Tension from Clusters and CMB resolved ?!?

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in collaboration with
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ClustersXCosmo

erc European Research Council

IAS Orsay

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

Outline

- Galaxy Clusters
  - thermal Sunyaev-Zeldovich effect
  - Planck results on cosmological parameters
    - Discrepancy with CMB primary anisotropies results

- Combination of tSZ probes: cosmological constraints
  - LCDM and extensions to standard model
  - Mass bias
    - Mass - redshift variation
  - Comparison with CMB results

Results based on:

- LS, Aghanim, Douspis
  A&A 614 (2018) A13
- LS, Douspis, Ritz, Aghanim, Babul
  A&A 626, A27 (2019)

Introduction

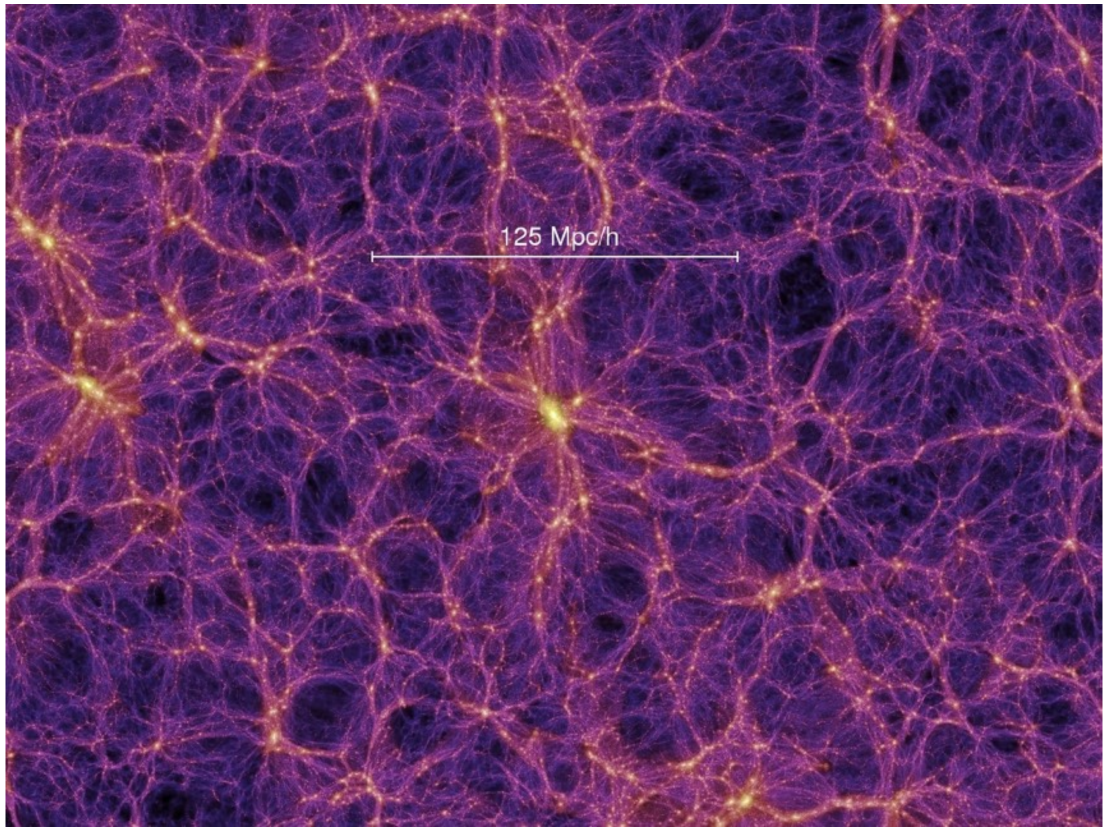
Galaxy Clusters

- Largest structures gravitationally bound in the Universe
- Strong dependence on cosmological parameters $\Omega_m,\ \sigma_8$

Matter density

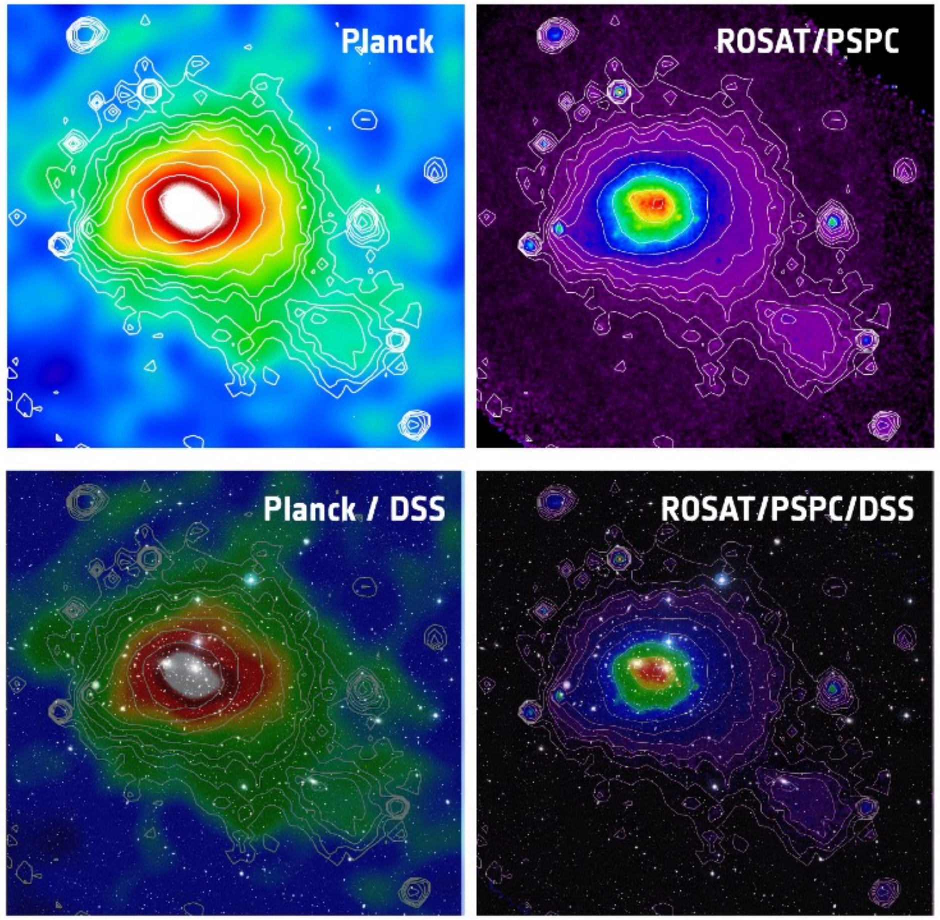
Variance of matter fluctuations

Evolution of clusters with **mass** and **redshift** is a sensitive cosmological probe



Millennium Simulation Project,
https://wwwmpa.mpa-garching.mpg.de/galform/virgo/millennium/

- **Multi-component systems:** dark matter and baryonic matter
- **Multiple wavelengths-probes observations**

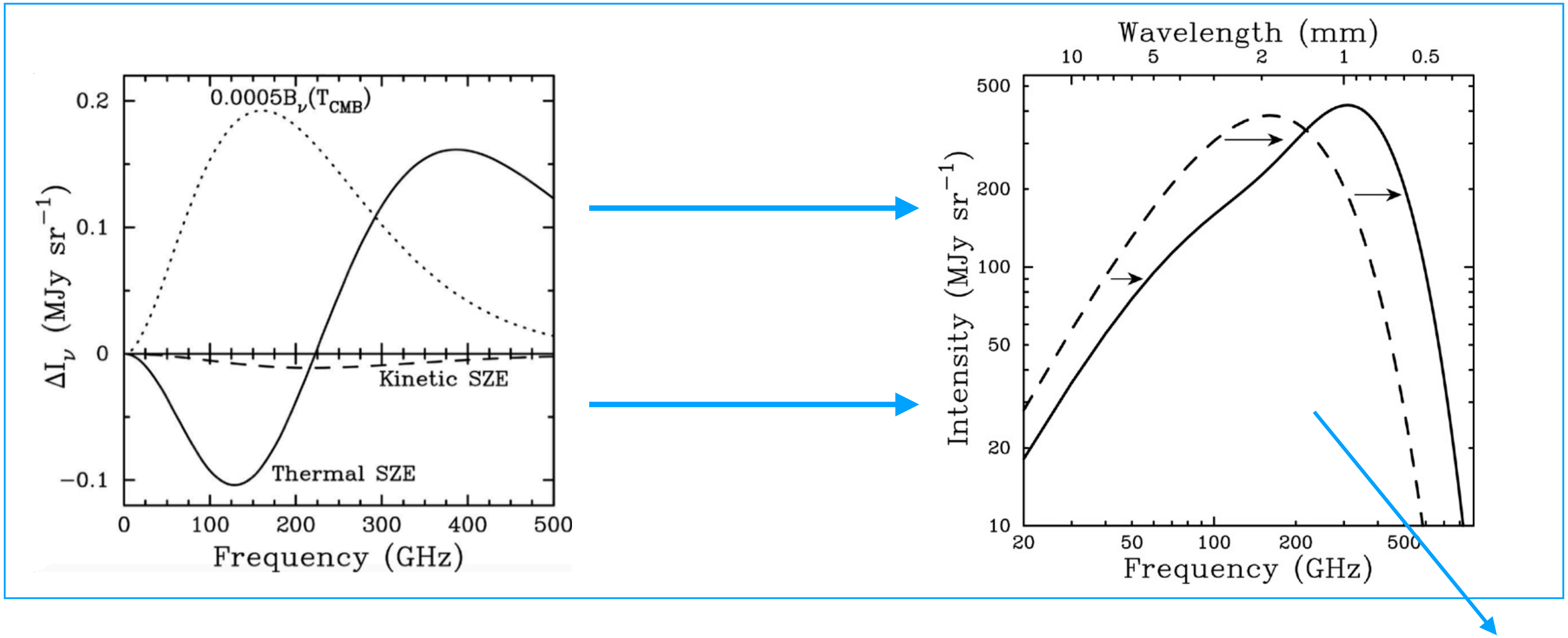


http://sci.esa.int/planck/47695-the-coma-cluster/

thermal Sunyaev-Zeldovich effect

Sunyaev and Zeldovich,
Astrophys. Space Sci. 7 (1970) 20

Interaction between CMB photons and hot gas in clusters:
Inverse Compton Scattering between CMB photons and hot electrons



change in CMB photons energy

(tSZ) Compton parameter

$$\boxed{y(\hat{\mathbf{n}}) = \int n_{\rm e} \frac{k_{\rm B} T_{\rm e}}{m_{\rm e} c^2} \sigma_{\rm T}\, ds}$$

Related to integrated electron pressure profile → Total thermal energy of clusters gas → Good mass proxy

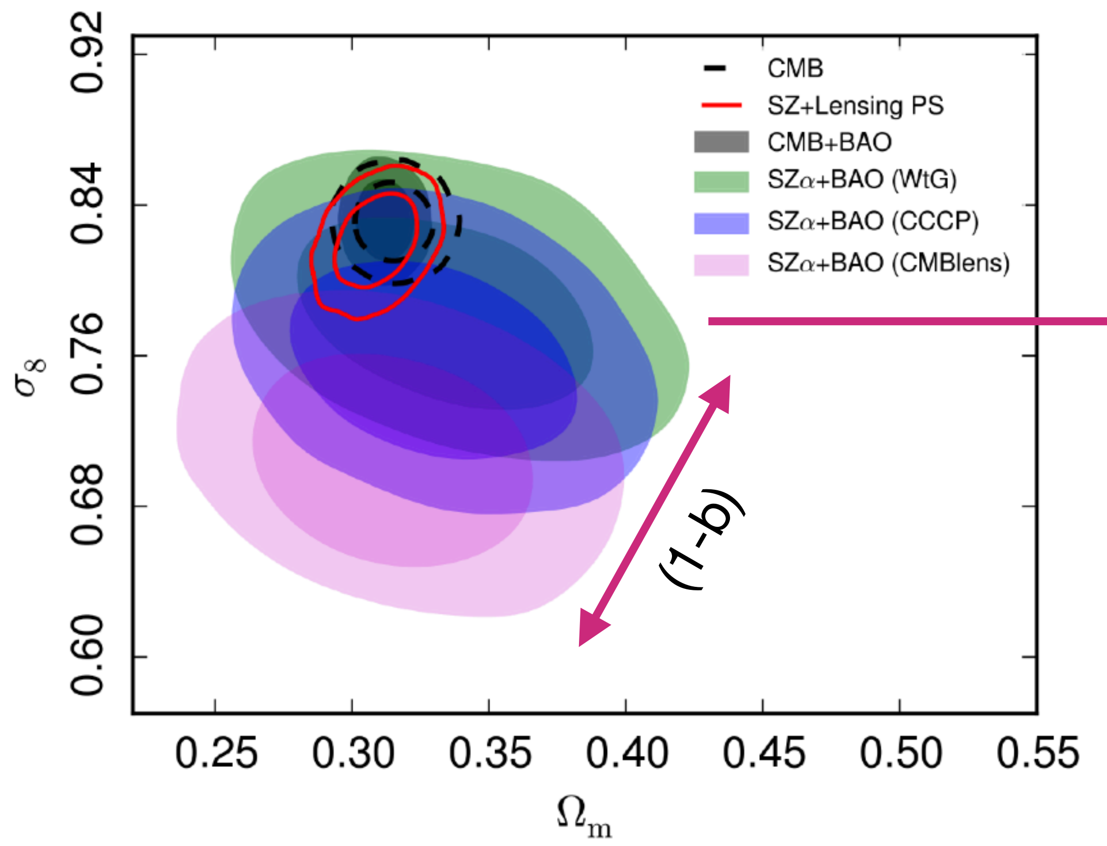
tSZ probes: Planck results

$\mathrm{NC}^{\mathrm{tSZ}}(z,q) \propto$ **Volume element** x **Selection Function** x **Mass Function**

related to

Scaling Relations

$$(1-b) = \frac{M_{\mathrm{est}}}{M_{\mathrm{true}}}$$



tension between CMB primary anisotropies and Galaxy Clusters:

$$\simeq 2.4\,\sigma \text{ on } \sigma_8$$

$\mathrm{CMB} + \mathrm{NC}^{\mathrm{tSZ}}: (1-b) = 0.58 \pm 0.04$

CCCP: $(1-b) = 0.780 \pm 0.092$

Hoekstra et al., MNRAS 449 (2015) no.1, 685

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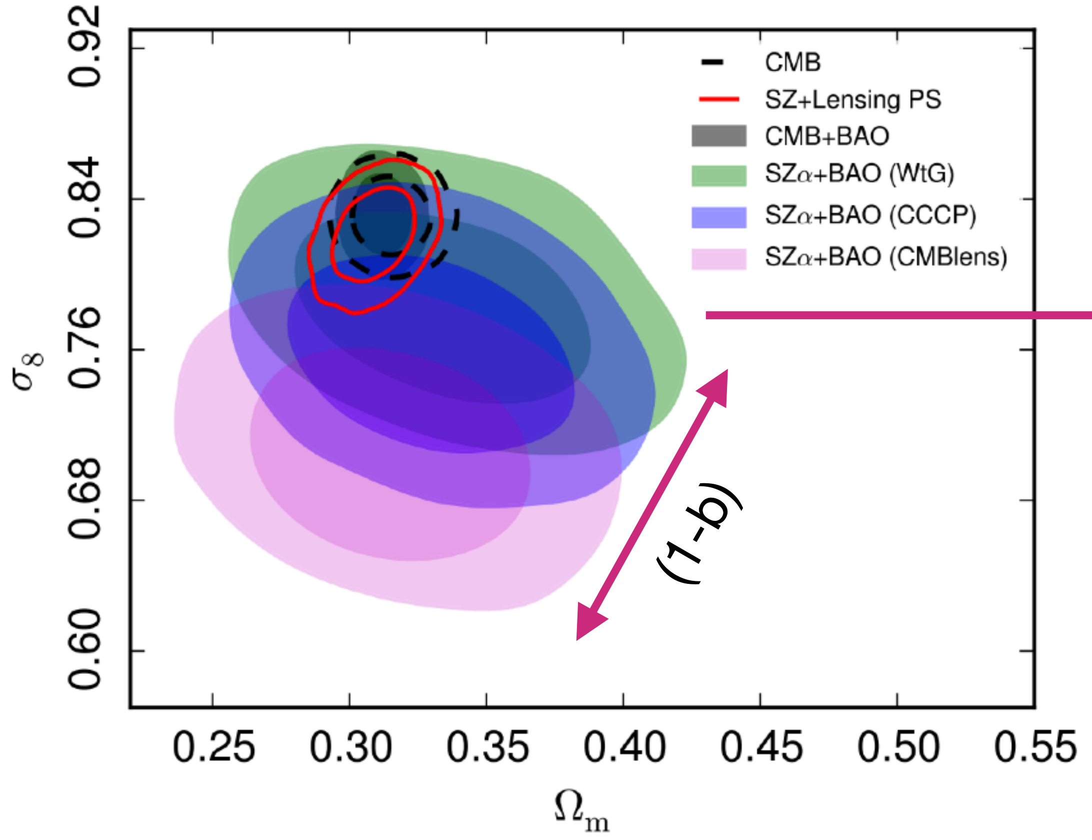

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$C_\ell^{\mathrm{tSZ}} \propto$ **Volume element** x **Mass Function** x **Pressure Profile** x **Scaling Relations**

tSZ Number Counts + Power Spectrum

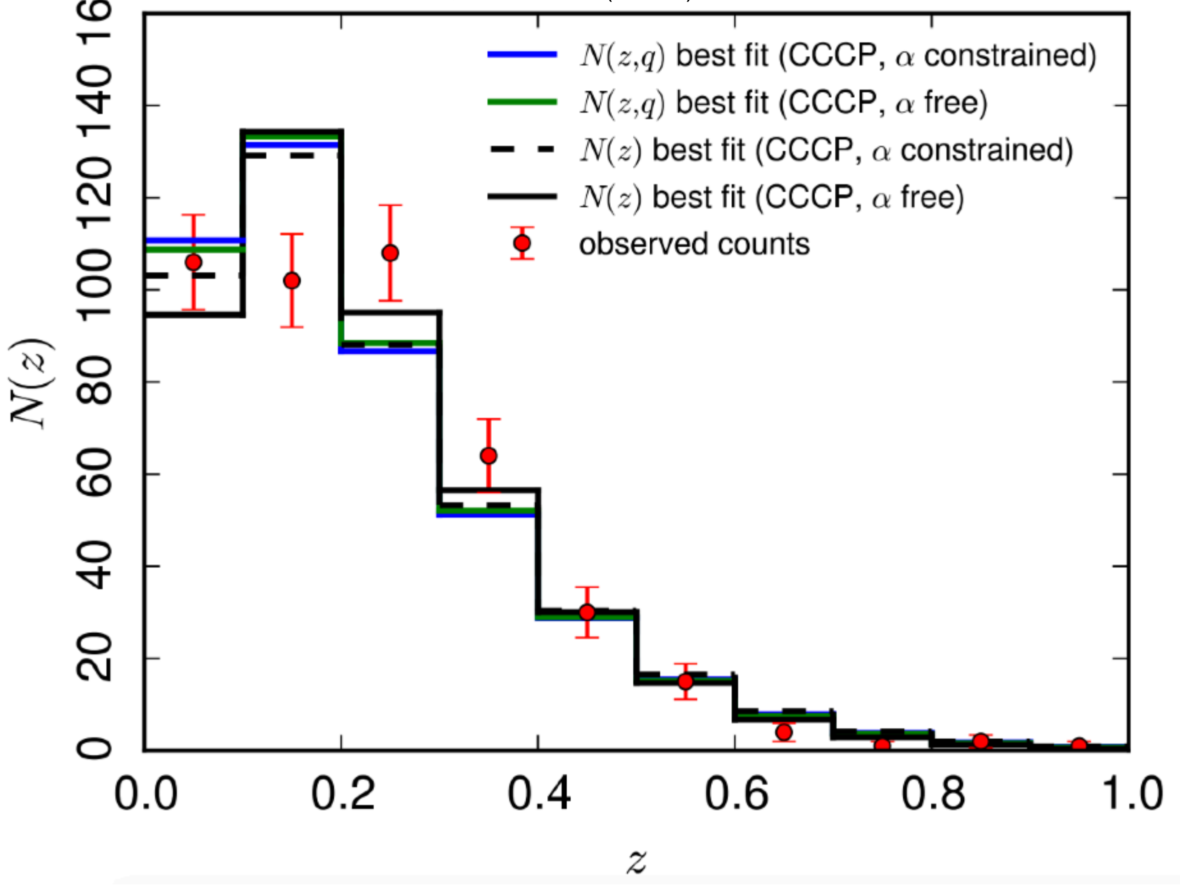
Combination of tSZ Number Counts and Power Spectrum

- Constraints on cosmological parameters
  - Standard model of cosmology
  - Extensions: massive neutrinos, EoS for Dark Energy

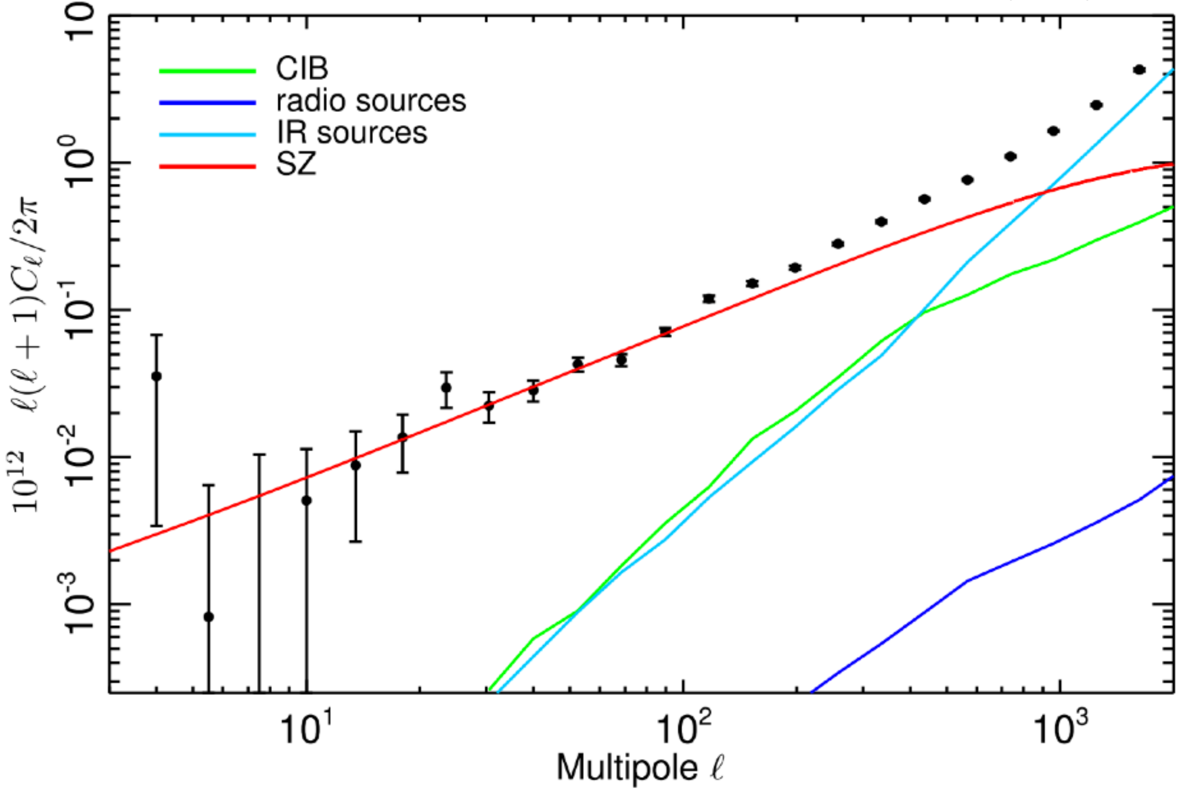
- Comparison with CMB primary anisotropies constraints

LS, Aghanim, Douspis A&A 614 (2018) A13

Planck Collaboration, A&A 594 (2016) A24



Planck Collaboration, A&A 594 (2016) A22



Dataset - Method

LS, Aghanim, Douspis
A&A 614 (2018) A13

- tSZ Number Counts + tSZ Power Spectrum
  - PSZ2 cosmological sample
  - from Planck y-map
    - $z = [0, 3]$
  - $\text{SPT data: } \ell = 3000$

    George, E. M. et al. 2015, Astrophys. J., 799, 177
- Sampling at the same time on **cosmological** and **scaling relation** parameters

Baseline

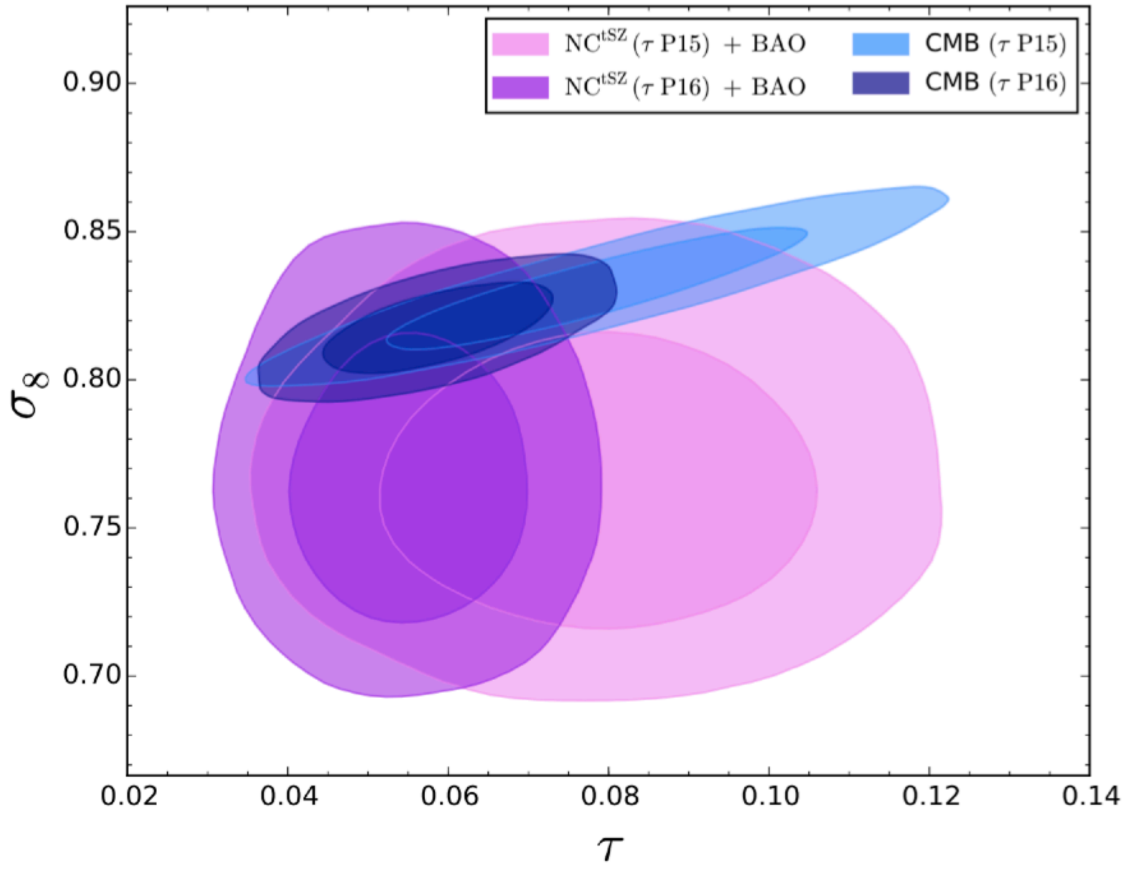
- Tinker mass function
- CCCP prior on mass bias $(1-b) = 0.780 \pm 0.092$

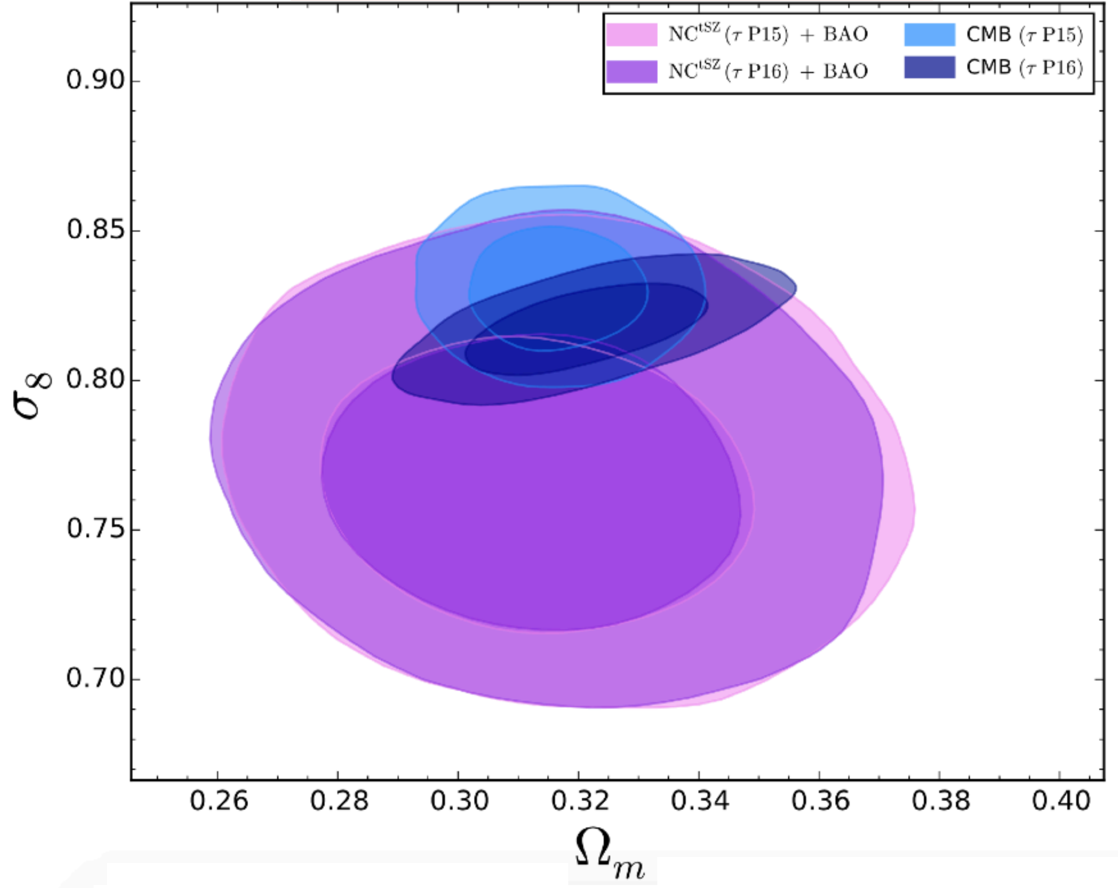
  Hoekstra et al., MNRAS 449 (2015) no.1, 685
- $\tau = 0.055 \pm 0.009$

  Planck Collaboration, A&A 596 (2016) A107

see Silvia Galli's talk

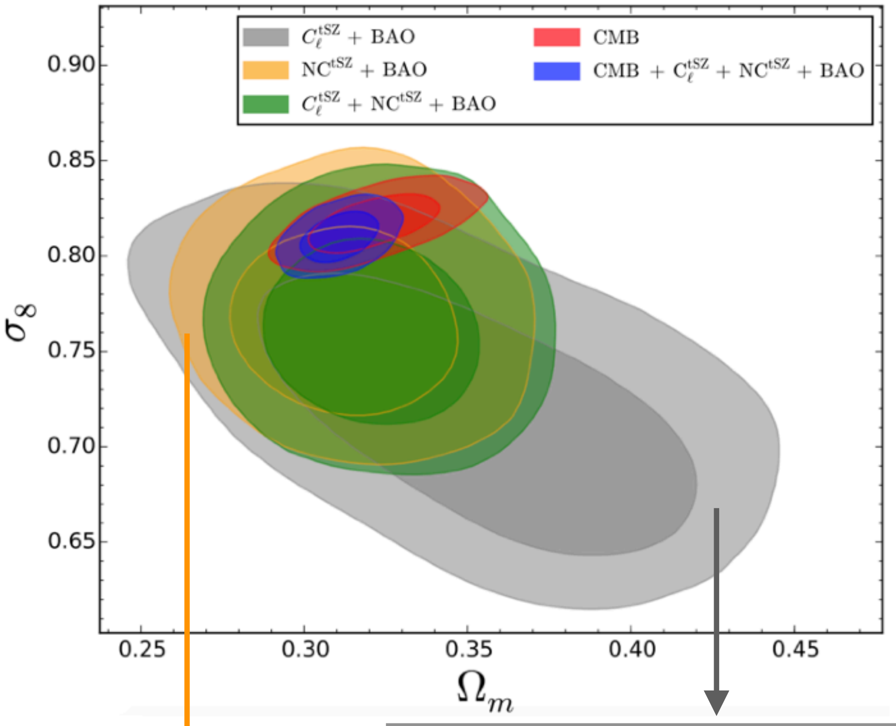
No more tension on σ_8
agreement at $1.5\,\sigma$



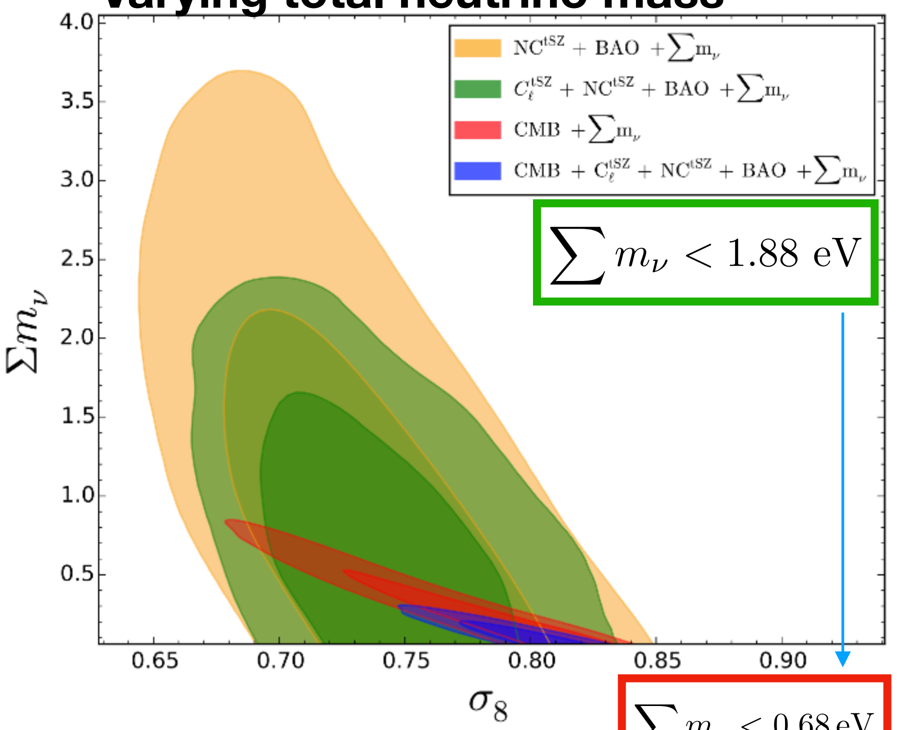


Results

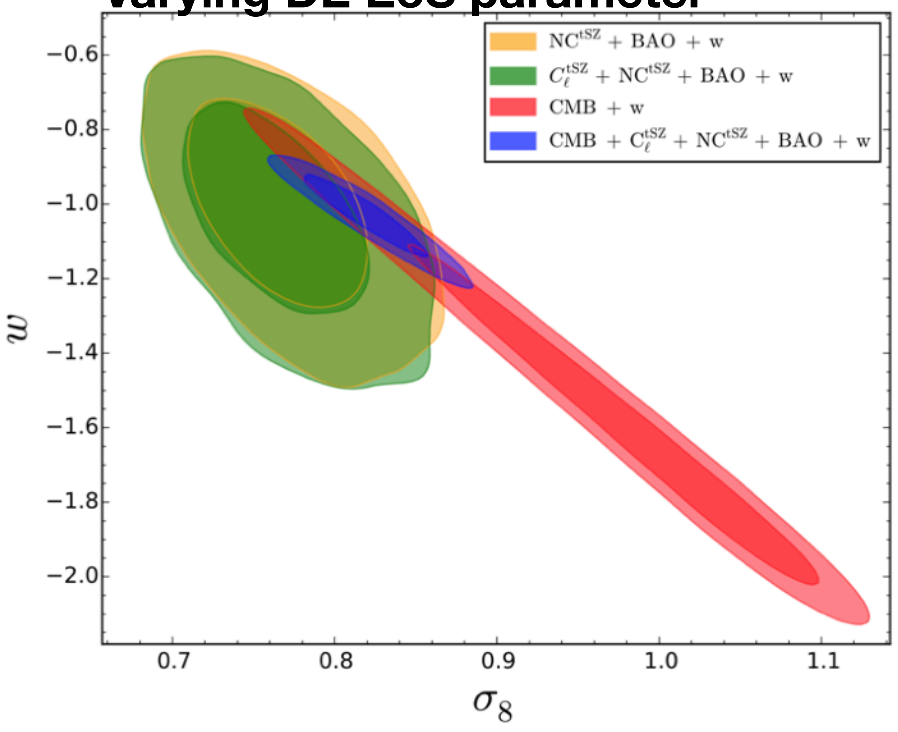
LCDM



Varying total neutrino mass



Varying DE EoS parameter



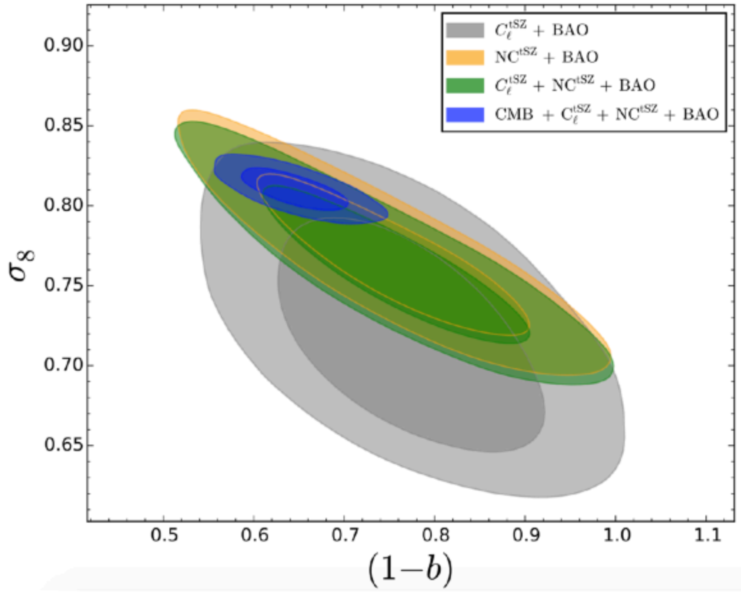
$$\sum m_\nu < 1.88 \text{ eV}$$

$$\sum m_\nu < 0.68\,\text{eV}$$

$$\sum m_\nu < 0.23\,\text{eV}$$

$$\mathrm{C}_\ell^{\rm tSZ} \propto \sigma_8^{8.1}\,\Omega_m^{3.2}\,(1-b)^{3.2}$$

$$\mathrm{NC}^{\rm tSZ} \propto \sigma_8^{9}\,\Omega_m^{3}\,(1-b)^{3.6}$$



No more tension on σ_8

Still discrepancy on (1-b).
Mass bias: strong source of systematics

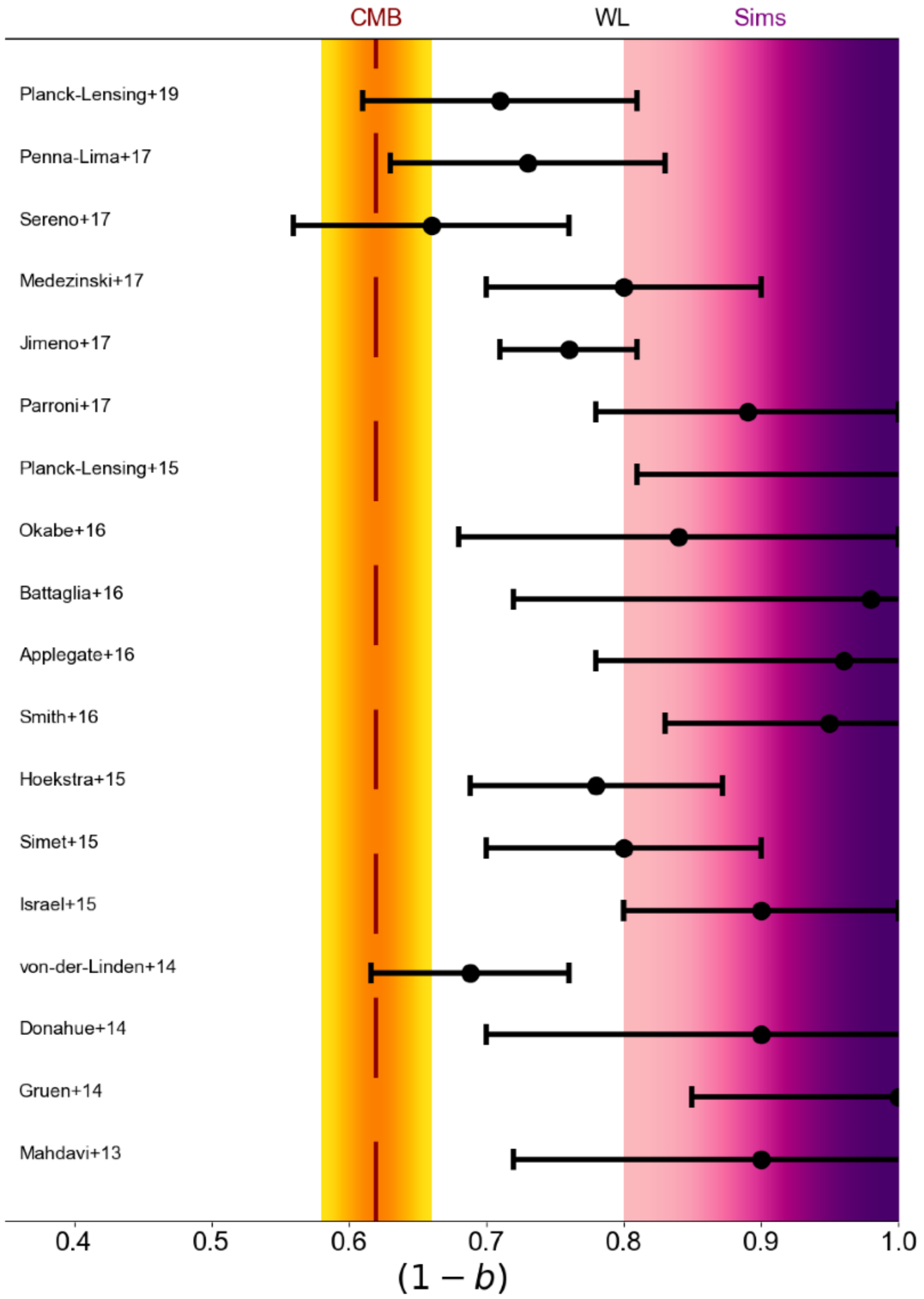
$(1-b) = 0.58 \pm 0.04$ P15

$(1-b) = 0.65 \pm 0.04$ LCDM
$(1-b) = 0.67 \pm 0.04$ Neutrinos
$(1-b) = 0.63 \pm 0.04$ DE

$(1-b) = 0.62 \pm 0.03$ P18

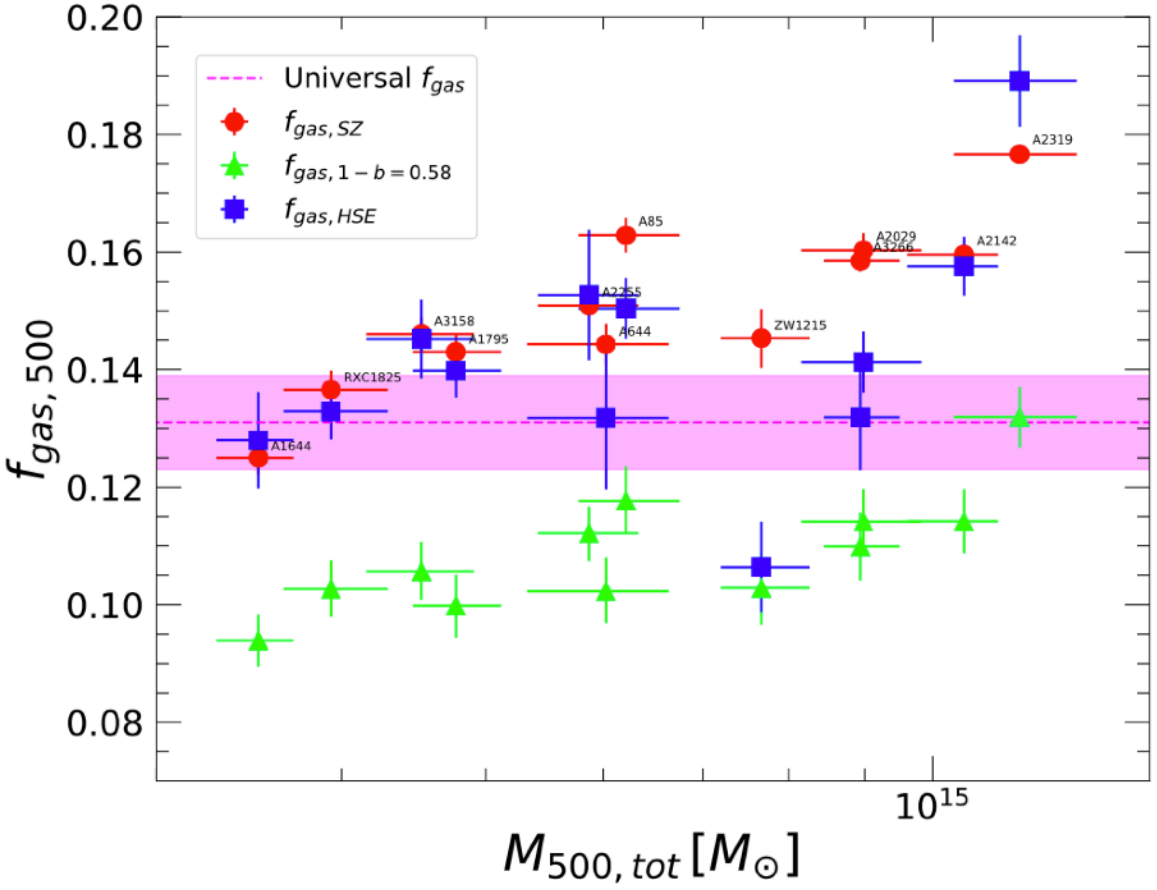
Mass bias

$(1-b) \simeq 0.6$ too low!



Salvati et al, A&A 614 (2018) A13

Gas fraction to evaluate mass bias



Eckert et al, A&A 621, A40 (2019)

Mass bias: M-z evolution

LS, Douspis, Ritz, Aghanim,
Babul. A&A 626, A27 (2019)

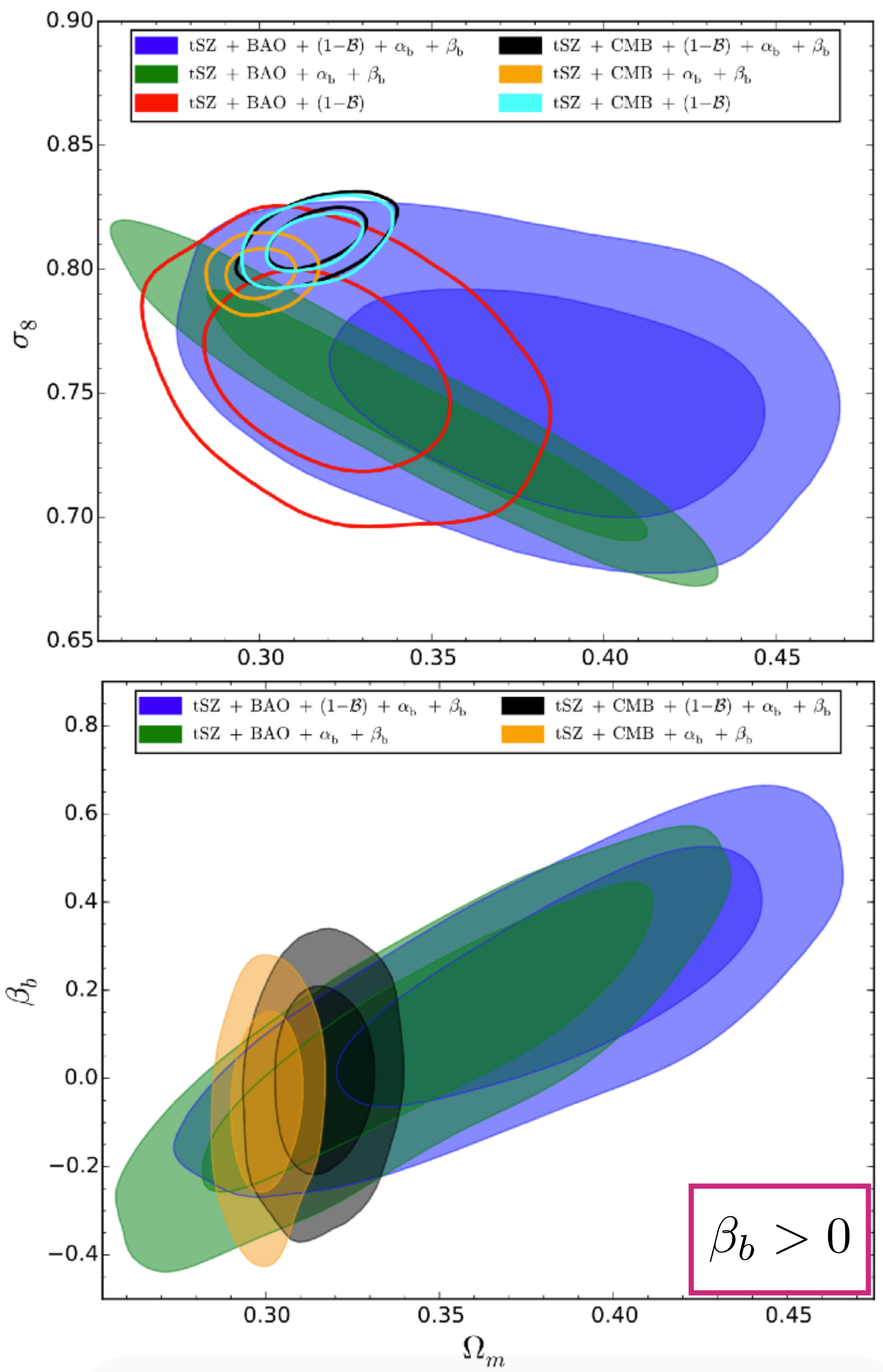
Same approach:
- tSZ NC + tSZ PS
- CCCP + Tinker
- Cosmological + Scaling Relation parameters

Mass-redshift Parametrisation

$$(1-b)_{\rm var} = (1-\mathcal{B}) \cdot \left(\frac{M}{M_*}\right)^{\alpha_b} \cdot \left(\frac{1+z}{1+z_*}\right)^{\beta_b}$$

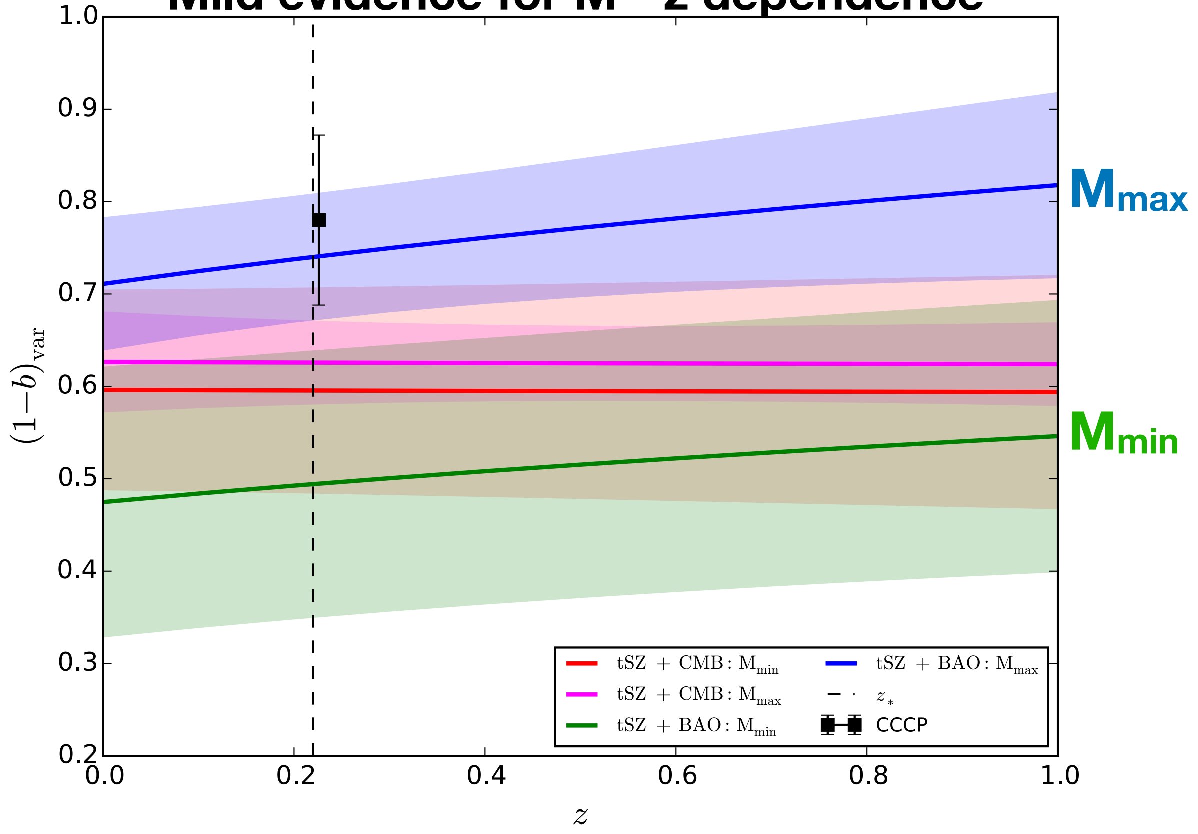
$4.82 \cdot 10^{14} M_\odot$
mean mass
of PSZ2 catalogue

0.22
median redshift
of PSZ2 catalogue



$\beta_b > 0$

Mild evidence for M - z dependence



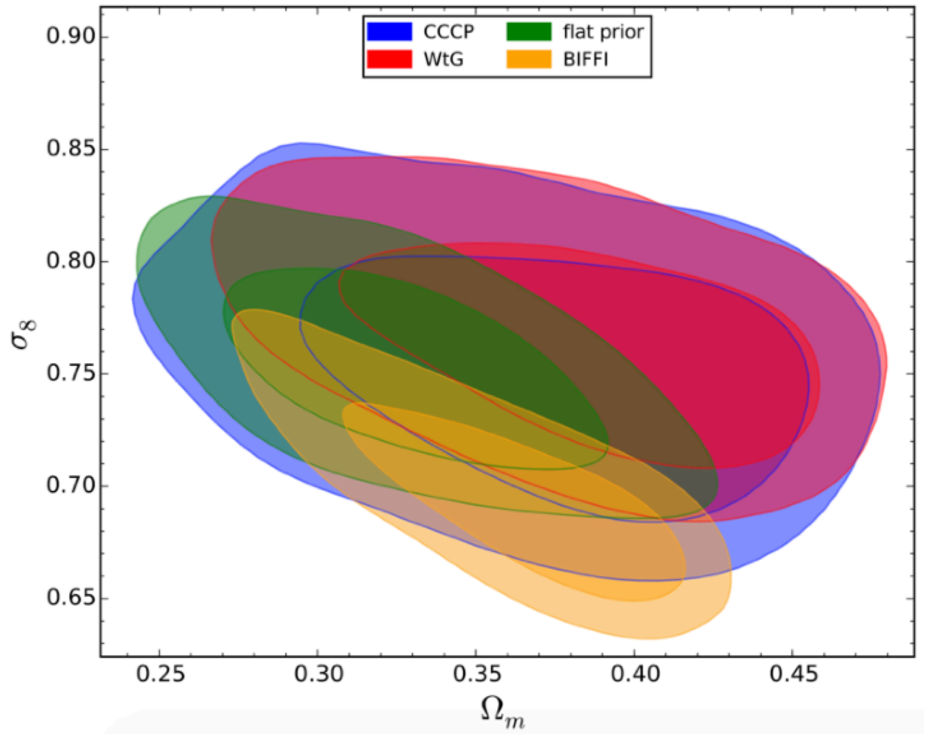
(1-b) increasing with redshift

Need fo further understanding!

Robustness tests Results

LS, Douspis, Ritz, Aghanim, Babul. A&A 626, A27 (2019)

1. Effect of mass bias calibrations

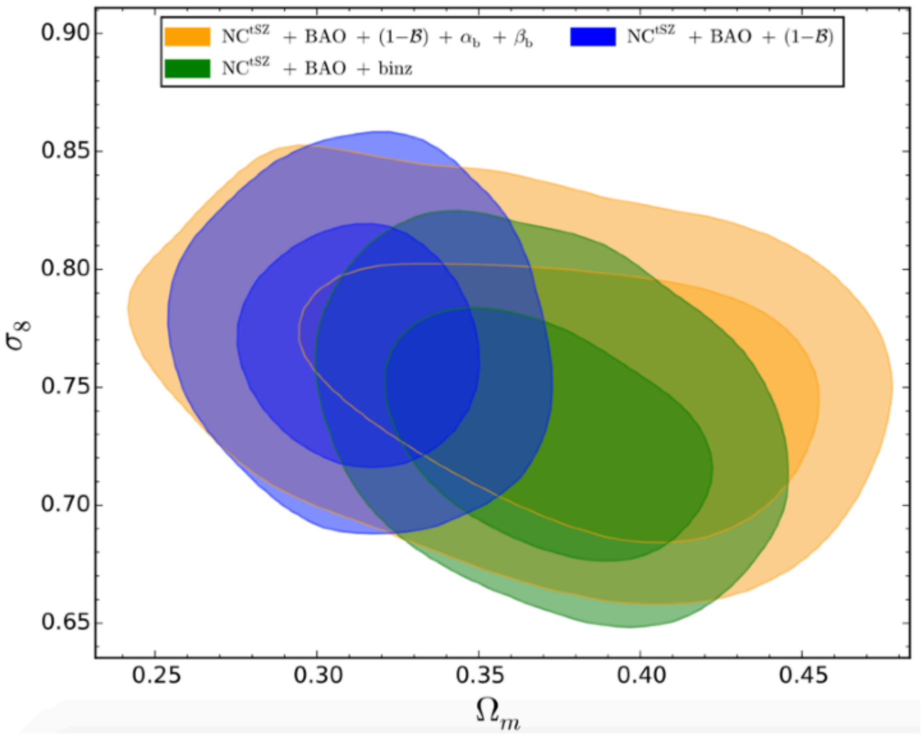


	$(1-b)_{\rm var}$	M	z	β_b
WtG	0.688 ± 0.072	$13.08 \cdot 10^{14} M_\odot$	0.31	$0.26^{+0.23}_{-0.17}$
von der Linden et al.. MNRAS 443 (2014) no.3. 1973				
CCCP	0.780 ± 0.092	$14.83 \cdot 10^{14} h^{-1} M_\odot$	0.246	$0.24^{+0.24}_{-0.18}$
Hoekstra et al.. MNRAS 449 (2015) no.1. 685				
BIFFI	0.877 ± 0.015	$10.53 \cdot 10^{14} M_\odot$	0	$0.27^{+0.22}_{-0.17}$
Biffi et al.. Astrophys. J. 827 (2016) no.2. 112				

Flat prior [0.6,1.0]

Ω_m	σ_8	$(1-\mathcal{B})$	α_b	β_b
0.330 ± 0.038	$0.753^{+0.026}_{-0.031}$	$0.756^{+0.056}_{-0.083}$	$0.005^{+0.029}_{-0.026}$	0.10 ± 0.16

2. Effect of M-z parametrisation



Redshift bins

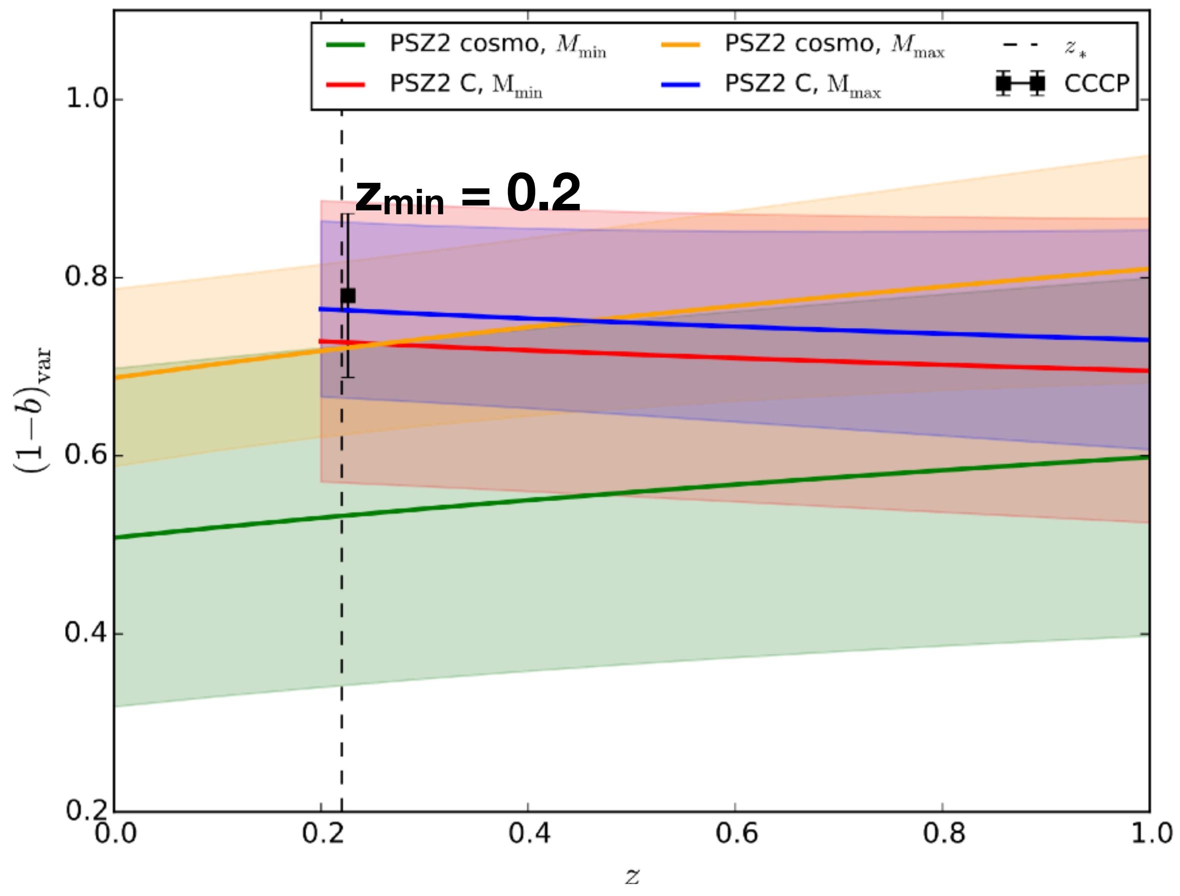
	bin 1	bin 2	bin 3	$(1-b)_2$
	$[0, 0.2]$	$[0.2, 0.5]$	$[0.5, 1]$	
CCCP	6	11	1	0.78 ± 0.092
PSZ2 cosmo sample	209	200	23	

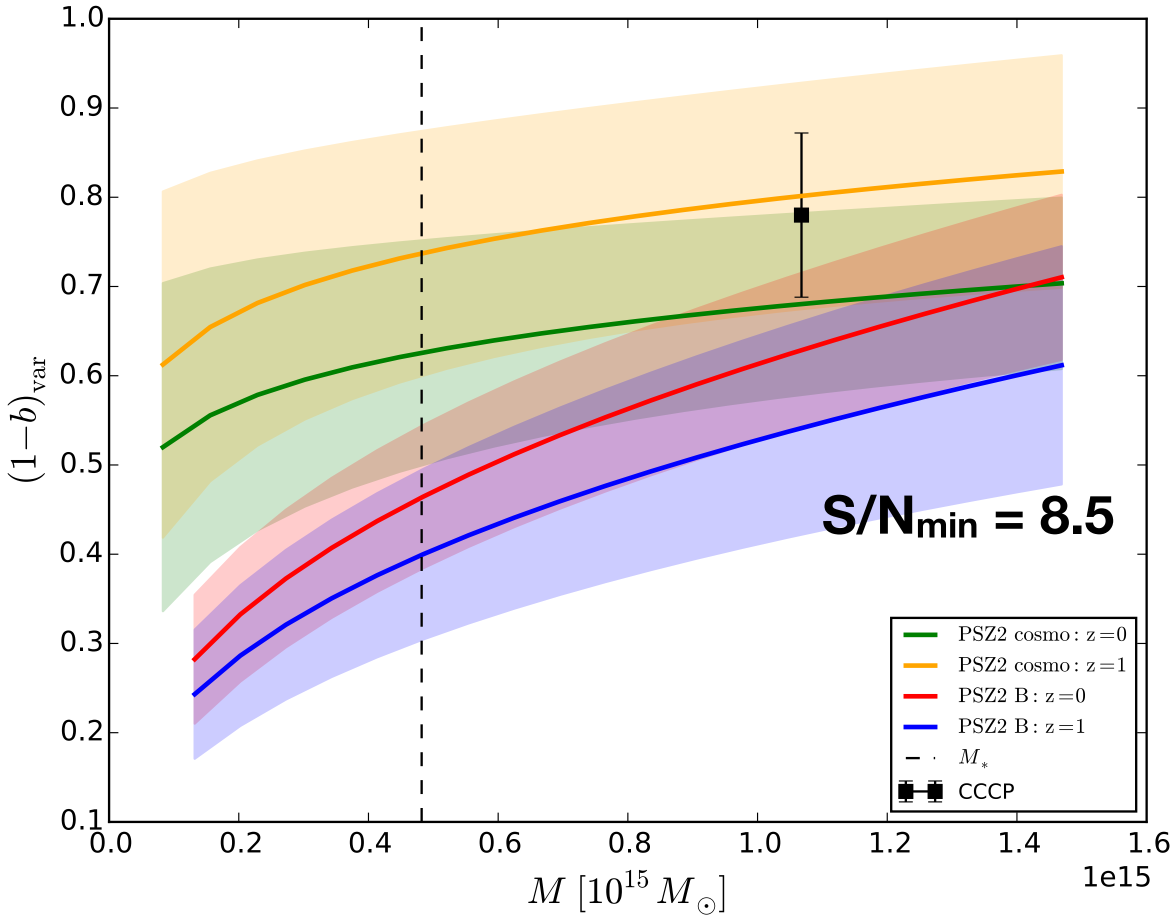
$(1-b)_1$	$(1-b)_2$	$(1-b)_3$
0.655 ± 0.078	0.775 ± 0.092	0.751 ± 0.095

Robustness tests Results

LS, Douspis, Ritz, Aghanim,
Babul. A&A 626, A27 (2019)

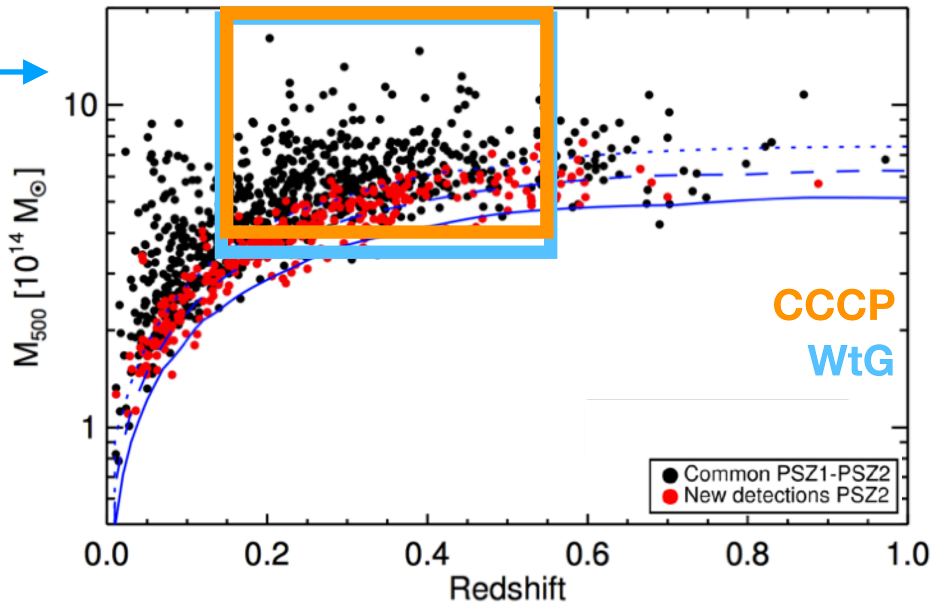
3. Selection effects





Results from other analyses

- WtG (22 clusters) and CCCP (18 clusters)
mass dependence: decreasing trend
- CoMaLit analysis Sereno&Ettori, MNRAS 468 (2017) no.3, 3322
redshift dependence: decreasing trend
(135 clusters)
- X-COP analysis Eckert et al, A&A 621, A40 (2019)
mass dependence: decreasing trend
(12 clusters)



Conclusions & Perspectives

Cosmology with Galaxy Clusters

No more tension between tSZ galaxy clusters and CMB

Mass bias calibration: large uncertainty

Evidence for non-constant mass bias

- Results depend on the cluster sample
- M-z parametrisation does not solve CMB - tSZ discrepancy

Improvements

- Larger samples for the calibrations
- Direct “internal calibration” (e.g. SPT 2018 analysis)
- Better description of cluster physics

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Thank you for your attention