The SZ-Mass scaling relation with The Sunyaev-Zeldovich Large Program of NIKA2 collaboration

Alice Moyer-Anin

On behalf of the NIKA2 collaboration

3rd year PhD student
Under the supervison of Frédéric Mayet

Cluster number count with SZ observations

The SZ Large Program of NIKA2

The SZ-Mass scaling relation

The LPSZ sample

Calibration method

Implication for cluster cosmology

Cosmology with the Sunyaev Zeldovich (SZ) effect

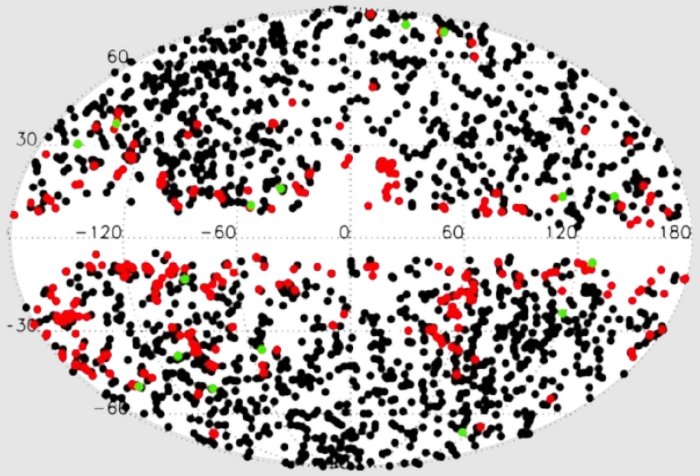
SZ thermal effect: CMB **distortion** related to the **electronic pressure** of the intra-cluster medium (ICM)

⟶ Compton parameter: $y = \frac{\sigma_T}{m_e c^2} \int P_e(r) dl$

Observable SZ Integrated quantity $Y_{SZ} \propto \int_0^{R_\Delta} y dS$

Tools SZ-Mass scaling relation

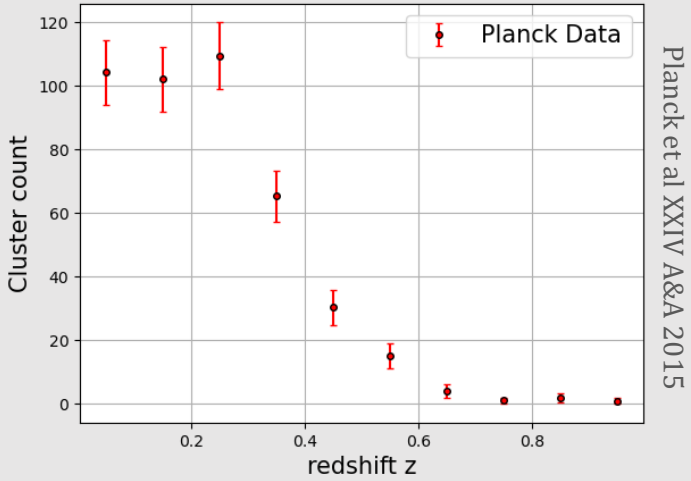
survey data
(Planck, SPT, …)



Planck et al XXVII A&A 2015

cluster catalog with SZ observations

Cluster number count



Planck et al XXIV A&A 2015

➔ **Constraint on cosmology** σ_8 and Ω_m

The SZ Large program of NIKA2

NIKA2 high-resolution camera (KIDs)

Installed at the IRAM 30 m telescope in Granada

Operating since 2017

ν observation	150 GHz	260 GHz	
Resolution	17.6'' ± 0.1''	11.1'' ± 0.2''	Resolved inner parts of clusters
Field of view	6.5'	6.5'	Full maps of the clusters

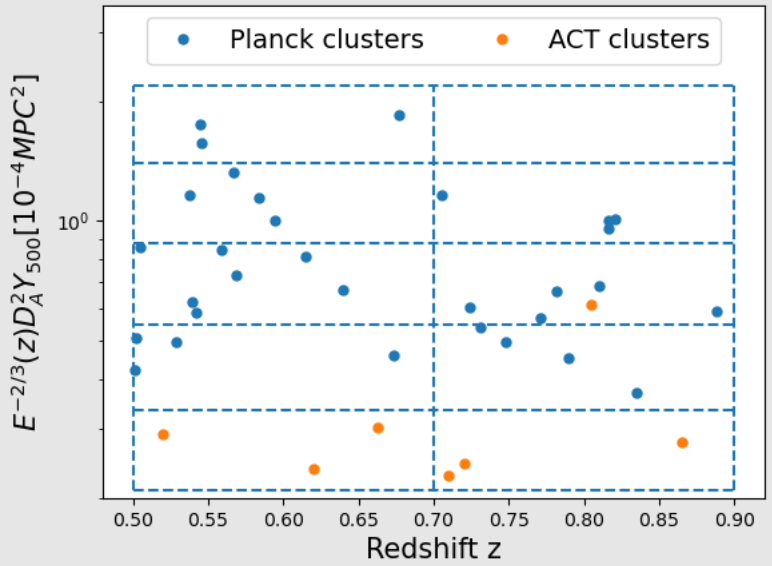
Adam *et al.* 2018
Perotto *et al.* 2020

→ *See Frédéric Talk*

SZ Large Program (observations finished in 2023)

Sample of 38 clusters fully observed

Selected with a box selection →



Box selection → insensitive to the underlying mass distribution

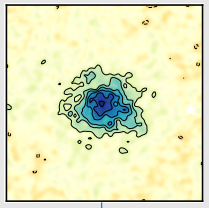
→ Suffisant range in Y_{500} and M_{500}

Clusters observed both in **SZ** (NIKA2) and **X-ray** (XMM Newton)

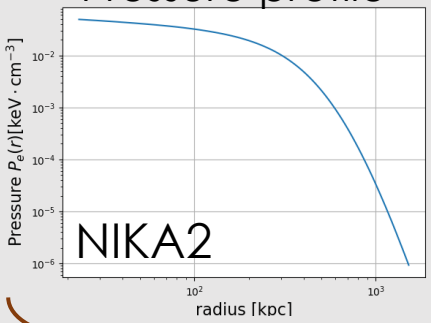
LPSZ official pipeline: PANCO2

Panco2 Kéruzoré *et al* TheOJA 2023

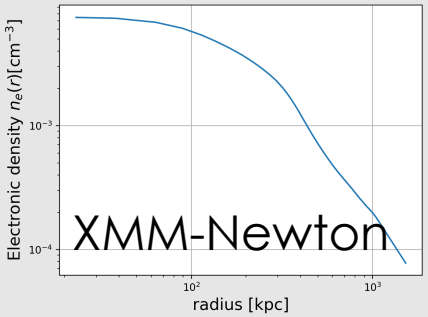
Map at 150 GHz



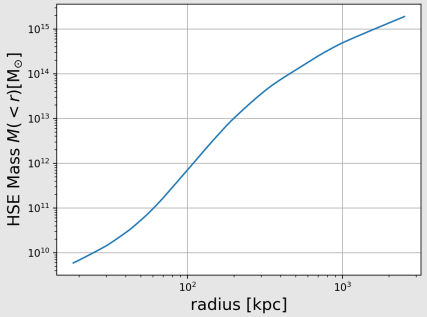
Pressure profile



Density profile from X data

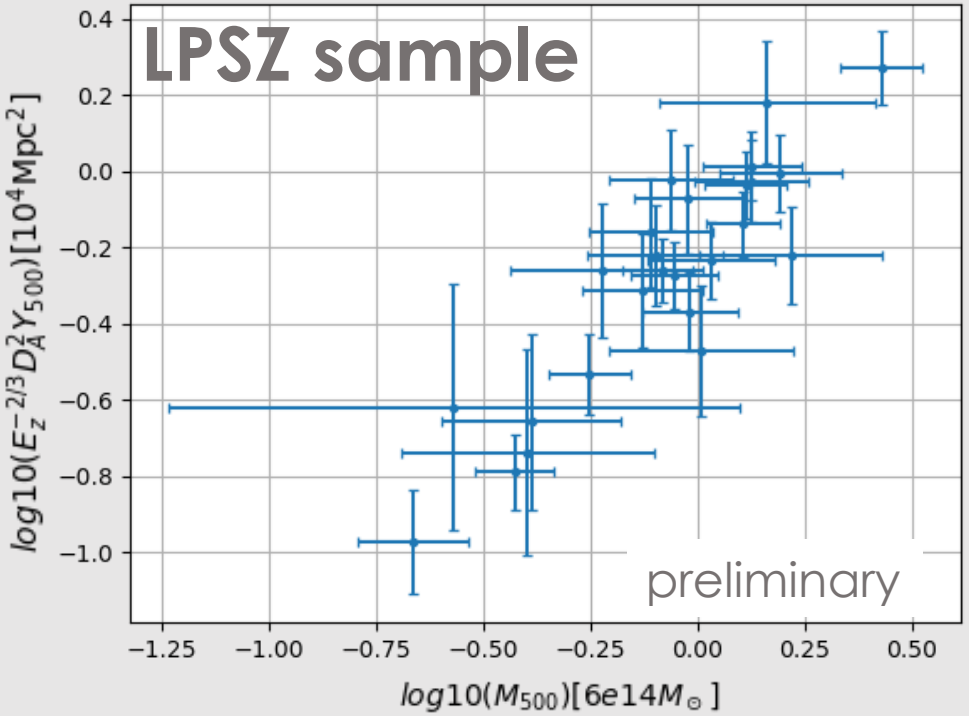


HSE Mass profile



Integrated quantities for 29 clusters : Y_{500}, M_{500}

M_{500} : integration up to R_{500}
Y_{500} : integration up to R_{500}
R_{500} : radius of a sphere of density 500 times ρ_c



➔ Used to calibrate the scaling relation

SZ scaling relation

$$E_z^{-2/3}\left(\frac{D_A^2(z)Y_{500}}{10^{-4}\mathrm{Mpc}^2}\right) = 10^{\alpha}\left(\frac{M_{500}}{6\times10^{14}M_{\odot}}\right)^{\beta}$$

Assumptions :
- spherical assumption
- hydrostatic equilibrium
- ideal gas assumption

In fact $P\left(\log(Y_{obs})|\log(M_{obs})\right) = \mathcal{N}\left(\alpha+\beta\log(M_{obs}),\sigma_{int}^2\right)$

three parameters

- α the intercept
- β the slope
- σ_{int} the scatter

different SZ-HEMass scaling relations:

	Planck 2013	Chandra-Planck 2024	NIKA2-LPSZ 2025
Data	XMM-Newton Planck	Chandra Planck	XMM-Newton NIKA2 + Planck
redshift	[0,0.45]	[0,0.35]	[0.5,0.9]
sample size	71	146	29
resolution	X : 6.6'' SZ : ~6 '	X : 0.2'' SZ : ~6'	X : 6.6'' SZ : 17.6''
mass estimation	derived X Mass	derived X Mass	SZ-X Mass

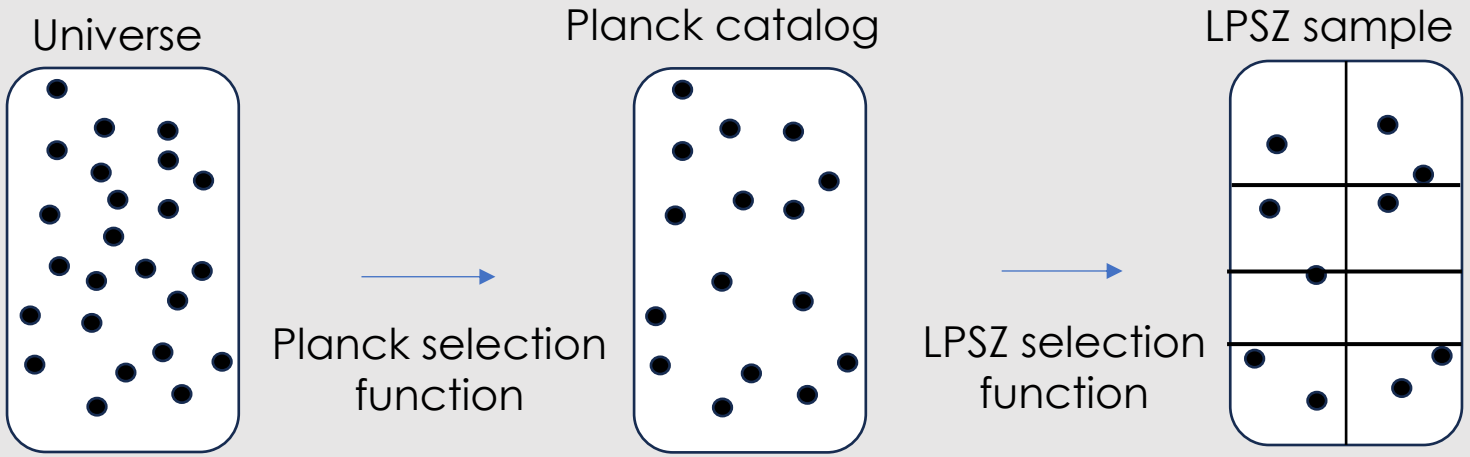
Planck 2013 results XX A&A G. Aymerich et al. A&A 2024

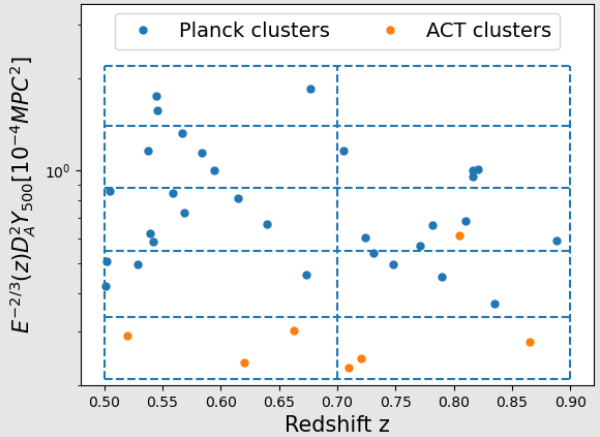
NIKA2-LPSZ

Aim: obtain a **scaling relation**
- At larger redshift
- With controlled systematics

including cluster morphology

LPSZ selection function



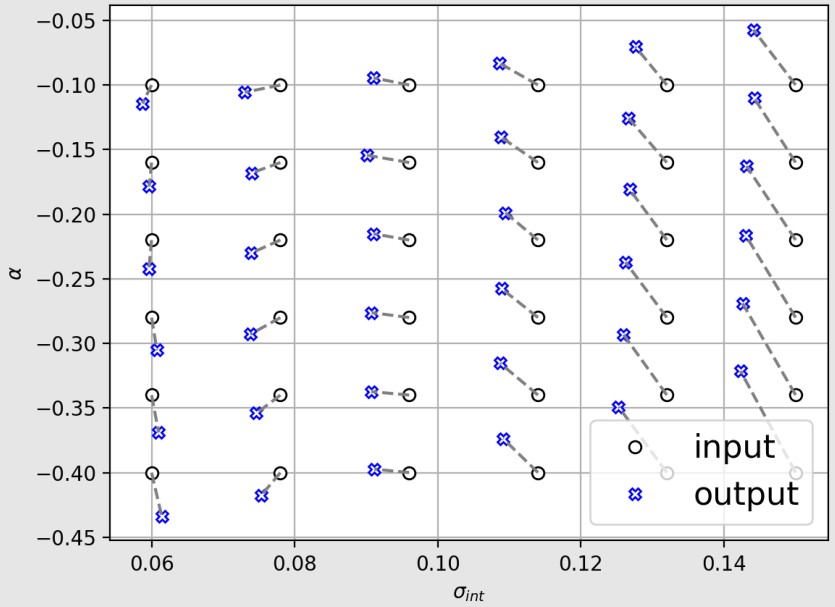


LPSZ selection function

Box selection → insensitive to the underlying mass distribution

→ No effect of Planck selection function

Effect of the LPSZ selection function



Problem: the box selection induces a shift on our parameter estimation
(as all selection functions)

How to take into account the LPSZ selection function?

Scaling relation LPSZ pipeline

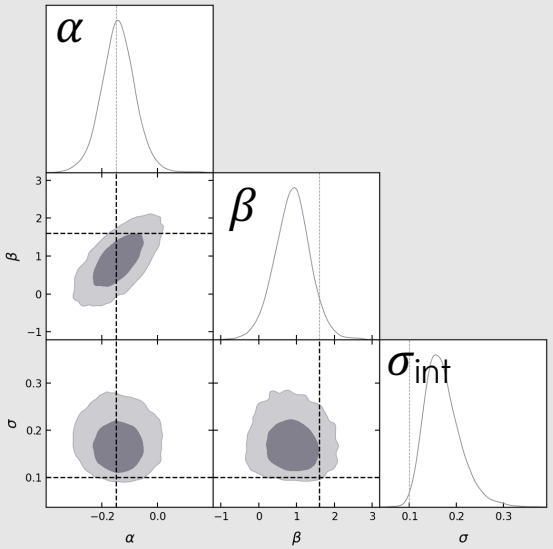
Tools

LIRA M. Sereno MNRAS (2016)

LInear Regression in Astronomy

Main characteristics:

- Gibbs sampling
- Bayesian hierarchical methods



Inputs:

Y_{500} and M_{500}

ρ_{cov} between Y_{500} and M_{500}

Error on Y_{500} and M_{500}

Output:

Pdf of α, β and σ_{int}

Box selection taken into account

SBI A . Tejero-Cantero et. al. JOSS (2020)

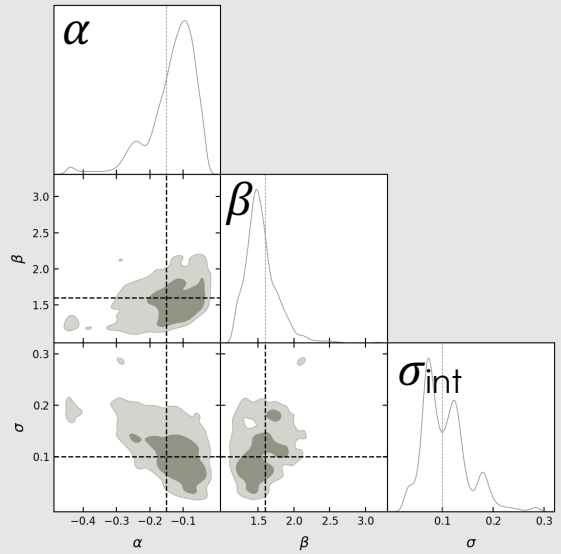
Simulation Based inference

Main characteristics:

- Based on Normalizing flow
- Likelihood free inference

Training with simulations

Gives $p(\theta \mid X)$ following X=LIRA outputs θ=Scaling relation



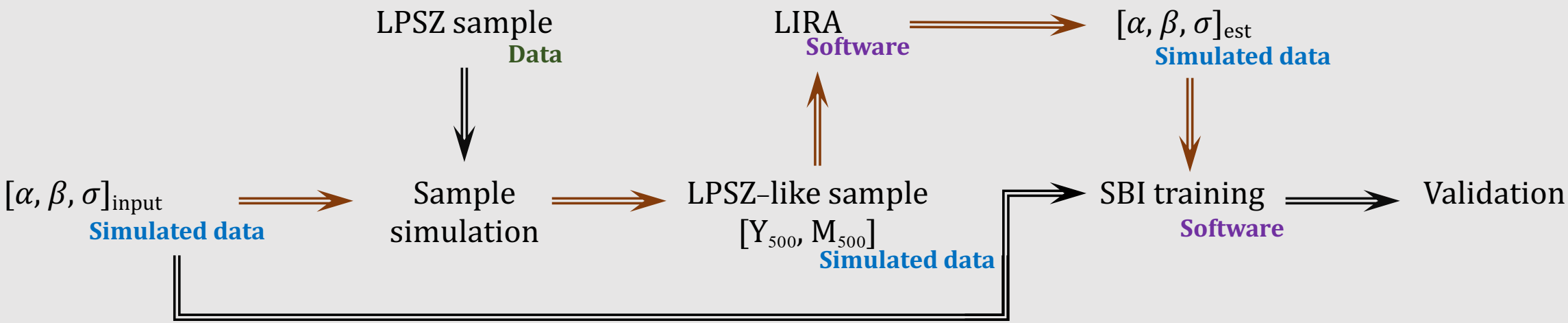
Input:

α, β and σ LIRA estimation

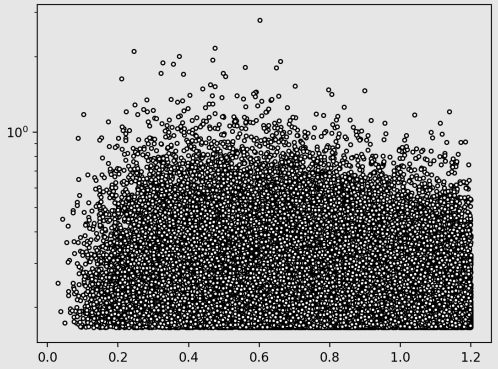
Output:

Pdf of underlying α, β and σ_{int}

Scaling relation LPSZ pipeline: SBI training

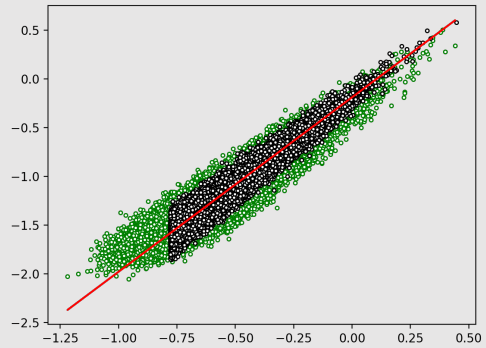


Sample simulation



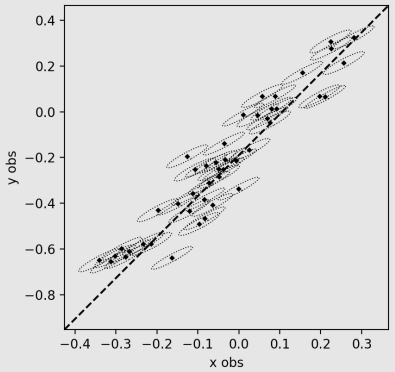
Mass redshift catalog

$[\alpha, \beta, \sigma]_{input}$



Catalog with known scaling relation

LPSZ
Box selection



LPSZ–like sample
$[Y_{500}, M_{500}]$

Can we trust the estimation with our pipeline?

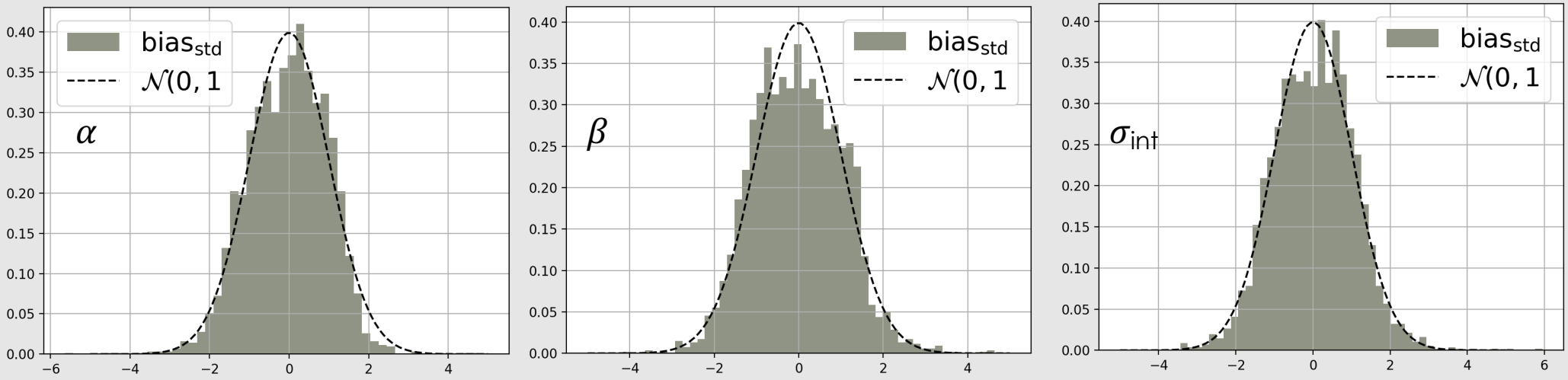
Preliminary Results: Validation

$$P\left(\log(Y_{obs})|\log(M_{obs})\right) = \mathcal{N}\left(\alpha + \beta\log(M_{obs}), {\sigma_{int}}^2\right)$$

Thanks to the method developped ➔ non-biased Scaling relation estimation

Validation metrics : $\mathrm{bias_{std}} = \dfrac{\alpha_{\mathrm{SBI}} - \alpha_{\mathrm{True}}}{\mathrm{std_{SBI}}}$ For a range of scaling relations

If $\mathrm{bias_{std}} \in [-2, 2]$ means input values within 2 σ error bars of SBI outputs

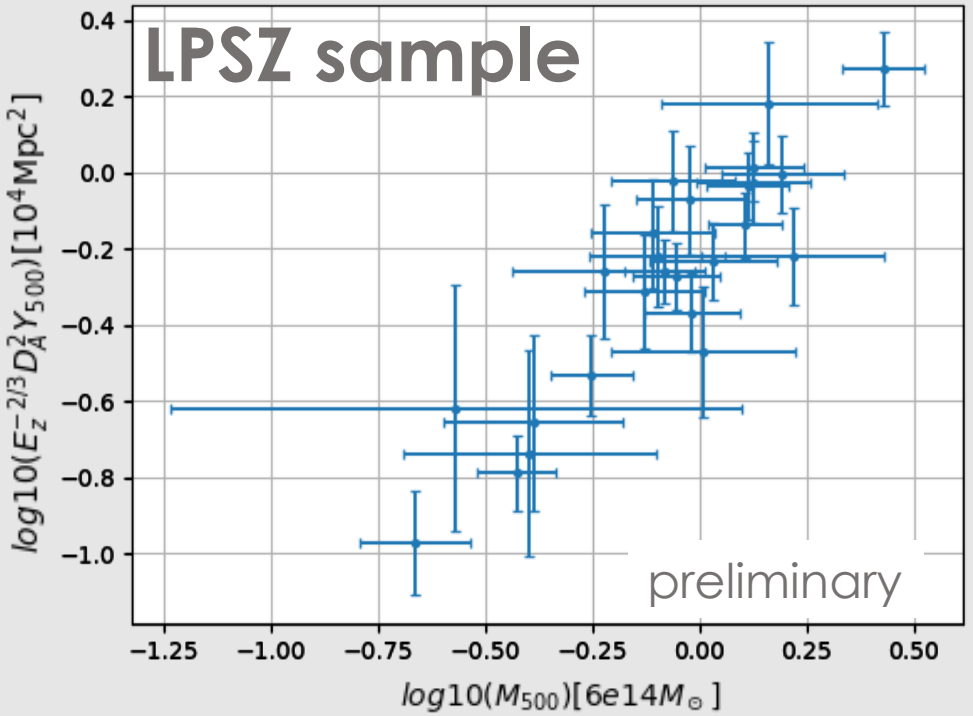


α, β and σ **unbiased** and with **coherent error bars**

Method validated for several scaling relations

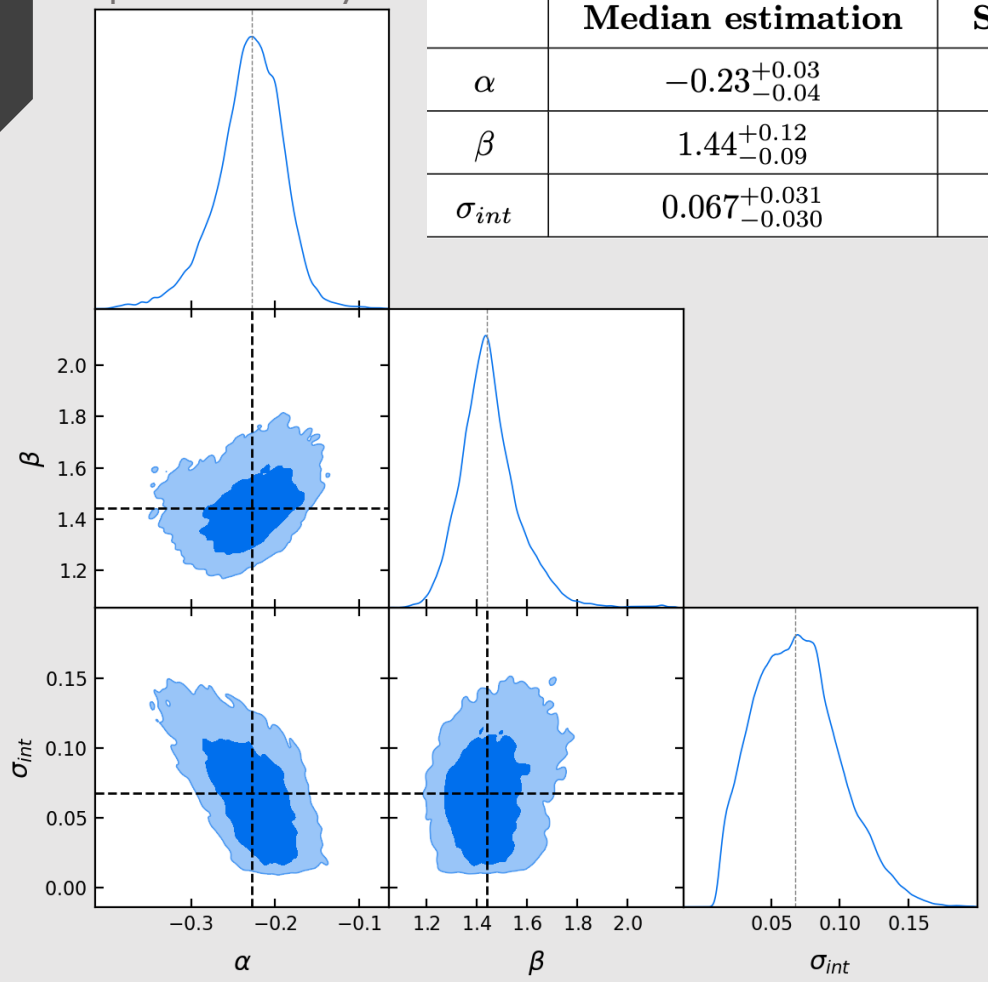
Method validated ✓

Applied on the LPSZ sample

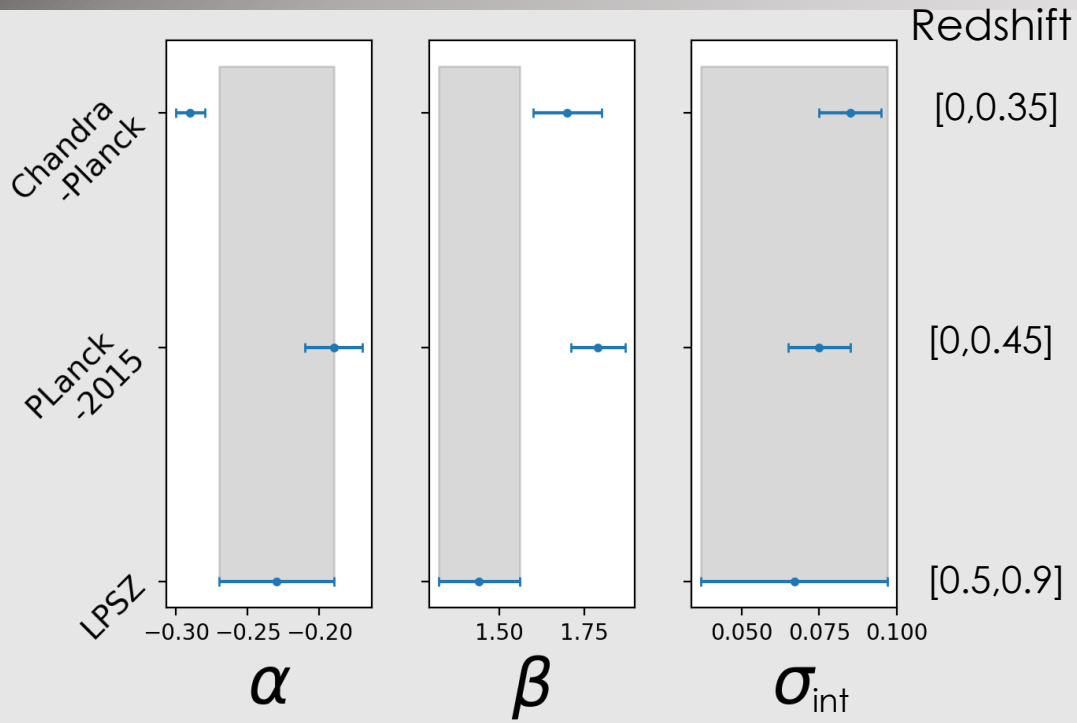


LPSZ preliminary result

preliminary



	Median estimation	Standard deviation
α	$-0.23^{+0.03}_{-0.04}$	0.04
β	$1.44^{+0.12}_{-0.09}$	0.12
σ_{int}	$0.067^{+0.031}_{-0.030}$	0.030



Planck 2013 results XX A&A
G. Aymerich et al. A&A 2024

Bigger errorbars

- Smaller sample
- Direct SZ-X Mass estimate

Smaller β value

- Hint of redshift evolution?

Application to cosmology

Sample used: Planck 2015 sample
Planck XXIV A&A (2015)

Analysed with Class-sz B. Bolliet et. al. EPJ Web Conf. (2024)
collaboration with B.Bolliet

LPSZ scaling relation

Planck scaling relation

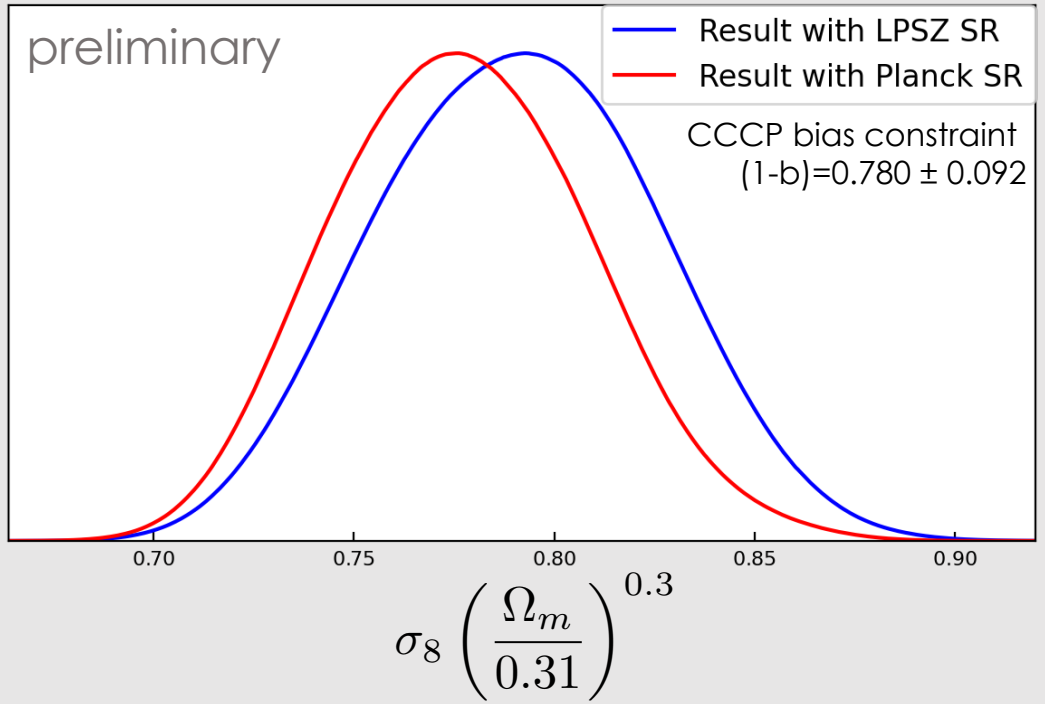
➔ Applied on same cluster catalog

Cosmological result

→ Comparison with Planck result

→ Combined parameter in agreement with Planck result

Planck scaling relation	0.777 ± 0.032
LPSZ scaling relation	0.791 ± 0.35

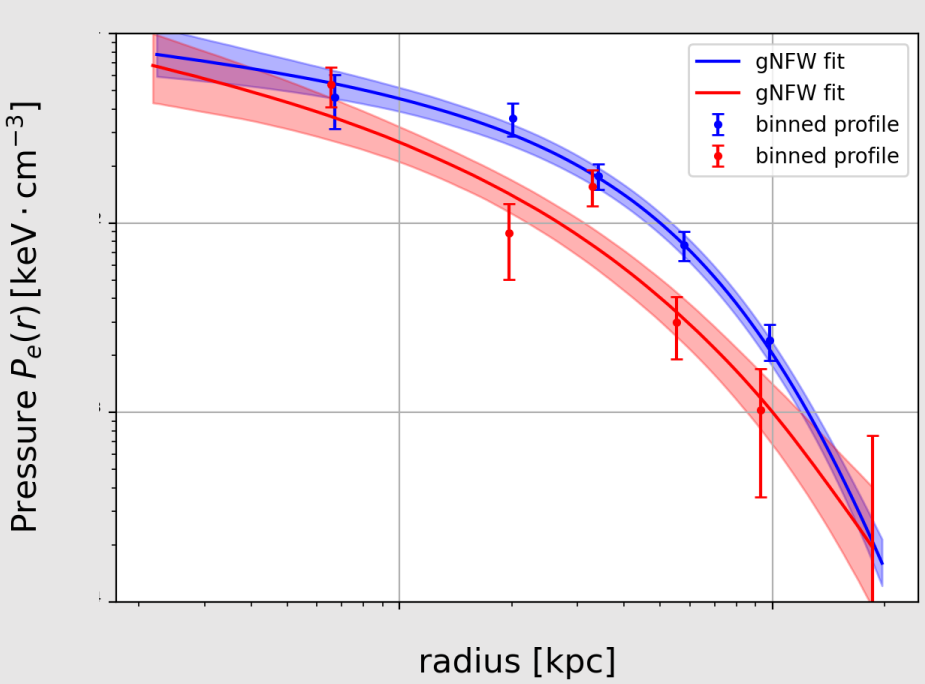


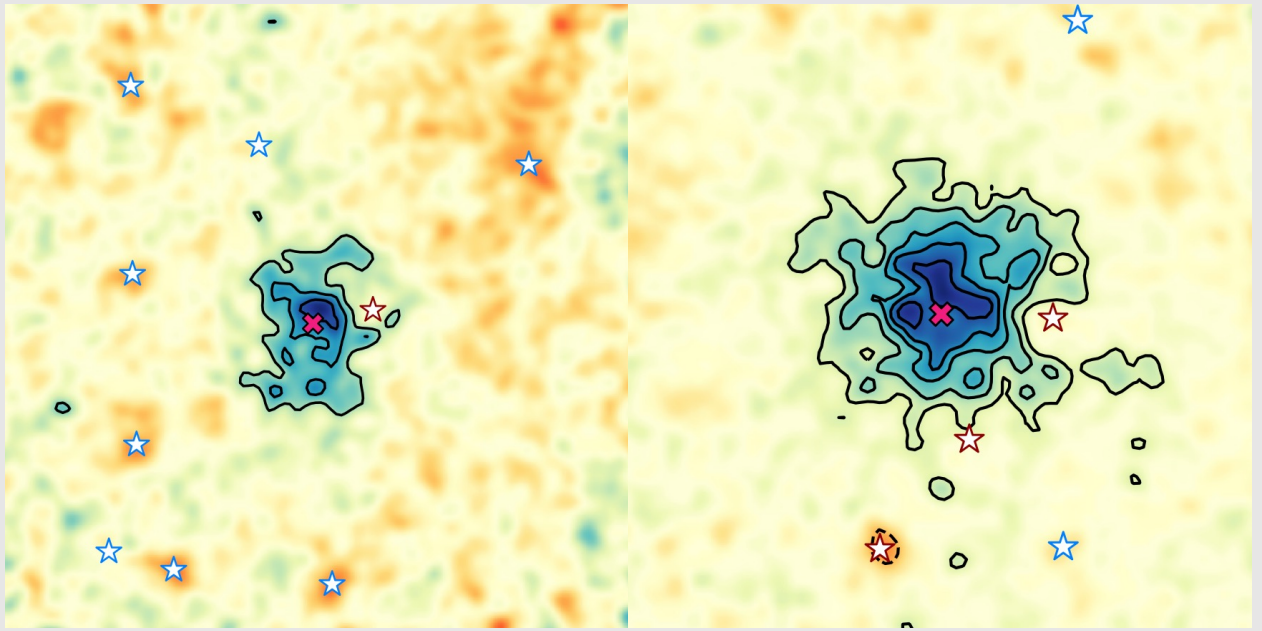
Conclusion

- An unbiased Scaling Relation pipeline
- Robustness test done
- First result of the scaling relation with
    - High angular resolution observations
    - Intermediate to high redshift clusters

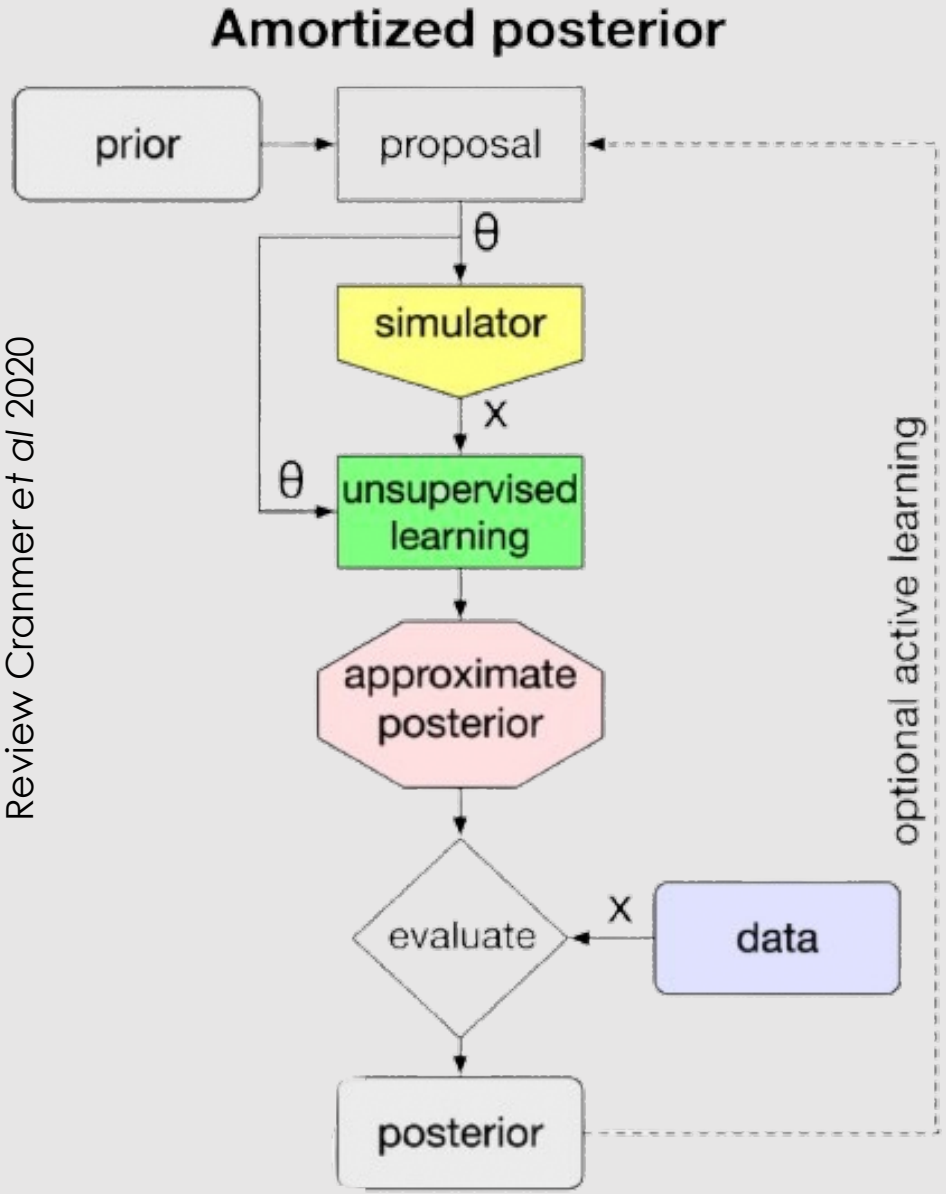
        → Paper in preparation
- Cosmological results
    - Combined parameter in agreement with Planck result

Thank you


gNFW fit
gNFW fit
binned profile
binned profile
Pressure $P_e(r)$ [keV · cm^{-3}]
radius [kpc]



Simulation based inference



Review Cranmer *et al* 2020

Several SBI type : here the SNPE is used

Sequential Neural Posterior estimation

→ Gives an estimation of the posterior given an observation $p(\theta \mid X)$

➔ $\theta = [\alpha_{True}, \beta_{True}, \sigma_{True}]$
➔ $X = [\alpha_{LIRA}, \beta_{LIRA}, \sigma_{LIRA}]$

For a given obs : the SBI will give all the model parameters that can reproduce this observation (distribution)

Comparison between observed and simulated data
→ Posterior estimation $p(\theta \mid X)$

Simulator: Same simulation as before: sample Y_{500}-M_{500}