Constraints on cosmological parameters from galaxy clusters

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in collaboration with Nabila Aghanim
and Marian Douspis

IAS Orsay

Advances in theoretical cosmology in light of data

Introduction

Galaxy clusters

Largest structures gravitationally bound in the Universe

↓ ↓ ↓

Strong dependence on cosmological parameters

Measurements of tSZ effect from Planck satellite

- Number counts
- tSZ power spectrum

↓ ↓ ↓

- LCDM model
- Extensions: $\sum m_\nu,\ w$
- comparison/combination with CMB T,P primary anisotropies

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Assumptions of the model

- Mass function
- Scaling relations
- Selection function → Planck 2015 results. XXVII. A&A 594 (2016) A27

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

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

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

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

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

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

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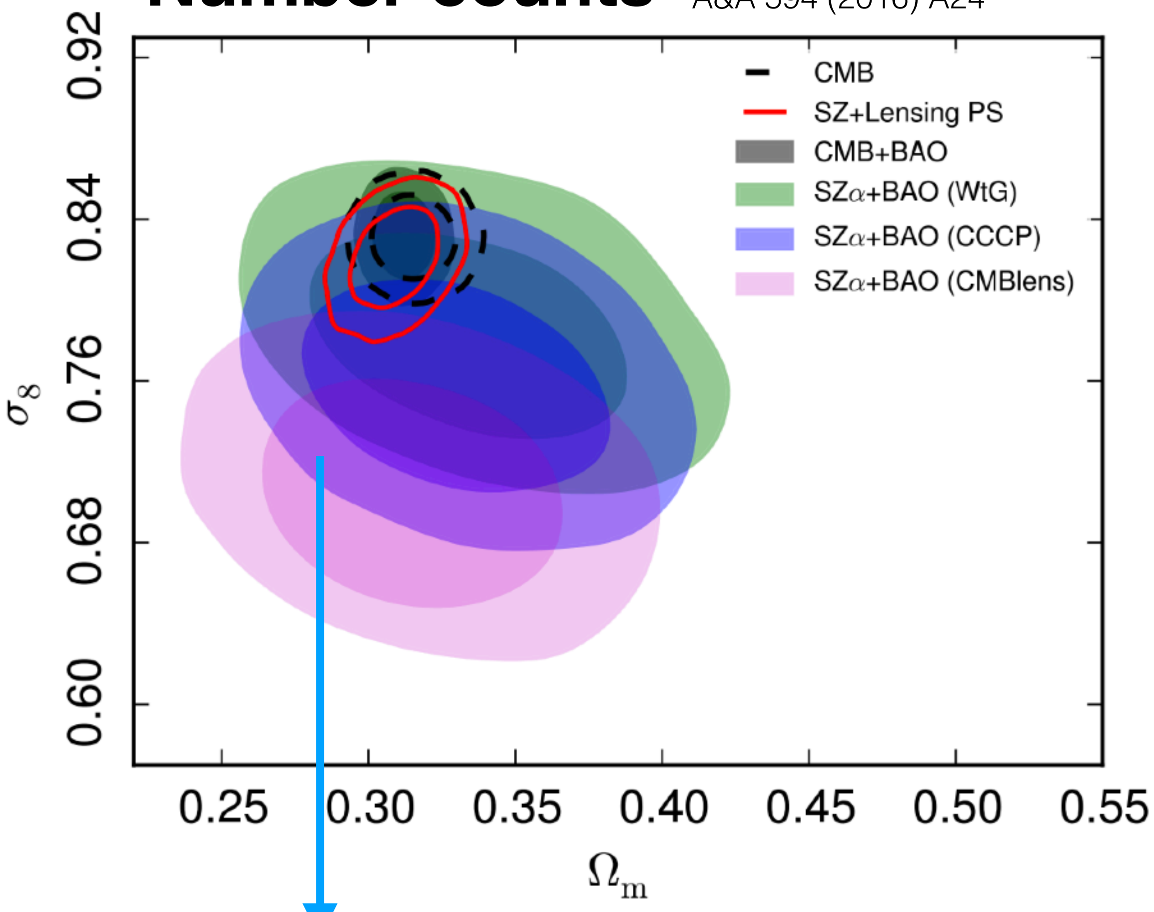
Planck 2015 results. XXIV. A&A 594 (2016) A24

Starting point

Number counts

Planck Collaboration, A&A 594 (2016) A24



$$\sigma_8 = 0.76 \pm 0.03$$
$$\Omega_m = 0.33 \pm 0.03$$
$$(1-b) = 0.780 \pm 0.092$$

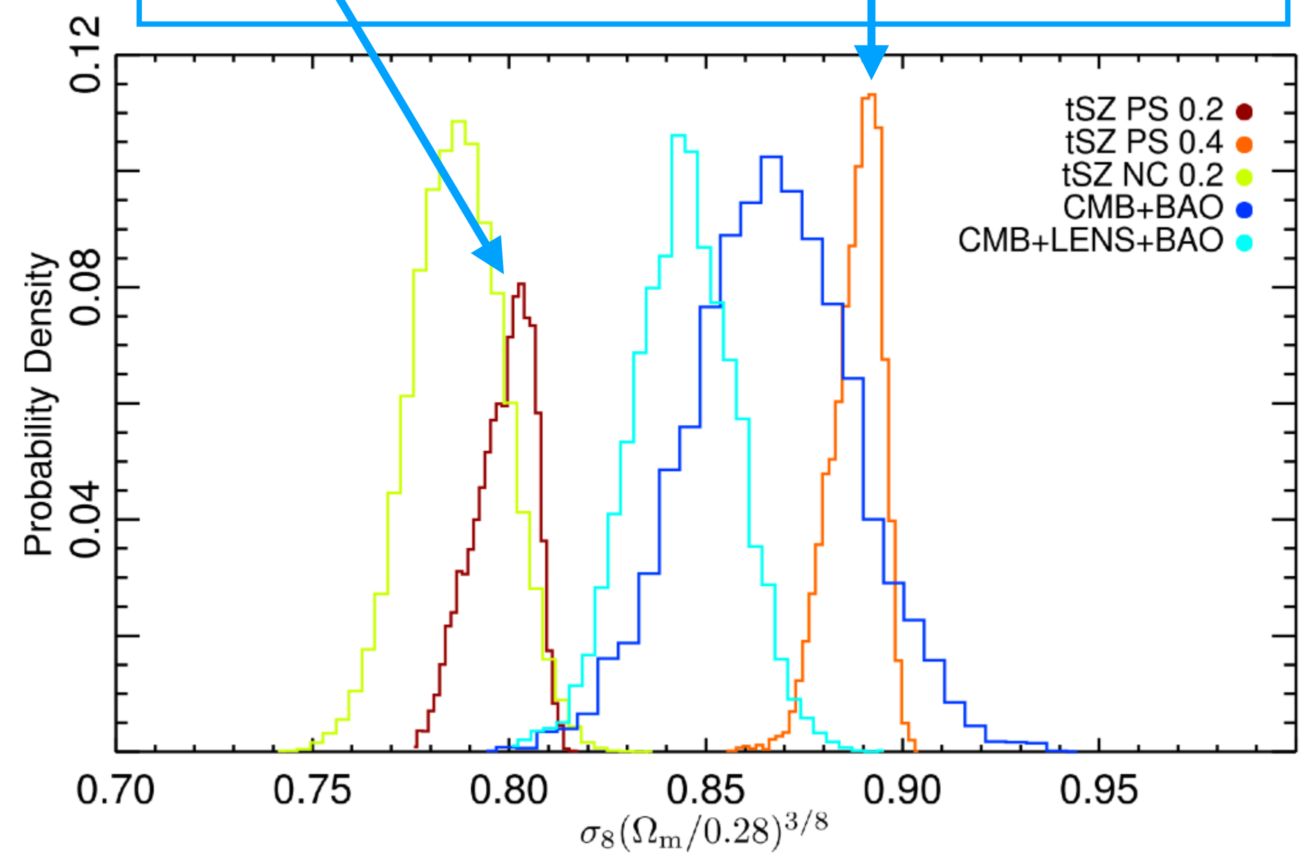
Hoekstra et al., MNRAS 449 (2015) no.1, 685

Power spectrum

Planck Collaboration, A&A 594 (2016) A22

$$\sigma_8(\Omega_m/0.28)^{3/8} = 0.80^{+0.01}_{-0.03}$$

$$\sigma_8(\Omega_m/0.28)^{3/8} = 0.90^{+0.01}_{-0.03}$$



CMB

Planck Collaboration, A&A 594 (2016) A13

$$\sigma_8 = 0.821 \pm 0.013$$
$$\Omega_m = 0.3156 \pm 0.0091$$

discrepancy between CMB data and number counts

$\simeq 2.4\,\sigma$ on σ_8

Dataset - Method

Salvati et al., in prep.

Number counts

- PSZ2 cosmological sample
- 438 clusters (MMF3), $z = [0, 1]$

Planck Collaboration, A&A 594 (2016) A24

Power spectrum

- $z = [0, 3]$
- $M_{500} = [10^{13} M_\odot, 5 \cdot 10^{15} M_\odot]$
- $\ell = 10 - 1000\,,\ 50\%$ of sky

Sampling on **cosmological** / **nuisance** parameters

<u>Baseline</u>

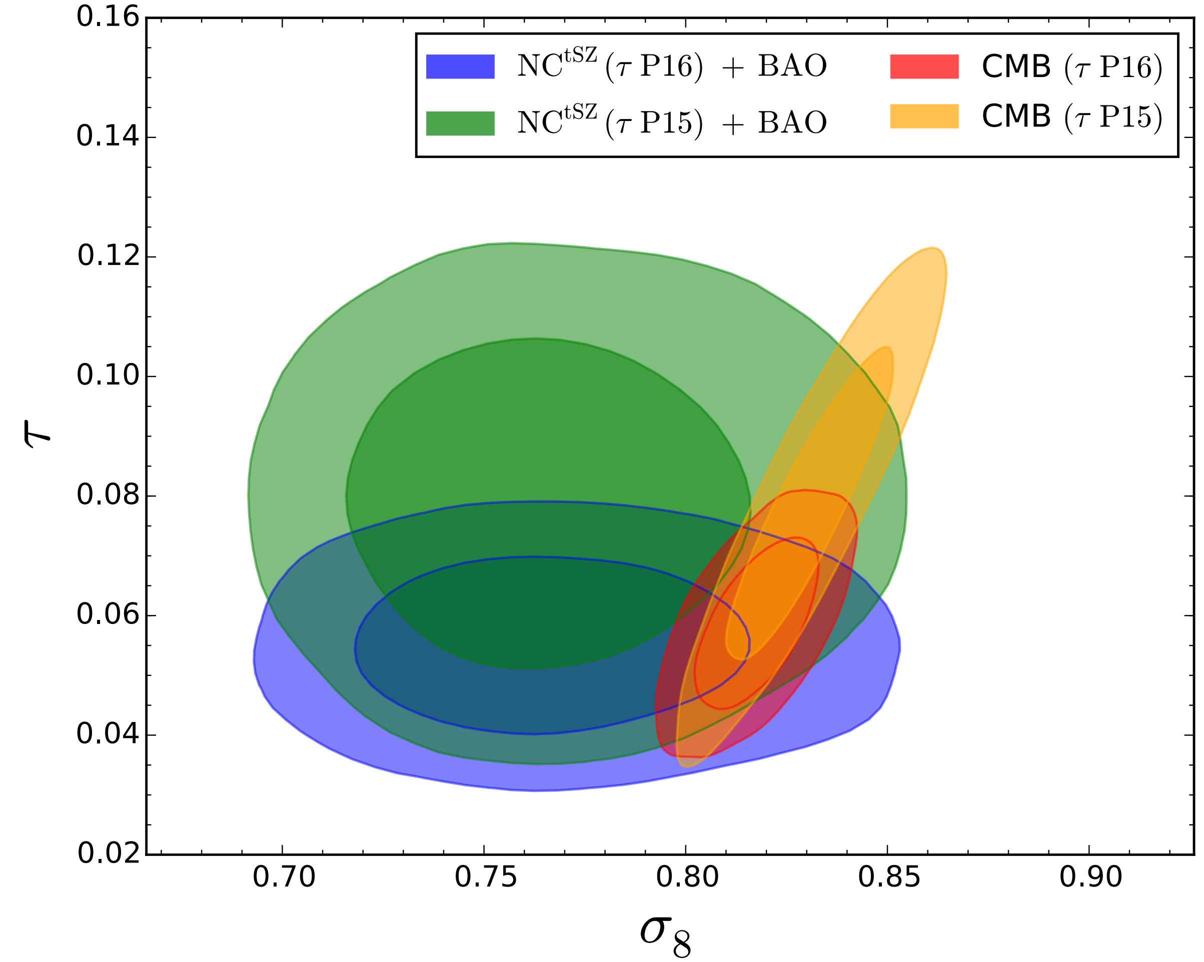
- Tinker mass function
- cccp prior on mass bias

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

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

- $\tau = 0.055 \pm 0.009$

Planck Collaboration, A&A 596 (2016) A107



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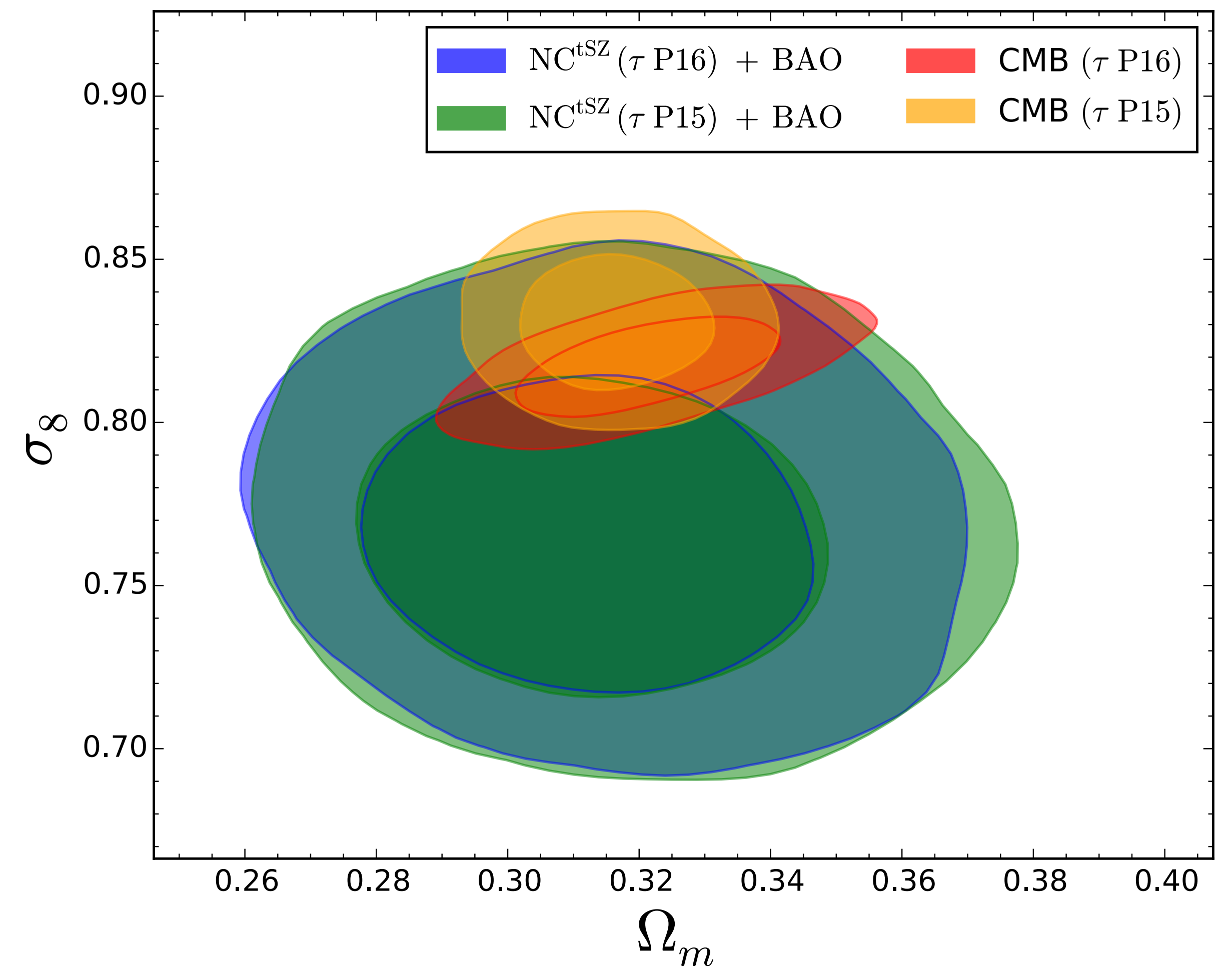
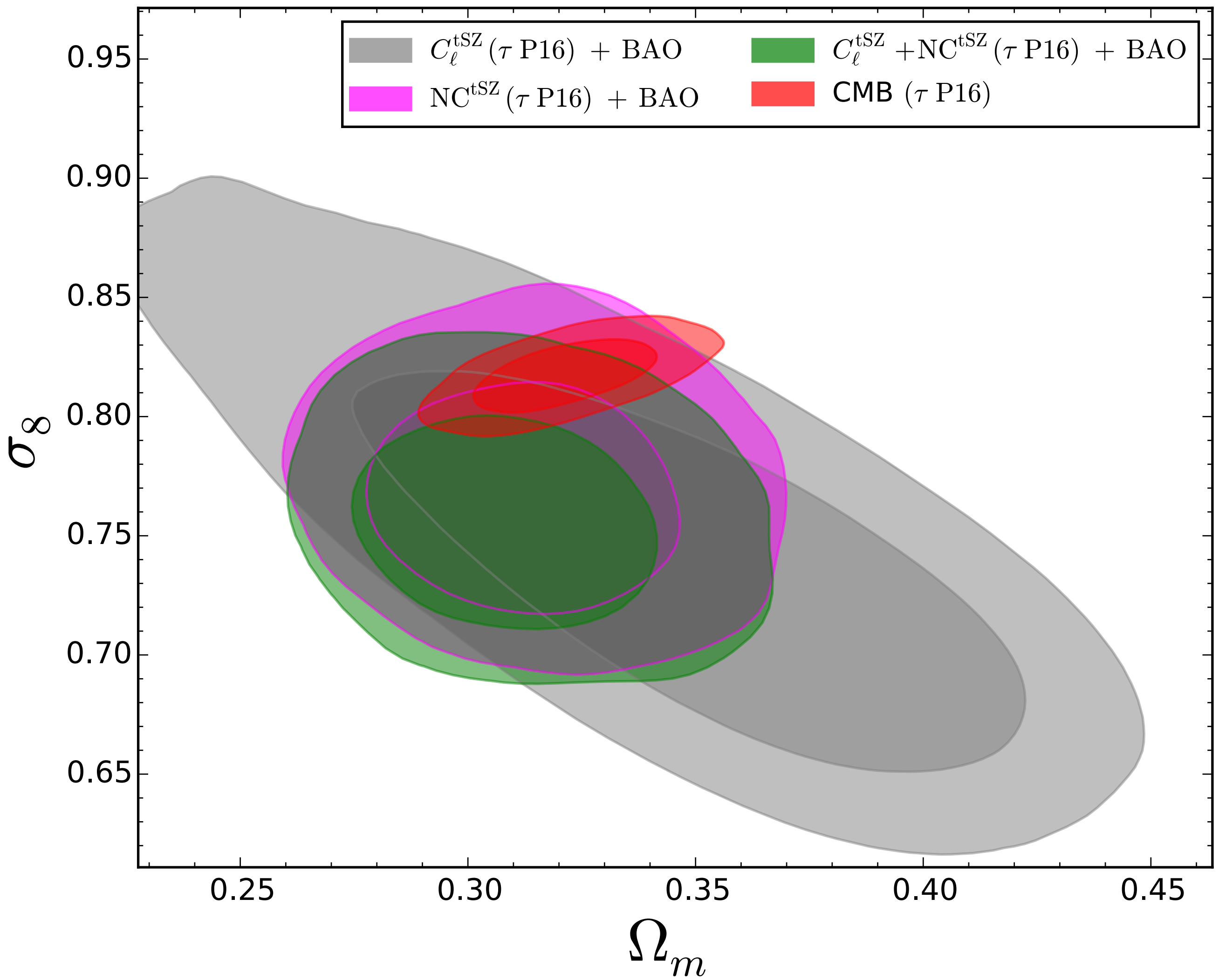
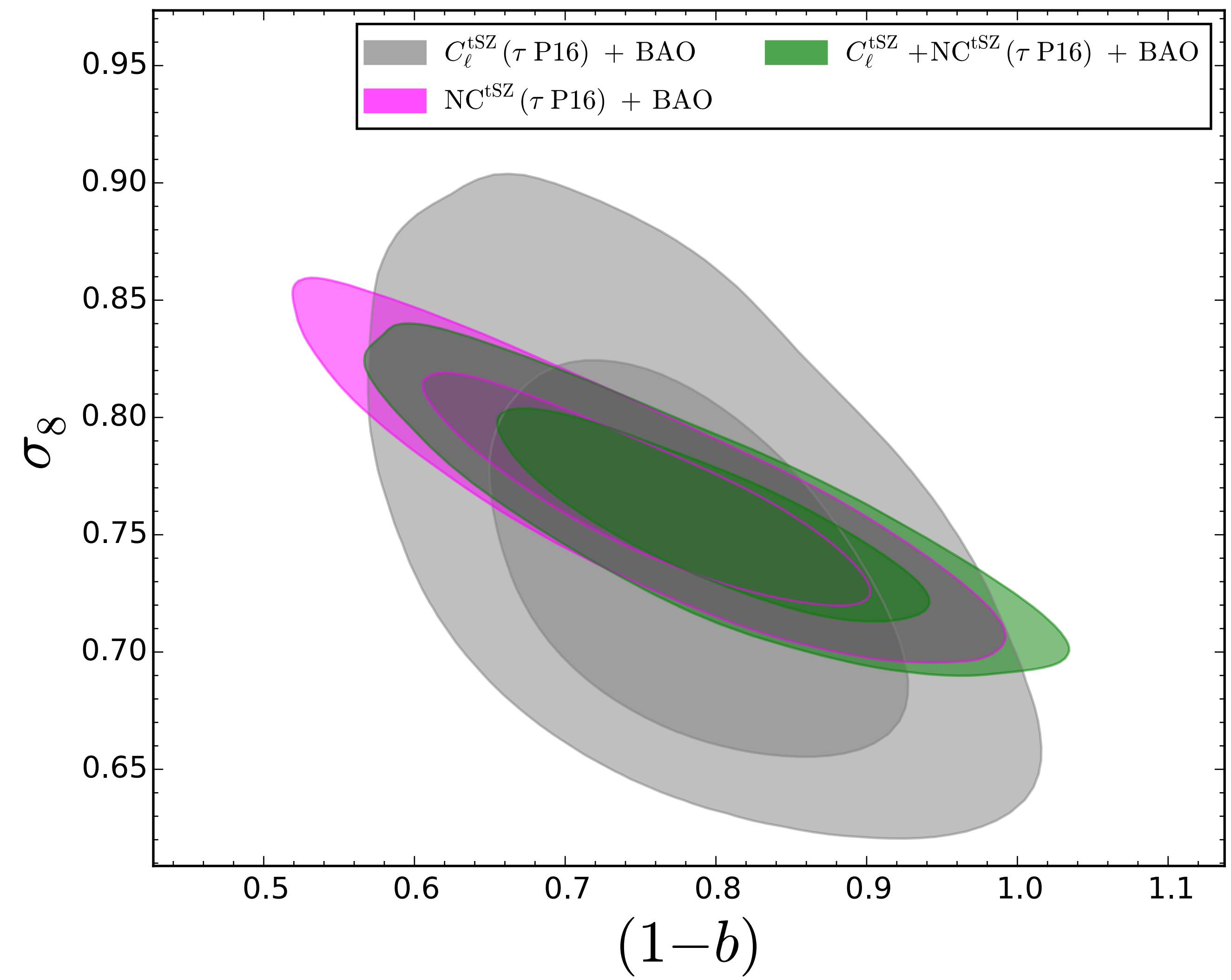
Planck Collaboration, A&A 596 (2016) A107







NC + BAO

$$\Omega_m = 0.314^{+0.020}_{-0.024}$$

$$\sigma_8 = 0.768^{+0.028}_{-0.035}$$

CMB

$$\Omega_m = 0.321^{+0.012}_{-0.014}$$

$$\sigma_8 = 0.817 \pm 0.010$$

NC + CL + BAO

$$\Omega_m = 0.311^{+0.019}_{-0.024}$$

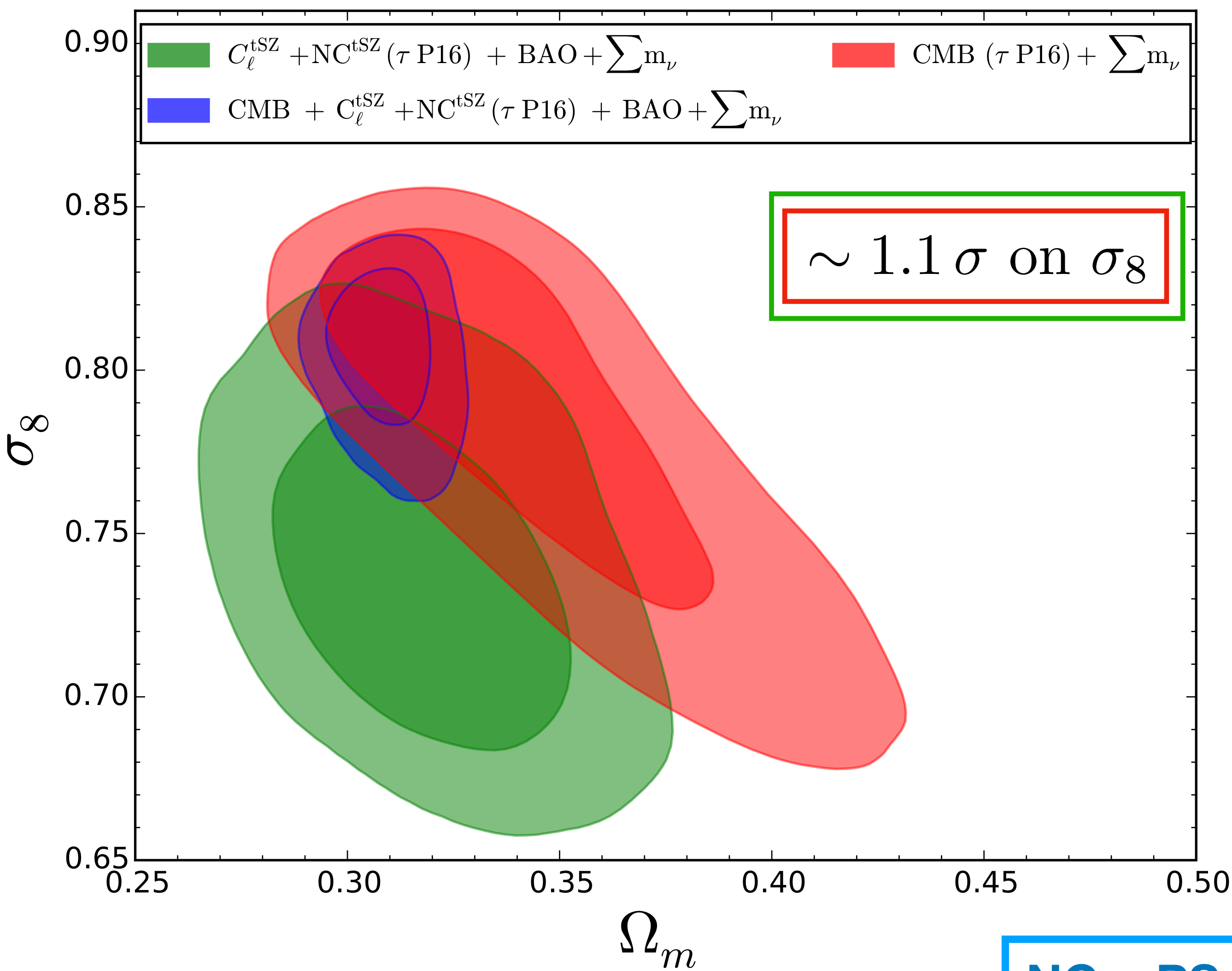
$$\sigma_8 = 0.758^{+0.026}_{-0.032}$$

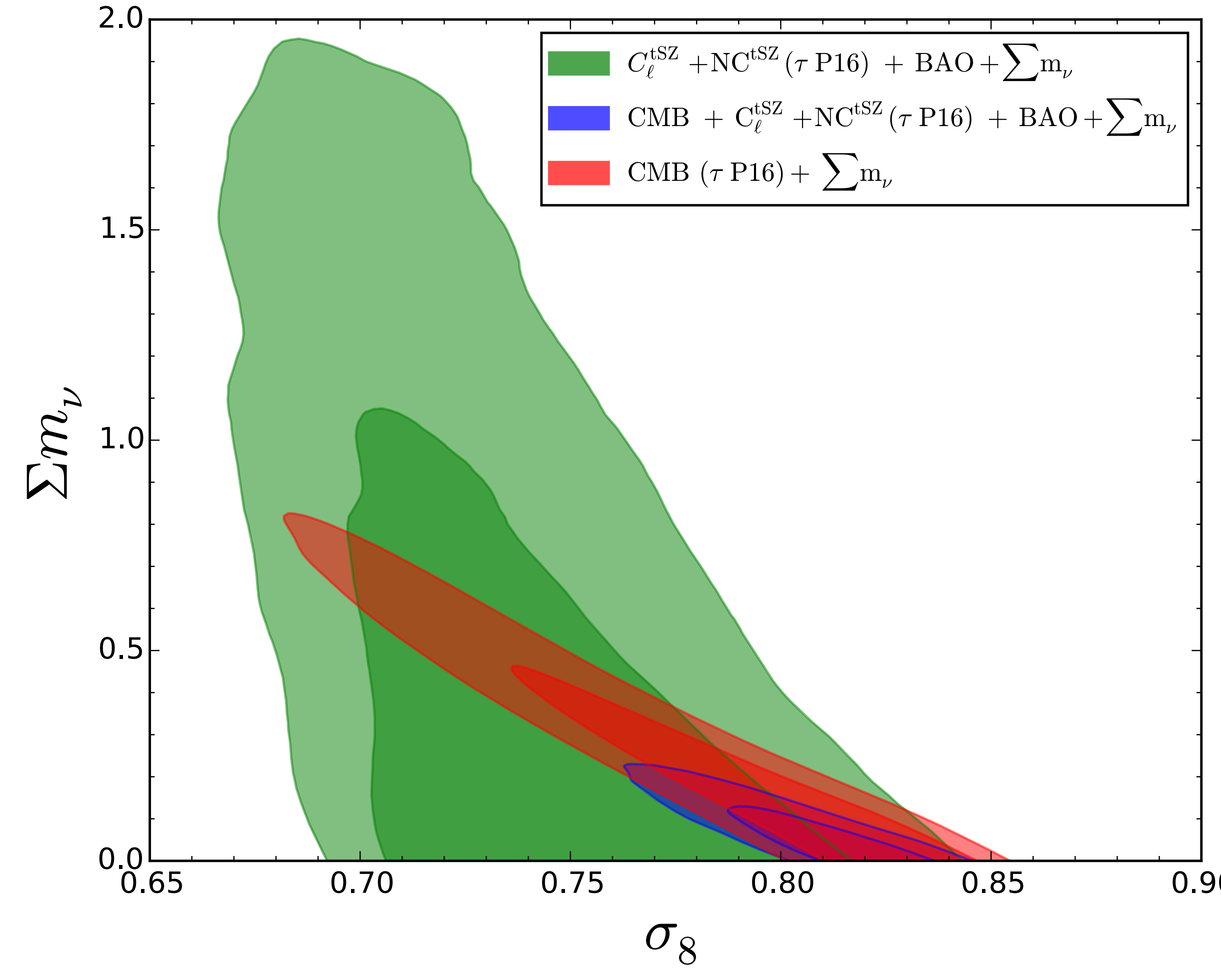
discrepancy $\sim 1.5\,\sigma$ on σ_8

discrepancy $\sim 2.1\,\sigma$ on σ_8

Results

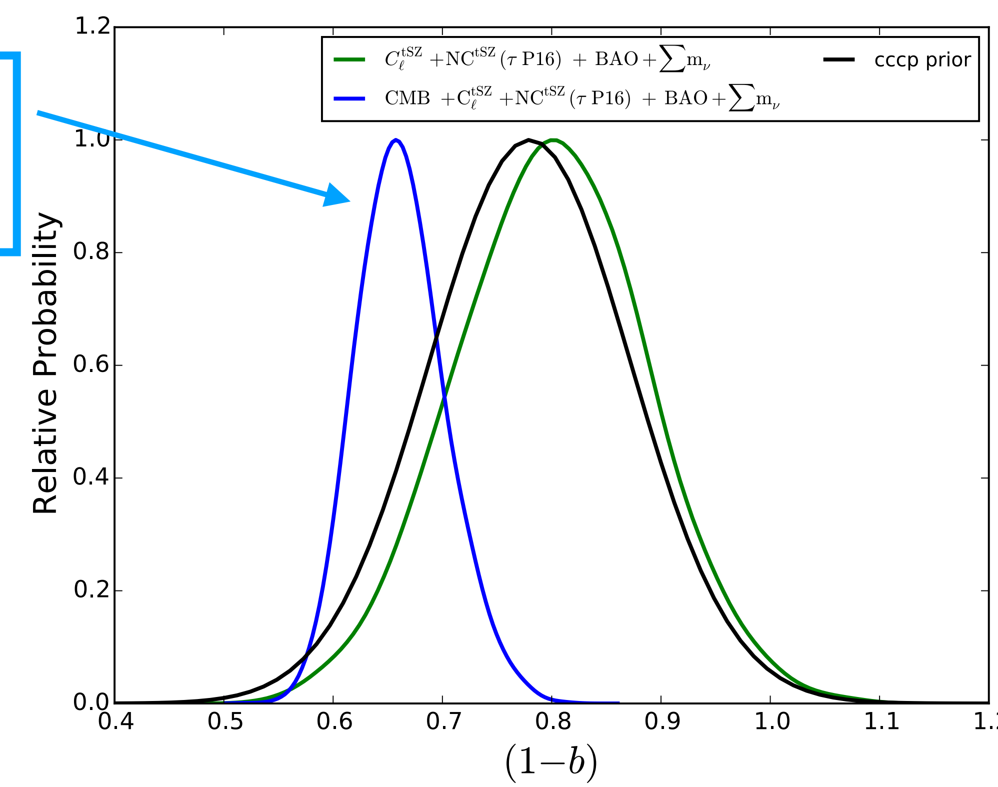
Salvati et al., in prep.





NC + PS + CMB + BAO

$(1-b) = 0.66 \pm 0.04$



NC + PS + BAO

$\sum m_\nu < 1.49\,\mathrm{eV}$

CMB

$\sum m_\nu < 0.65\,\mathrm{eV}$

NC + PS + CMB + BAO

$\sum m_\nu < 0.18\,\mathrm{eV}$

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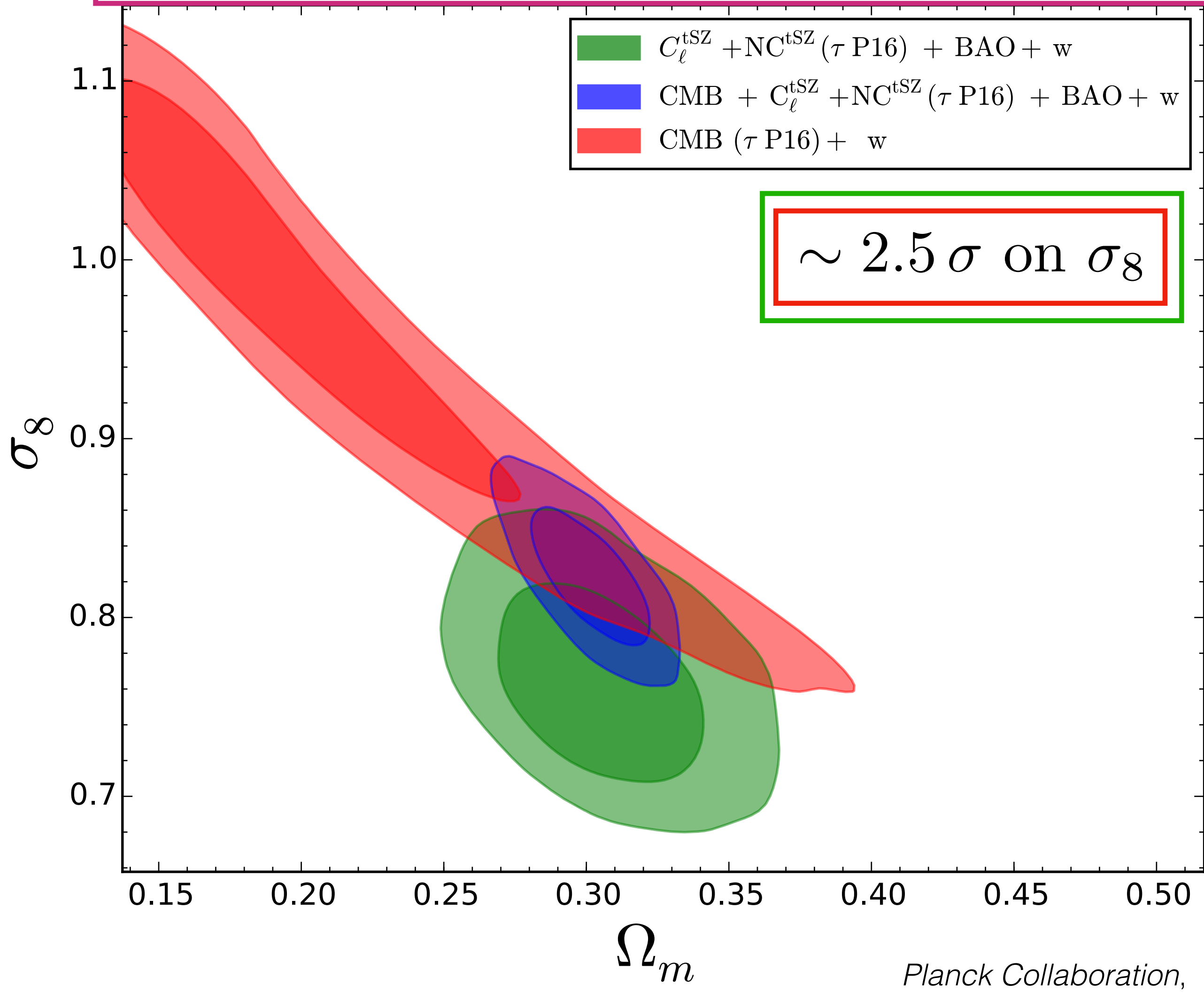
NC + CMB + BAO

$\sum m_\nu < 0.20\,\mathrm{eV}$

dark energy EoS Results

Salvati et al., in prep.

varying EoS parameter w → constant-w model



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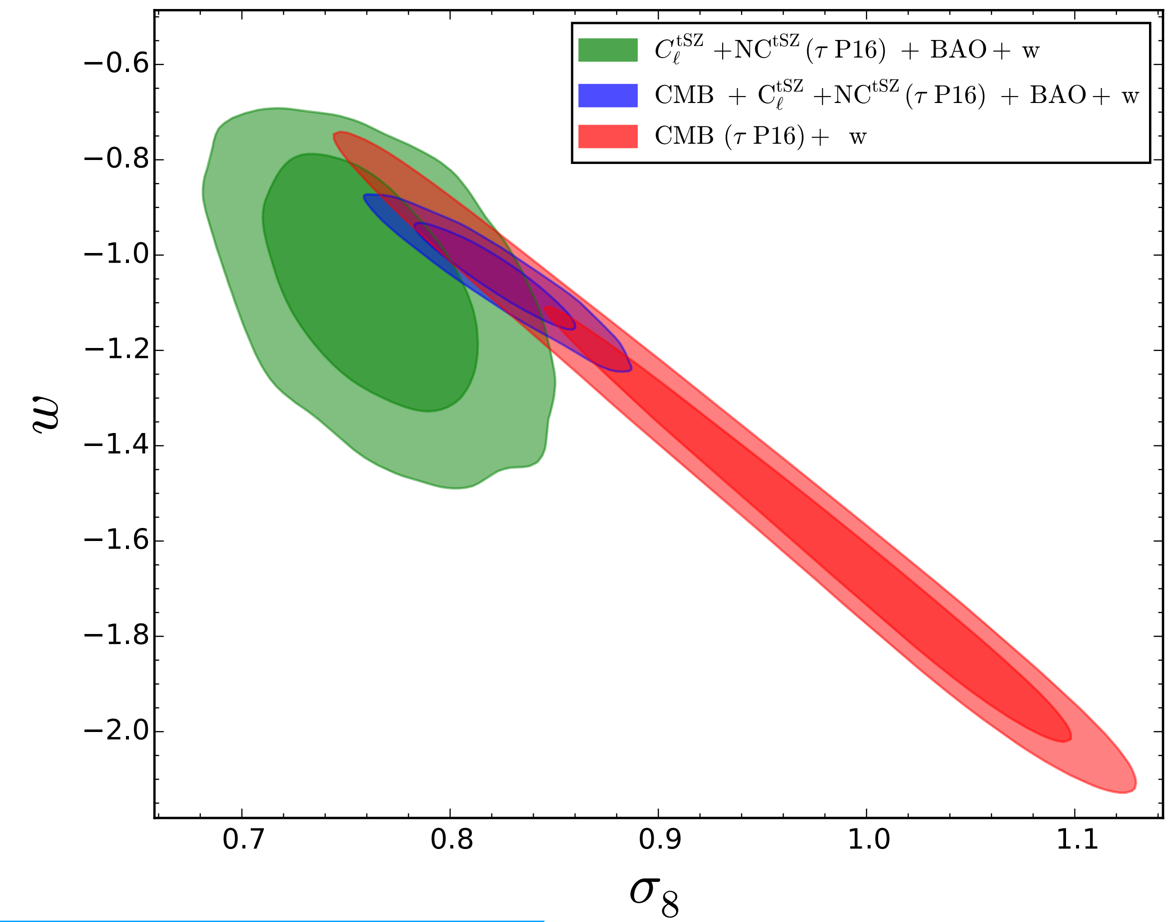
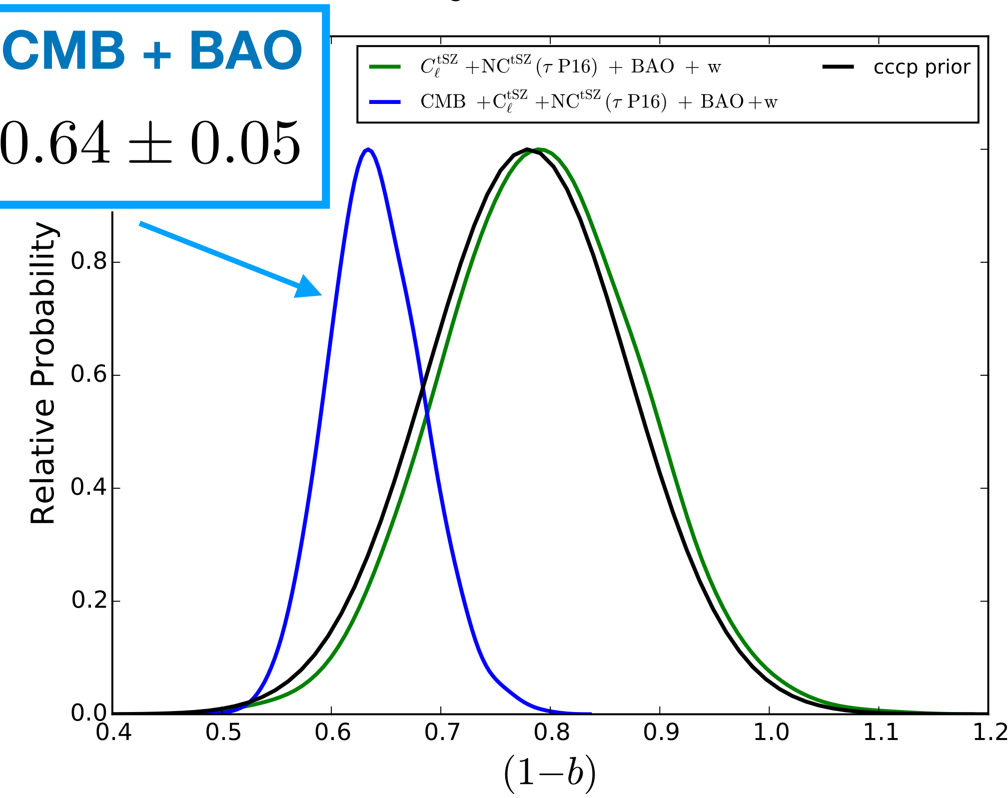


NC + PS + CMB + BAO

$$(1-b) = 0.64 \pm 0.05$$



NC + PS + BAO

$$w = -1.09^{+0.21}_{-0.15}$$

NC + BAO

$$w = -1.01 \pm 0.18$$

NC + PS + CMB + BAO

$$w = -1.06^{+0.08}_{-0.06}$$

CMB

$$w = -1.56^{+0.21}_{-0.40}$$

Conclusions

Constraints on cosmological parameters from tSZ observations

Number counts
+
tSZ power spectrum

- improvement in constraining power
- able in constraining extensions to LCDM
- still discrepancy wrt CMB primary anisotropie

How to improve these results

- better knowledge of cluster physics
  - break degeneracy between nuisance and cosmological parameters
  - better description of the mass bias
- different modelling of mass function
- consider "n^{th} order" terms in building the theoretical model

Back-up

Model

Galaxy Clusters through SZ effect

- Number counts (NC) (observed)
- Power spectrum (PS)

Selection function

$$\frac{dN}{dz} = \int d\Omega \int dM_{500}\, \hat{\chi}(z, M_{500}, l, b)\, \frac{dN(M_{500}, z)}{dM_{500}} \frac{dV}{dz\, d\Omega}$$

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

$$C_\ell^{\rm 1halo} = \int dz \frac{dV}{dz\, d\Omega} \int dM_{500} \frac{dN(M_{500}, z)}{dM} |\tilde{y}_\ell(M_{500}, z)|^2$$

$$C_\ell^{\rm 2halo} = \int dz \frac{dV}{dz\, d\Omega} \left[\int dM_{500} \frac{dN(M_{500}, z)}{dM} |\tilde{y}_\ell(M_{500}, z)|\, B(M_{500}, z)\right]^2 P(k, z)$$

Mass function

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

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

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

Scaling relations

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

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

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

Scaling relations

1. <u>Baseline for mass - proxy relation</u>

from 20 local relaxed clusters

Arnaud et al., A&A 474 (2007) L37

HE mass: biased estimator of true mass

- departure from HE equilibrium
- instrument calibration
- T inhomogeneities
- residual selection bias

$$E^{-2/3}\, Y_X = 10^{A\pm\sigma_A}\,[(1-b)M_{500}]^{\alpha\pm\sigma_\alpha}$$

from best-fit: mass proxy definition

$$M_{500}^{Y_X} = 10^{\pm\sigma_A/\alpha}\,[(1-b)\,M_{500}]^{1\pm\sigma_\alpha/\alpha}$$

$Y_{500} - M_{500}$
independent of dynamical state

✦ pass through Xray

- low-scatter mass proxy
- minimum HE bias

Scaling relations

2. Relation $Y_{500} - M_{500}^{Y_X}$

from 71 Planck clusters with Xray follow-up from XMM-Newton

$$E^{-2/3}(z)\left[\frac{D_A^2\,Y_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = 10^{-0.19\pm0.01}\left[\frac{M_{500}^{Y_X}}{6\cdot10^{14}\,M_\odot}\right]^{1.79\pm0.06}$$

corrected for Malmquist bias

3. Combining everything

$$E^{-2/3}(z)\left[\frac{D_A^2\,Y_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = 10^{-0.19\pm0.02}\left[\frac{(1-b)\,M_{500}}{6\cdot10^{14}\,M_\odot}\right]^{1.79\pm0.08}$$

Mass bias

$$M_{500}^{\mathrm{HE}} = (1-b)M_{500}$$

$Y_{500} - M_{500}$

Comparison between observations and numerical simulations

Mass dependance: $b = b\left(M_{500}^{\mathrm{true}}\right)$

$$M_{500}^{\mathrm{obs}} = \left[1 - b\left(M_{500}^{\mathrm{true}}\right)\right] M_{500}^{\mathrm{true}}$$

$$R_{500}^{\mathrm{obs}} = \left[1 - b\left(M_{500}^{\mathrm{true}}\right)\right]^{1/3} R_{500}^{\mathrm{true}}$$

Corresponding relations:

$$Y(< R_{500}^{\mathrm{true}}) = A_{\mathrm{true}} \left[M_{500}^{\mathrm{true}}\right]^{\beta}$$

$$Y(< R_{500}^{\mathrm{obs}}) = A_{\mathrm{obs}} \left[M_{500}^{\mathrm{obs}}\right]^{\alpha}$$

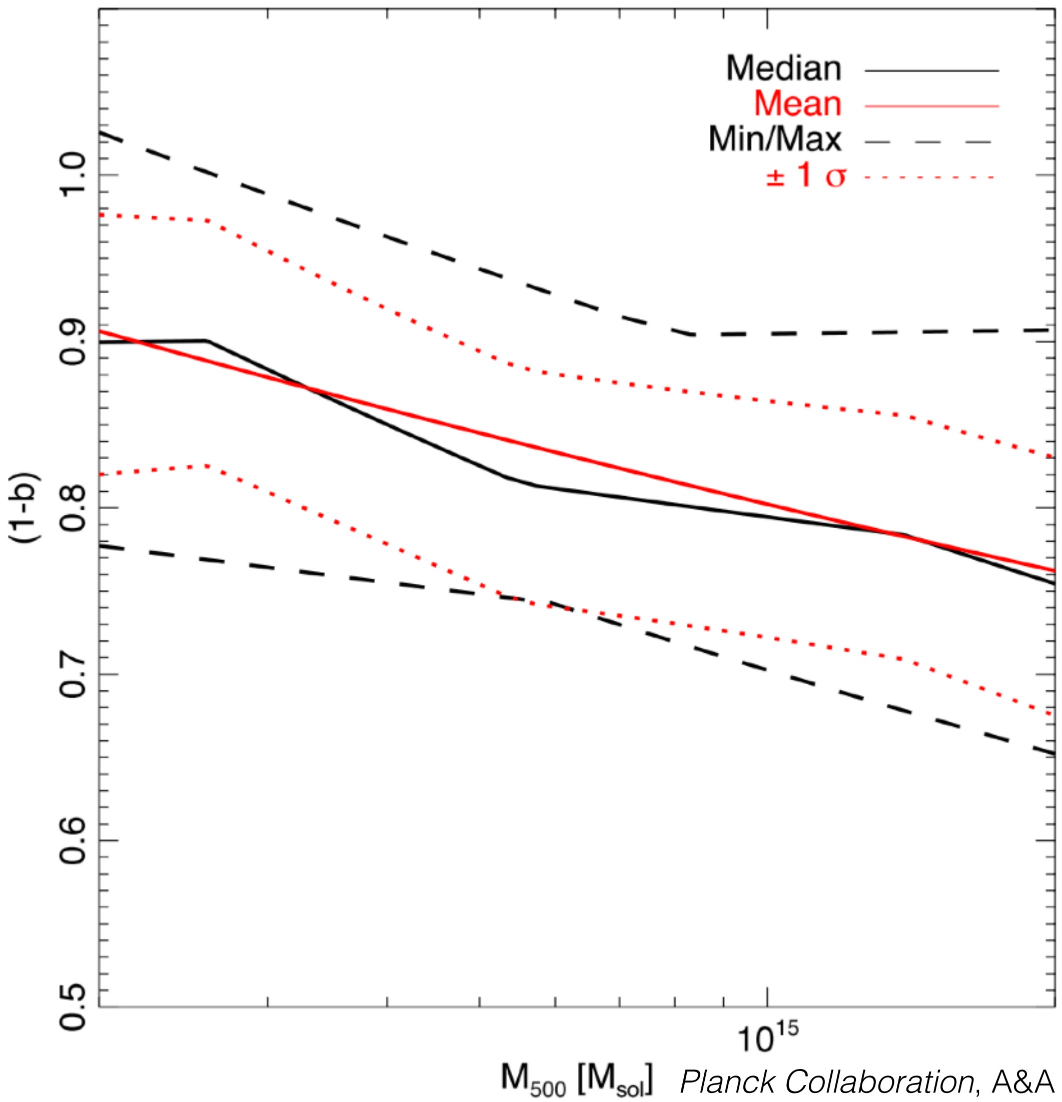
$$Y(< R_{500}^{\mathrm{true}})/Y(< R_{500}^{\mathrm{obs}}) \propto (1-b)^{-1/4}$$

$$\left[1 - b\left(M_{500}^{\mathrm{true}}\right)\right] = \left[\frac{A_{\mathrm{true}}\left(M_{500}^{\mathrm{true}}\right)^{\beta}}{A_{\mathrm{obs}}\left(M_{500}^{\mathrm{obs}}\right)^{\alpha}}\right]^{-1/4+\alpha}$$

mass-dependent bias implies different slopes for observed and simulated relations

Mass bias

$$\left[1 - b\left(M_{500}^{\mathrm{true}}\right)\right] = \left[\frac{A_{\mathrm{true}}\left(M_{500}^{\mathrm{true}}\right)^{\beta}}{A_{\mathrm{obs}}\left(M_{500}^{\mathrm{obs}}\right)^{\alpha}}\right]^{-1/4+\alpha}$$



Planck Collaboration, A&A 571 (2014) A20

$$(1 - b) = [0.7, 1.0]$$

$$(1 - b)_{\mathrm{mean}} \simeq 0.8$$