Systematic effects in Y-M scaling relation

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On behalf on Nika2 collaboration

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Under the supervison of Frédéric Mayet

Plan

- Cluster cosmology
- Y-M Scaling relation : definition and state of the art
- NIKA2 SZ Large Program (LPSZ)
- Systematic effects on the LPSZ scaling relation related with
    - Selection function
    - white and correlated noise

Clusters cosmology

Constraining cosmological parameters with galaxy clusters

Cluster number count can constrain some parameters: $\frac{dN}{dMdz}$ ➔ need **redshift** and **mass**

BUT Mass is not an observable

Then ➔ scaling relation relating observable and mass

Several large scale surveys observe in millimeter domain (Planck, ACT, SPT, …, SO, CMBS4)

→ They can detect clusters with the SZ effect (CMB distortion)

assets : SZ redshift independant

SZ have a distinct spectral feature

SZ observable: Y_{500}

integrated Compton parameter up to R_{500}

HSE Cluster mass: M_{500}

mass inside a sphere with density equal to $500\rho_c$

} Scaling relation linking Y_{500} and M_{500}

Y-M scaling relation

Power law between Y_{500} and M_{500} :

$$H^{\frac{2}{3}}(z)Y_{500} = 10^{\alpha} M_{500}^{\beta}$$

Underlying theory :
- spherical assumption
- ideal gas assumption
- hydrostatic equilibrium

→ α = -0.33 β = 5/3

In reality $\boldsymbol{P(log\,(Y_{500})|log(M_{500})) = N(\alpha + \beta log(M_{500}), \sigma^2)}$ deviation due to complex physic processes

σ : Intrinsic dispersion

3 parameters α, β, et σ

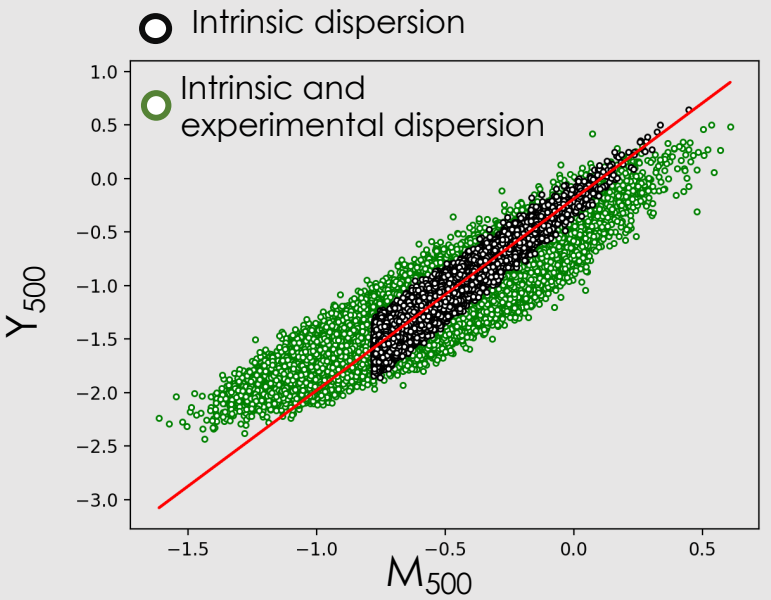
Why σ is important?

- Define the quality of the mass proxy (together with the bias)
- Must be taken into account for cluster cosmology

But it is difficult to measure

↓

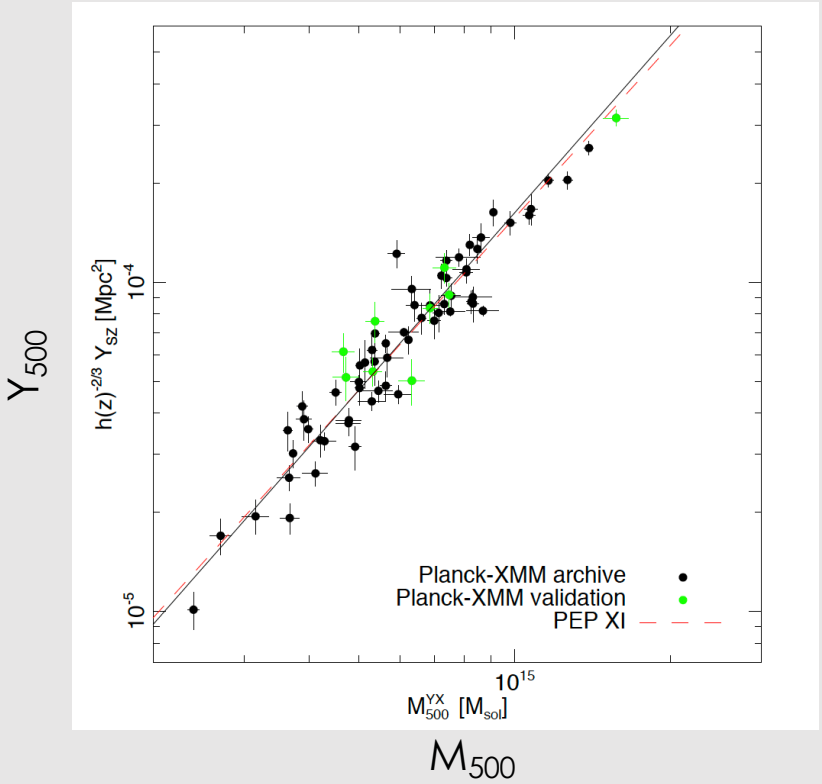
2 different dispersions → **intrinsic** dispersion
→ **experimental** dispersion



Challenge : estimate the intrinsic dispersion

Planck collaboration estimation

Planck 2013 results XX A&A



Planck collaboration estimation :

α = -0.19 ± 0.02 β = 1.79 ± 0.08 σ = 0.075 ± 0.01

- Data from Planck + XMM-NEWTON (REXCESS)
- Estimated with low redshift clusters (z<0.45)
- indirect link between Y_{500} and M_{500}

  Mass computed from X data only

  Compton Parameter integrated up to R^X_{500} and X centered relation between Y_{5R500} and Y_{R500}

71 clusters

NIKA2 LPSZ

38 clusters selected from Planck and ACT catalog

Aim: Estimate

- the scaling relation
- The mean pressure Profile (See C. Hanser talk)

NIKA2 LPSZ estimation :

- Data from NIKA2 + XMM-NEWTON + Planck
- High redshift clusters (0.5-0.9)
- resolved clusters (use clusters morphology)
- Direct link between Y_{500} and M_{500} (HSE)

Aim: obtain a scaling relation
- At larger redshift
- With more understandable systematics

Sample observed with NIKA2 Camera: high resolution camera
In Granada Pico Veleta
IRAM 30-m telescope

λ observation	1.2 mm	2 mm
Resolution in arcsec	11.1 ± 0.2	17.6 ± 0.1

L. Perotto et al., A&A 2020

NIKA2 map : cluster substructures can be seen More information for systematic effects

NIKA2 Large Program SZ

Example of NIKA2 resolution : PSZ2G144 F.Ruppin et al., A&A 2018

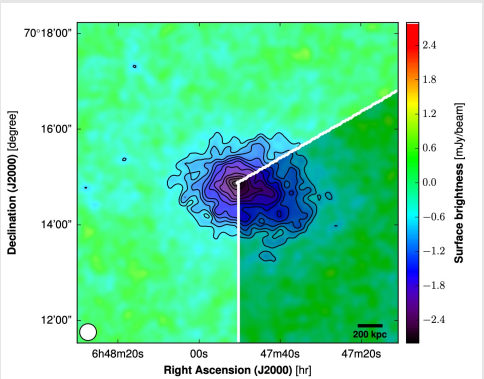
Cluster with an overpressure region

- cluster analysed entirely (with the overpressure)
- cluster analysed without the overpressure part (mask)

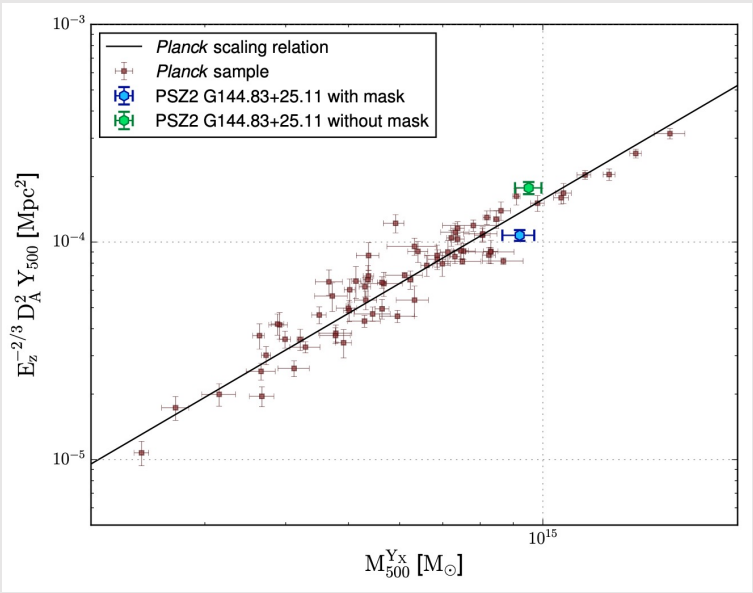
Mass changes with or without the mask

→ Change in M-Y plan

→ Induces a systematic effect

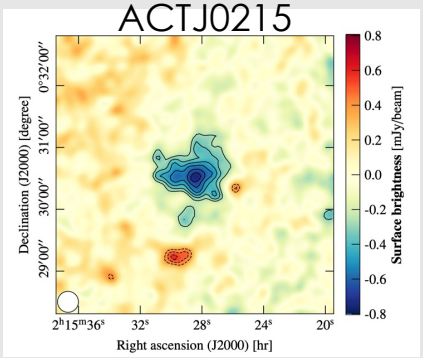


PSZ2G144



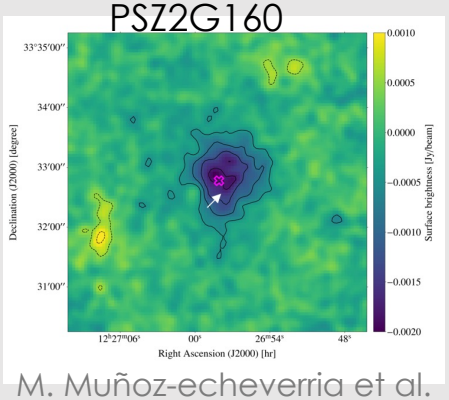
F.Ruppin et al., A&A 2018

ACTJ0215



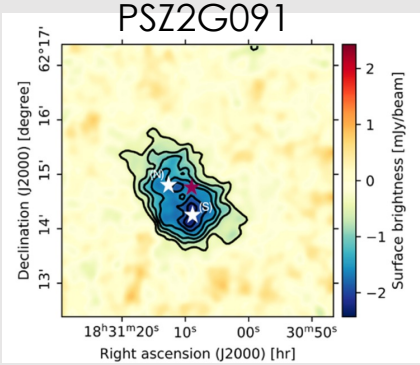
F. Keruzoré et al. A&A 2020

PSZ2G160



M. Muñoz-echeverria et al. A&A 2023

PSZ2G091



E. Artis et al., EPJ Web of conference 2022

Some clusters have complex morphologies ➔ deviation from HSE assumptions
(double, substructures, elliptical)

➔ Impact on scaling relation? On cosmology?

LPSZ selection function

LPSZ selection function :

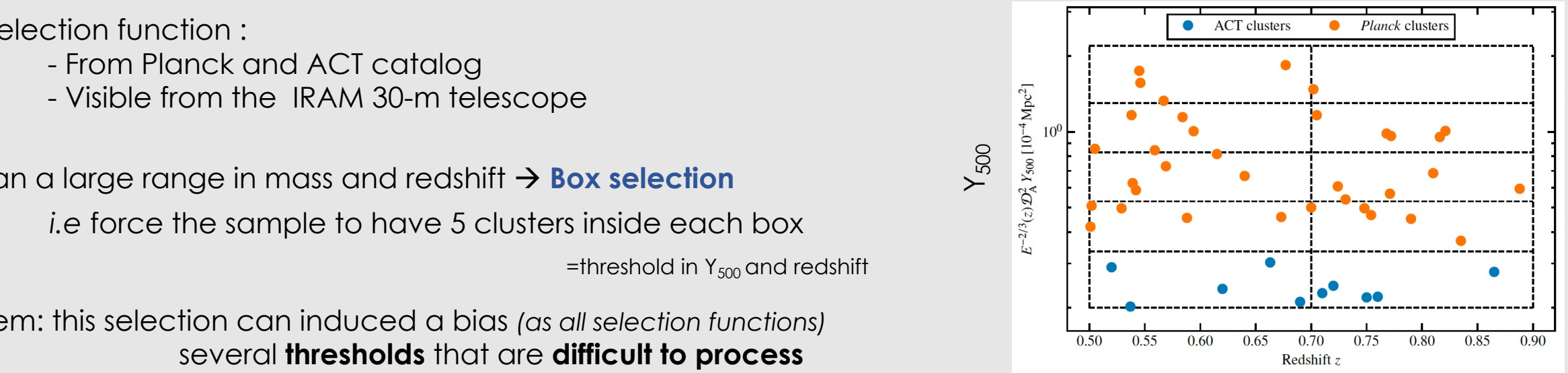
- From Planck and ACT catalog
- Visible from the IRAM 30-m telescope

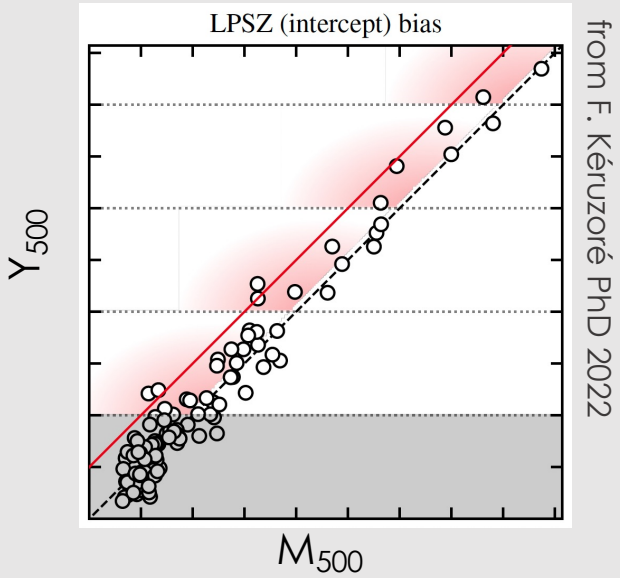
To span a large range in mass and redshift → **Box selection**

i.e force the sample to have 5 clusters inside each box

=threshold in Y_{500} and redshift

Problem: this selection can induced a bias *(as all selection functions)*
several **thresholds** that are **difficult to process**





4 thresholds in Y_{500}

→ Can not consider each threshold in the analysis

- One cluster below the threshold can still be in the sample

→ 4 *Malmquist-like bias* for each box

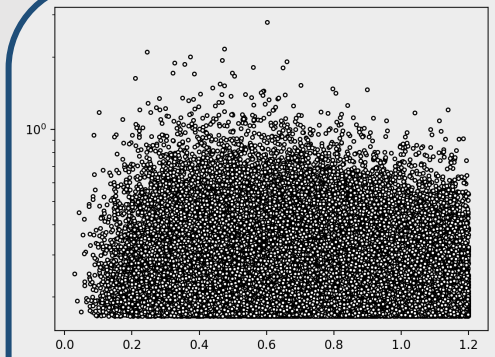
➔ Induces a bias on parameter α the intercept

Study of systematic effects

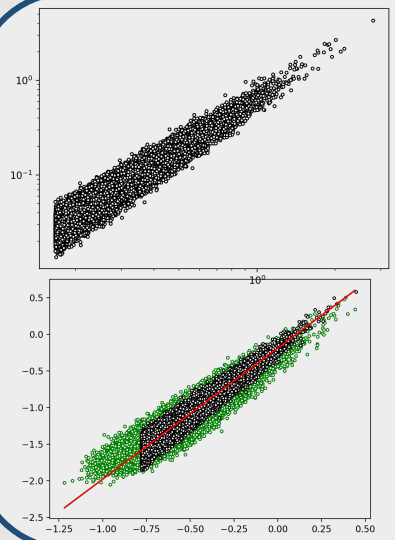
Systematic effects of the NIKA2-LPSZ scaling relation

- sample simulations
  - accounting for the box selection effect
- Estimating scaling relation parameters with LIRA code
- Identification and correction of systematic effects

Sample simulation



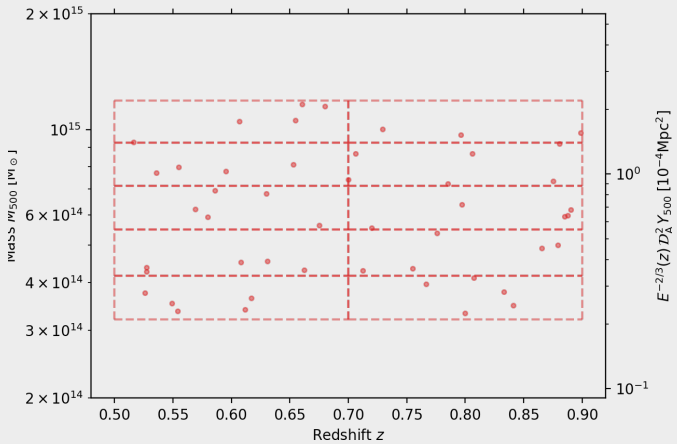
M_{500}-z catalog
Tinker et al., A&A 2010



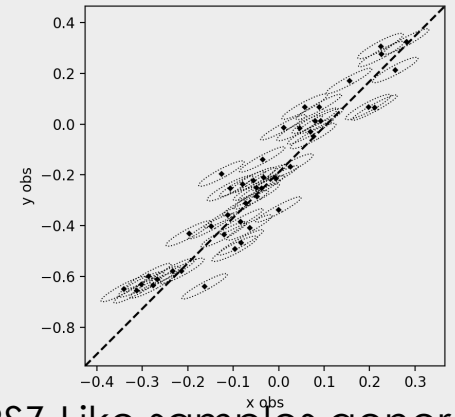
Y_{500} attribution from M_{500} and z
From chosen scaling relation
α β σ

Error bars simulation :
New value drawn inside error bar
Errors, correlation between Y_{500} and M_{500}

Simulation parameters



Box selection (LPSZ-like)
Distribution inside boxes

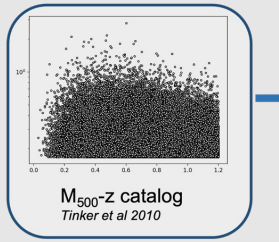


LPSZ-Like samples generated with known scaling relation

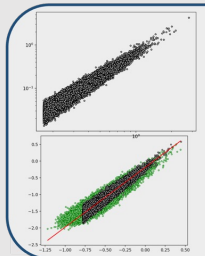
Method from F. Kéruzoré PhD 2022

Sample simulation

Need statistics to estimate the systematics → 5000 samples regressed : we can conclude on possible bias

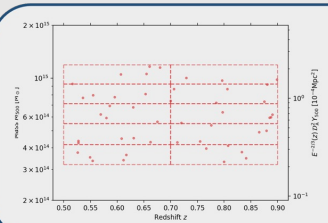


M_{500}-z catalog
Tinker et al 2010

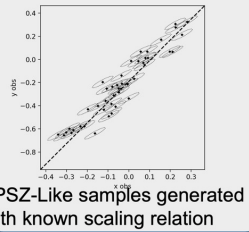


Y_{500} attribution from M_{500} and z
From chosen scaling relation
$\alpha\ \beta\ \sigma$

Error bars simulation :
New value drawn inside error bar
Errors, correlation between Y and M



Box selection (LPSZ-like)
Distribution inside boxes



LPSZ-Like samples generated
with known scaling relation

Method from F. Kéruzoré PhD 2022

X 5000 regressed by LIRA

α, β and σ estimation

Comparison between input and output $[\alpha, \beta, \sigma]$

LIRA : Linear Regression in Astronomy

M. Sereno , MNRAS 2016

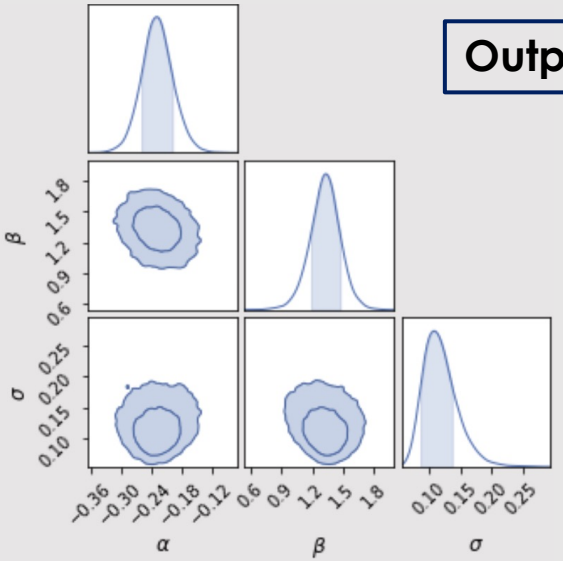
Input :

- Y_{500} -Error on Y_{500} -Correlation between Y_{500} and M_{500} distribution
- M_{500} -Error on M_{500}

MCMC Gibbs sampling

✶ Propagate error and correlation to the output

✶ Separate experimental and intrinsic dispersion



Output : Probability density distribution of the estimated parameters α, β and σ

Output example : median of the distribution will be taken as the output value

Parameters bias

Sample simulations done for different scaling relation parameters

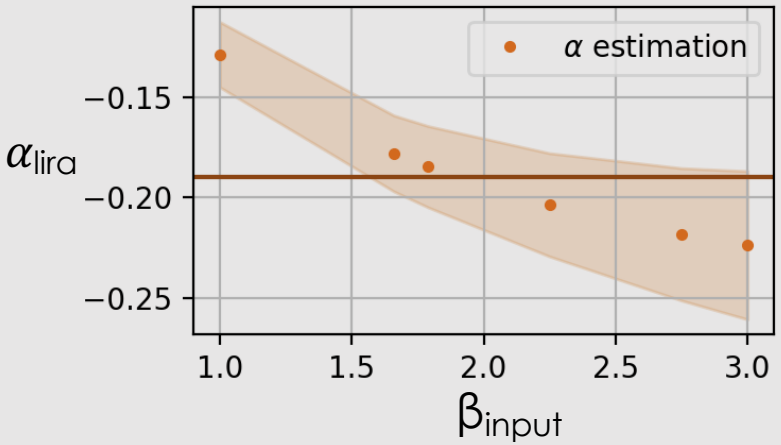
→ Each time only one parameter is modified

➔ See how it affects the estimation of other parameters

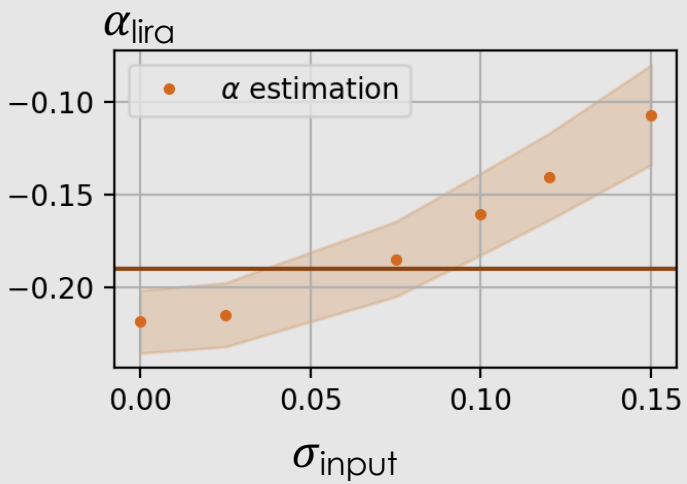
Parameters bias

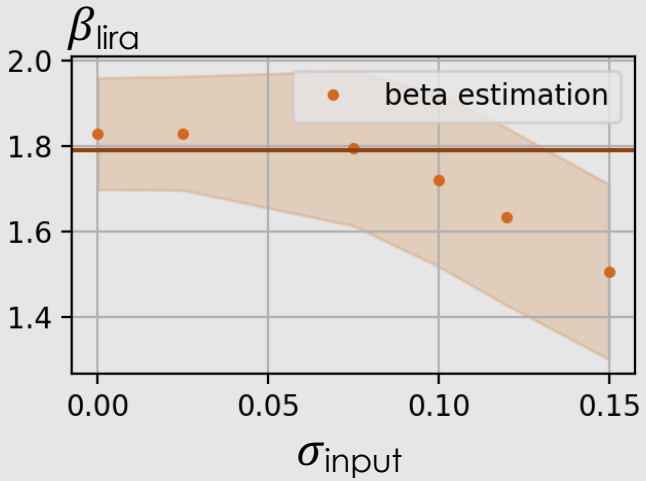
Scaling relation parameters are correlated :

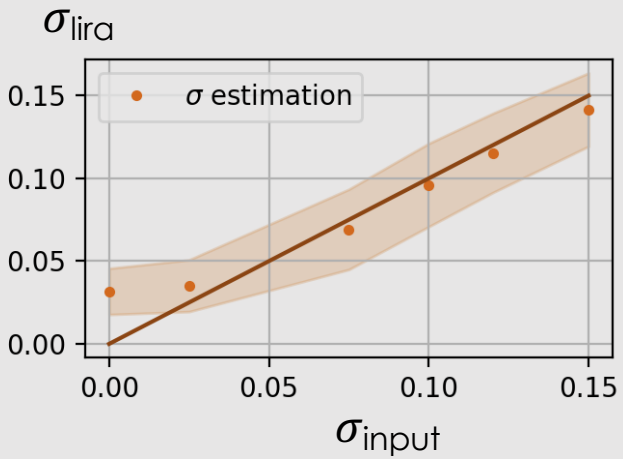
For all values of α → good estimation of all parameters
For all values of β → good estimation of α if β ∈ [1.70,2.30] (a small bias exists)
good estimation of σ



For all values of σ → **non negligible bias on α and β**







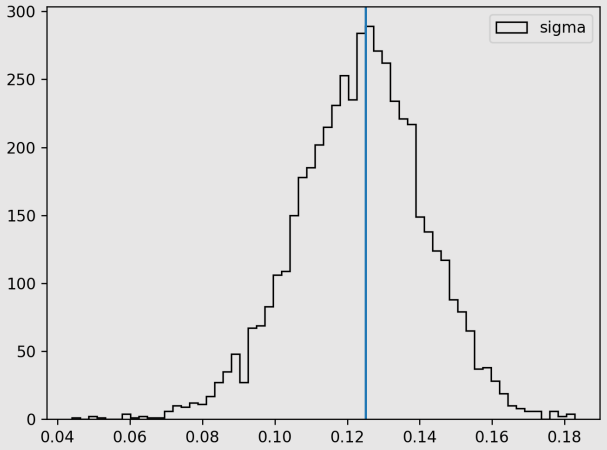
Each point represents the median of the 5000 lira estimation, contour represent 1σ of this distribution

➔ Good news : • σ always well estimated
• linear relation between σ value and bias (for σ>0.25)
• This bias can be parametrised → **Bias(σ, β)**

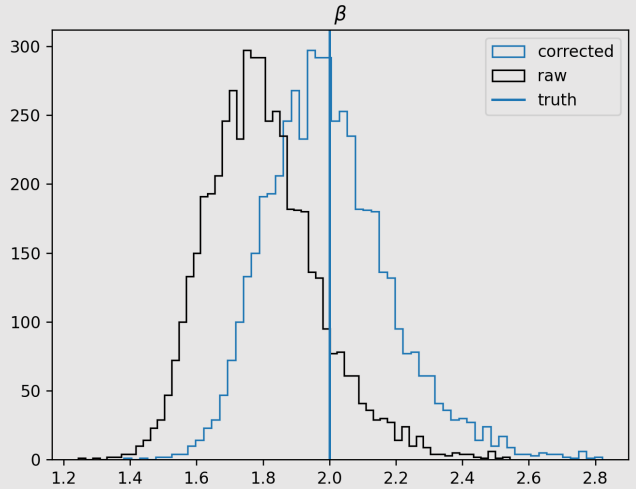
Bias correction

Testing the correction on an example : Input scaling relation : **α= -0.15 β=2 σ=0.125**

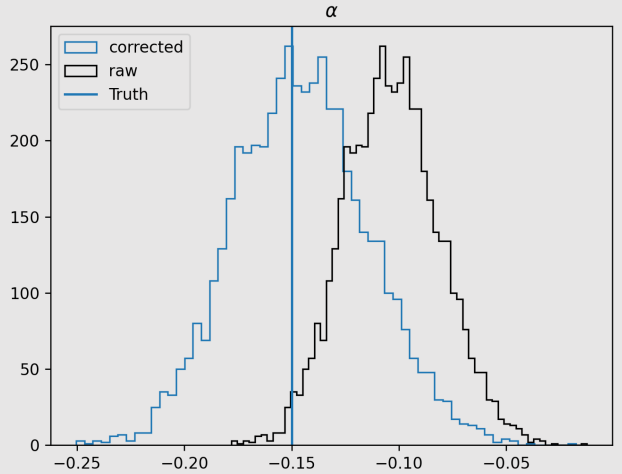
Use the sample simulation with typical error and typical correlation between Y and M of the LPSZ sample 5 clusters per box
5000 samples generated



σ_{raw}=0.12439



$\beta_{corrected}$=β_{raw}/(1+bias(σ_{raw}))



$\alpha_{corrected}$=α_{raw}/(1+bias(σ_{raw},$\beta_{corrected}$))

Correction thanks to bias parametrization as a function of σ_{raw} and $\beta_{corrected}$

Conclusion ➔ *we can retrieve scaling relation parameters for any σ, β and α*

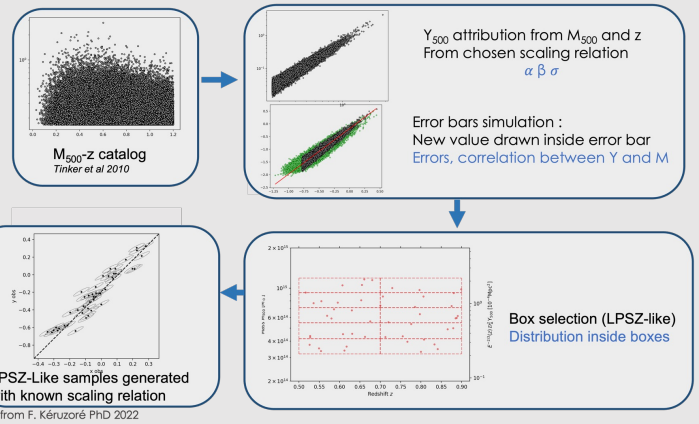
Intermediate conclusion

- LPSZ Box selection induces a bias
  - ➔ We can correct it by parametrizing the bias
  - ➔ Selection function is accounted for

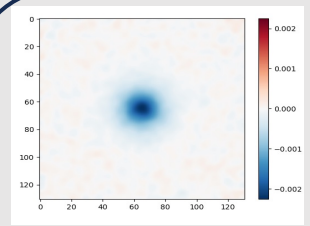
- What is the effect of the map analysis pipeline?
  - From maps to integrated quantities : PANCO2 (F.Kéruzoré et al. Open J Astro 2023)
    - Map simulations

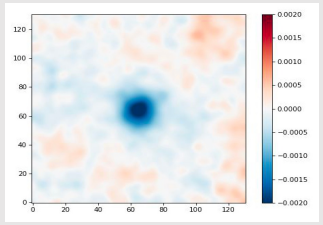
- What is the effect of white noise / correlated noise on the scaling relation?

Map simulation



Same steps as before

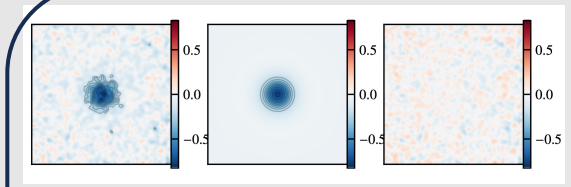




map simulation

Pressure profile gNFW
Typical noise
NIKA2 beam
Transfer function

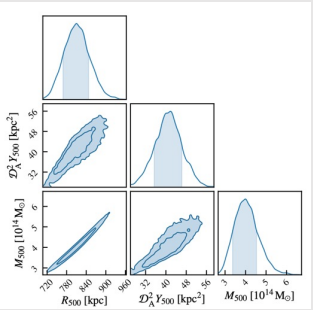
PANCO 2



Map analysis by panco2 (MCMC)

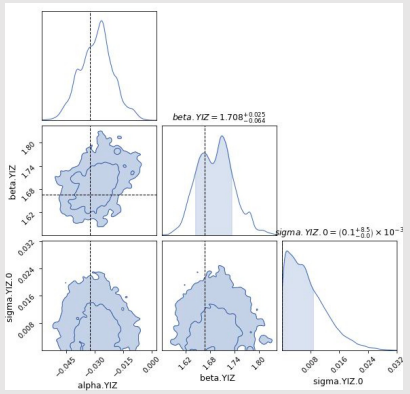
Integrated value estimation

M_{500} Y_{500}



F.Kéruzoré et al. Open J of astro 2023

LIRA



Comparison between input and output of α β σ With LIRA

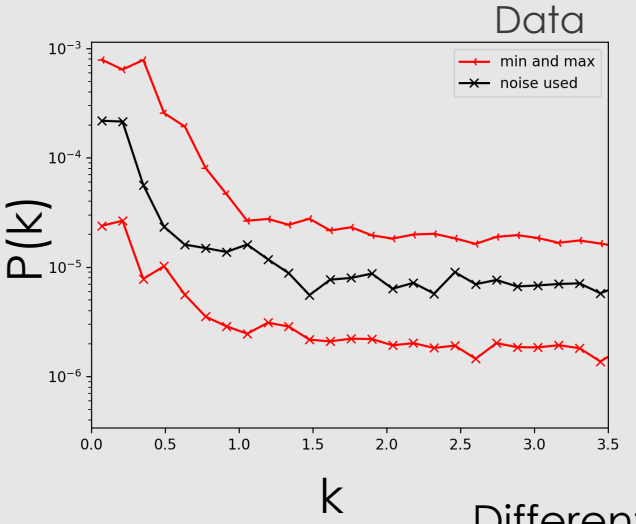
Noise generation

White noise

White noise generation corresponding to the rms amplitude

Same rms map for all simulated maps

Correlated noise



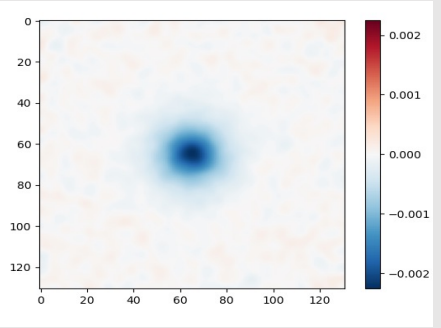
Power spectrum calculation of a NIKA2-LPSZ noise map

P(k) obtain from a typical noise map

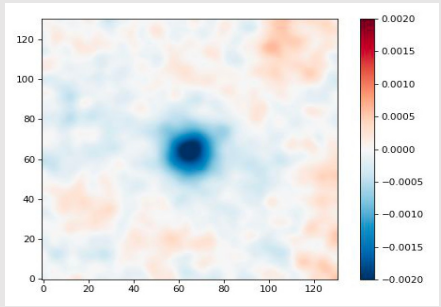
Different correlated noise generated with this power spectrum
- Co-additioning clusters maps and noise

➔ Clusters with different correlated noise but same P(k)

Map with white noise



Map with correlated noise



2 simulated samples

Effect of correlated noise

For each cluster: Y_{500} and M_{500} always within Panco2 estimation (with or without correlated noise)

considering central value of Y_{500} and M_{500} : Bias and dispersion of the sample

White noise	Mean relative bias	Dispersion relative error
Y_{500}	-0.06%	1.1%
M_{500}	0.7%	2.2%

Correlated noise	Mean relative bias	Dispersion relative error
Y_{500}	0.15%	2.5%
M_{500}	0.4%	5%

White noise :

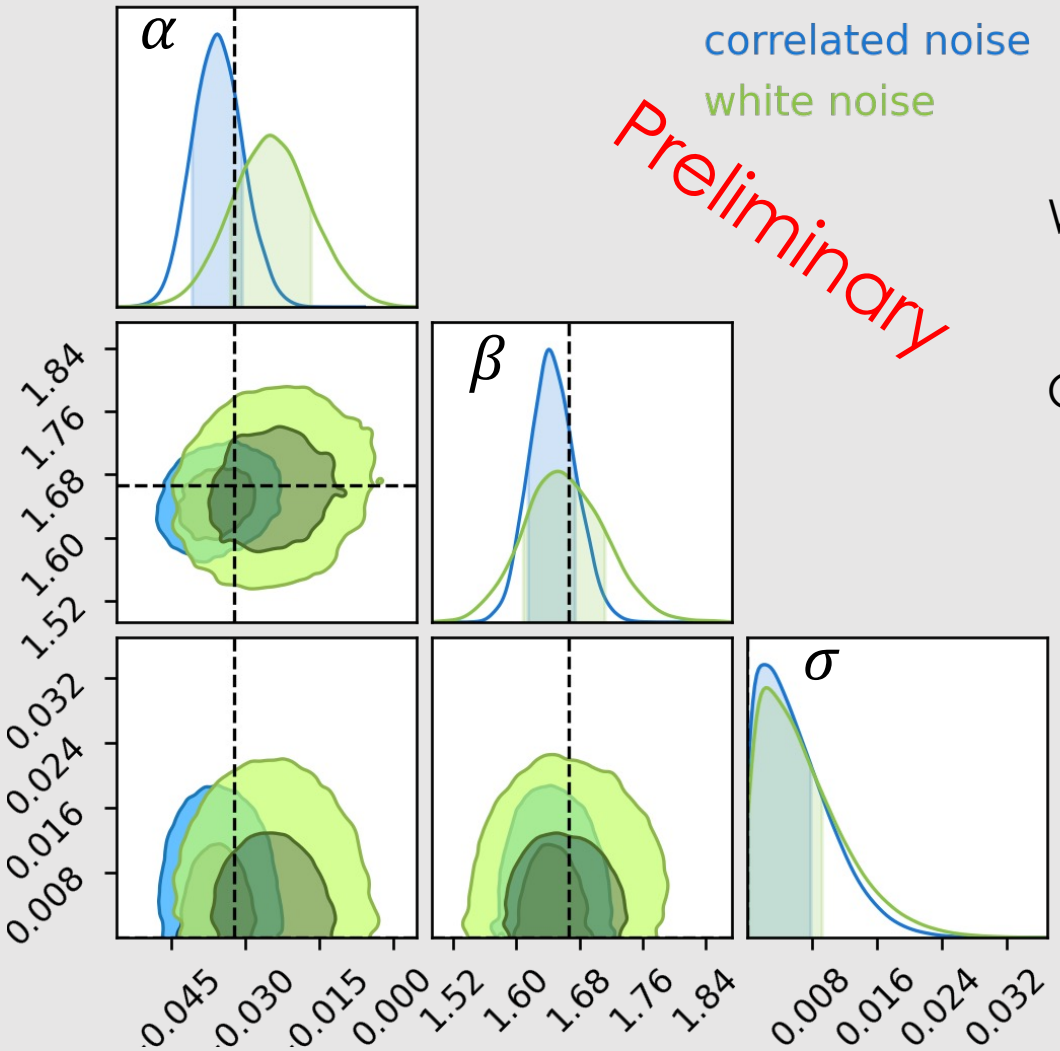
- No bias on Y_{500} and M_{500}
- Small dispersion

Correlated noise:

- No notable effects on mean relative bias
- Dispersion on integrated values ~2 times larger

➔ Effect on the scaling relation

Effect of correlated noise



White noise :

Scaling relation parameters are retrieved

Correlated noise :

Scaling relation parameters are retrieved

Smaller error bars from the treatment of correlated noise

→ more constraint (noise covariance matrix)

Estimation within 95% CL for both samples

Conclusion

Several samples created to study different systematic effects

Systematic effects exist due to

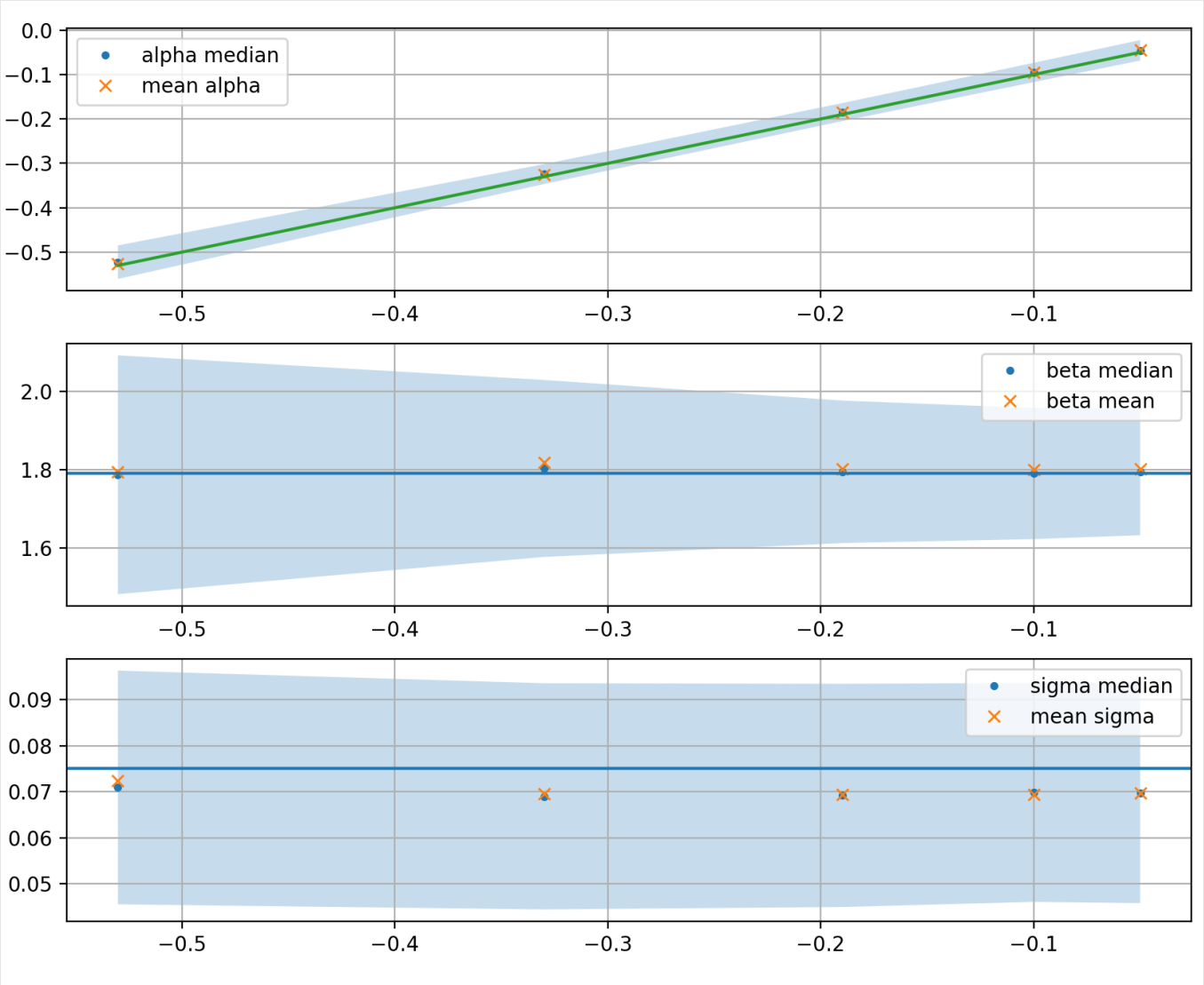
- LPSZ selection function → accounted for (correction)
- NIKA2 map analysis→ no bias

→ Full study underwork (with the simulations)

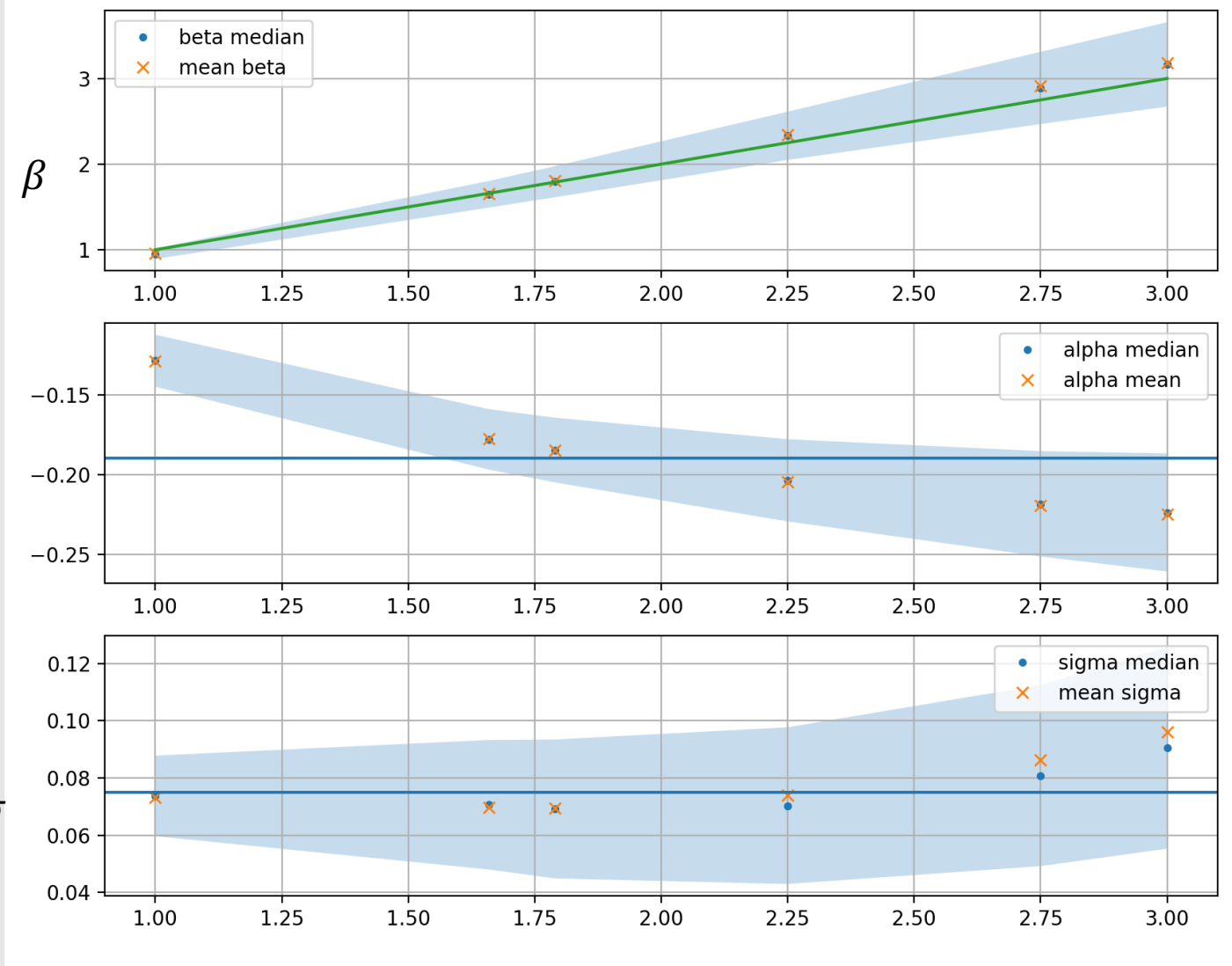
- On the way to the LPSZ scaling relation (with real NIKA2 data)

  and to understand the associated systematics

➔ Soon to come : impact of this scaling relation on cosmological parameters


α
alpha median
mean alpha
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.5
−0.4
−0.3
−0.2
−0.1
β
beta median
beta mean
2.0
1.8
1.6
−0.5
−0.4
−0.3
−0.2
−0.1
σ
sigma median
mean sigma
0.09
0.08
0.07
0.06
0.05
−0.5
−0.4
−0.3
−0.2
−0.1

Selection function

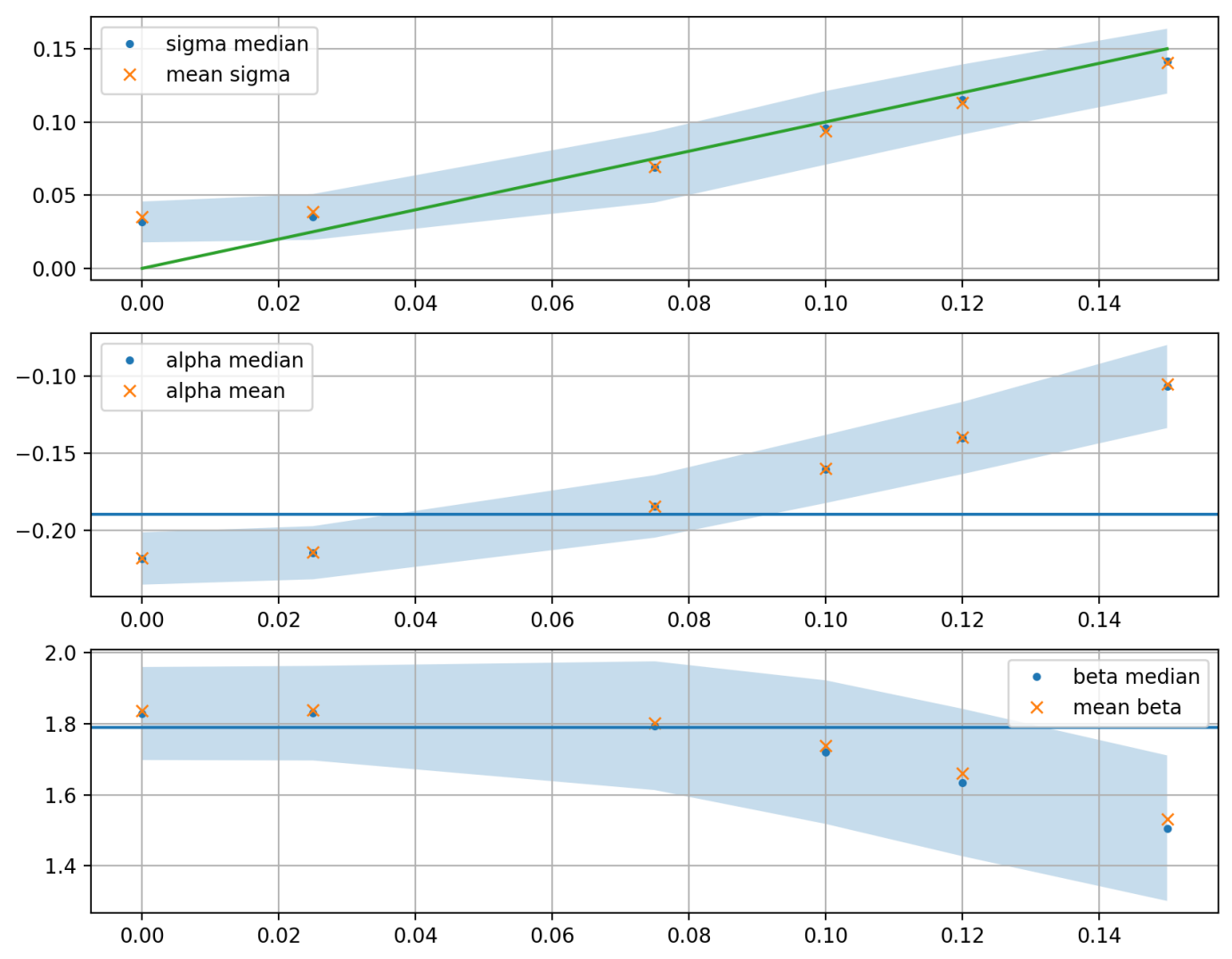


Selection function

σ

α

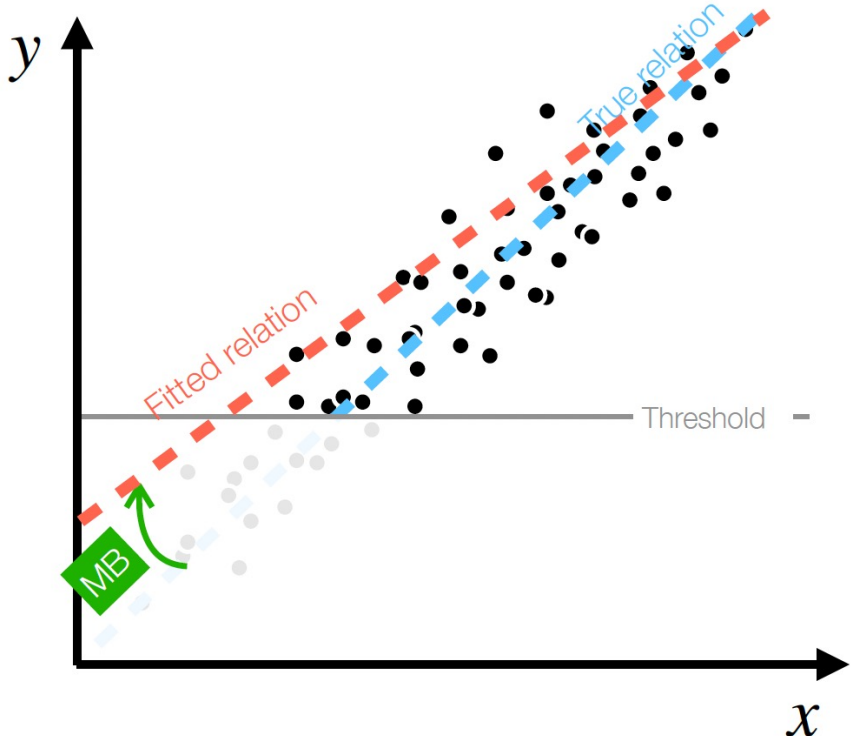
β

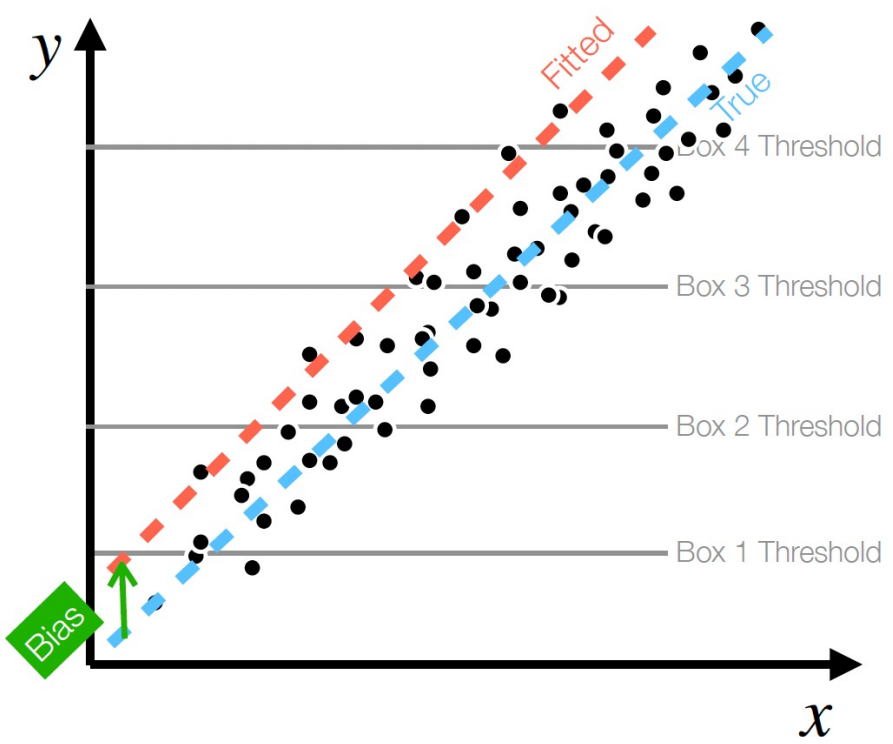


Slide taken from PhD defense of F. Kéruzoré in 2021

Bias interpretation on α

Florian Kéruzoré
Soutenance de thèse
27/09/2021





Malmquist bias : Over-representation

Above a threshold

→ Rotation : Bias on the slope β

Here : Over-representation on boxes limits

→ Shift : Bias on the intercept α