Impact of the mean pressure profile of galaxy clusters on tSZ cosmological constraints

Florian Ruppin

Observing the millimeter Universe with the NIKA2 camera

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MIT KAVLI INSTITUTE

Planck

NIKA2

Content

I - Cosmology from the tSZ power spectrum

II - Current status of tSZ cosmology

III - Mean pressure profile of the cluster population

IV - Analysis of the *Planck* tSZ power spectrum

V - Impact of a pressure profile modification on σ_8 and Ω_m

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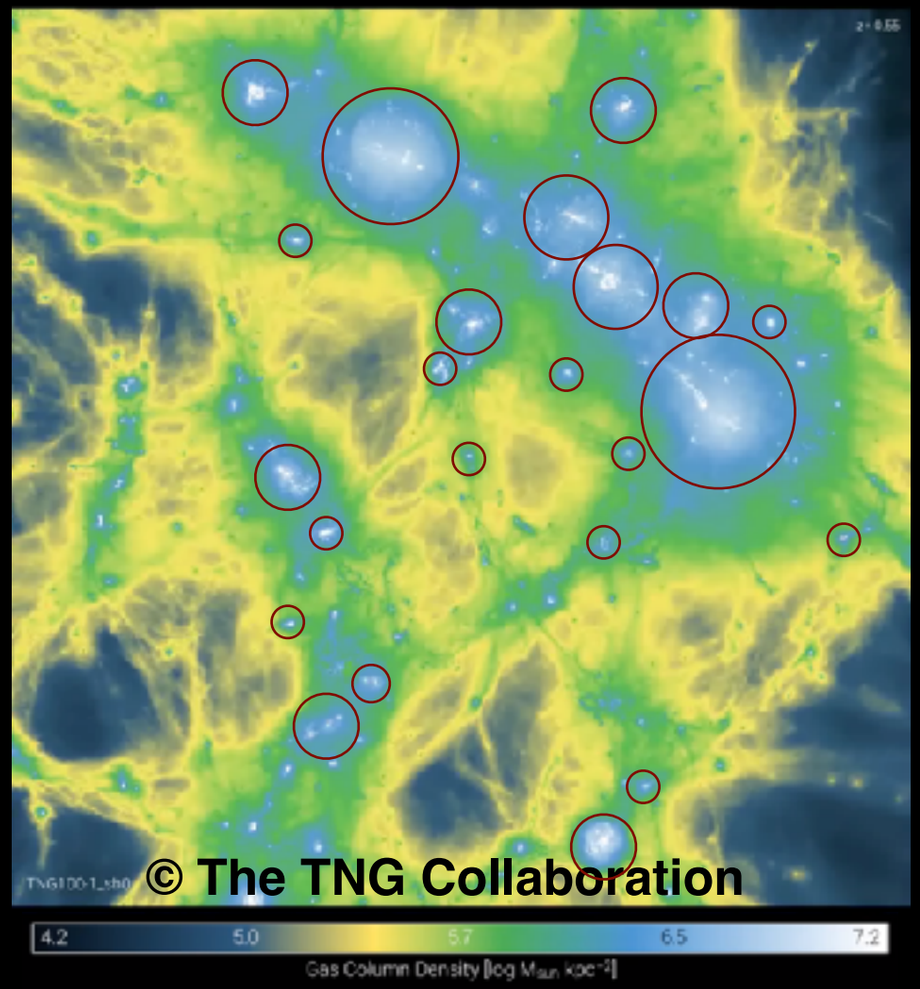
Cosmology from the tSZ power spectrum



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Hierarchical structure formation:

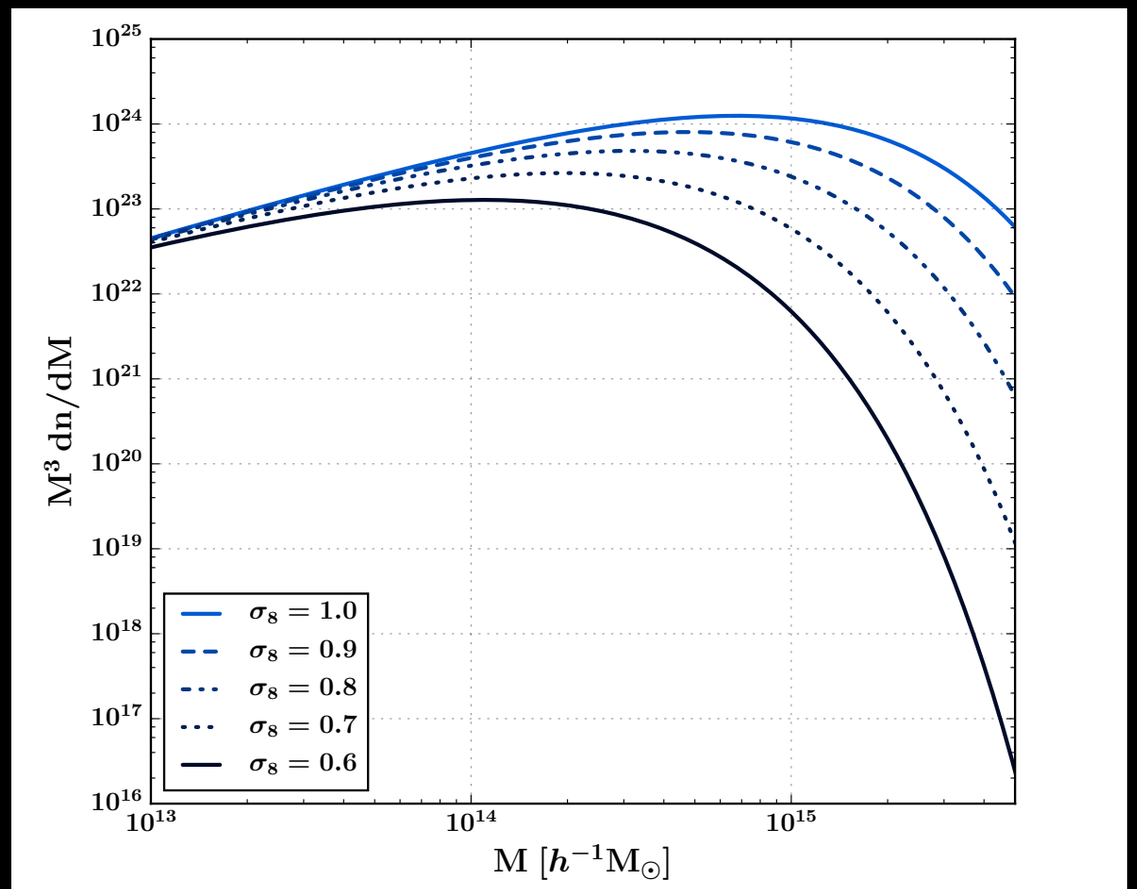
- Little things collapse first, big things collapse later
- The Halo model: spherical collapse + virialization
- Self-similar model: cluster properties given by gravitational physics

Distribution of galaxy clusters:

- Mass function $\dfrac{d^2n}{dMdz}$

  Number density of clusters per unit of mass and redshift
- Large amplitude variations for different σ_8 and Ω_m values

Halo mass function



Cosmology from the tSZ power spectrum

- Power spectrum of the tSZ effect: $C_\ell^{\rm tSZ} = \int \frac{dV}{dz d\Omega} dz \int \frac{dn}{dM_{500}} \left| \frac{4\pi R_{500}}{\ell_{500}^2} \frac{\sigma_T}{m_e c^2} P_{500} I_{\mathcal{P}(\ell_{500})} \right|^2 dM_{500}$

Volume element — *Mass function* — *Scaling parameter*

2D Fourier transform of the mean pressure profile

With $I_{\mathcal{P}(\ell_{500})} = \int x^2 \frac{\sin(\ell x/\ell_{500})}{\ell x/\ell_{500}} \mathcal{P}(x)\, dx$

And $\mathcal{P}(x)$: the **mean pressure profile**

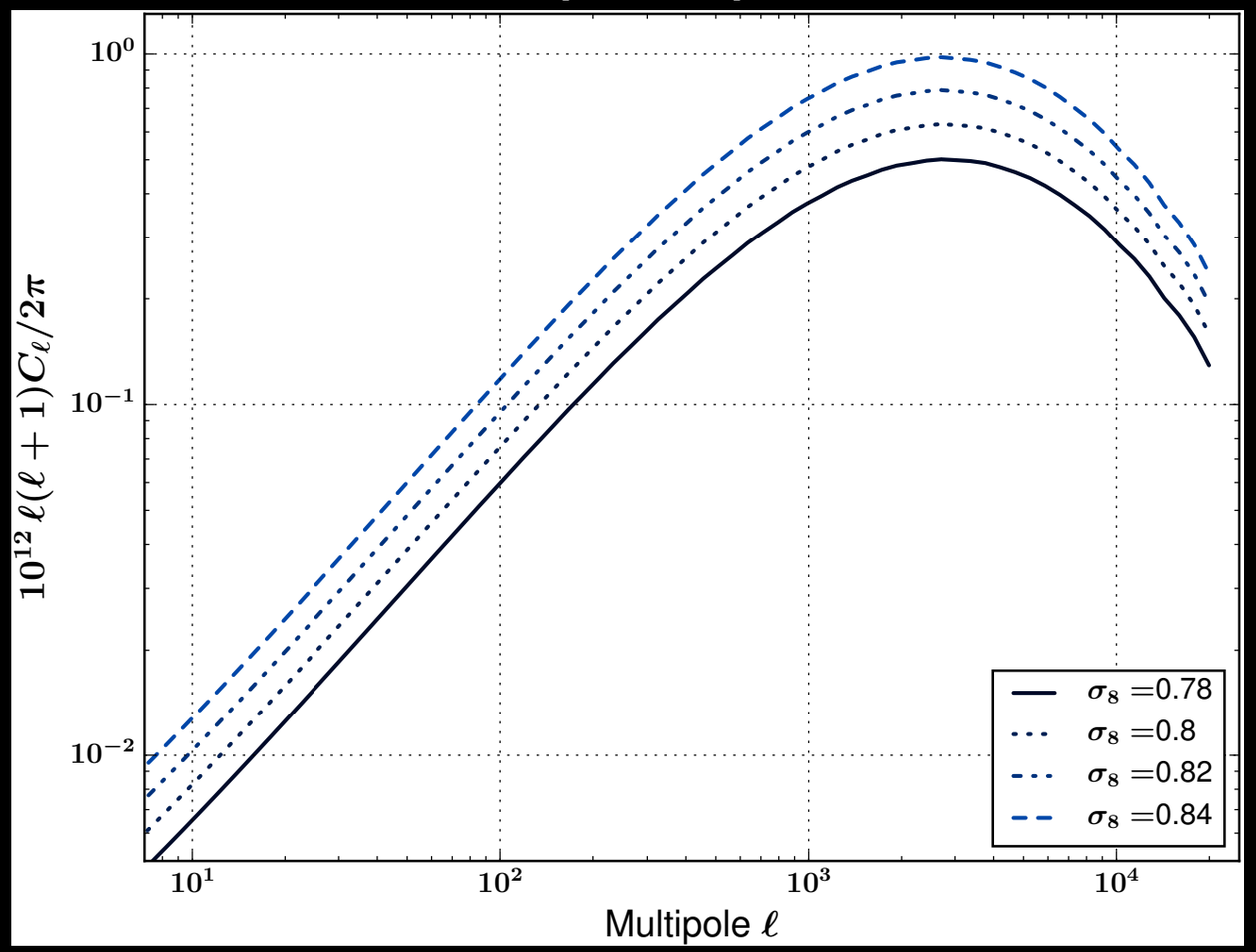
- **Amplitude of the tSZ power spectrum depends on:**

σ_8 and Ω_m: amplitude of the mass function

Hubble parameter h: volume element

Hydrostatic bias b: included in the scaling parameter

tSZ power spectrum



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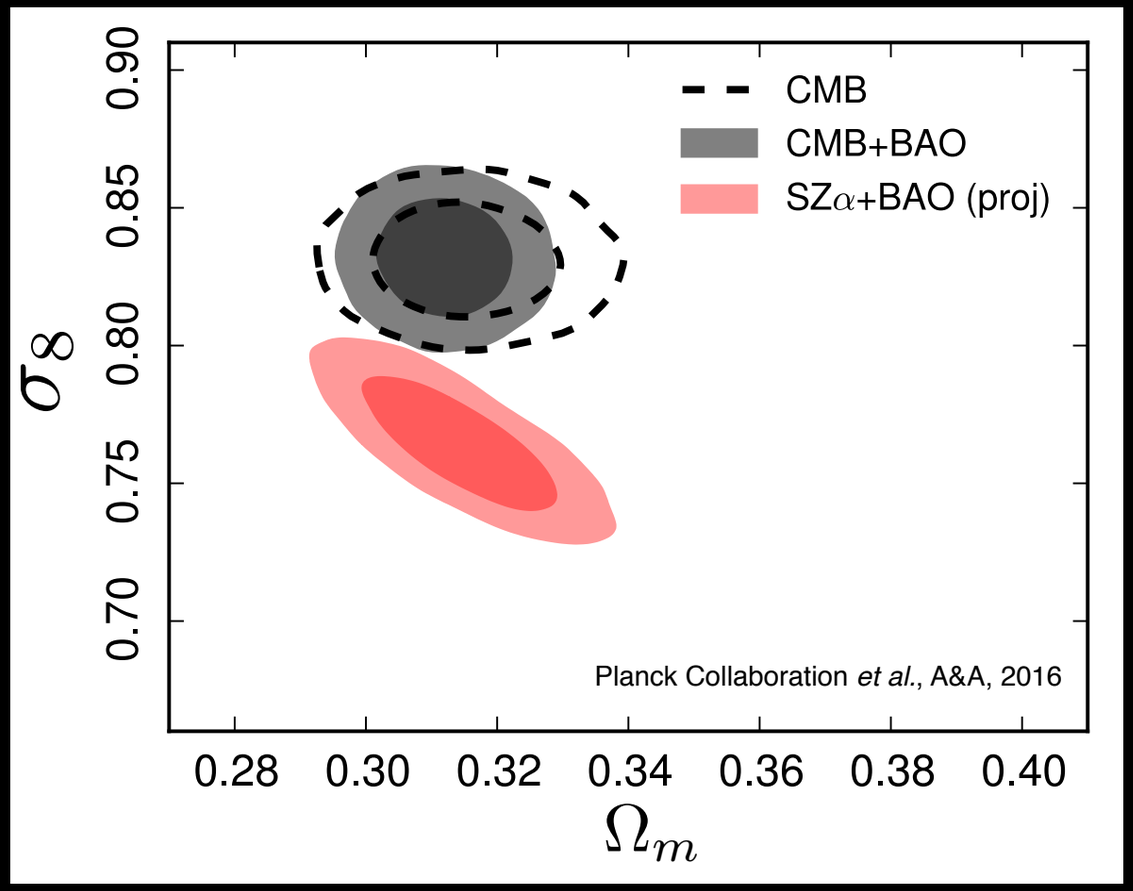


Tension between cosmological constraints from CMB and *Planck* cluster catalog for $b = 0.2$

Option 1: Limit in the standard $\Lambda\mathrm{CDM}$ model

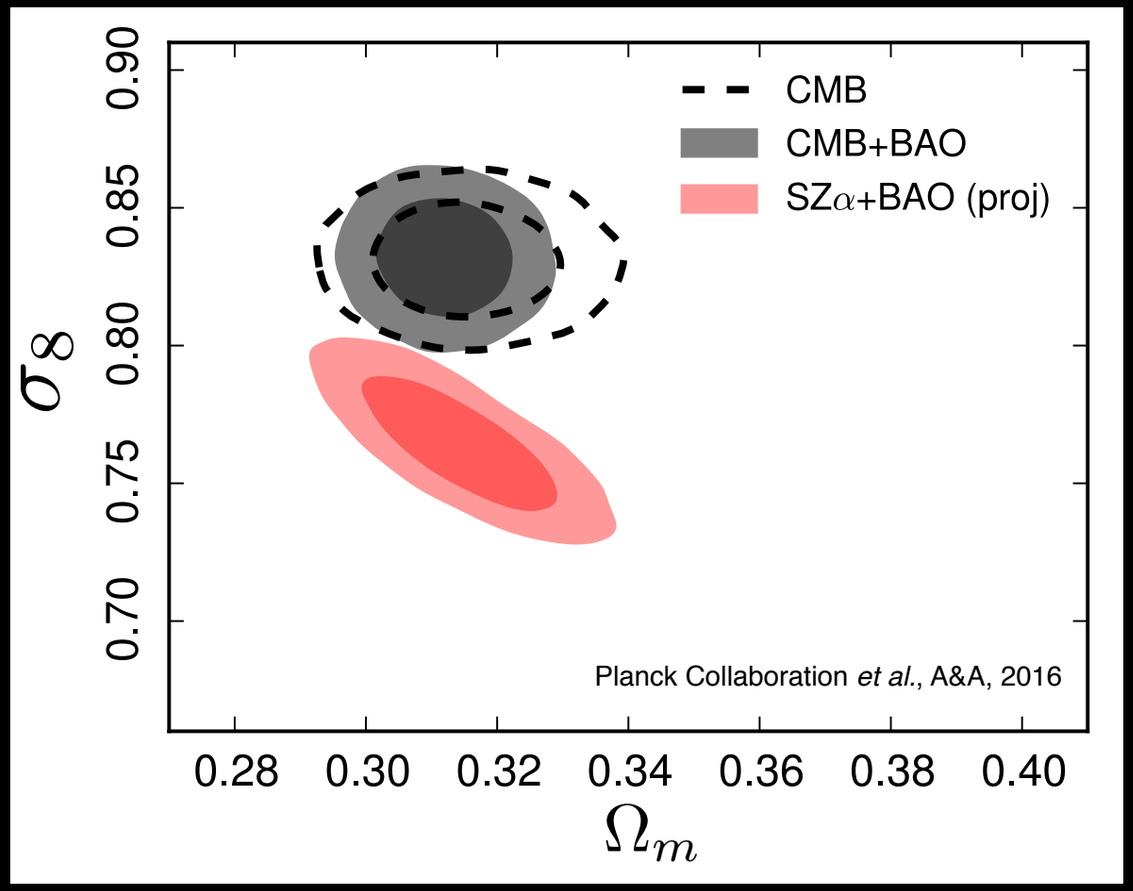
- Neutrino mass
- Modified gravity
- Etc.

Option 2 : Bias and systematic effects

- Wrong estimate of hydrostatic bias
- Pressure profile and scaling relation at $z \gtrsim 0.4$

1st Assumption: tension not due to limit in $\Lambda\mathrm{CDM}$ model

Current status of tSZ cosmology



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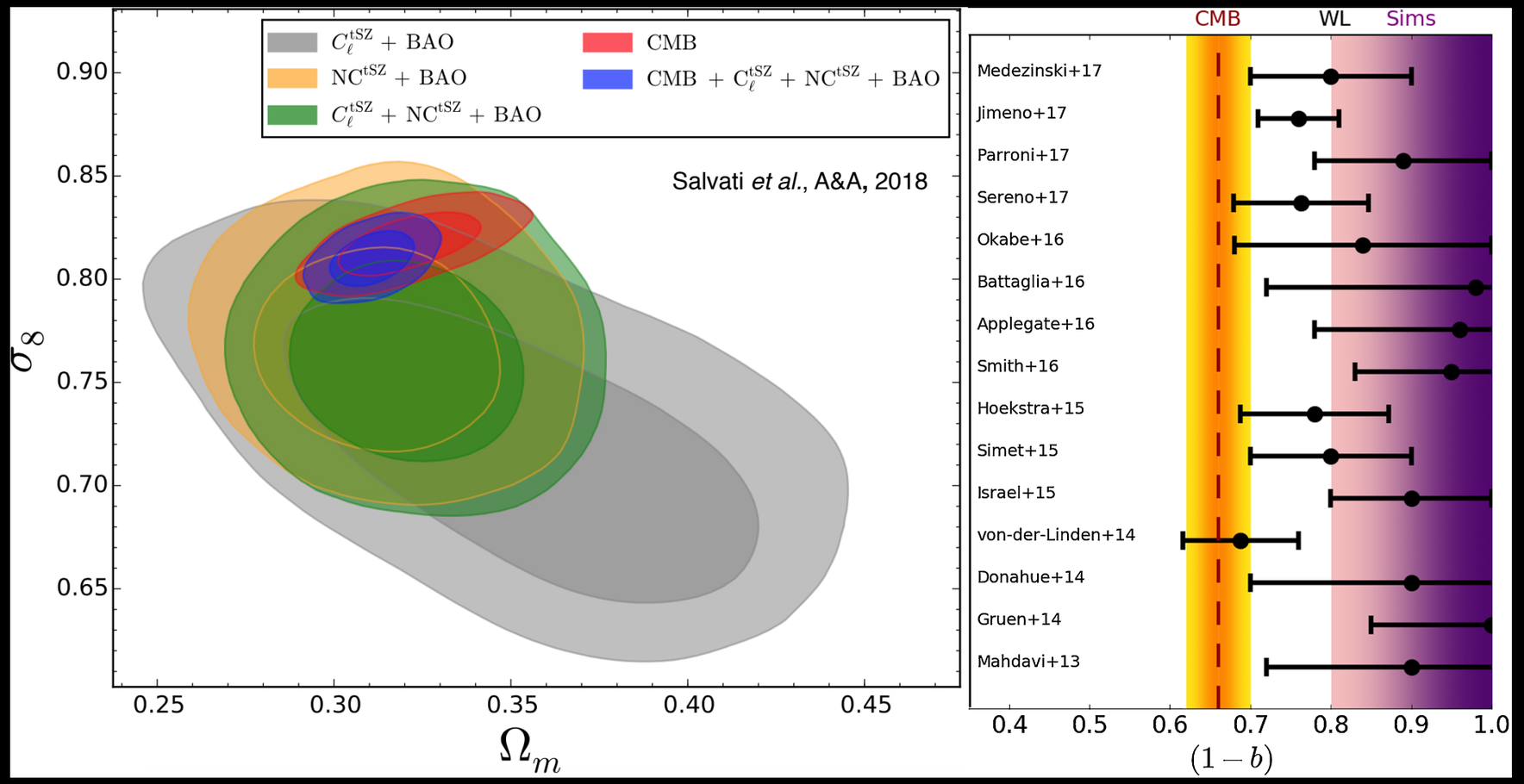

- **Most recent analyses:** - take into account new *Planck* cosmology
  - take into account uncertainties on mass bias measurements

→ **Tension between cosmological parameters is not significant**

- **Joint analysis CMB+clusters** → $b \sim 0.4$ **in tension with values from observations+simulations**

2nd Assumption: tension not fully due to wrong estimate of hydrostatic bias

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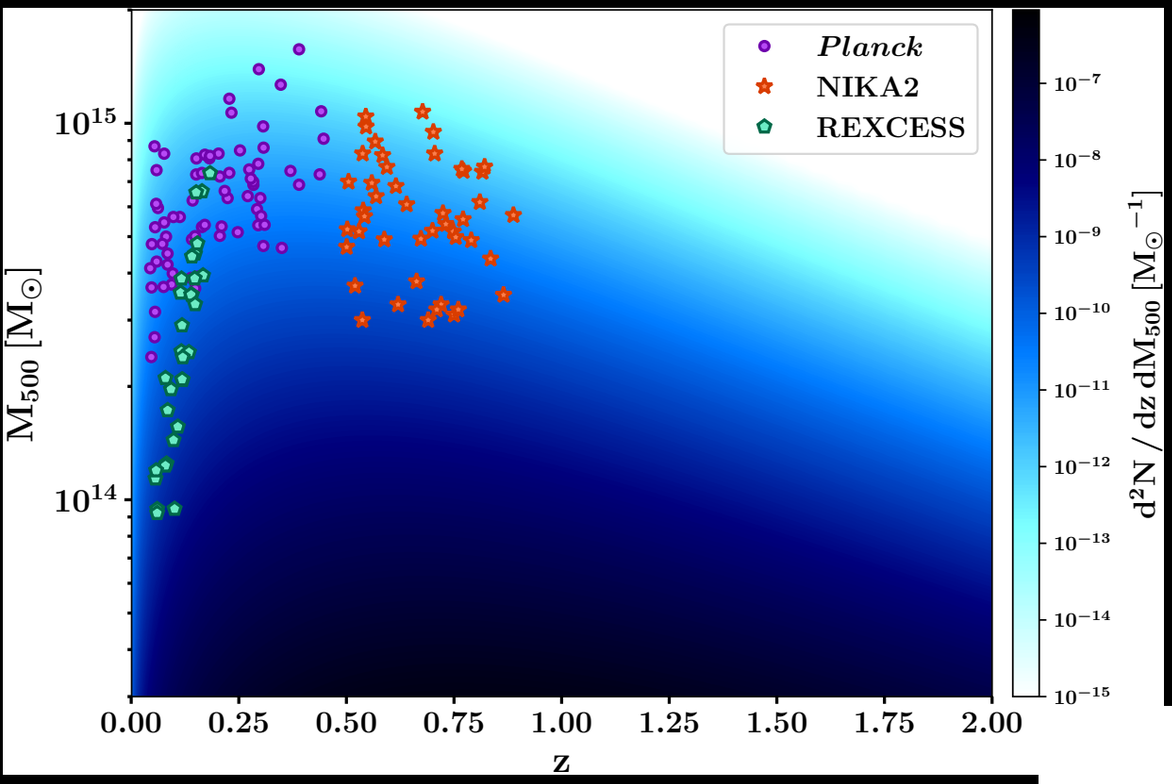

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- **Mean pressure profile:**
  amplitude of the tSZ power spectrum and shape at high ℓ
- **Most widely used profiles:**
  computed at high mass and low redshift $z \lesssim 0.4$

Potentially not representative of the cluster population

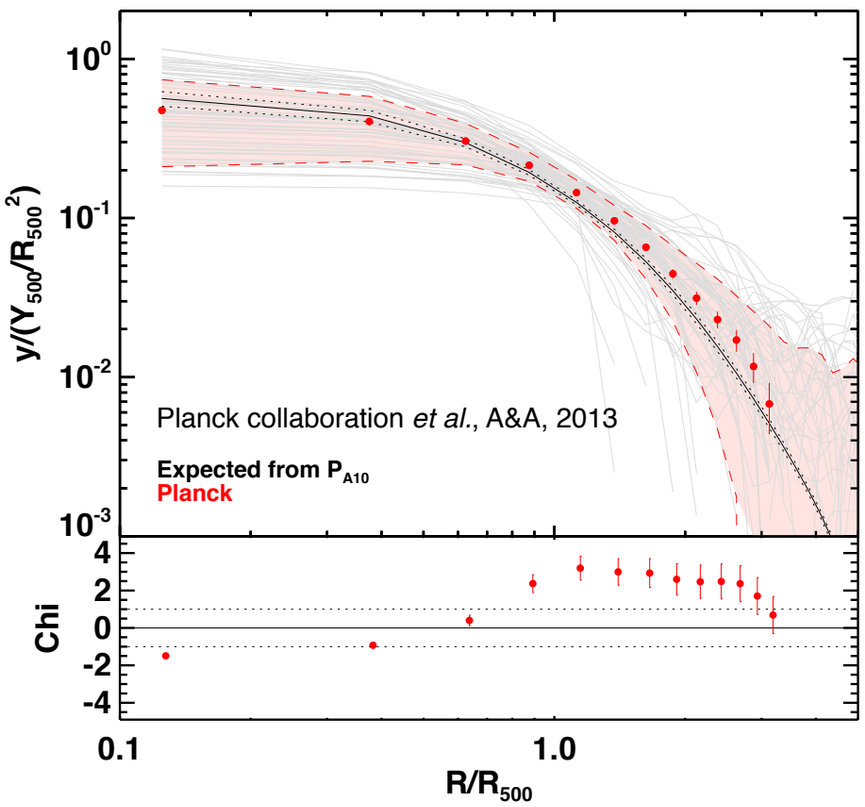
- Slight difference between outer slopes of *Planck* and REXCESS profiles

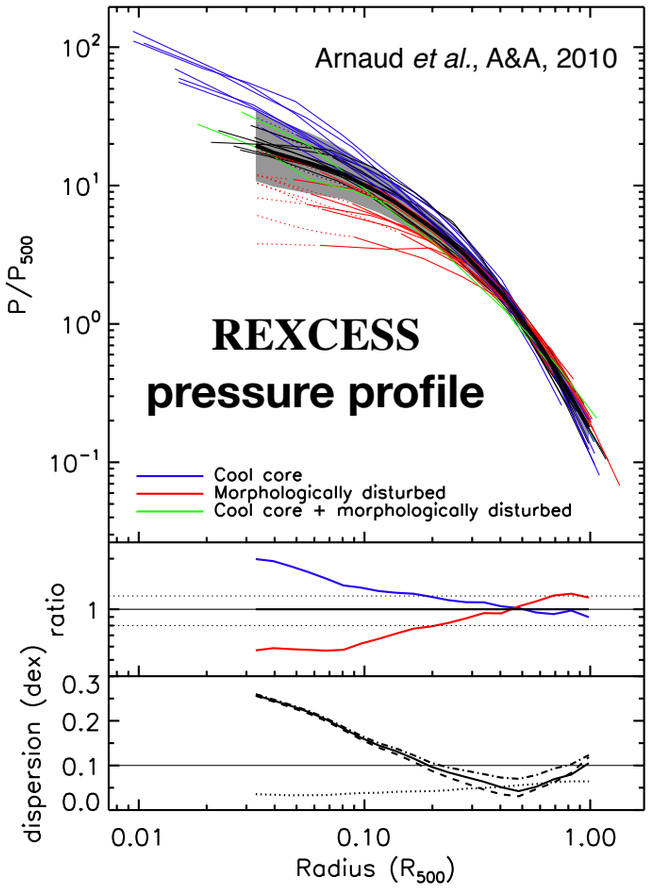
  → ICM thermodynamics in **X and SZ**

- **Redshift evolution:**
  - relaxed VS disturbed cores/morphologies

- **Importance of the intrinsic scatter:**
  - selection function, distribution skewness

***Planck* pressure profile**





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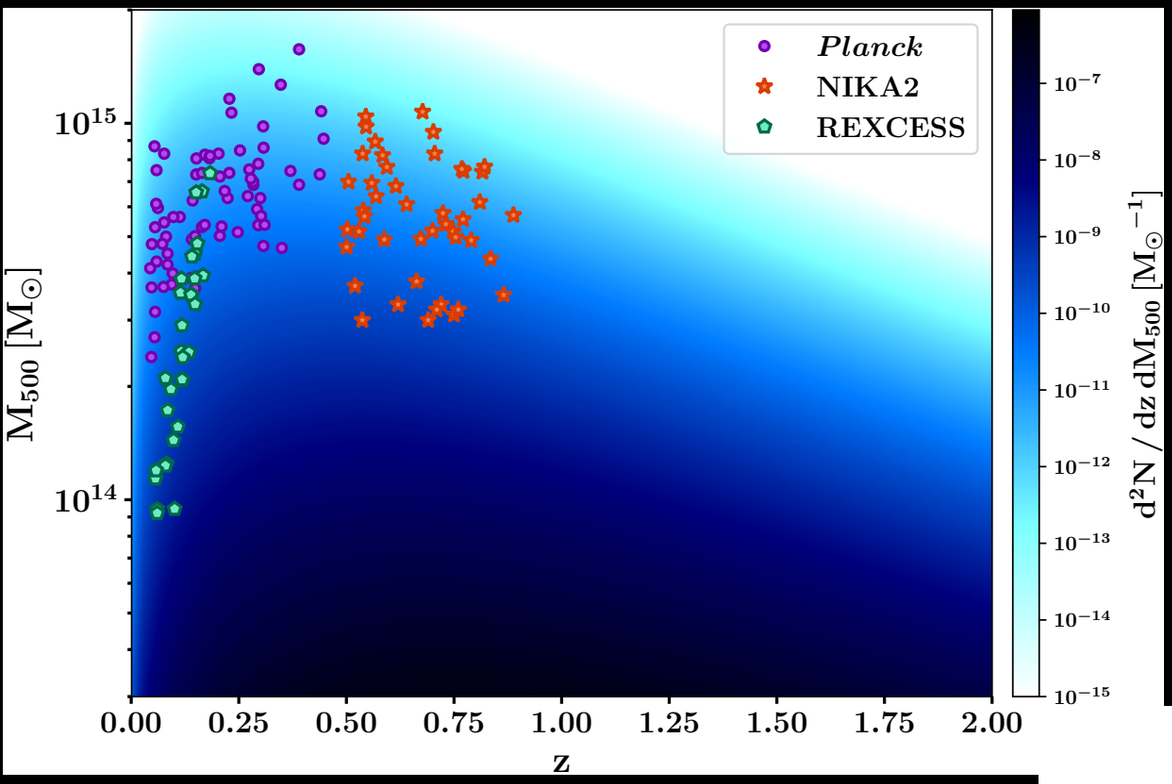

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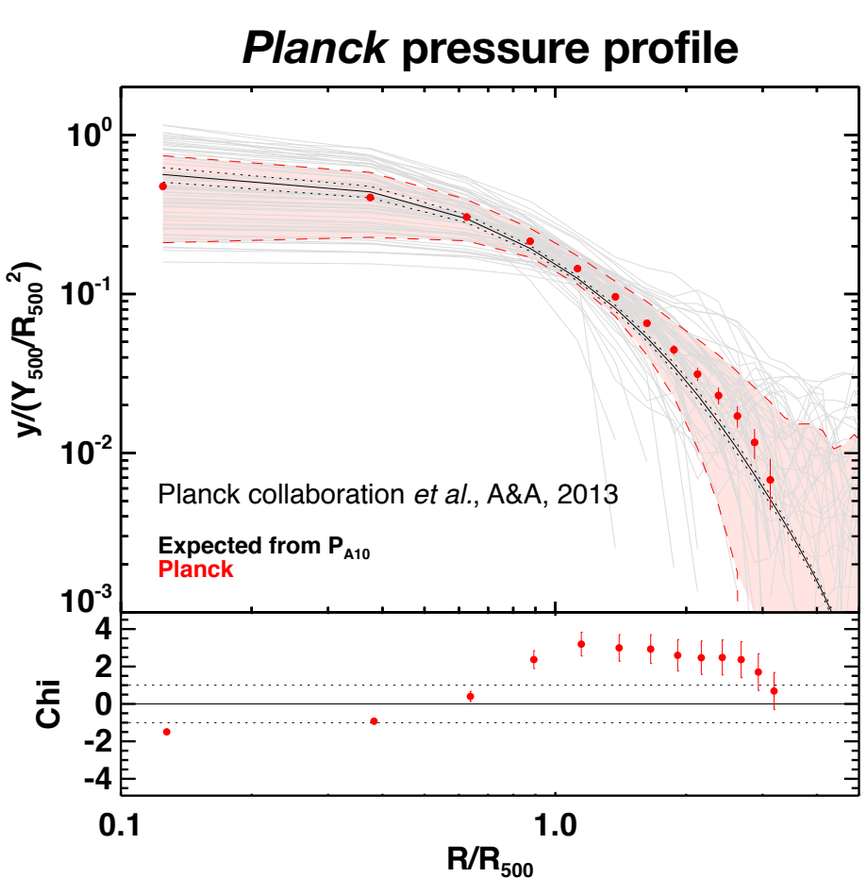

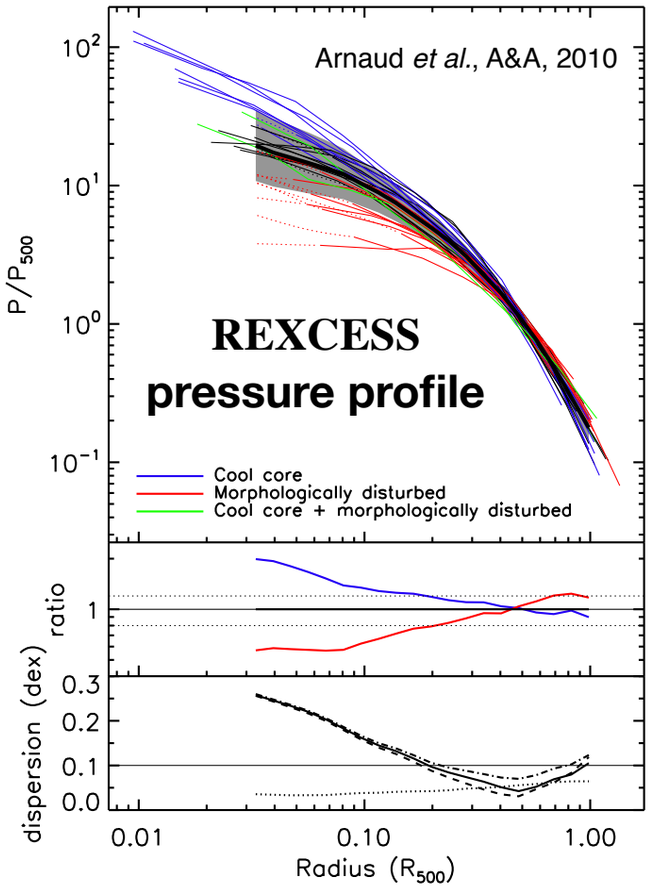

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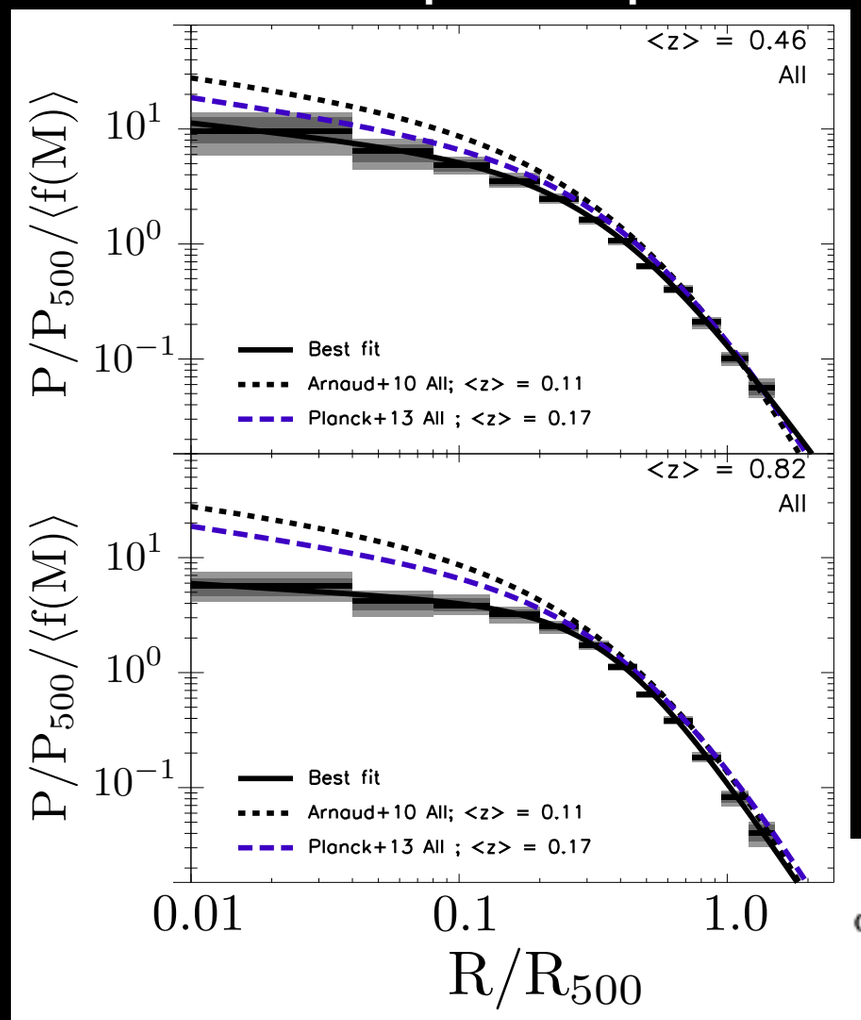
Mean normalized pressure profiles



Eckert et al., A&A, 2013

Eckert et al., A&A, 2019

- **Observed redshift evolution of the mean pressure profile:**
  - In X-ray: ICM seems slightly cooler at high z *(McDonald et al., ApJ, 2014)*
  - In SZ: on-going NIKA2 SZ large program, 45 clusters at $0.5 < z < 0.9$

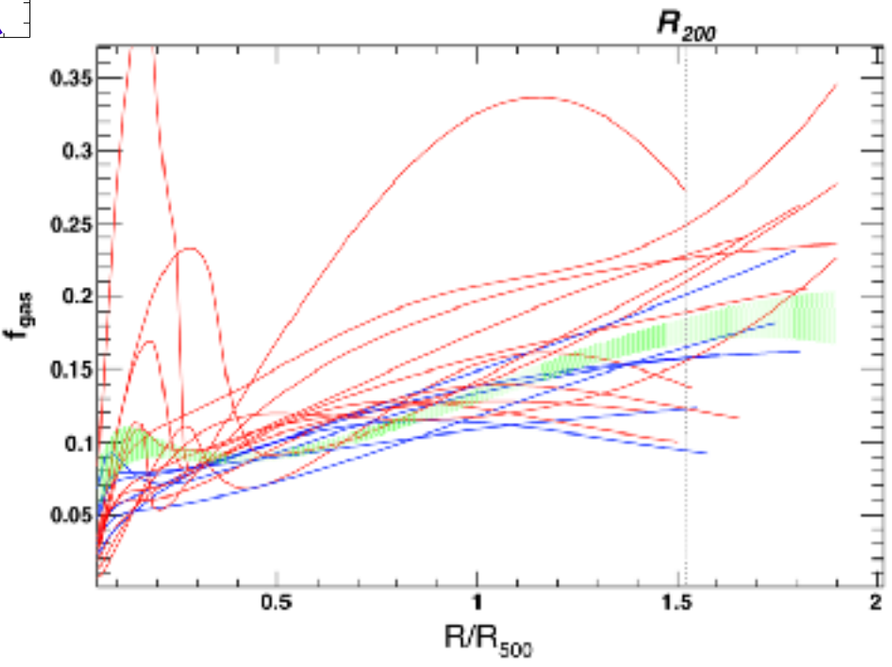
- **Importance of the gas mass fraction:**

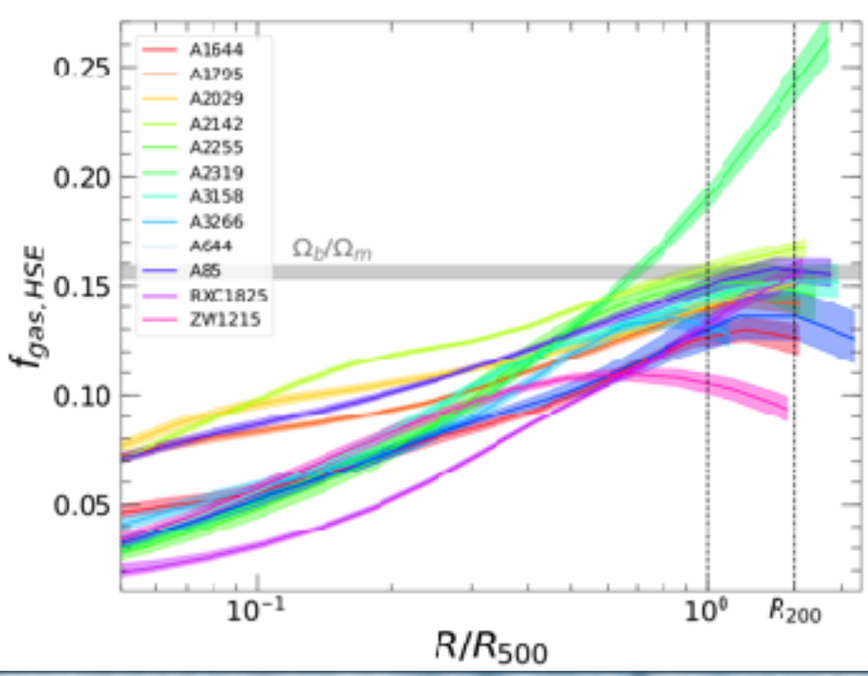
Hydrostatic mass: $M_{HSE}(r) \propto \frac{r^2}{n_e(r)} \times \frac{d\,P_e(r)}{dr}$

ICM density — ICM pressure

For a given cluster mass: less gas → less thermal pressure

Gas mass fraction profiles





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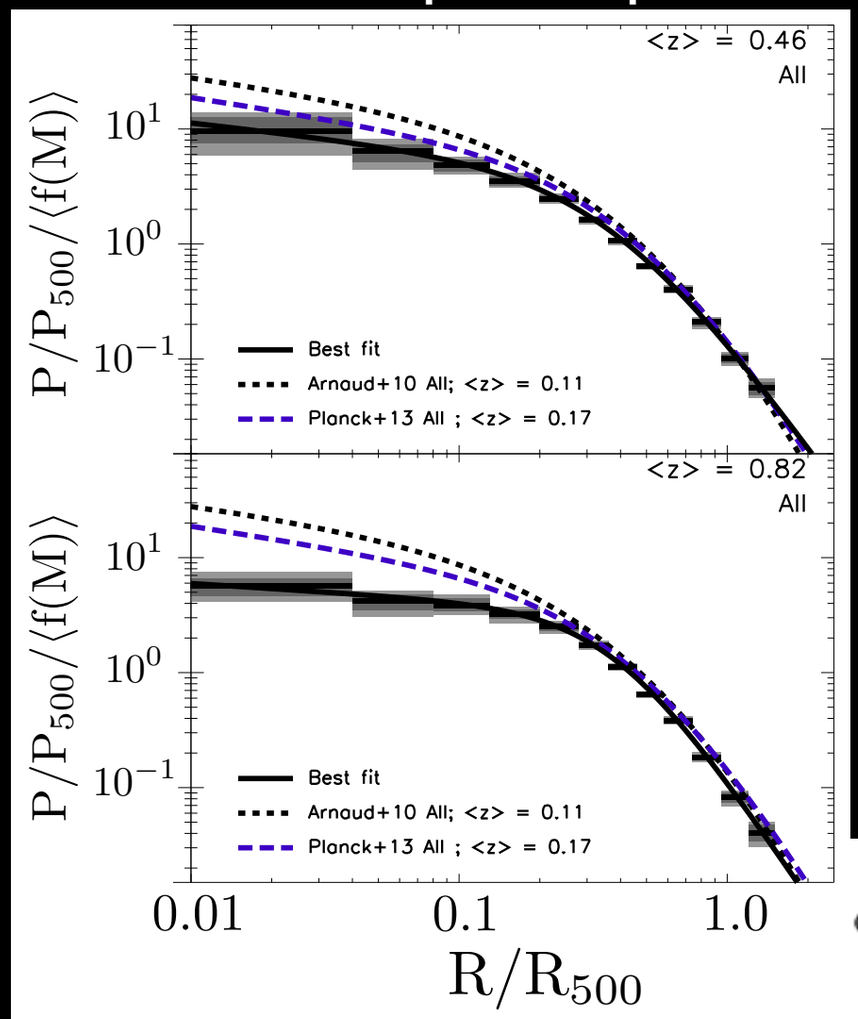

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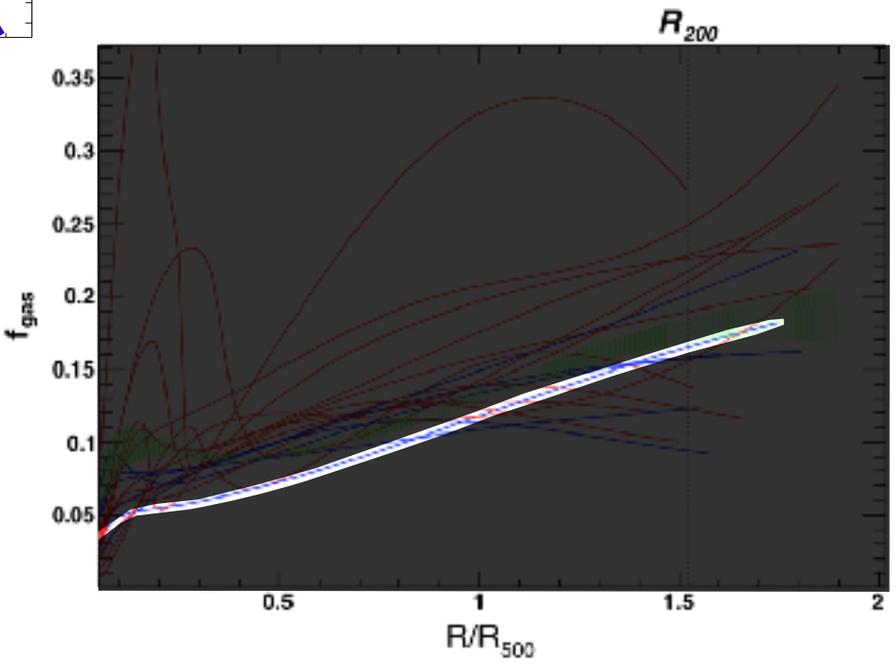

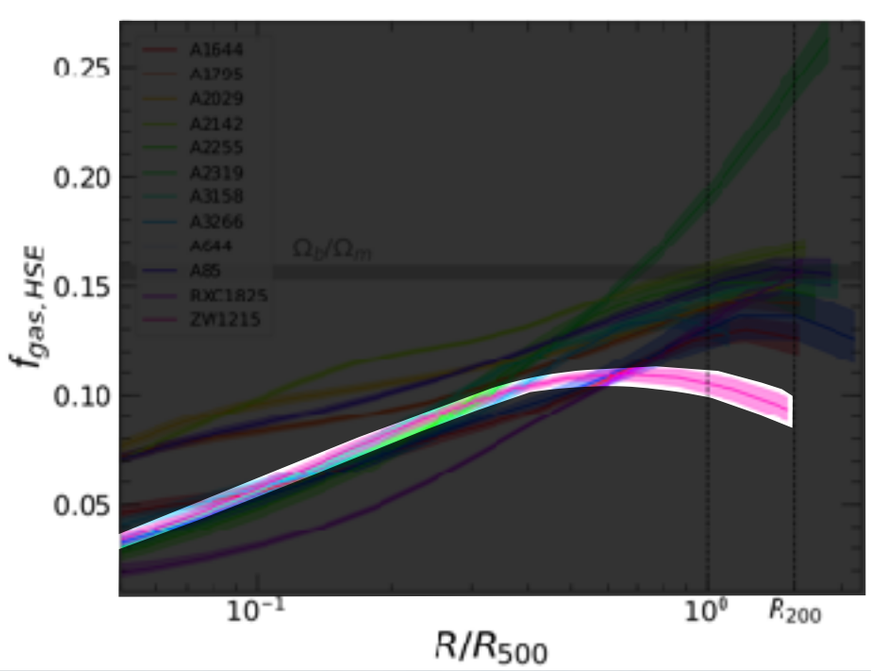

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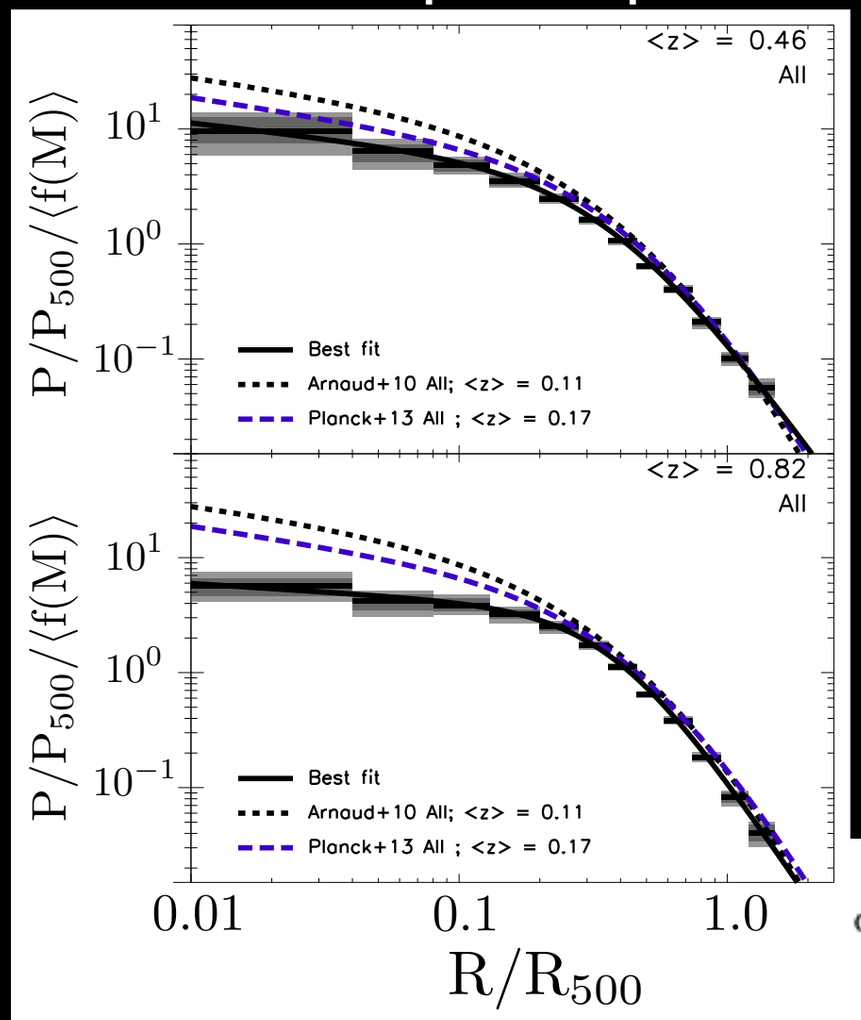

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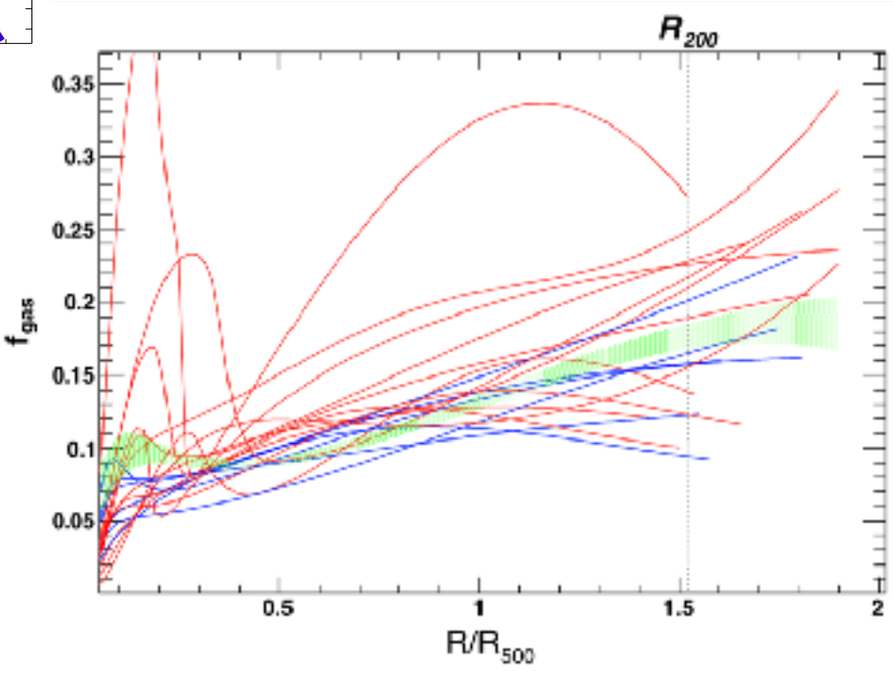

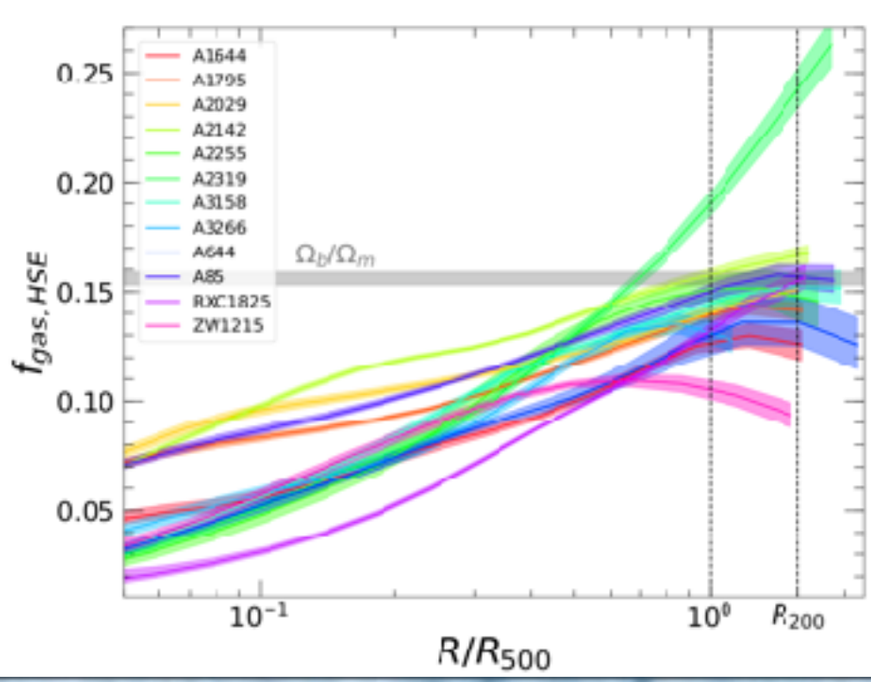

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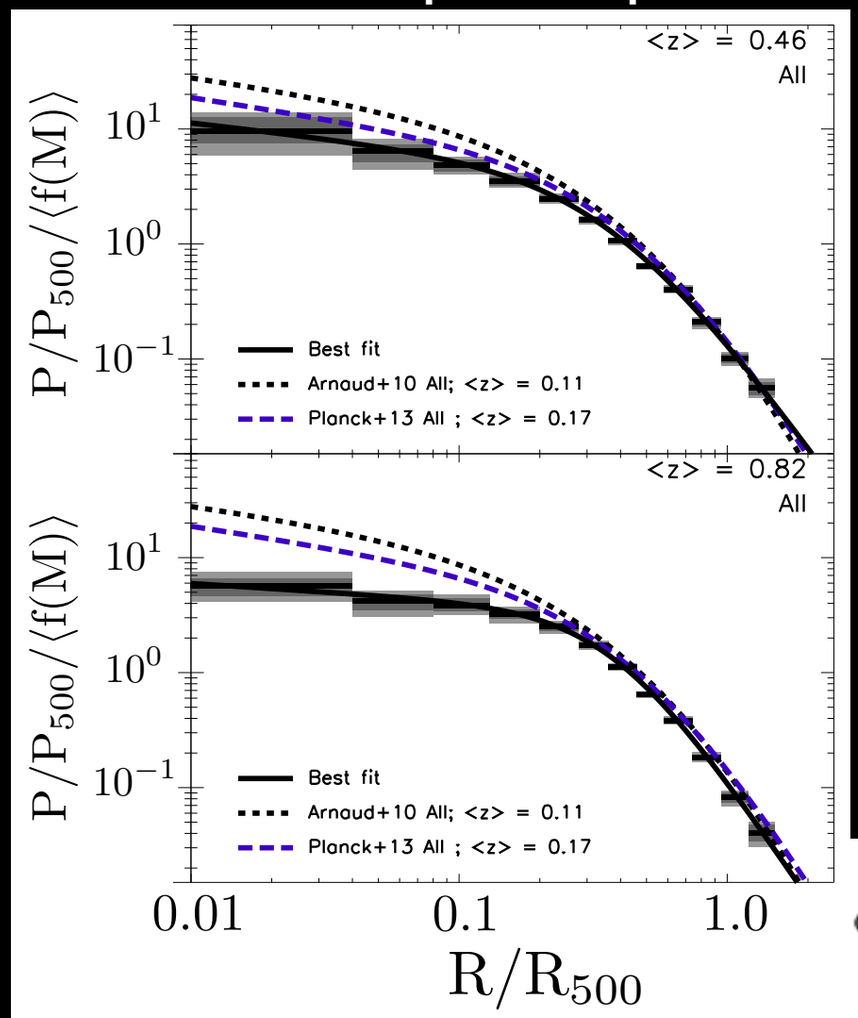

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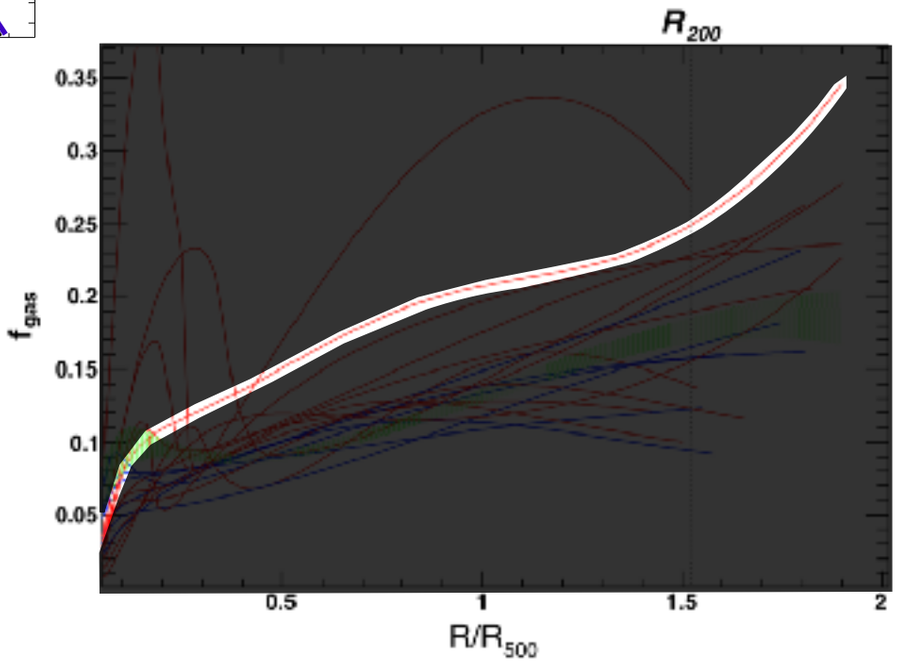

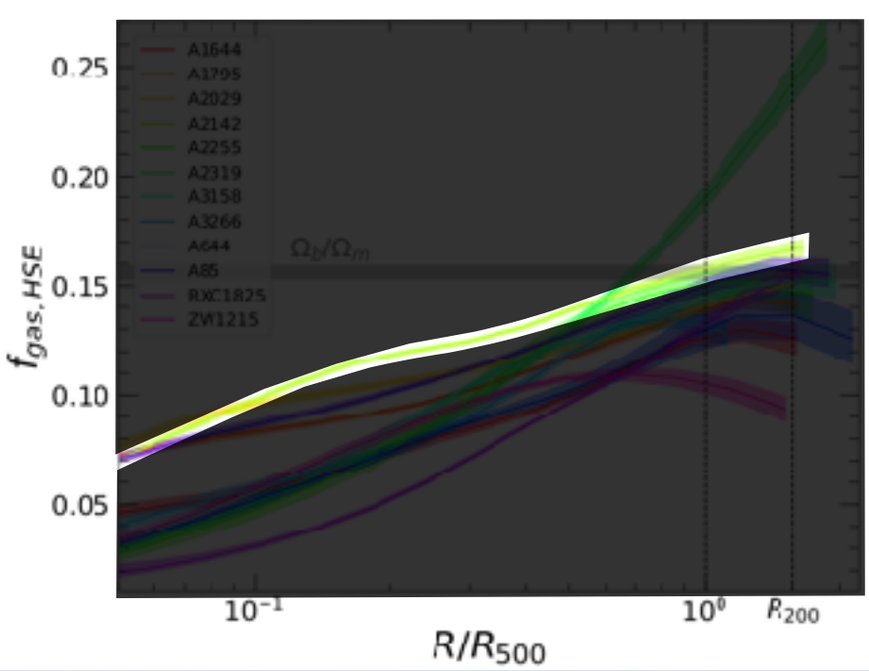

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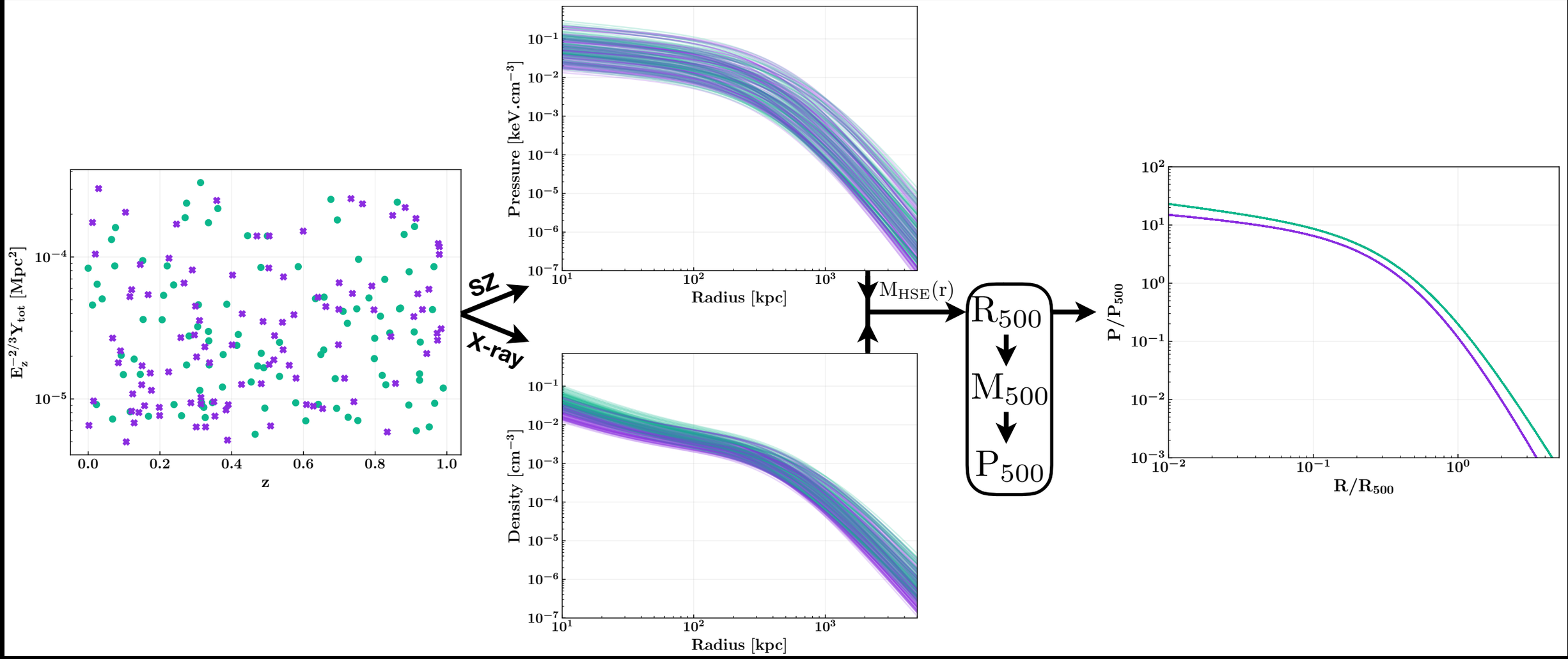
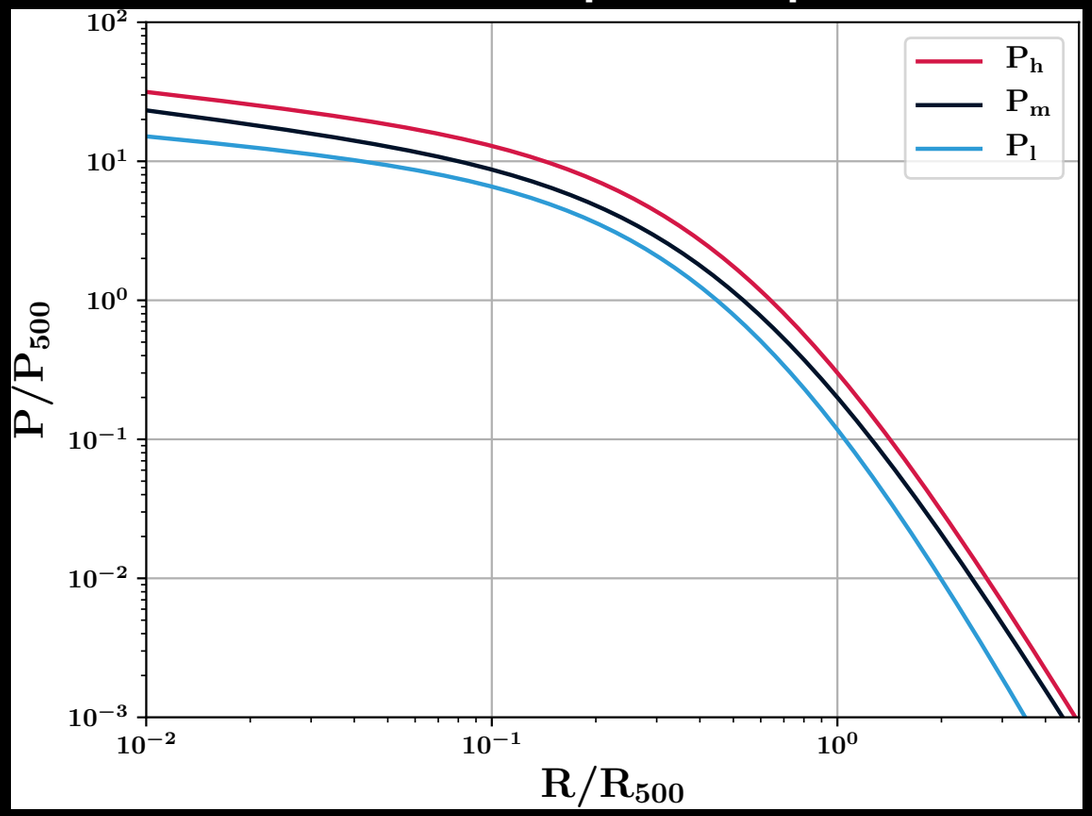


- **Impact of gas mass fraction on mean pressure profile:**
  - Similar distributions of clusters in $\mathrm{Y_{tot}} - z$ plane
  - Pressure profiles and density profiles with different gas mass fractions → hydrostatic mass profiles
  - Scale pressure profiles using same definition of $P_{500} \propto E_z^{8/3} M_{500}^{2/3+0.12}$

Similar distributions in $\mathrm{Y_{tot}}$ but different mean normalized pressure profiles

Mean pressure profile of the cluster population

Mean normalized pressure profiles



Definition of three **mean pressure profiles**

- The mean pressure profile of the *Planck* collaboration
  Similar to the A10 profile used for cosmological analyses
- Two extreme cases given:
  - The intrinsic scatter of the profile distributions at low z
  - Current constraints on the gas mass fraction profiles

Associated gas mass fraction profiles

Gas mass fraction profiles knowing z, M_{500}, and $\mathbb{P}(x)$:

- Assume NFW model for mass profile $M_{\rm tot}(r)$
- Hydrostatic mass profile: $\begin{cases} M_{\rm HSE}(r) = (1-b)M_{\rm tot}(r) \\ b \in [0, 0.4] \end{cases}$
- Density profile from HSE mass and pressure profile

Gas mass fraction: $f_{\rm gas}(r) = M_{\rm gas}(r)/M_{\rm tot}(r)$

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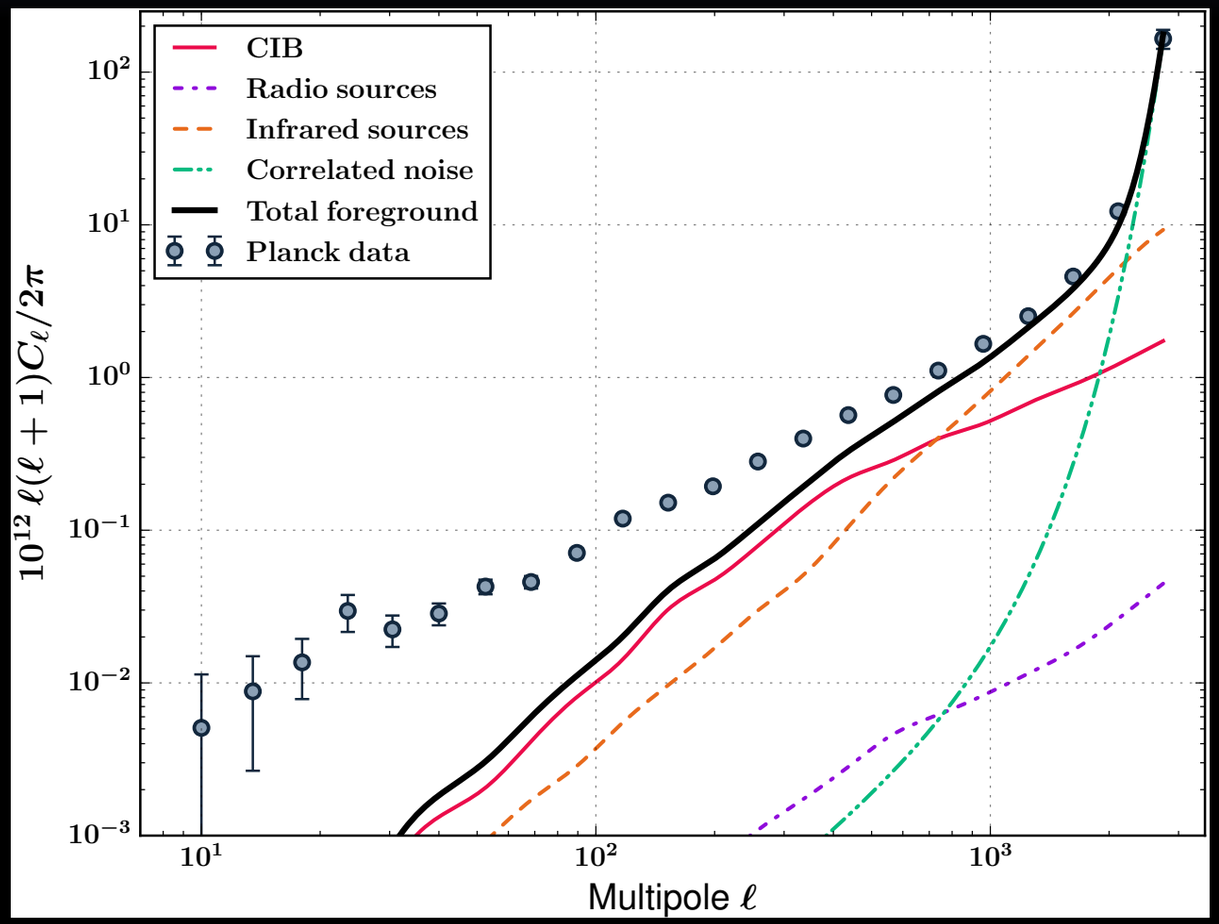


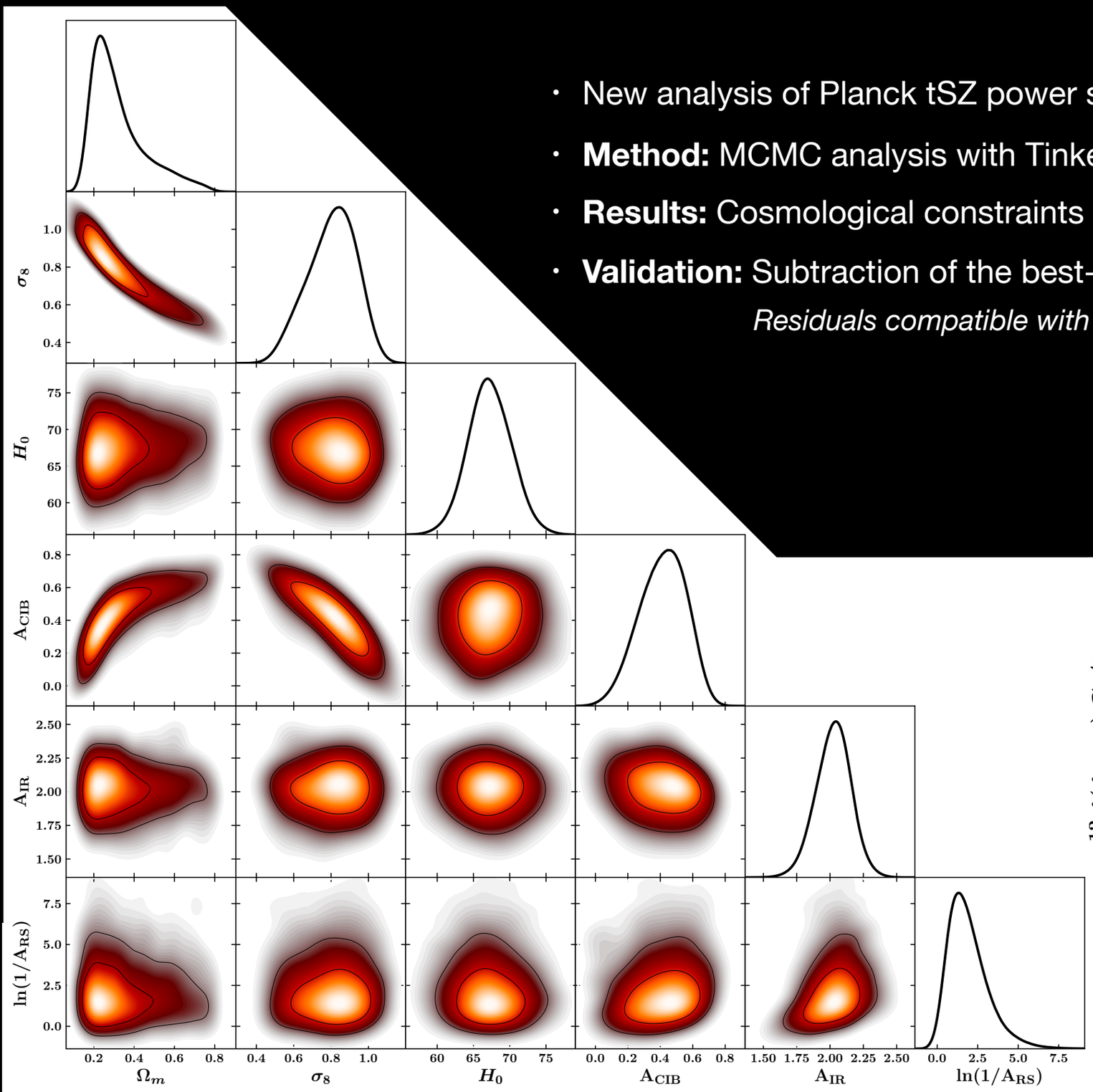
- Use angular power spectrum of the tSZ effect measured by *Planck* *Planck collaboration et al., A&A, 2016*
- **Power spectrum components:**
  - tSZ power spectrum
  - Contaminants:
    - Cosmic Infrared Background (CIB)
    - Radio and Infrared sources
    - Spatially correlated noise

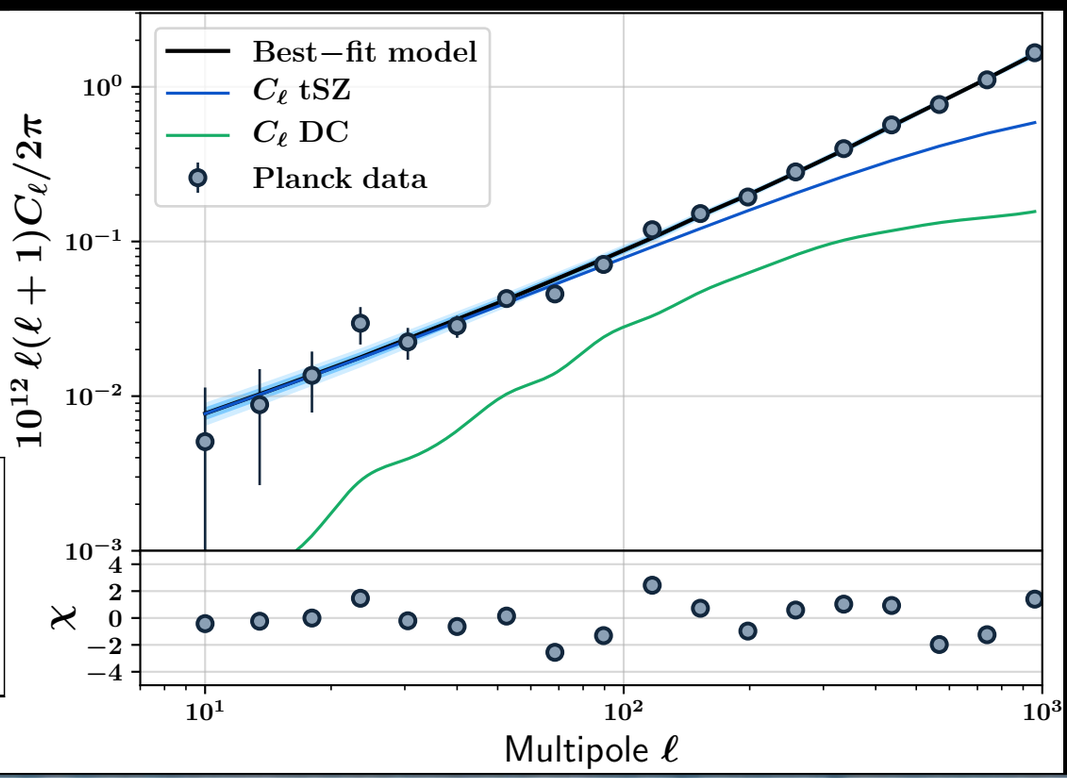
Fit *Planck* power spectrum for $\ell < 1000$

Analysis of the *Planck* tSZ power spectrum

- New analysis of Planck tSZ power spectrum with the three mean pressure profiles
- **Method:** MCMC analysis with Tinker *et al.* mass function
- **Results:** Cosmological constraints + amplitude of contaminant power spectra
- **Validation:** Subtraction of the best-fit model to the Planck data

  Residuals compatible with noise at all ℓ





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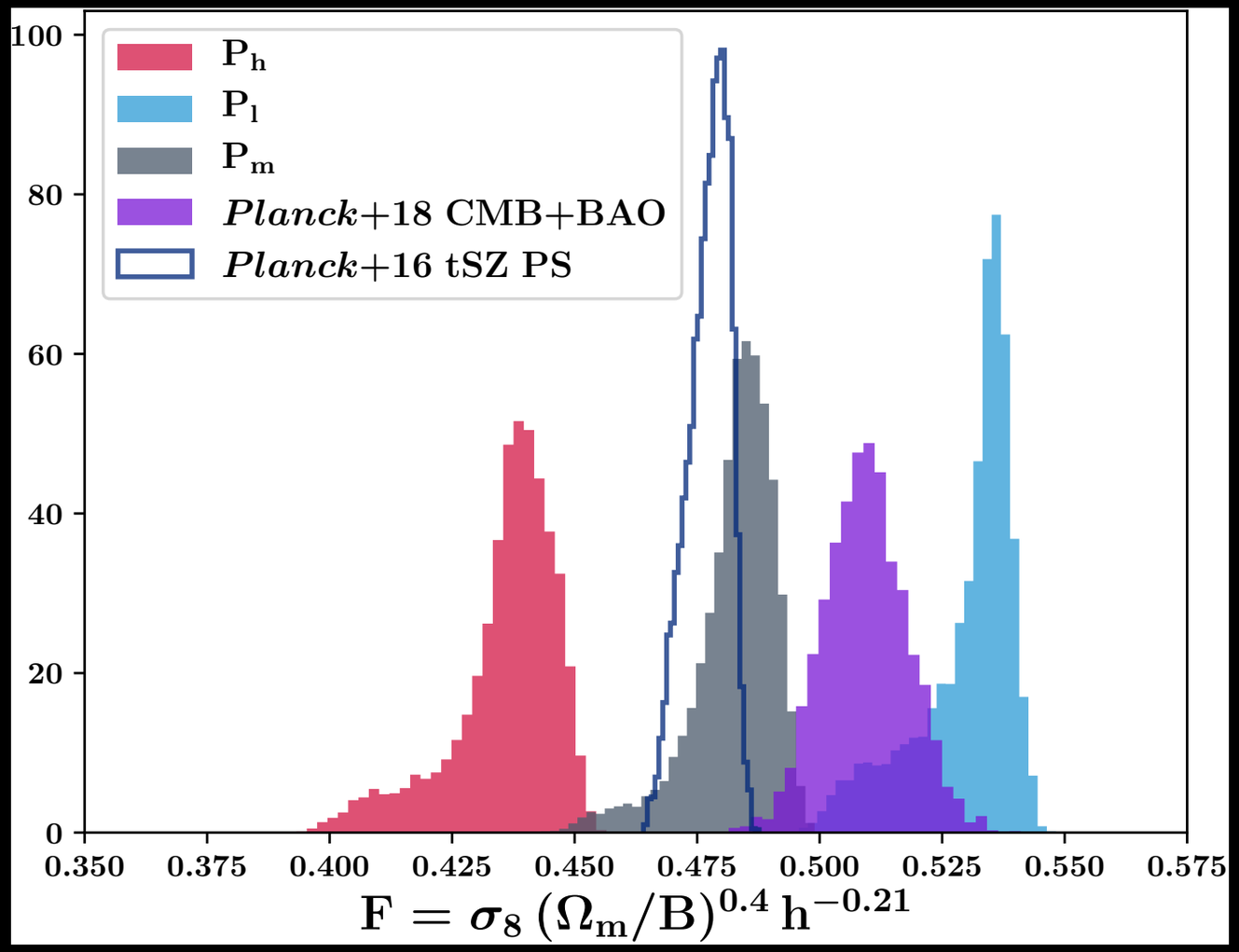
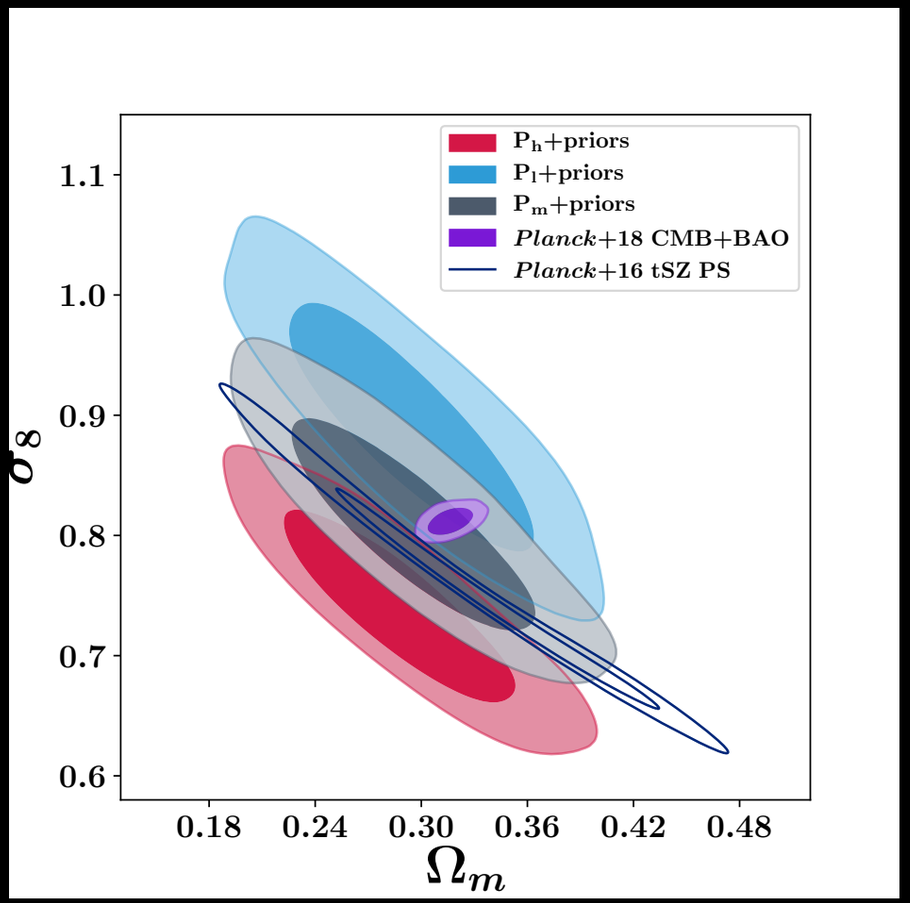


- **Cosmological constraints:** significant differences for the three mean pressure profiles
- Estimates obtained with $\mathbb{P}_m$ profile compatible with previous constraints
- CMB constraints enclosed between the ones obtained with $\mathbb{P}_m$ and $\mathbb{P}_l$ profiles

Cosmological tension can be solved with mean pressure profile variations

Impact of the pressure profile on tSZ cosmology



- Prior on:
  - b *Lensing VS X-ray/SZ mass* → $b = 0.2 \pm 0.08$
  - Ω_m *Baryon acoustic oscillations (BAO)* → $\Omega_m = 0.3 \pm 0.05$

- Cosmological constraints on σ_8 and Ω_m

No significant tension between CMB and tSZ PS constraints with $\mathbb{P}_m$

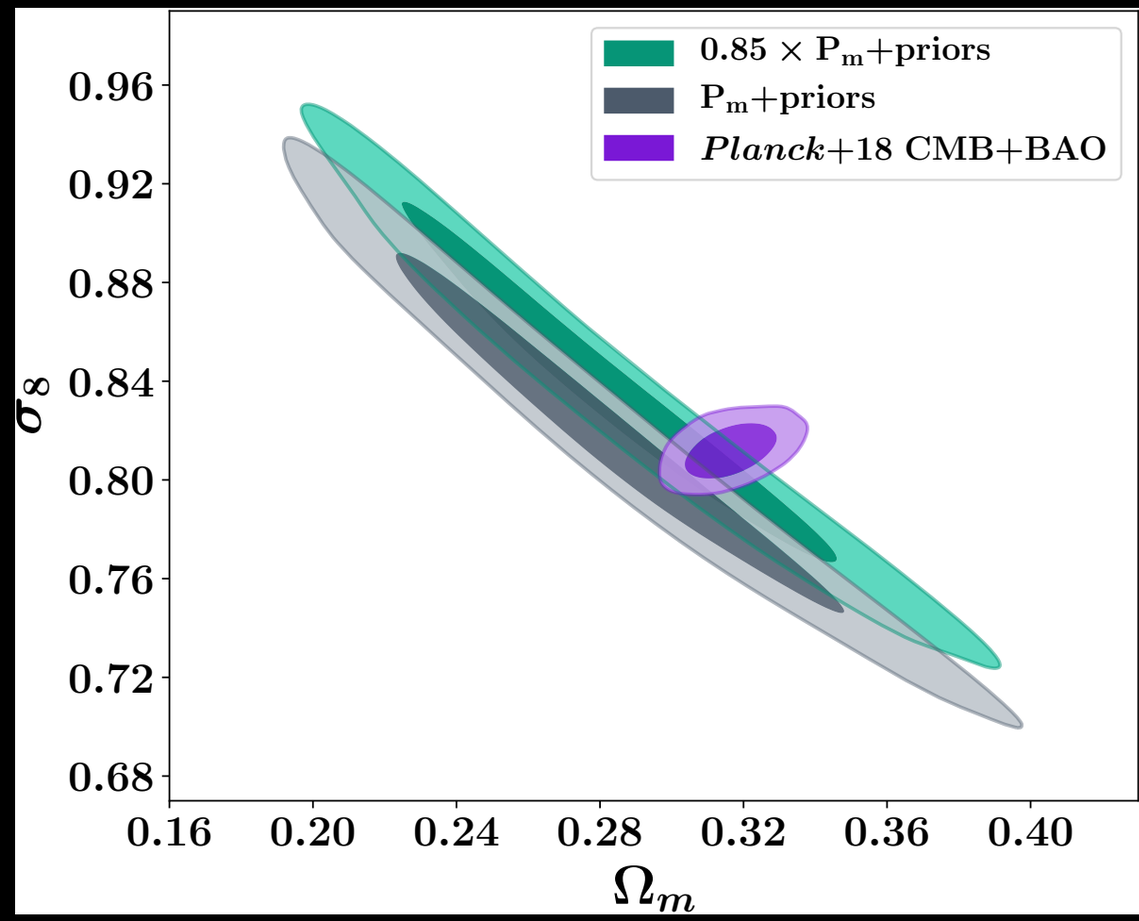
- **Possible future?**

  Prior on hydrostatic bias $b = 0.2 \pm 0.01$

  Better lensing mass estimates with e.g. Euclide

  → Tension with current CMB constraints

15% decrease of mean pressure profile → tension canceled



Conclusions / Perspectives

- If everything is taken into account: no cosmological tension **BUT** issue with hydrostatic bias value
  → Need to explore other sources of bias in tSZ cosmological analyses
- Mild indications of redshift evolution of ICM profiles
  → Wrong calibration of mean normalized pressure profile = potential source of bias
- New analysis of *Planck* tSZ power spectrum using extreme cases for mean pressure profile
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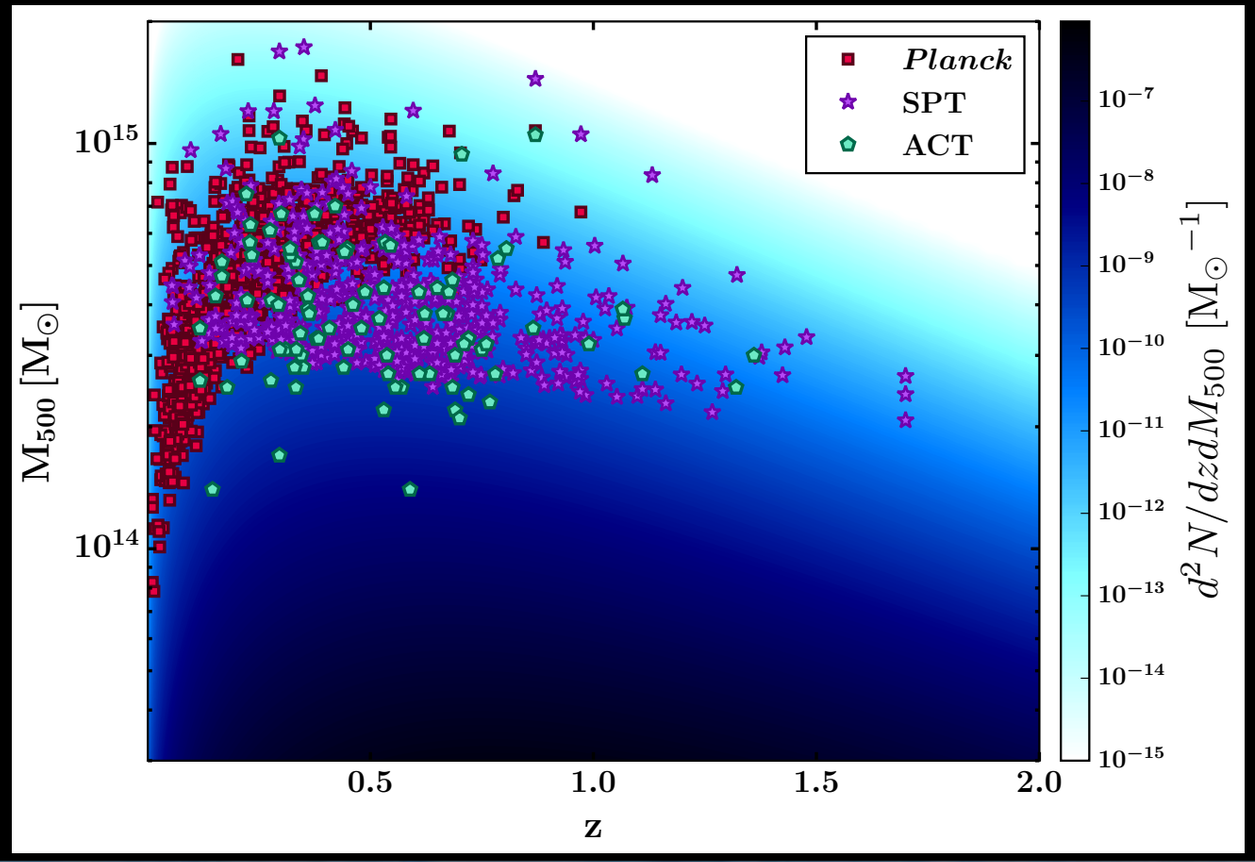
Perspectives:

- Need to estimate cluster thermodynamic properties at high z *X-ray/SZ analyses*
- Need to understand progenitor physics *low mass systems*



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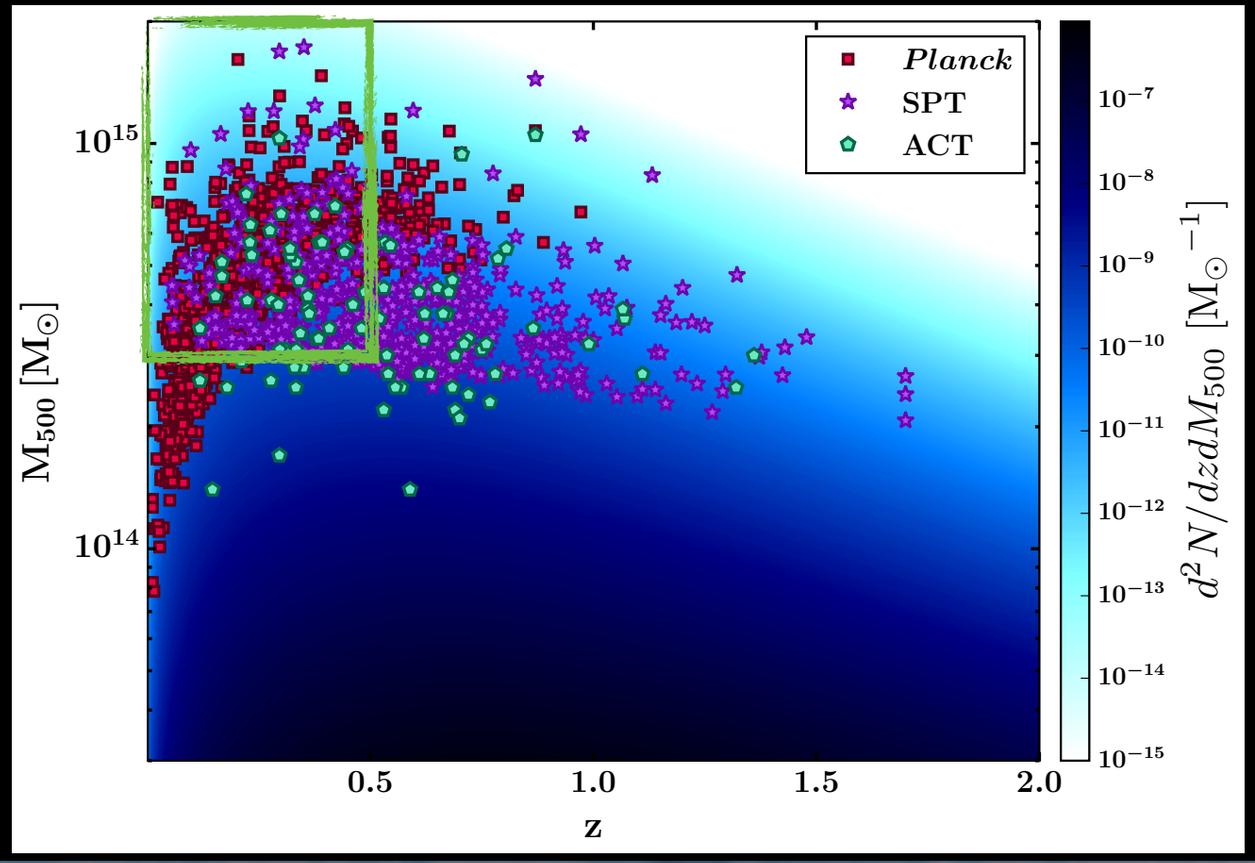

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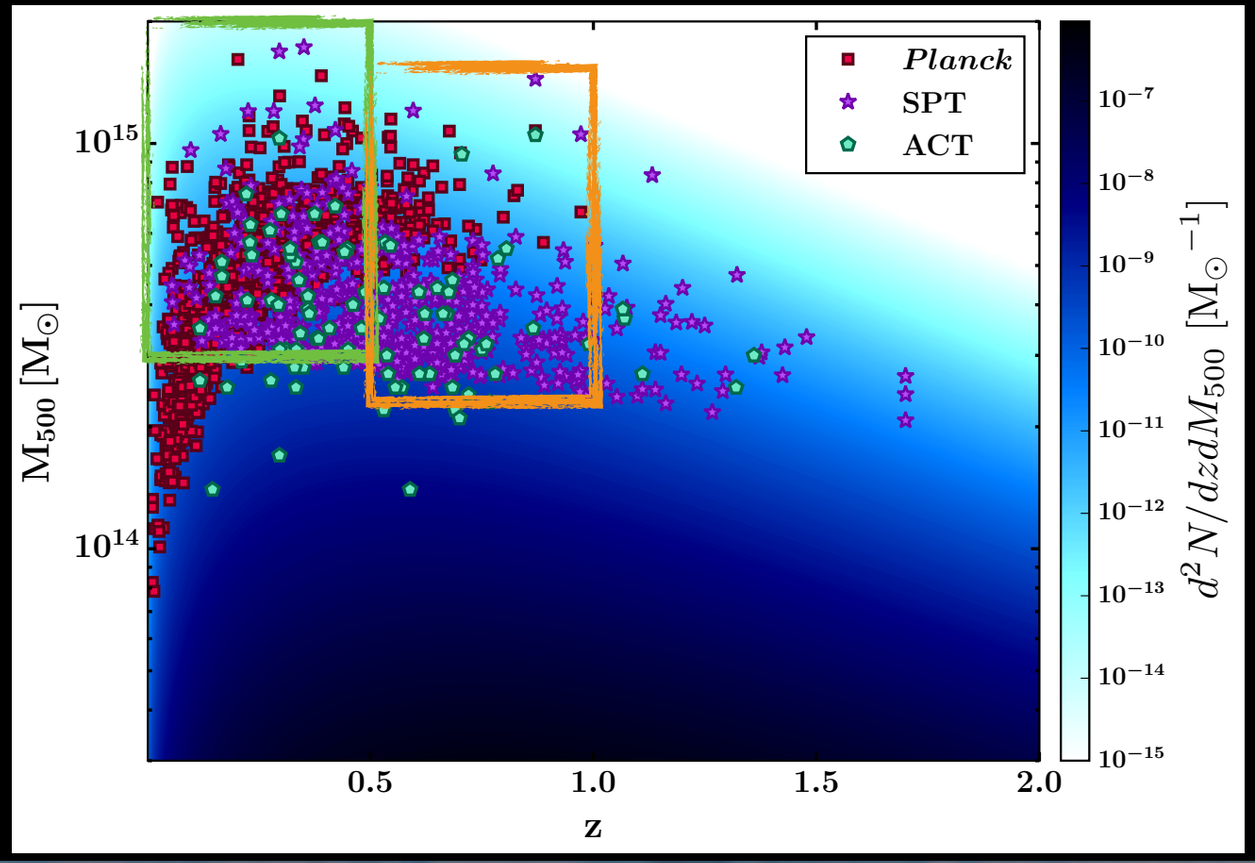

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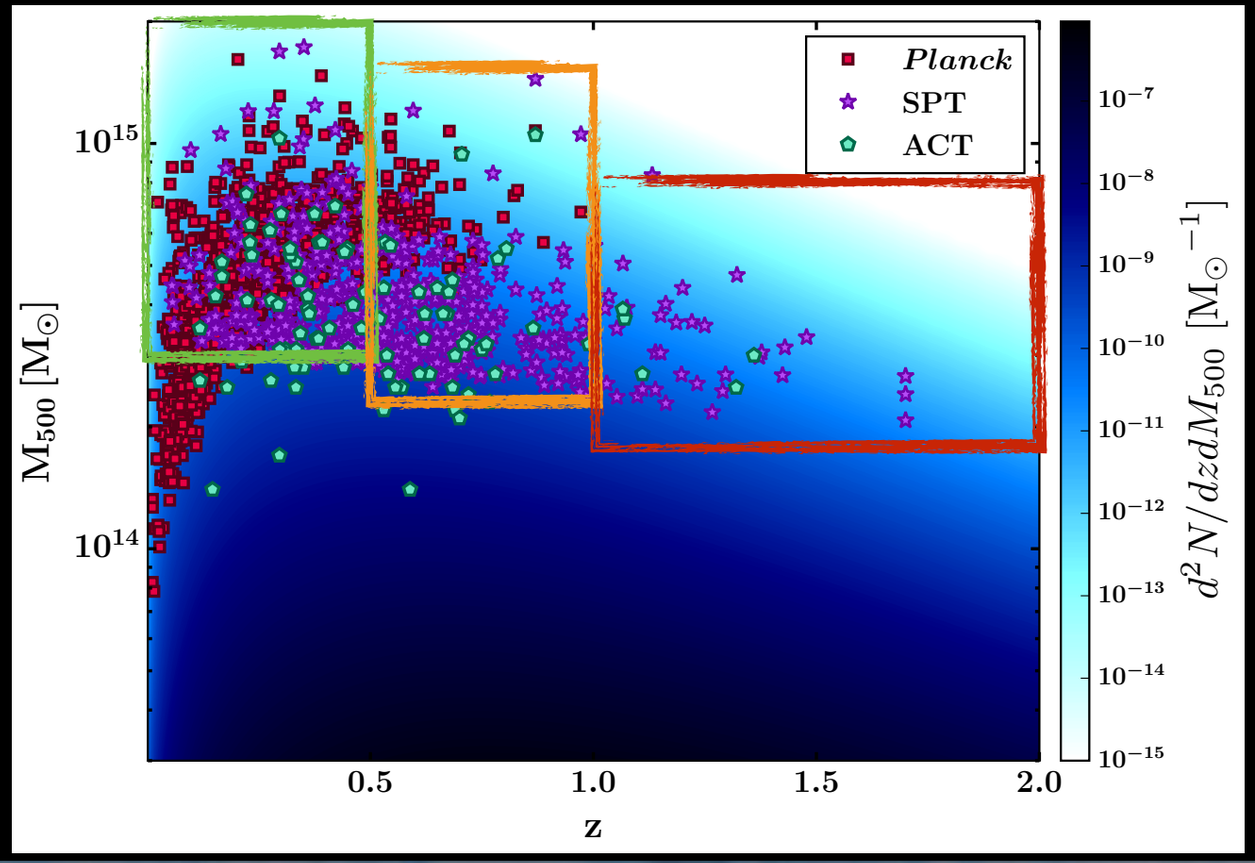

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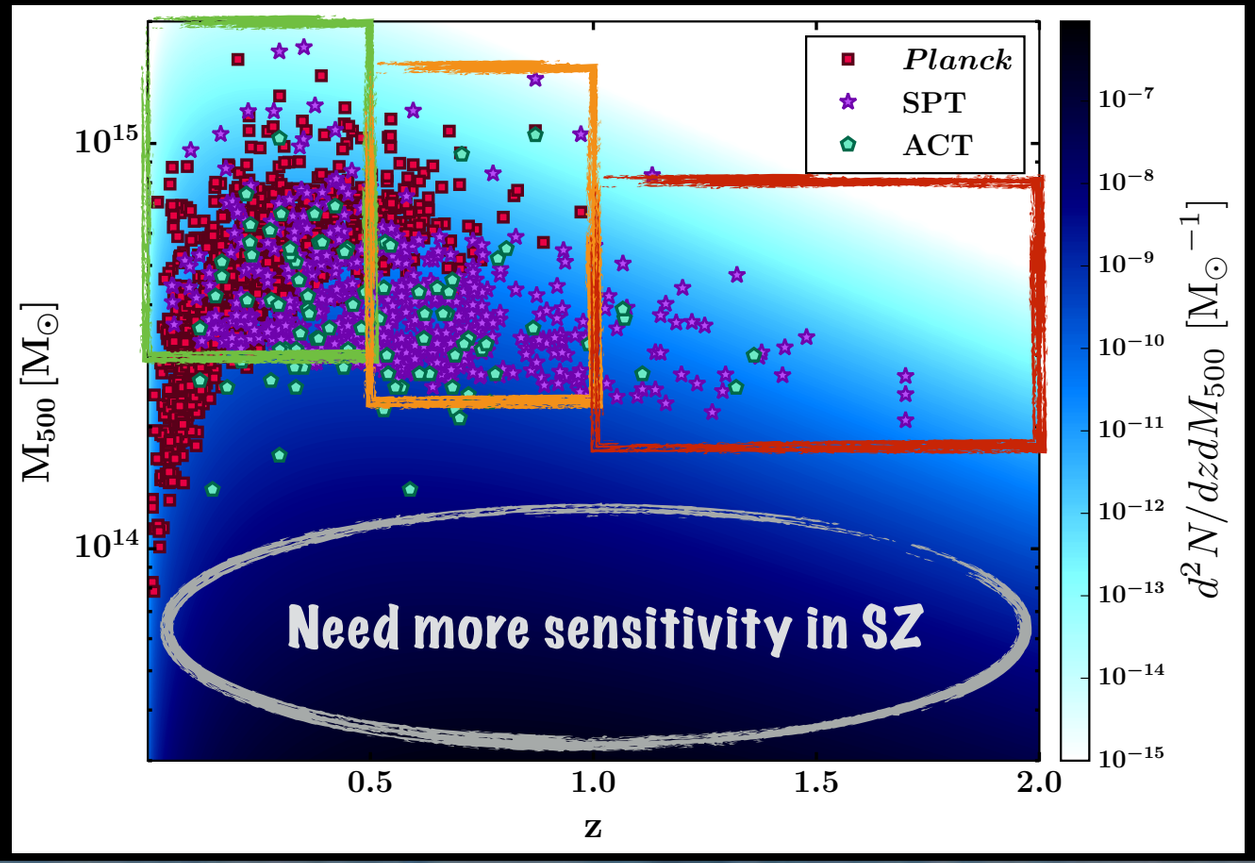

Thank you

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