Cosmology with galaxy clusters: impact of theoretical and observational systematic uncertainties

Laura Salvati

Outline

- Clusters detected with tSZ effect
  - Mass calibration problem
    - State of the art
    - Improve the analysis
      - Mass and redshift evolution of the mass bias
    - Further analysis
      - Combining Planck and SPT cluster catalogs
- Future cluster surveys
  - General forecasts analysis
    - Impact of the mass function calibration

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

Multi-wavelengths analysis:
Unique way to calibrate cluster mass

Observations
Survey and detection strategy

Planck tSZ clusters

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

- $\alpha,\ Y_*$ → from X-ray observations
- $(1-b)$ → from WL mass evaluations
- $\beta = 2/3$ → from self-similarity

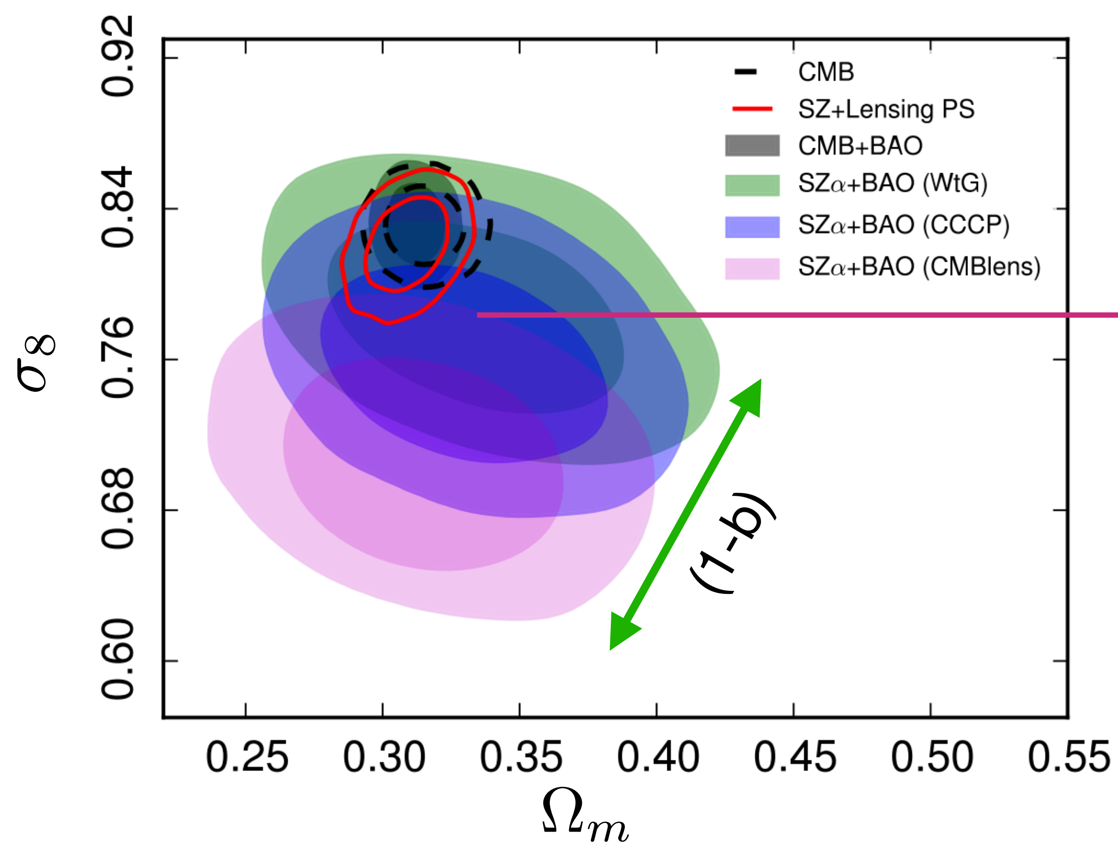
Planck Collaboration, A&A 594 (2016) A24

Planck: Mass calibration

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

Cluster number counts:

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



tension between CMB primary anisotropies and Galaxy Clusters:

$\simeq 2.4\,\sigma$ on σ_8

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

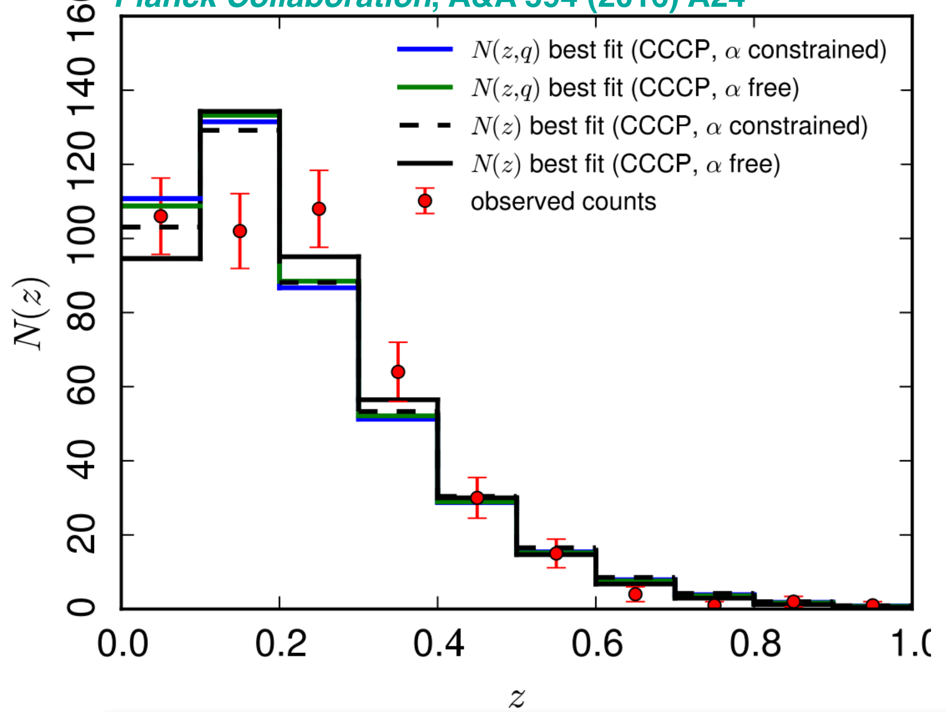
$$\mathrm{CMB + NC^{tSZ}}: (1-b) = 0.58 \pm 0.04$$

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

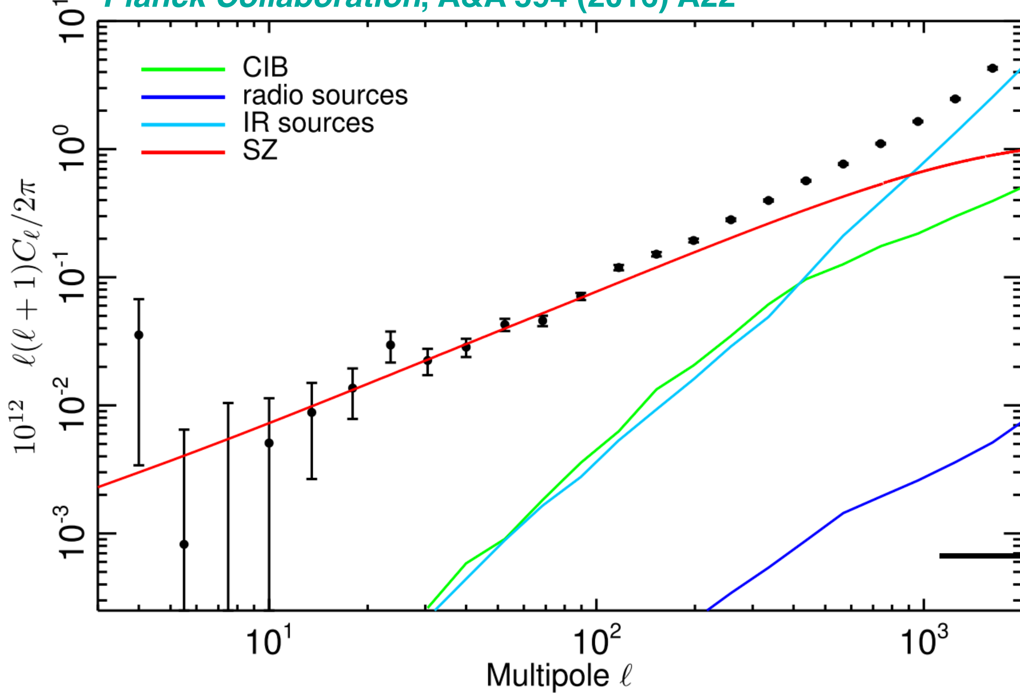
Hoekstra et al., MNRAS 449 (2015) no.1, 685

tSZ Number Counts + Power Spectrum

Planck Collaboration, A&A 594 (2016) A24



Planck Collaboration, A&A 594 (2016) A22

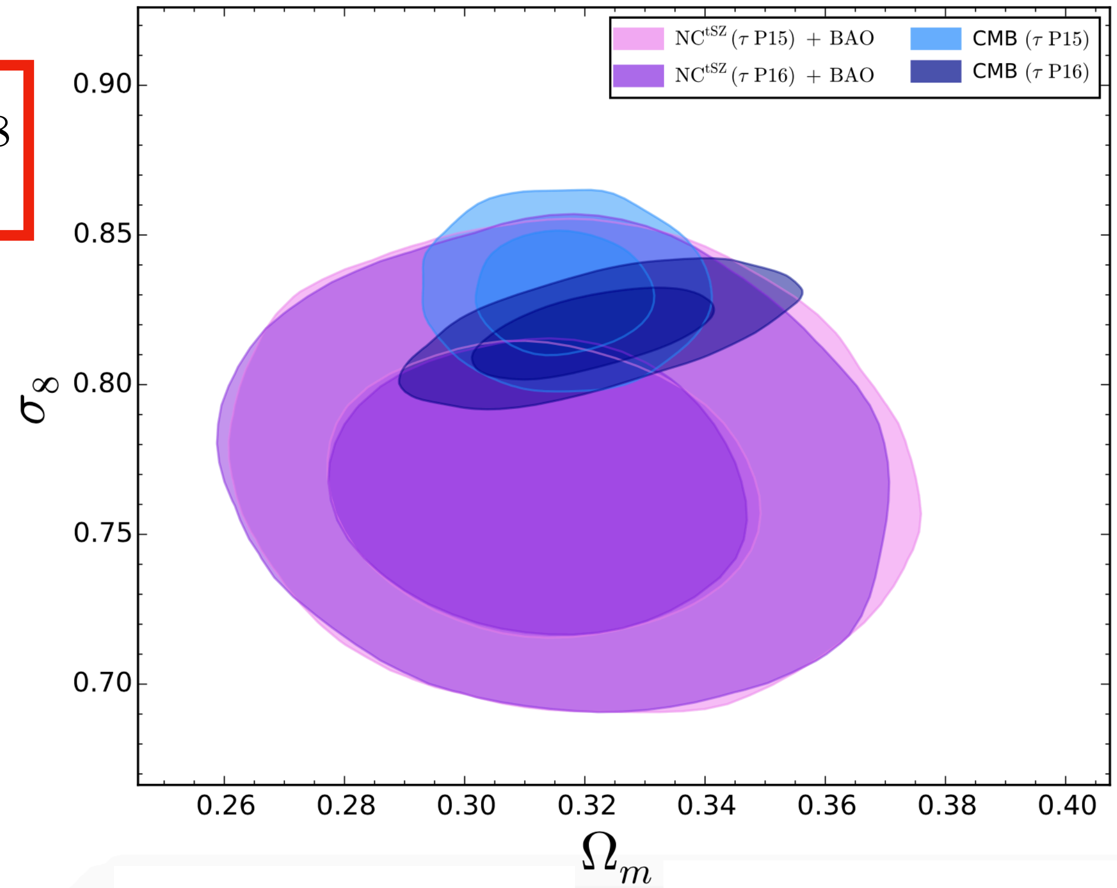


+

tSZ from
SPT data: $\ell = 3000$
George, E. M. et al. 2015, Astrophys. J., 799, 177

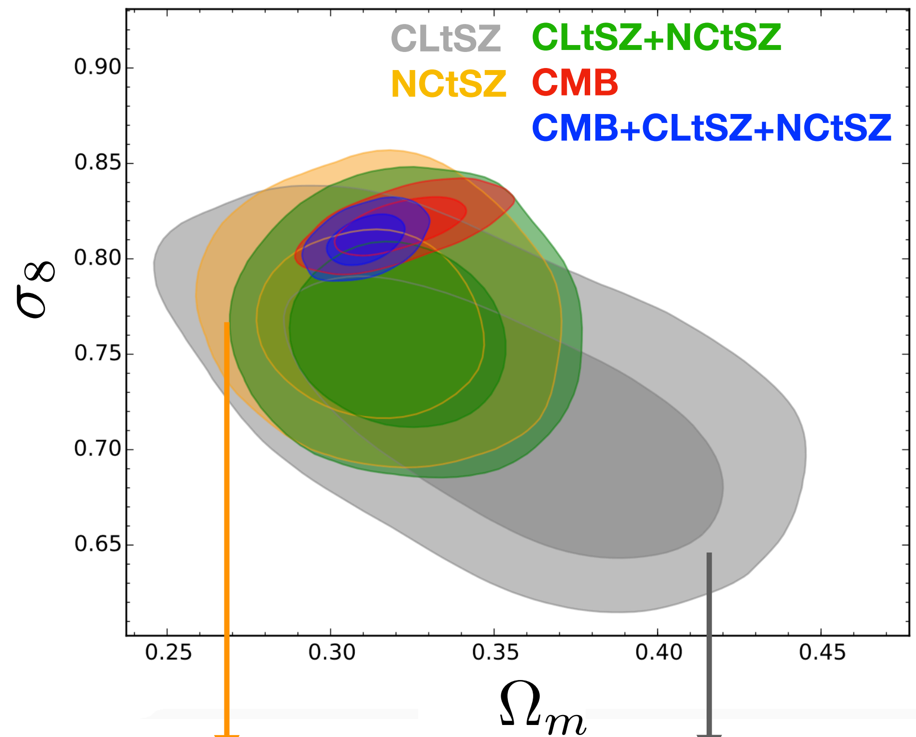
see Douspis' talk

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



Results

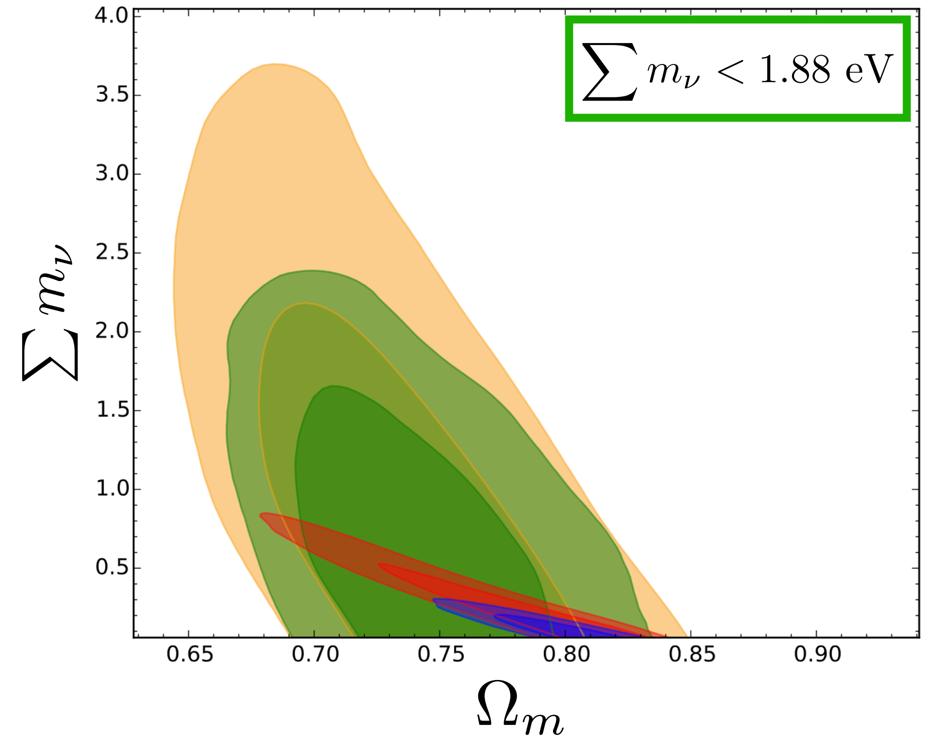
LCDM



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

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

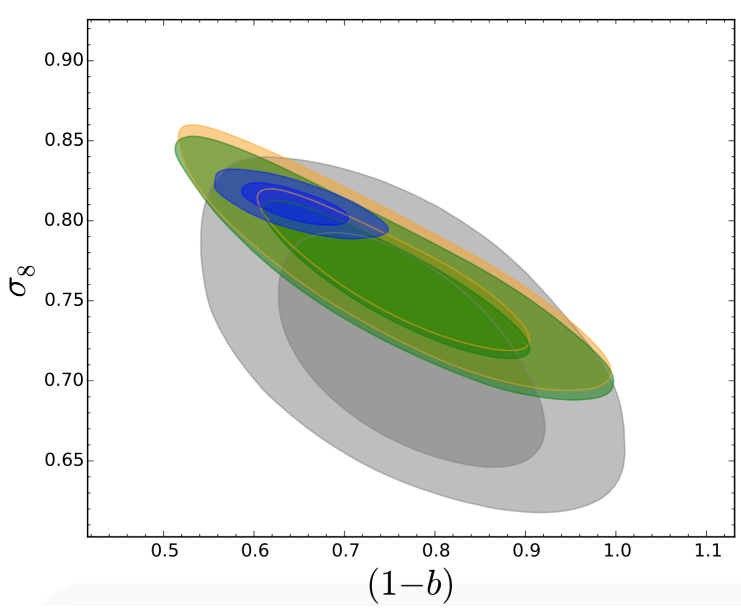
Varying total neutrino mass



$\sum m_\nu < 1.88$ eV

$\sum m_\nu < 0.68$ eV

$\sum m_\nu < 0.23$ eV



No more tension on σ_8

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

CMB + NCtSZ

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

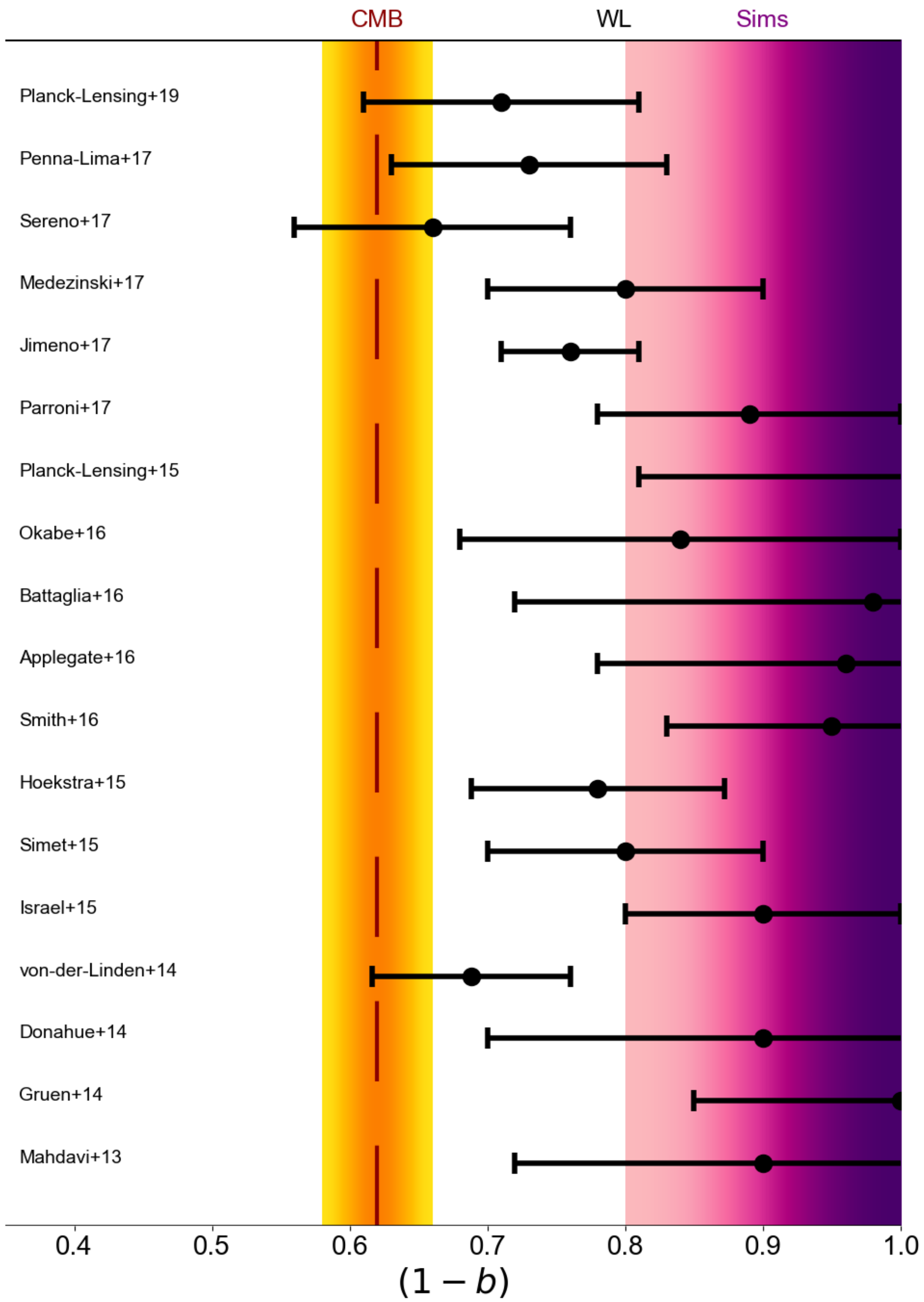
$(1-b) = 0.65 \pm 0.04$ LCDM
$(1-b) = 0.67 \pm 0.04$ Neutrinos
$(1-b) = 0.63 \pm 0.04$ DE

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

Mass bias

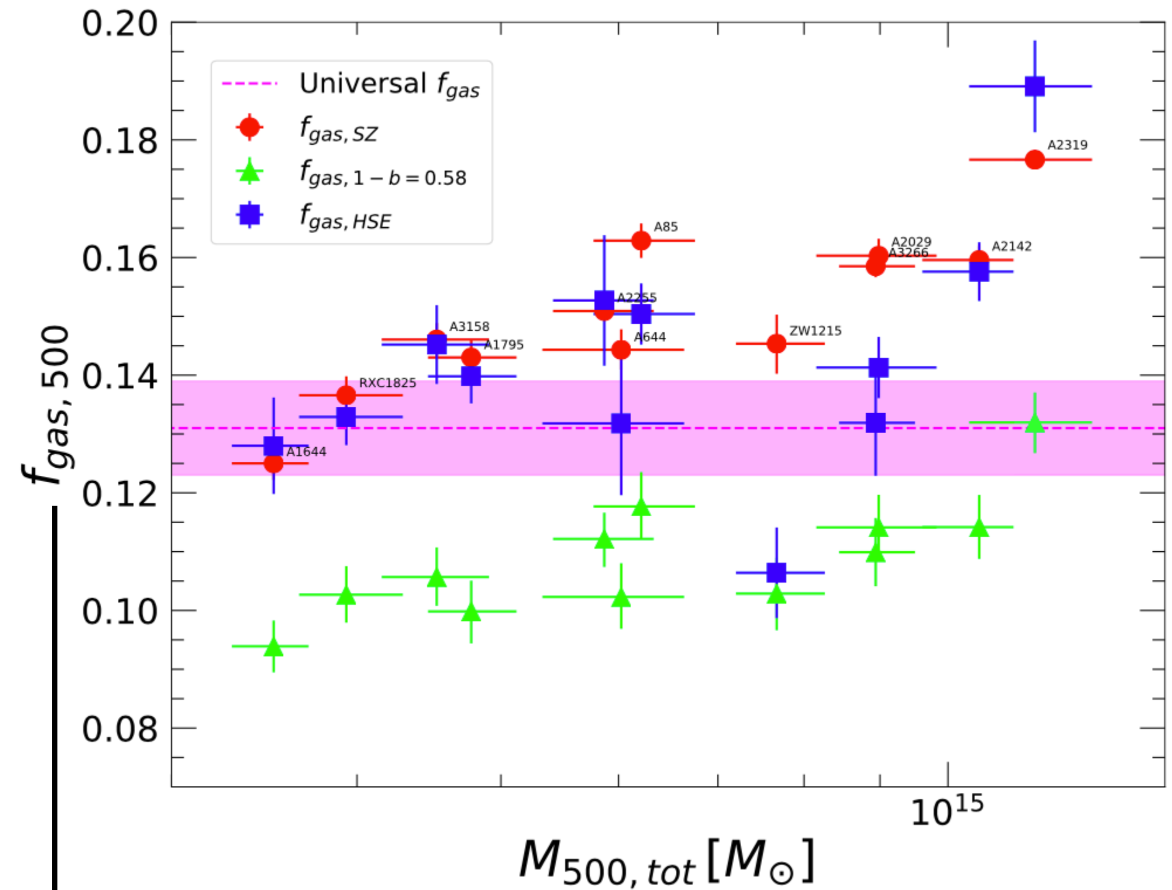
$(1-b) \simeq 0.6$ too low!

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



see also results in
Gianfagna et al, MNRAS 502 (2021) no.4, 5115-5133

Gas fraction to evaluate mass bias



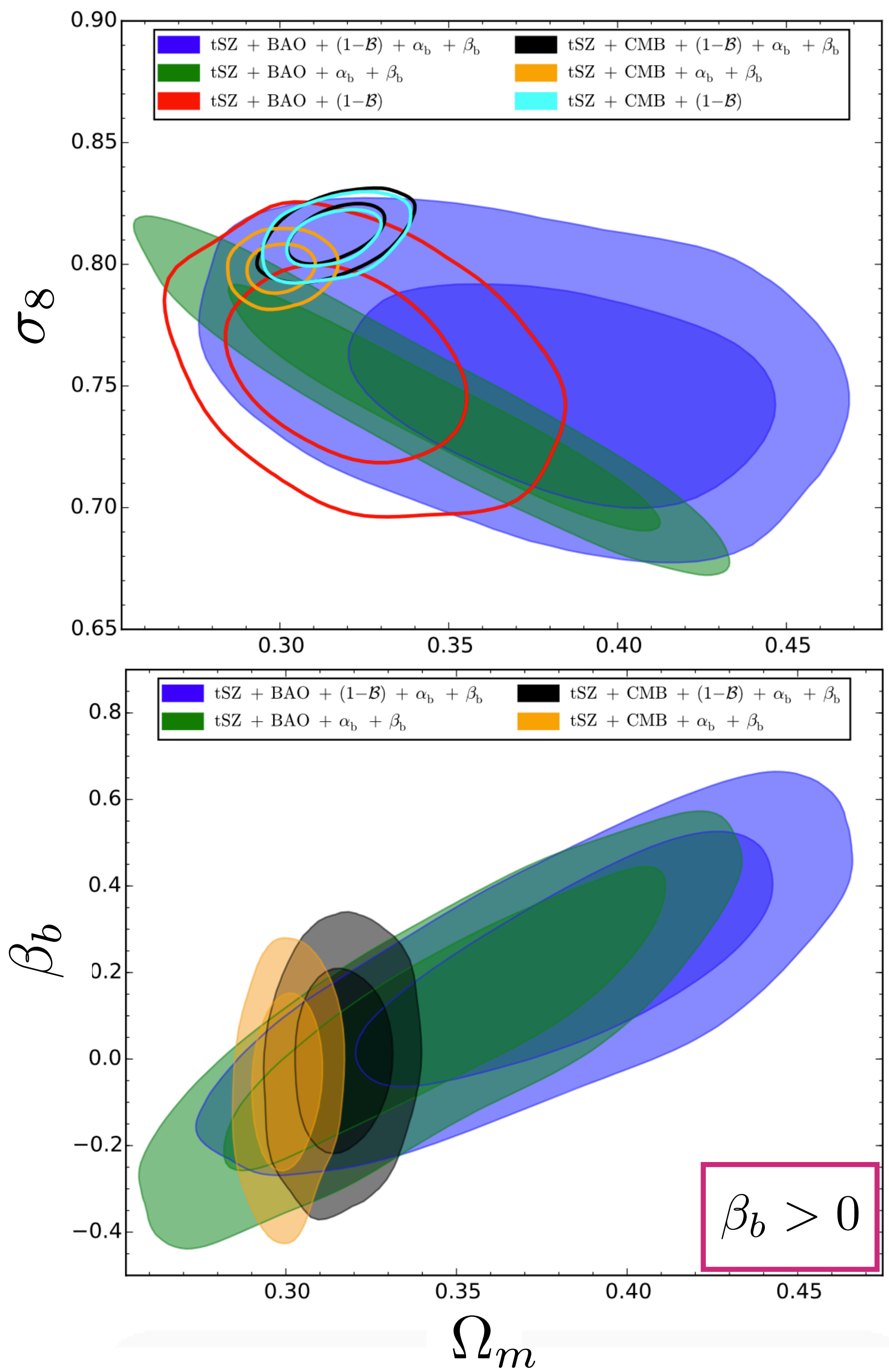
Eckert et al, A&A 621, A40 (2019)

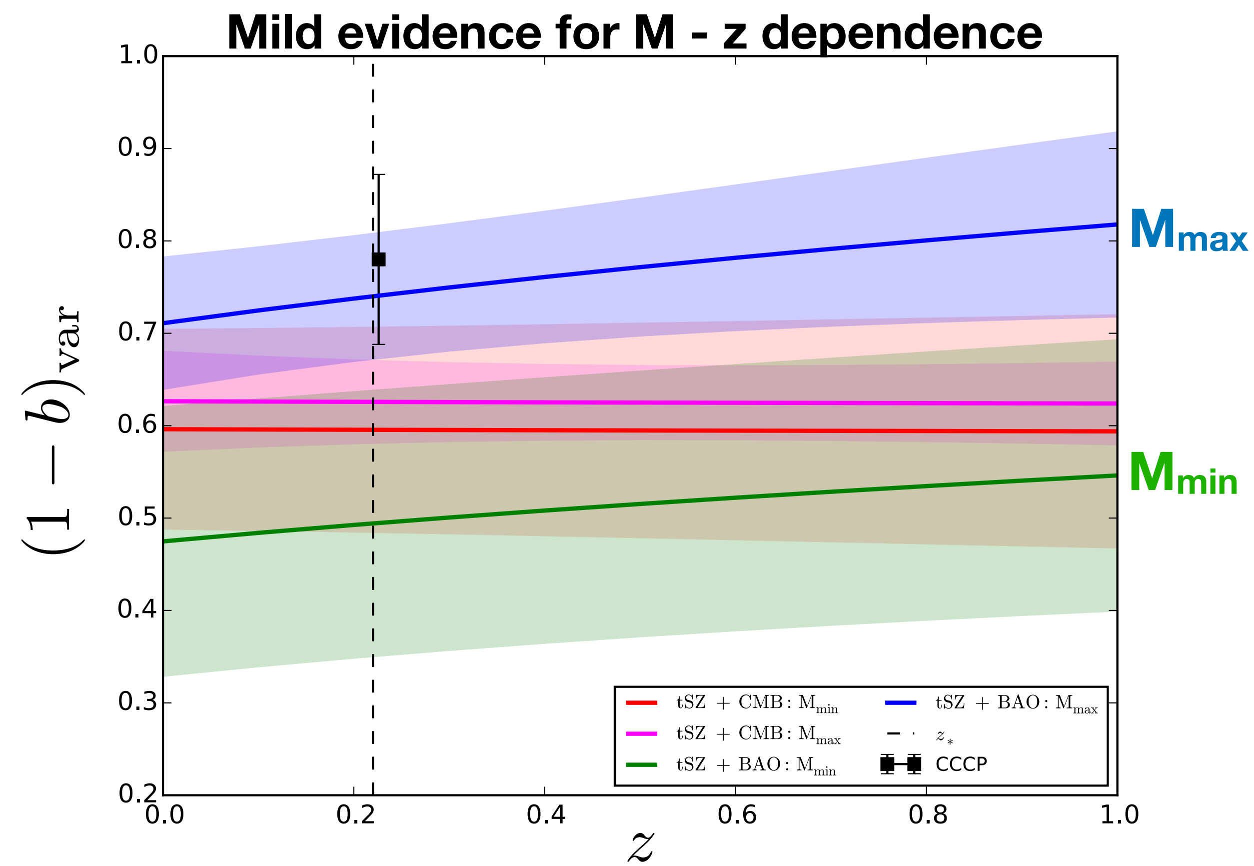
see Wicker's talk

Mass bias: M-z evolution

Mass-redshift Parametrisation

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



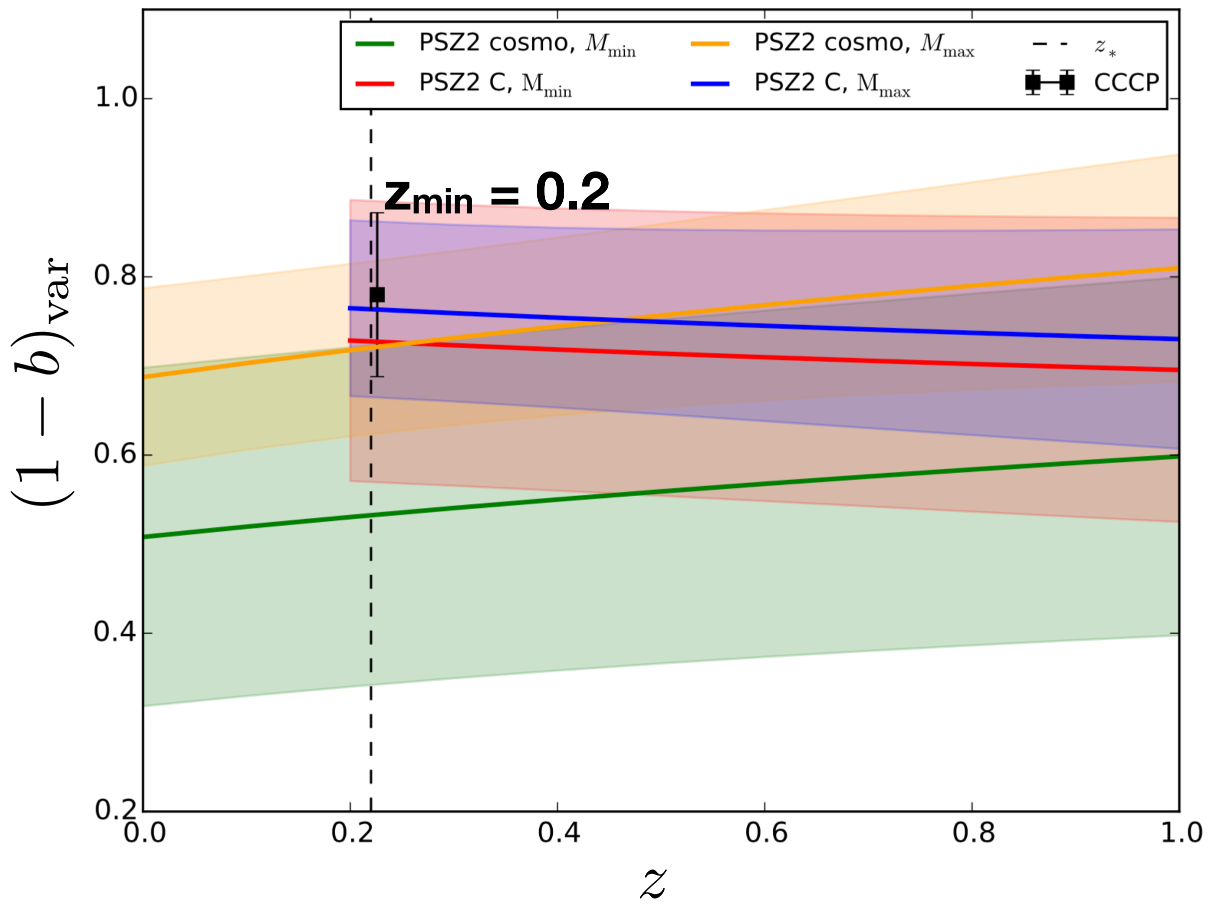


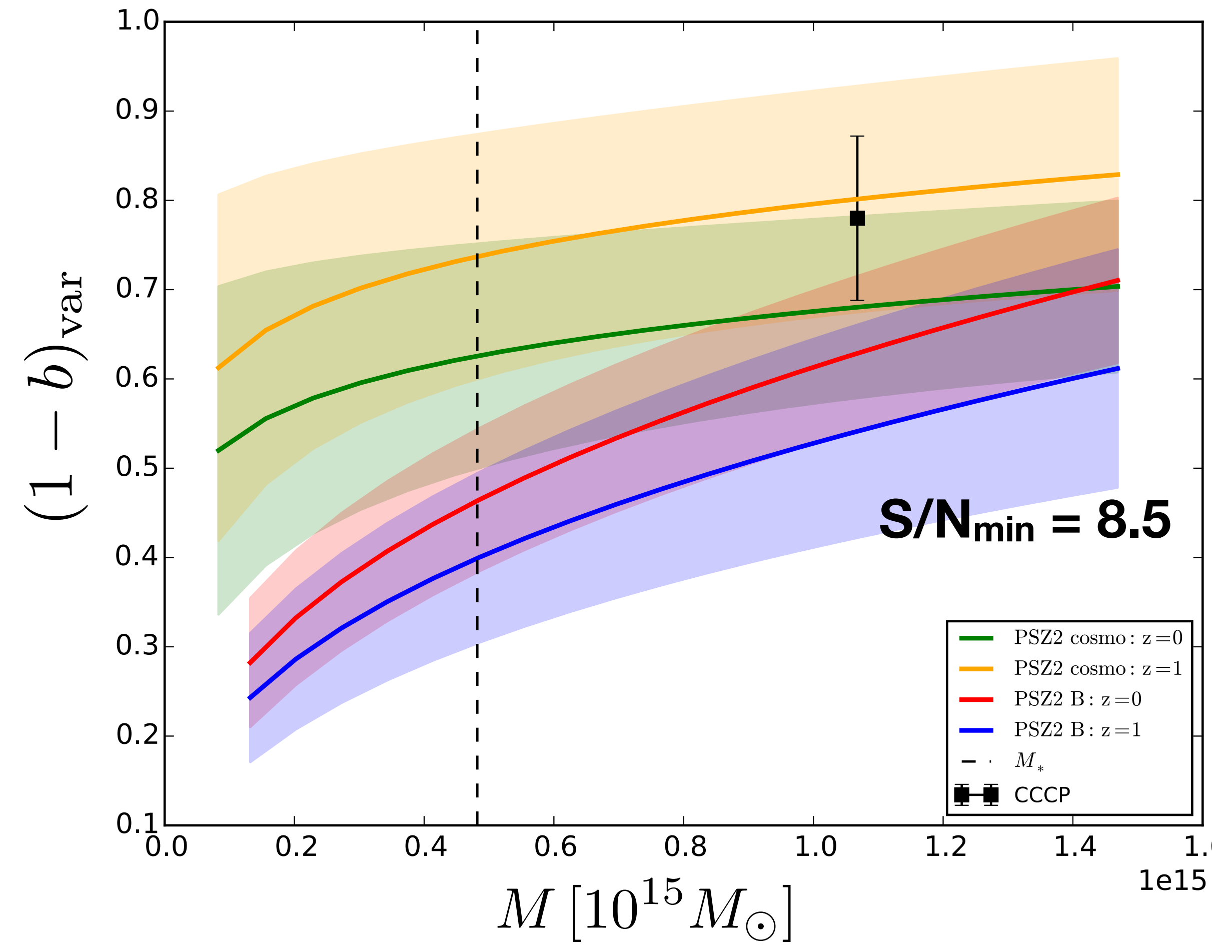
(1-b) increasing with redshift

Need fo further understanding!

Mass bias: M-z evolution

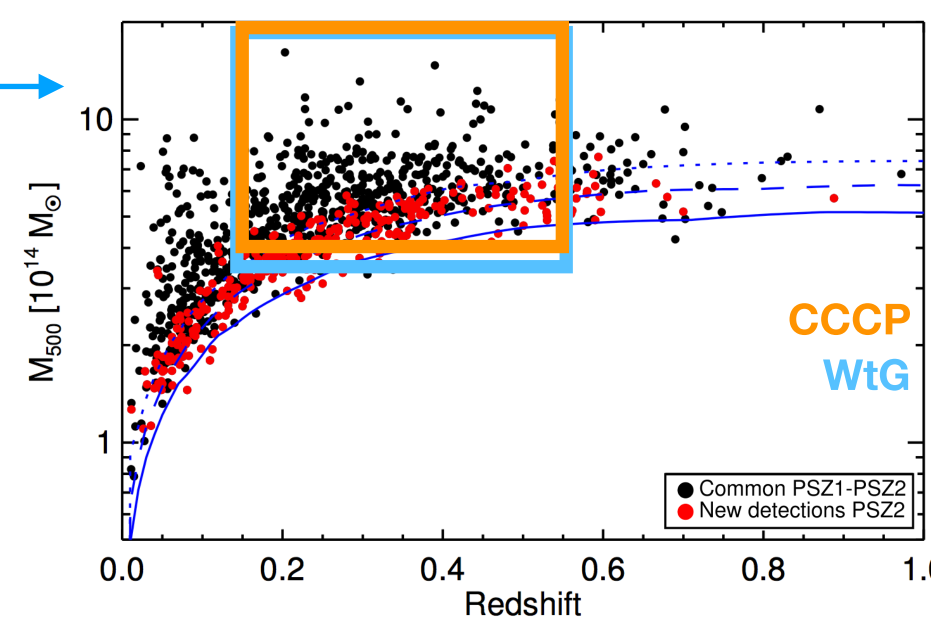
Selection effects





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)

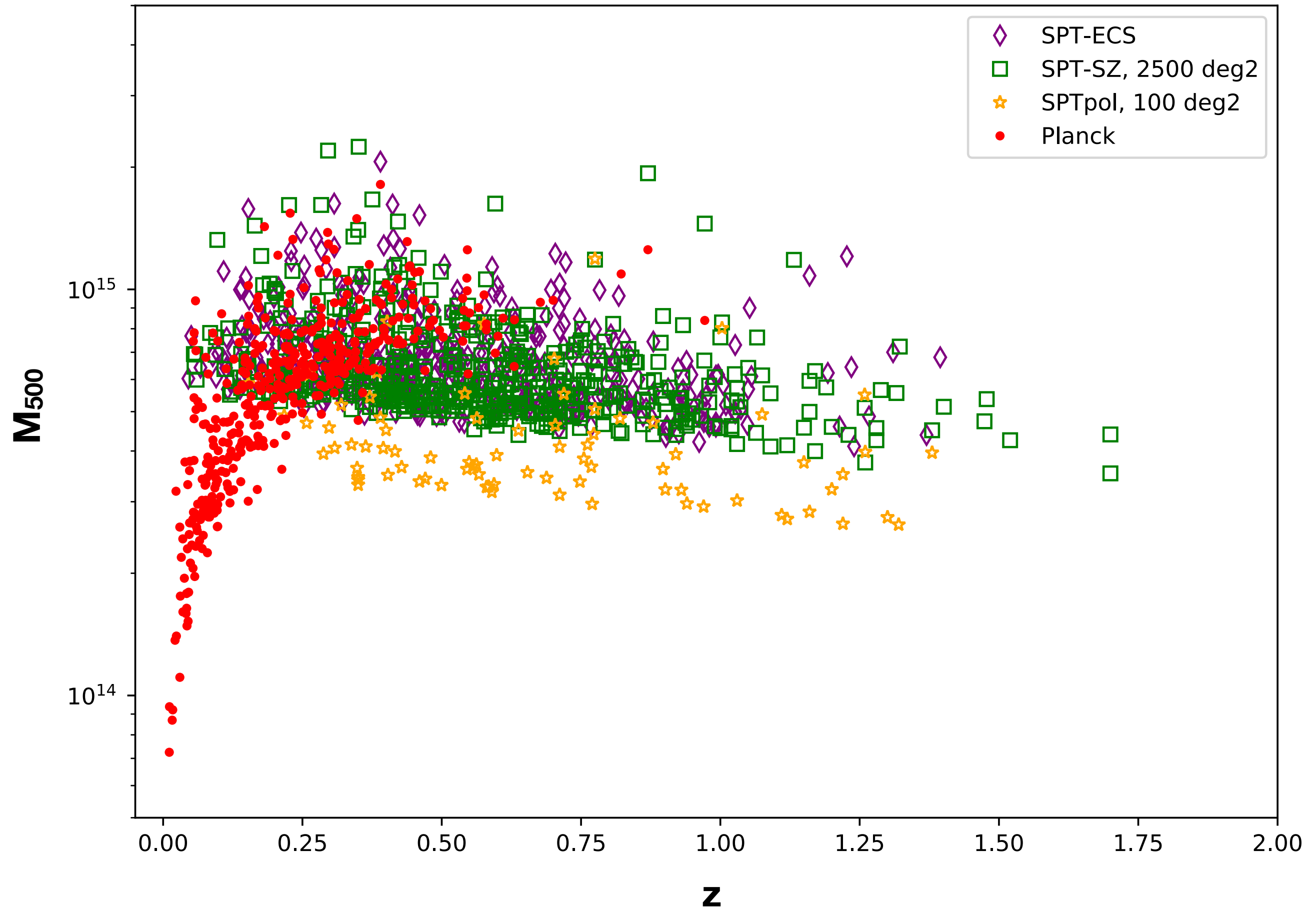


Planck+SPT

PRELIMINARY !!!!!

- Mass calibration depends on selection choices
  - provide alternative calibration of the scaling relation using consistent and complementary data

- Combine Planck and SPT cluster catalogs:
  - constrain and characterise Planck scaling relation



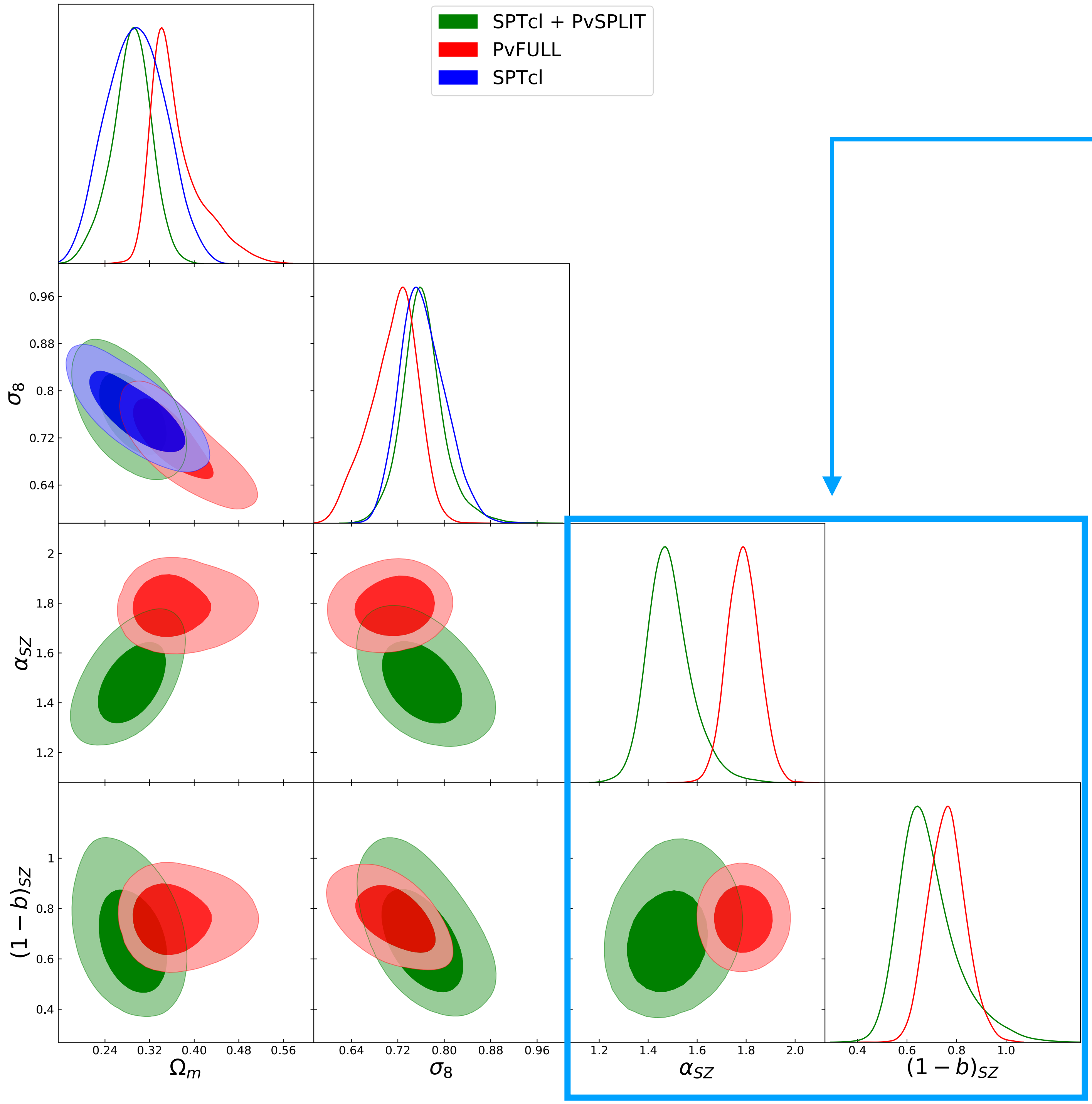
Planck+SPT

Salvati, Saro + SPT collab.
In preparation

PRELIMINARY !!!!!

SPT cluster catalog from Bleem+ 2015
following analysis in Bocquet+ 2019
With mass calibration from Schrabback+18, Dietrich+19

using new version of Planck cluster likelihood



	SPTcl + PvSPLIT	PvFULL	SPTcl
Ω_m	$0.29^{+0.04}_{-0.03}$	$0.37^{+0.02}_{-0.05}$	0.30 ± 0.03
σ_8	$0.76^{+0.03}_{-0.04}$	$0.71^{+0.04}_{-0.03}$	$0.76^{+0.03}_{-0.04}$
$(1-b)_{\rm SZ}$	$0.69^{+0.07}_{-0.14}$	$0.76^{+0.07}_{-0.08}$	-
$\alpha_{\rm SZ}$	$1.49^{+0.07}_{-0.10}$	1.78 ± 0.06	-
$\beta_{\rm SZ}$	0.67	0.67	-

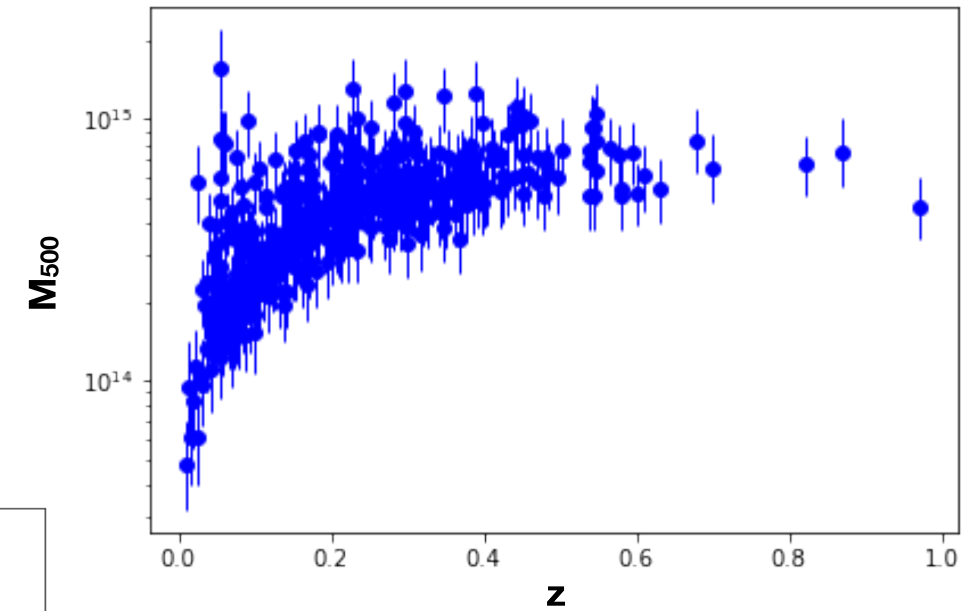
$$E^{-\beta}(z)\left[\frac{D_A^2(z)\,Y_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)\,M_{500}}{6\cdot 10^{14} M_\odot}\right]^{\alpha}$$

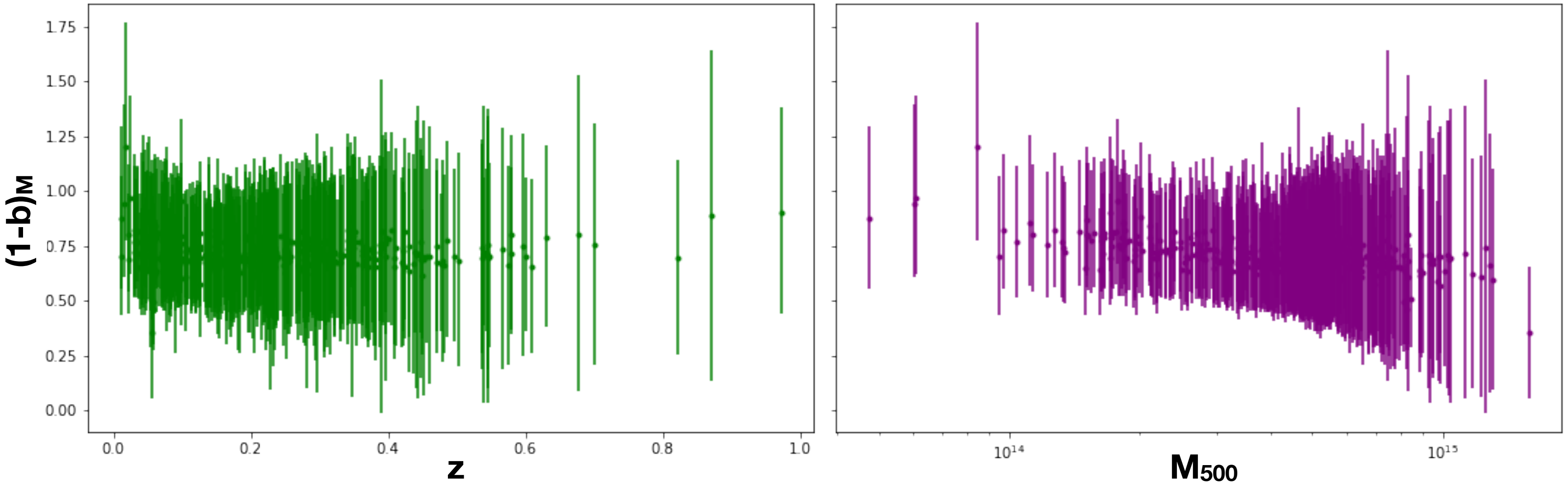
Planck+SPT

PRELIMINARY !!!!!

From SPTcl+PvSPLIT results

- new mass evaluation for PSZ2 clusters
- evaluation of the bias for PSZ2 clusters for which we have M_{SZ}





$$(1-b)_M = A_{\mathrm{Mz}} \cdot \left(\frac{M_{500}}{M_*}\right)^{\gamma_M} \cdot \left(\frac{1+z}{1+z_*}\right)^{\gamma_z}$$

Parameter	Value
A_{Mz}	$0.69\ ^{+0.05}_{-0.09}$
γ_M	$-0.40^{+0.04}_{-0.06}$
γ_z	0.74 ± 0.13

evidence for M,z evolution

Mass calibration

- Interplay between astrophysics and cosmology in the cluster formation and evolution
  - strong correlation between cosmological and scaling relation parameters
- Mass calibration: largest source of uncertainties in current cluster cosmology
  - need for large and representative samples for the mass calibration

see talks from Gianfagna, Giocoli, Kéruzoré, Muñoz Echeverría

- NIKA2:
  - High resolution
  - Large redshift range
  - Representative cosmological sample

→

- Characterise cluster properties and their evolution
- Lead to high precision/accuracy cluster cosmology

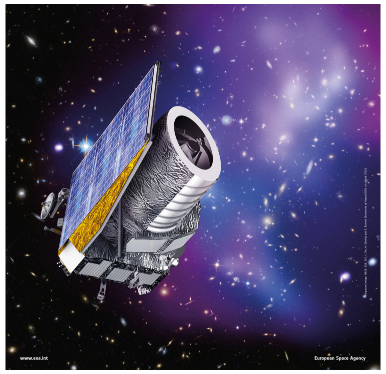
What's next?

Future surveys: ~ thousands of clusters → **Accuracy/precision on cosmological parameters: dominated by systematic uncertainties**

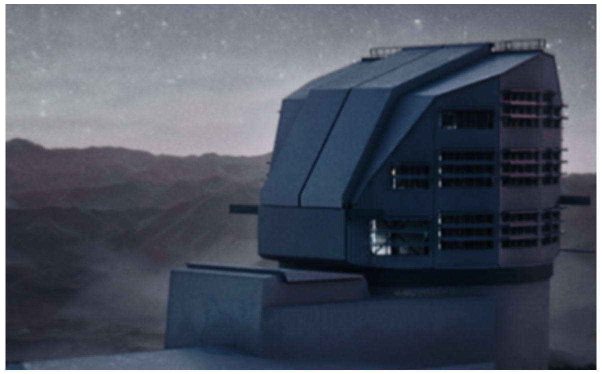
Cluster number counts:

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

Combined impact of scaling relation and mass function calibration



Euclid satellite



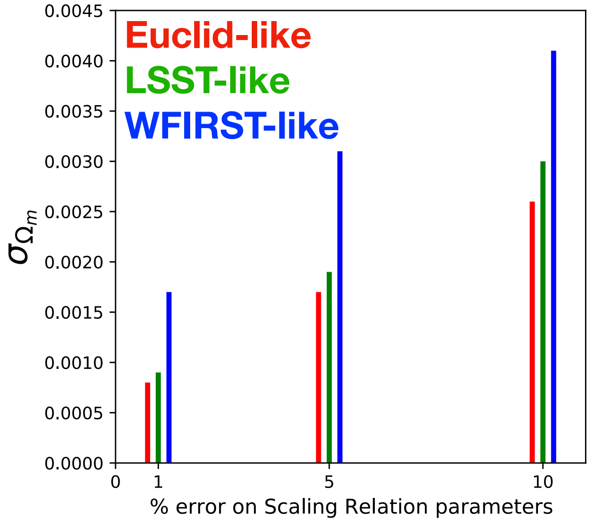
LSST
Vera Rubin telescope

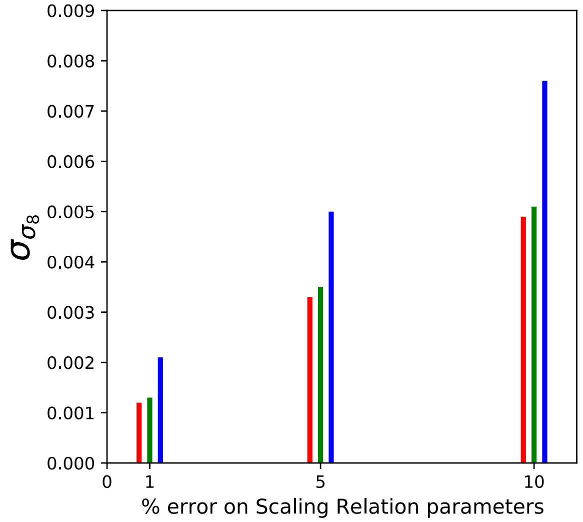
WFIRST
Nancy Grace Roman space telescope

see Artis' talk

Source of systematics

Impact of survey area and SR accuracy





Increasing accuracy on cosmological parameters

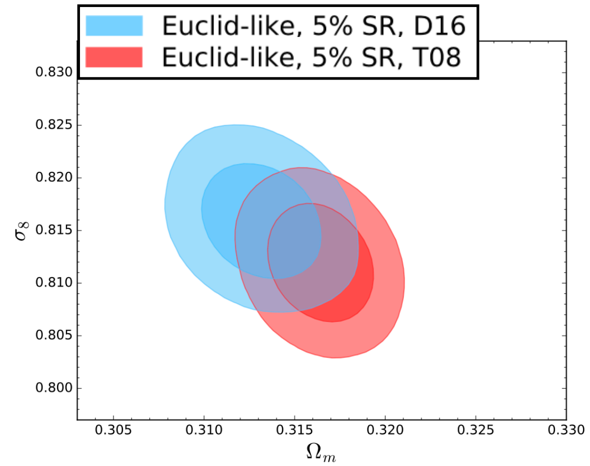
- Larger survey area: larger cluster sample
- More accurate calibration for SR

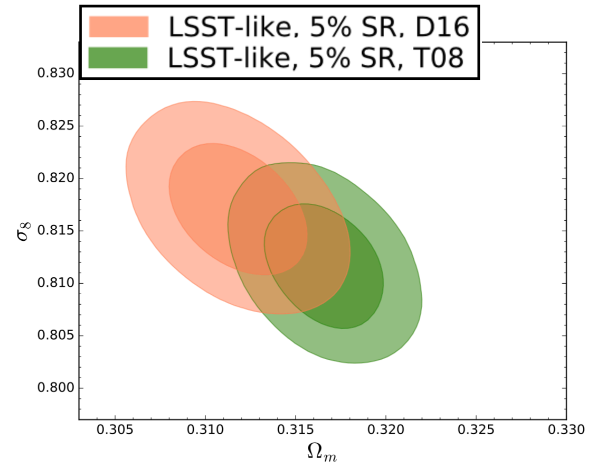
Planck results:

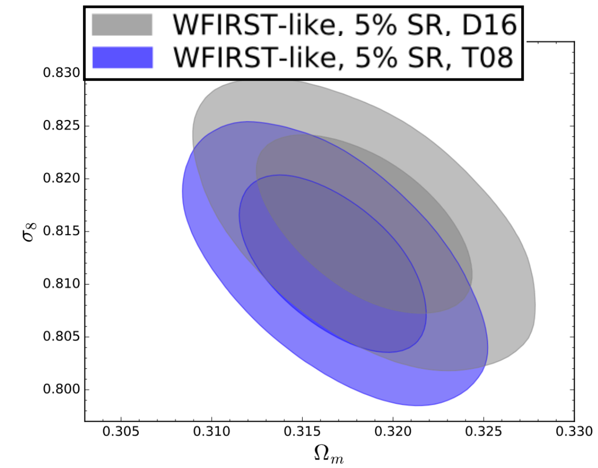
$\sigma_{\sigma_8} = 0.03,\ \sigma_{\Omega_m} = 0.03$

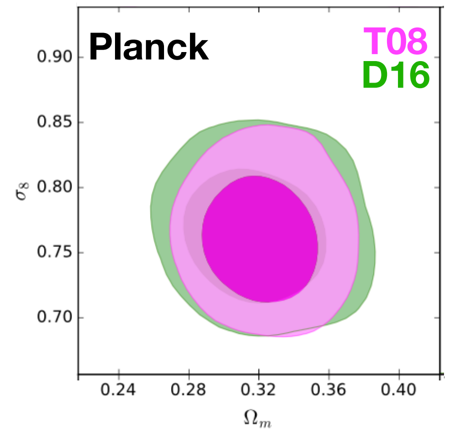
Impact of Mass Function

NON NEGLIGIBLE!









Mass Function

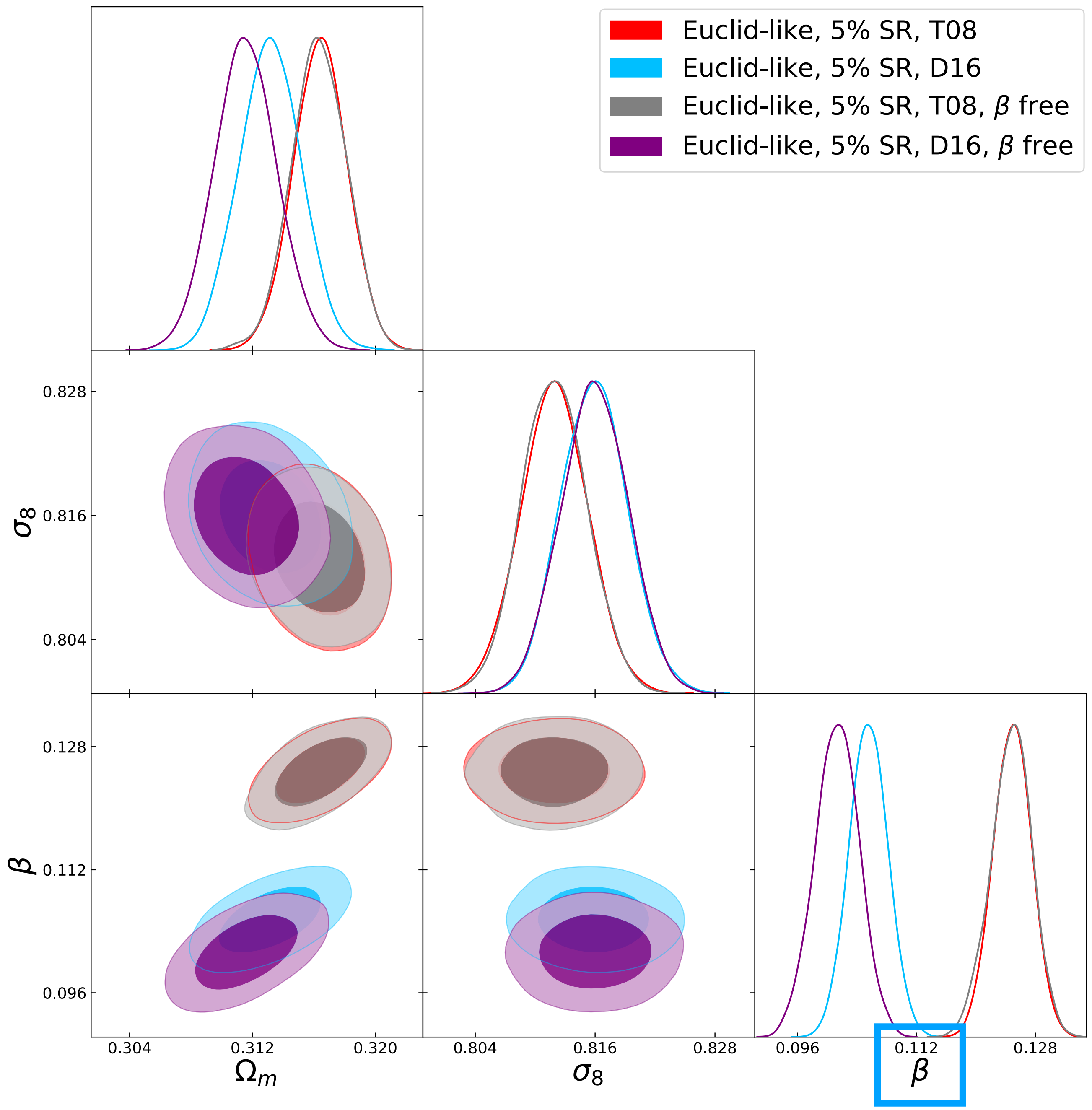
Evidence for different z-evolution for T08 and D16

D16 vs T08

- Consistent in the intermediate mass range
- D16 predicts more clusters at high z
- Compensating for different z-evolution

$\beta_{\rm D16} < \beta_{\rm T08}$

LCDM



z-evolution of the scatter

$$\sigma^2_{\ln M}(z) = \sigma^2_{\ln M,0} - 1 + (1+z)^{2\beta}$$

Mass Function

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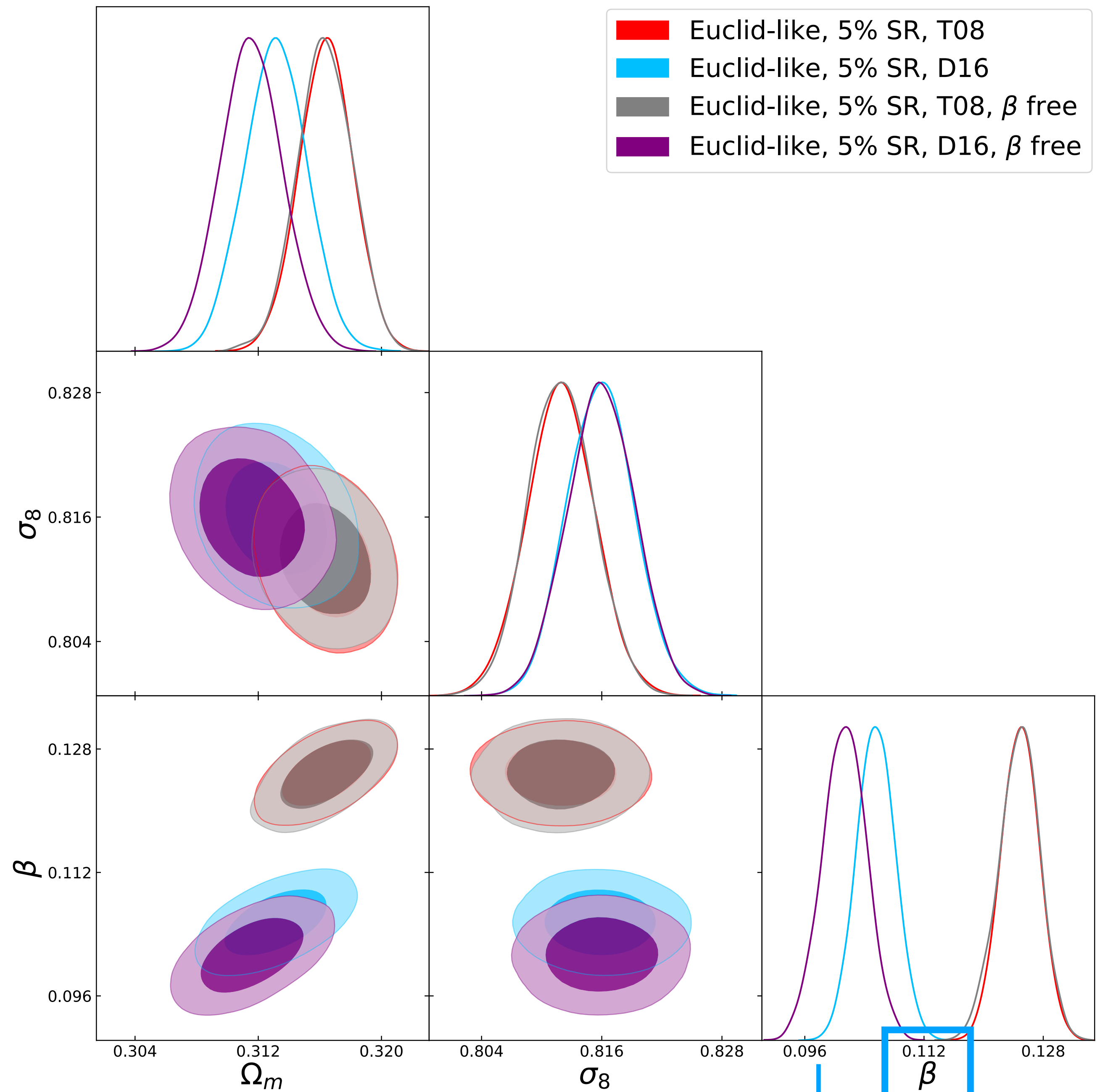
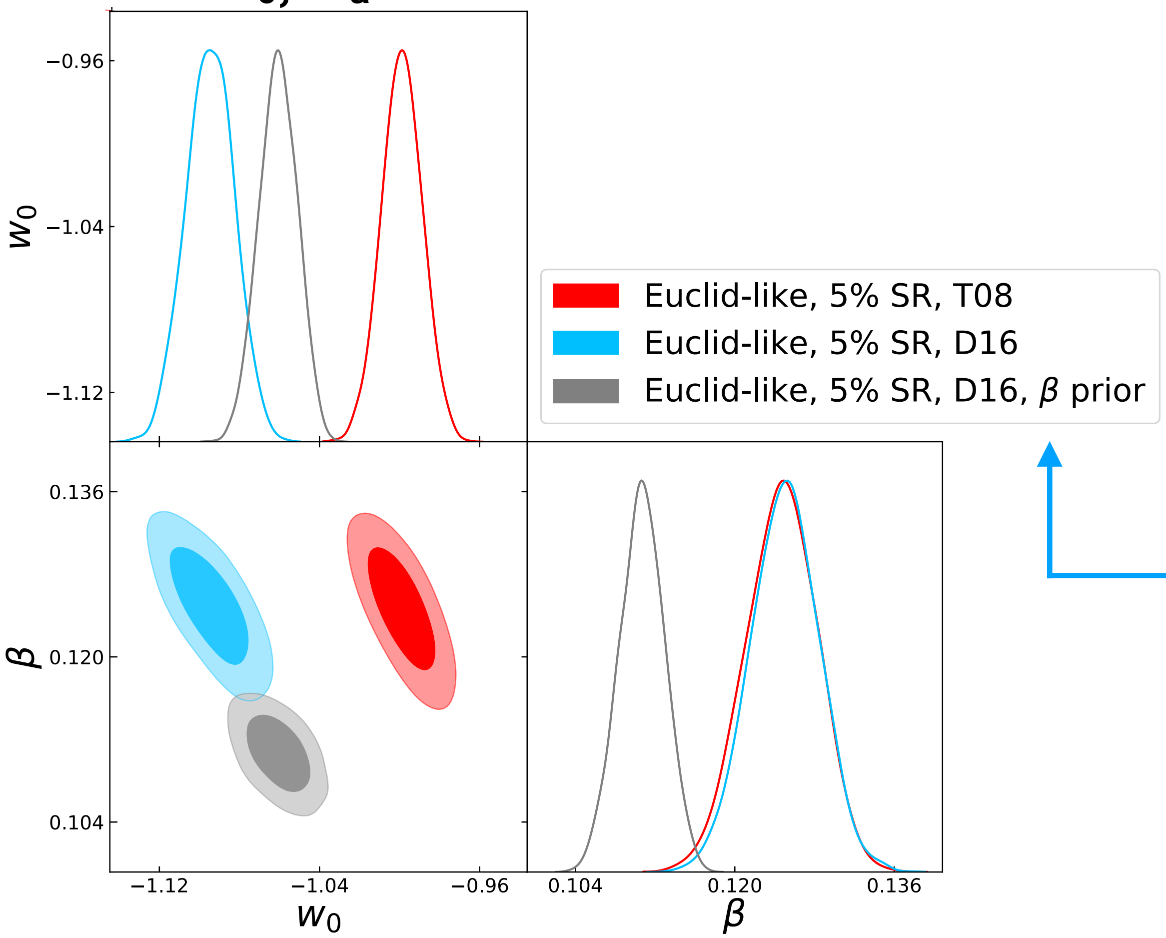


β

z-evolution of the scatter

$$\sigma^2_{\ln M}(z) = \sigma^2_{\ln M,0} - 1 + (1+z)^{2\beta}$$

DE: w_0, w_a



Conclusion

Future of Galaxy Clusters: high precision/accuracy cosmology
.. looking forward for future cluster surveys ..

Multi-wavelength observations + hydrodynamical simulations
- **to describe interplay between astrophysics and cosmology**

Improve modelling and calibration of
- **Scaling Relations**
- **Mass Function**

Thank you!