Cosmological Tension between CMB and LSS

M. DOUSPIS

Institut d'Astrophysique Spatiale, Orsay, France

with

S. Ilic, G. Hurier, F. Lacasa, *L. Salvati*, A. Ritz, N. Aghanim

A&A 582, A79 (2015) *A&A. 576, A90 (2015)* *A&A 604 A71 (2017)* *A&A 614 A13 (2018)*

Tension on Ω_M and σ_8 between CMB and (*Planck*) clusters

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PLAN

- **Origine of the tension**
  - SZ effect and products in *Planck*
  - Cosmology with clusters
  - Results (2013) and limits of analyses
- **Updates on the tension**
- **(not) solving the tension**
  - Extensions of LCDM
  - Extensions on cluster mass estimates

WHY CLUSTERS OF GALAXIES ?

Largest objects gravitationally bound in the Universe make them

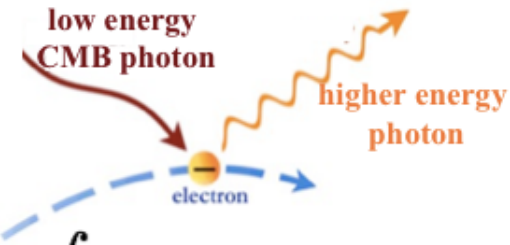
highly sensitive **to global cosmological evolution,**

in particular to the amount of matter: Ω_M

the variance of matter fluctuations: σ_8

LOOKING FOR CLUSTERS

Inverse Compton
→ SZ effect

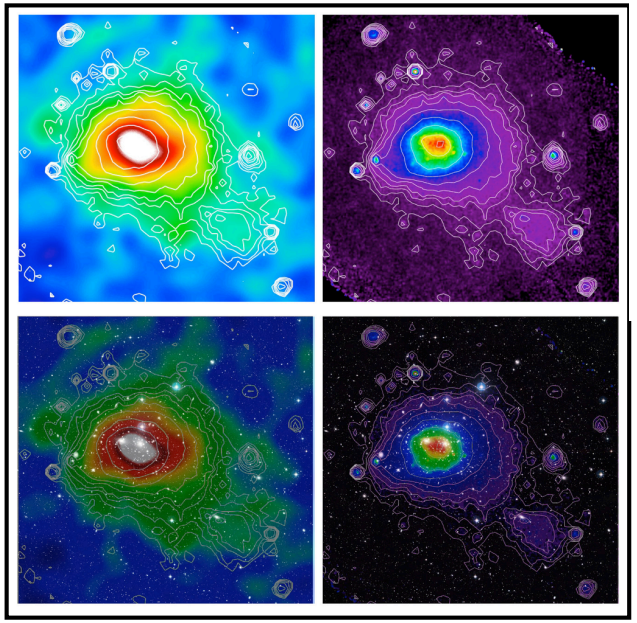


$$F_\nu \propto \int_\Omega (P = n_e T) d\Omega$$

Number of galaxies
→Optical/IR

Cold Gas

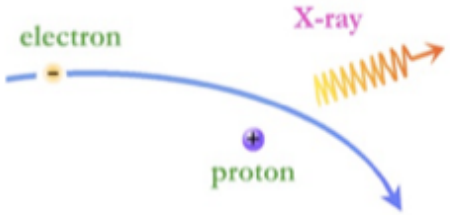
Hot Gas



courtesy of Pointecouteau

non thermal emission
→radio

Bremsstrahlung
→ X-ray emission



$$E_X \propto \int_V n_e^2 \Lambda(T) dV$$

Weak/Strong lensing
velocity dispersion
→Optical/IR

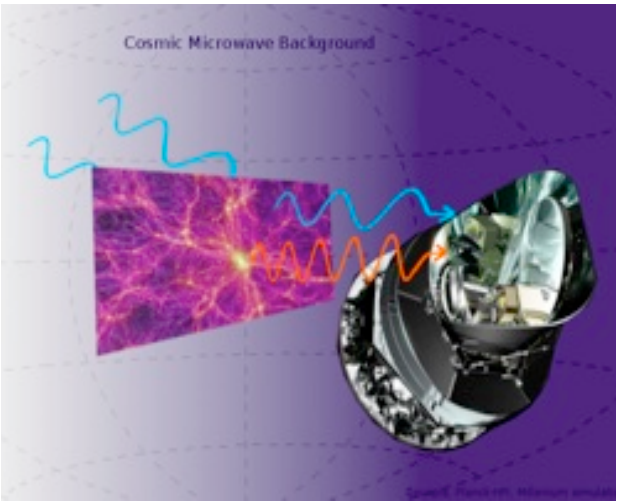
+Dark Matter

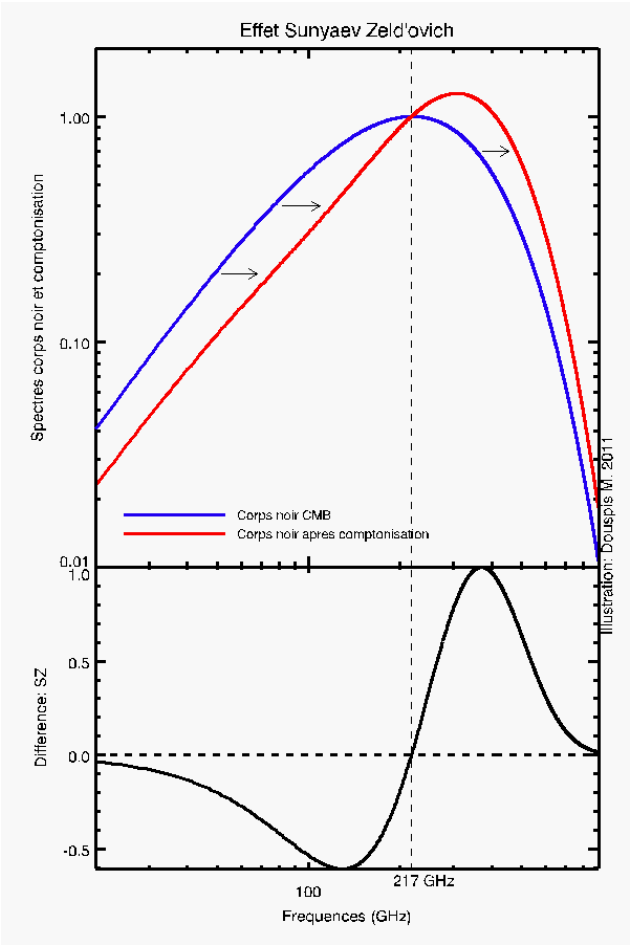
SZ EFFECT: HOT BARYON TRACER

Inverse Compton distortion = Sunyaev-Zeldovich effect

R. A. Sunyaev

Ya. B. Zeldovich





$$y = \int \frac{k_B T_e}{m_e c^2} n_e \sigma_T dl$$

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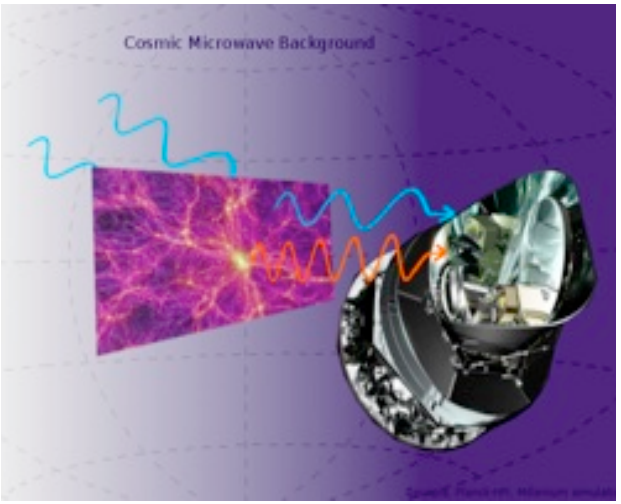

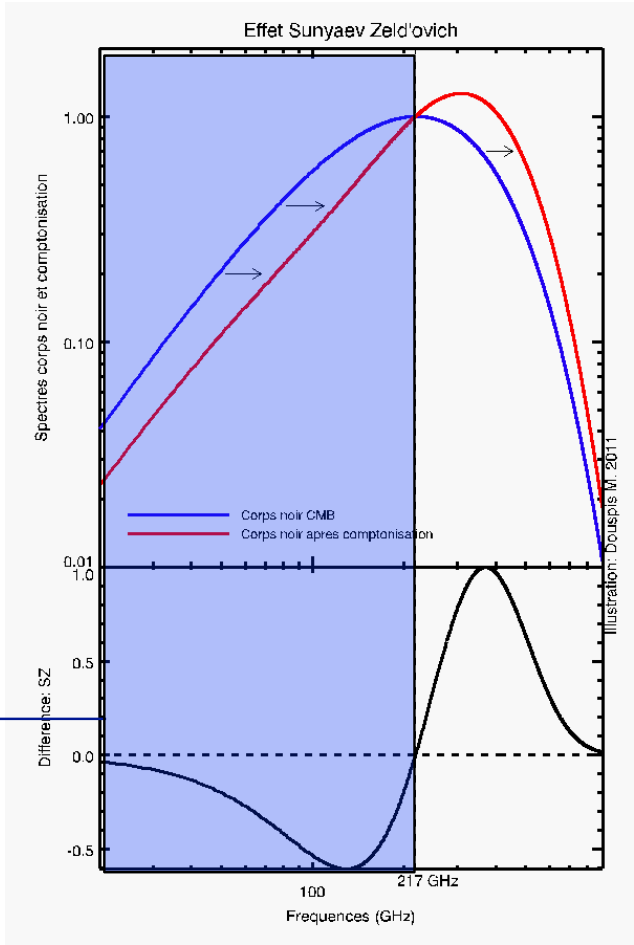

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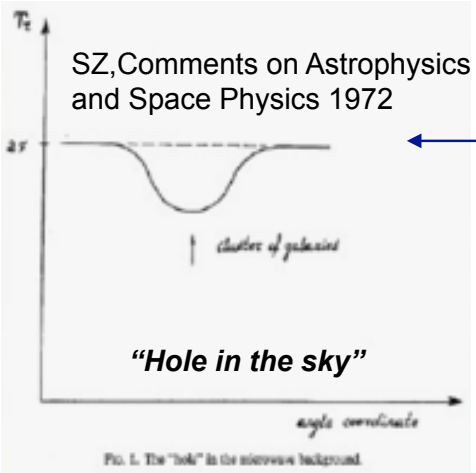

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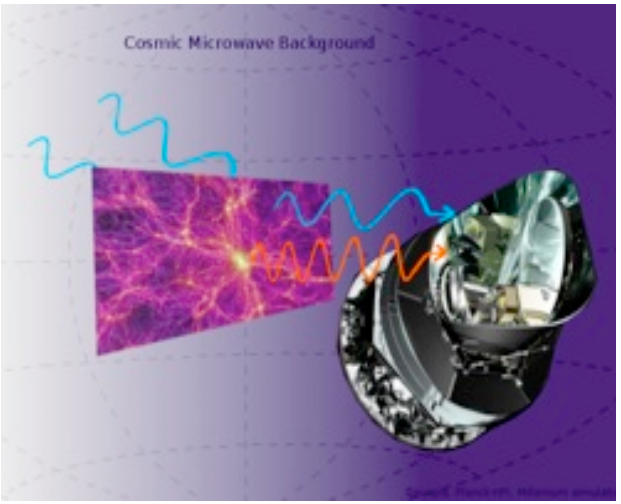

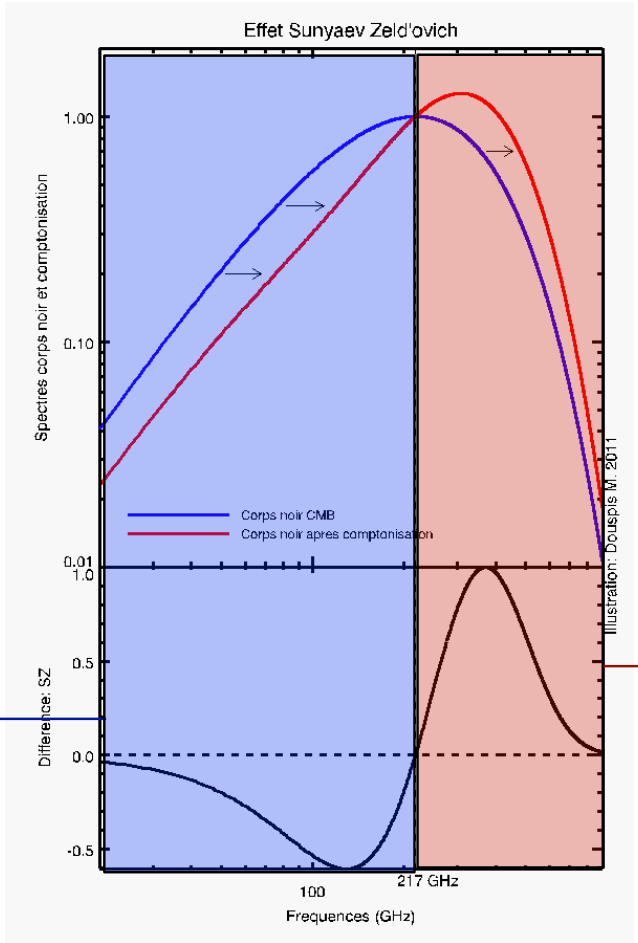

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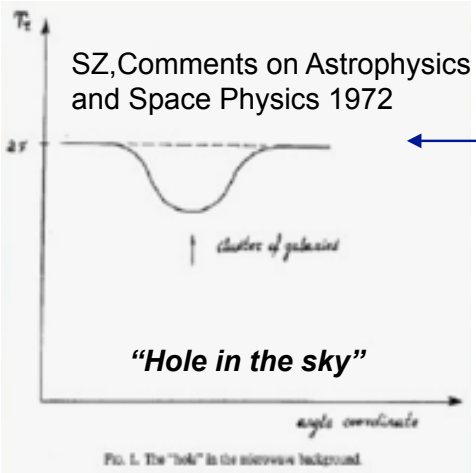
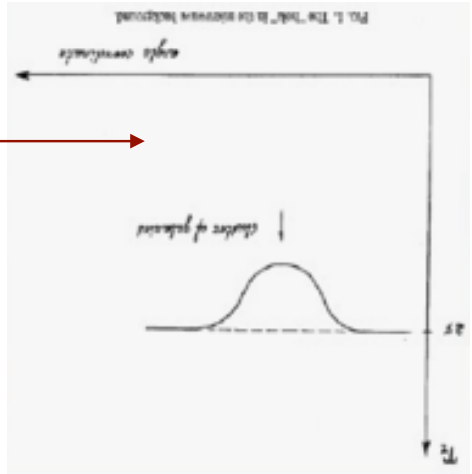
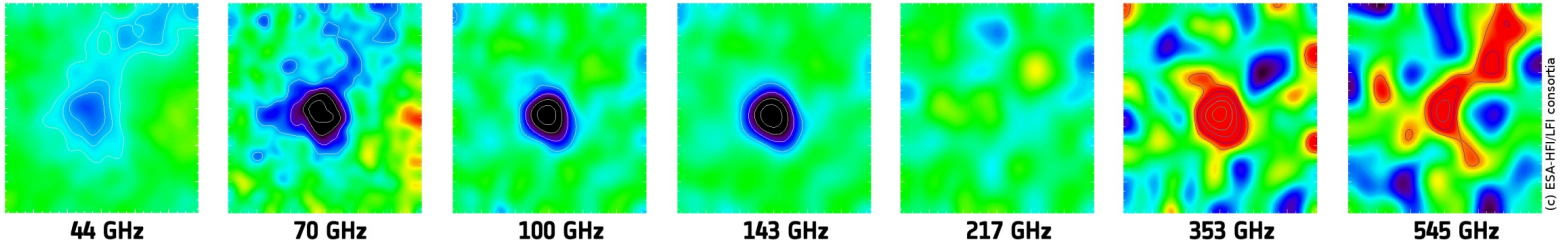
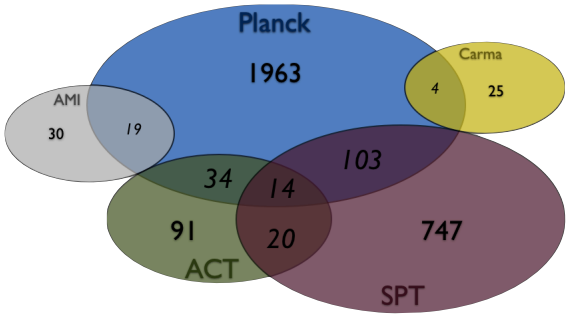


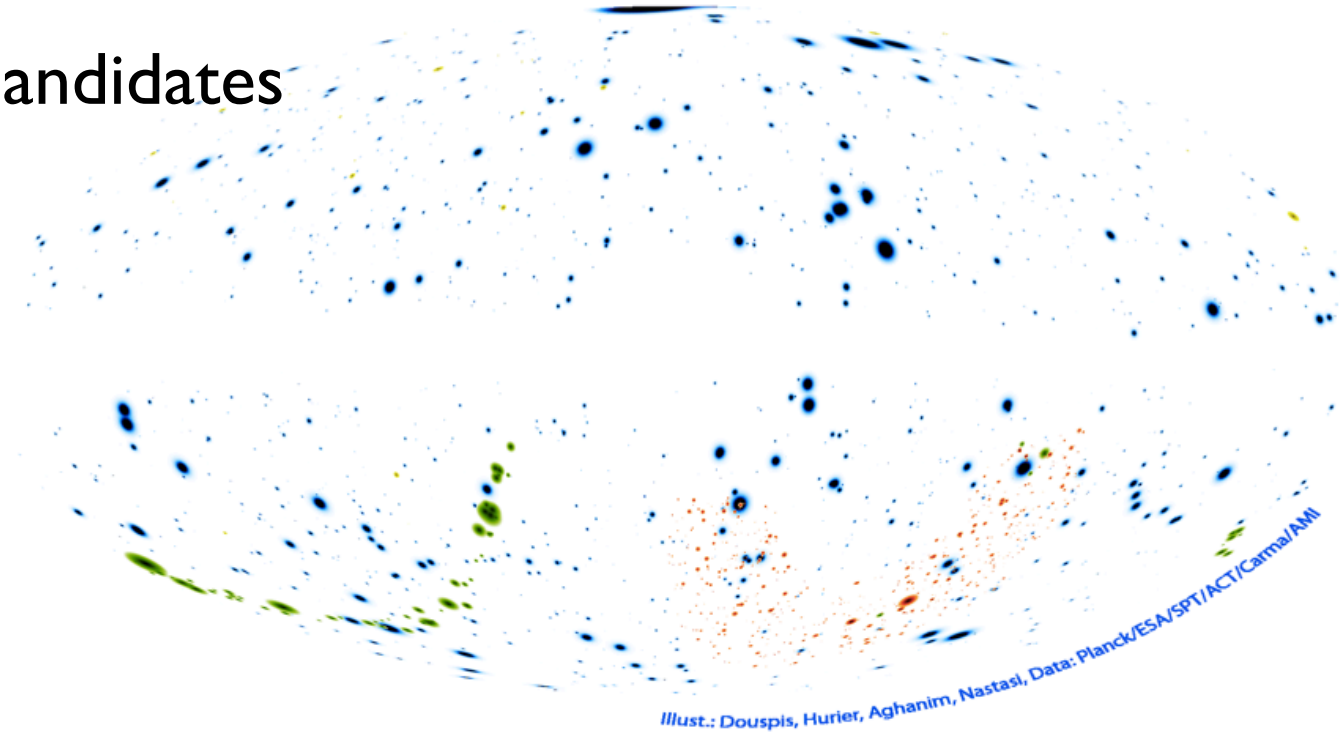


SZ CLUSTERS



2690 clusters and candidates



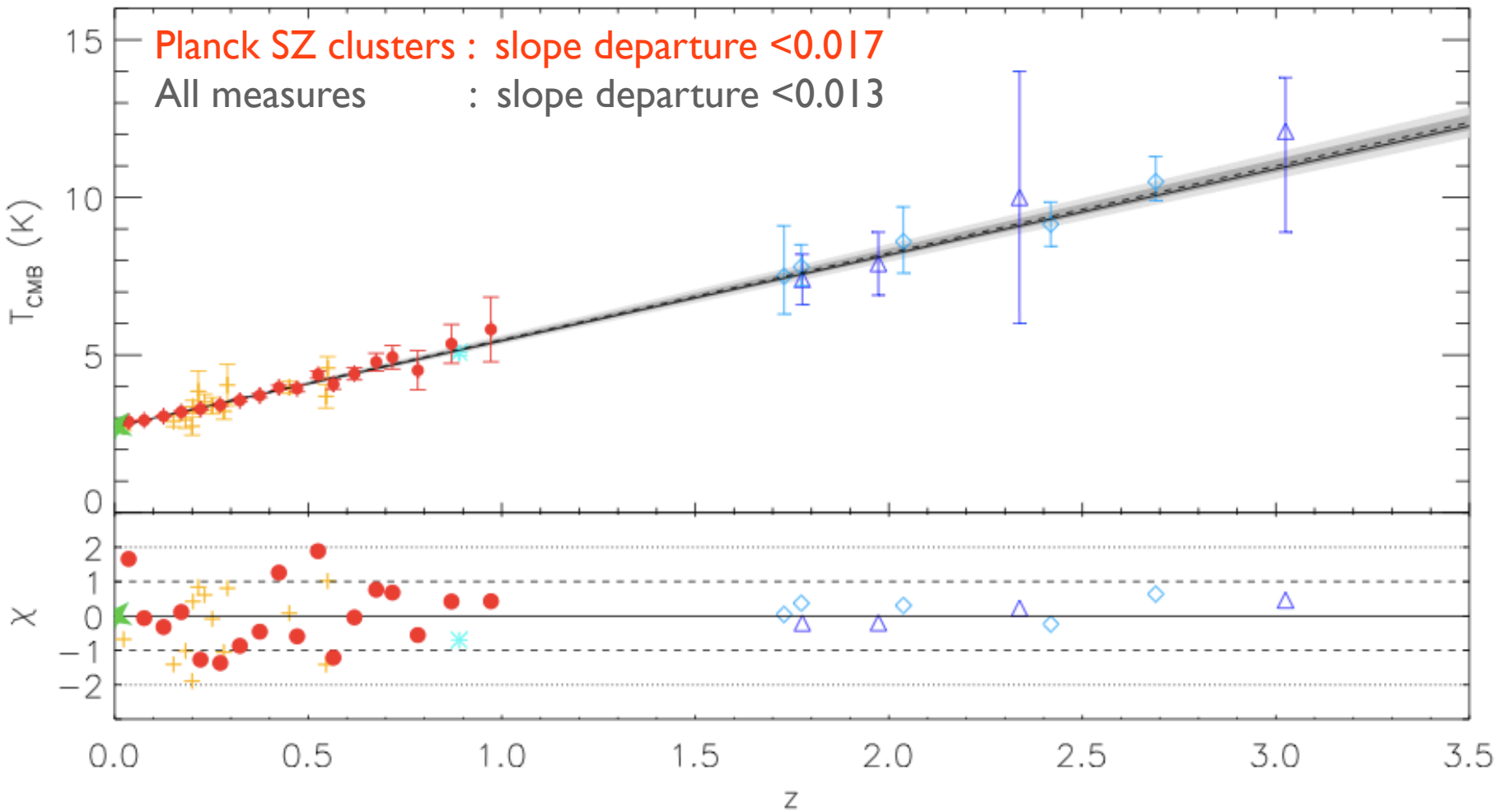


high purity and well behaved completeness → cosmological samples (200-400)

SZ metacatalogue available at szcluster-db.ias.u-psud.fr, Douspis et al. sub A&A

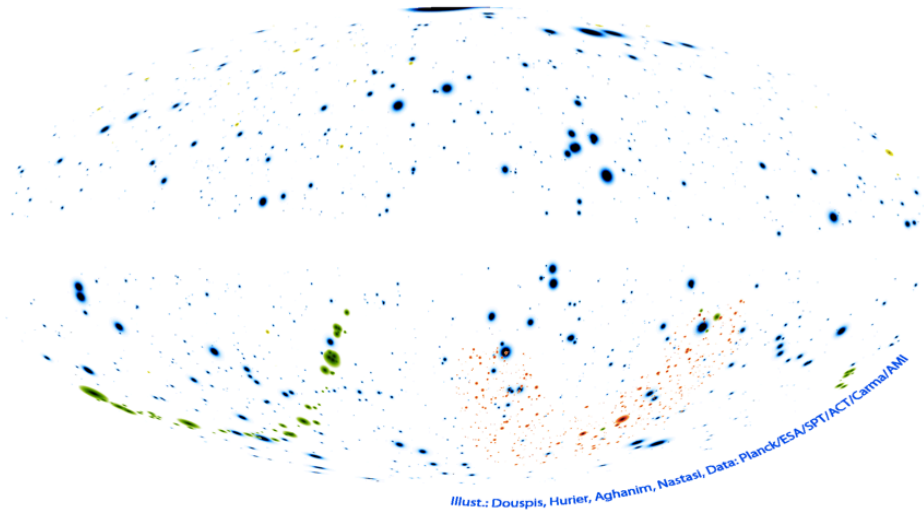
CMB TEMPERATURE

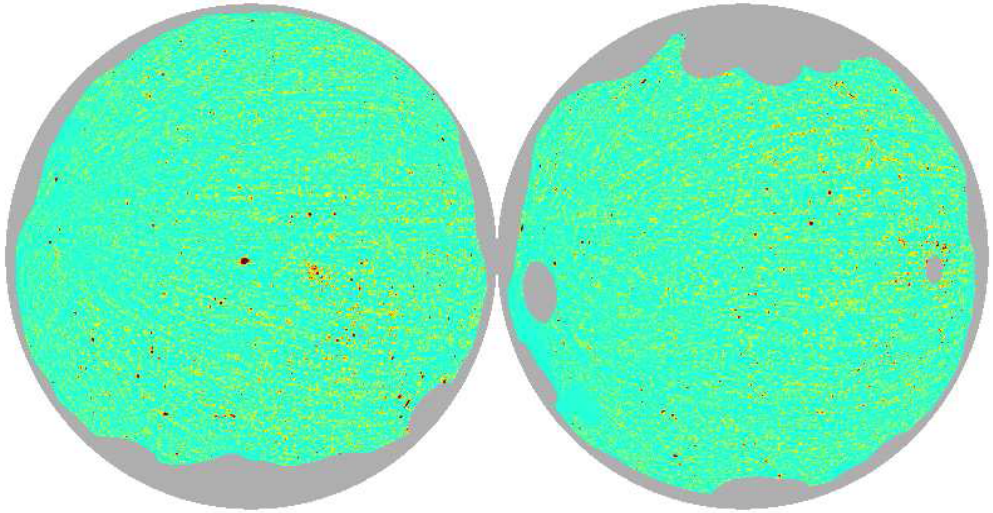
$$T_{CMB}(z) = T_{CMB}(z=0)\,(1+z)^{1-\beta}$$

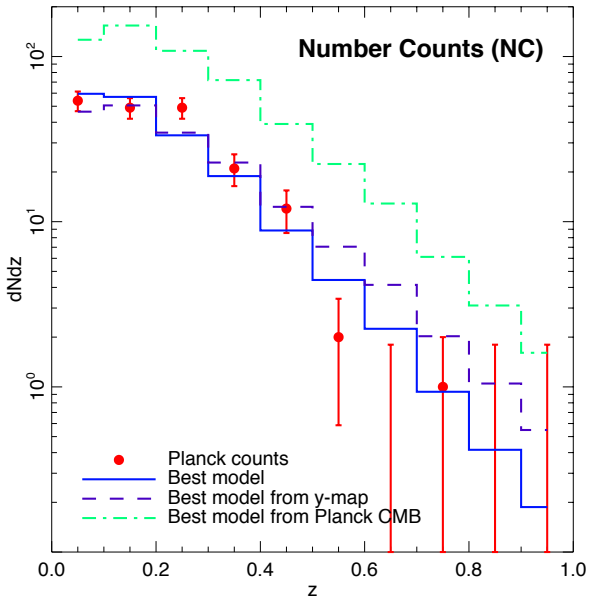


Hurier, Aghanim, Douspis, Pointecouteau, A&A 2013

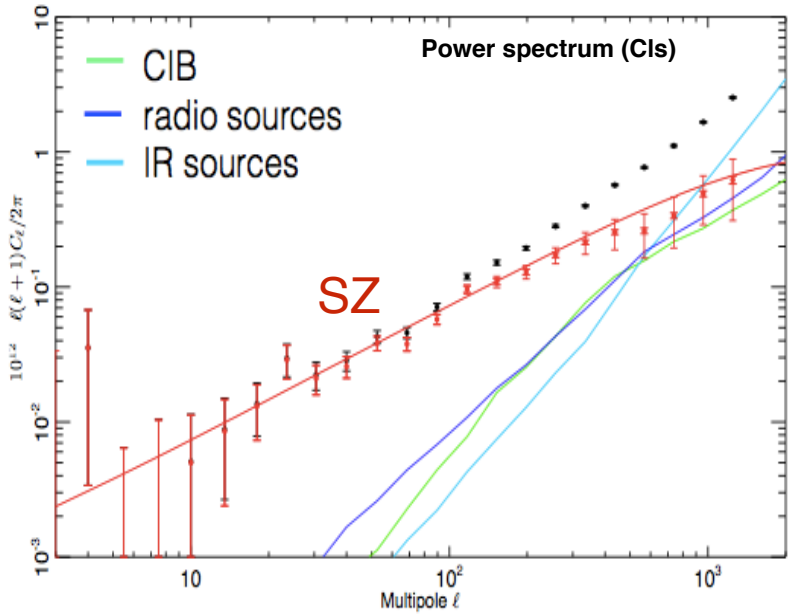
SZ PROBES IN *PLANCK*







Planck 2013, 2015



COSMOLOGY FROM SZ

$$dN/Cls[\Theta] \equiv \iiint dMdz \; dV \; \chi(obs) \; S(obs - M) \; \frac{dN}{dMdz} \; p(M,z)$$

Completness

How much clusters your probe finds compare to the true number / mask on the sky : given by experiment

Scaling relation

Needed to relate the observable (flux, size) to the mass and redshift. Given by comparison HM with simulations or WL measurements *[Planck 2013., Nagai et al., ...]*

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

Cosmology

Clusters and SZ power spectrum are both geometrical and growth probes

Mass function

Number of halos in bins of mass and redshift. From numerical simulations, known 10% scatter between teams *[Tinker et al., Watson et al., Despali et al.]*

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

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

Profile

Describes the spatial distribution of the hot gas (for Cls). Assume Universal pressure profile, the GNFW *[Nagai et al., Arnaud et al., Planck 2014]*

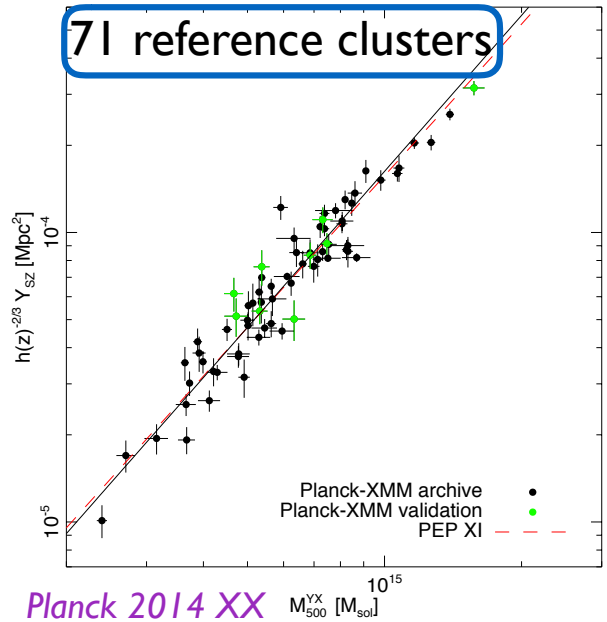
TRICKY INGREDIENT: THE MASS

- Masses obtained from scaling relations+HMB

$$E^{-\beta}(z)\left[\frac{D_A^2(z)\bar{Y}_{500}}{10^{-4}\,\mathrm{Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)M_{500}}{6\times10^{14}\,\mathrm{M_{sol}}}\right]^{\alpha}$$

$$M_{500} = (1-b)M_{true}$$

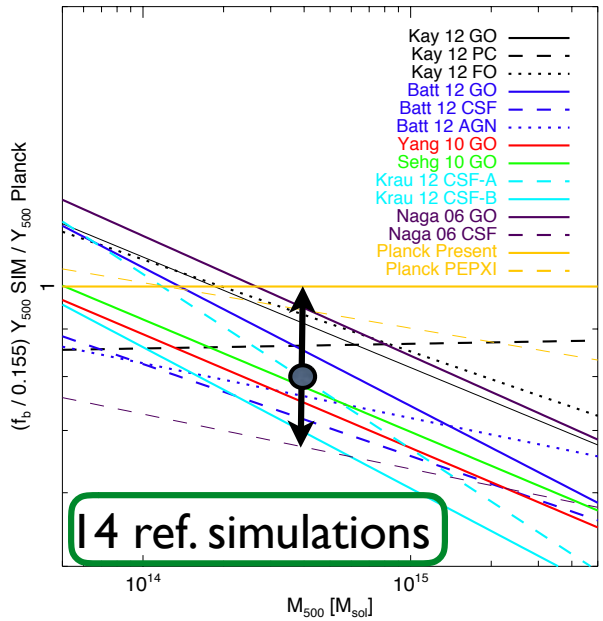
Hydro-Mass-Bias + ignorance



Planck 2014 XX

- Our study converges towards [2013]

$$(1-b) = 0.8\ in\ [0.7-1.0]$$



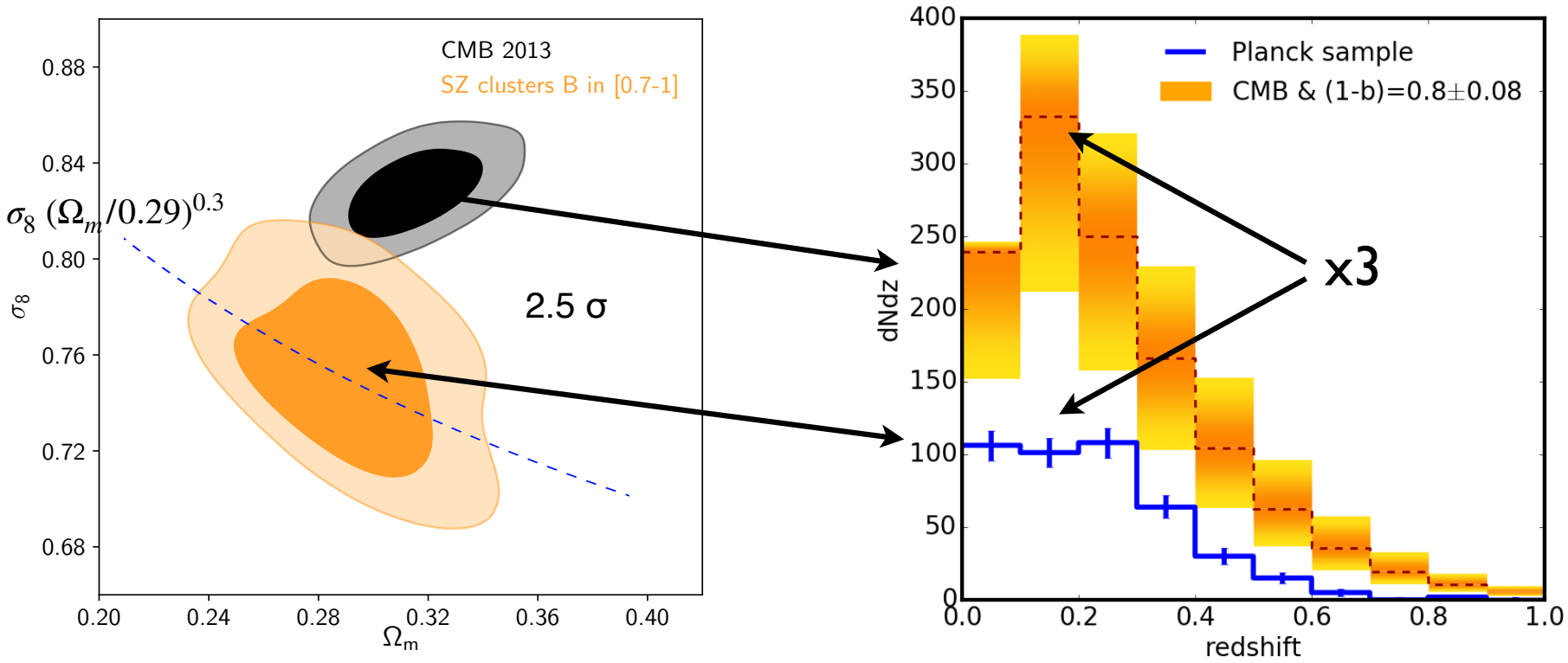
Degeneracy cosmology/bias:

$$dN \propto \sigma_8^9\ \Omega_m^3\ (1-b)^{3.6}$$

PLANCK SZ CLUSTER COSMOLOGY

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

Planck 2013 XX showed:

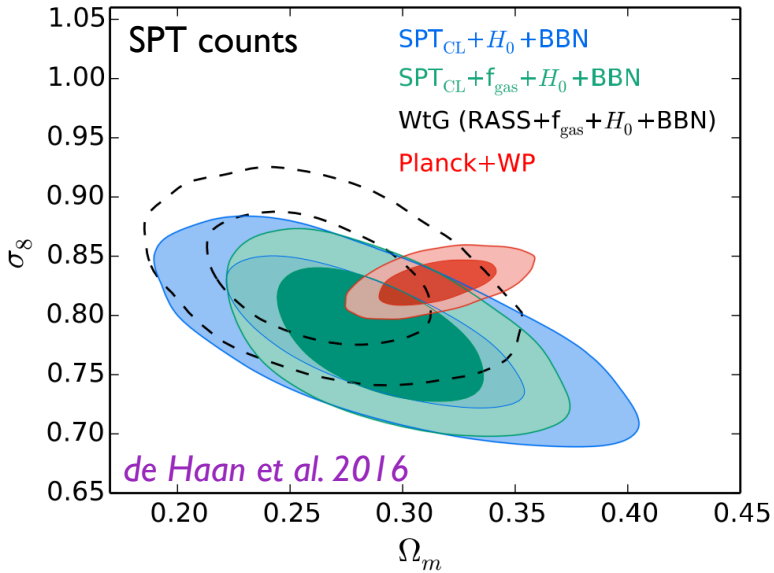


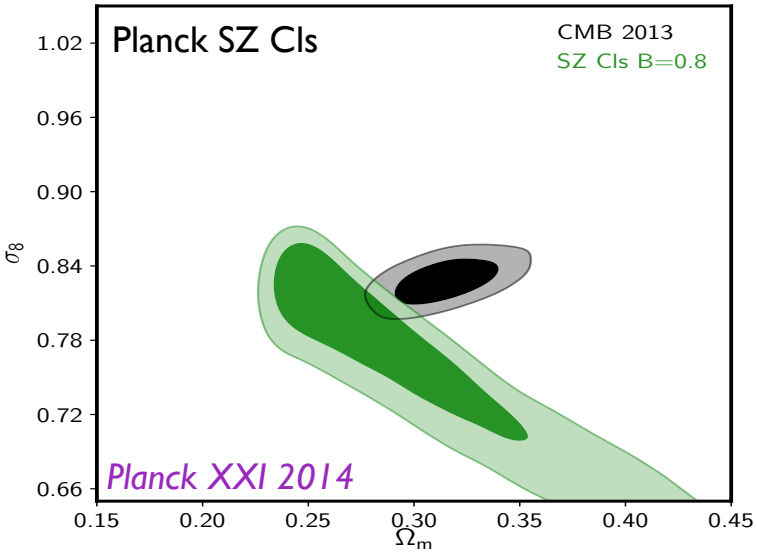
idem : Planck 2015 XXIV

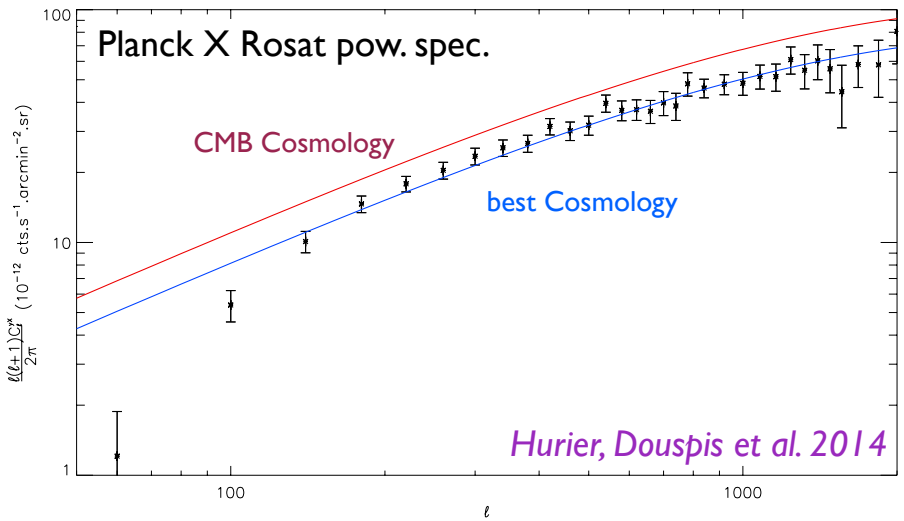
Salvati, Douspis, Aghanim (2017)

Planck CMB-Cluster Tension !

ARE *PLANCK* SZ COUNTS WRONG?







- 1-PDF
  - PLCK: $\sigma_8 = 0.779 \pm 0.02$
  - ACT: $\sigma_8 = 0.793 \pm 0.04$

Planck 2014 XXI

Colin Hill, 2014

- Bispectrum
  - PLCK: $\sigma_8 = 0.74 \pm 0.04$
  - SPT: $\sigma_8 = 0.787 \pm 0.03$

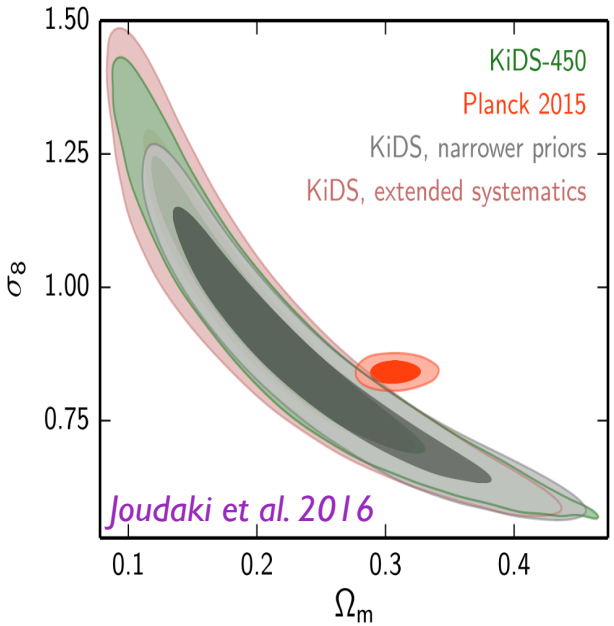
Hurier & Lacasa, 2017

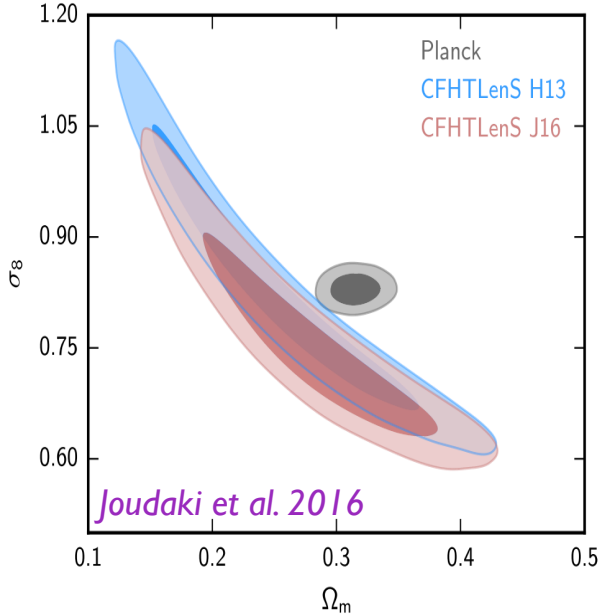
Crawford, 2014

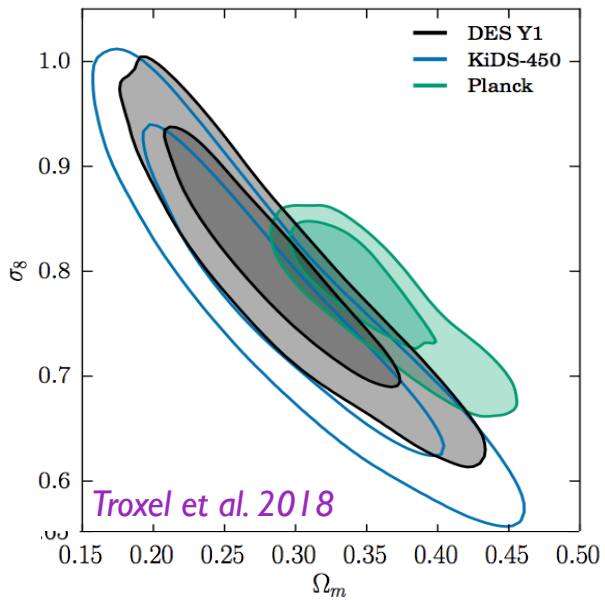
Agreement with other SZ cluster and SZ studies

IS SZ WRONG ?

Cosmic shear tomography measurements

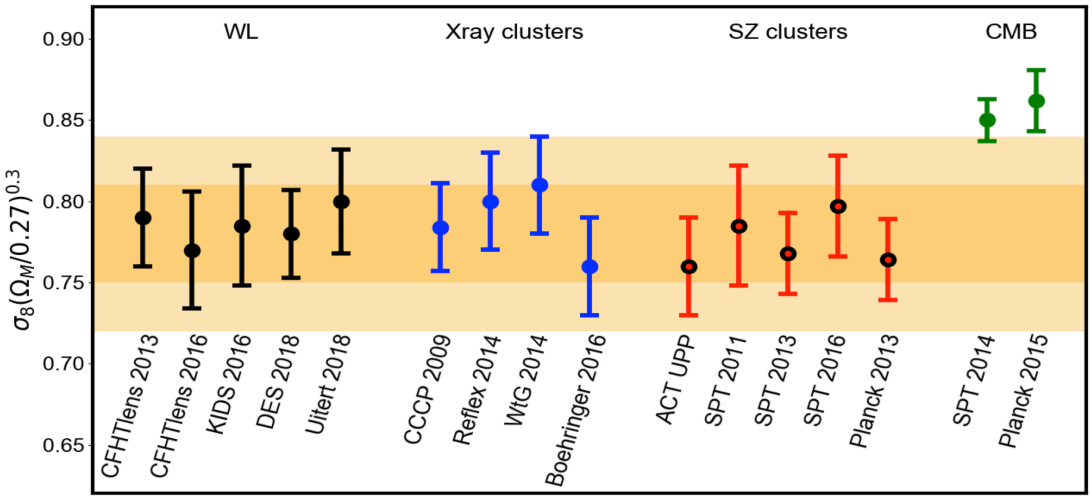






Consistency with Xray clusters

- local sample *Ilic et al. 2015*
- high mass sample *Boehringer et al. 2016*



Douspis et al.

Consistency of SZ with other analyses

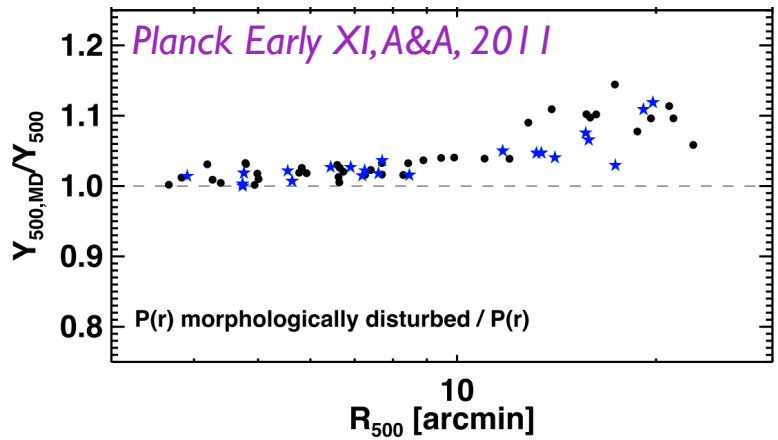
OTHER SYSTEMATICS

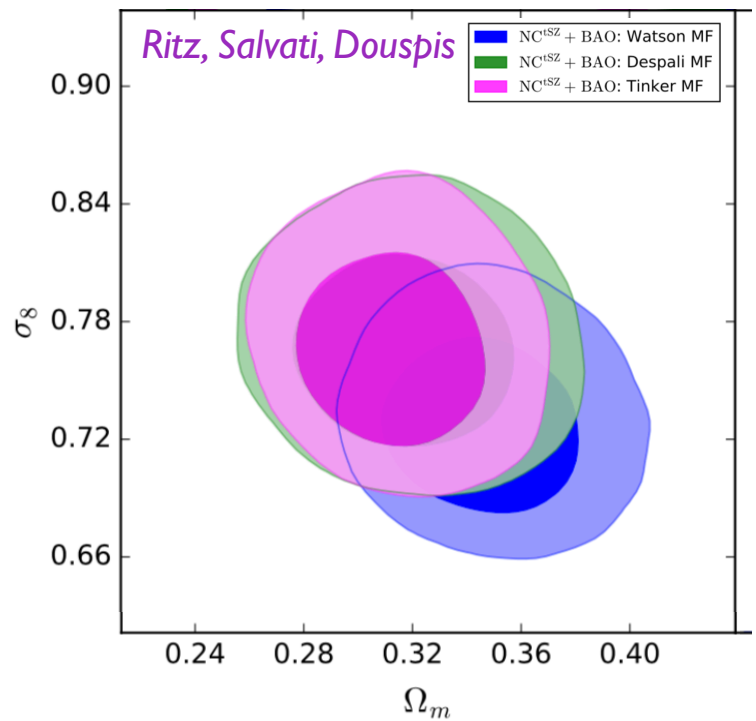
- Less numerous cool core in SZ
  - need different profile <10%
- XMM/Chandra calibration
  - ~10% effect on scalings

    eg. Israel 2015
- Mass function uncertainty
  - ~10% scatter, baryonic effects ?

    eg. Martizzi 2013
- Evolution of scaling/bias
  - with z, with Mass ? [see later]
- Non thermal gaz motion

  eg. Nagai et al. 2016





UPDATES SINCE 2014

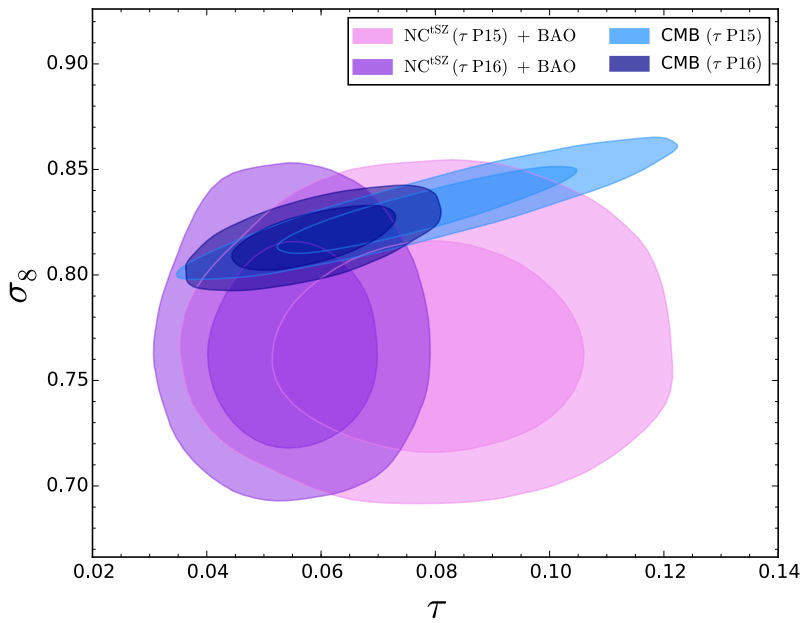
- Clusters
  - PSZ2Lens bias estimation on 29 SZ clusters in CFHT confirms **(1-b)~0.8±0.1**

    Sereno et al. 2017
  - 189 → **400** clusters

    Planck 2016
  - **Combination** SZ Counts + SZ spectrum

    Salvati, Douspis, Aghanim 2018

➡ **Same constraints (Ω_M and σ_8)**



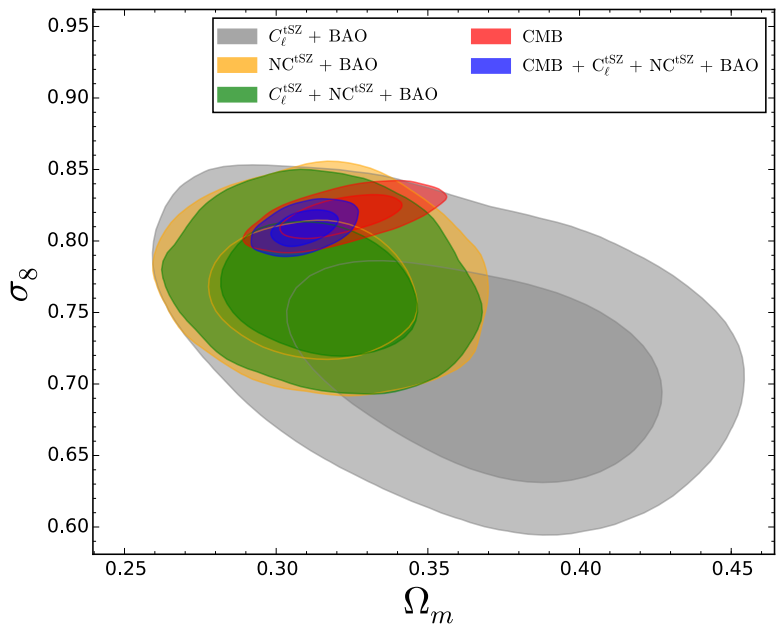
- CMB
  - New estimation of reionisation optical depth (HFI EE): $\tau \sim 0.06$

➡ **Lower σ_8**

Planck XLVII 2016

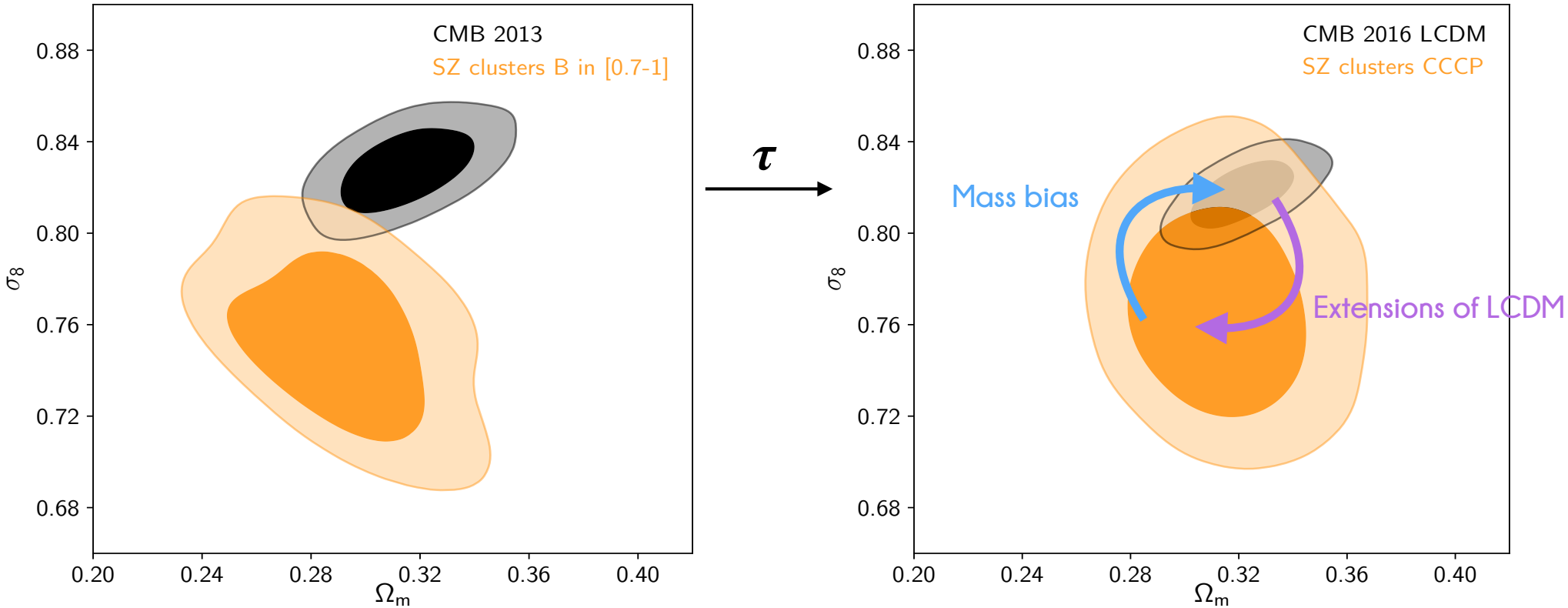
➡ tension in LCDM reduced to 1.5 σ

➡ combination gives (1-b)=0.64



Salvati, Douspis, Aghanim (A&A 2018)

HOW TO RECONCILE SZ & CMB?

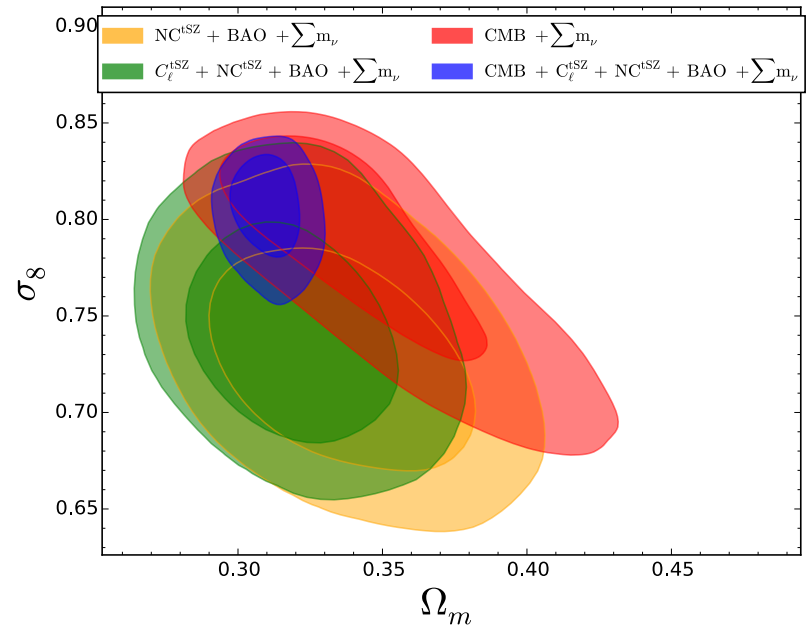


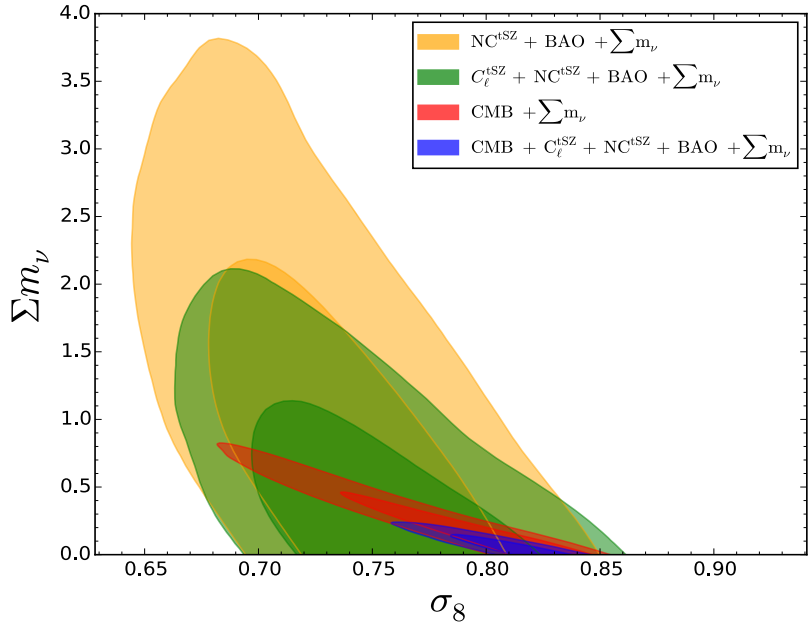
- Investigate extension of LCDM to move CMB down
- Investigate Mass bias to move clusters up

COSMOLOGICAL MODEL EXTENSIONS

- Massive neutrinos
  - Reduces tension 1.3 σ
  - $\sum m_\nu < 0.23$ eV

Salvati, Douspis, Aghanim (2018)

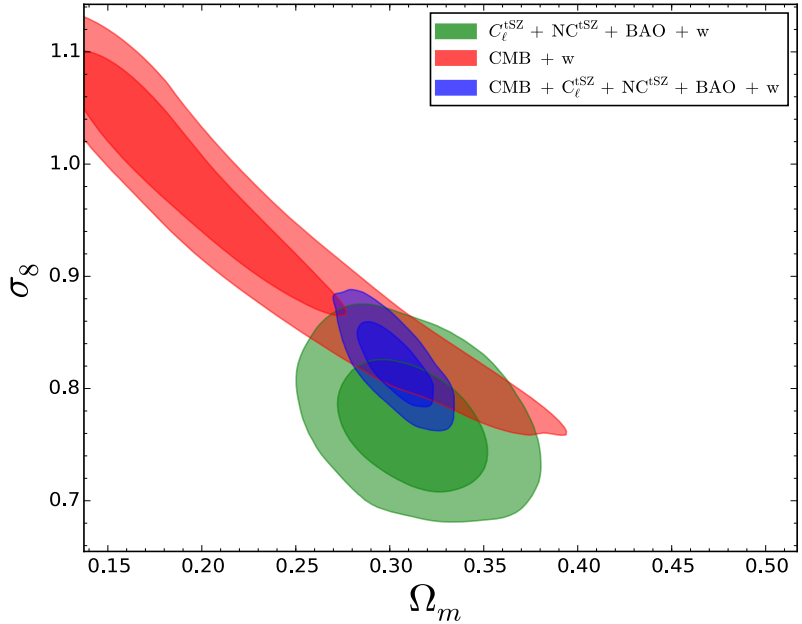


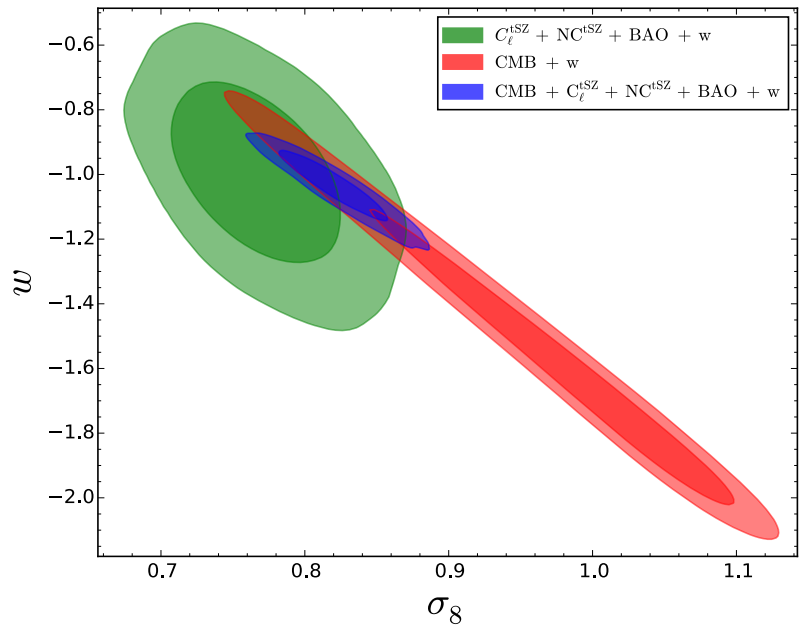


COSMOLOGICAL MODEL EXTENSIONS

- Massive neutrinos
  - Reduces tension 1.2 σ
  - $\sum m_\nu < 0.19$ eV
- Non-lambda Dark energy
  - Clusters break degeneracies but LCDM preferred

Salvati, Douspis, Aghanim (2018)

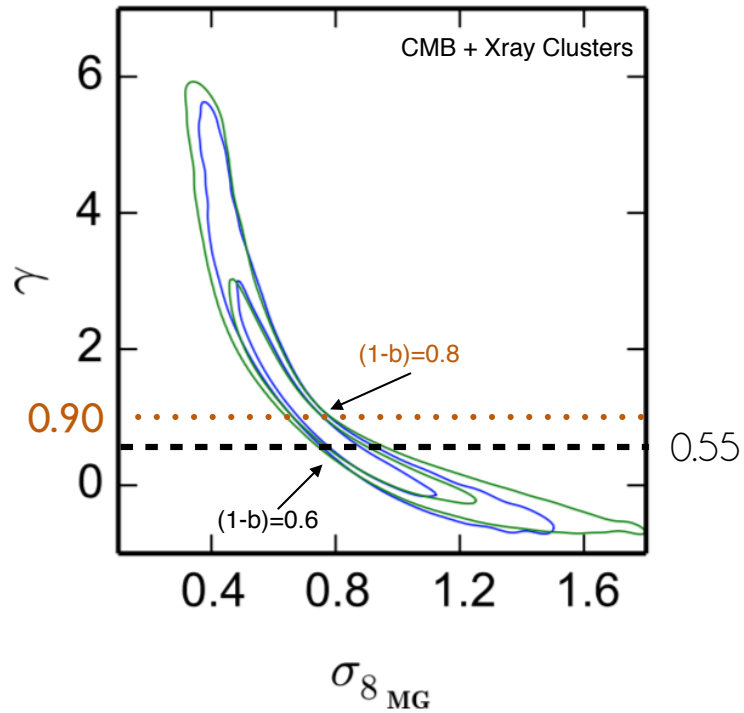




COSMOLOGICAL MODEL EXTENSIONS

- Massive neutrinos
  - Reduces tension 1.2 σ
  - $\sum m_\nu < 0.19$ eV
- Non-lambda Dark energy
  - Clusters break degeneracies but LCDM preferred
- Modified GR
  - needs γ ~0.9 to get CMB with (1-b) ~ 0.8

Sakr et al. 2018

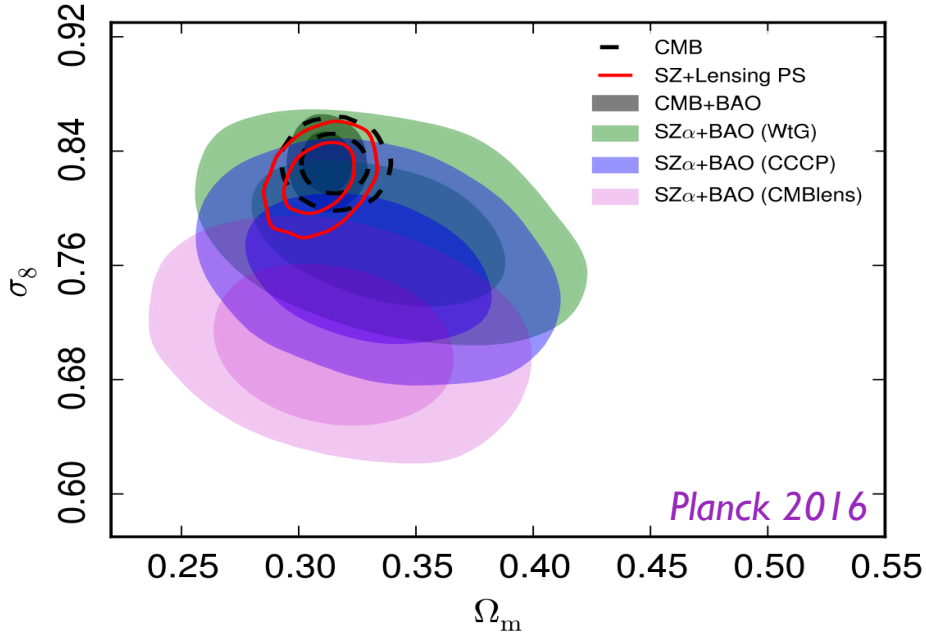


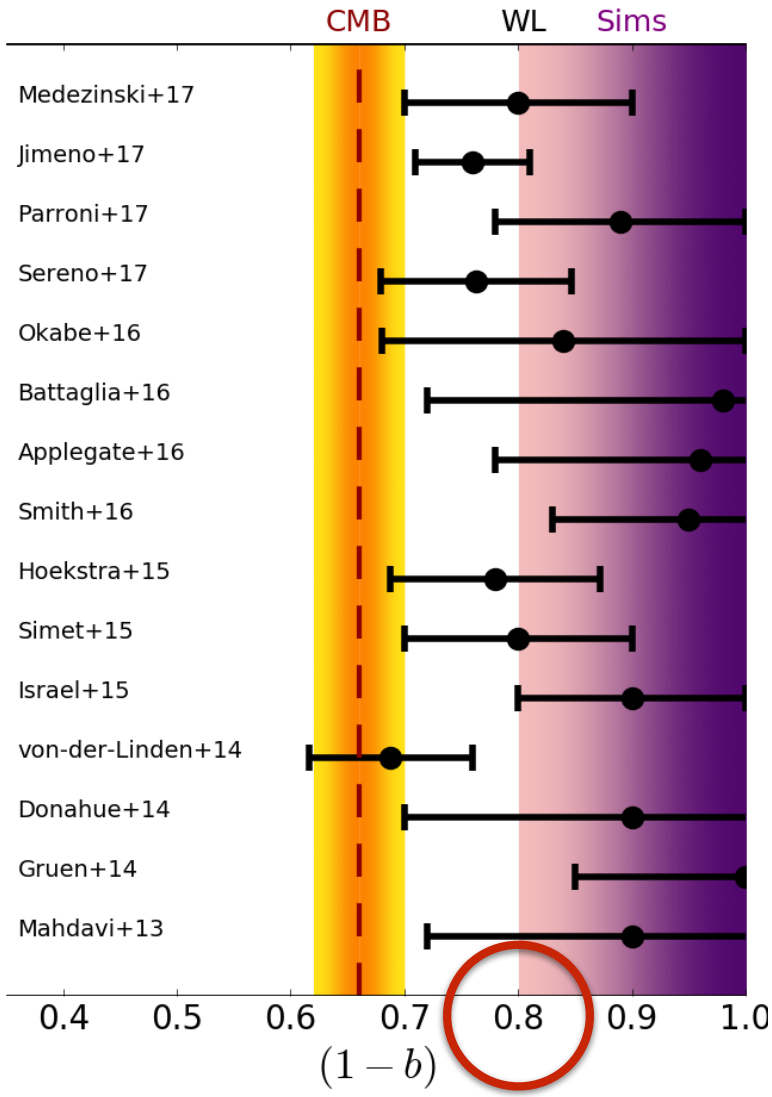
adapted from Sakr et al. 2018

➡ Non trivial extensions

MASS BIAS: SIMS → WL

- **Weak Lensing for the mass estimation:**
  - traces directly the total mass
  - recalibrate your M: $Y_{SZ} \propto M^{YX} = (1-b)M_{WL}$





➡ (1-b)~0.8±0.1

➡ small not necessarily representative samples (high mass, high z), unbiased ?

MASS BIAS EXTENSIONS: B(z,M)

- Bias **measured** at given mass and redshift (WL window)
- but **varies** with z, M (hints)
- 2 studies:

A.

$$(1-b)_{var} = (1-b)_{meas}\left(\frac{M}{M_*}\right)^{\alpha_b}\left[\frac{(1+z)}{(1+z_*)}\right]^{\beta_b}$$

$M_* = 6 \cdot 10^{14} M_\odot$ → consistent with scaling relations

$z_* = 0.22$ → median value of the P15 catalog

B.

Bins in redshift, with different bias values

$z < 0.2$ → $(1-b)_1$

$0.2 \leq z < 0.55$ → $(1-b)_2$ measured

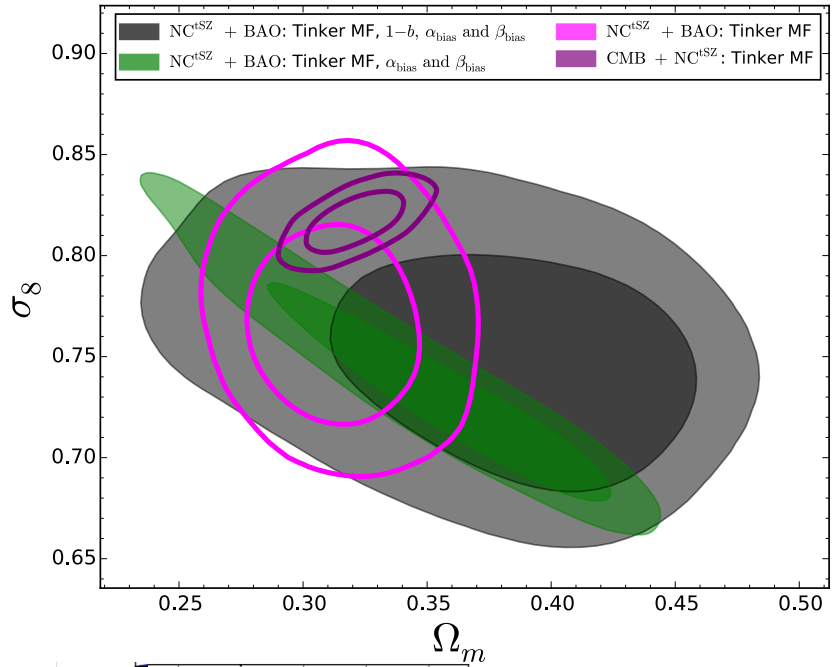
$0.55 < z$ → $(1-b)_3$

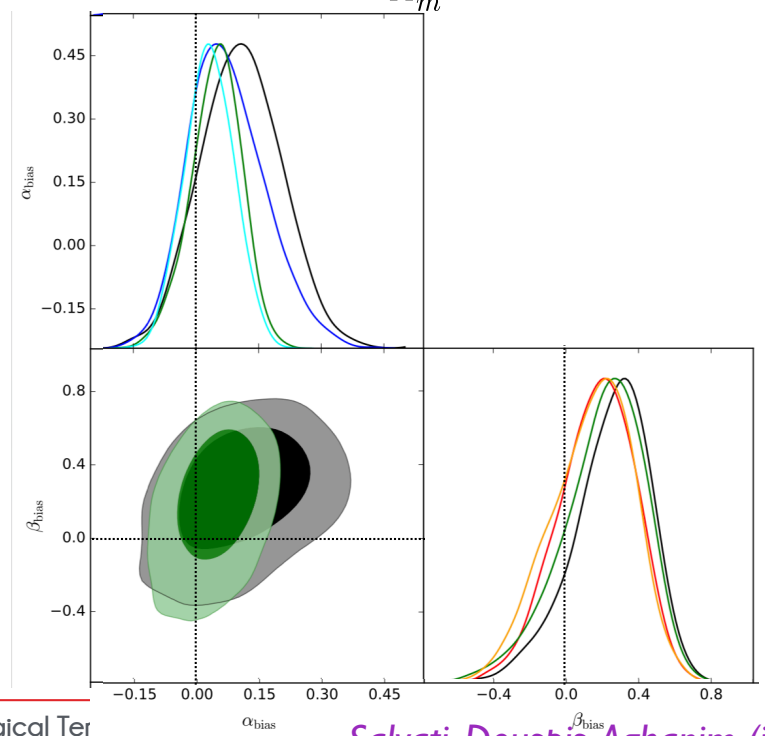
MASS BIAS EXTENSIONS: B(z,M)

- [A]
- clusters only
- in black with **(1-b), α, β free**
- In green with **(1-b)=0.8, and α, β free**

➡ Adopting a bias with free evolution does not help in lowering the tension

➡ no clear evolution found





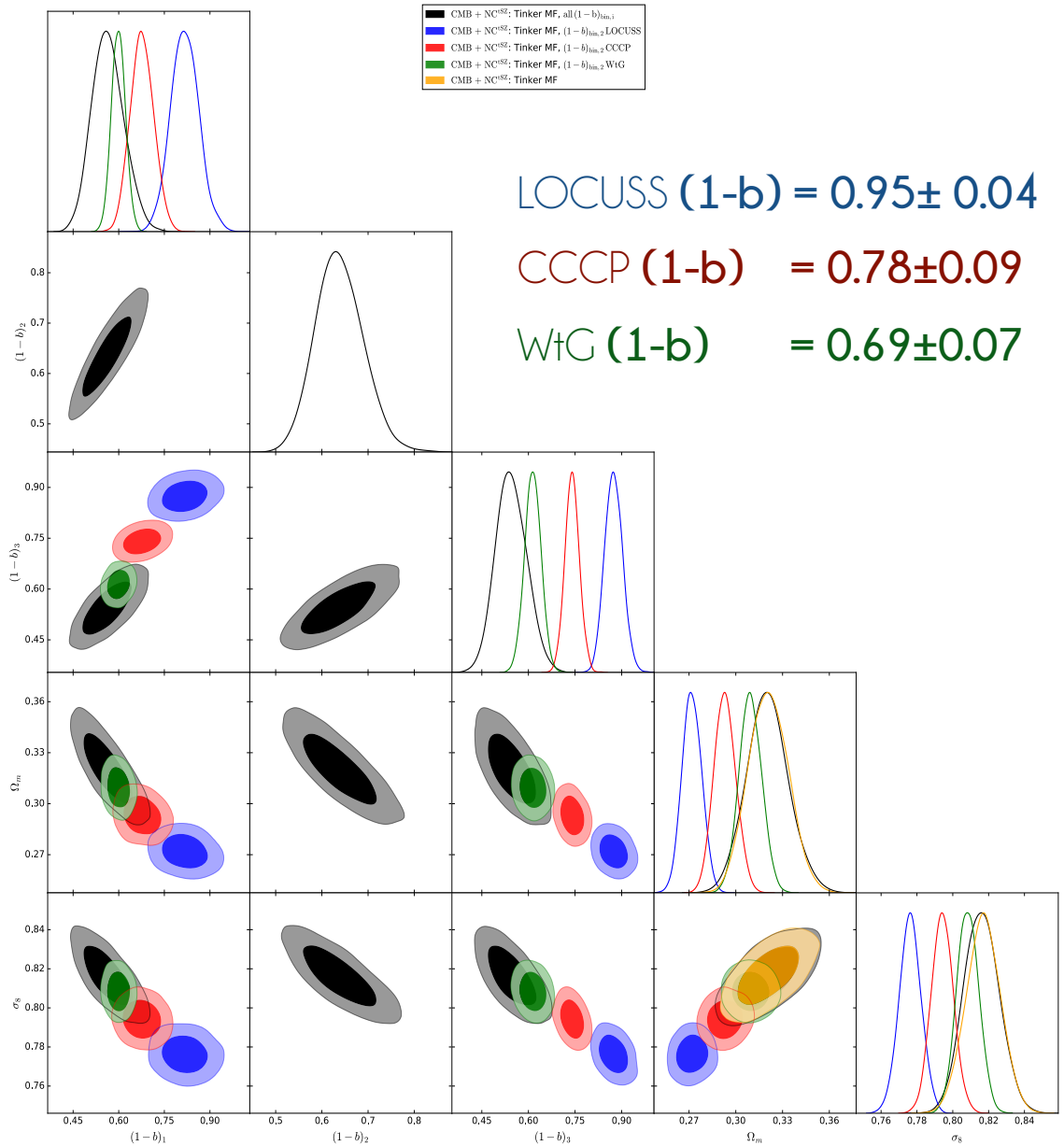
Salvati, Douspis, Aghanim (in prep)

MASS BIAS EXTENSIONS: B(z,M)

- [B]
- CMB+clusters
- in **black** all $(1\text{-}b)_i$ free
- in **color**, for each measured bias we assume **(1-b)± σ** in the bin of z of the measure

➡ **no possibility to counter balance measured bias by z-evolution**

➡ **no clear evolution found**



LOCUSS **(1-b)** = 0.95± 0.04

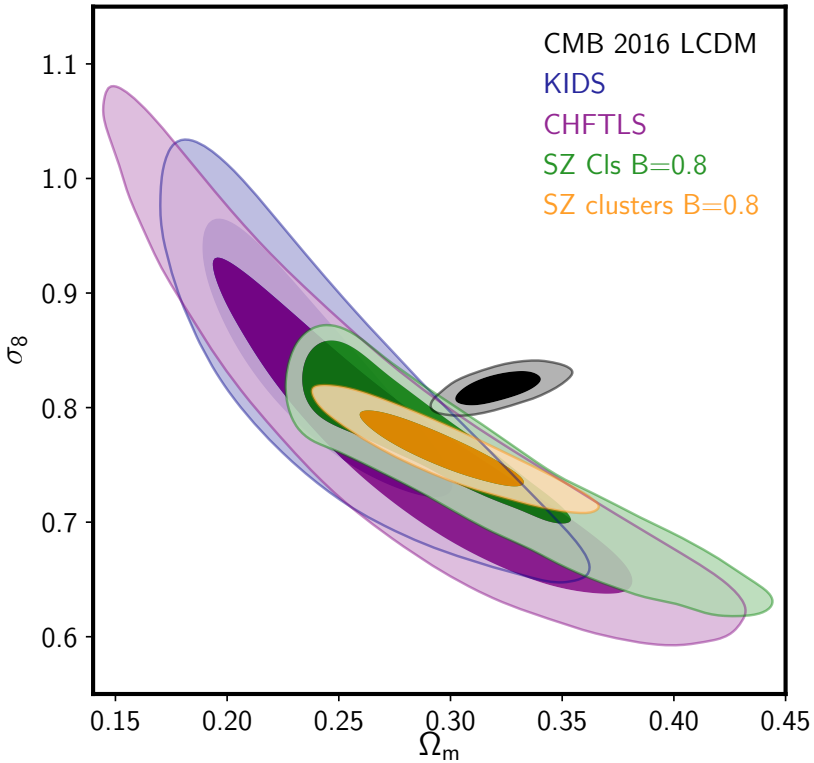
CCCP **(1-b)** = 0.78±0.09

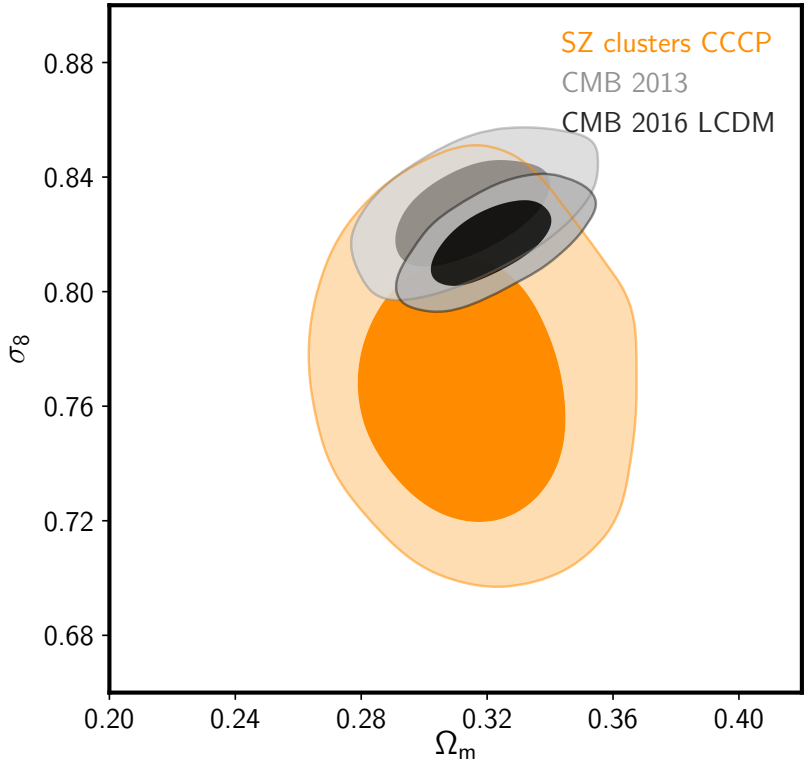
WtG **(1-b)** = 0.69±0.07

Salvati, Douspis, Aghanim (in prep)

CONCLUSIONS

- Tension between SZ Clusters and CMB is reduced by the new value of reionisation optical depth



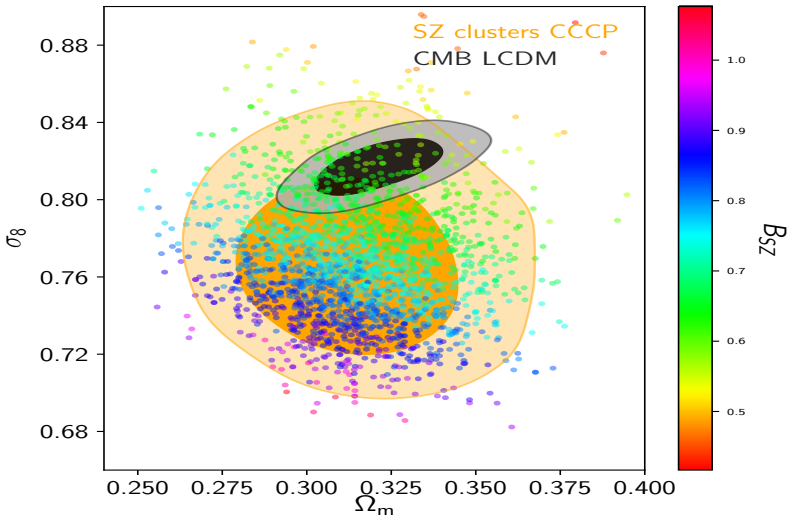


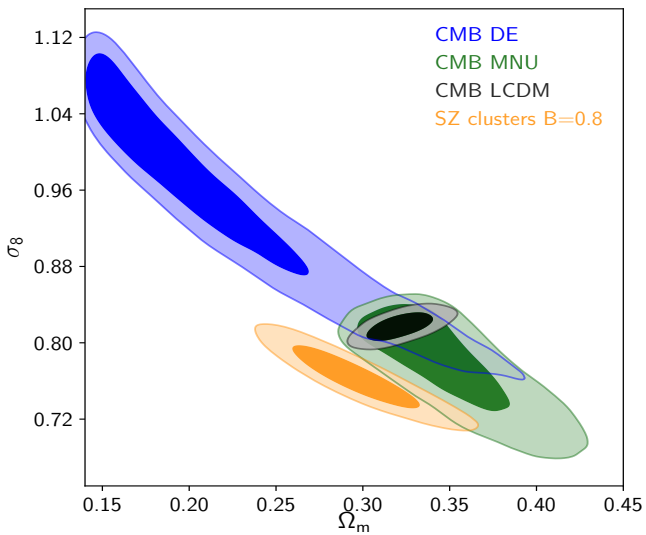
- Tension exists with other LSS probes at the same level (lowering with time)

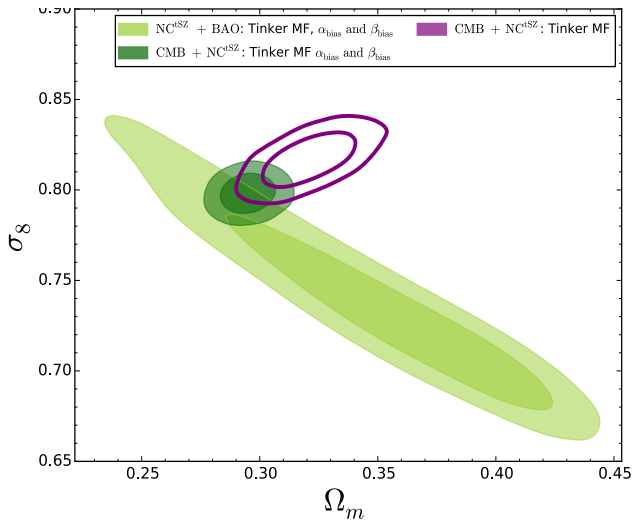
- obvious systematics are discarded (eg. MF)

CONCLUSIONS

- Extensions of LCDM need to be extreme (or not yet tried)





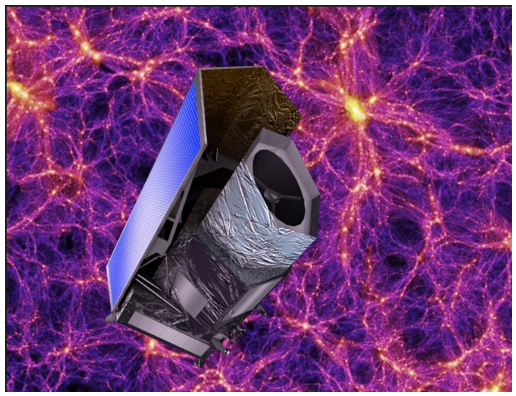


- bias has to be big ~ 0.6 (not in agreement with sims and most of WL mass estimates)

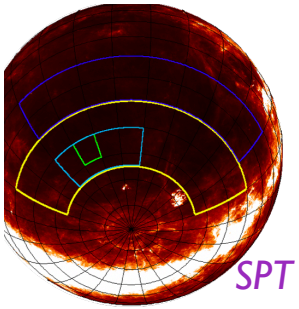
- and some evolution of the bias with M or z does not help

PERSPECTIVES

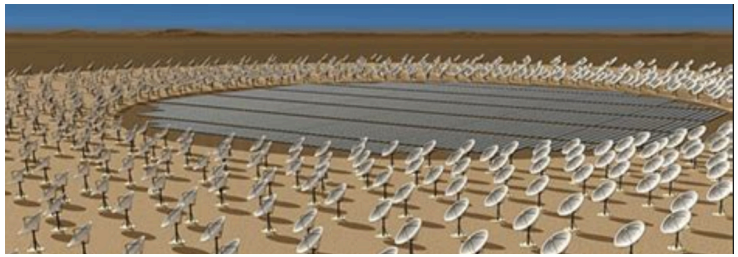
- Upcoming observations and surveys will provide better and more numerous cluster mass estimates from strong and weak lensing → coordination to probe the same clusters in different wavelenghts
- large surveys (SZ, Radio, X, Opt) will also provide new catalogs potentialy at higher redshift useful to probe evolutions
- Theoretical aspects are still to be tested
  - baryonic effect on mass function
  - local inhomogeneity
  - baryonic and non thermal effects in Clusters (outflow of baryons, B field, AGN, shocks, mergers)



Euclid



SPT 3G, +



SKA

eRosita

Dark Side of the Universe

BACKUP

MODEL

slide from Laura Salvati

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

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

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

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

$$T_{\ell\ell'} \simeq \int_0^{z_{\rm max}} dz \frac{dV_c}{dz d\Omega} \int_{M_{\rm min}}^{M_{\rm max}} dM \left[\frac{dN(M_{500}, z)}{dM_{500}} |\tilde{y}_\ell(M_{500}, z)|^2 |\tilde{y}_{\ell'}(M_{500}, z)|^2\right]$$

Selection function

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

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) 70

Scaling Relations

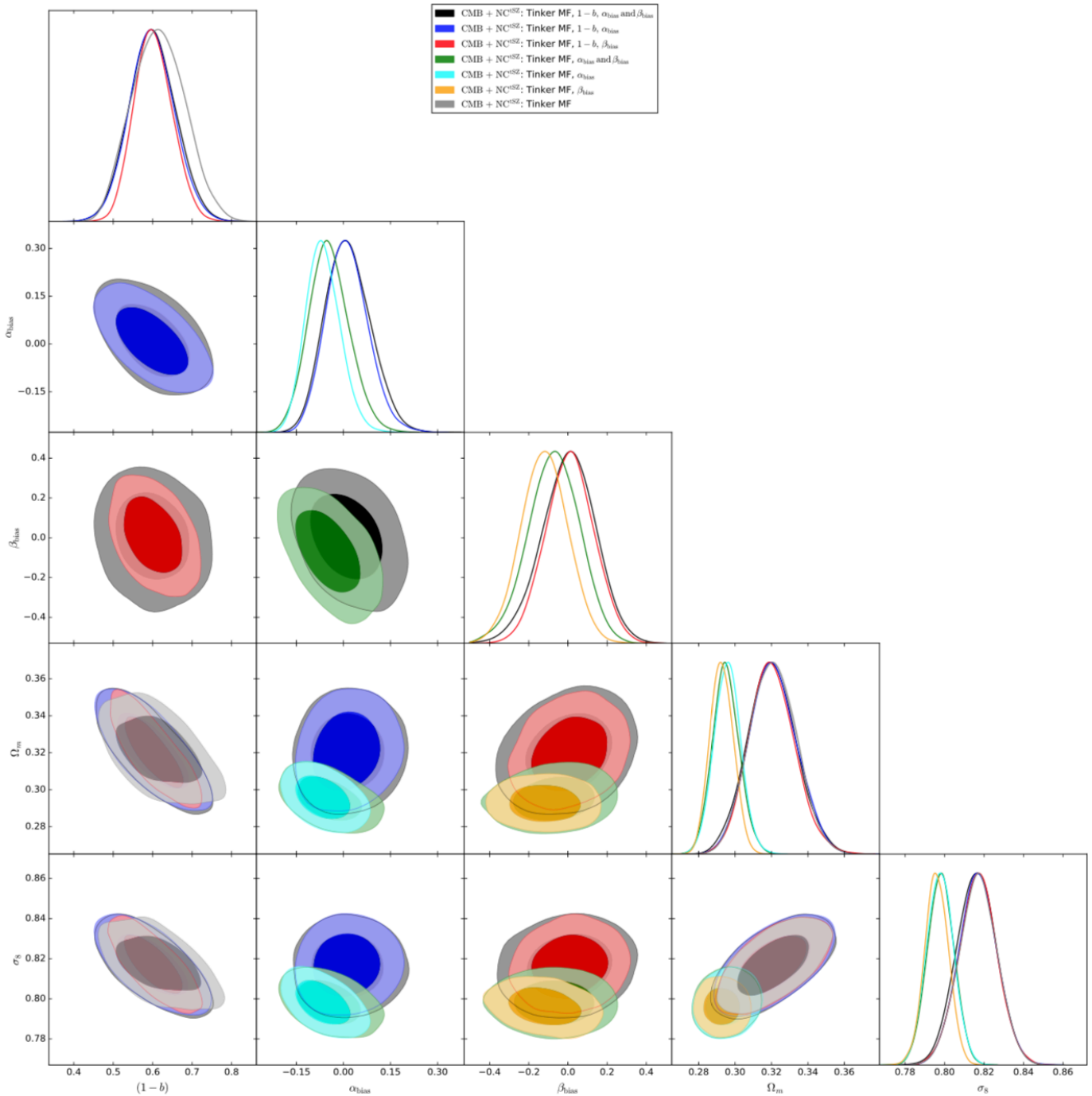
$$E^{-\beta}(z) \left[\frac{D_A^2(z) \, Y_{500}}{10^{-4}\,{\rm Mpc}^2}\right] = Y_* \left[\frac{h}{0.7}\right]^{-2+\alpha} \left[\frac{(1-b) \, M_{500}}{6 \cdot 10^{14} M_\odot}\right]^{\alpha}$$

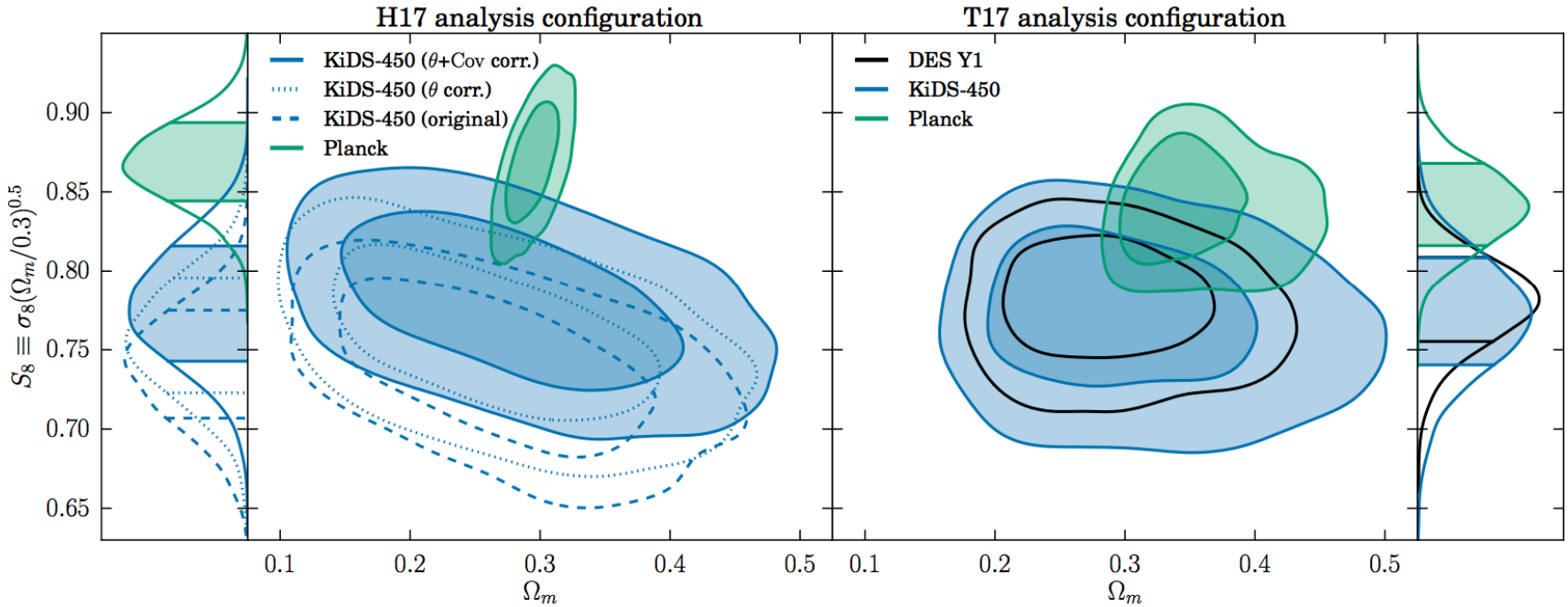
$$\theta_{500} = \theta_* \left[\frac{h}{0.7}\right]^{-2/3} \left[\frac{(1-b) \, M_{500}}{3 \cdot 10^{14} \, M_\odot}\right]^{1/3} E^{-2/3}(z) \left[\frac{D_A(z)}{500\,{\rm Mpc}}\right]^{-1}$$

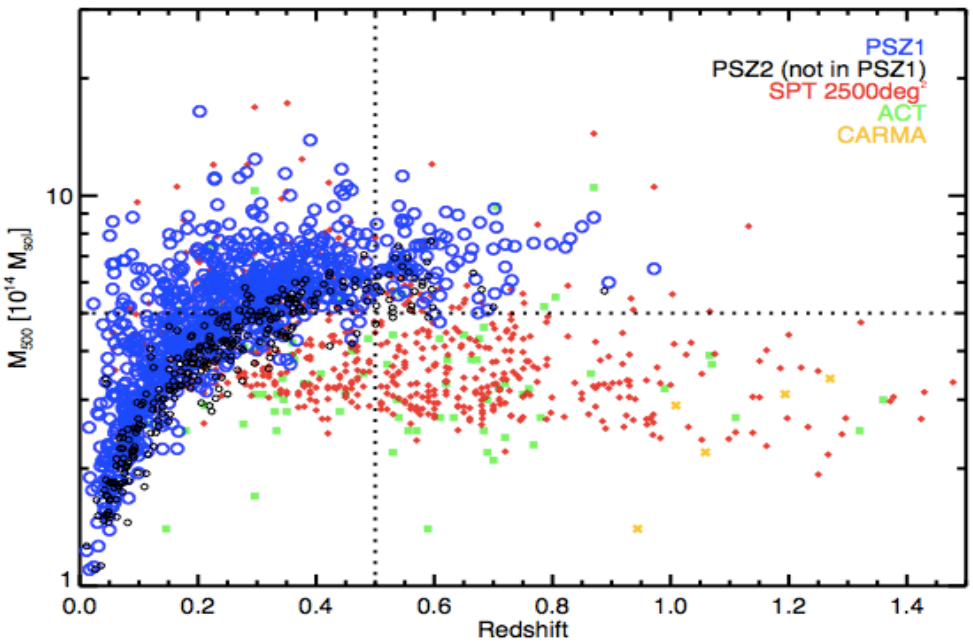
Planck 2015 results. XXIV. A&A 594 (2016) A24

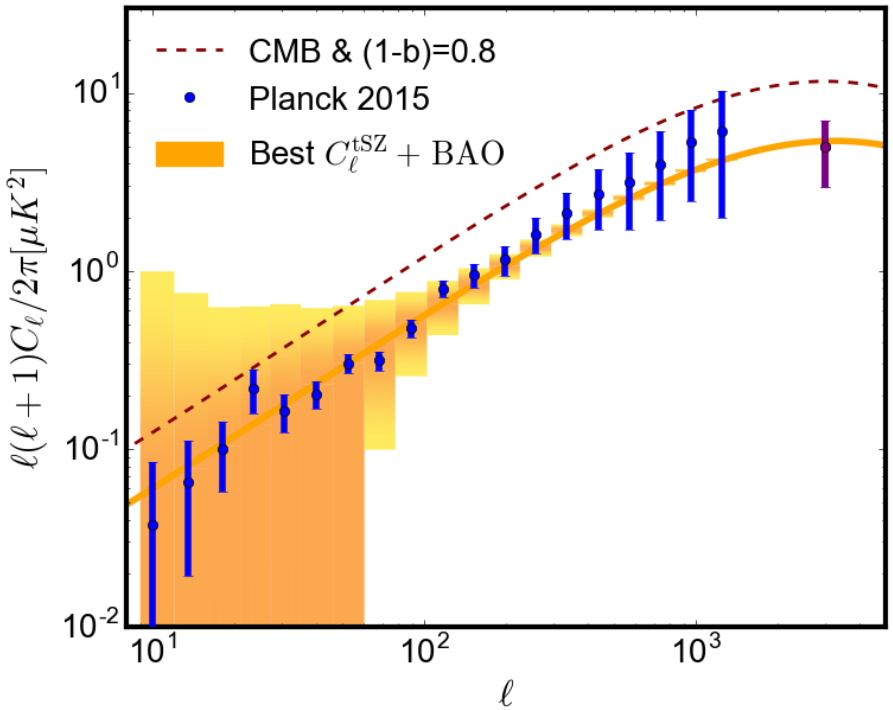
$$(1-b) = \frac{M_{\rm est}}{M_{\rm true}}$$

MASS BIAS ?


CMB + NC$^{\rm tSZ}$: Tinker MF, $1-b$, $\alpha_{\rm bias}$ and $\beta_{\rm bias}$
CMB + NC$^{\rm tSZ}$: Tinker MF, $1-b$, $\alpha_{\rm bias}$
CMB + NC$^{\rm tSZ}$: Tinker MF, $1-b$, $\beta_{\rm bias}$
CMB + NC$^{\rm tSZ}$: Tinker MF, $\alpha_{\rm bias}$ and $\beta_{\rm bias}$
CMB + NC$^{\rm tSZ}$: Tinker MF, $\alpha_{\rm bias}$
CMB + NC$^{\rm tSZ}$: Tinker MF, $\beta_{\rm bias}$
CMB + NC$^{\rm tSZ}$: Tinker MF
$(1-b)$
$\alpha_{\rm bias}$
$\beta_{\rm bias}$
Ω_m
σ_8


H17 analysis configuration
T17 analysis configuration
KiDS-450 (θ+Cov corr.)
KiDS-450 (θ corr.)
KiDS-450 (original)
Planck
DES Y1
KiDS-450
Planck
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$
Ω_m

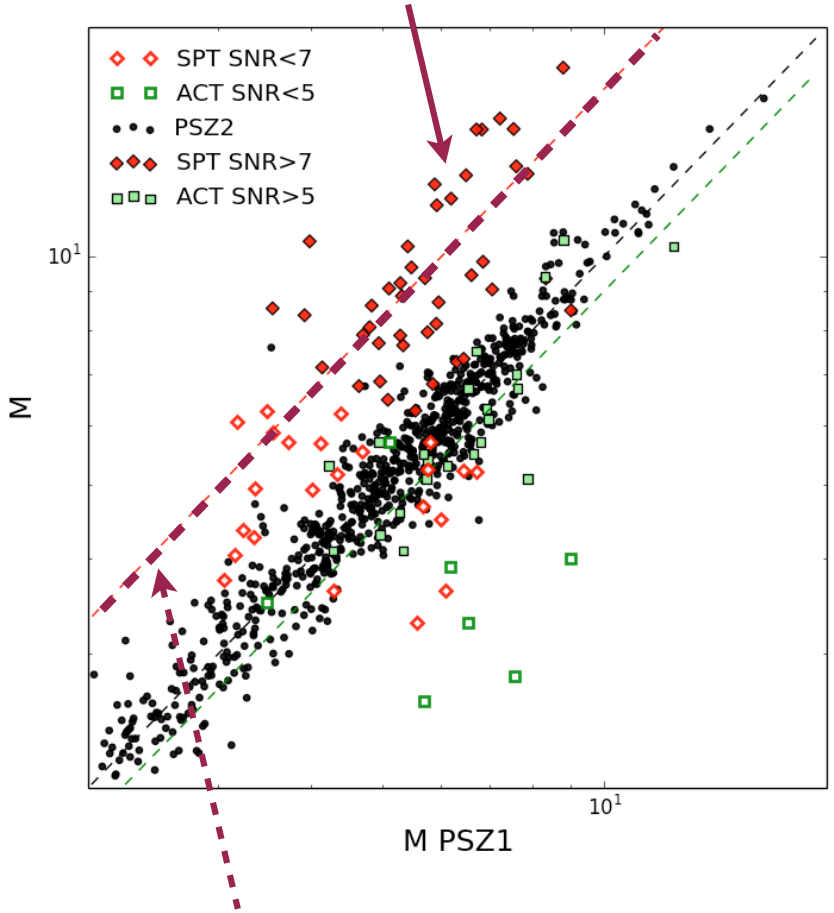

PSZ1
PSZ2 (not in PSZ1)
SPT 2500deg²
ACT
CARMA
M_{500} [10^{14} $M_{\odot}$]
Redshift

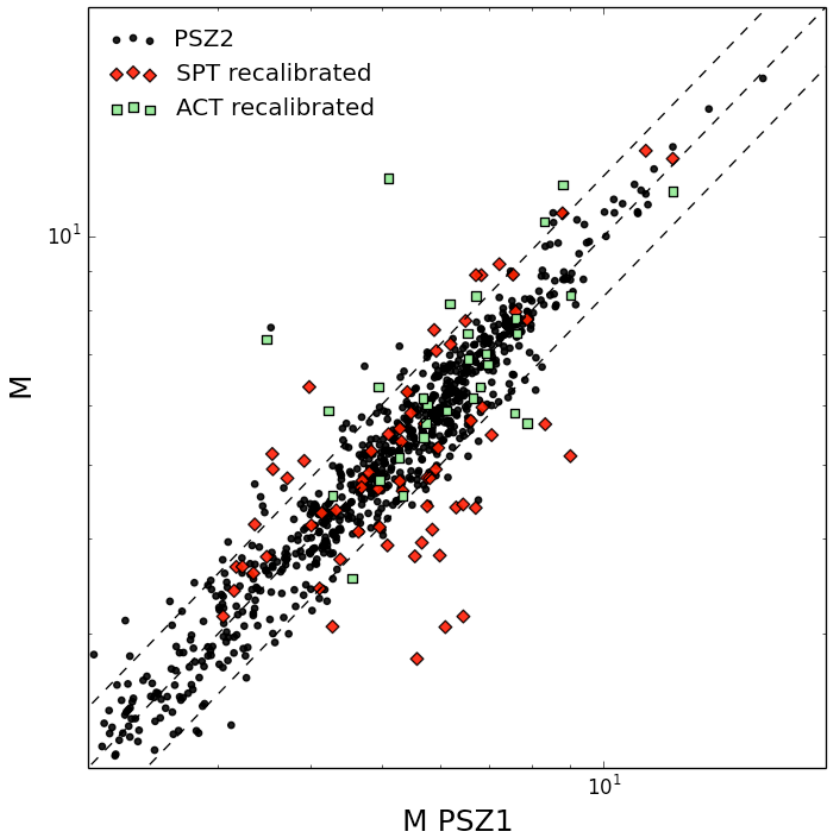

CMB & (1-b)=0.8
Planck 2015
Best C_ℓ^{tSZ} + BAO
$\ell(\ell+1)C_\ell/2\pi[\mu K^2]$
ℓ

INDIRECT COMPARISON

Comparison of masses from SPT (abundance) and Planck (HydM)

SPT masses assume CMB cosmology



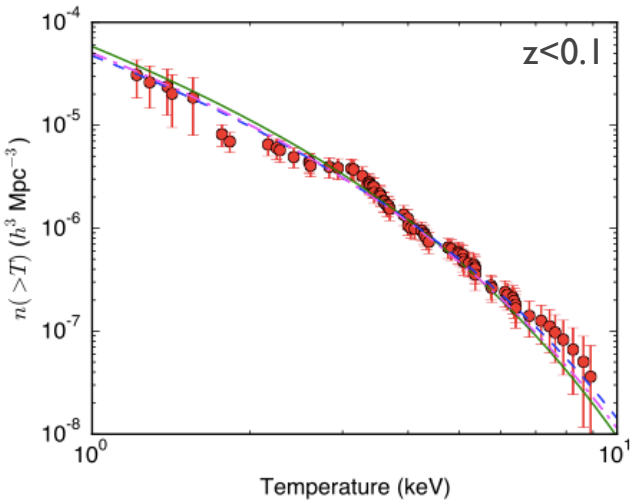


$M_{PSZ} = 0.6\ M_{SPT}$ → consistency SPT-Planck (at least for high SNR/masses)

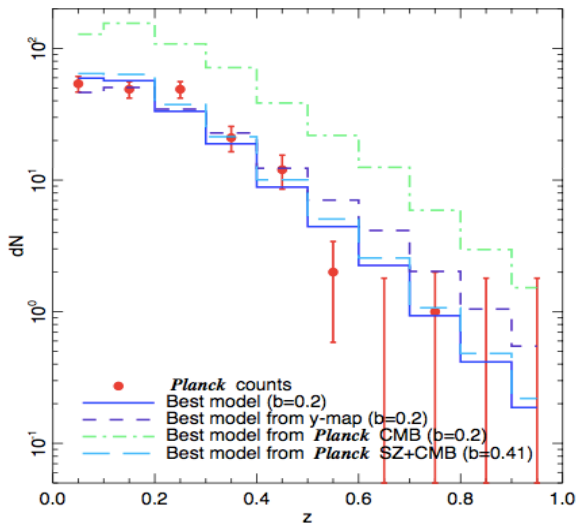
Douspis, sub.A&A, 2015

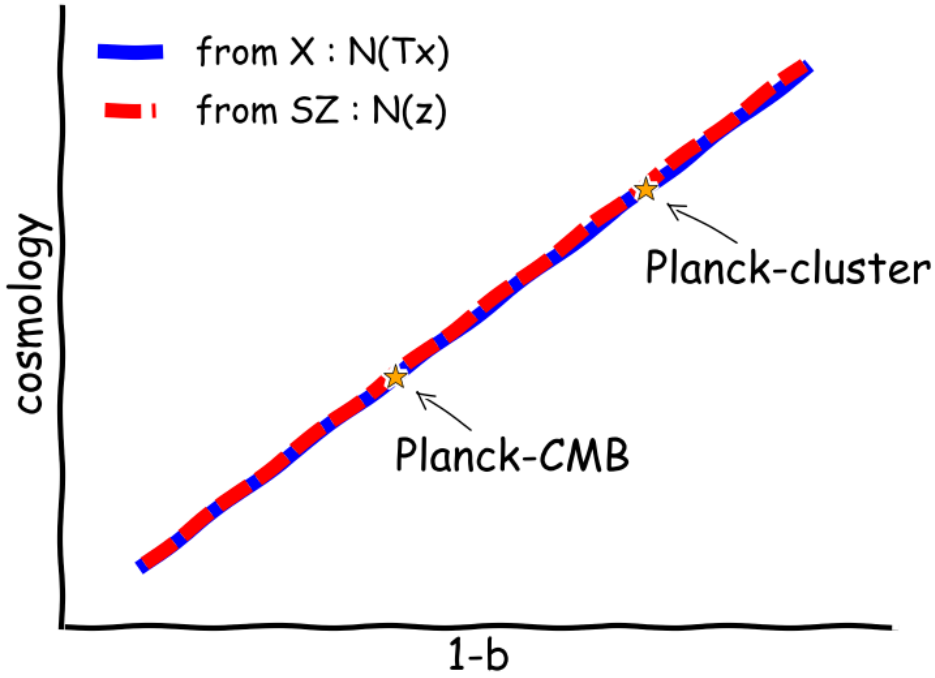
INDIRECT COMPARISON

Comparison of abundances of Xray local clusters (Tx) with SZ clusters (z=[0-1])



Masses for a cosmo

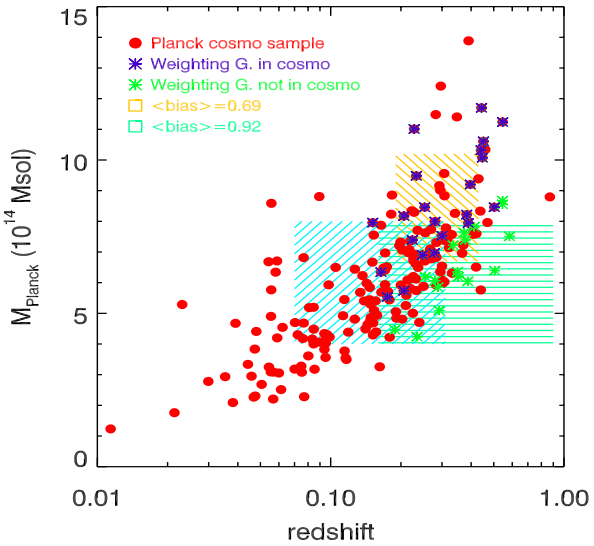




Ilic, Blanchard, Douspis, A&A, 2015

WEAK LENSING

- Several studies on small (not necessarily representative) samples

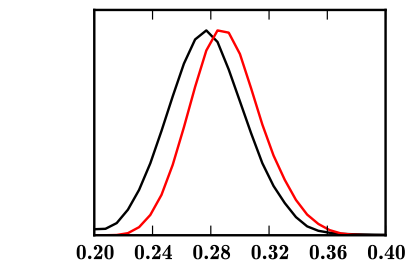


Zhang+10	X/WL	**~0.9**
Mahdavi+13	X/WL	**~0.9**
Israel+14,15	X/WL	**~1 Chandra ~0.8 XMM**
Donahue+14	X/WL	**~0.7-1.1**
Gruen+14	X/WL	**~1**
Smith+15	X/WL	**~0.95**
Okabe+15	X/WL	**~0.8**
Applegate+15	X/WL	**~1**
Simet+15	X/WL	**~0.8**
von der linden+14	SZ/WL	**~0.7**
Hoekstra+15	SZ/WL	**~0.8**
Battaglia+15	SZ/WL	**~1**
Maughan+15	X/caustic	~1
Smith+15	SZ/X	~0.95
Douspis+15	SZ/SZ	~1
Ilic+15	X/SZ	~1
Battaglia+15	SZ/SZ	~1
Sayers+16	SZ/SZ	~0.93
Sereno+17	SZ/WL	**~0.76**

1-b ~ 0.80

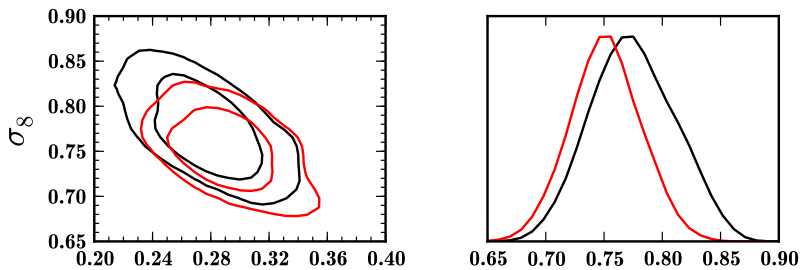
Weak Lensing is a good way to go but needs better/larger samples and lower systematics

e.g. New technics for SZ-WL correl. Shirasaki 2016



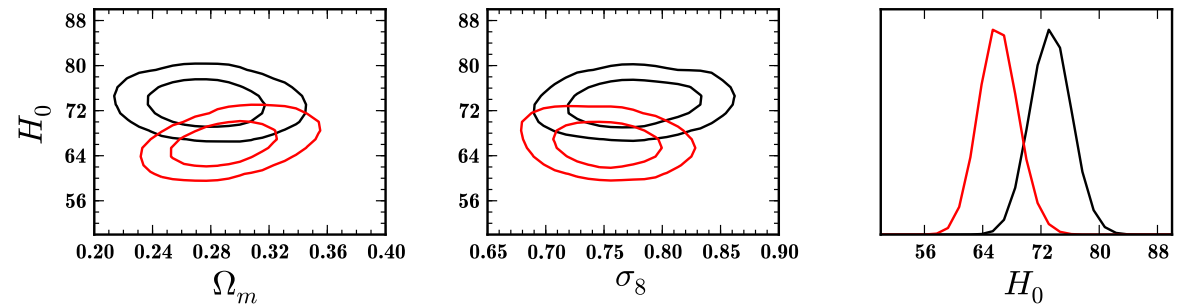
SZ+HST

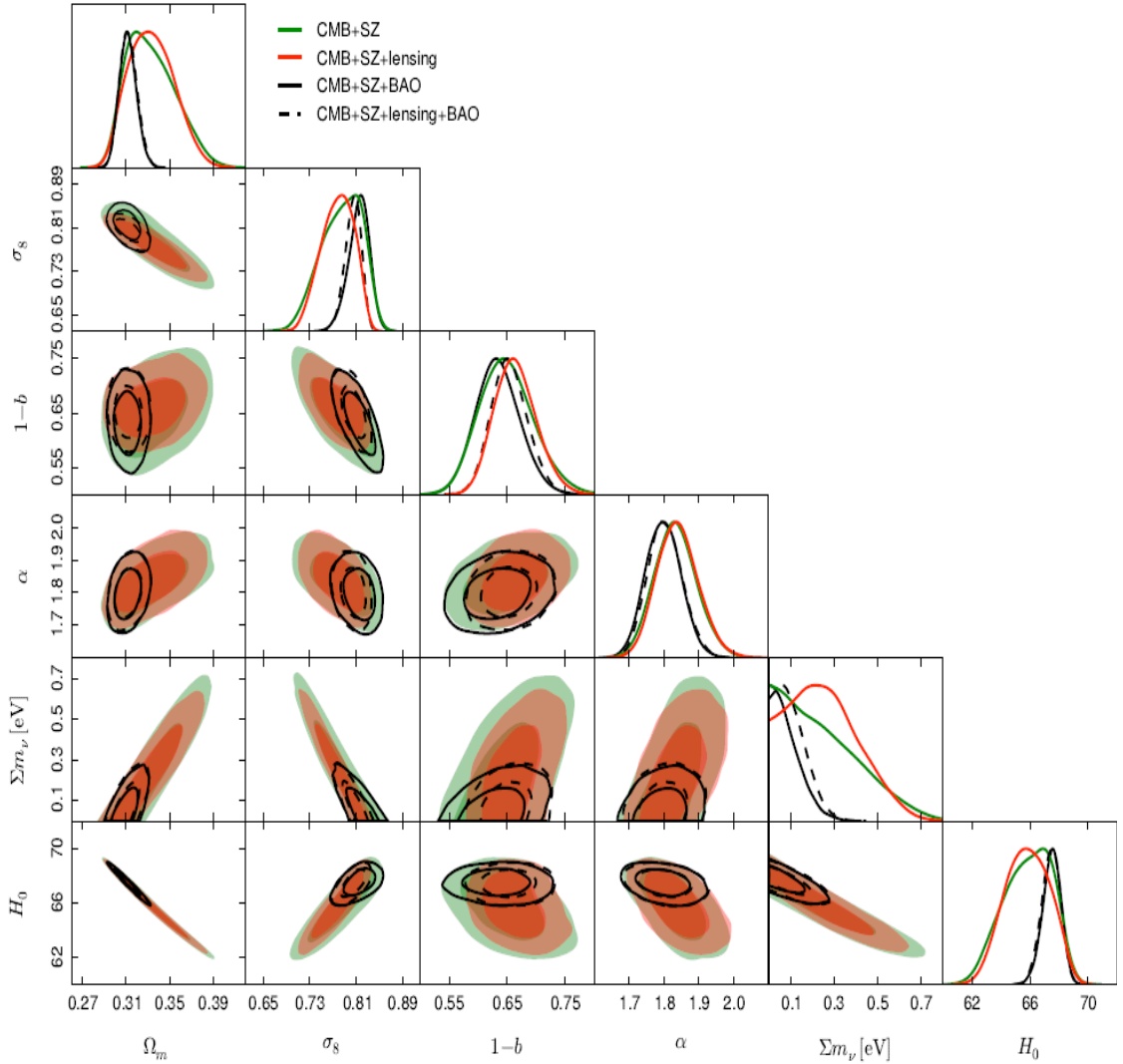
SZ+BAO



degeneracy

$$\sigma_8(\Omega_m/0.29)^{0.32}$$





NOTE

Tension

- on amount and fluctuation amplitude of matter: **Ω_M and σ_8**

Large Scale Structures

- Mostly **clusters of galaxy**
- Biased towards SZ clusters with *Planck*