The cluster counts tension : calibration issue or new physics ?

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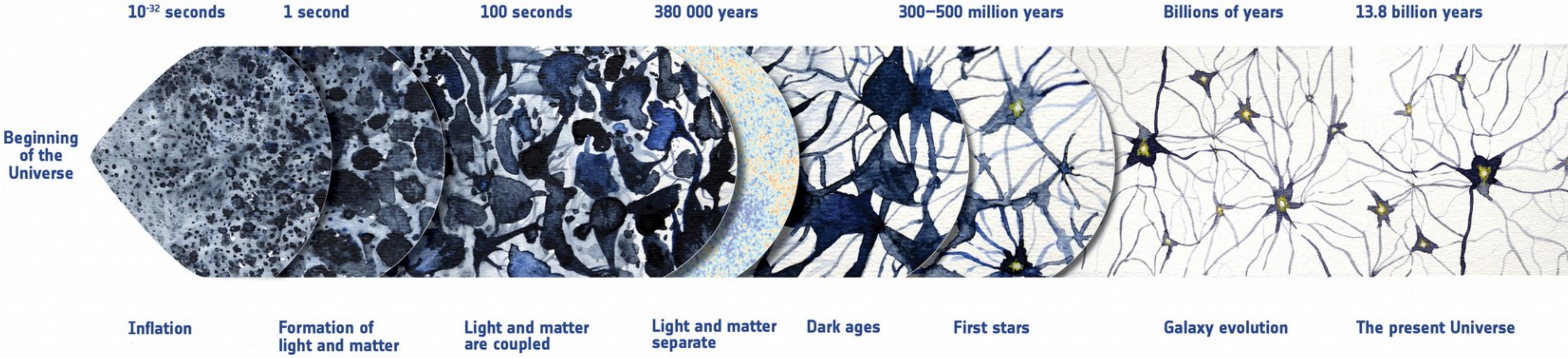
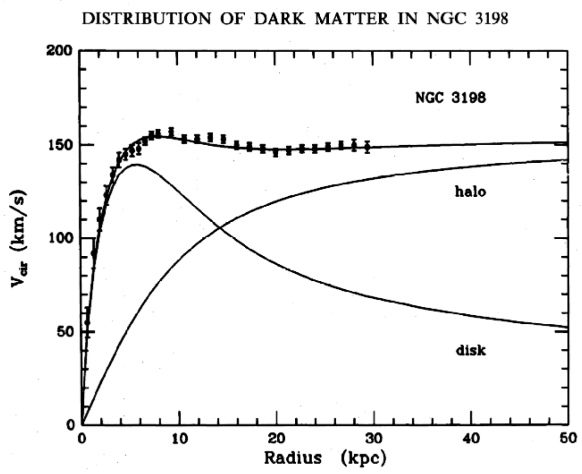
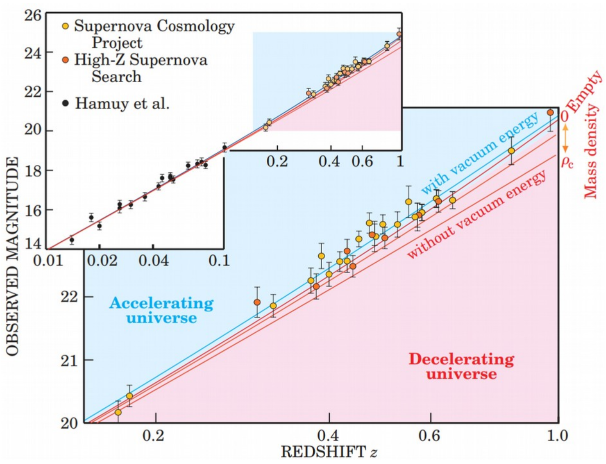
The standard model of cosmology

- The ΛCDM paradigm: a simple model, with many successes…



- … but rests on pillars "shrouded in darkness":
  - Dark matter
  - Dark energy





<u>Most economical model, but many alternatives exist</u>

Clusters as cosmological probes

Clusters of galaxies:

- Largest structures in the Universe → closer to linear regime than 1-pt GCF
- Exponentially sensitive to growth rate of structure → great probes of DE

Use as cosmological probe:

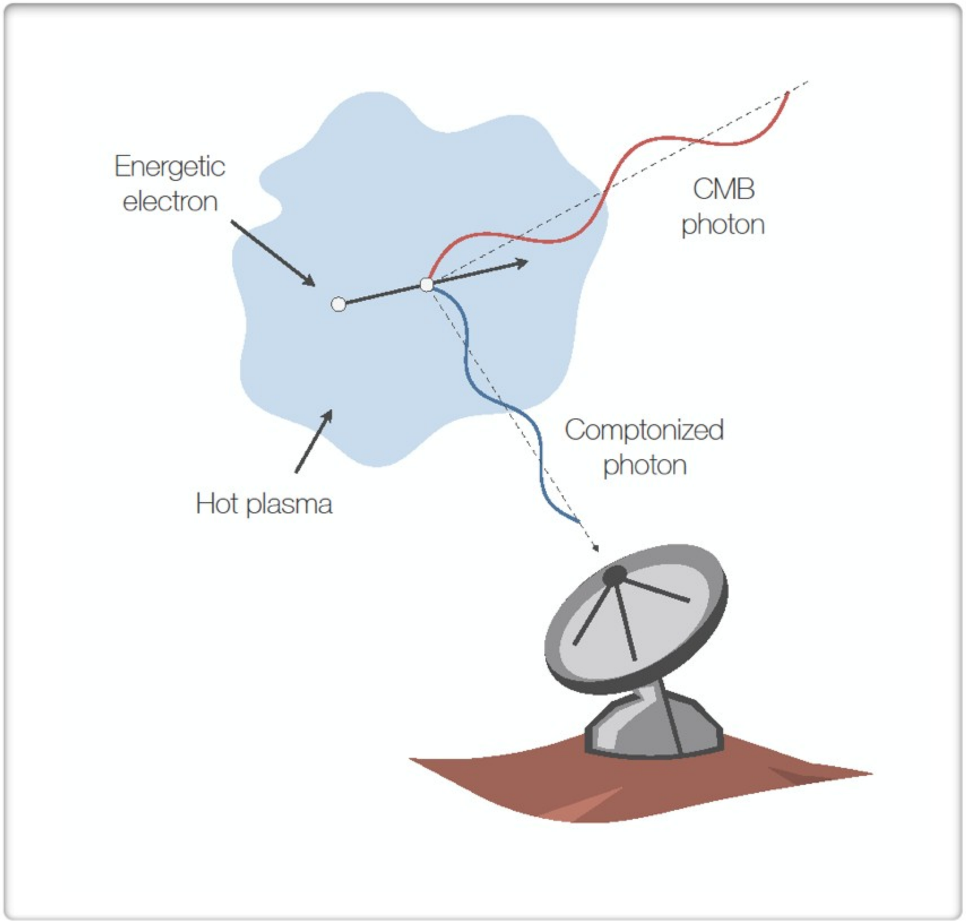
- Main principle : compare predicted and observed N(M,z)
- (Fairly) robust framework for predicting abundances ↔ “mass function” (Press & Schechter 1974 and “successors”)

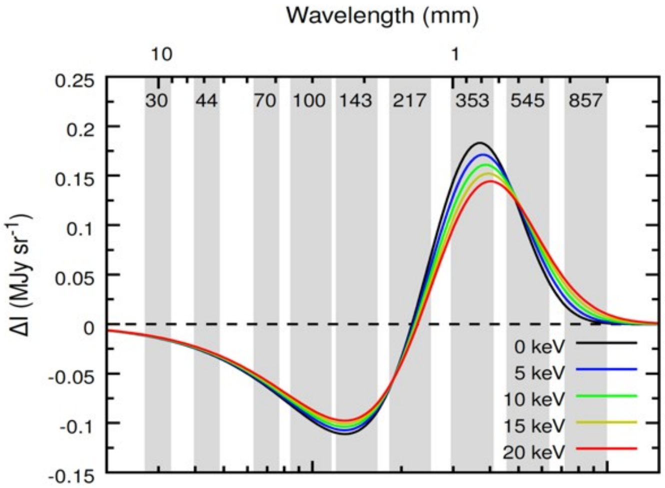
Obstacles:

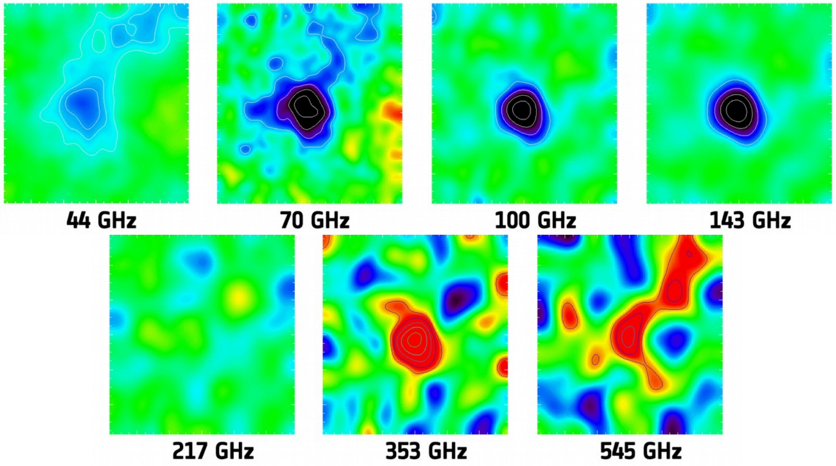
- Detecting/identifying clusters in data (what even *is* a cluster ??)
- Total mass is not an observable : proxies (temperature, richness, ...) & “scaling laws” required → no consensus on those laws

The curious case of Planck SZ clusters

Planck Sunyaev-Zel'dovich cluster sample :
439 clusters detected via their imprint in CMB T map



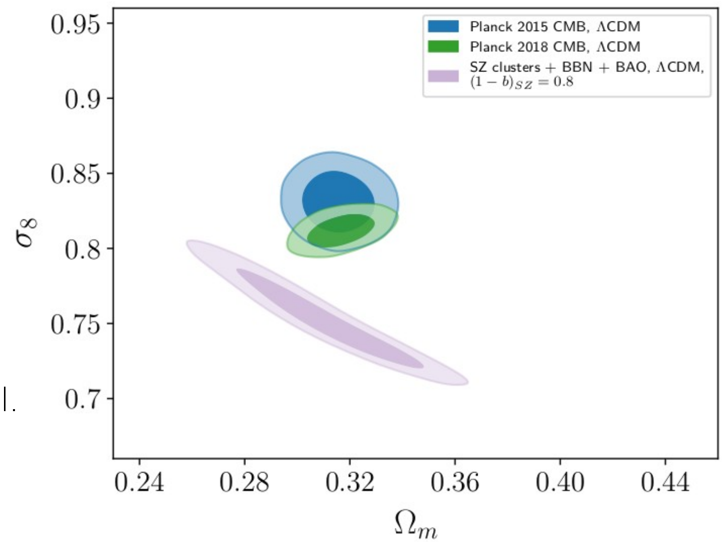


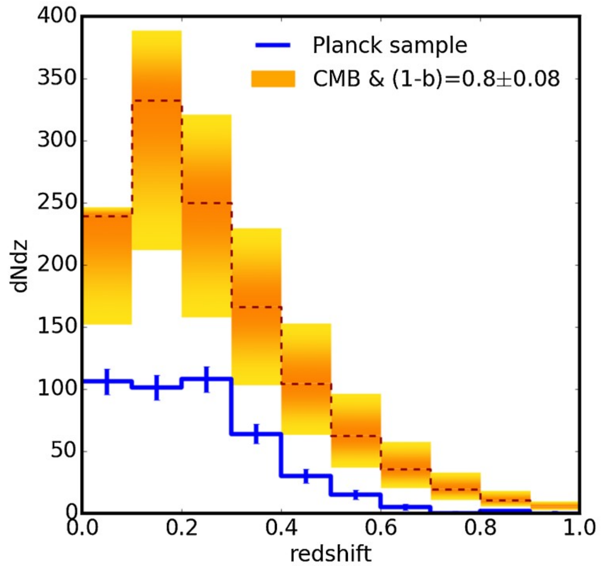


The curious case of Planck SZ clusters

SZ abundances in tension with CMB constraints...

Ilić et al. 2019





Salvati et al. 2018

...but depends on crucial details of the analysis:

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

SZ scaling law

established by X-ray observations

assuming hydrostatic equilibrium : fiducial (1-b) = 0.8

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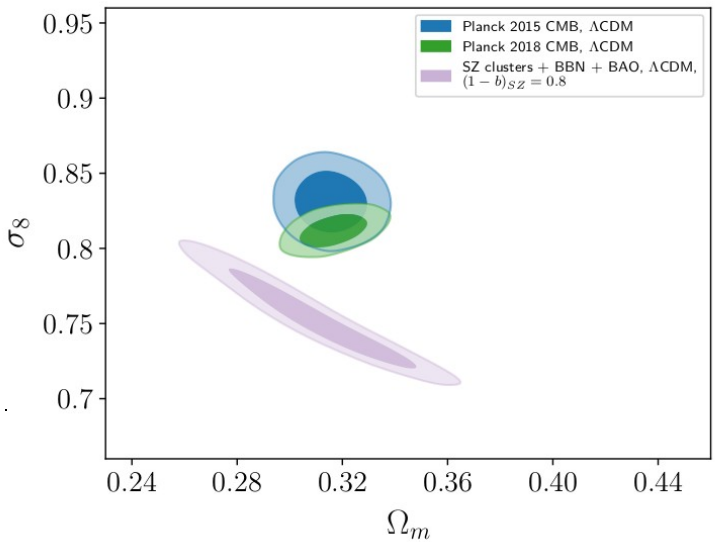
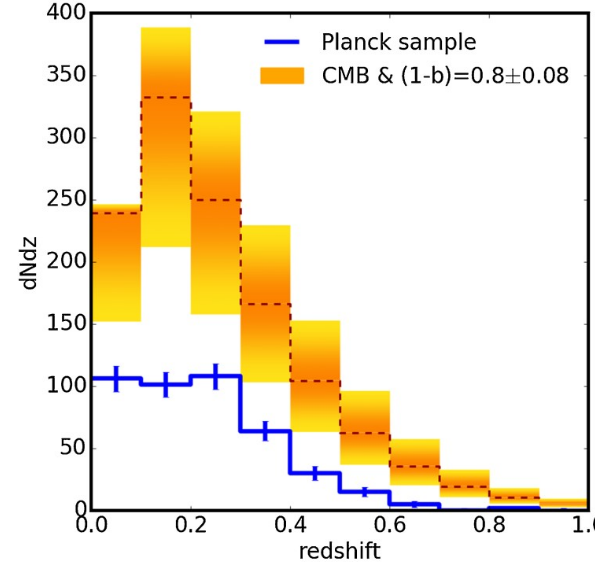


Ilić et al. 2019



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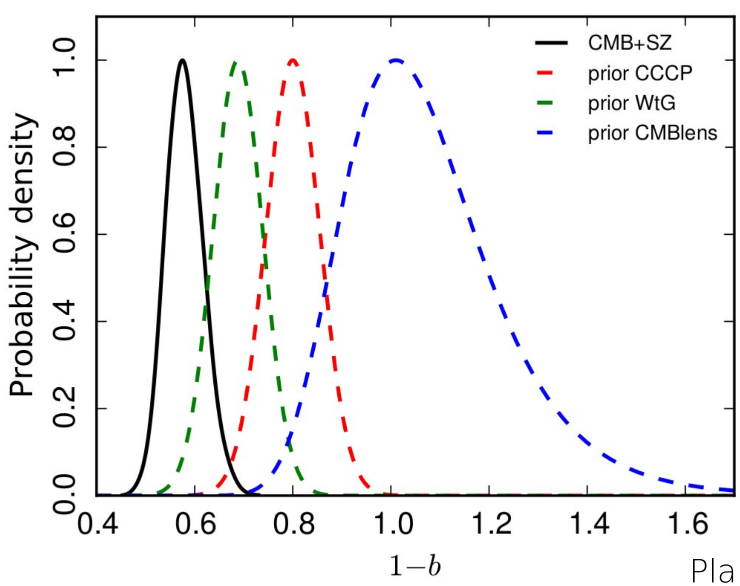
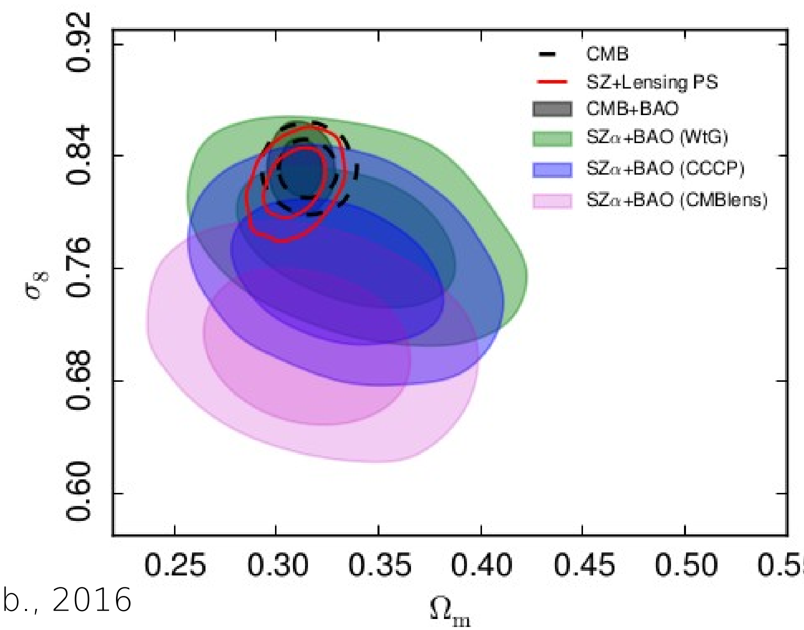
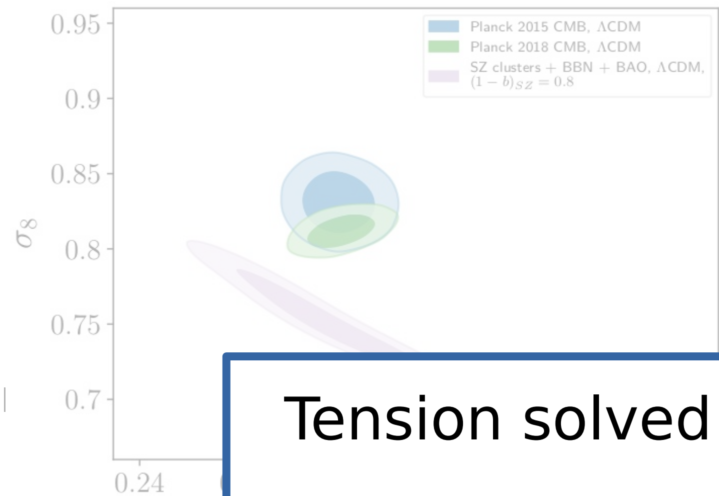




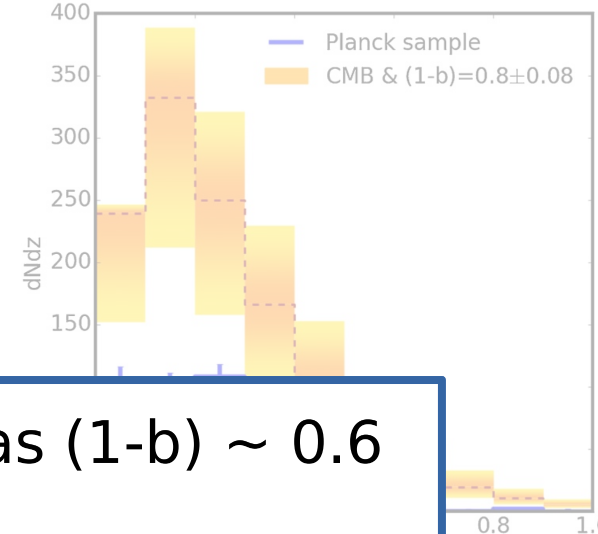
Planck collab., 2016

The curious case of Planck SZ clusters

SZ abundances in tension with CMB constraints...



Ilić et al 2019

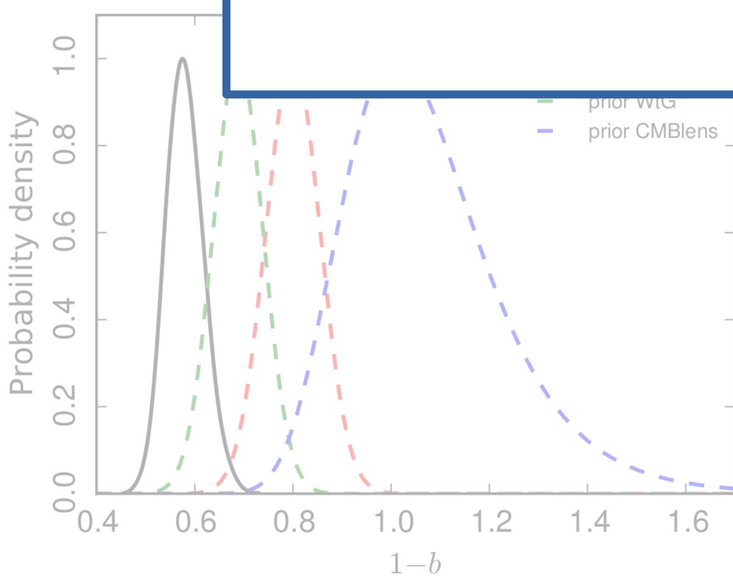


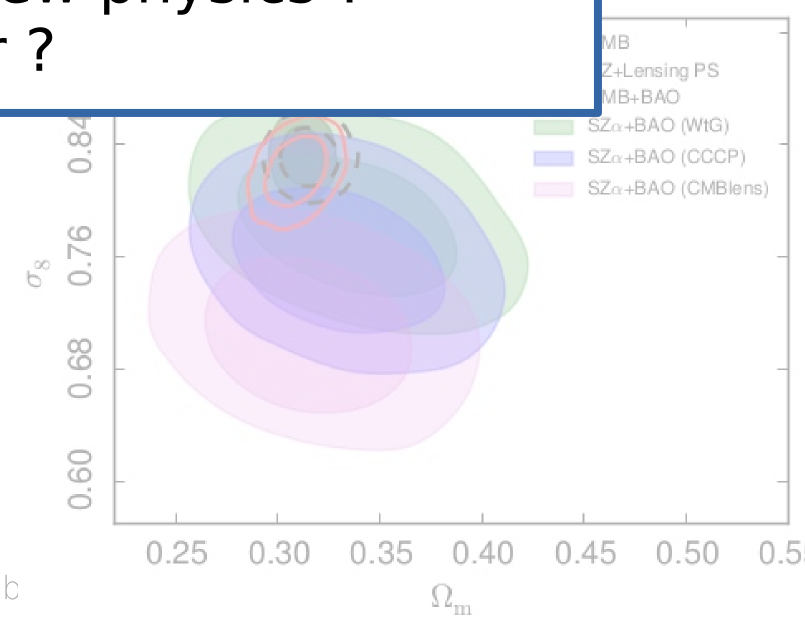
Salvati et al. 2018

...but depen

Tension solved if mass bias (1-b) ~ 0.6

→ Problem with cluster mass calibration
...or signs of new physics ?
...or ?



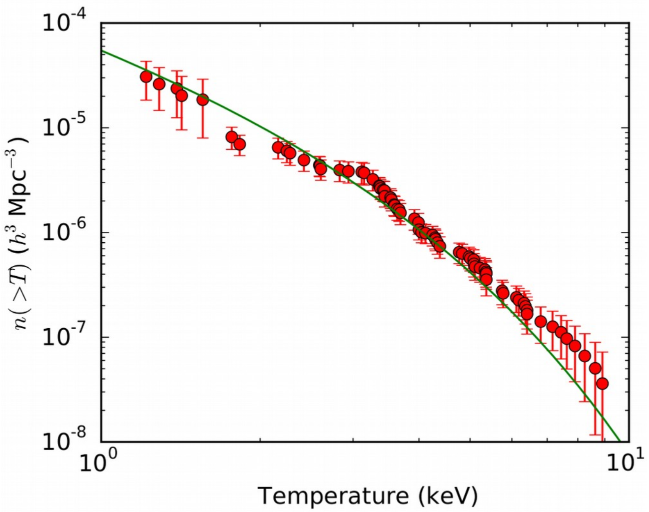


nck collab

An independent local X-ray sample

Ilić, Blanchard, Douspis, 2015, A&A :

- Built robust, flux-limit sample of ~80 local X-ray clusters ($z < 0.1$)
- Constructed an observed local N(T)



Cosmological analysis :

- T_X-M scaling law with simple assumptions (viral theorem + cluster definition)

$$T = A_{T-M}(h\,M_\Delta)^{2/3}\left(\frac{\Omega_m \Delta(z)}{178}\right)^{1/3}(1+z)$$

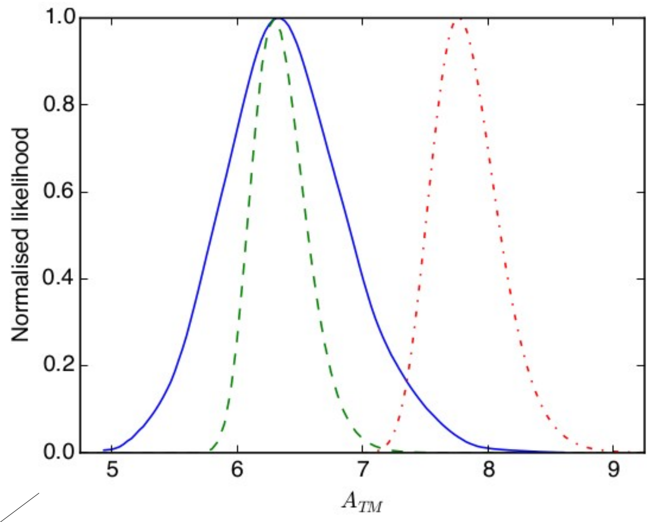
- New likelihood module in CosmoMC + CMB data
- Calibration/amplitude is left free
  → New parameter in the cosmological analysis,
  "let the data decide what it prefers"

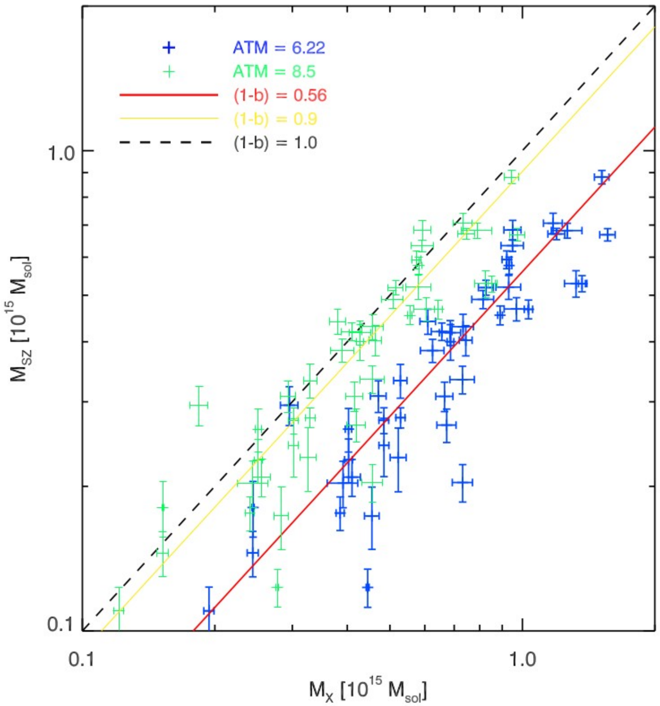
An independent local X-ray sample

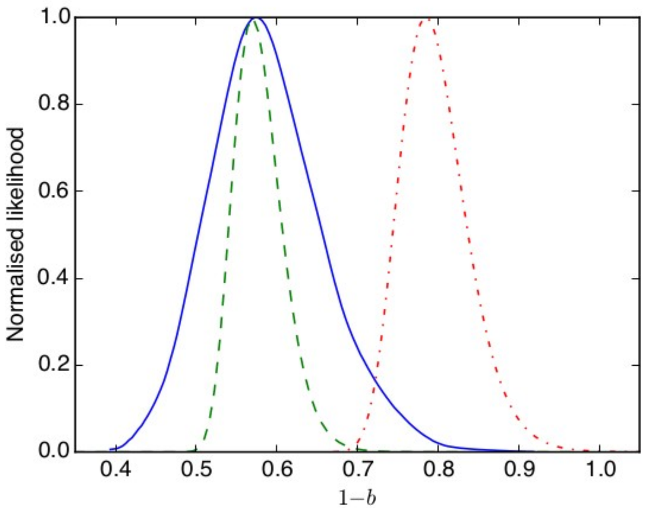
Results :

- Posterior distribution for $A_{T\text{-}M}$ calibration ⇄ X-ray masses

- Subset of clusters both in X-ray and SZ → derive equivalence between $A_{T\text{-}M}$ and (1-b)







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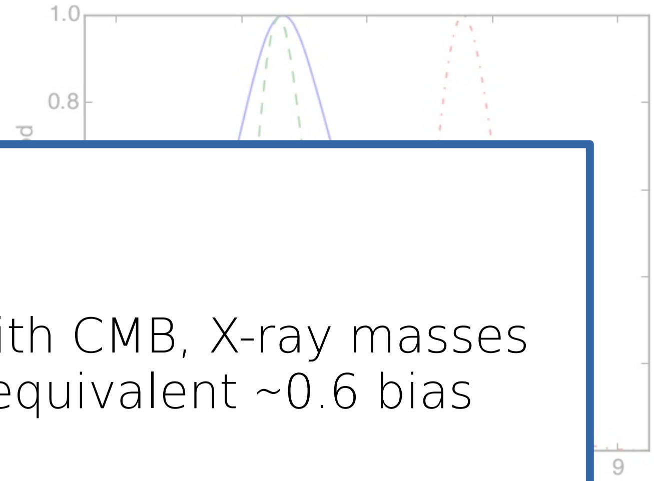
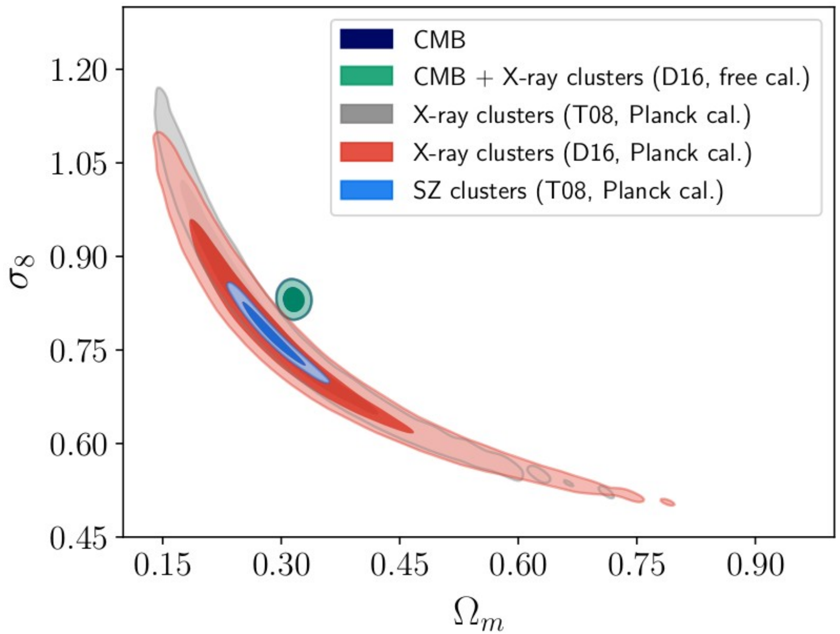
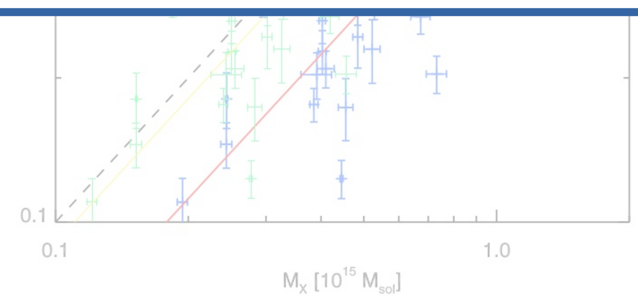
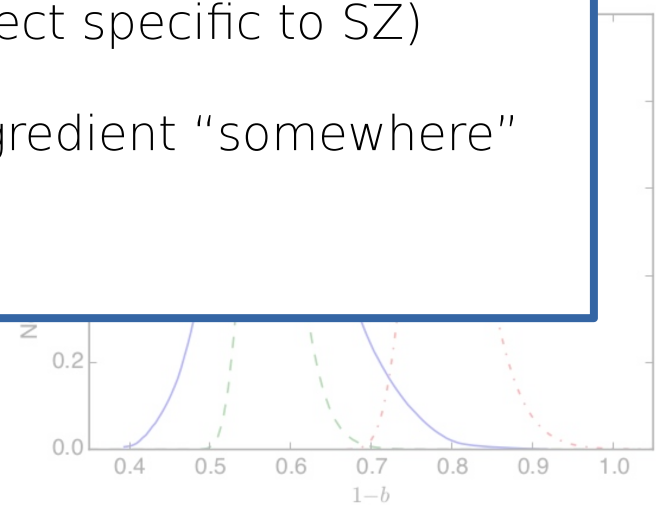




- To agree with CMB, X-ray masses also need equivalent ~0.6 bias
- X-ray & SZ abundances agree (not an effect specific to SZ)
- Missing ingredient “somewhere”





Revisiting the Planck SZ sample

Ilić, Sakr, Blanchard, 2018 & 2019, A&A :

- Reanalysis of SZ (& X-ray) clusters sample in broader cosmological context
- Same philosophy : calibration(s) as free parameters, let CMB + Clusters decide what they prefer
- Two extensions to LCDM explored:

$$\sum m_\nu \neq 0$$

Massive neutrinos

$$f\left(= \frac{d\ln D}{d\ln a}\right) = [\Omega_m(a)]^\gamma$$

$$\gamma \neq 6/11$$

Phenomenological modification of gravity

Revisiting the Planck SZ sample

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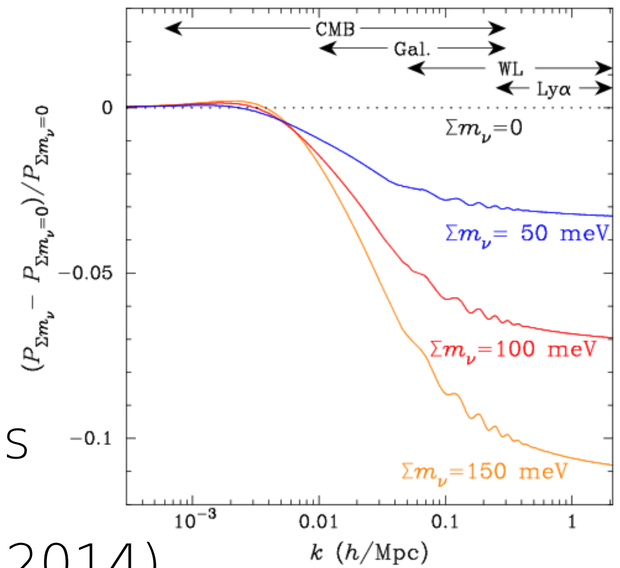
- **Neutrinos** : damping of matter fluctuations → lower σ_8
- Implemented in our pipeline at Boltzmann code level (CAMB)
- Additional ingredient : amended mass function ("neutrinos prescription", cf. Costanzi et al. 2013; Castorina et al. 2014)



$$T_{\mathrm{cdm+b+}\nu} \longrightarrow T_{\mathrm{cdm+b}}$$
$$\rho_{\mathrm{cdm+b+}\nu} \longrightarrow \rho_{\mathrm{cdm+b}}$$

Massive neutrinos

Phenomenological modification of gravity

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- Reanalysis of SZ (& X-ray) clusters sample in broader cosmological context

- Simple **modification of growth rate** of structures at late times
- "gamma" parametrisation not appropriate for CMB
- Implemented in the mass function (only) at power spectrum level

$$P_{\mathrm{m,MG}}(k, z, \gamma) = P_{\mathrm{m}}(k, z) \left(\frac{D(z_*)}{D(z)} \frac{D_{\mathrm{MG}}(z, \gamma)}{D_{\mathrm{MG}}(z_*, \gamma)} \right)^2$$

Massive neutrinos

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$$\sum m_\nu \neq 0$$

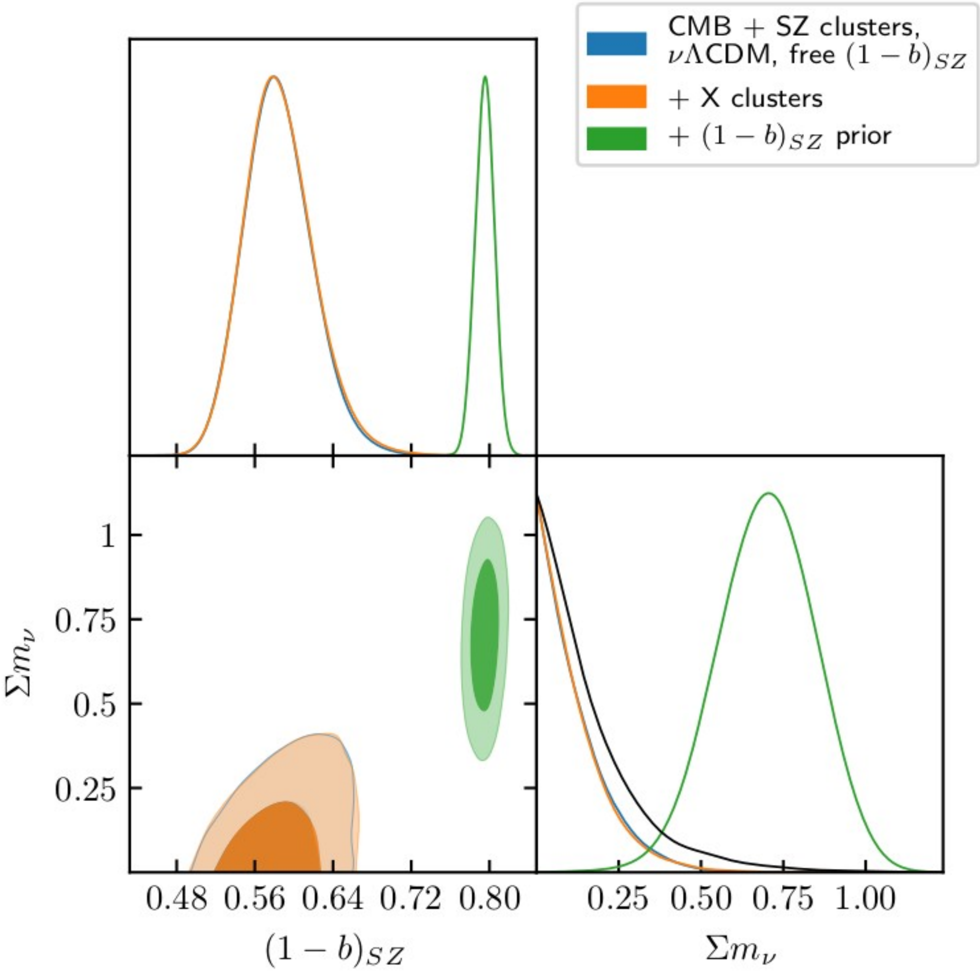
$$f\left(= \frac{d\ln D}{d\ln a}\right) = [\Omega_m(a)]^\gamma$$

$$\gamma \neq 6/11$$

<u>What happens to our previous conclusions in these new contexts ?</u>

Revisiting the Planck SZ sample

Massive neutrinos as a solution to the tension :



- No correlation between calibration and neutrinos masses
- (1-b) ~ 0.6 still favored
- (1-b) ~ 0.8 yields very large neutrino masses

Revisiting the Planck SZ sample

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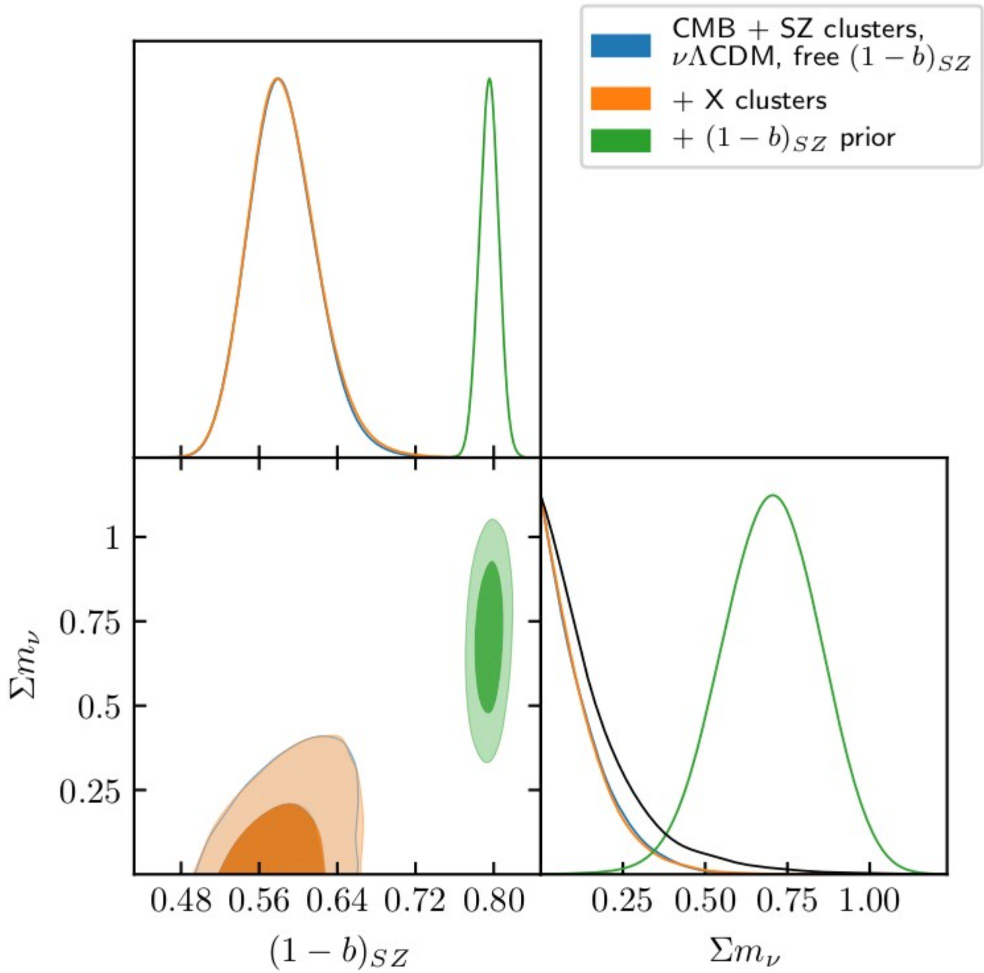

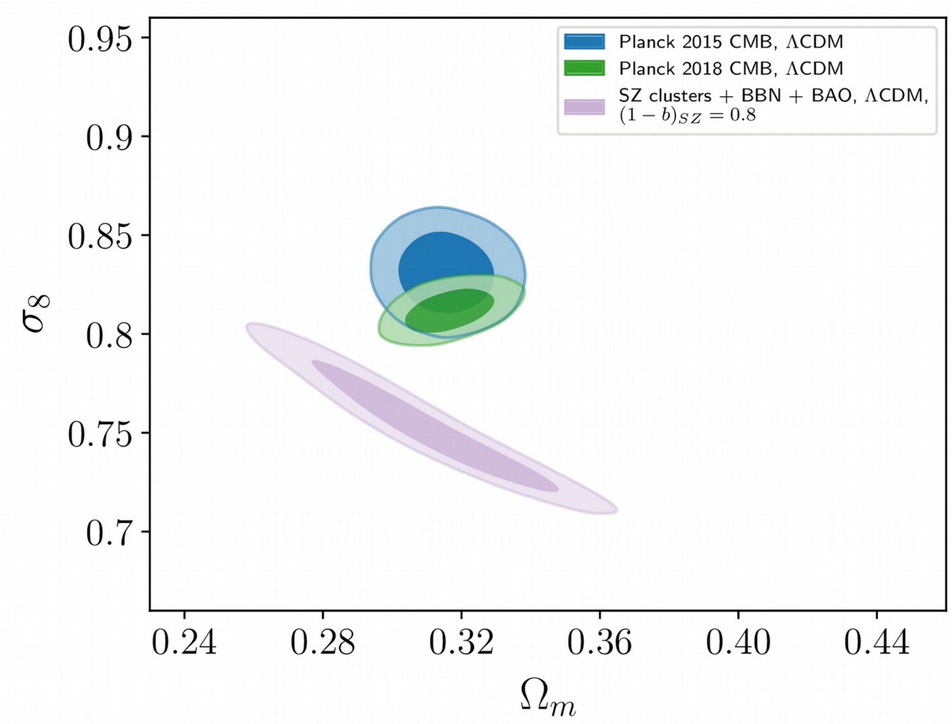

Revisiting the Planck SZ sample

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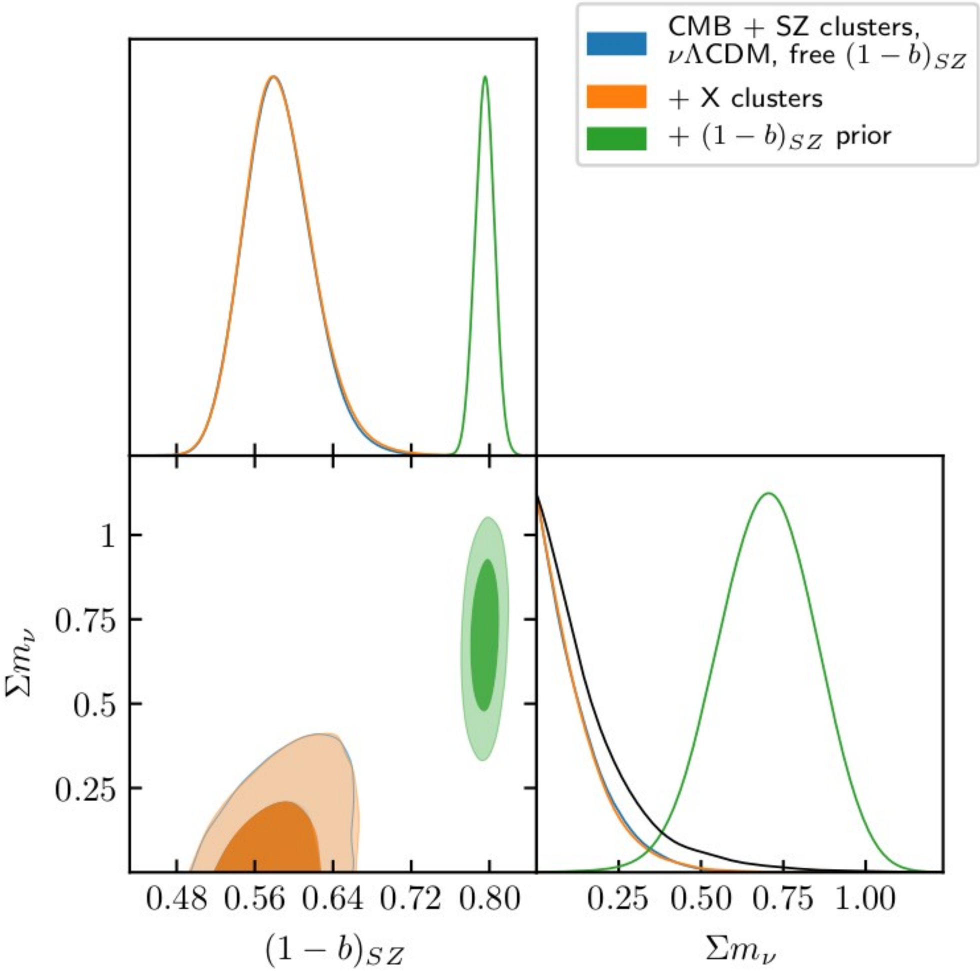
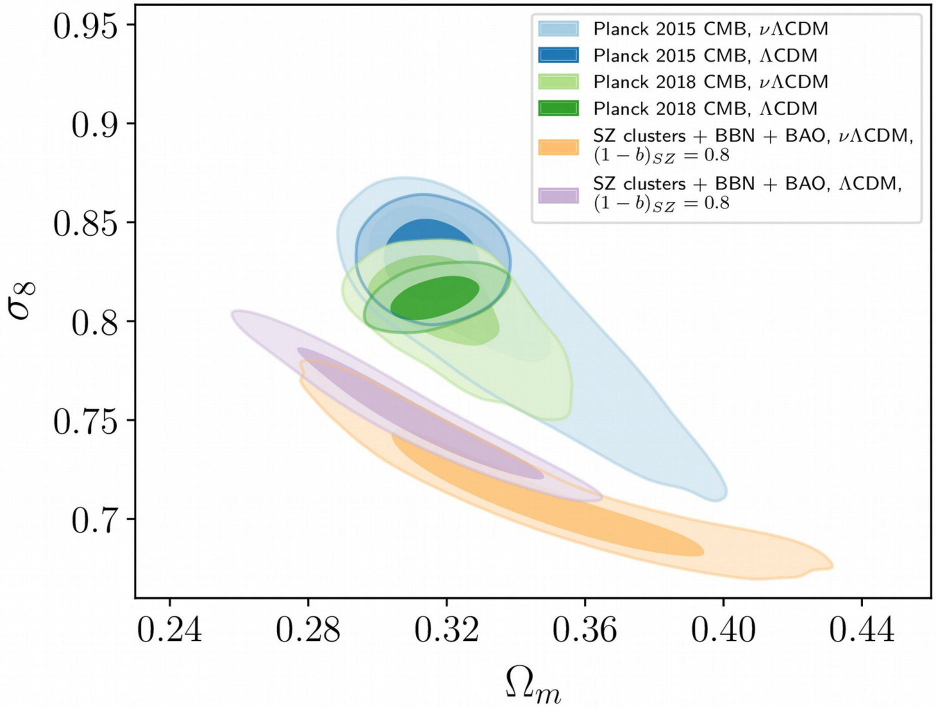
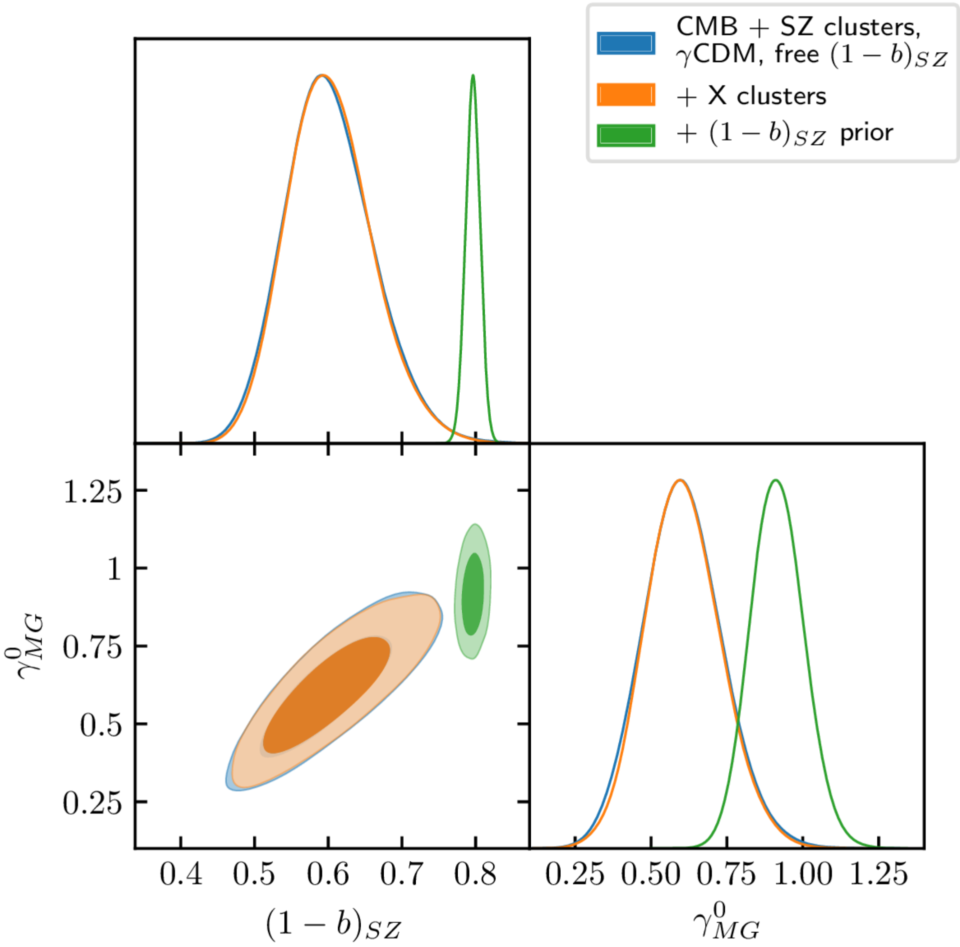




<u>Massive neutrinos do not solve the tension</u>

Revisiting the Planck SZ sample

Phenomenological modification of gravity as a solution :

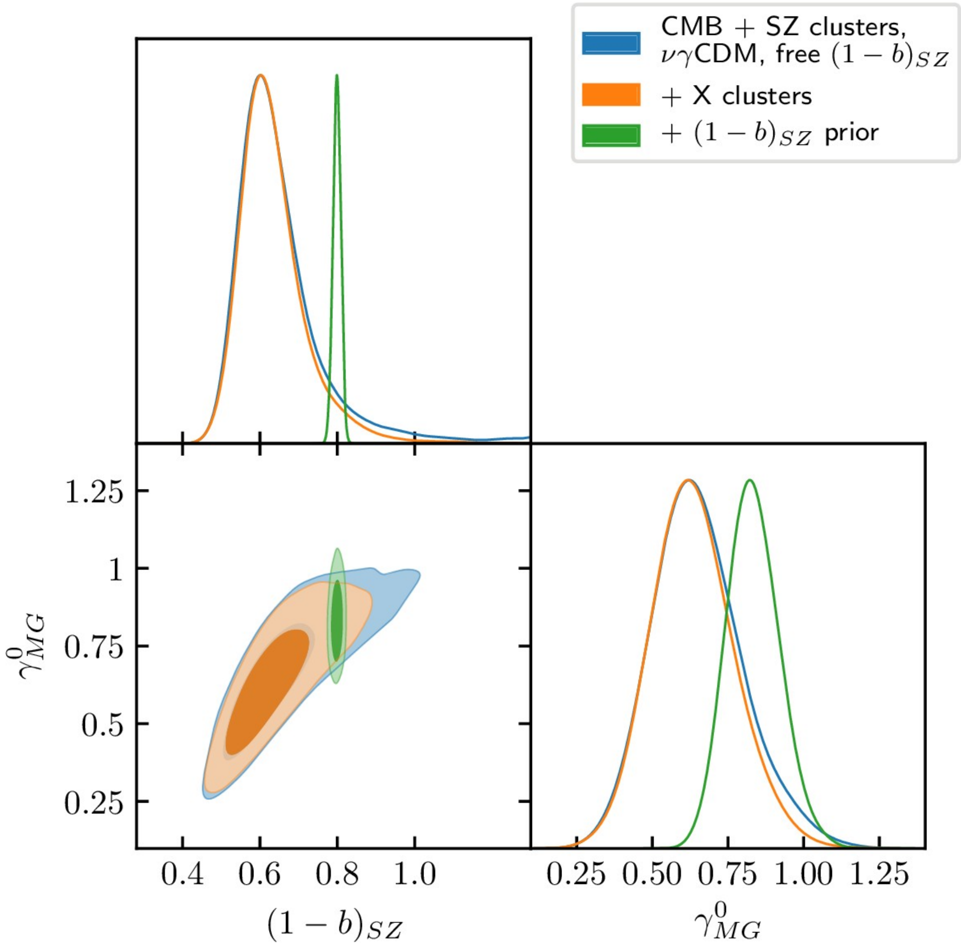


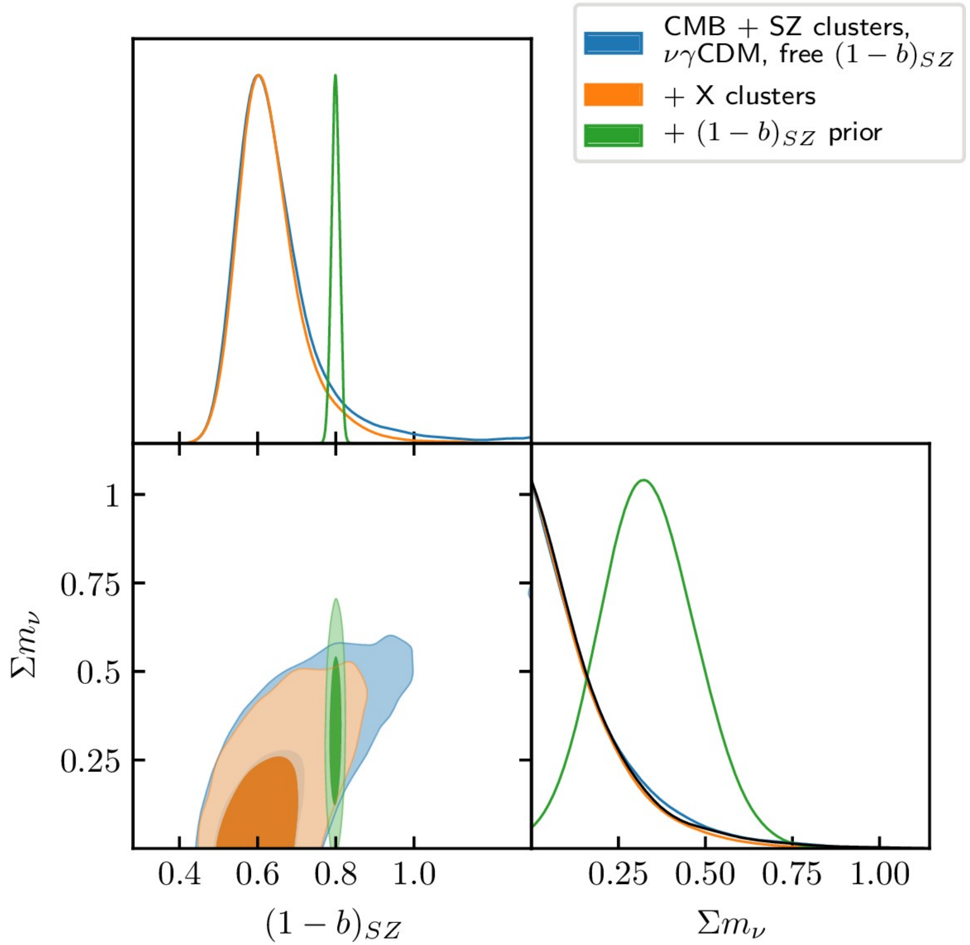
- Strong correlation between calibration and gamma
- (1-b) ~ 0.6 still favored
- (1-b) ~ 0.8 yields large unrealistic gamma

Revisiting the Planck SZ sample

Phenomenological modification of gravity as a solution :

+ massive neutrinos





<u>Standard calibration compatible only at the >2 sigma level</u>
<u>(but with significant deviation from standard cosmology)</u>

Revisiting the Planck SZ sample

Additional “model” : free σ_8 via rescaling of late P(k,z)

Revisiting the Planck SZ sample

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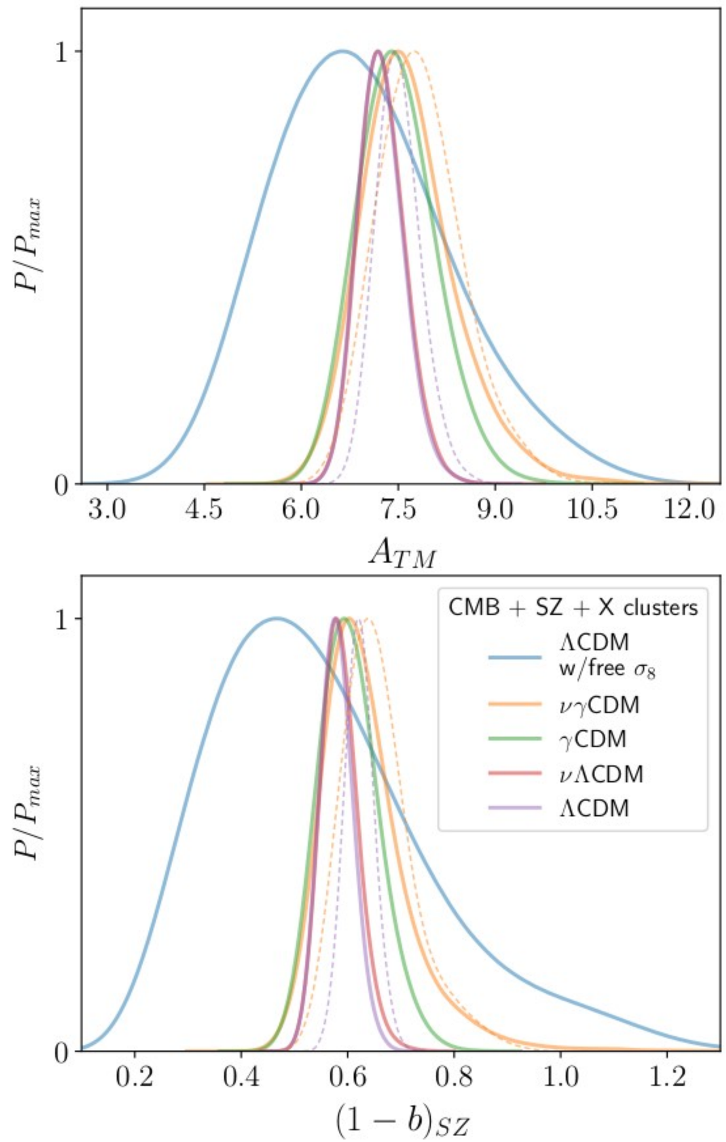

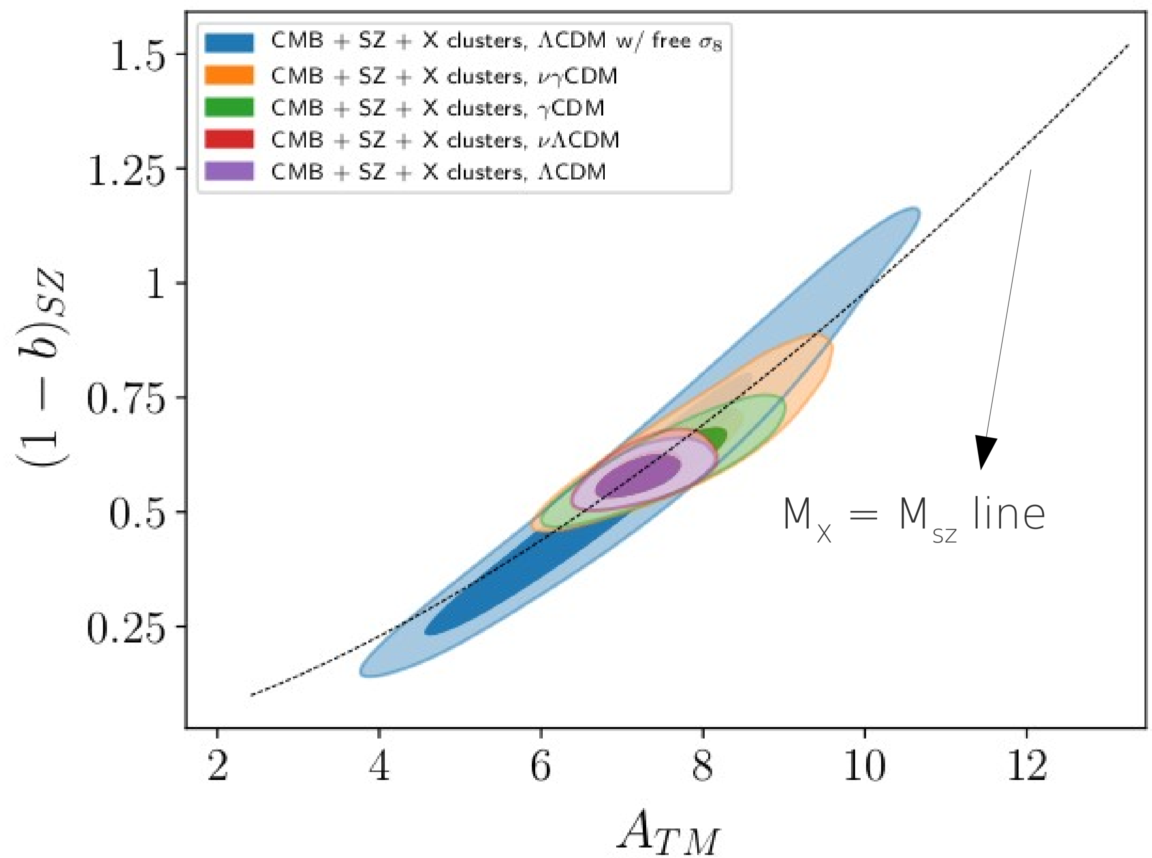

Revisiting the Planck SZ sample

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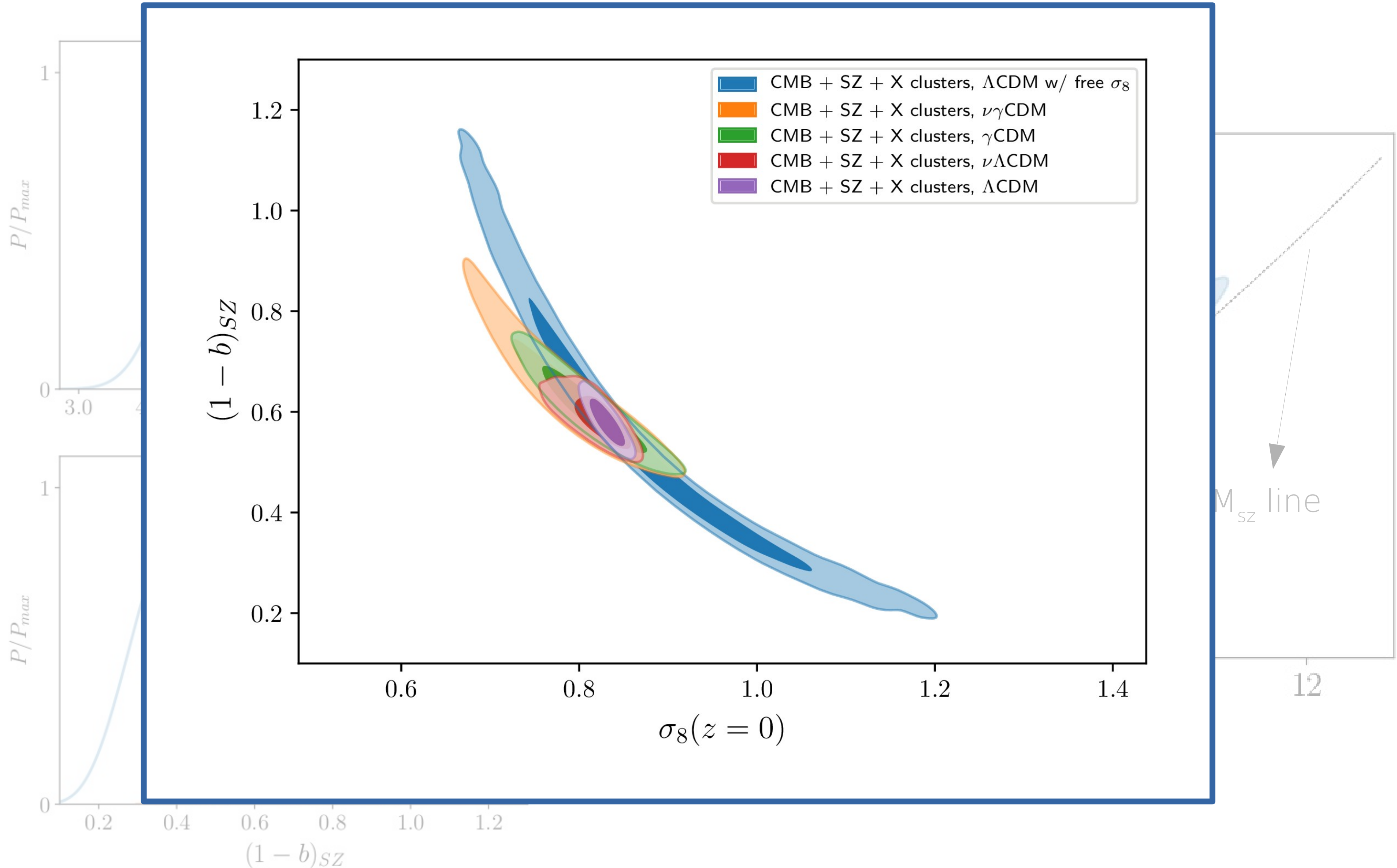

Conclusions and perspectives

Conclusions :

- Remarkable **consistency** across all cosmological scenarios and clusters samples considered
- Non-standard calibration (1-b) ~ 0.6 **observationally preferred**
- Neutrinos cannot solve the CMB-Clusters tension
- If standard calibration (1-b) ~ 0.8 confirmed, **significant departure from ΛCDM required**

Perspectives :

- New surveys (Euclid, LSST) → increased statistics, deeper samples
- New mass calibration opportunities (lensing measurements)
- Application of machine learning techniques ?

Thank you
for your attention !