Constraining the mass and redshift evolution of the hydrostatic mass bias using the gas mass fraction in galaxy clusters

Raphaël Wicker (IAS)

Marian Douspis, Laura Salvati and Nabila Aghanim

OUTLINE

- INTRODUCTION : Galaxy clusters and their gas mass fraction
- The hydrostatic mass bias in a cosmological study
- Sample dependence of the results
- Insights on the value of the bias
- CONCLUSION

Galaxy clusters and their gas mass fraction

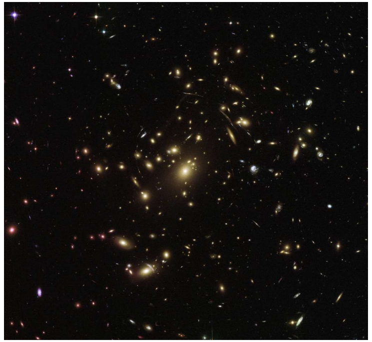
- Hierarchical structure formation : tiny perturbations gradually collapse to form larger structures, into the peaks of the cosmic web.
- Galaxy clusters : in the nodes of the cosmic web
- Most massive gravitationally bound structures of the universe

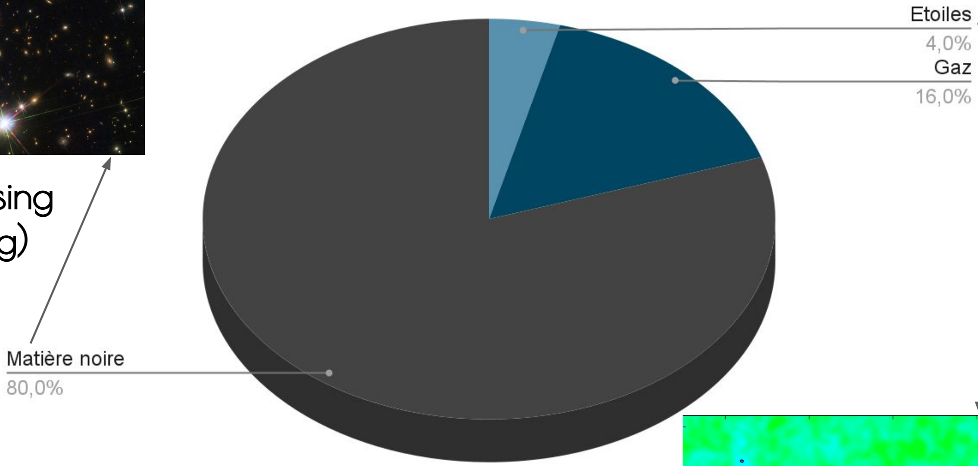
PSZ1G311.65-18-.48
Credits : ESA, NASA, HST, Rivera-Thorsen et al.

Gravitational lensing
(Weak and strong)

Abell 2357
Crédits: ESA, HST, NASA

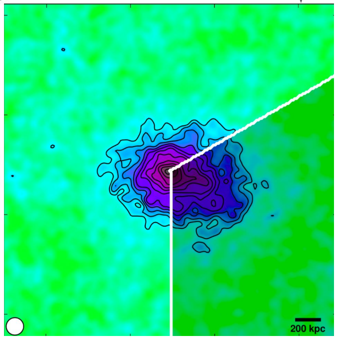
Optical





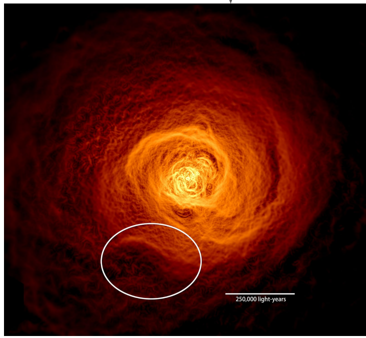
SZ Effect

X-rays



PSZ2 G144.83+25.11
NIKA2, Ruppin et al. 2017

Perseus cluster
Chandra, Walker et al. 2017



Galaxy clusters and their gas mass fraction

Galaxy clusters can be used to constrain cosmological parameters.

- Number counts, clustering, sparsity etc…
- One can also use $f_{gas} = \frac{M_{gas}}{M_{tot}}$

Measured using the gas density profile *inside a certain radius*

Measured using the gas density and temperature profiles, *assuming hydrostatic equilibrium (HE)*

$$f_{gas} \propto \frac{\Omega_b}{\Omega_m}$$

Galaxy clusters and their gas mass fraction

BYOPIC

Assuming HE introduces a bias in the total mass measurement : the *hydrostatic mass bias*.

$$M_{mes} = B \times M_{true}$$

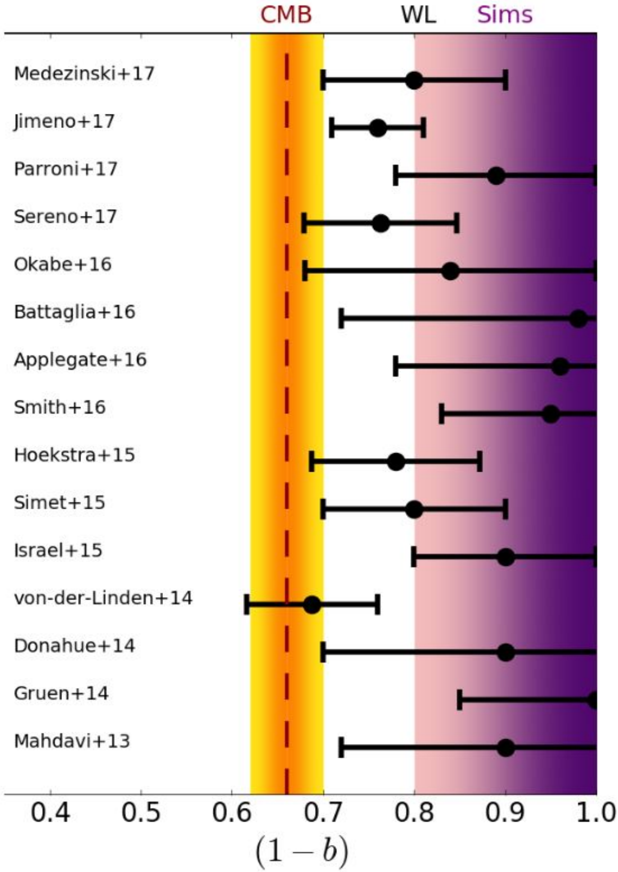
$$\Rightarrow f_{gas} = \frac{M_{gas}}{M_{mes}} = \frac{M_{gas}}{B \times M_{true}}$$

The hydrostatic mass bias in a cosmological study

Problem : the value of this parameter is still openly debated.

- Directly observed (mainly via WL) and simulated: $B \sim 0.8$
- From a combination of *Planck* CMB+SZ number counts : $B \sim 0.6$

Yet, this bias impacts the cosmological constraints obtained from clusters.



Salvati et al. 2018

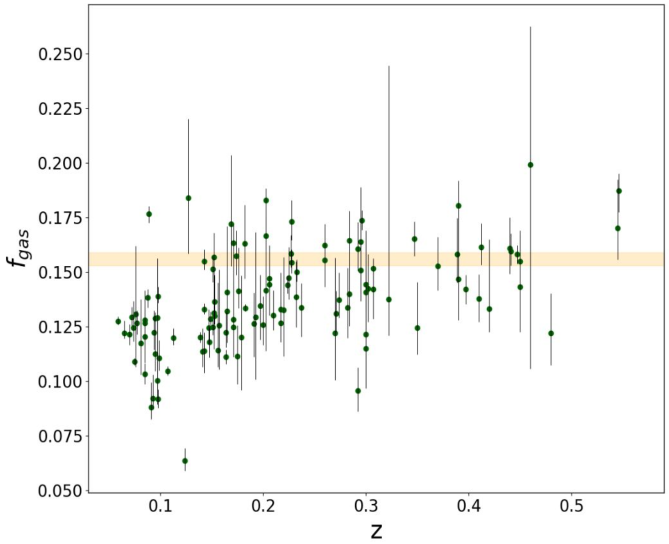
The hydrostatic mass bias in a cosmological study

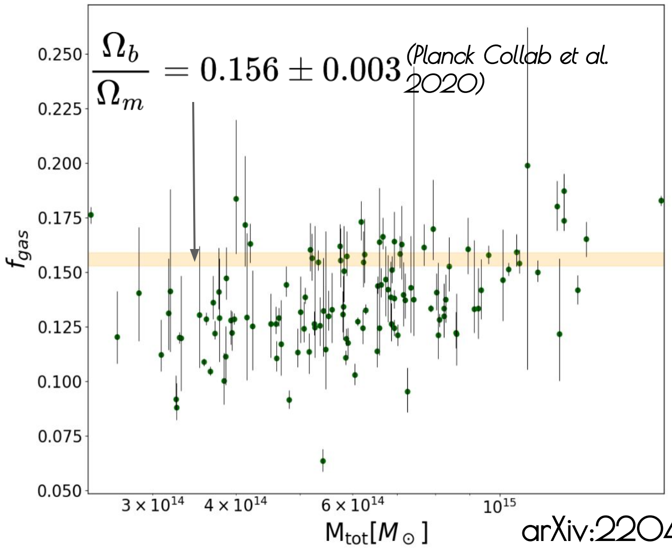
- Purpose : study the hydrostatic mass bias using cluster gas mass fraction data
- In particular : look for an evolution of B with M and z

THE HYDROSTATIC MASS BIAS IN A COSMOLOGICAL STUDY

BYOPIC

- Purpose : study the hydrostatic mass bias using cluster gas mass fraction data
- In particular : look for an evolution of B with M and z





Wicker et al, 2022

arXiv:2204.12823

120 clusters from the Planck-ESZ sample. Observed by XMM-Newton, data taken at R_{500}

$z \in [0.059; 0.546]$

$M_{500} \in [2.22; 17.5] \times 10^{14} M_\odot$

The hydrostatic mass bias in a cosmological study

$$f_{gas,Th}(M,z) = \boxed{K}\,\boxed{\frac{\Upsilon(M,z)}{B(M,z)}}\,\boxed{A(z)\left(\frac{\Omega_b}{\Omega_m}\right)\left(\frac{D_A^{ref}(z)}{D_A(z)}\right)^{3/2}} - \boxed{f_*}$$

Instrumental effects

Baryonic effects

Cosmology

Stellar content

Allen et al. 2008

… and we assume self-similarity

The hydrostatic mass bias in a cosmological study

We check how assuming a *constant* or *varying* bias impacts our cosmological constraints from gas fraction.

The hydrostatic mass bias in a cosmological study

We check how assuming a *constant* or ***varying*** bias impacts our cosmological constraints from gas fraction.

Redshift dependence

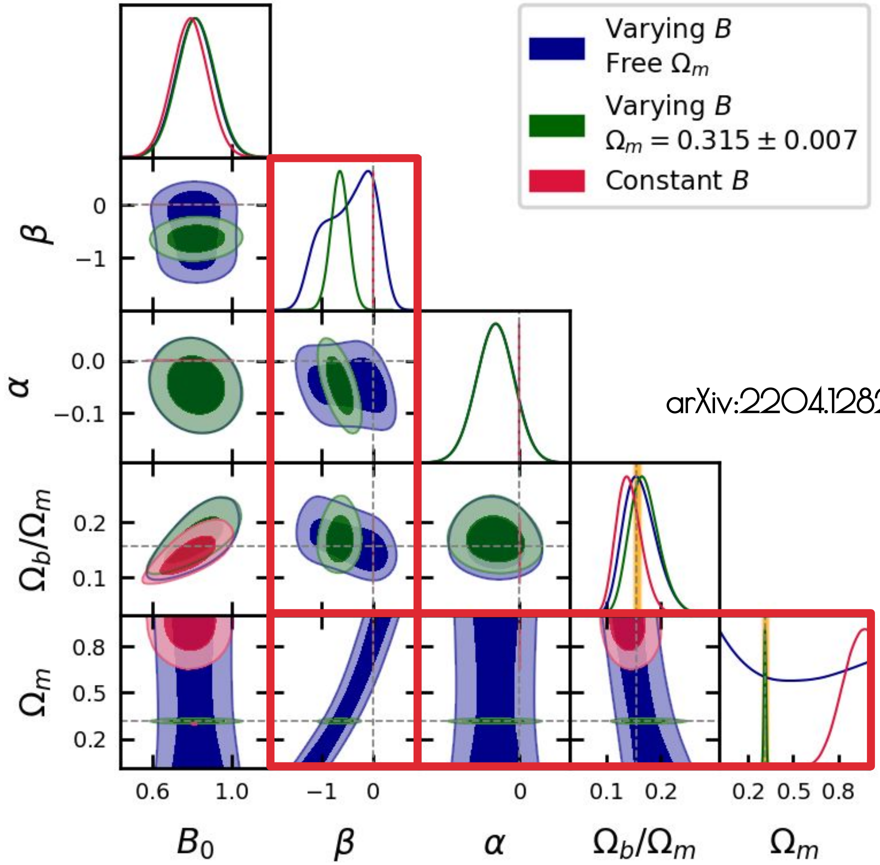
Mass dependence

$$B(M, z) = \boxed{B_0}\left(\frac{M}{\langle M\rangle}\right)^{\boxed{\alpha}}\left(\frac{1+z}{\langle 1+z\rangle}\right)^{\boxed{\beta}}$$

Amplitude

=> 3 free parameters to describe the bias

The hydrostatic mass bias in a cosmological study



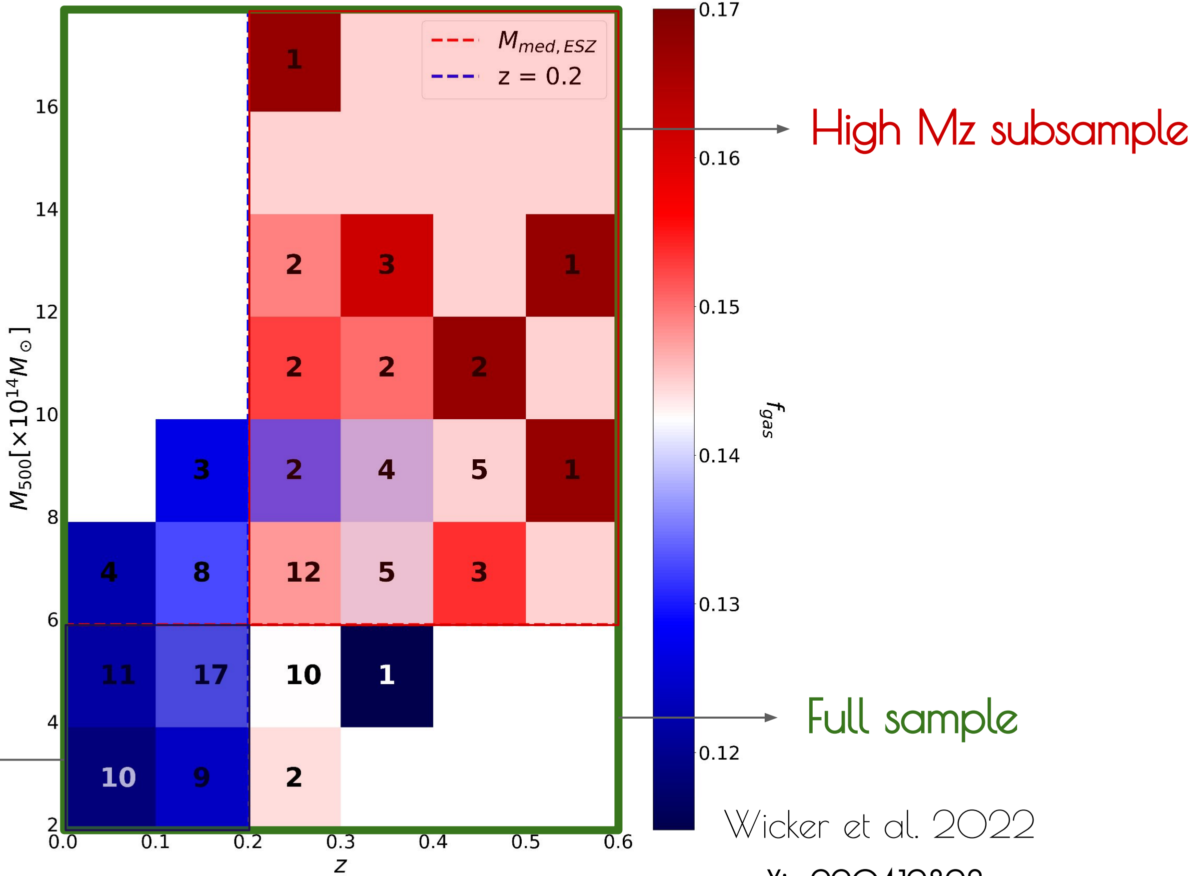
Wicker et al. 2022

arXiv:2204.12823

- Degeneracy between β and Ω_m : higher, closer to 0 β calls for higher Ω_m
- Assuming a constant bias $(\alpha = \beta = 0)$ leads to aberrant values of $\Omega_m > 0.860$
- When assuming a standard *Planck* cosmology, $\beta = -0.64 \pm 0.17$ is incompatible with 0
- α is compatible with 0, B_0 with ~ 0.8

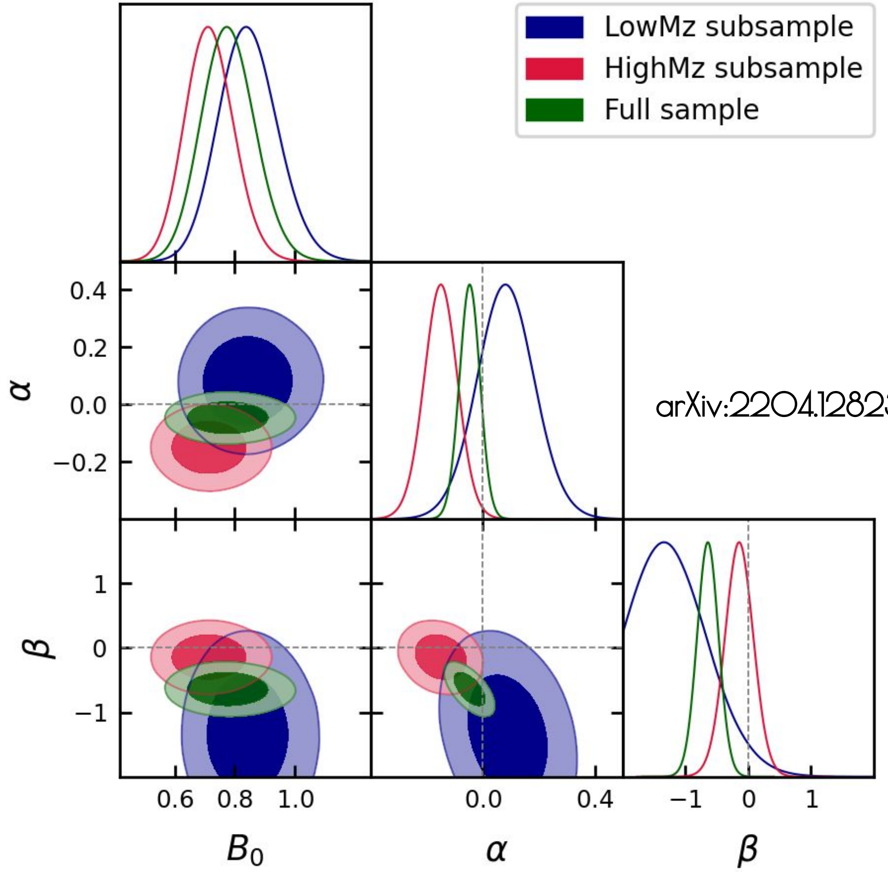
Sample dependence of the results

We seem to need an evolution of the bias. But does that depend on our sample ?



Wicker et al. 2022
arXiv:2204.12823

Sample dependence of the results

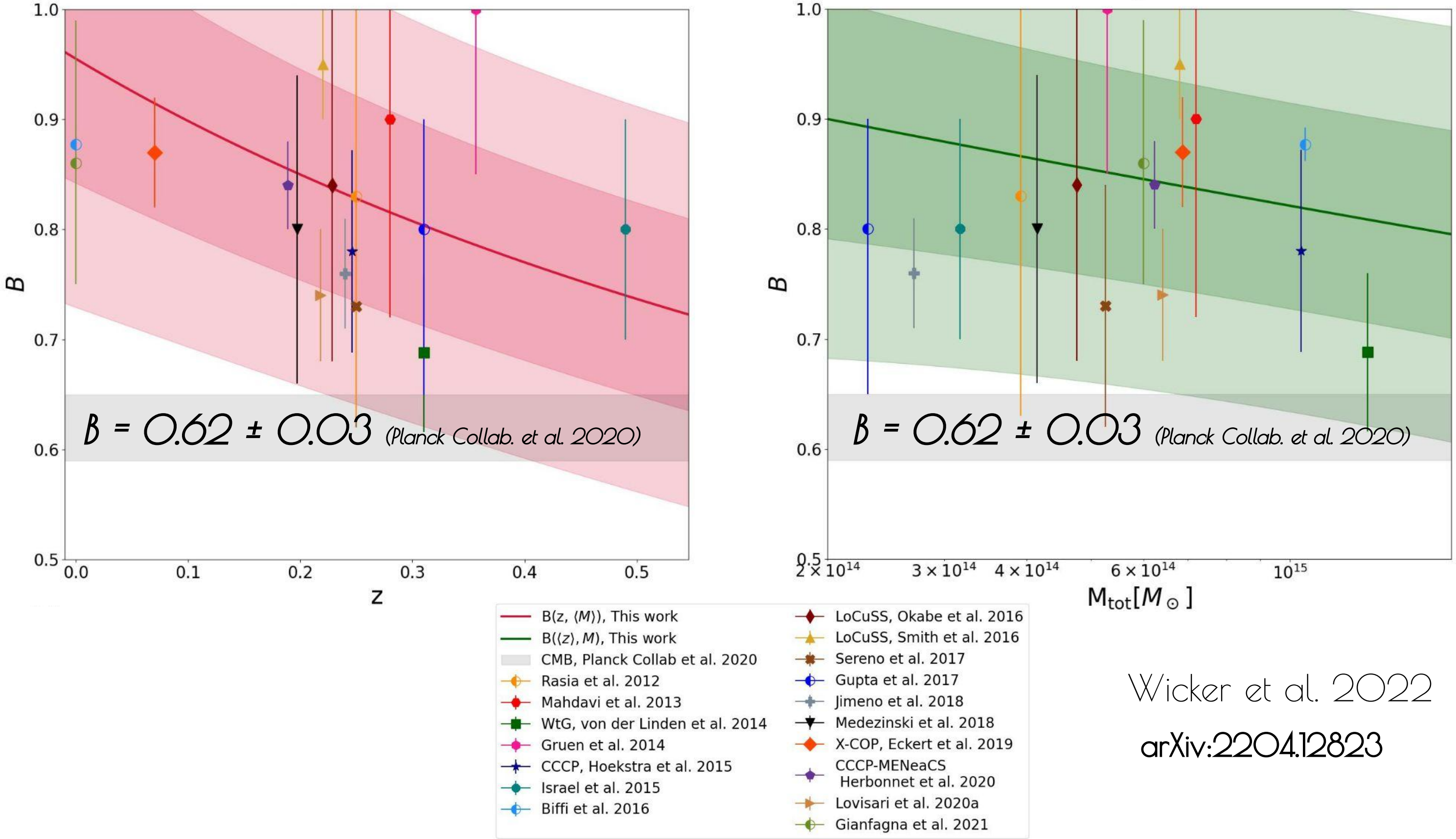


Wicker et al. 2022

arXiv:2204.12823

- All samples favor an amplitude $B_0 \sim 0.8$.
- *Low Mz*: favors a **strong redshift evolution**, but is fully compatible with **no mass evolution**
- *High Mz*: fully compatible with **no redshift evolution**, but **favors a mass evolution**
- *Full sample*: Strongly **favors a redshift evolution**, compatible with **no mass evolution**

Insights on the value of the bias

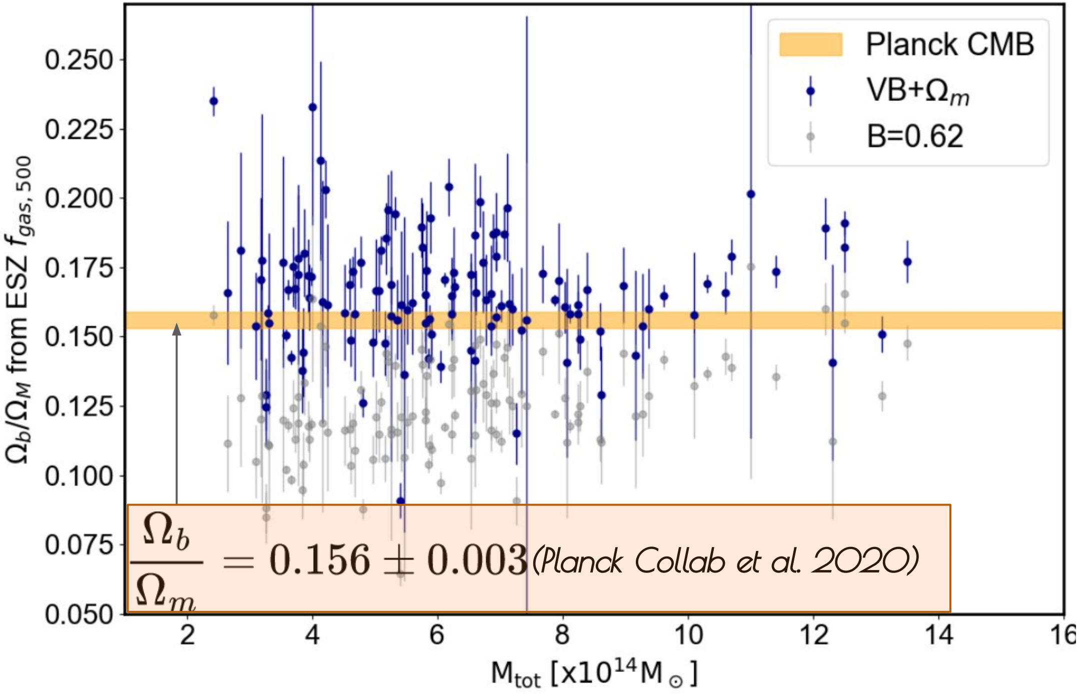


Wicker et al. 2022

arXiv:2204.12823

Insights on the value of the bias

If we assume *B=0.62* from Planck Collab. et al (2020), we then obtain $\Omega_b/\Omega_m = 0.108 \pm 0.018$, *in tension with Planck measurements.*



Wicker et al. 2022
arXiv:2204.12823

Conclusion

- *A possible evolution of the bias cannot be neglected* when doing cosmology with gas fraction, a fortiori with clusters
- *Selection effects remain important* and need to be taken into account
- *We however are compatible with B ~ 0.8*, in agreement with a collection of other measurements
- *Next step(s) :* combination of gas fraction with number counts

Thank you !

	Bias evolution study	**Sample dependence of the results**	**Reference**
Parameter	Prior	Prior	
B_0	–	$\mathcal{U}(0.3, 1.7)$	–
$B(z_{CCCP}, M_{CCCP})$	$\boldsymbol{\mathcal{N}(0.84, 0.04)}$	–	1
f_*	$\mathcal{N}(0.015, 0.005)$	$\mathcal{N}(0.015, 0.005)$	2
Υ_0	$\boldsymbol{\mathcal{N}(0.85, 0.03)}$	$\boldsymbol{\mathcal{N}(0.85, 0.03)}$	3
K	$\mathcal{N}(1, 0.1)$	$\mathcal{N}(1, 0.1)$	4
σ_f	$\mathcal{U}(0, 1)$	$\mathcal{U}(0, 1)$	–
h	$\mathcal{N}(0.674, 0.005)$	$\mathcal{N}(0.674, 0.005)$	5
Ω_b/Ω_m	$\mathcal{U}(0.05, 0.3)$	$\mathcal{N}(0.156, 0.003)$	5
Ω_m	$\mathcal{U}(0.01, 1)$ **(CB, VB)** or $\mathcal{N}(0.315, 0.007)$ **(VB +** $\boldsymbol{\Omega_m}$**)**	$\mathcal{N}(0.315, 0.007)$	5
α	Fixed at 0 **(CB)** or $\mathcal{U}(-2, 2)$ **(VB, VB +** $\boldsymbol{\Omega_m}$**)**	$\mathcal{U}(-2, 2)$	–
β	Fixed at 0 **(CB)** or $\mathcal{U}(-2, 2)$ **(VB, VB +** $\boldsymbol{\Omega_m}$**)**	$\mathcal{U}(-2, 2)$	–

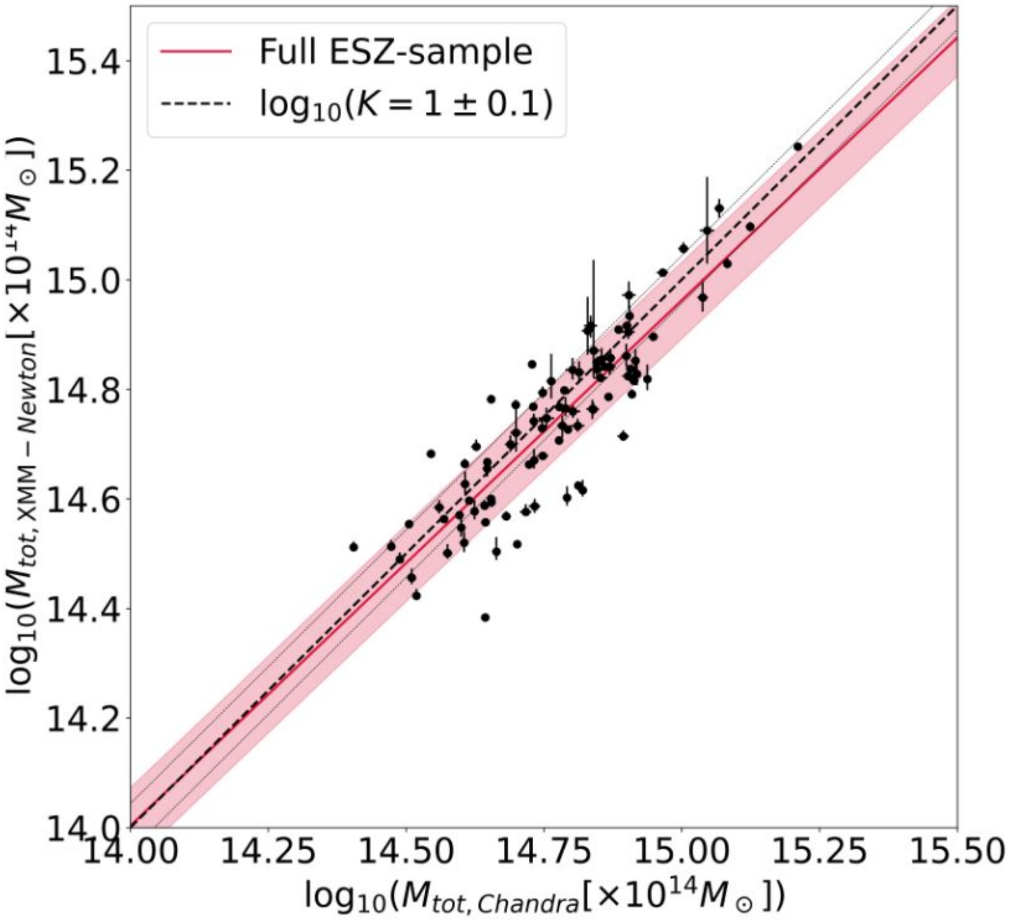
References. (1) Herbonnet et al. (2020); (2)Eckert et al. (2019); (3)Planelles et al. (2013); (4)Allen et al. (2008); (5)Planck Collaboration et al. (2020).

$$A(z) = \left(\frac{\theta_{500}^{ref}}{\theta_{500}}\right)^{\eta} \simeq \left(\frac{H(z)D_A(z)}{[H(z)D_A(z)]^{ref}}\right)^{\eta}$$

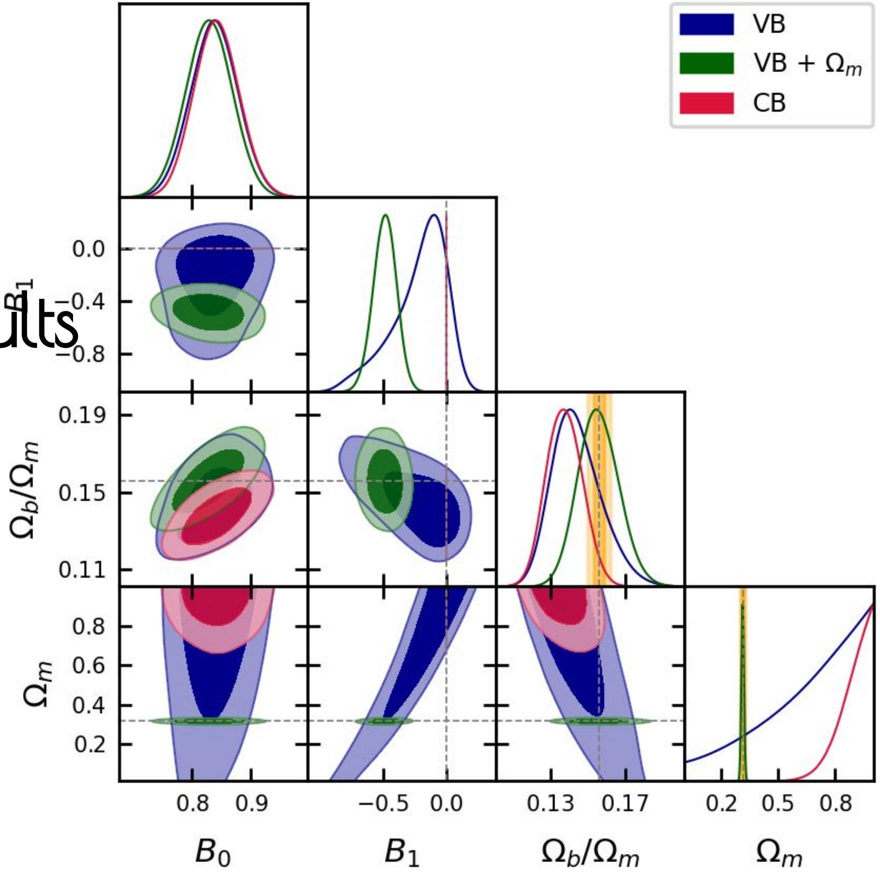
Parameter	CB	VB	VB + Ω_m
B_0	0.842 ± 0.040	0.832 ± 0.041	0.828 ± 0.039
α	0	-0.056 ± 0.037	-0.057 ± 0.038
β	0	$-0.43^{+0.61}_{-0.37}$	-0.64 ± 0.18
Ω_b/Ω_m	$0.140^{+0.014}_{-0.020}$	$0.154^{+0.018}_{-0.026}$	$0.160^{+0.016}_{-0.025}$
Ω_m	> 0.860	–	0.315 ± 0.007

Parameter	LowMz subsample	HighMz subsample	Full sample
$\mathbf{B_0}$	$\mathbf{0.92^{+0.10}_{-0.11}}$	$\mathbf{0.767 \pm 0.086}$	$\mathbf{0.840 \pm 0.095}$
$\boldsymbol{\alpha}$	$\mathbf{0.09 \pm 0.11}$	$\mathbf{-0.149 \pm 0.058}$	$\mathbf{-0.057 \pm 0.038}$
$\boldsymbol{\beta}$	$\mathbf{-0.995^{+0.44}_{-0.77}}$	$\mathbf{-0.08 \pm 0.23}$	$\mathbf{-0.64 \pm 0.18}$

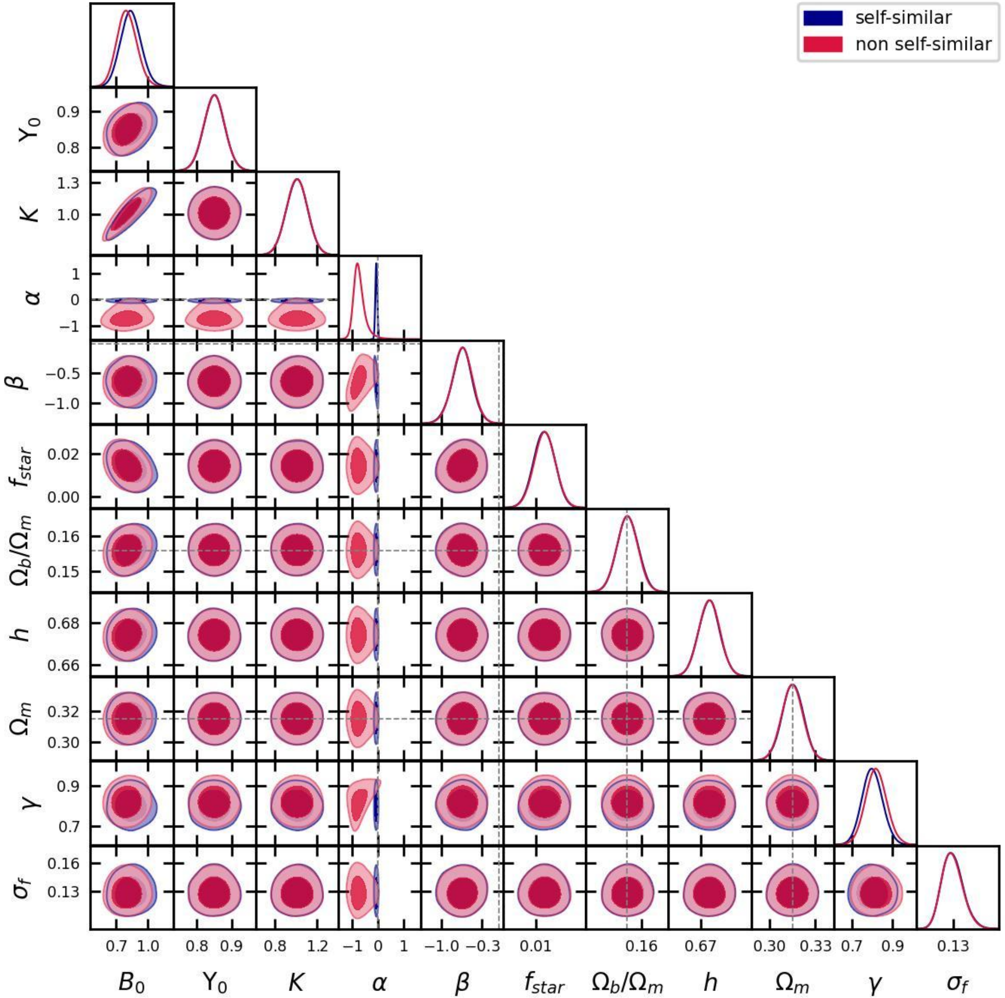
Calibration bias : M(XMM) vs M(Chandra)



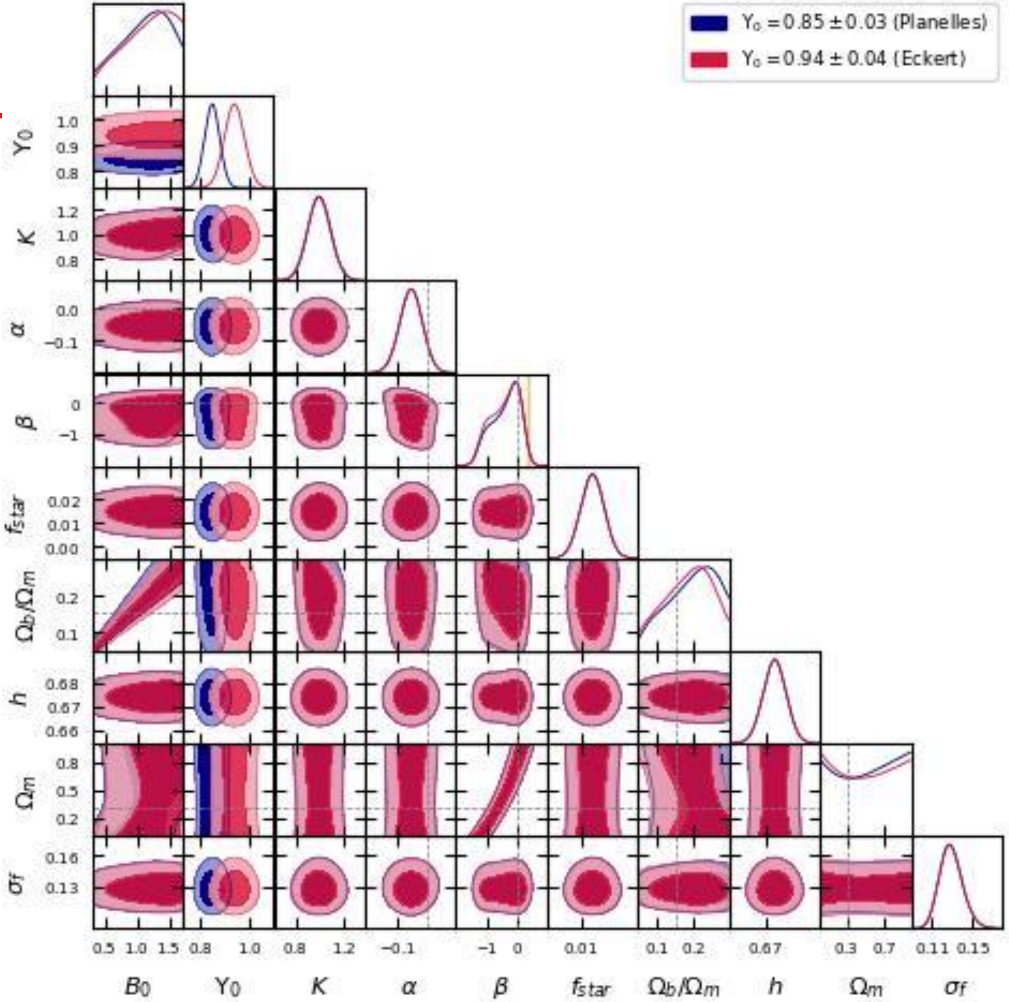
Dependence on parametrization : results assuming a linear dependence with M and z



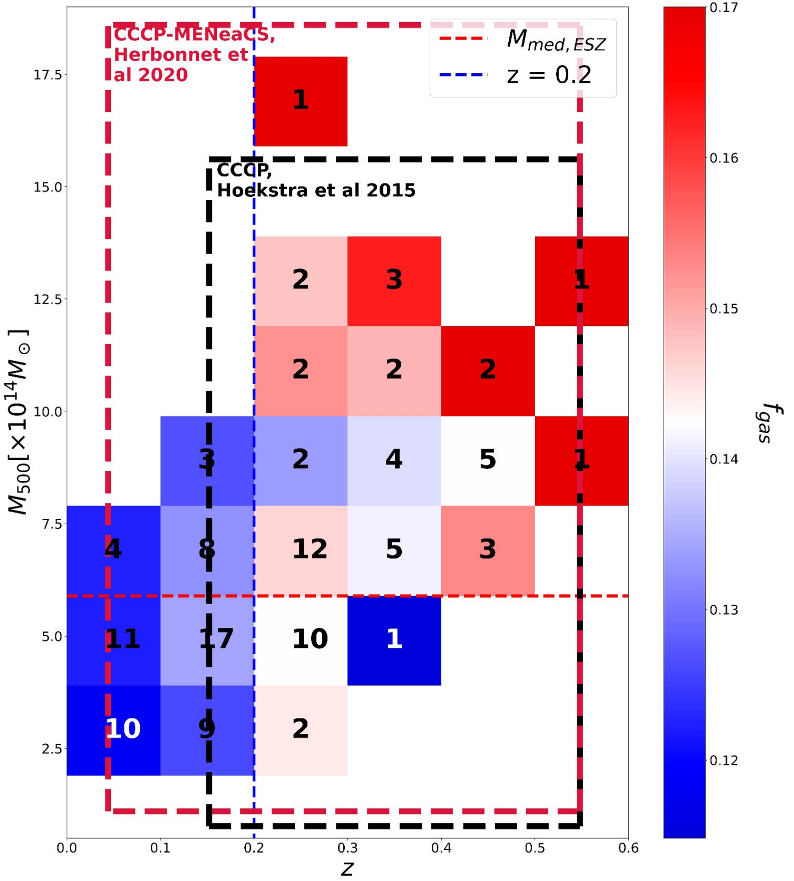
Taking into account (or not) deviations from self-similarity



Role of the depletion factor



Validity of our prior on Btot(z, M)



Looking into a possible effect from a redshift dependence of the mass distribution