Cluster cosmology: impact of the mass calibration on the σ_8 tension

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in collaboration with
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Outline

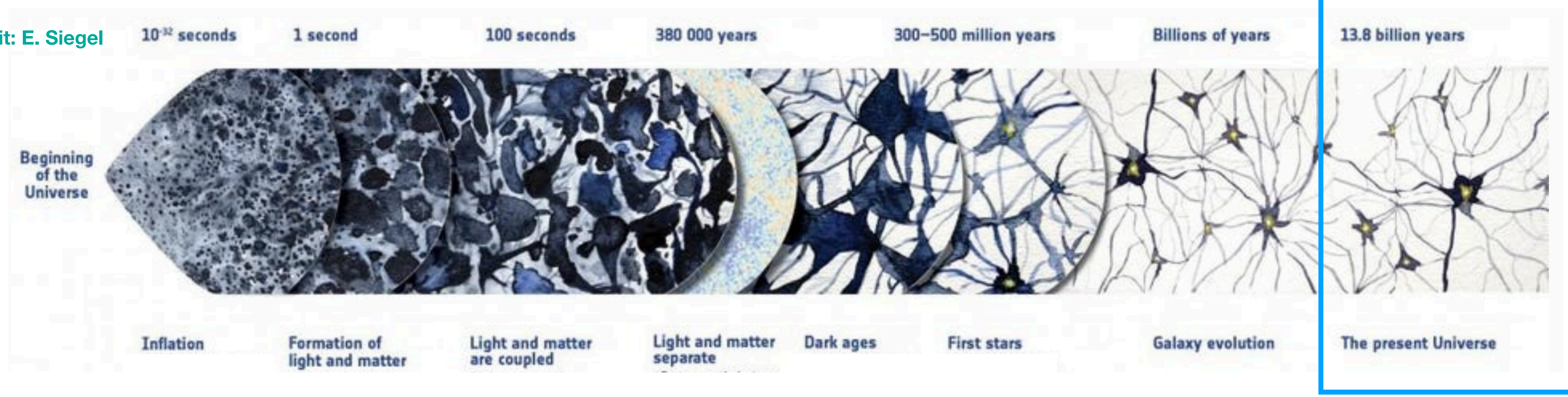
- Cosmology with Galaxy Clusters
  - thermal Sunyaev-Zeldovich effect
  - impact of mass calibration

- Characterise the mass bias
  - Results based on
    - Salvati+ A&A 614, A13 (2018)
    - Salvati+ A&A 626, A27 (2019)

Introduction

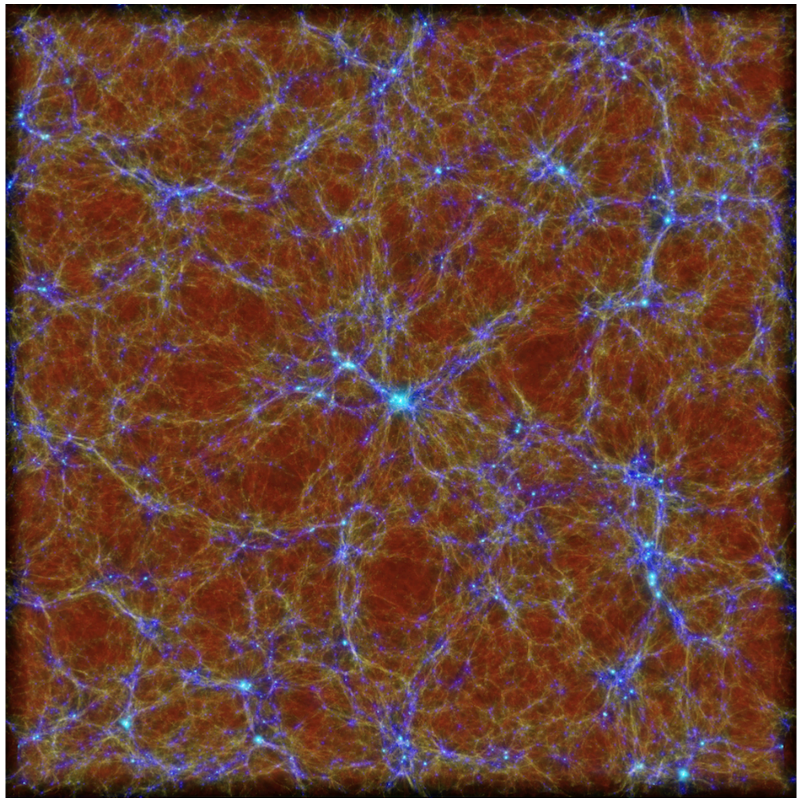
Galaxy Clusters

Credit: E. Siegel



- Largest gravitationally bound structures in the Universe
- Peaks in the cosmic web
- Multi-component systems:
  - Observables at different wavelengths

<u>Dependence on cosmological parameters:</u> $\sigma_8, \ \Omega_m$



Credit: Hirschmann et al. 2014

Cluster cosmology

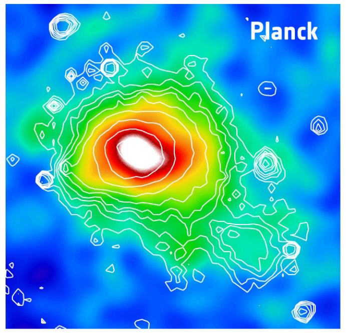
Cluster cosmology: *mass* and *redshift* of clusters

Cluster number counts:

NC(z,obs) = **Mass Function** x **Scaling Relations** x **Selection Function**

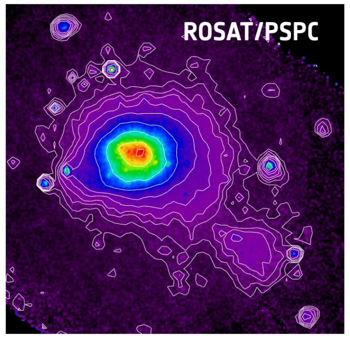
Cosmology/theory
Theoretical NC(z,M)

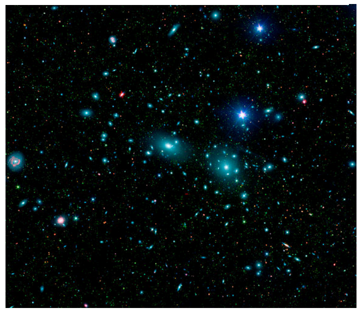
Astrophysics
Survey observable - cluster mass



mm-wavelengths
Hot gas

Xray-wavelengths
Hot gas





Optical wavelengths
Galaxies

COMA cluster

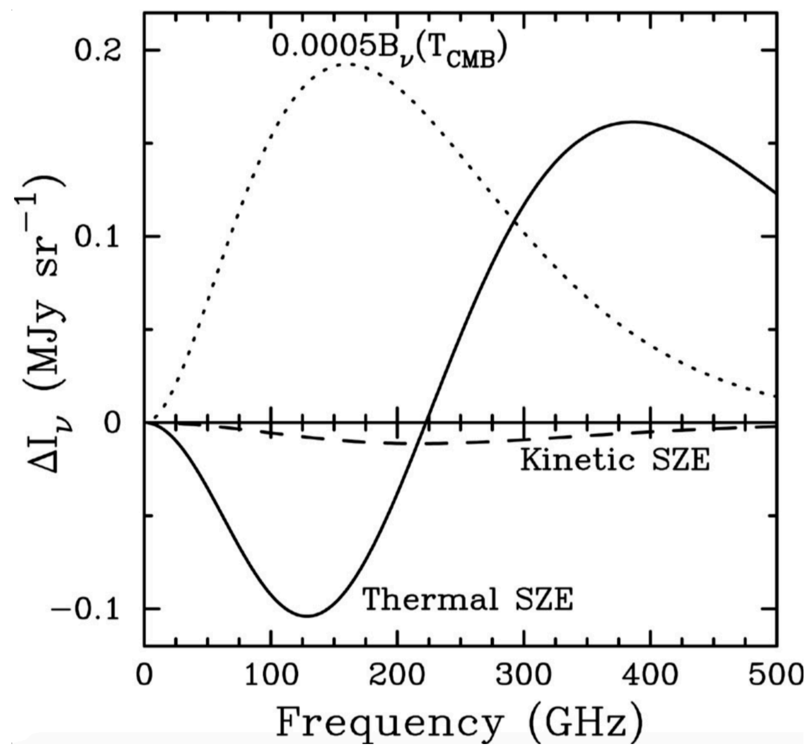
Multi-wavelengths analysis:
Unique way to calibrate cluster mass

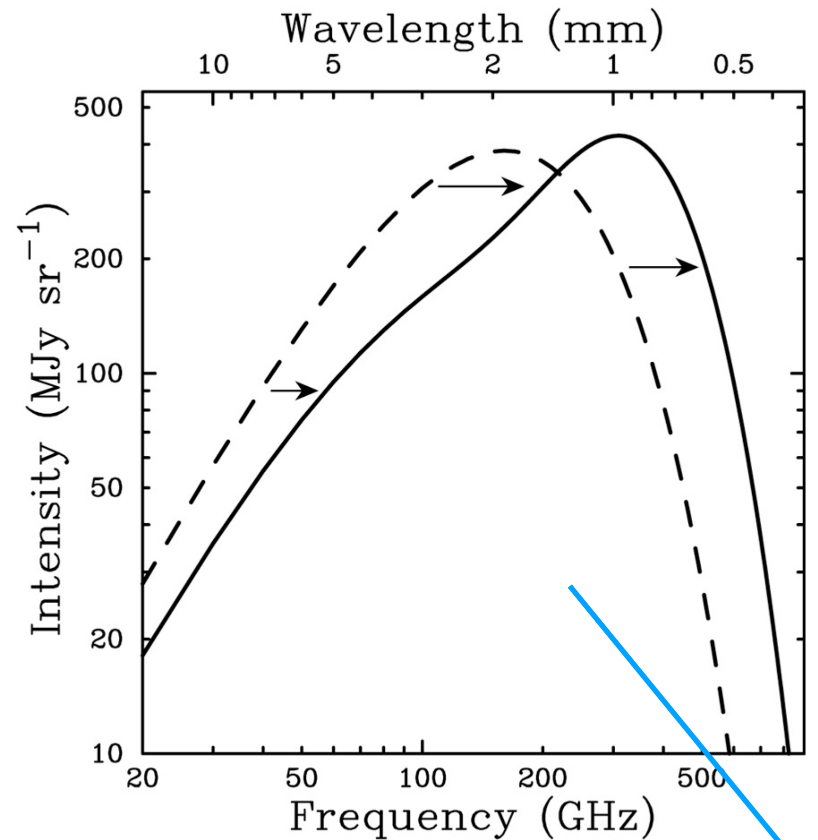
Observations
Survey and detection strategy

Constraints on cosmological parameters:
precise characterisation of the building blocks

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

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

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

Mass calibration

Cluster number counts:

***NC(z,obs)* = Mass Function x Scaling Relations x Selection Function**

- Self-similarity: gravity is the only acting force
- Spherical symmetry
- Hydrostatic equilibrium

$$\rightarrow Y_{\rm SZ} D_A^2 \propto M_{\rm tot}^{5/3} E(z)^{2/3}$$

Planck Scaling Relations

$$E^{-\beta}(z)\left[\frac{D_A^2(z)\,Y_{500}}{10^{-4}\,{\rm Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)\,M_{500}}{6\cdot 10^{14} M_\odot}\right]^{\alpha}$$

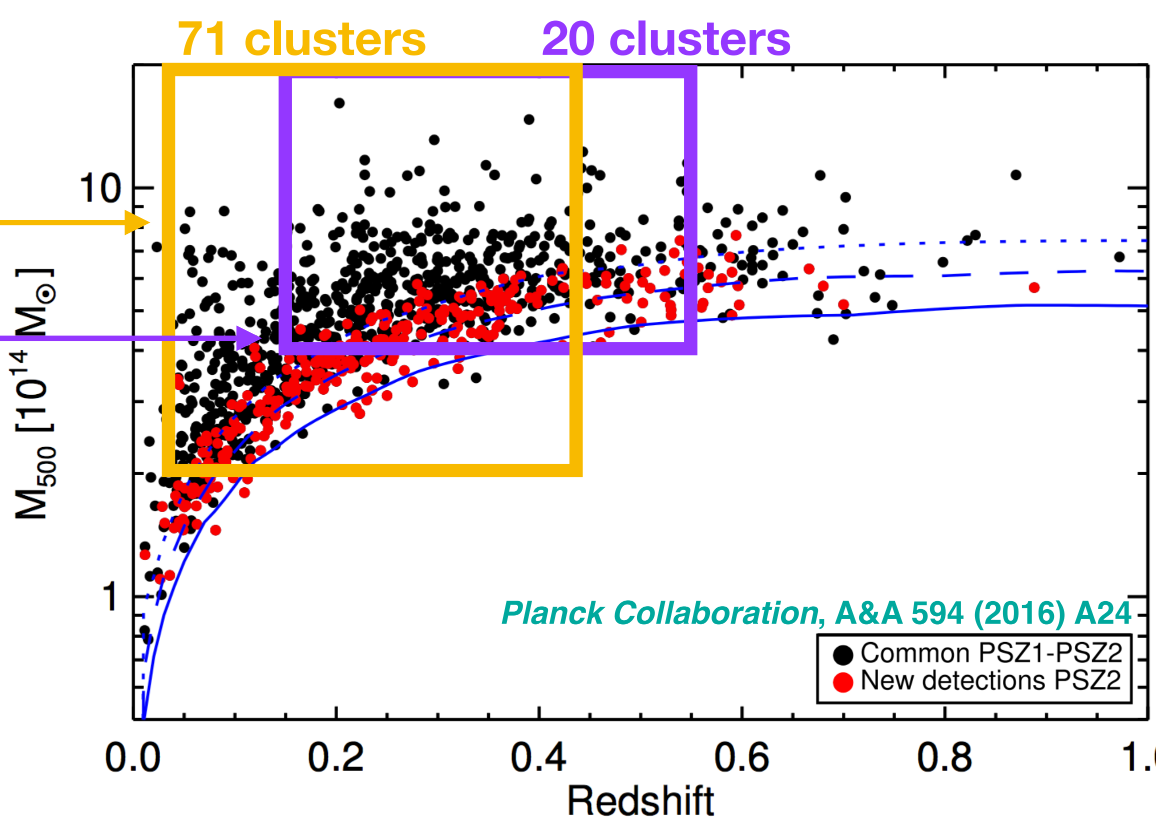
$\alpha,\ Y_*$ → from X-ray observations

$(1-b)$ → from WL mass evaluations

$\beta = 2/3$ → from self-similarity

Planck Collaboration, A&A 594 (2016) A24

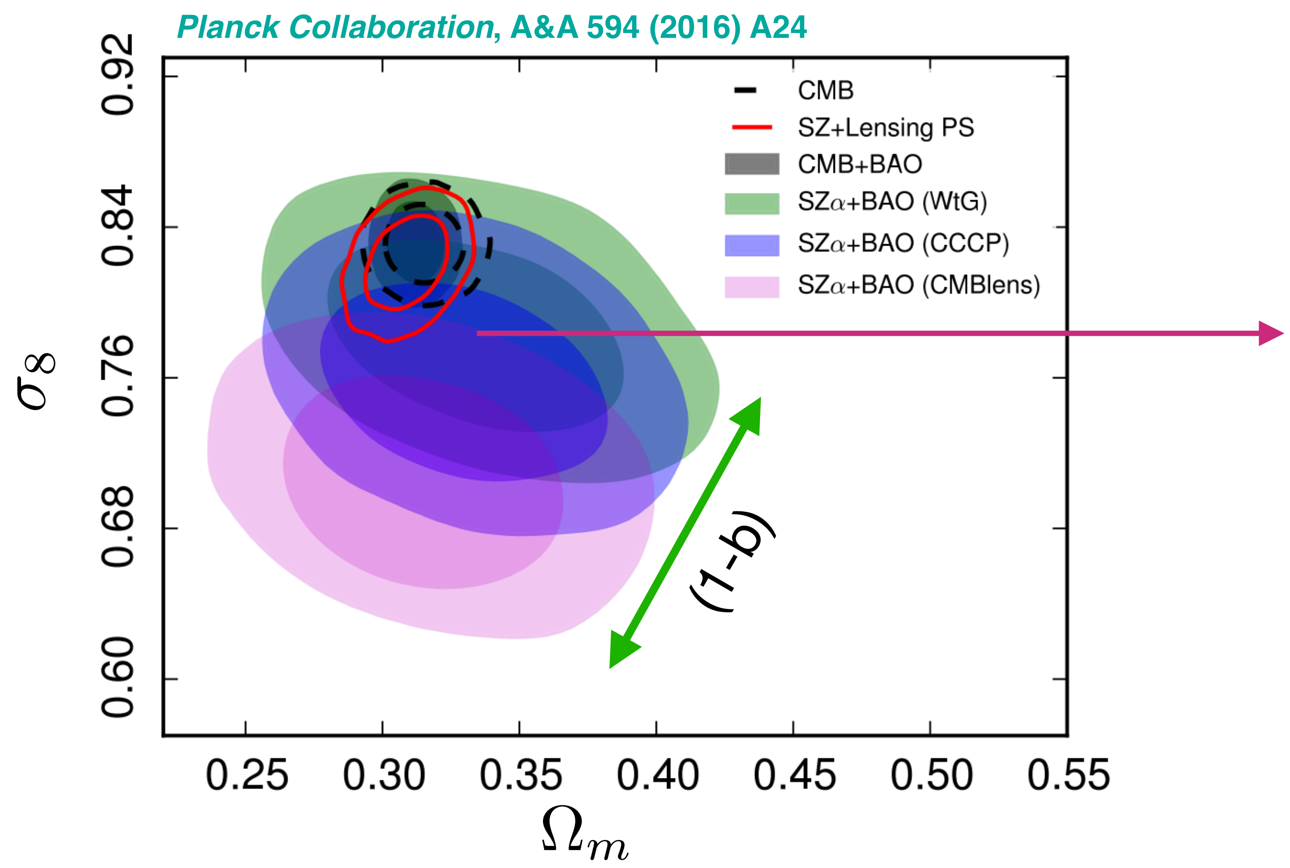
Planck cosmological cluster sample: 439 clusters



Mass calibration and cosmology

Cluster number counts:

***NC(z,obs)* = Mass Function x Scaling Relations x Selection Function**



tension between CMB primary anisotropies and Galaxy Clusters:

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

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

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

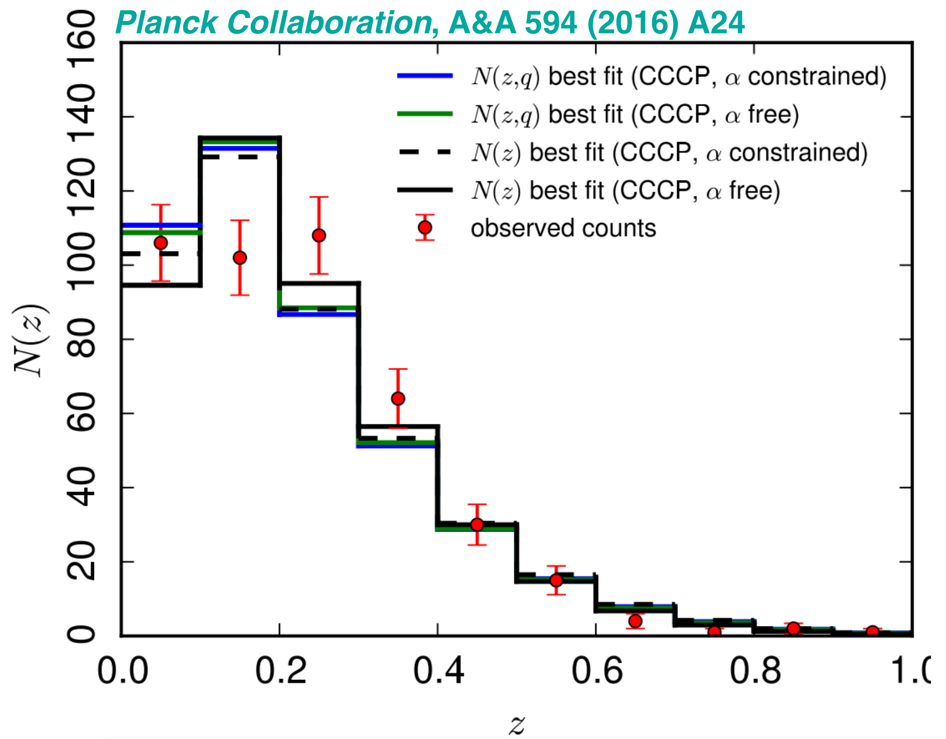
$$\text{CCCP:} \ (1-b) = 0.780 \pm 0.092$$

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

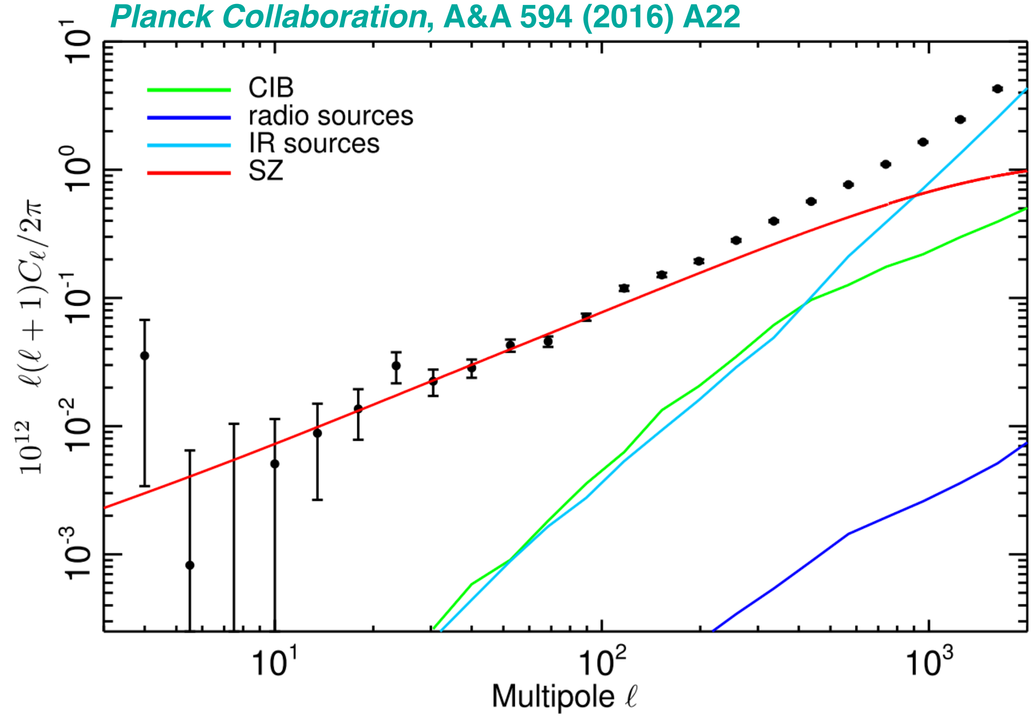
Mass calibration: largest source of uncertainty in current cluster cosmology

tSZ Number Counts + Power Spectrum

Planck Collaboration, A&A 594 (2016) A24



Planck Collaboration, A&A 594 (2016) A22



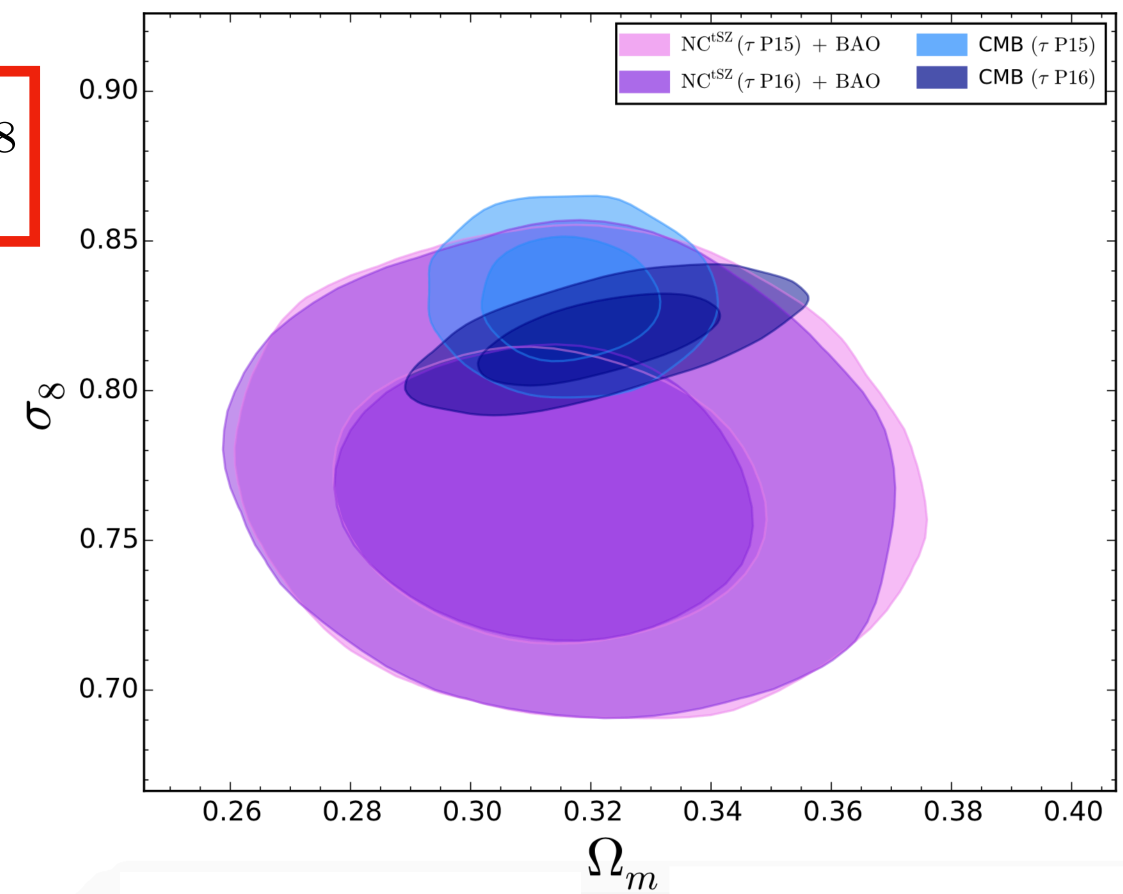
\+

tSZ from

SPT data: $\ell = 3000$

George, E. M. et al. 2015, Astrophys. J., 799, 177

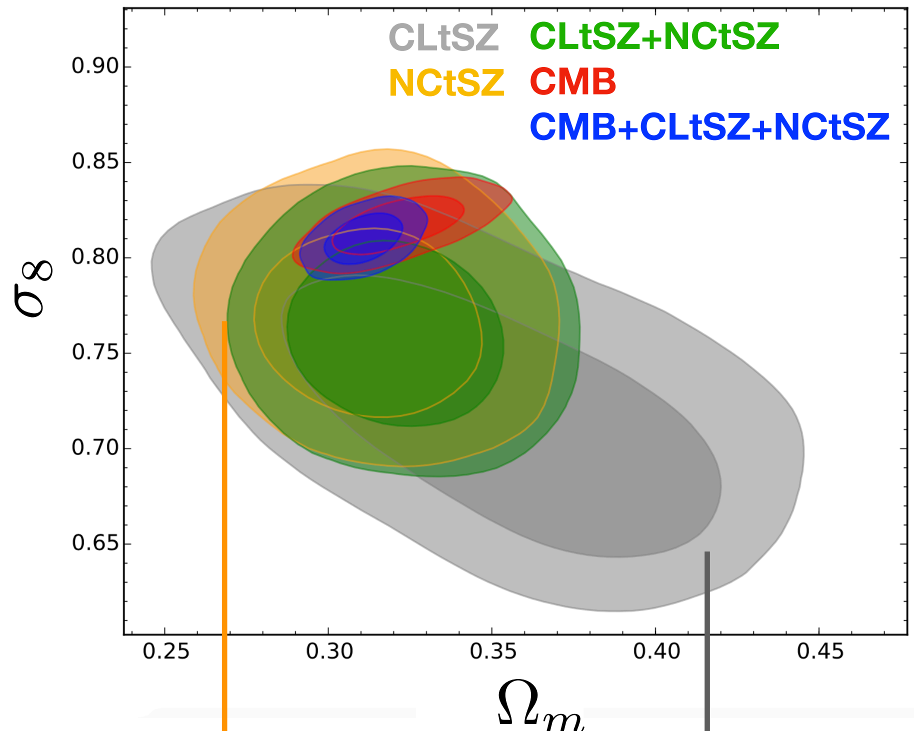
No more tension on σ_8 agreement at $1.5\,\sigma$



tSZ Number Counts + Power Spectrum

Salvati+ A&A 614, A13 (2018)

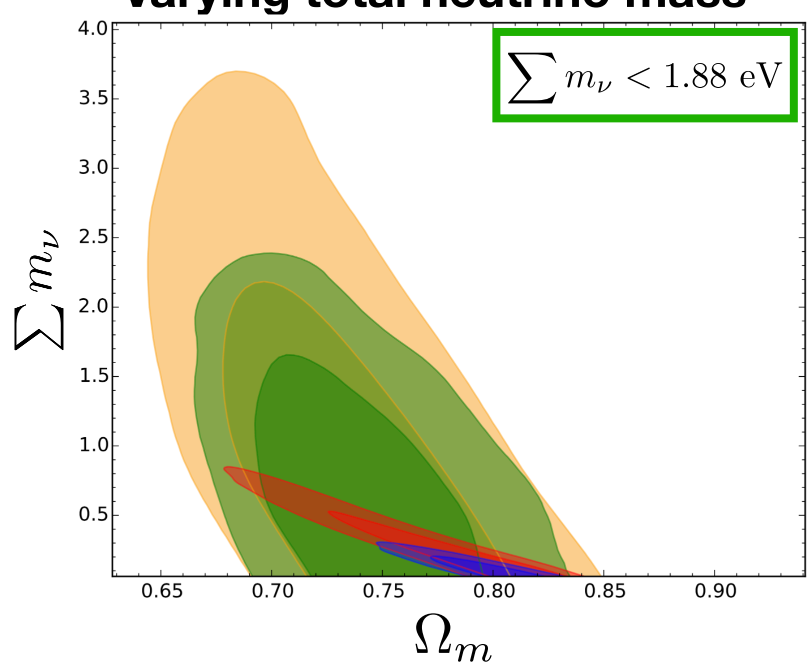
LCDM



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

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

Varying total neutrino mass



$\sum m_\nu < 1.88$ eV

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

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

No more tension on σ_8

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

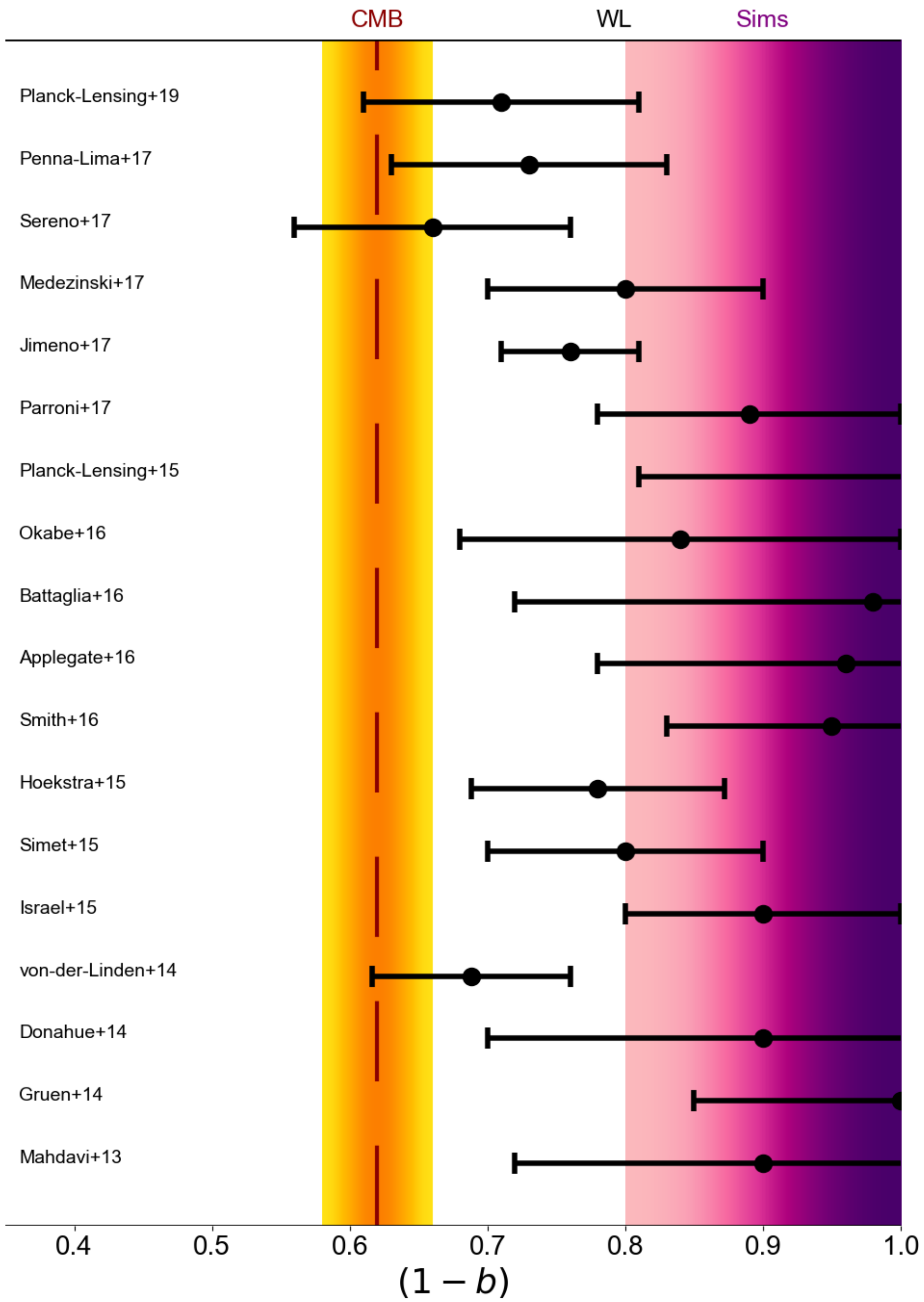
$(1-b) = 0.62 \pm 0.03$ P18

Tension moved to the mass bias ?!?

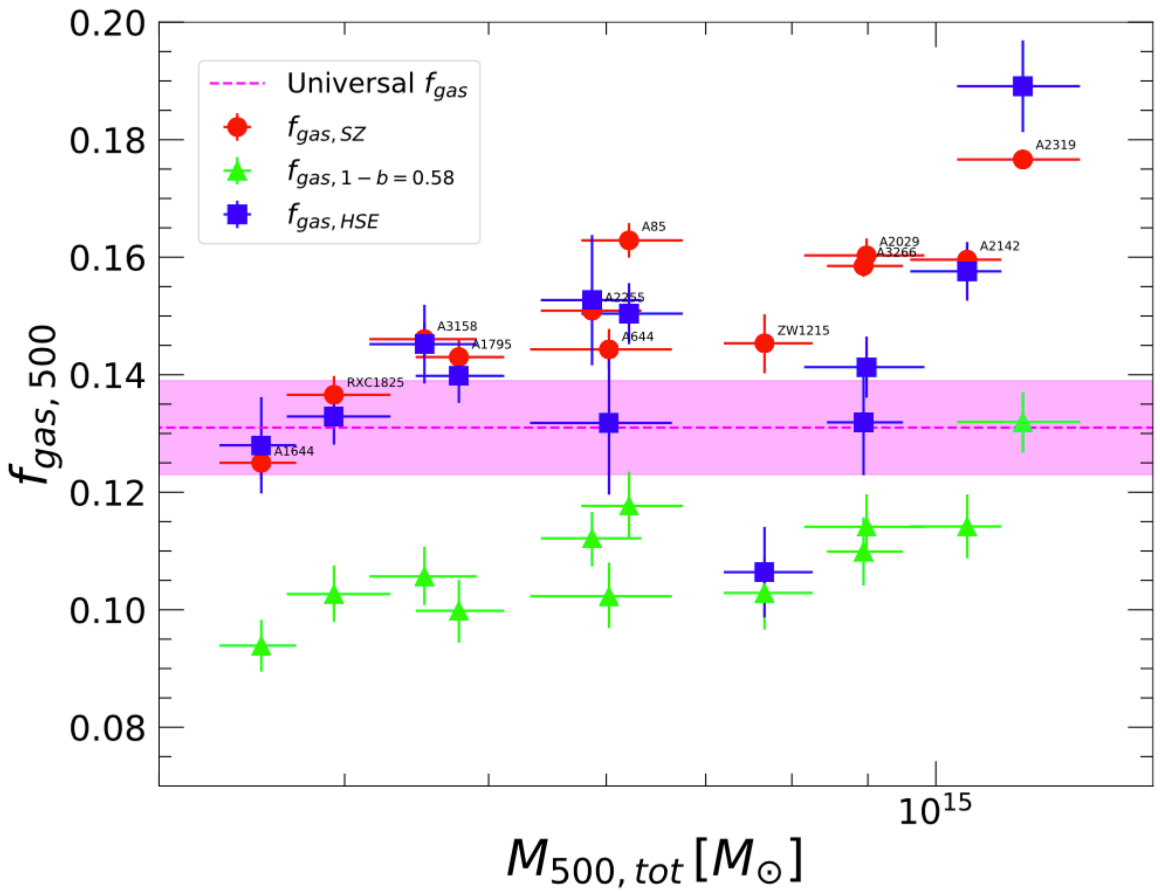
Mass bias

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

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



Gas fraction to evaluate mass bias



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

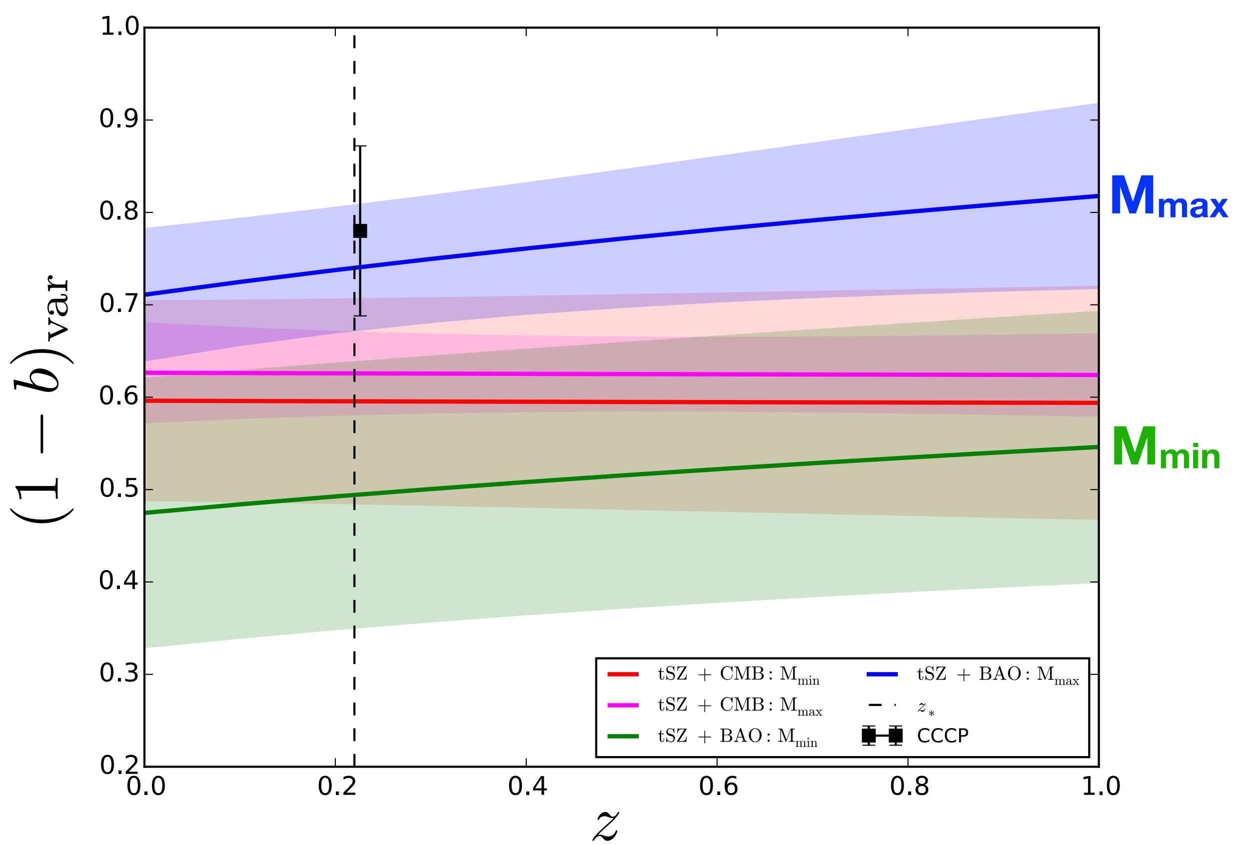
Salvati+ A&A 626, A27 (2019)

Mass-redshift Parametrisation

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

CMB+tSZ probes: constant $(1\text{-}b)_{var}$ ~ 0.6

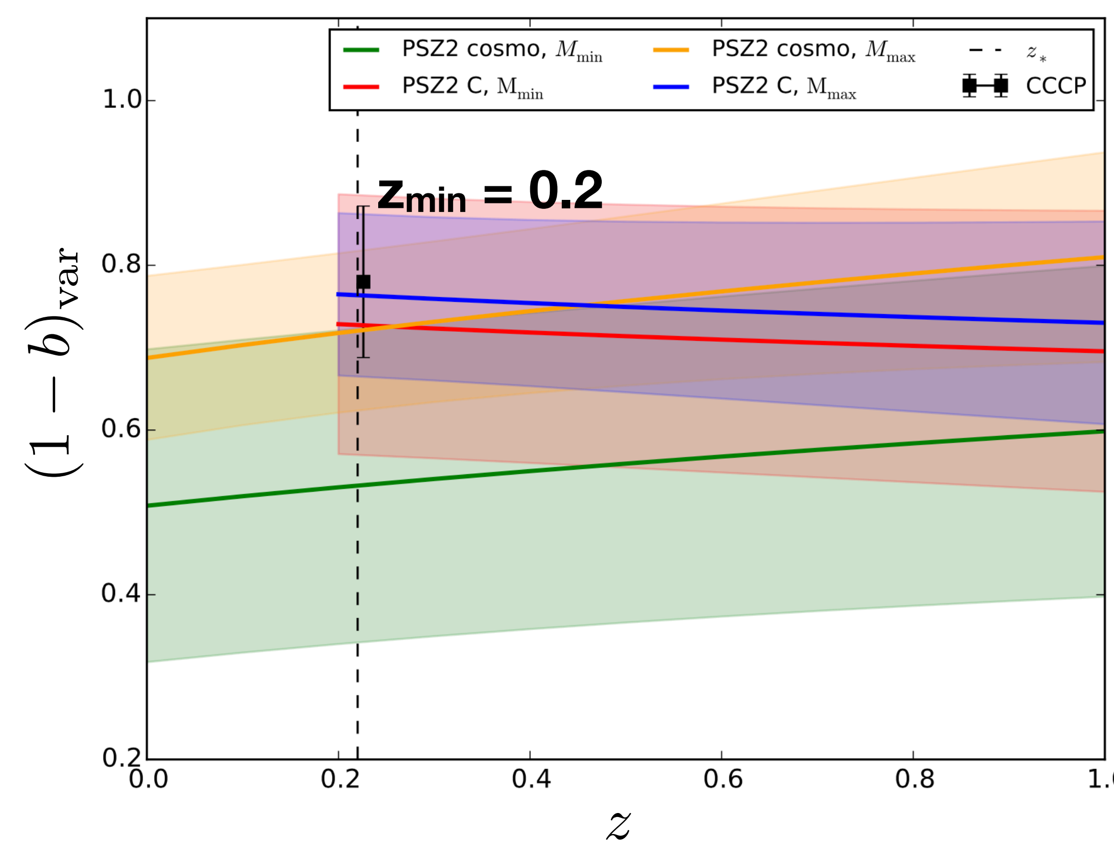
Mild evidence for M - z dependence



$\beta_b > 0$

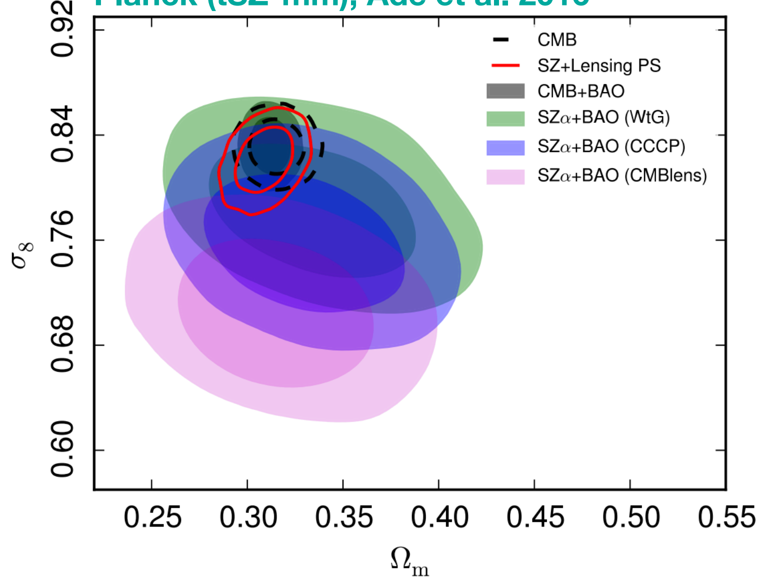
(1-b) increasing with redshift

Selection effect

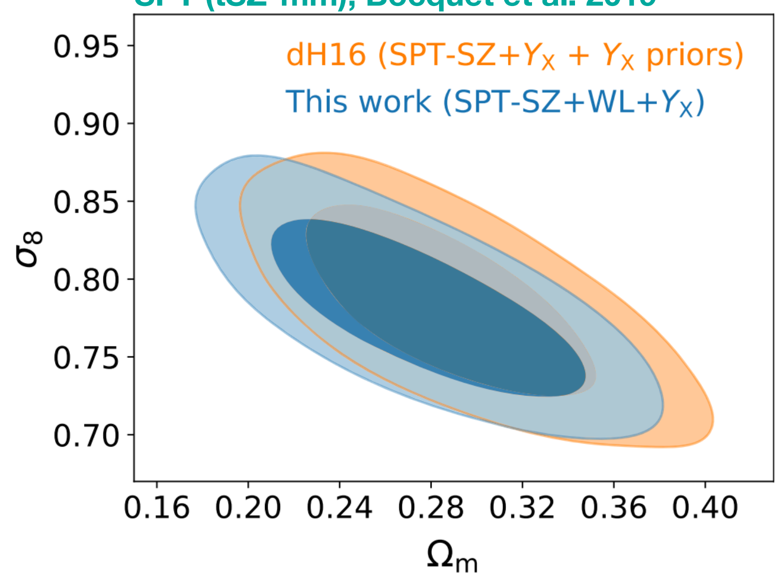


Mass calibration: largest source of uncertainties in current cluster cosmology

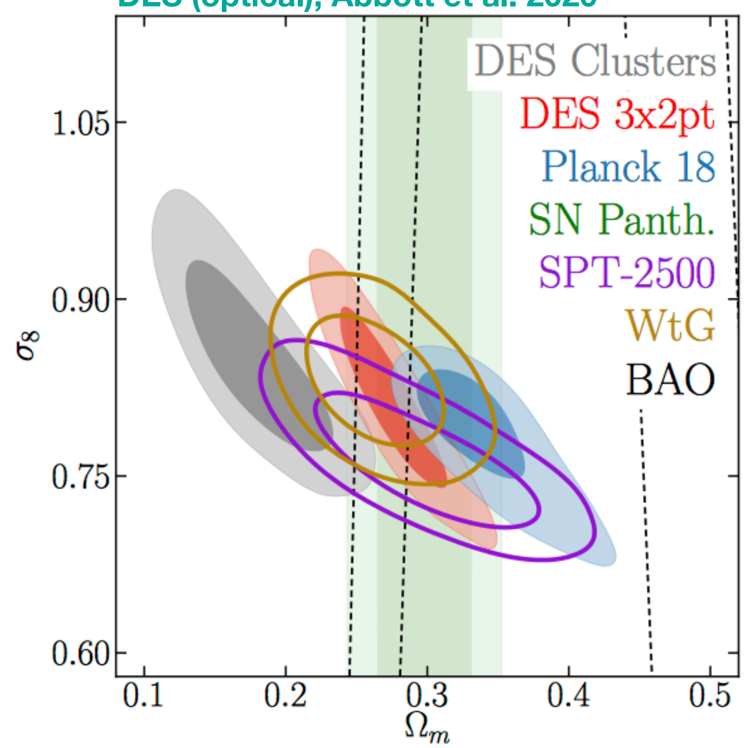
Planck (tSZ-mm), Ade et al. 2016



SPT (tSZ-mm), Bocquet et al. 2019



DES (optical), Abbott et al. 2020



- Improve theoretical modelling: interplay between cosmology and astrophysics
  - Move on from assumptions of self-similarity and HE
- Hydro-dynamical simulations
- Larger multi-wavelength catalogs

Check if there is still room for TENSIONS!

Thank you for your attention

Backup

tSZ Number Counts + Power Spectrum

tSZ Number counts

$$n_i = \int_{z_i}^{z_{i+1}} dz \int d\Omega \frac{dV_c}{dz d\Omega} \int_{M_{\rm min}}^{M_{\rm max}} dM_{500}\, \hat{\chi}(z, M_{500}; l, b) \frac{dN(M_{500}, z)}{dM_{500}}$$

tSZ Power Spectrum

$$C_\ell^{\rm tSZ} = C_\ell^{\rm 1halo} + C_\ell^{\rm 2halo}$$

$$C_\ell^{\rm 1halo} = \int_0^{z_{\rm max}} dz \frac{dV_c}{dz d\Omega} \int_{M_{\rm min}}^{M_{\rm max}} dM \frac{dN(M_{500}, z)}{dM_{500}} |\tilde{y}_\ell(M_{500}, z)|^2 \cdot \exp\left(\frac{1}{2}\sigma^2_{\ln Y^*}\right)$$

$$C_\ell^{\rm 2halo} = \int_0^{z_{\rm max}} dz \frac{dV_c}{dz d\Omega} \left[\int_{M_{\rm min}}^{M_{\rm max}} dM \frac{dN(M_{500}, z)}{dM_{500}} \tilde{y}_\ell(M_{500}, z) B(M_{500}, z)\right]^2 P(k, z)$$

Mass function

$$\frac{dN(M_{500}, z)}{dM_{500}} = f(\sigma) \frac{\rho_m(z=0)}{M_{500}} \frac{d\ln\sigma^{-1}}{dM_{500}}$$

$$f(\sigma) = A\left[1 + \left(\frac{\sigma}{b}\right)^{-a}\right] \exp\left(-\frac{c}{\sigma^2}\right)$$

Tinker et al., Astrophys. J. 688 (2008) 709

Scaling Relations

$$E^{-\beta}(z) \left[\frac{D_A^2(z)\, Y_{500}}{10^{-4}\,{\rm Mpc}^2}\right] = Y_* \left[\frac{h}{0.7}\right]^{-2+\alpha} \left[\frac{(1-b)\, M_{500}}{6 \cdot 10^{14} M_\odot}\right]^{\alpha}$$

$$\theta_{500} = \theta_* \left[\frac{h}{0.7}\right]^{-2/3} \left[\frac{(1-b)\, M_{500}}{3 \cdot 10^{14}\, M_\odot}\right]^{1/3} E^{-2/3}(z) \left[\frac{D_A(z)}{500\,{\rm Mpc}}\right]^{-1}$$

Planck 2015 results. XXIV. A&A 594 (2016) A24

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

Selection function

Planck 2015 results. XXVII. A&A 594 (2016) A27

Universal Pressure Profile

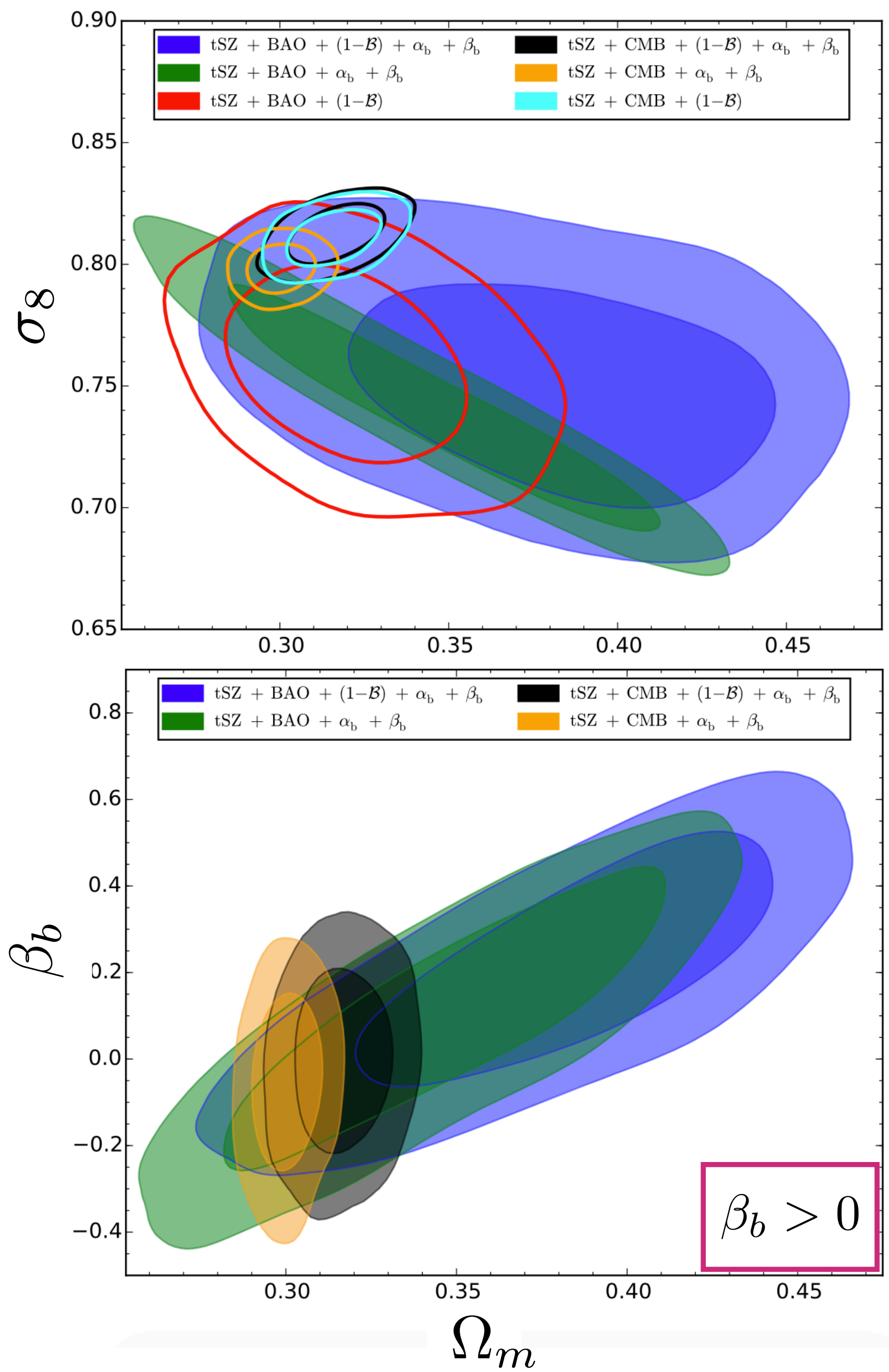
Arnaud et al., A&A 517 (2010) A92

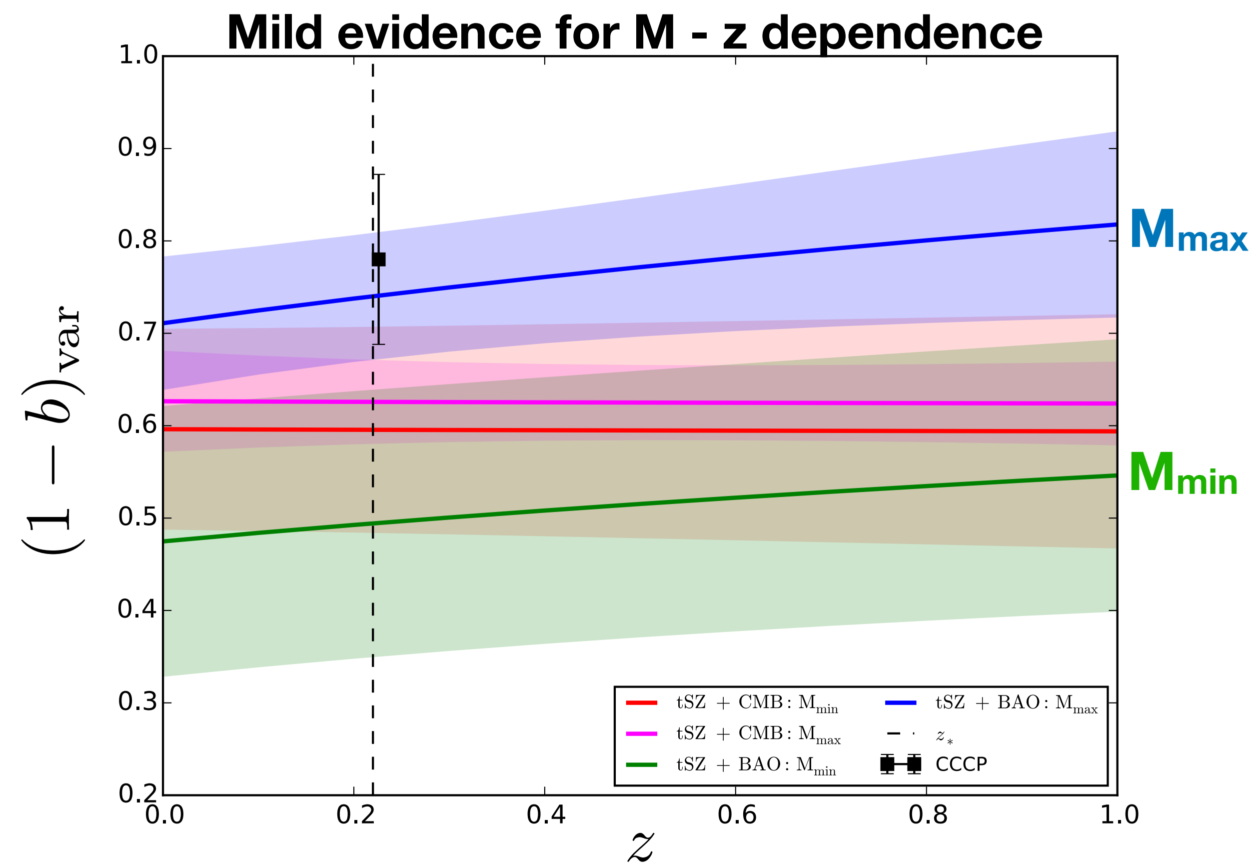
Mass bias: M-z evolution

Mass-redshift Parametrisation

Salvati+ A&A 626, A27 (2019)

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



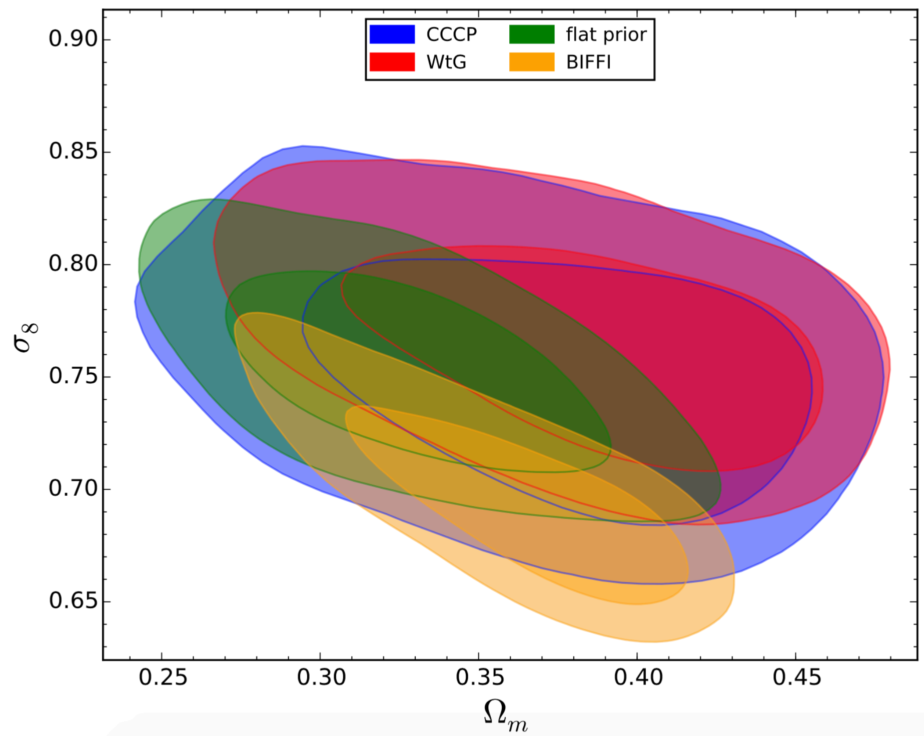


(1-b) increasing with redshift

Need fo further understanding!

Mass bias: M-z evolution

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	$0.26^{+0.23}_{-0.17}$
CCCP	0.780 ± 0.092	$14.83 \cdot 10^{14} h^{-1} M_\odot$	0.246	$0.24^{+0.24}_{-0.18}$
BIFFI	0.877 ± 0.015	$10.53 \cdot 10^{14} M_\odot$	0	$0.27^{+0.22}_{-0.17}$

WtG: von der Linden et al., MNRAS 443 (2014) no.3, 1973

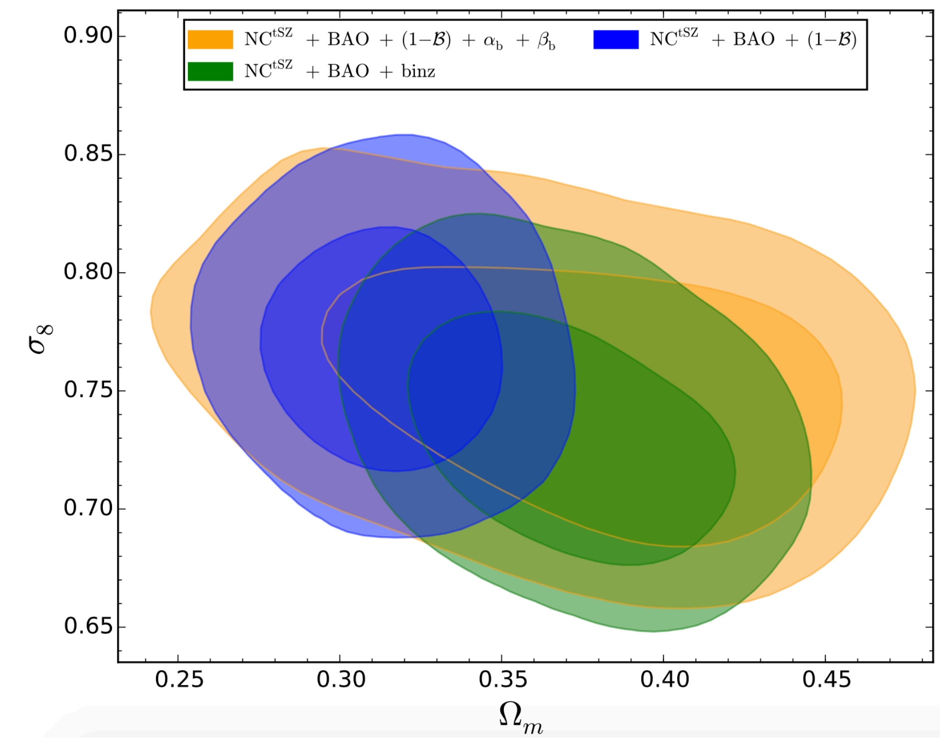
CCCP: Hoekstra et al., MNRAS 449 (2015) no.1, 685

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

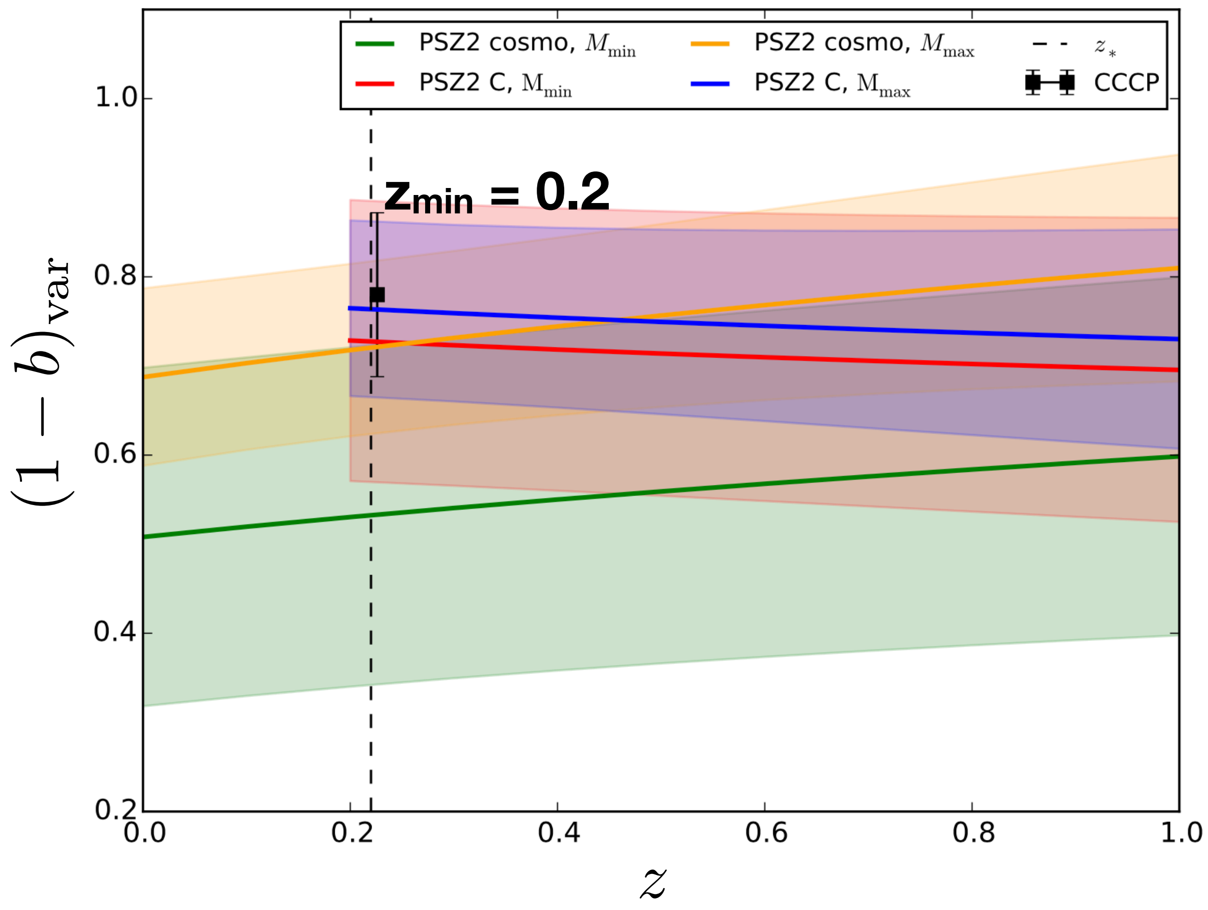
$(1-b)_1$	$(1-b)_2$	$(1-b)_3$
0.655 ± 0.078	0.775 ± 0.092	0.751 ± 0.095

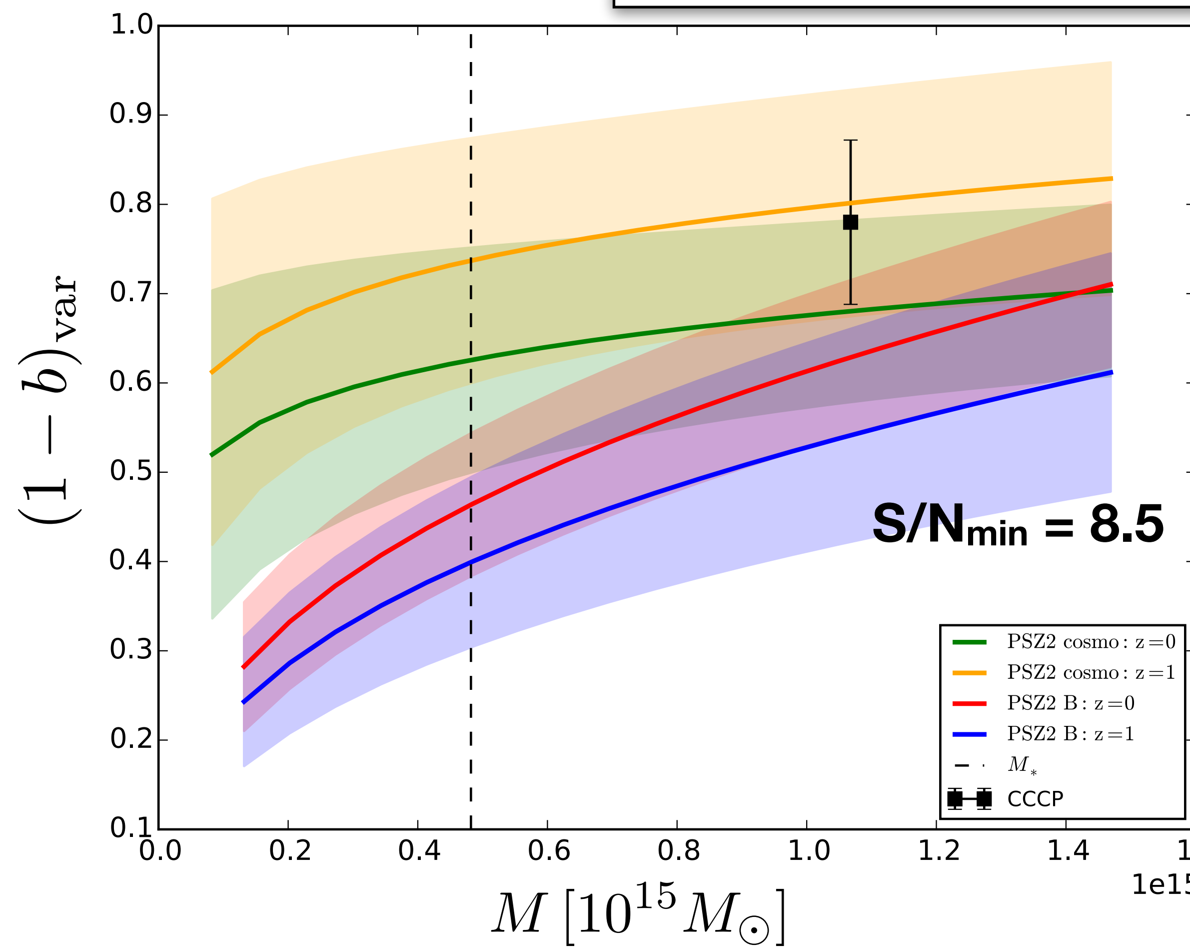
Salvati+ A&A 626, A27 (2019)

Mass bias: M-z evolution

Selection effects

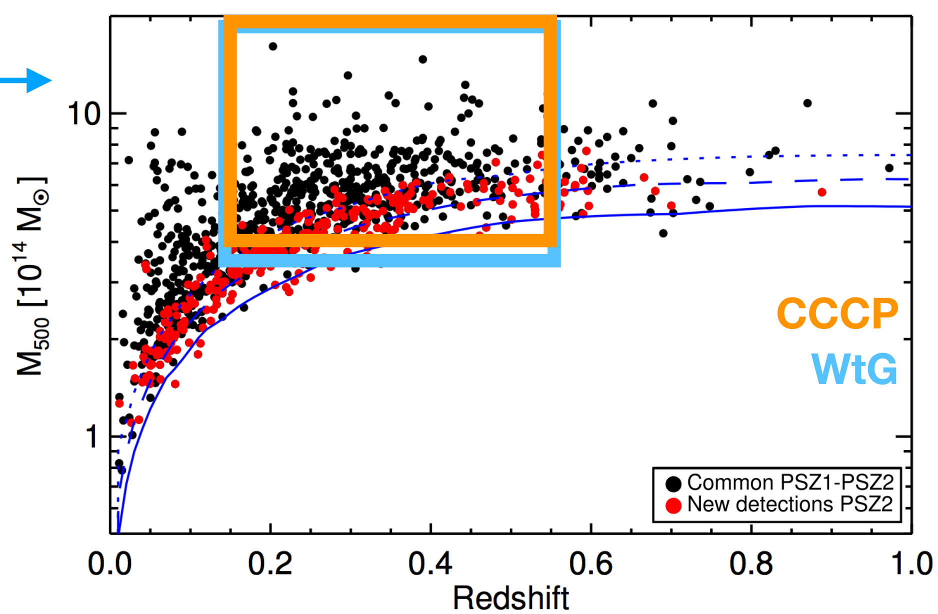
Salvati+ A&A 626, A27 (2019)





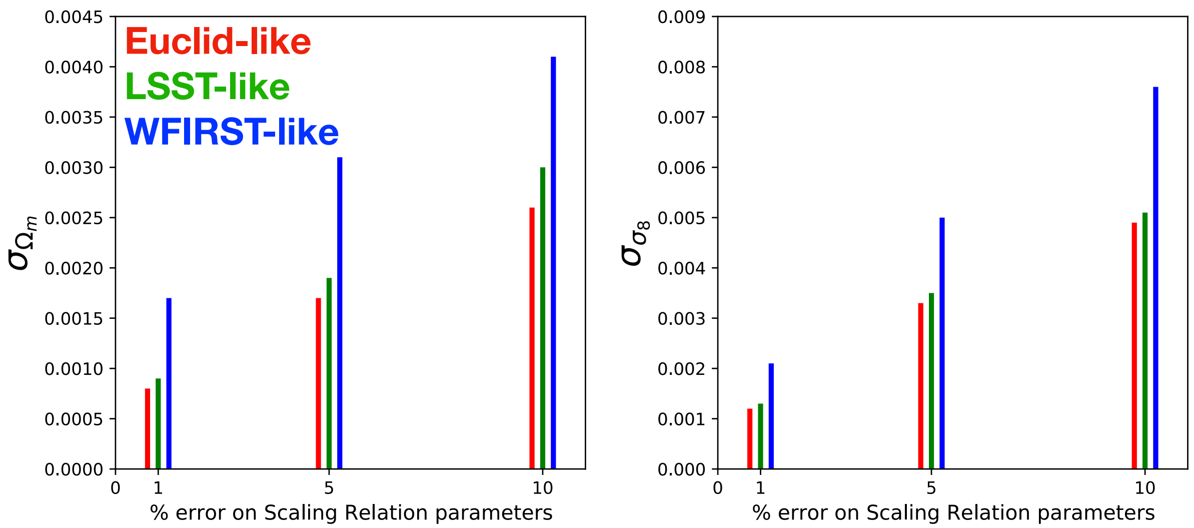
Results from other analyses

- 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)



Impact of Mass Function

Impact of survey area and SR accuracy



Increasing accuracy on cosmological parameters

- Larger survey area: larger cluster sample
- More accurate calibration for SR

Planck results:
$\sigma_{\sigma_8} = 0.03,\ \sigma_{\Omega_m} = 0.03$

Impact of Mass Function

NON NEGLIGIBLE!