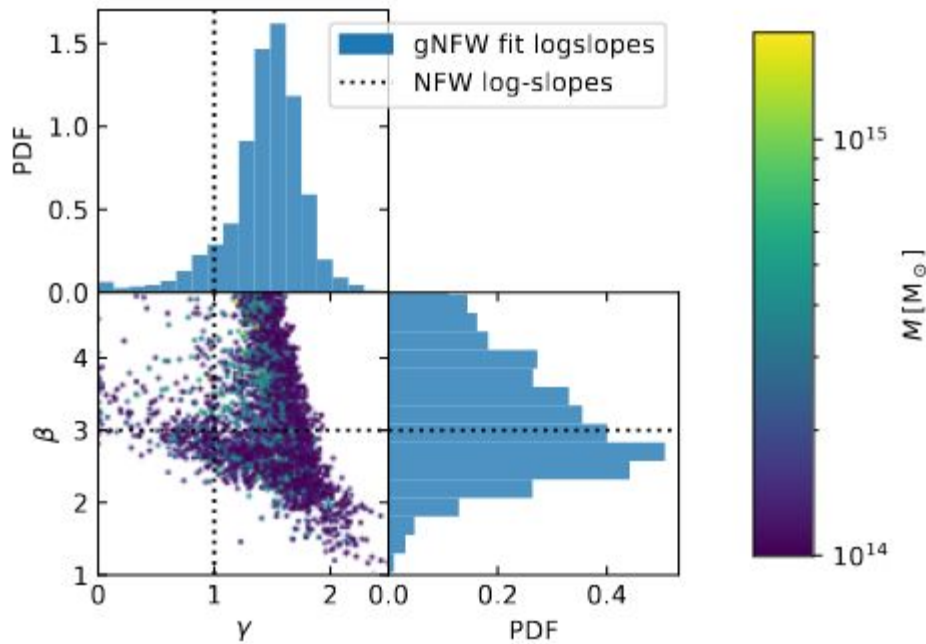


Fig. 9: Probability density distribution of the parameters  $\gamma$  (inner slope, upper panel) and  $\beta$  (outer slope, right panel) of Eq. (10) of the successful gNFW profile fits. The central panel shows the scatter plot between the two parameters colour-coded by  $M$ . The dotted lines show the NFW parameters  $\gamma = 1$  and  $\beta = 3$ .

$$\rho_{\text{gNFW}}(r) = \frac{\rho_0}{(r/r_s)^\gamma (1 + r/r_s)^{\beta-\gamma}}.$$

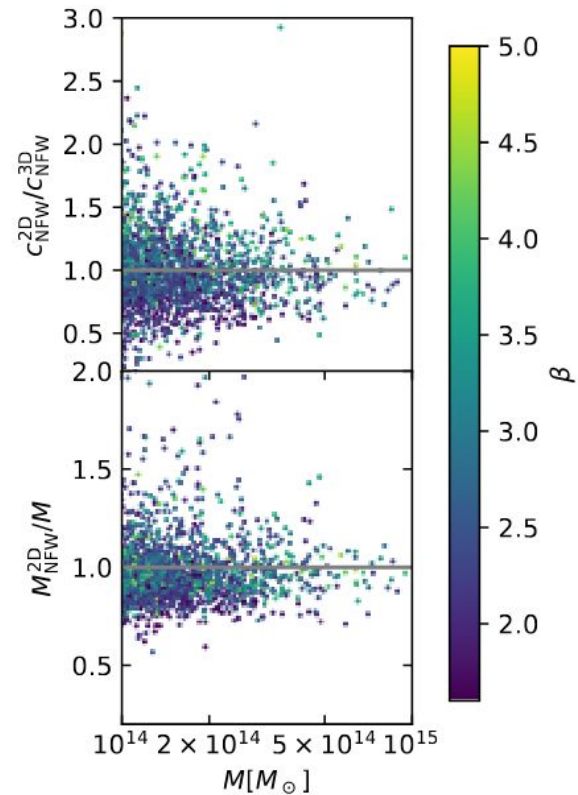
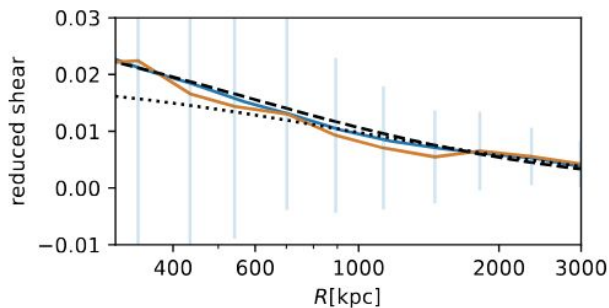
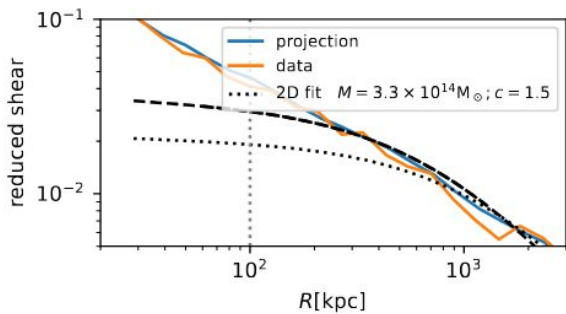
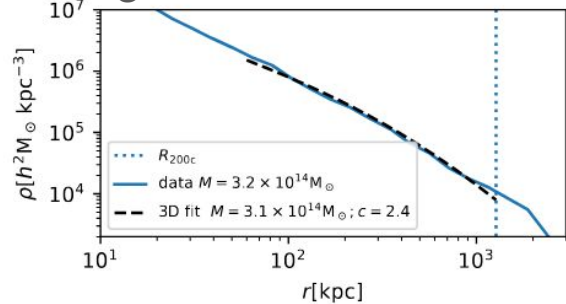
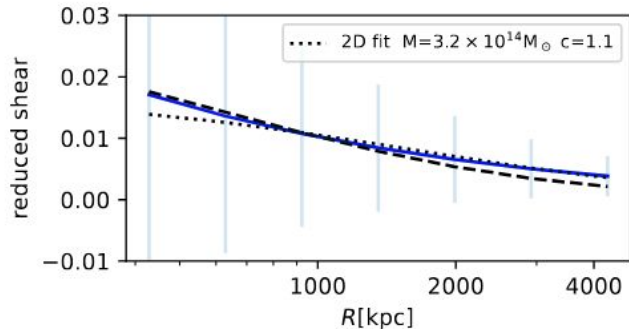
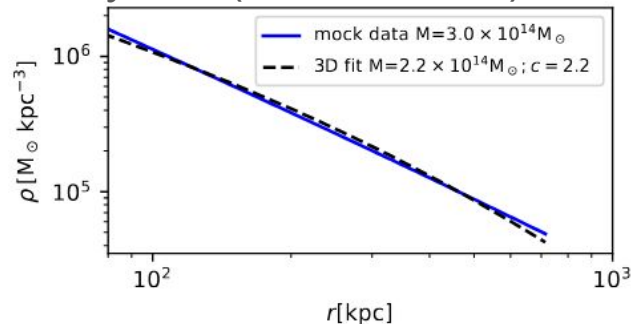


Fig. 10: Ratio between 2D NFW profile fit parameters and 3D parameters for haloes with a successful 3D gNFW profile fit. Upper panel: the ratio between concentrations; lower panel: the ratio between halo masses. Points are colour-coded by the external log-slope  $\beta$  of the 3D fit of gNFW.

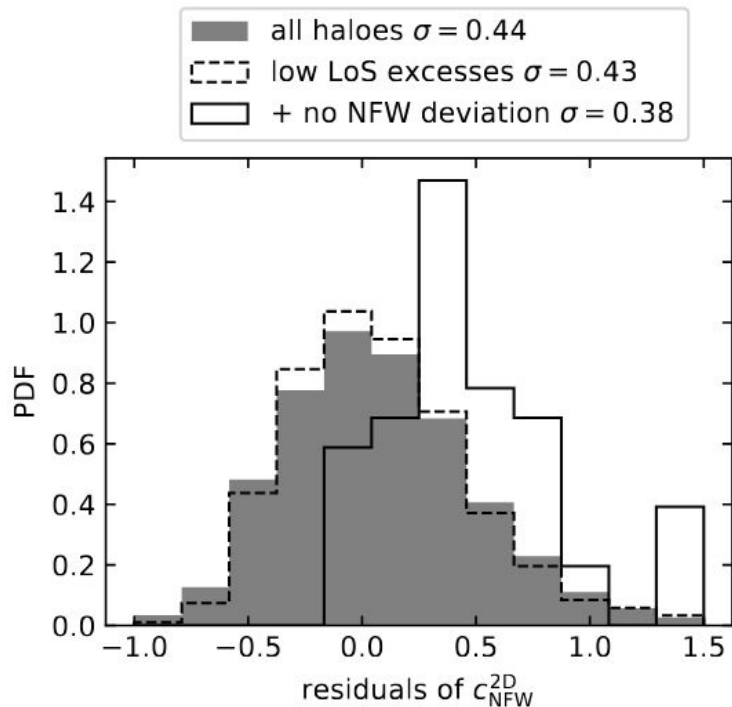
# Magneticum:



# analytical (thx colossus)

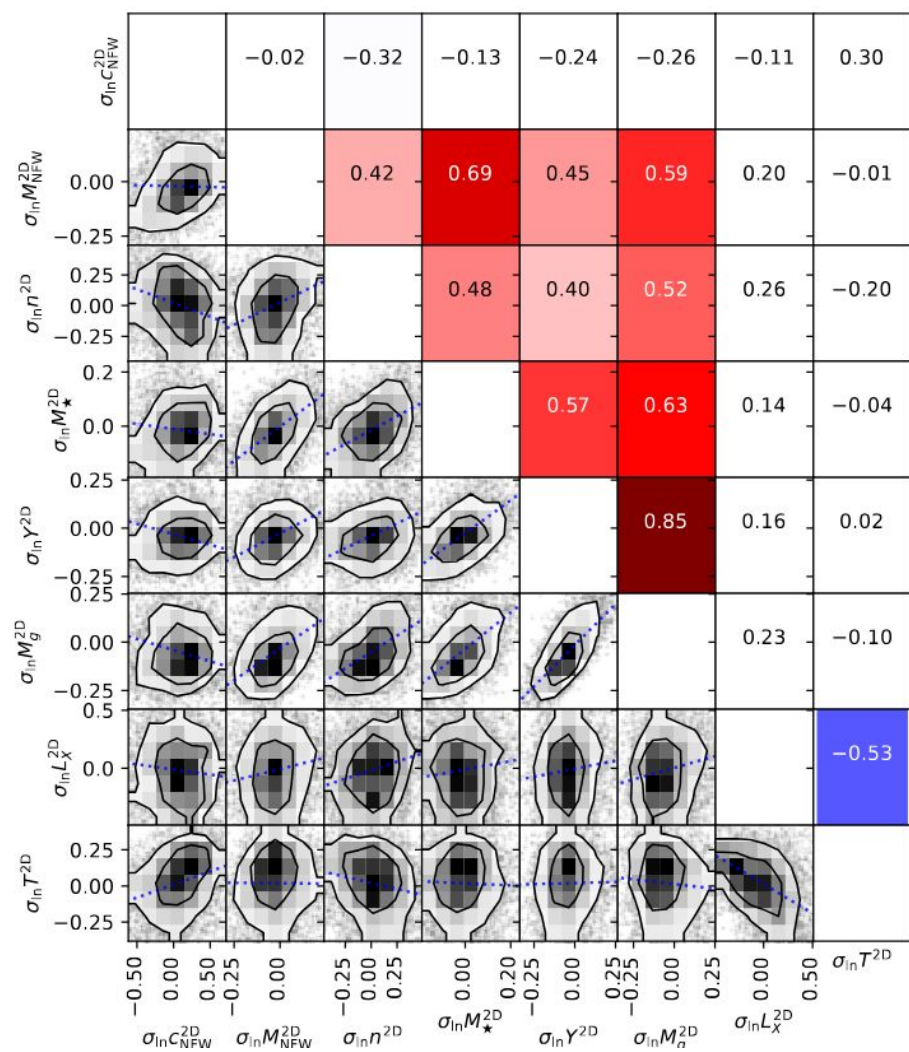


- deviation of fullphysics profiles from NFW do biased the final weak lensing concentration reconstruction
- this happens only in the reduced shear profile (3D is not affected)



**Fig. 11.** Residuals of lensing concentrations with respect to the power-law fit. As in Fig. 7, the dashed line histogram indicates the residuals for objects with low LoS effects (low value of  $M^{2D}/M$ ). The solid line histogram contains the additional constraints of halos with  $\beta$  and  $\gamma$  parameters close to the ones of an NFW profile ( $2.8 < \beta < 3.2$  and  $0.8 < \gamma < 1.2$ ). Each histogram label reports the scatter  $\sigma$  of the residuals.

Now: let's analyse the covariance between observables



- possible correlation can be observed: hot and cold baryon will strongly correlate
- is it because of projection effects?

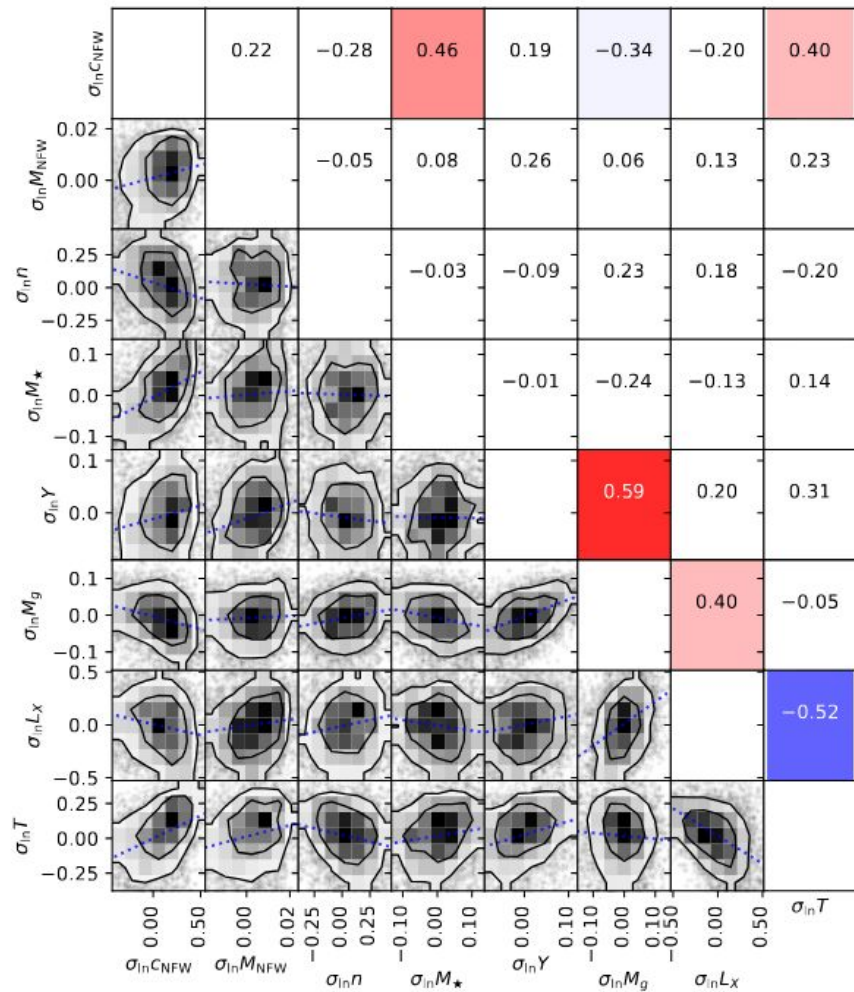
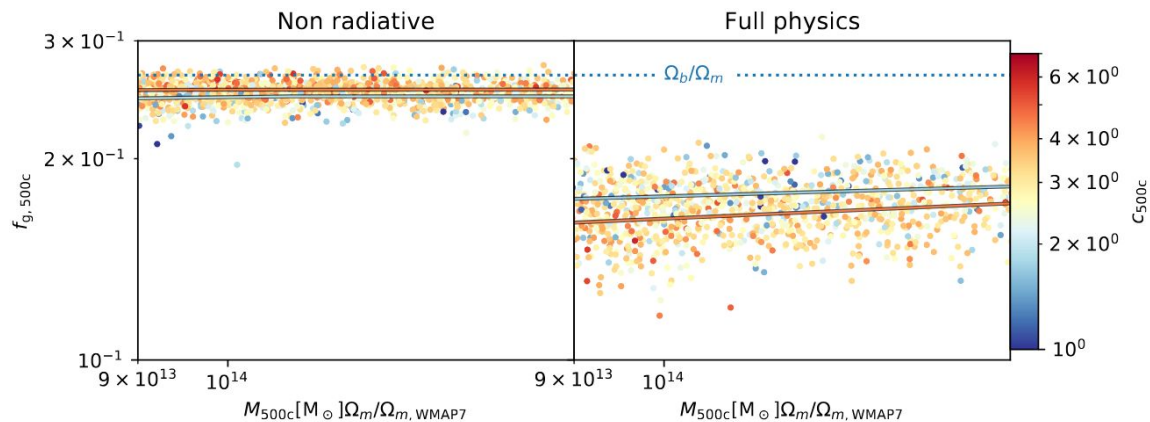
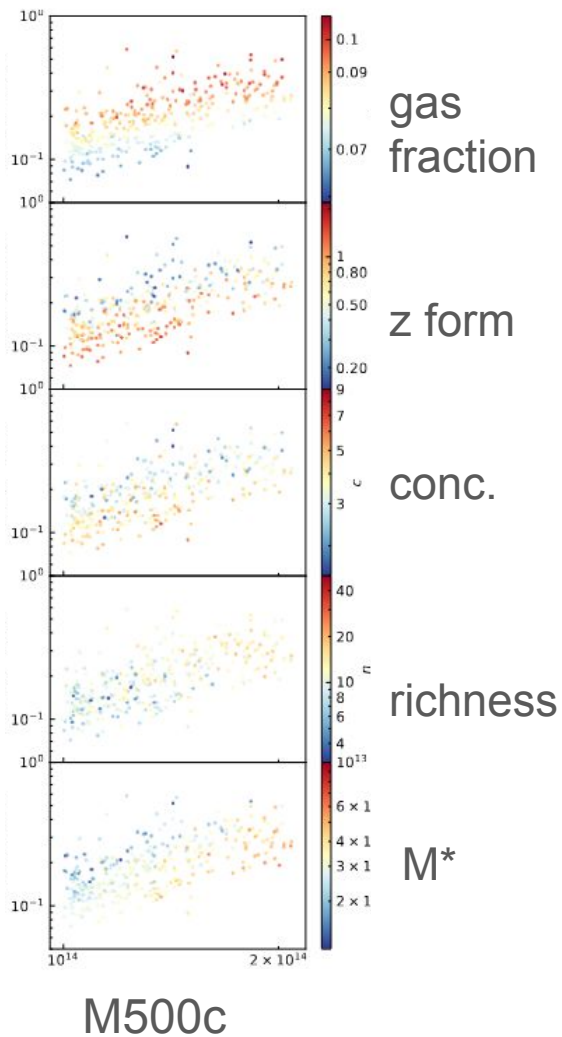


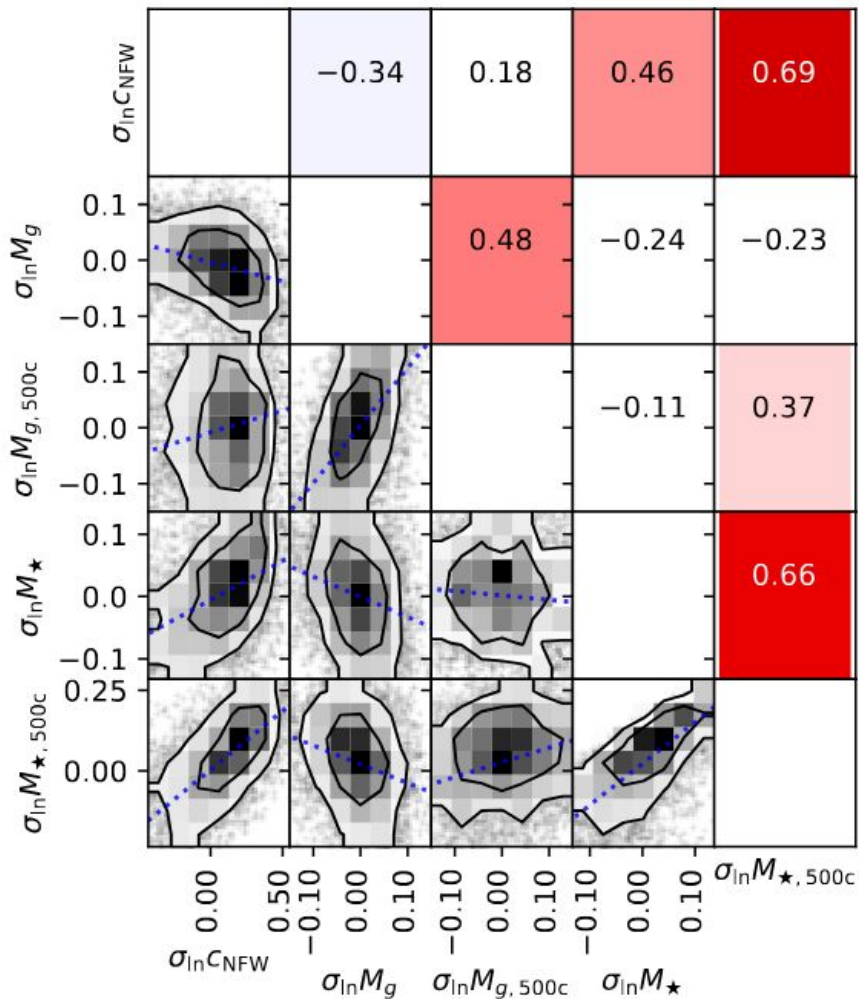
Fig. 14: As Fig. 13, here we show the quantities computed in the 3D space.

Y axis: Lx (from APEC, similar to Euclid paper, used Biffi tables)



**Fig. 8.** Gas fraction  $f_g$  vs. halo mass  $M_{500c}$  for Magneticum Box 1a/mr non-radiative run (*left panel*) and full-physics run (*right panel*). Points are colour-coded by concentration within  $R_{500c}$ . Lines show the average gas fraction for the two quantiles in gas concentration, up to 16% in blue, and from 85% in red, both coloured according to their average concentration. The non-radiative simulation shows a slight dependence of concentration on gas fraction, while full-physics runs show the opposite behaviour: the gas fraction is anti-correlated with concentration. Masses are corrected to WMAP7  $\Omega_m$  for consistency with the other results of this study.

see Ragagnin+22b



mixing observables from different apertures (500 and 200 crit) will add an additional bias on the sparsity! (thus, on dynamical state)

see the Ragagnin+25 appendix for more info

## 5 HALO SPARSITY

### 5.1 Definition

(see Balmes13)

We introduce the halo sparsity defined as the ratio of the halo mass measured at two different overdensities  $\Delta_1$  and  $\Delta_2$ ,

$$s_{\Delta_1\Delta_2} \equiv \frac{M_{\Delta_1}}{M_{\Delta_2}}, \quad (5)$$

# Conclusions

- 2D effects so important they can hide the intrinsic correlation between multi wavelength observables
- Mixing multiwave length observables on different apertures will add a correlation with the sparsity
- full physics simulation total mater profile deviation from NFW profile do impact the reduced shear (as opposed to the 3D case, where these deviations have no effect). This adds a bias in the mass-concentration reconstruction