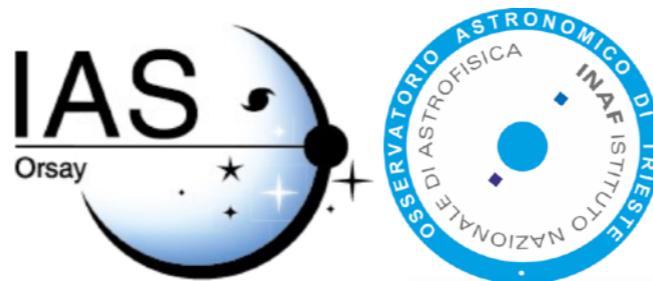




Cosmology with Galaxy Clusters

Laura Salvati



Outline

- Galaxy clusters as a cosmological probe
- Current cluster surveys in mm-wavelengths
 - Planck
 - Impact of the mass calibration
- Future cluster surveys
 - Impact of the mass function modelling

In collaboration with
M. Douspis and
N. Aghanim

Galaxy clusters

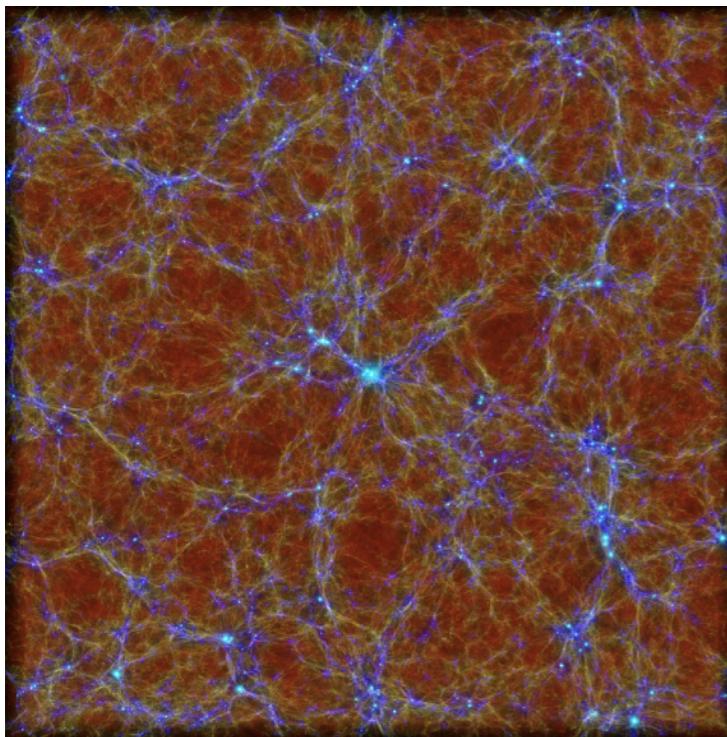
Galaxy clusters as cosmological probe

- Largest gravitationally bound structures in the Universe
- Describe matter distribution in recent Universe
- Strong dependence on cosmological parameters

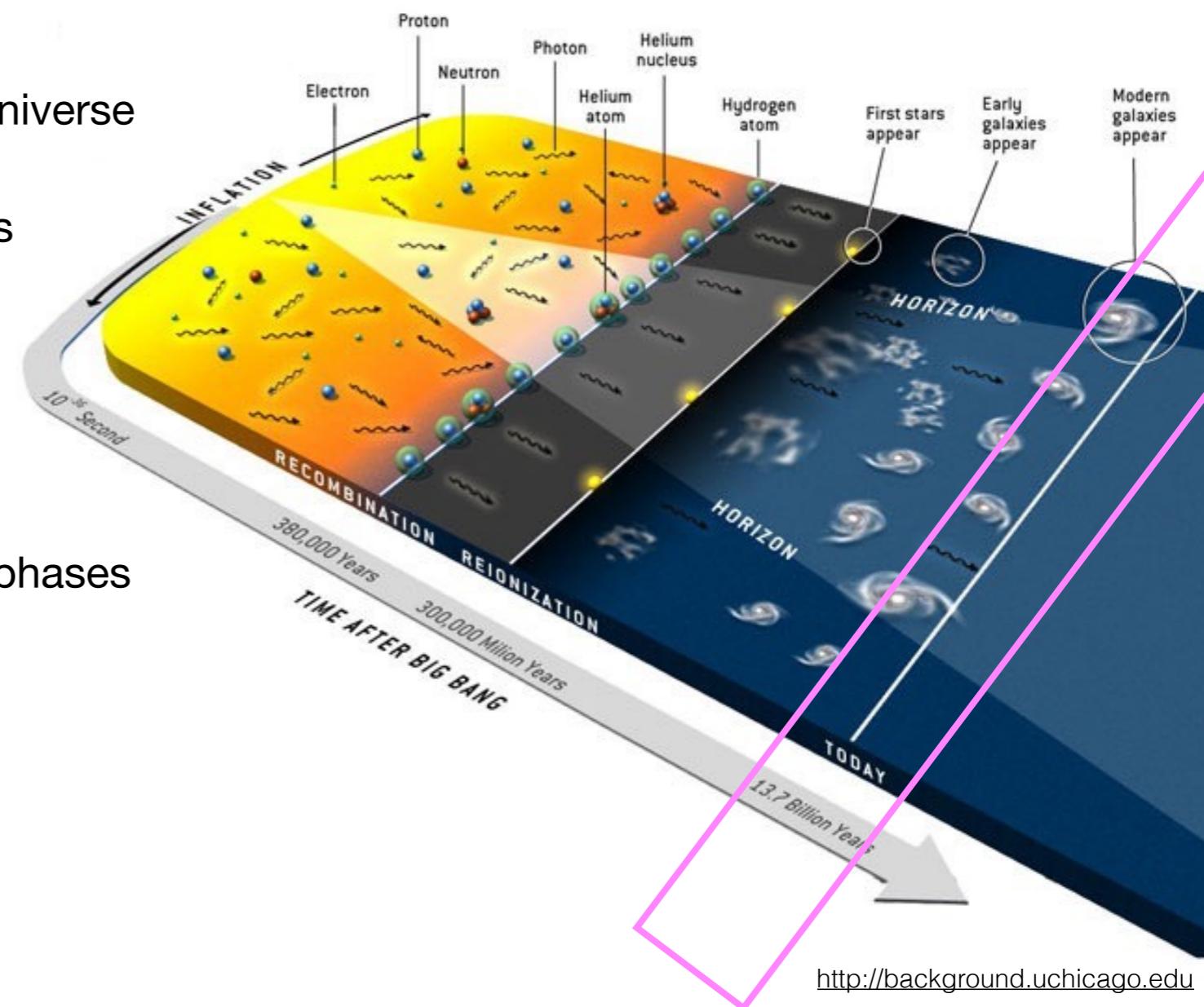
$$\Omega_m, \sigma_8$$

Observations

- Multi-component systems
 - Dark matter and baryons matter in different phases
- Observables at multiple wavelengths



Credit: Hirschmann et al. 2014



<http://background.uchicago.edu>

Cosmology with Galaxy Clusters

Cluster cosmology: mass and *redshift* of clusters

Cluster number counts:

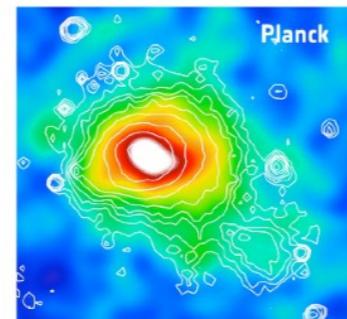
$$NC(z,obs) = \text{Mass Function} \times \text{Scaling Relations} \times \text{Selection Function}$$

Cosmology/theory

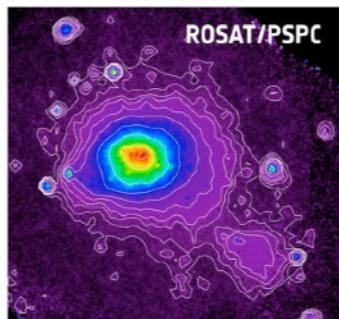
Theoretical $NC(z,M)$

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

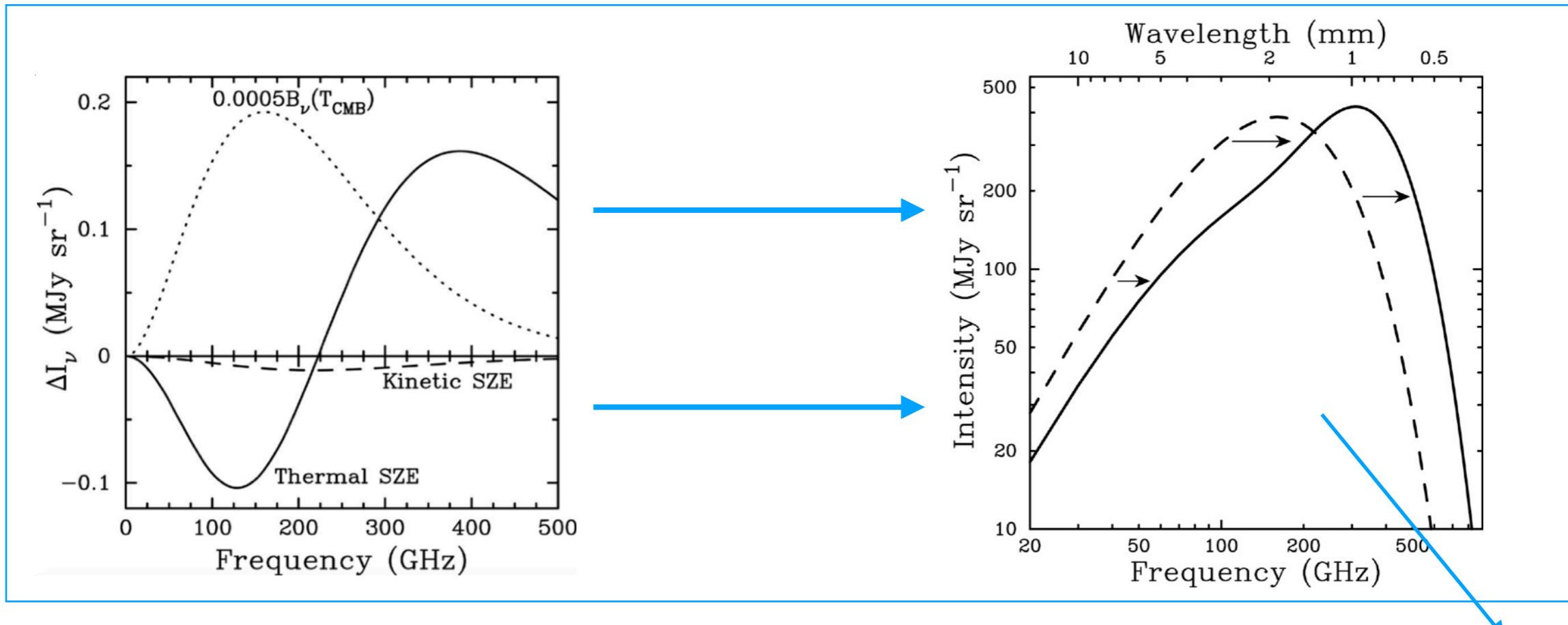
Constraints on cosmological parameters:
precise characterisation of the building blocks

Clusters in mm: tSZ effect

Interaction between CMB photons and hot gas in clusters:

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

Inverse Compton Scattering between CMB photons and hot electrons



(tSZ) Compton parameter

$$y(\hat{\mathbf{n}}) = \int n_e \frac{k_B T_e}{m_e c^2} \sigma_T ds$$

change in CMB
photons energy

Related to integrated
electron pressure profile

Total thermal energy of
clusters gas

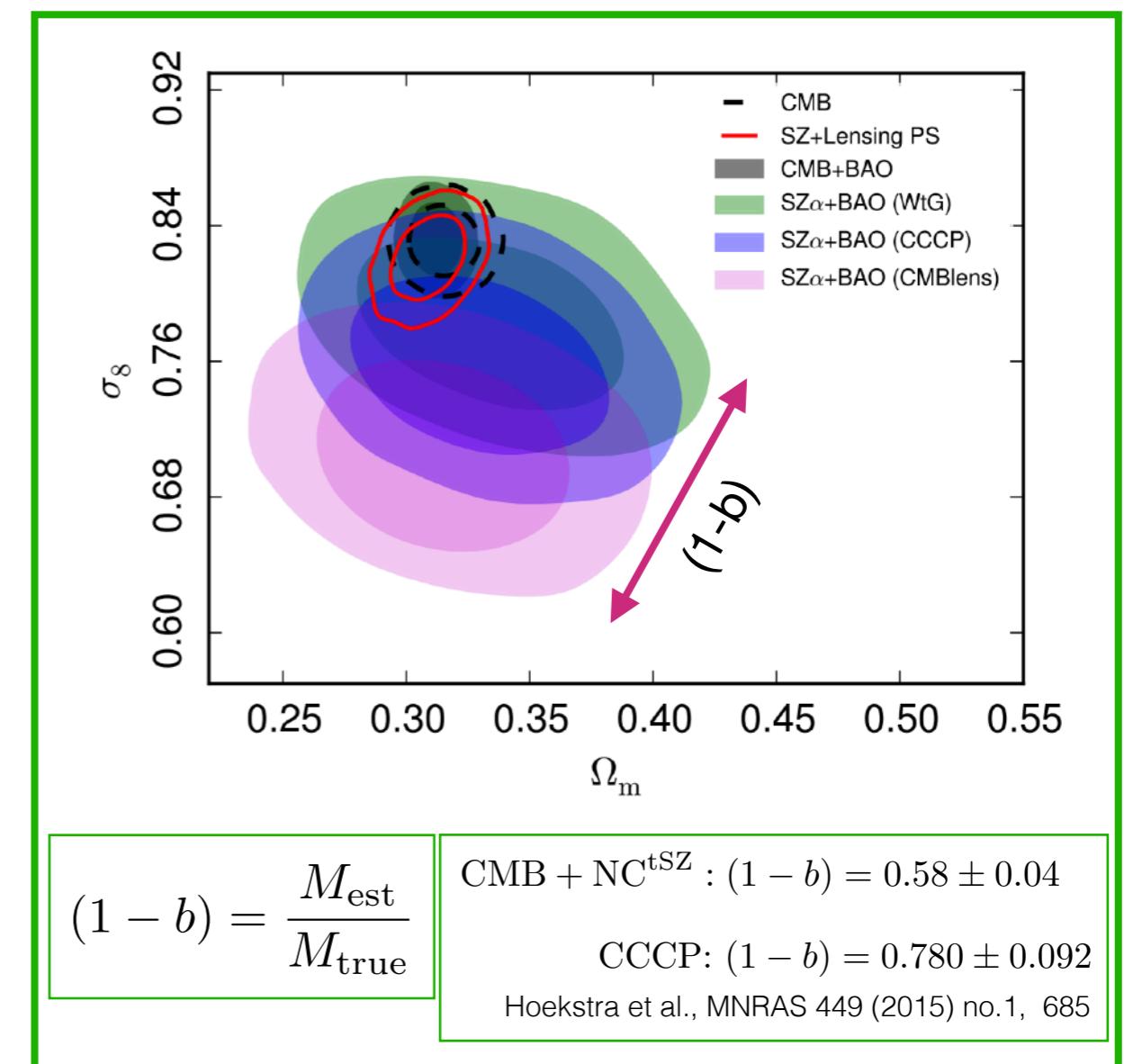
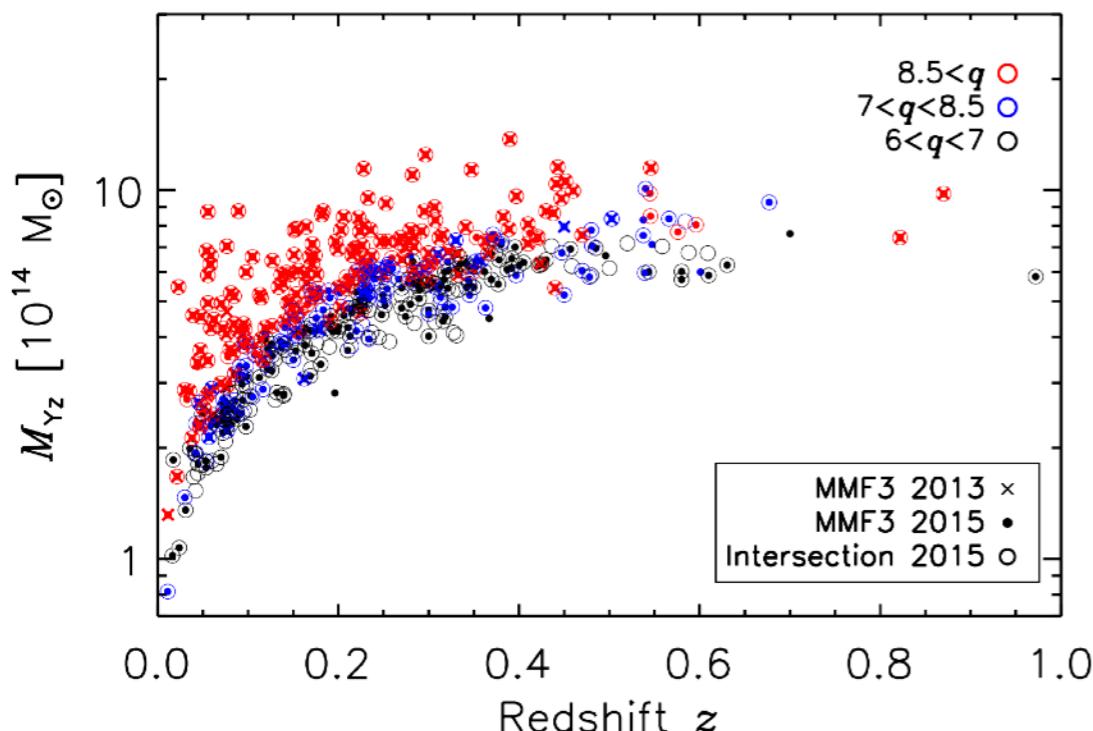
Good mass proxy

Clusters in mm: Planck satellite

Planck 2015. A&A 594, A24 (2016)

Planck 2015. A&A 594, A27 (2016)

- Full sky survey
- 1653 clusters detected in 65% of the sky
- Cosmological sample:
 - 439 clusters
 - $z = [0, 1]$



in 2015

tension between CMB primary
anisotropies and Galaxy Clusters:

$\simeq 2.4 \sigma$ on σ_8

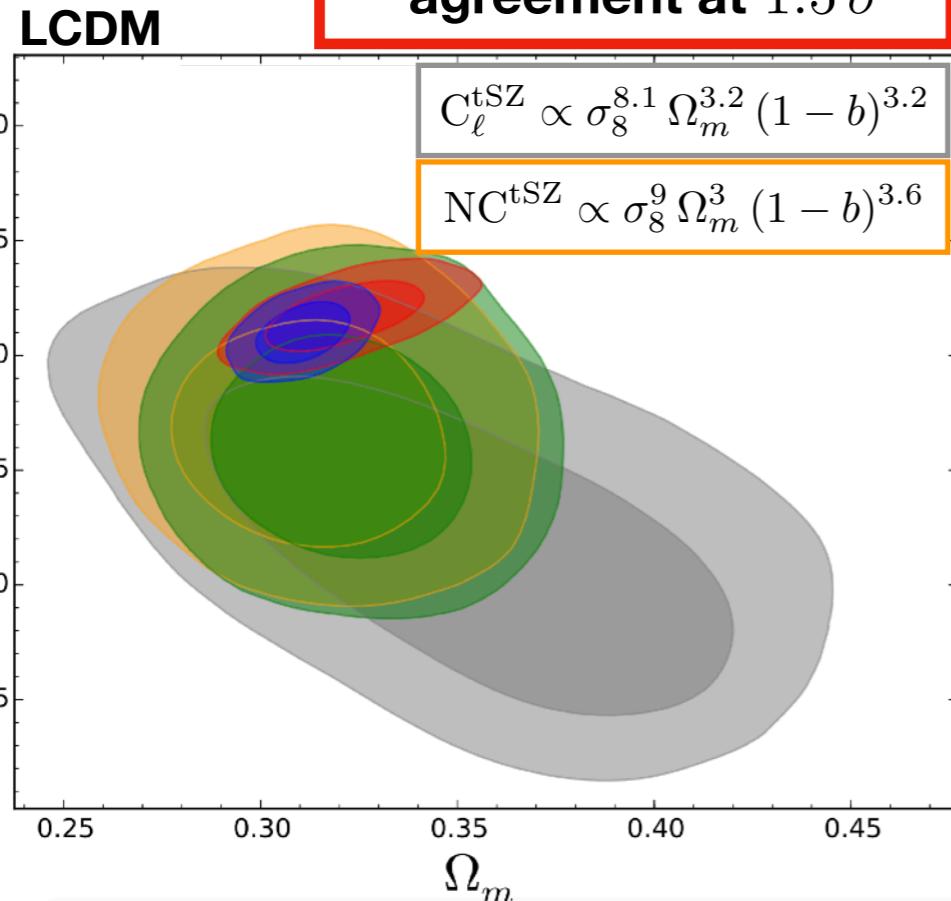
New analysis of Planck data

Salvati+ 2018

tSZ number counts + tSZ power spectrum

- Cosmological parameters
- Calibration of the mass bias
- Extensions to LCDM

No more tension on σ_8
agreement at 1.5σ



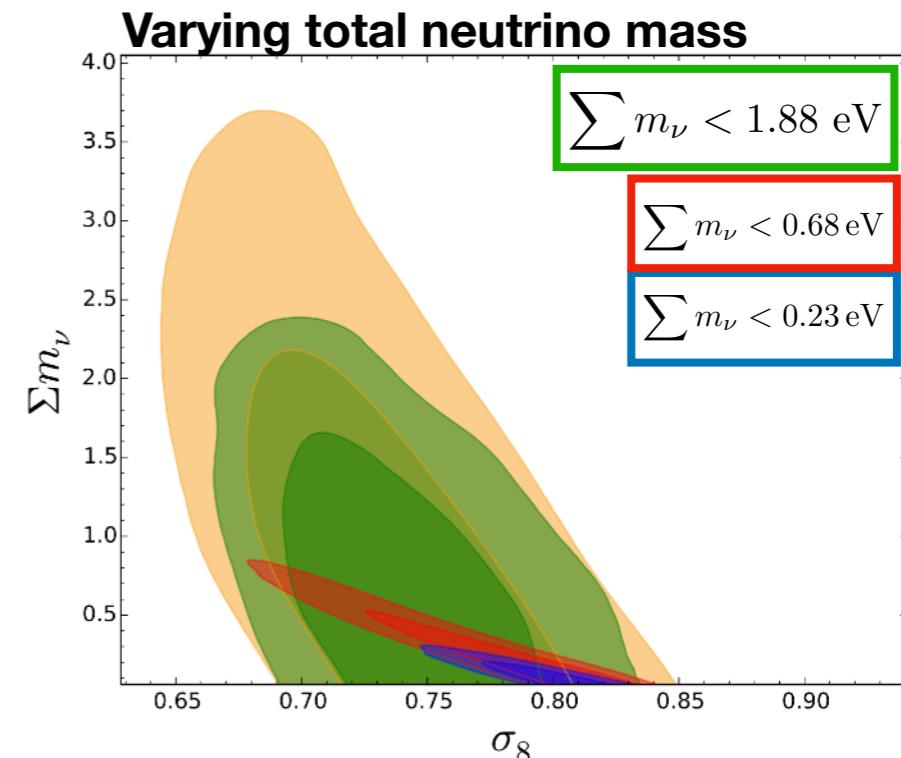
CL+BAO

NC+BAO

NC+CL+BAO

CMB

CMB+NC+CL+BAO



Still discrepancy on mass bias

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

$(1-b) = 0.65 \pm 0.04$ LCDM

$(1-b) = 0.67 \pm 0.04$ Neutrinos

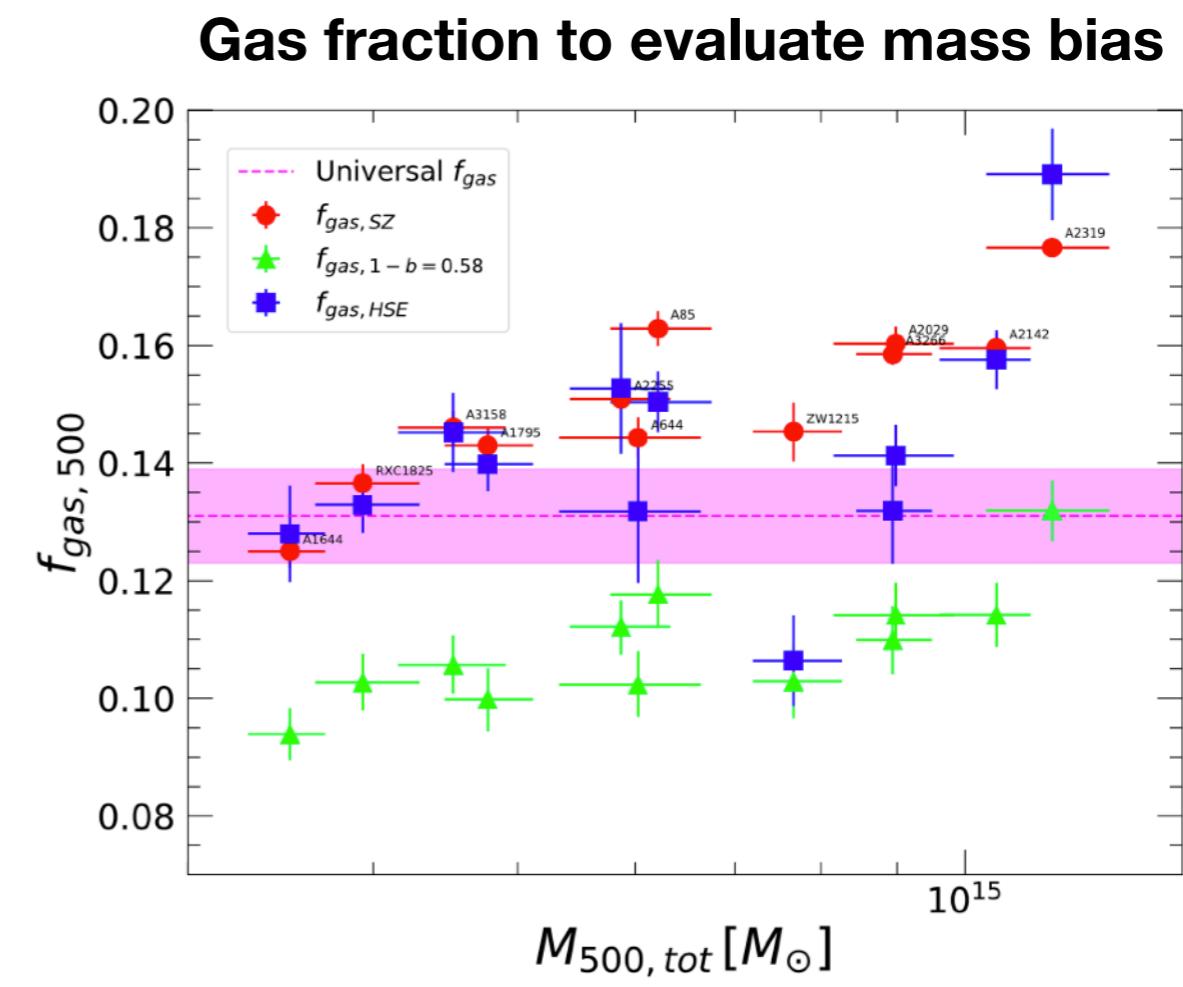
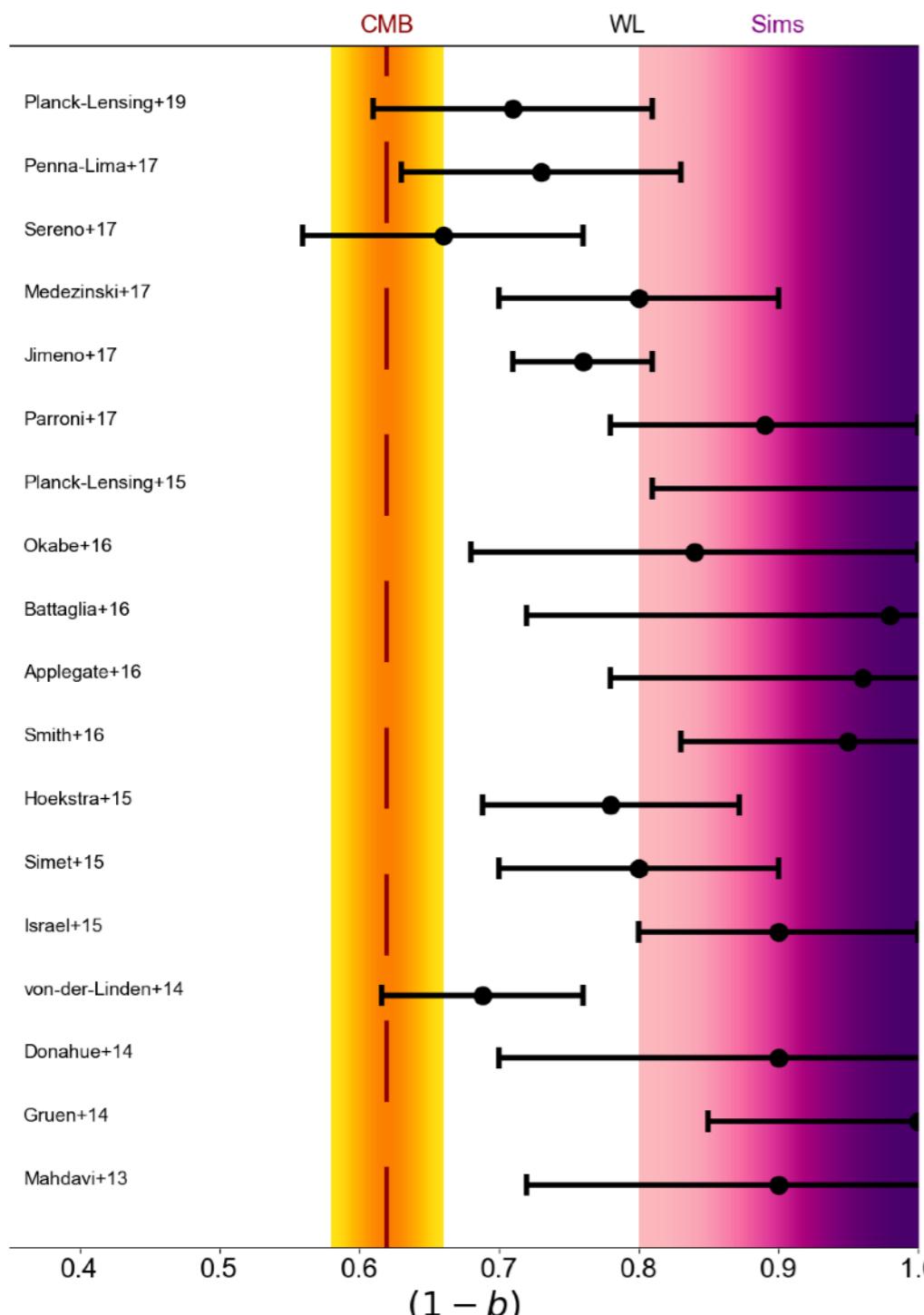
$(1-b) = 0.63 \pm 0.04$ DE

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

Mass bias

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

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



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

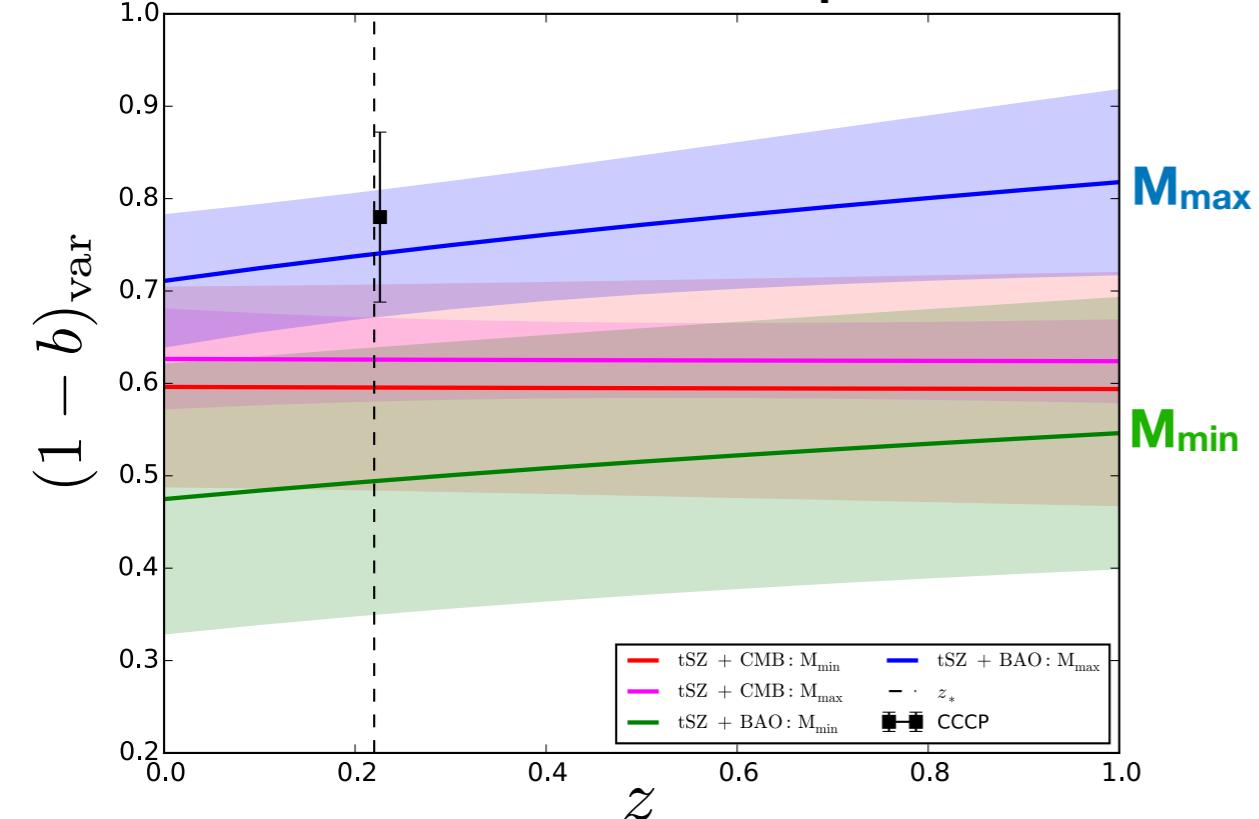
Mass bias: M-z evolution

Salvati+ 2019

tSZ number counts + tSZ power spectrum

- Calibration of the mass bias

Mild evidence for M - z dependence



(1-b) increasing with redshift

Need for further understanding!

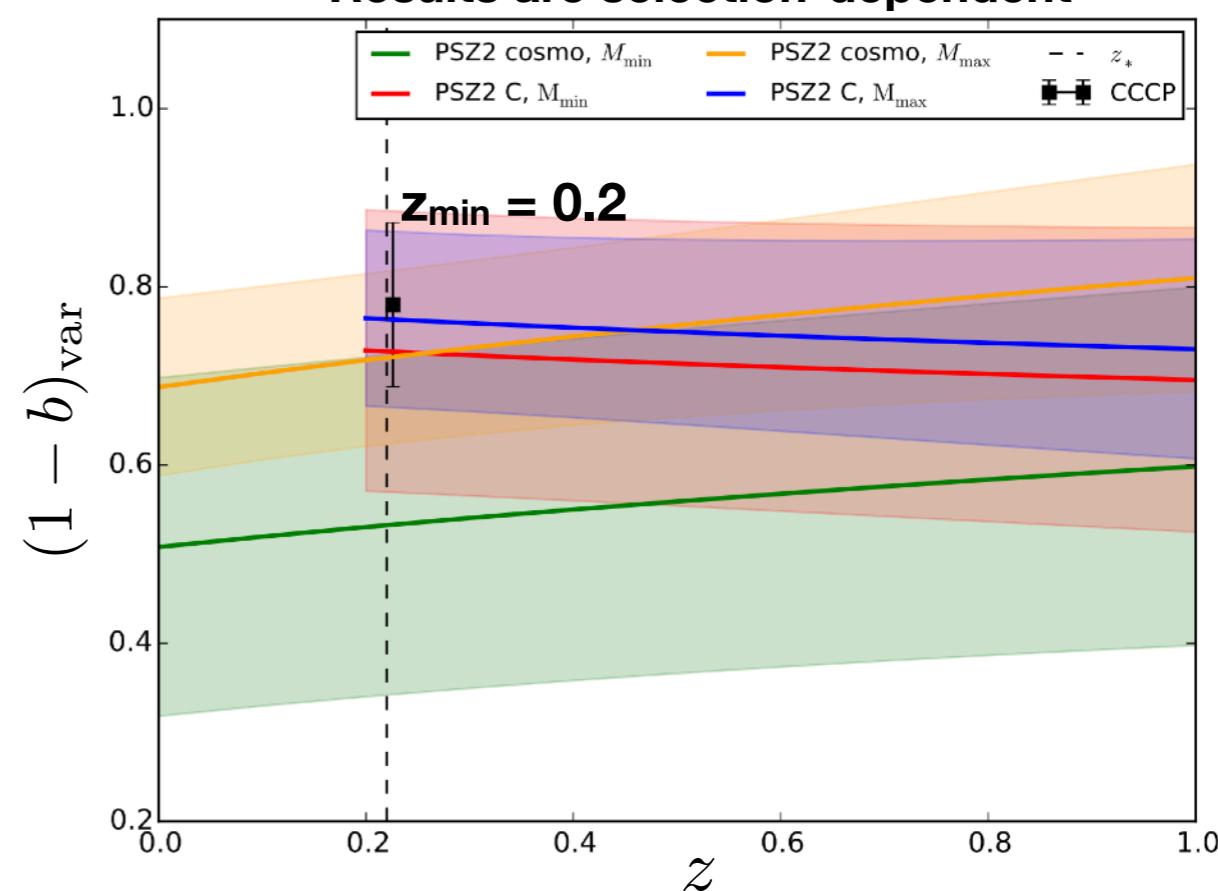
Mass-redshift Parametrisation

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

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

0.22
median redshift
of PSZ2 catalogue

Results are selection-dependent



Future cluster surveys

Salvati+ 2020

Current surveys: ~ hundreds of clusters

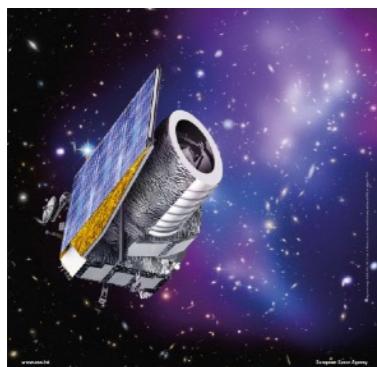


Mass Calibration: largest source of systematics

Future surveys: ~ thousands of clusters



Accuracy/precision on cosmological parameters:
dominated by systematic uncertainties



Euclid satellite



LSST -
Vera Rubin telescope

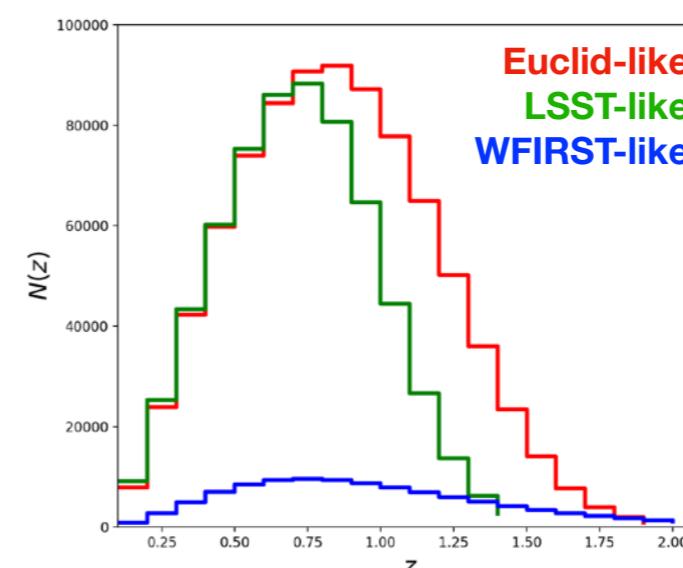


WFIRST -
Nancy Grace Roman space
telescope

- **Euclid-like**
survey area: 15000 deg²
 $z = [0.1, 1.9]$

- **LSST-like**
survey area: 18000 deg²
 $z = [0.1, 1.4]$

- **WFIRST-like**
survey area: 2400 deg²
 $z = [0.1, 2.0]$

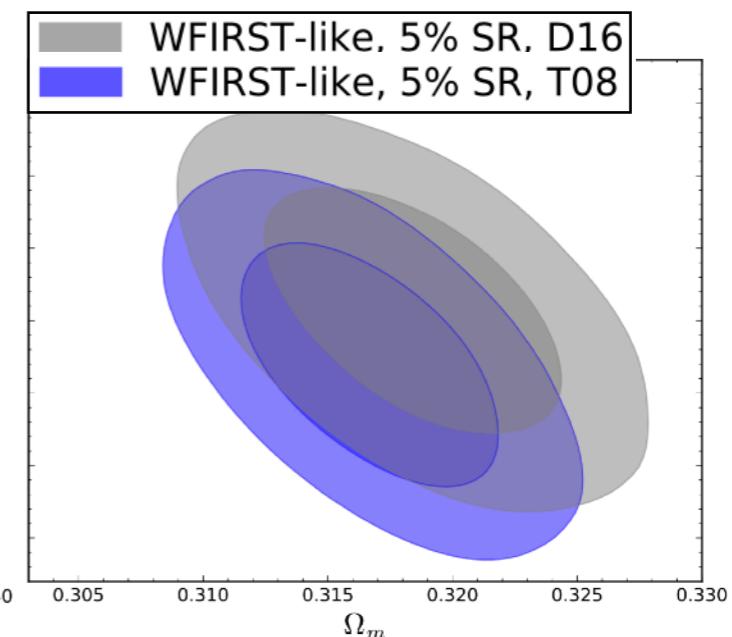
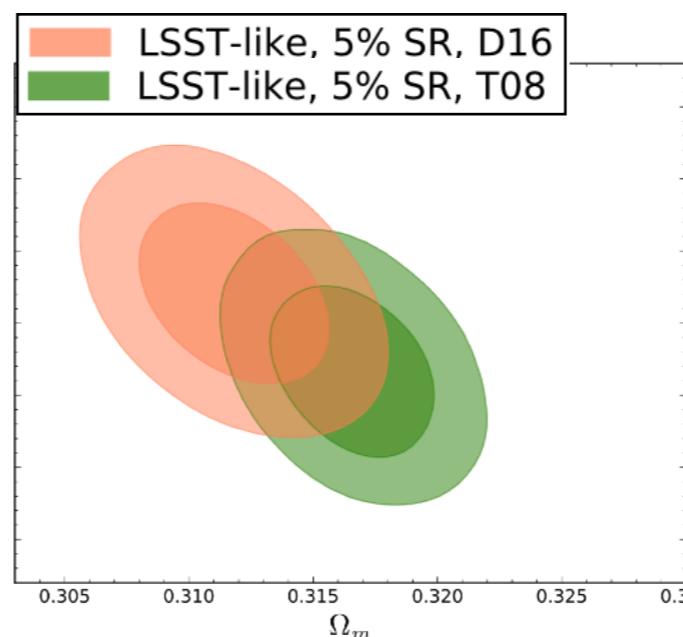
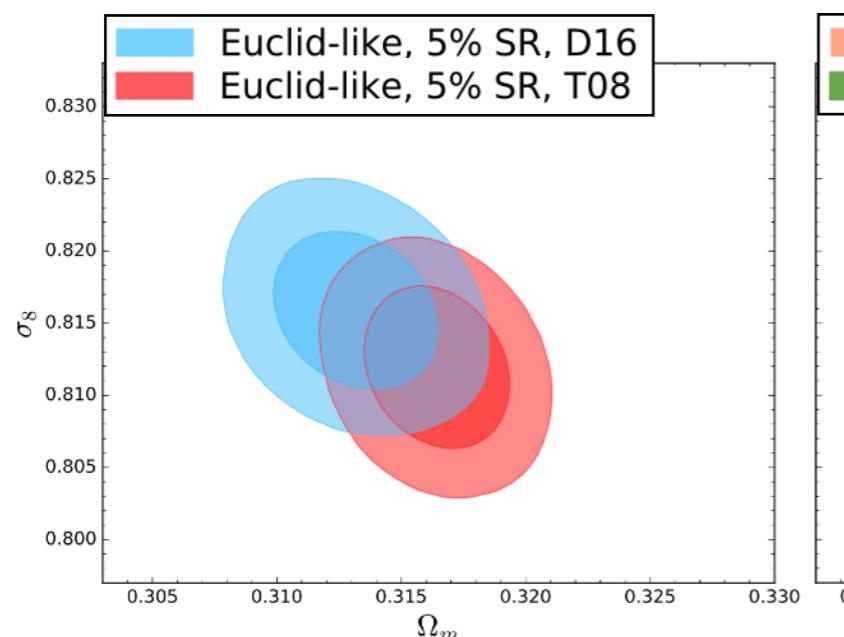
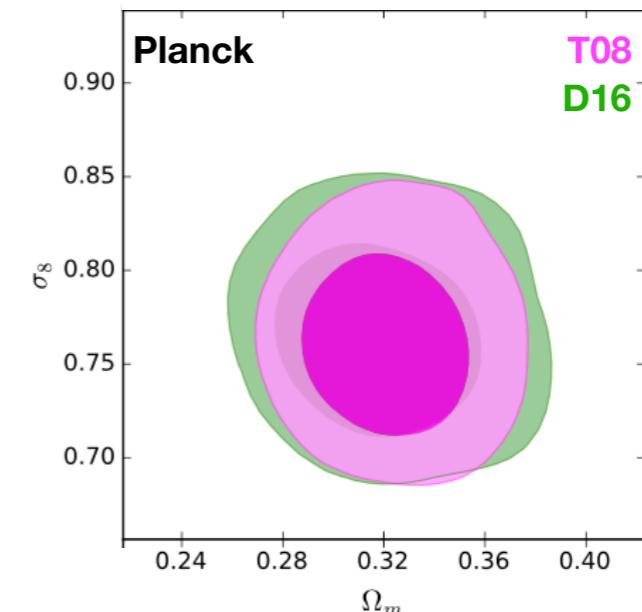


Impact of the mass function

Salvati+ 2020

Mass function in cluster cosmology: NC(M,z)

- Fitting formula from numerical simulations
- T08: Tinker+ 2008
- D16: Despali+ 2016



Increasing precision and accuracy on cosmological constraints

Choice of the Mass Function: NON-NEGIGIBLE source of systematic uncertainty

Conclusions

- Galaxy clusters: powerful cosmological probe
- Link between cosmology and astrophysics
- Impact of systematic uncertainties
 - theoretical modelling
 - observational effects
- Improve the cosmological analysis
 - Use of numerical simulations
 - Use of multi-wavelength observations

Thank you!