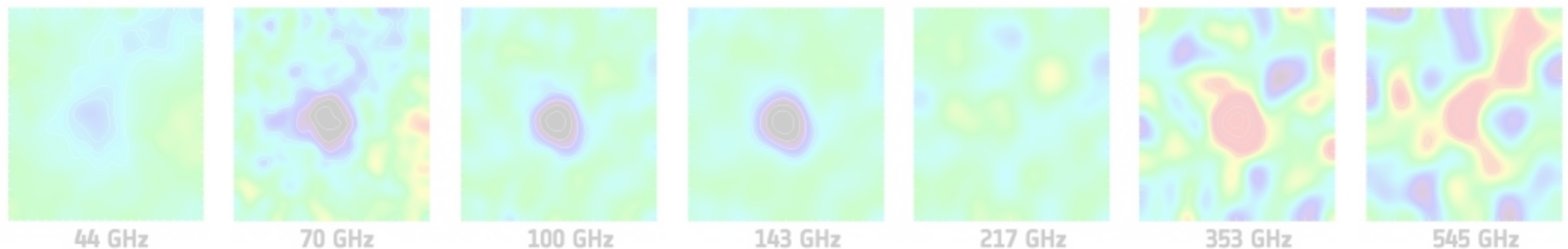
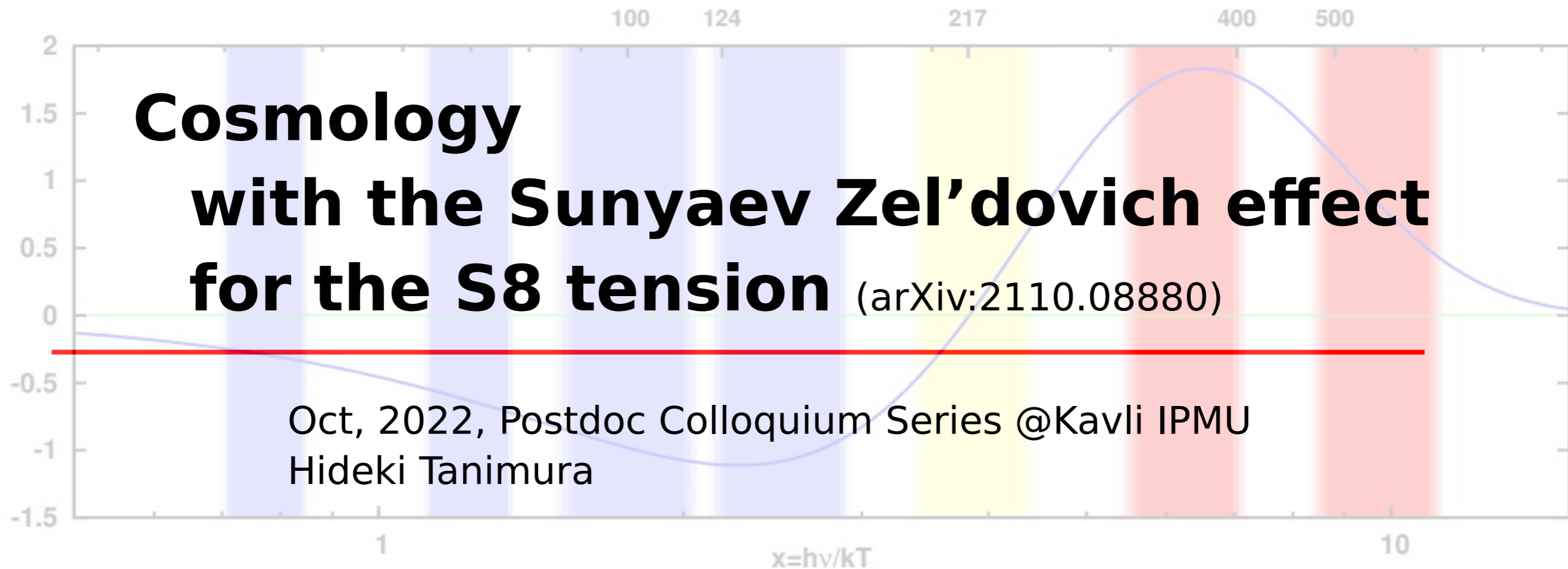
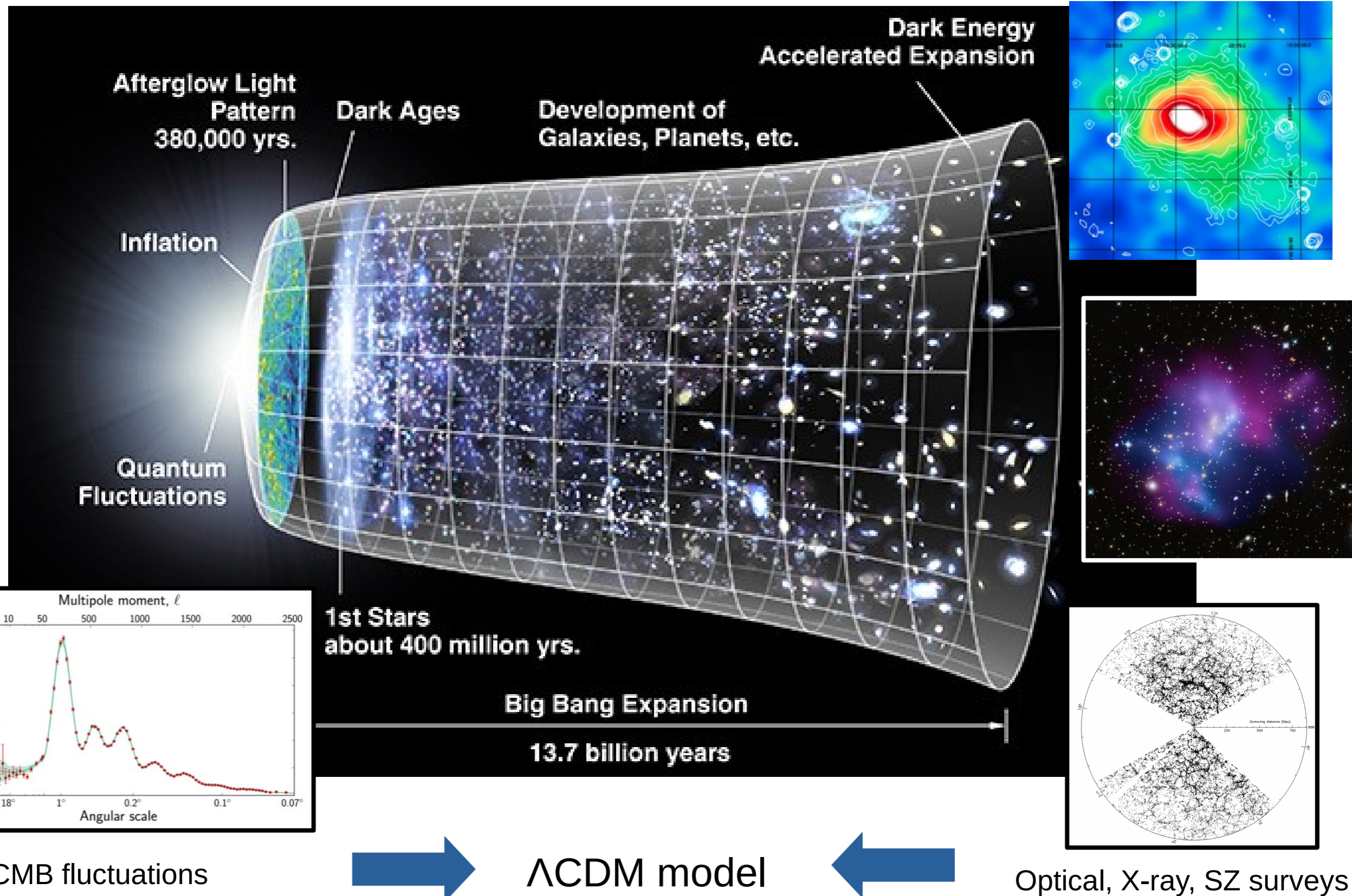

Cosmology with the Sunyaev Zel'dovich effect for the S8 tension (arXiv:2110.08880)

Oct, 2022, Postdoc Colloquium Series @Kavli IPMU
Hideki Tanimura



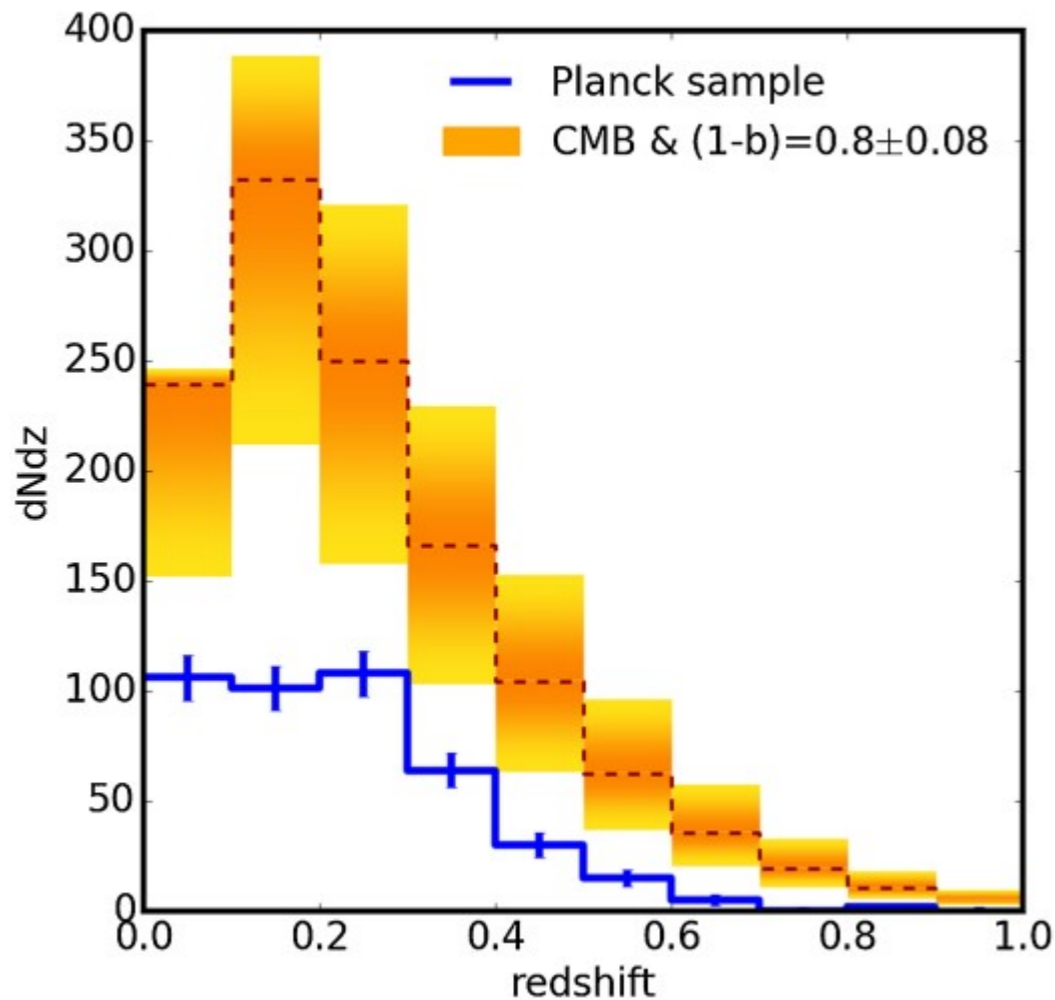
Λ CDM model



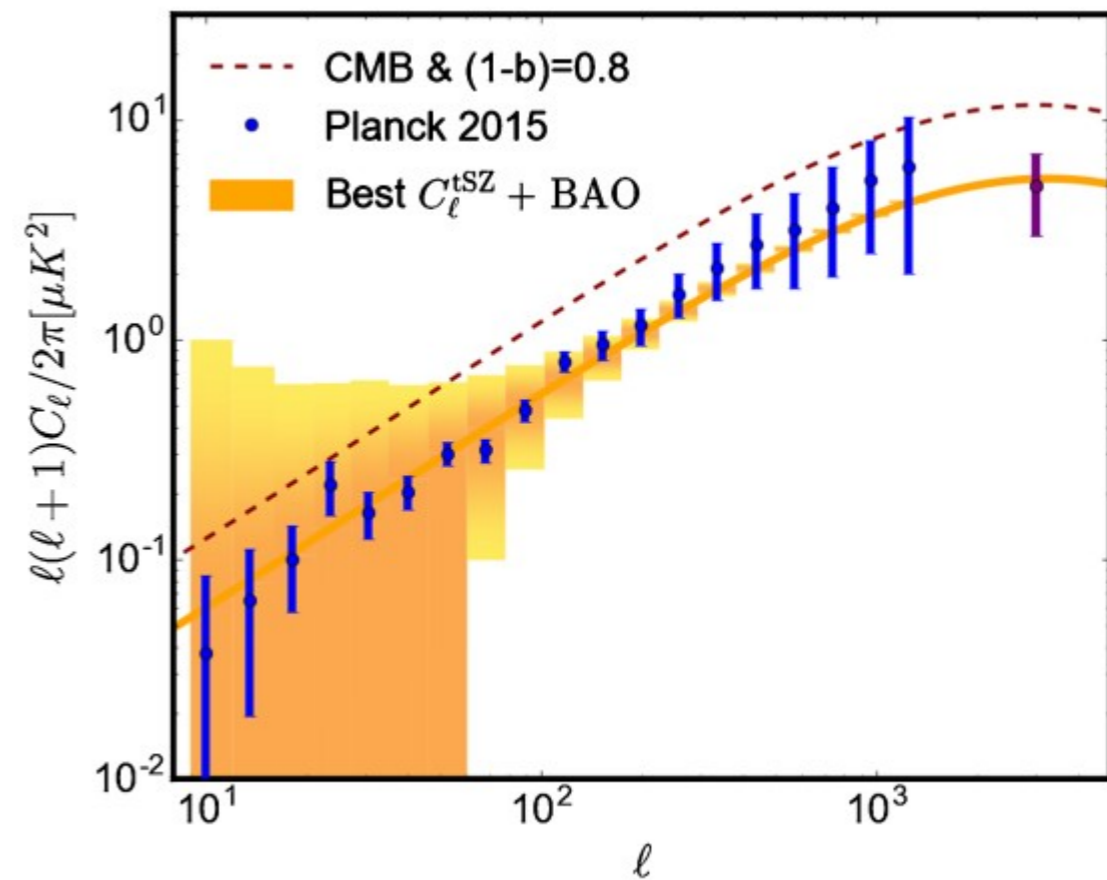
Motivation: S_8 tension

S_8 ($\equiv \sigma_8(\Omega_m/0.3)^{0.5}$) represents the amplitude of the structure formation;
 σ_8 : the amplitude of matter density fluctuations and Ω_m : matter density.

SZ cluster number count



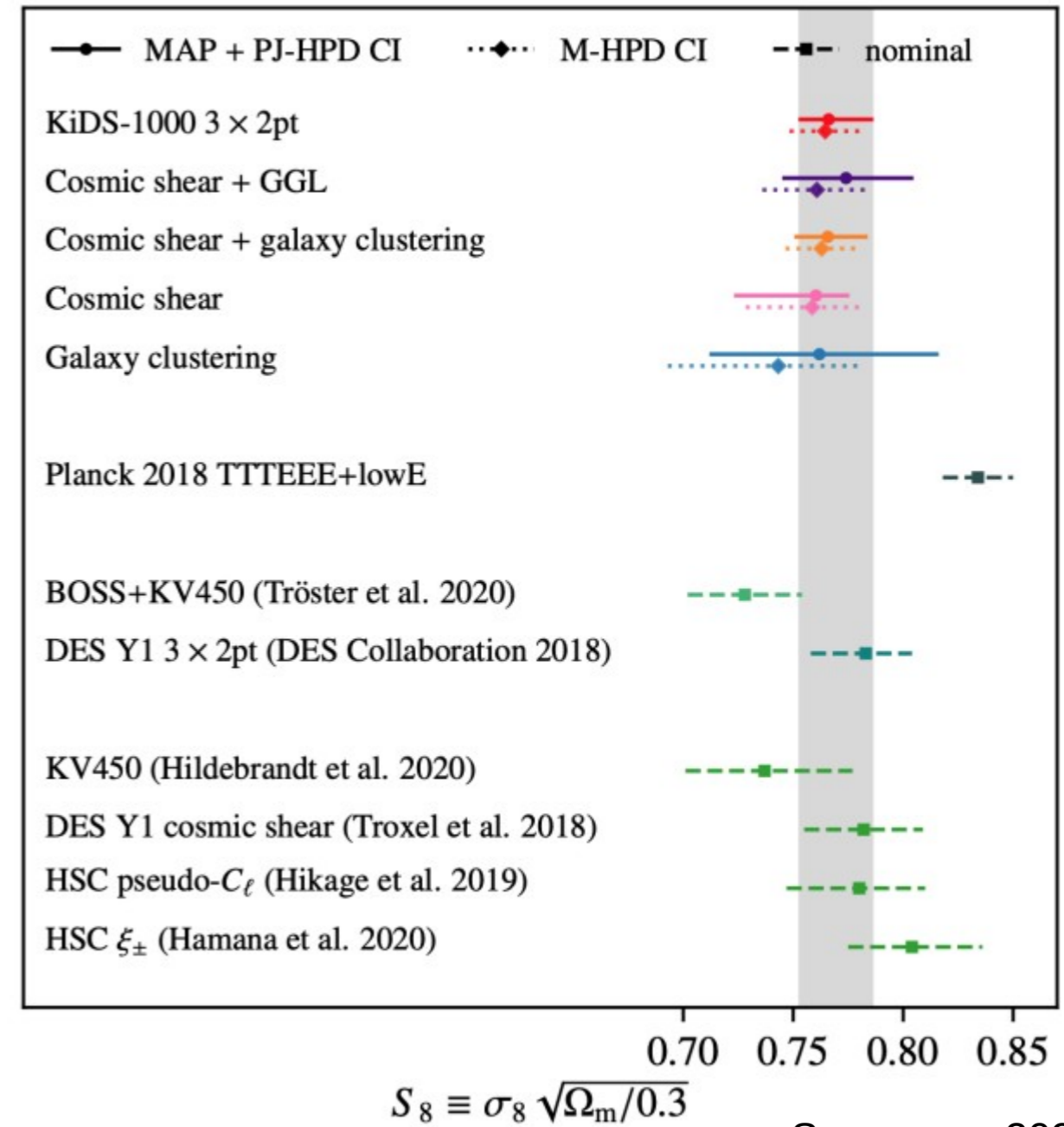
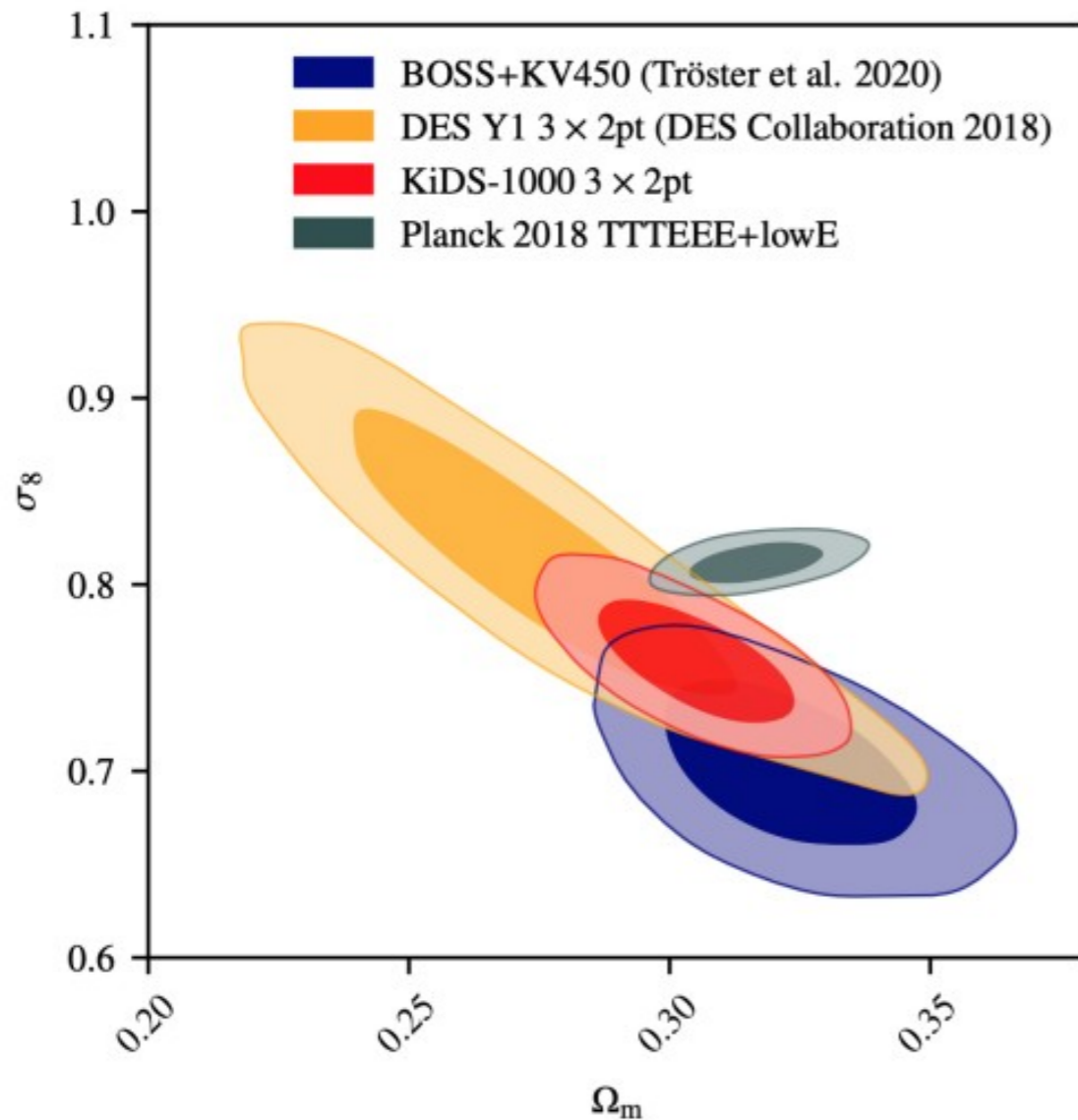
SZ power spectrum



Salvati et al 2018

Motivation: S_8 tension

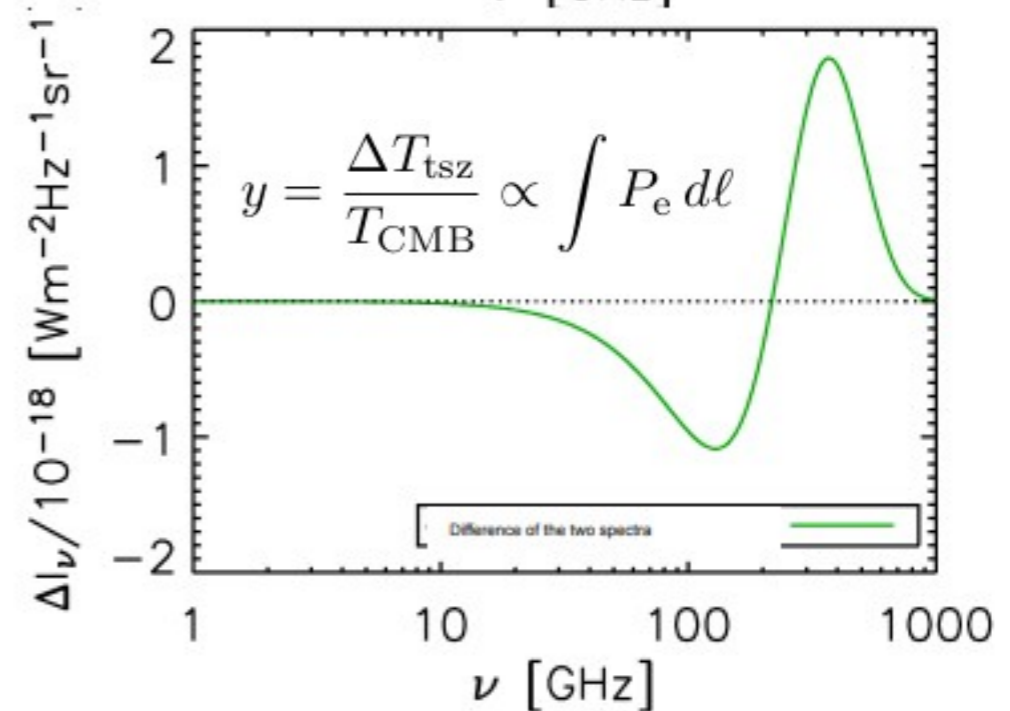
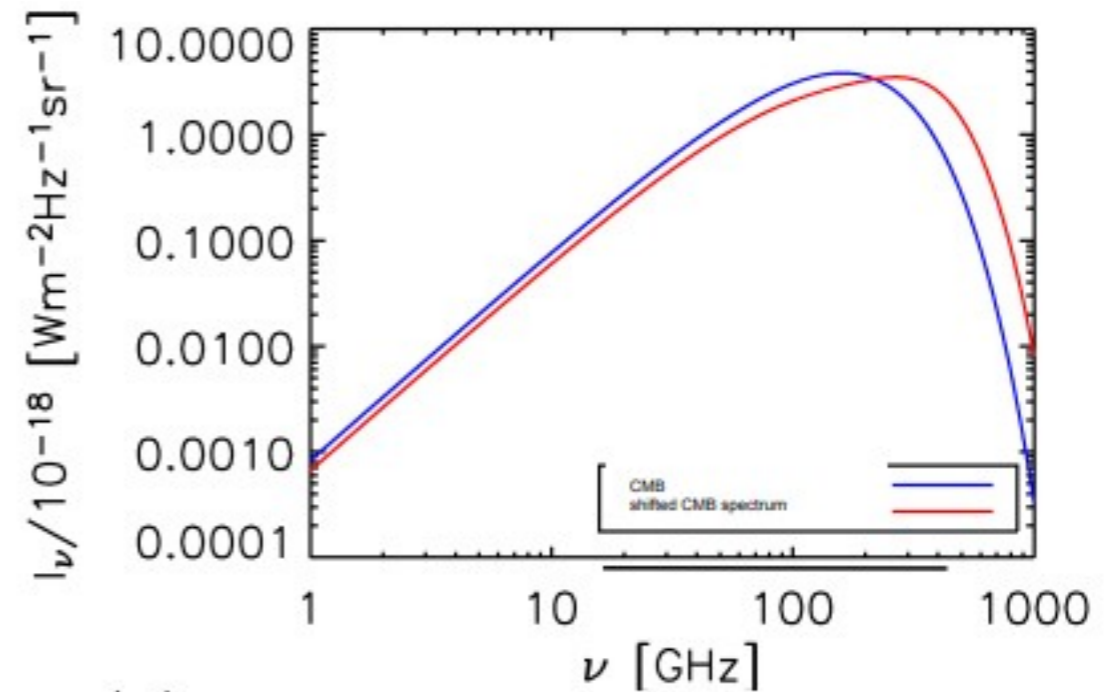
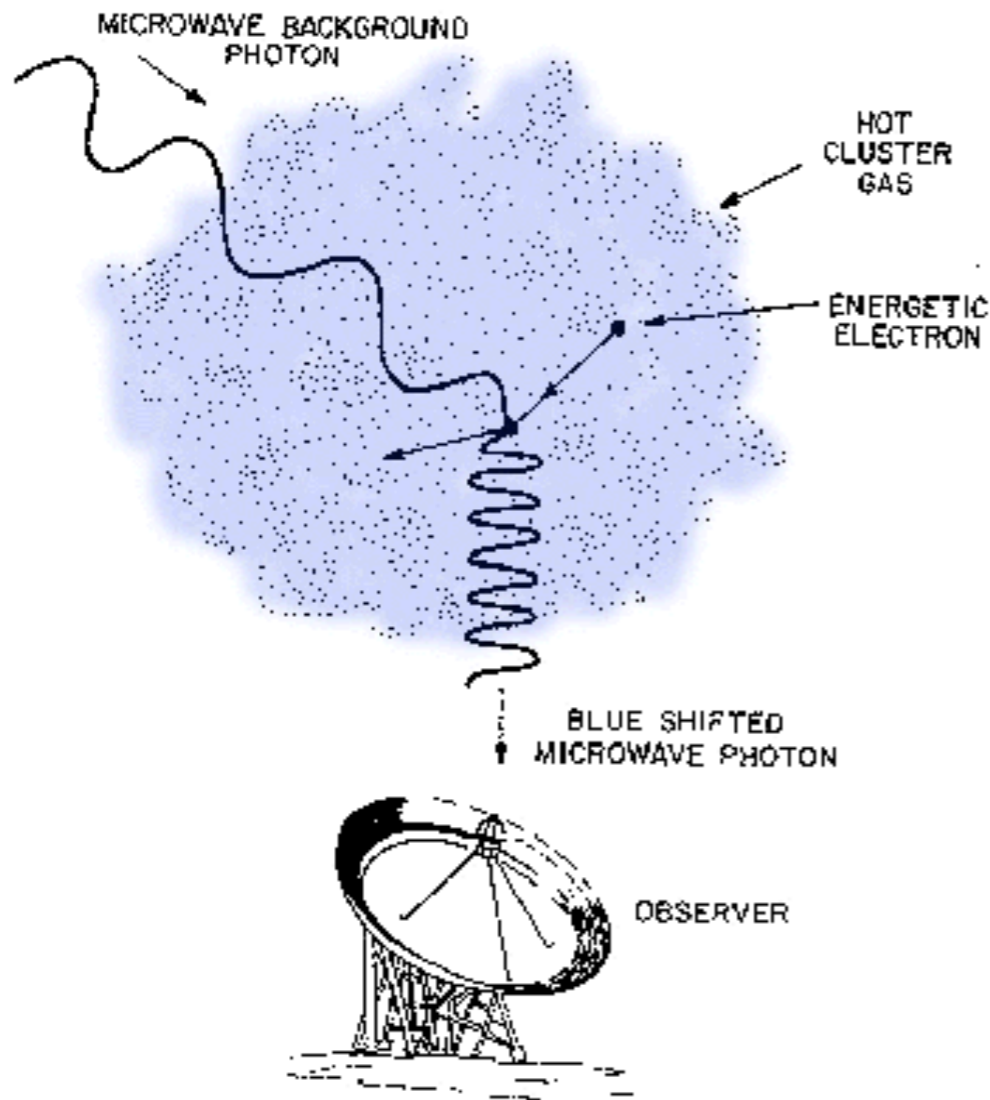
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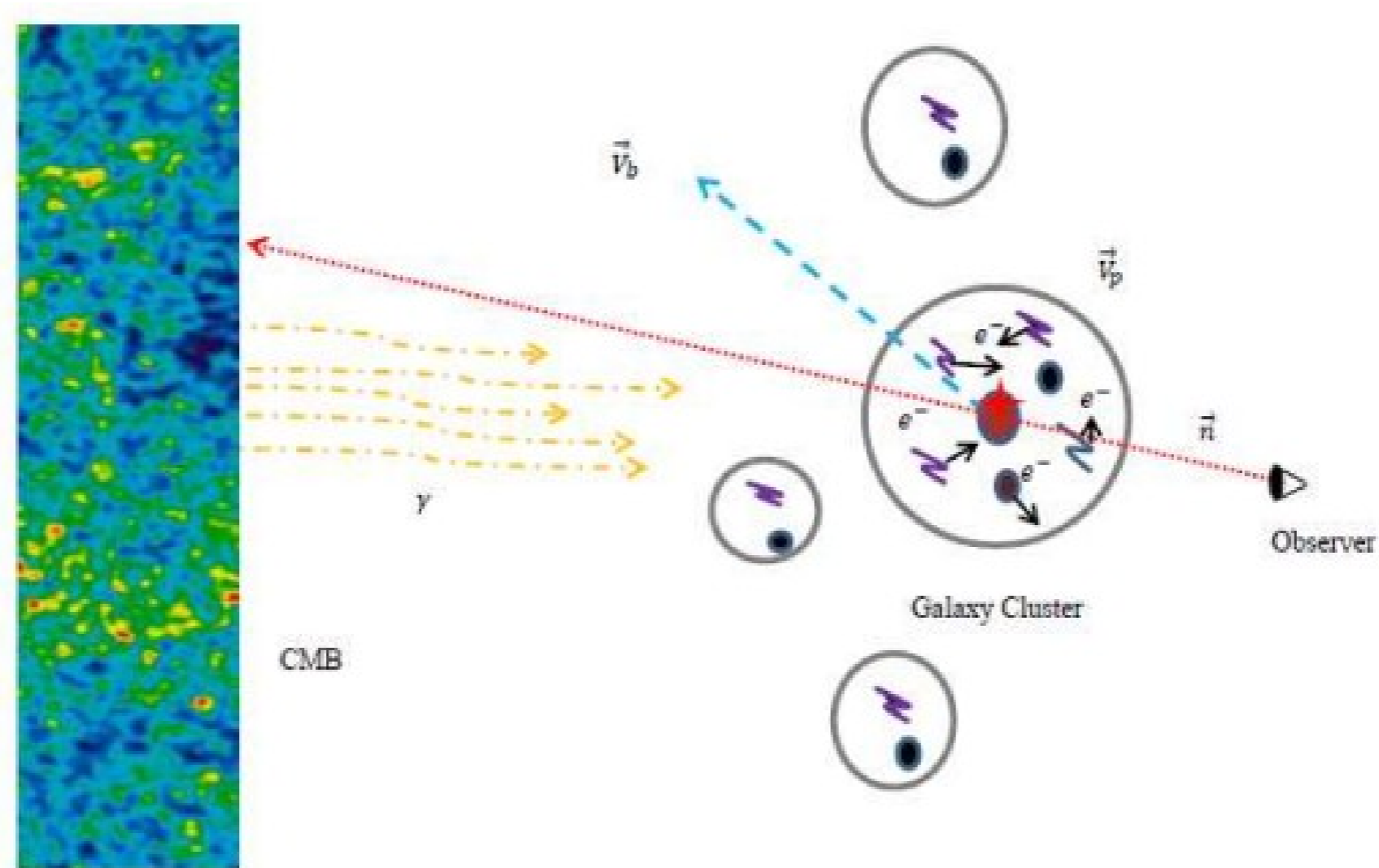
Snowmass 2021

Sunyaev-Zel'dovich(SZ) Effect

SZ effect is the distortion of the CMB spectrum caused by high energy electrons in galaxy clusters (in the cosmic web).



Why SZ effect?



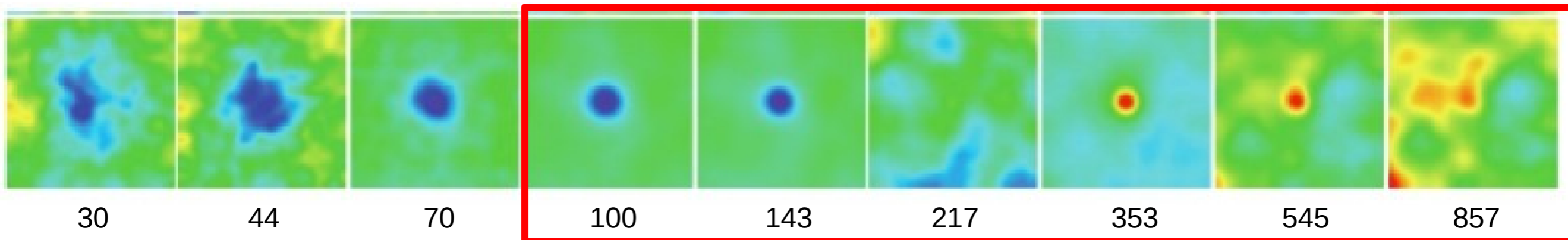
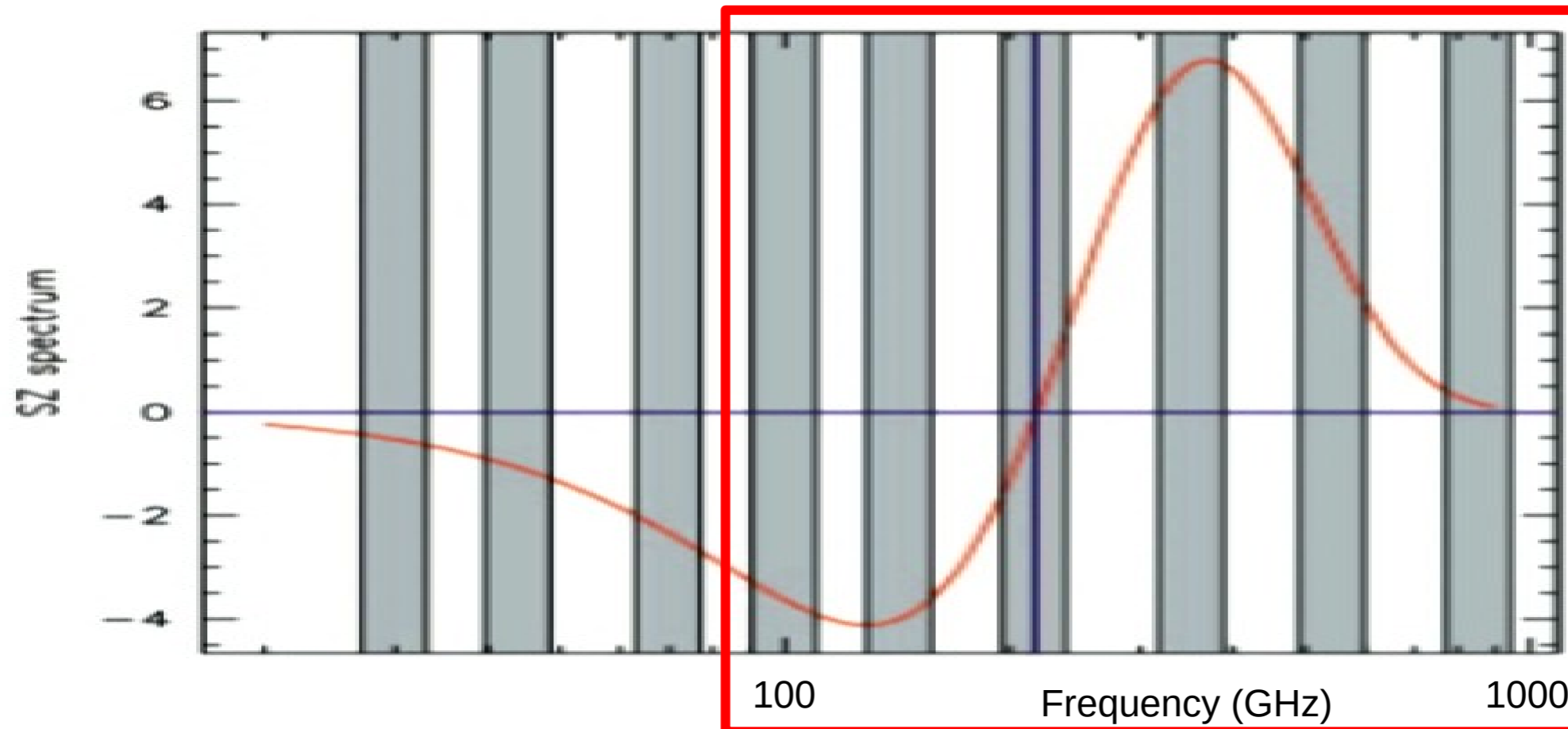
Baghran et al 2019

SZ effect is

- proportional to gas pressure and can be used to probe gravitational potential.
- independent of redshift and keeps all the pressure between CMB and us.
- sensitive to σ_8 and Ω_m cosmological parameters as $SZ \propto \sigma_8^8 \Omega_m^3$.

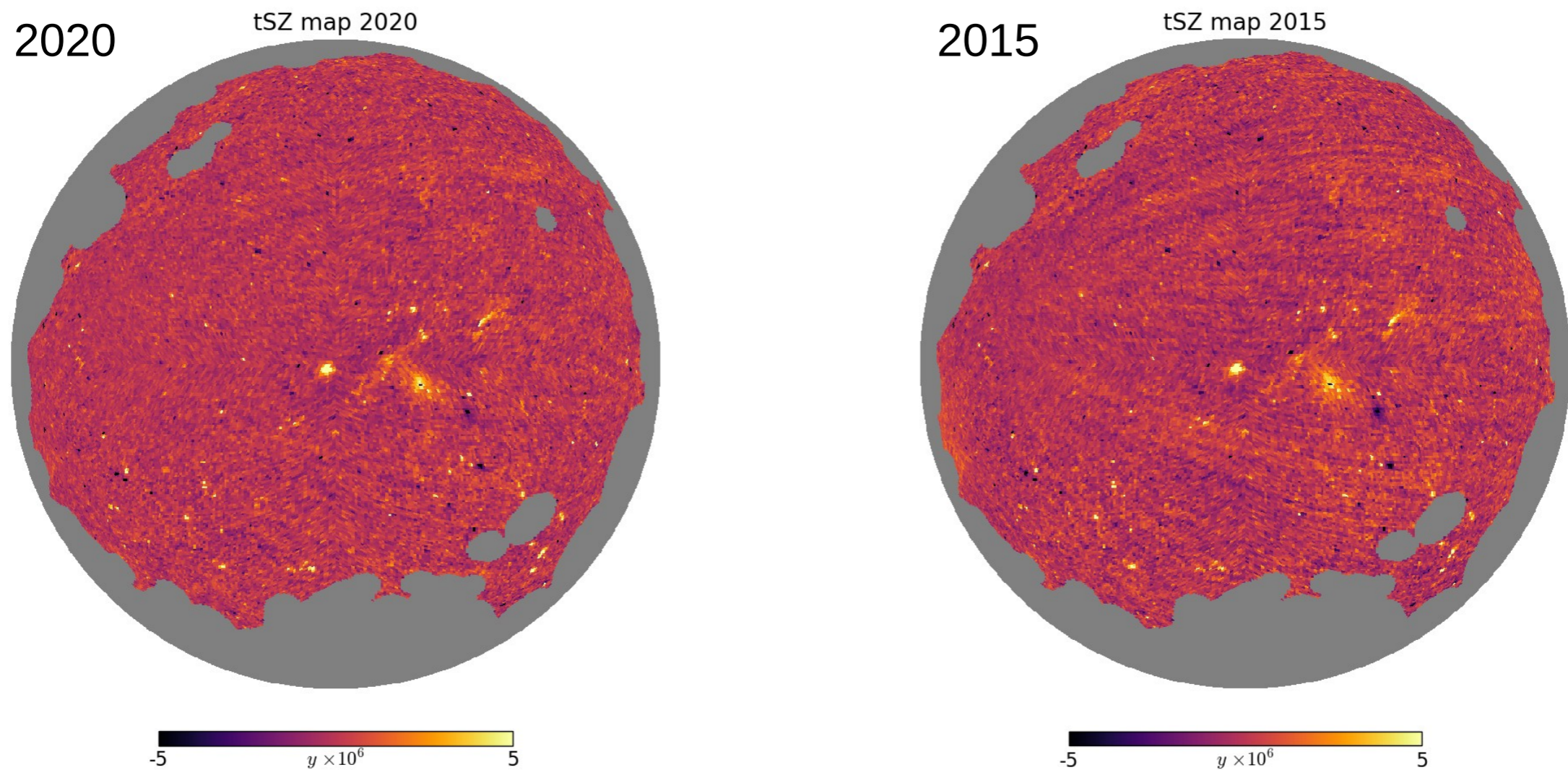
SZ measurement

Using the latest Planck PR4 data released in 2020, SZ signal is extracted by applying the MILCA algorithm (Hurier et al., 2013) for HFI 6 frequency maps.



SZ map

New SZ map (10') compared with the old SZ map in 2015 (Planck 2015 results XXII).

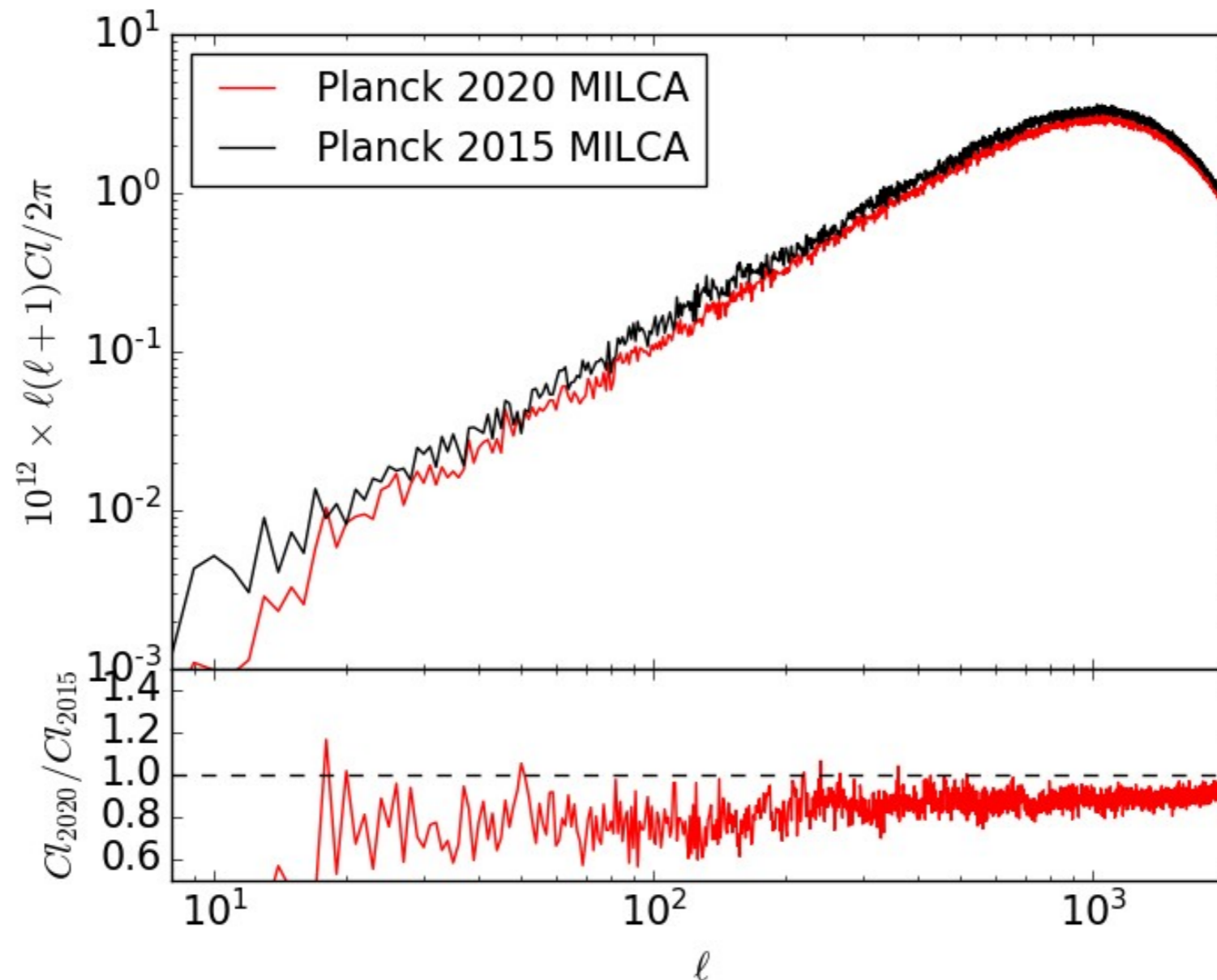


The level of survey strip pattern is significantly reduced in our new y -map due to the de-stripping procedure in the PR4's band maps.

SZ power spectrum

The amplitude of power spectrum from our SZ map is lower.

It is due to 8% more data and minimal survey strips in the latest Planck maps, and our window function that suppresses residual foreground emissions.



Model of SZ power spectrum

The SZ power spectrum is modeled with a halo model prescription.
 (Only one-halo term is shown here.)

$$C_{\ell}^{SZ} = \int dz \frac{d^2V}{dzd\Omega} \int dM \frac{dn(M, z)}{dM} |\tilde{y}_{\ell}(M, z)|^2$$

.....
 Halo mass function SZ signal in a halo

$$\tilde{y}_{\ell}(M, z) = \frac{\sigma_T}{m_e c^2} \frac{4\pi r_s}{\ell_s^2} \int dx x^2 \frac{\sin(\ell x / \ell_s)}{\ell x / \ell_s} P_e(x, M, z)$$

.....
 pressure in a halo

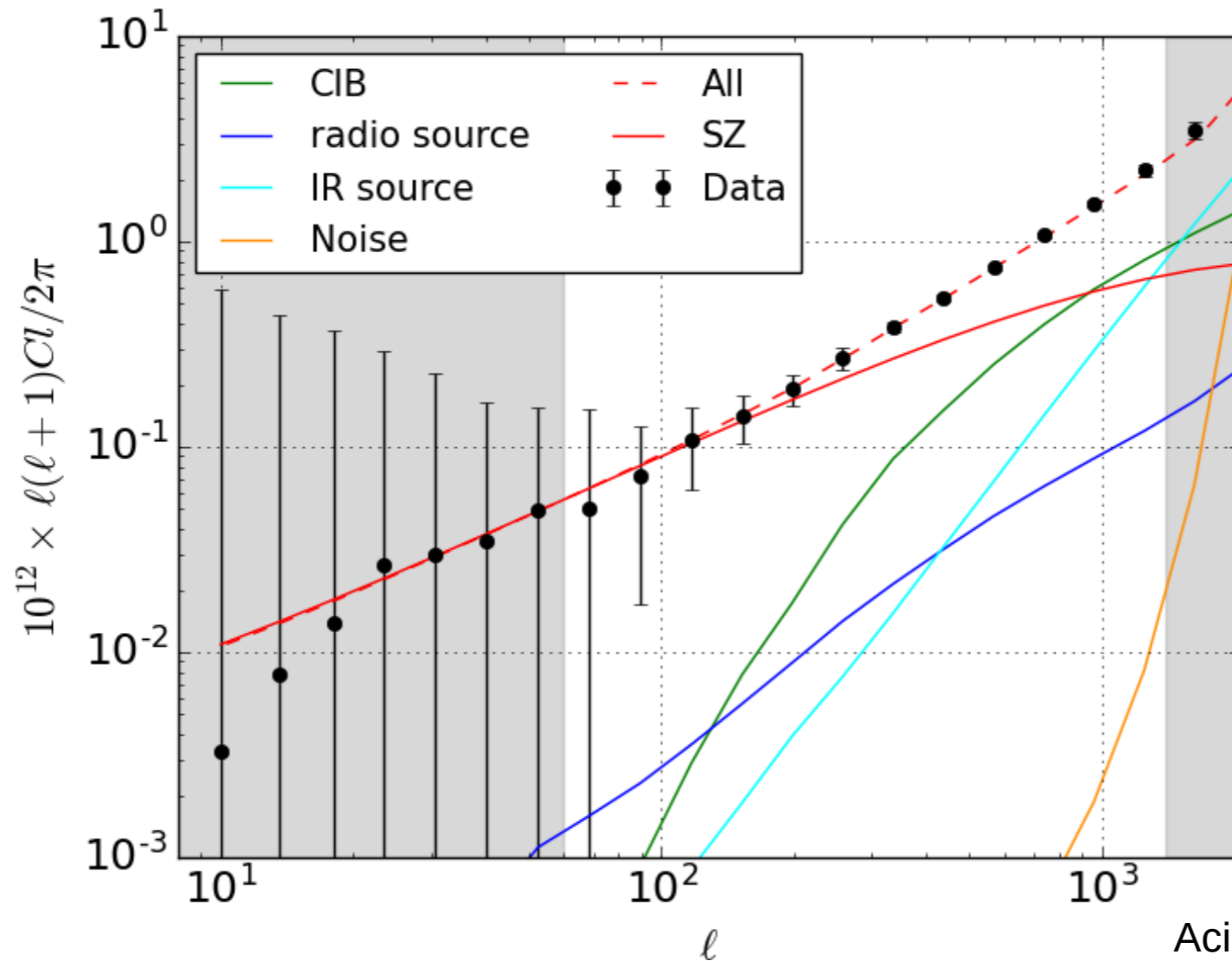
$$\frac{P(r)}{P_{500}} = \mathbb{P}(x) \quad P_{500} = 1.65 \times 10^{-3} \left[\frac{H(z)}{H_0} \right]^{8/3} \\ \times \left[\frac{(1-b) M_{500}}{3 \times 10^{14} (h/0.7)^{-1} M_{\odot}} \right]^{2/3+\alpha_p} \left(\frac{h}{0.7} \right)^2 \text{ keV cm}^{-3}$$

.....
 mass bias

Cosmological analysis with MCMC

Cosmological analysis under Λ CDM including contaminations in the SZ map;

$$C_\ell^m = C_\ell^{\text{tSZ}}(\Omega_m, \sigma_8, b) + A_{\text{CIB}} C_\ell^{\text{CIB}} + A_{\text{IR}} C_\ell^{\text{IR}} + A_{\text{rad}} C_\ell^{\text{rad}} + A_{\text{CN}} C_\ell^{\text{CN}}$$

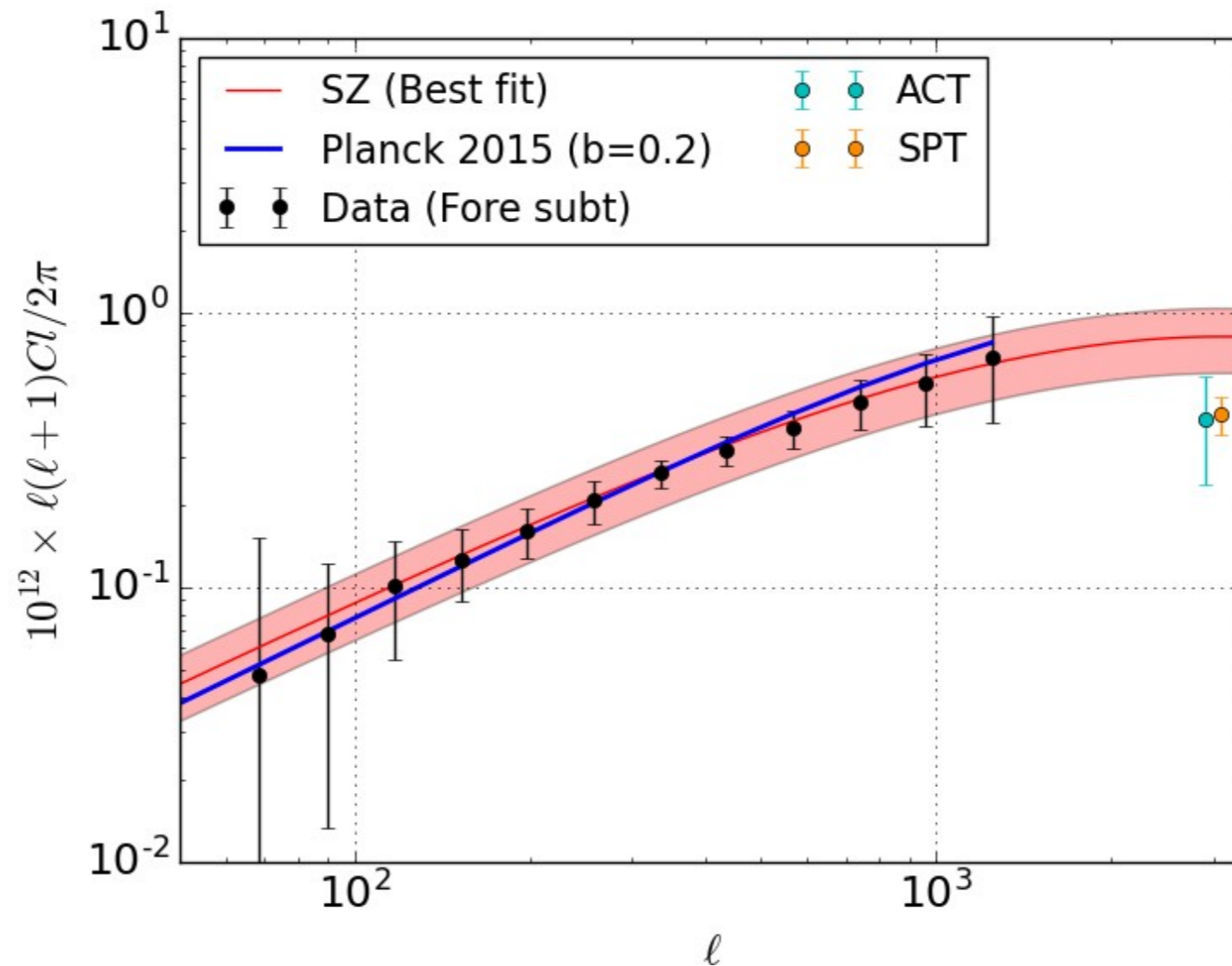


$A_{\text{CIB}} = 0.82 \pm 0.16$, $A_{\text{IR}} = 1.18 \pm 0.34$,
 $A_{\text{rad}} = 1.02 \pm 0.48$, $A_{\text{CN}} = 1.03 \pm 0.47$.

SZ signals dominates our y-map at $60 < \ell < 600$.

Our best SZ model

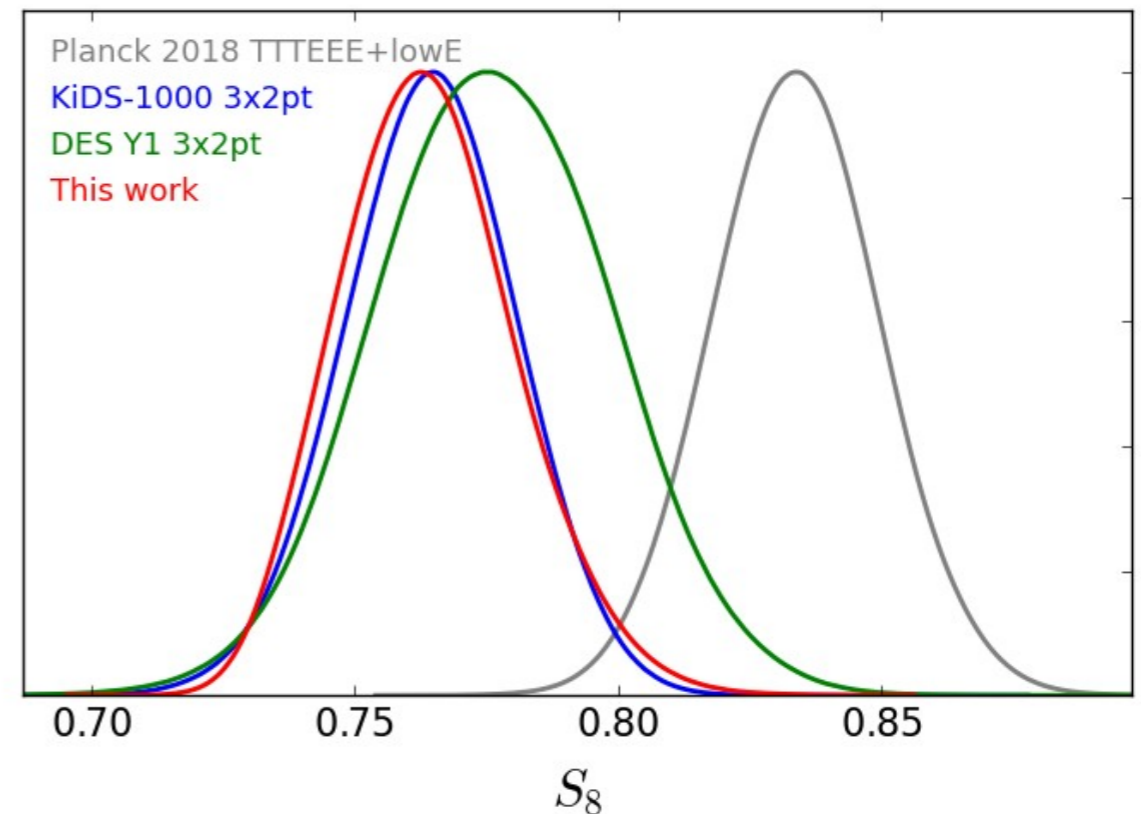
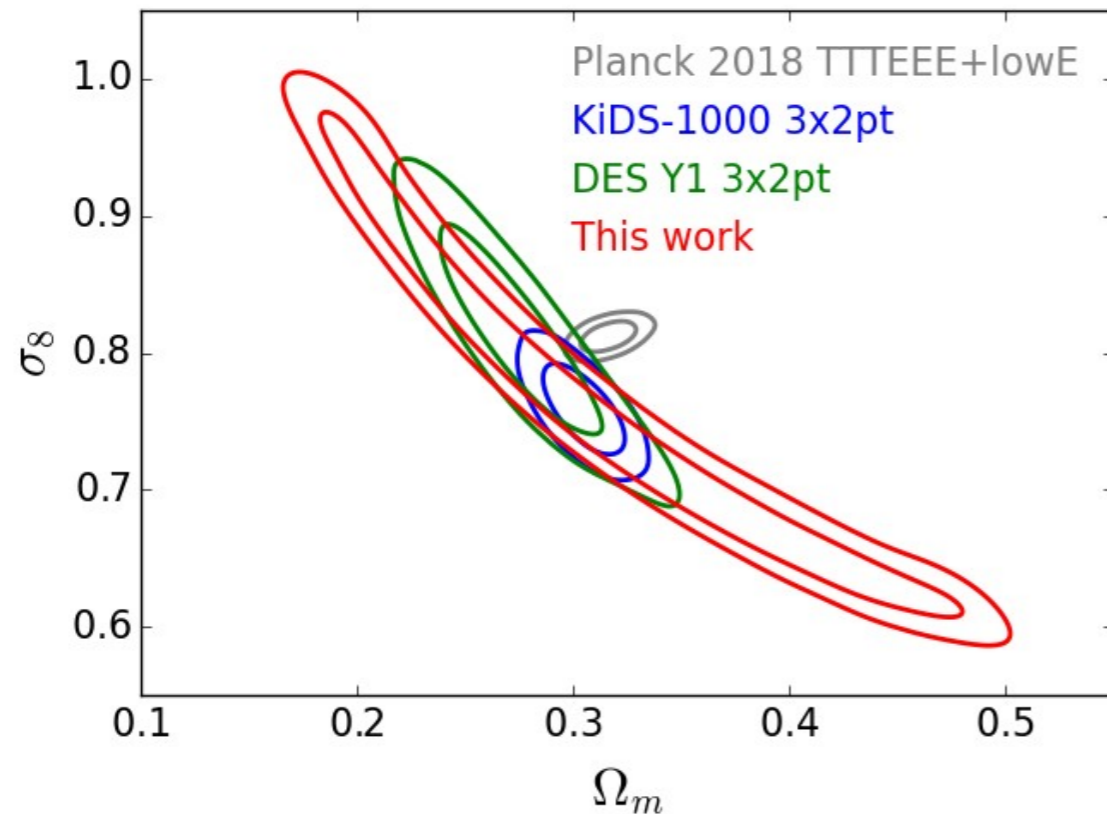
Our best SZ model is consistent with a previous result from the Planck 2015 but has a slight tension with ACT (cyan, Dunkley et al. 2013) and SPT (orange, Reichardt et al. 2021).



Cosmological parameter estimate

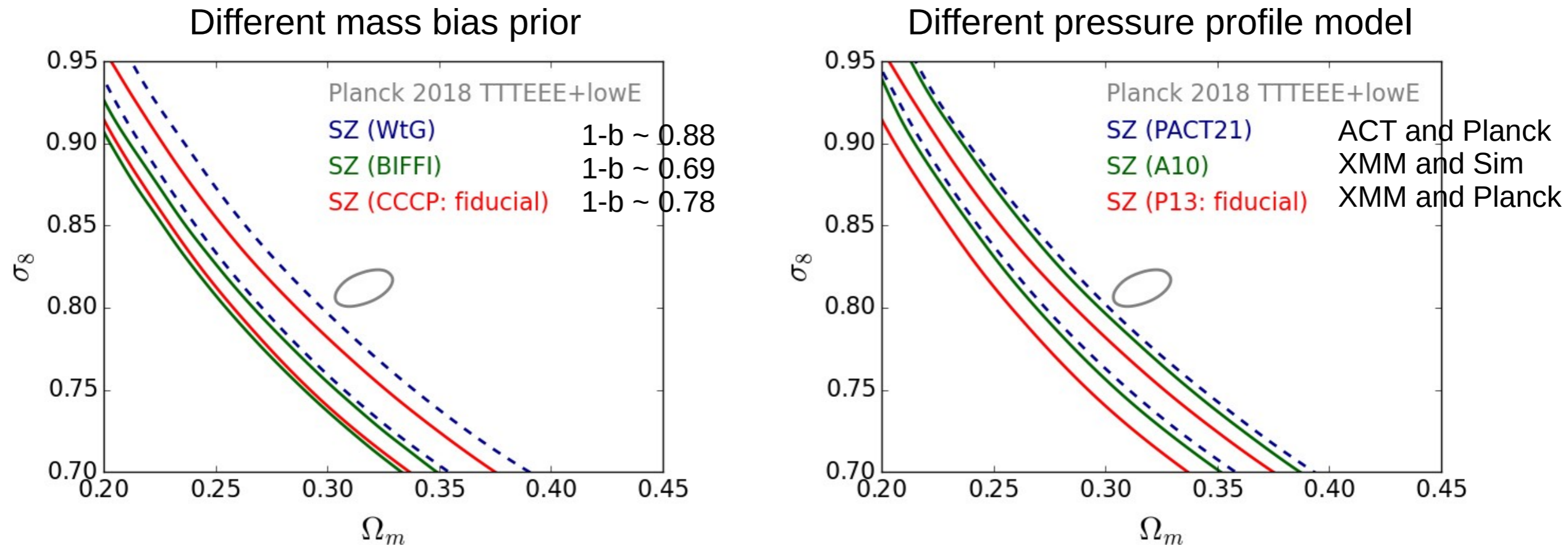
SZ cosmological parameters

- consistent with KiDS-1000 3x2pt (Heymans et al 2021) and DES Y1 3x2pt results (DES 2018).
- slight tension with the Planck CMB's result,



Systematics

Systematics in the cosmological analysis
with the SZ power spectrum analysis..



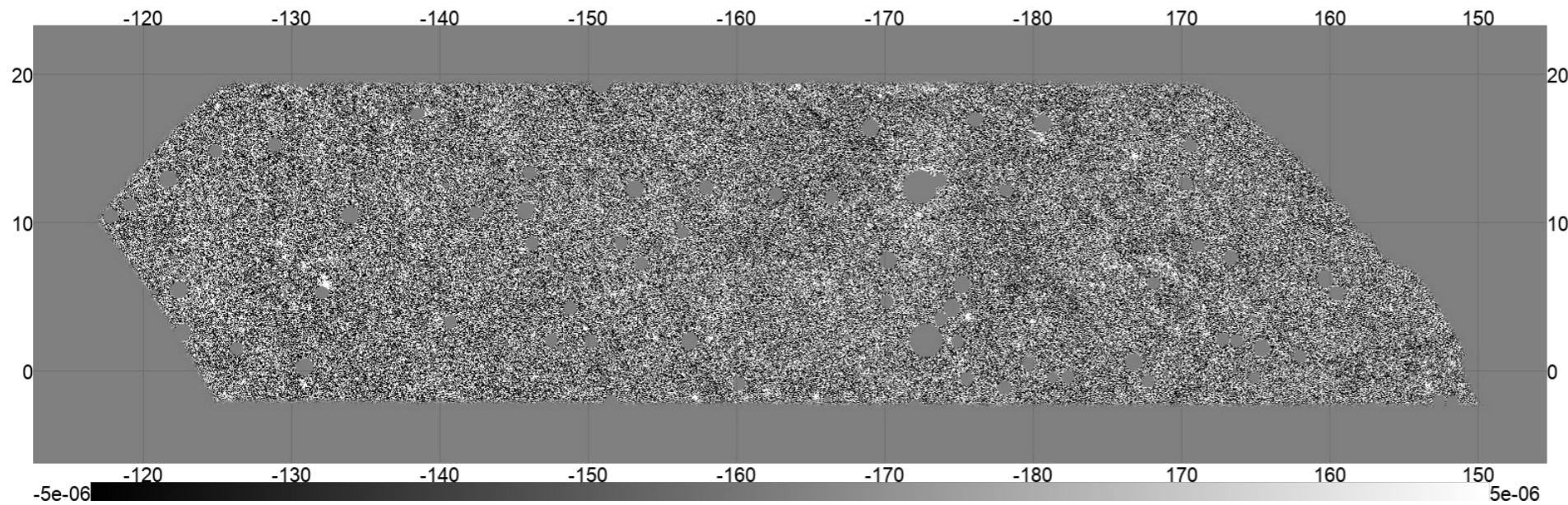
We obtained $S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5} = 0.764^{+0.015}_{-0.018} (stat) {}^{+0.031}_{-0.016} (sys)$

Our S_8 value is consistent with the Planck CMB's $S_8 = 0.830 \pm 0.013$ within 2σ .

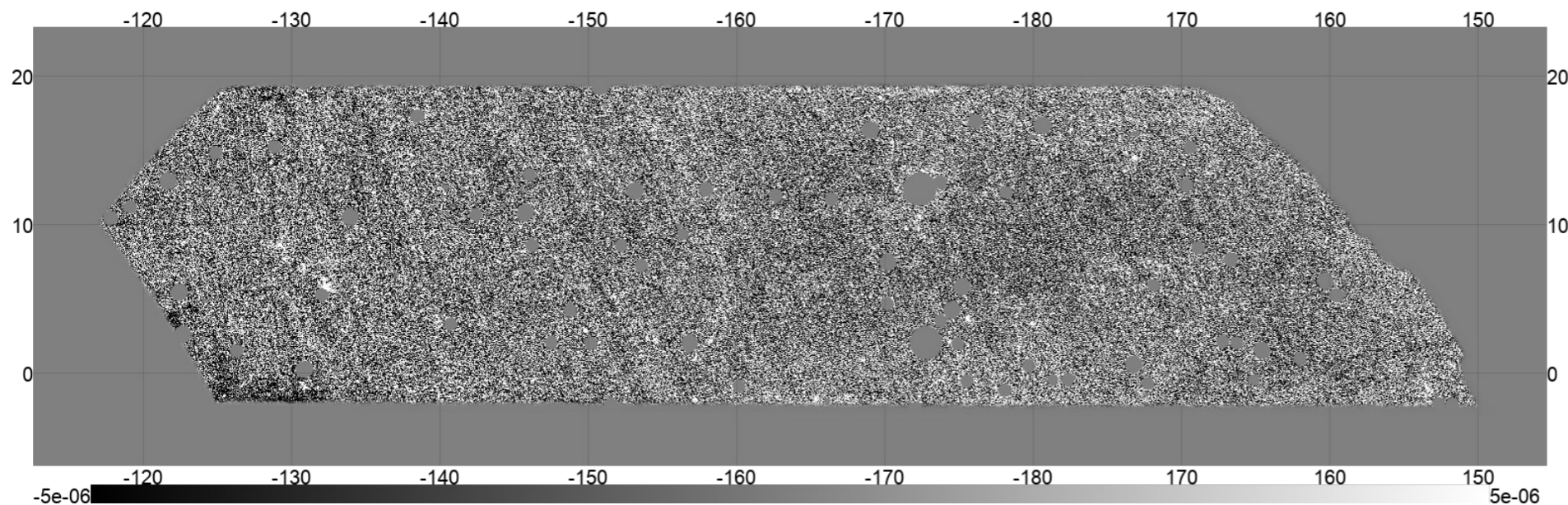
Improvement by ACTPol data

PACT (Planck+ACTPol) SZ map

to better constrain the cosmological parameters and the pressure profile model



PACT SZ map (2.4') in BN
(Planck DR4 + ACTPol)
→ Will be applied to
17,000 deg² ACTPol data

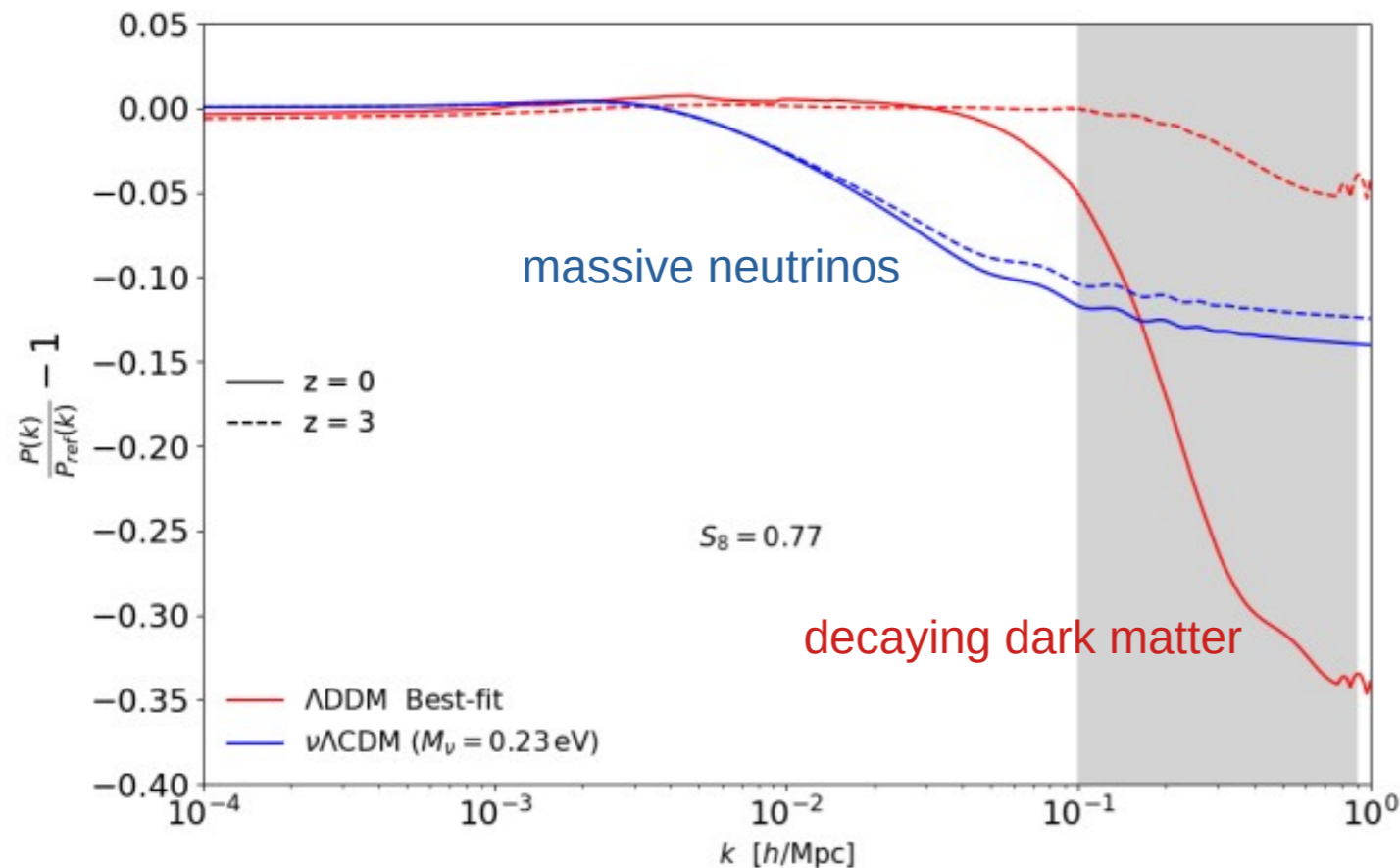


Public ACT SZ map (2.4')
(Planck DR2 + ACTPol)

Madhavacheril
et al 2020

What causes the S_8 tension?

Key to solve the S_8 tension is the cosmic evolution.

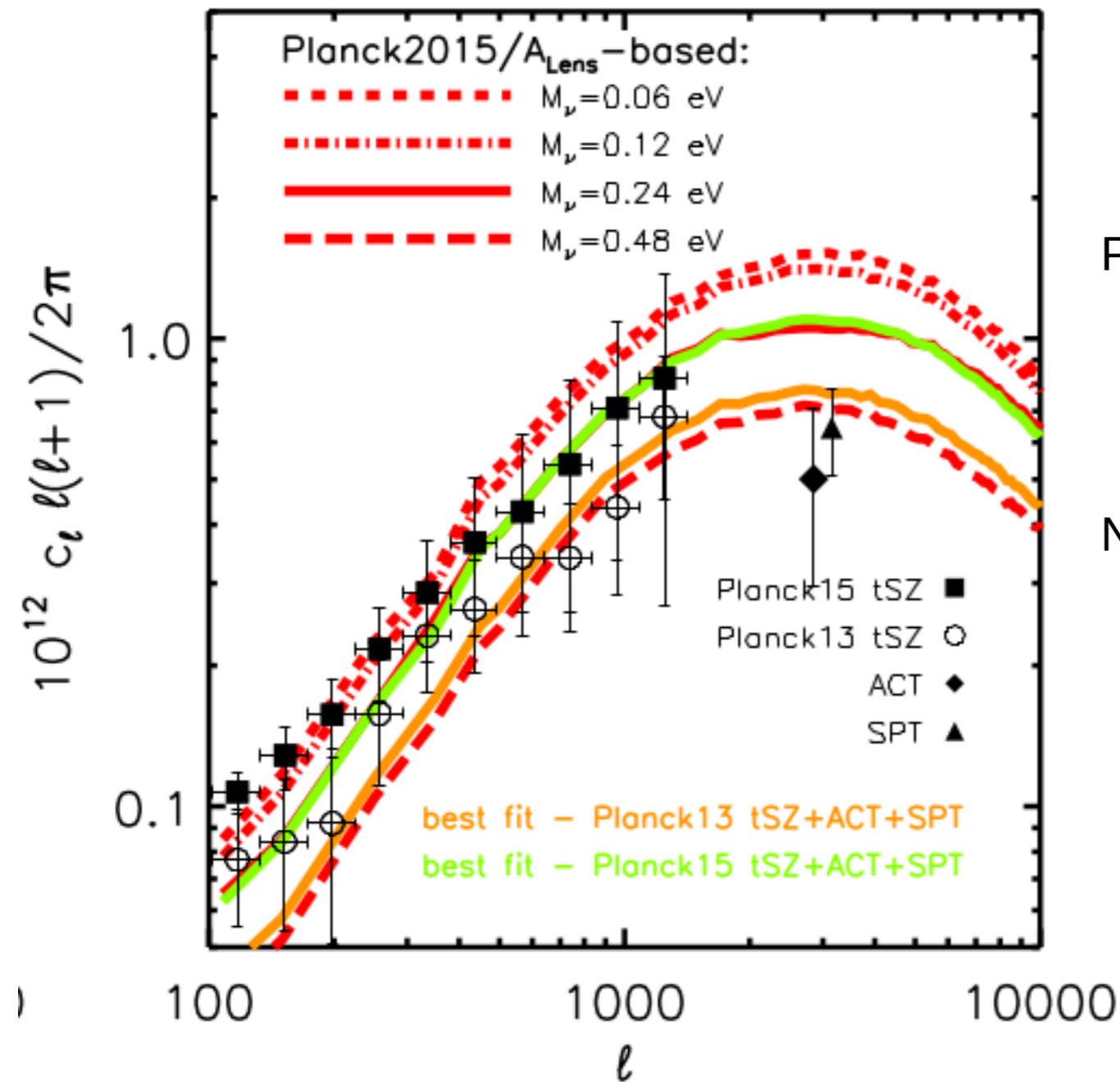


Two different types of matter evolution (from $z = 3$ to $z = 0$), yielding the same S_8 value (Abellan et al 2020).

Even for the same S_8 value, massive neutrino and decaying dark matter scenario predict different time evolution and different scale dependence.

SZ power spectrum with massive neutrino

Comparison of the observed and predicted SZ angular power spectra from BAHAMAS hydrodynamic simulations with different neutrino mass



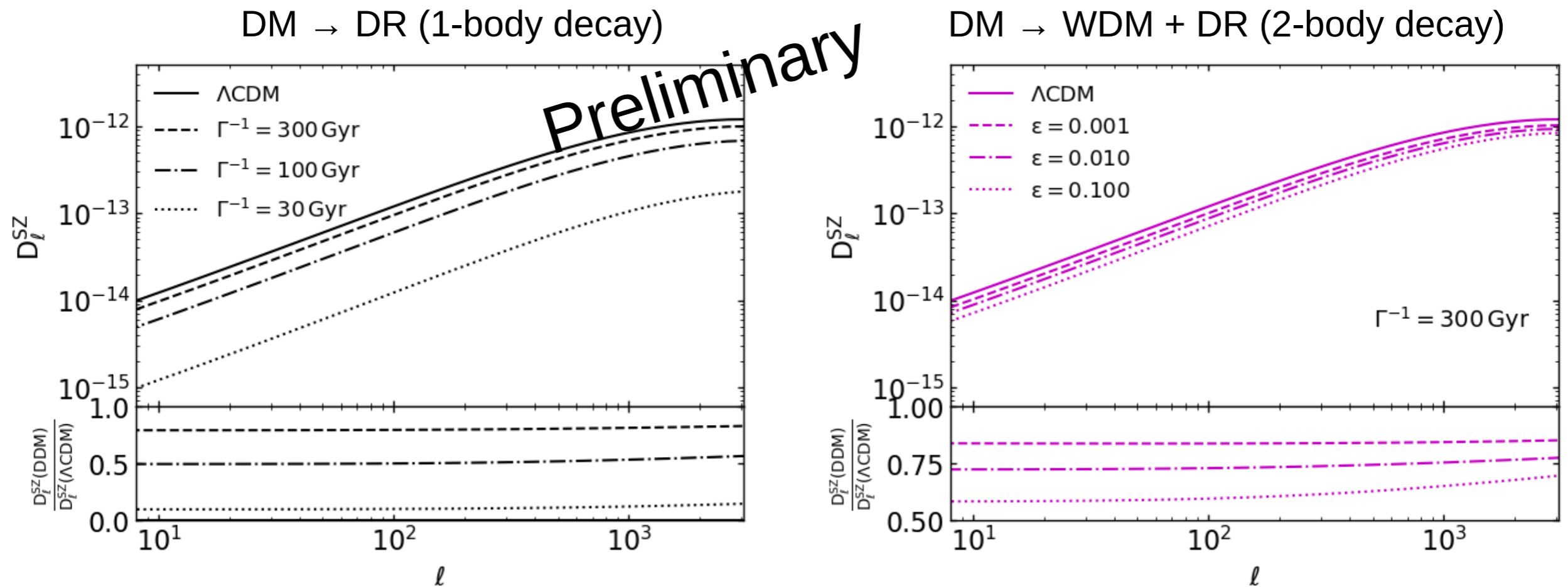
Planck2015+SPT+ACT prefers $M_\nu \sim 0.24$ eV, but the bad fitting due to the unknown inconsistency between Planck and ACT/SPT

Note: BAHAMAS includes baryonic effects, which do not explain the inconsistency.

McCarthy et al 2018

SZ power spectrum in DDM scenario

Two DDM models can be considered in Abellan et al 2022.

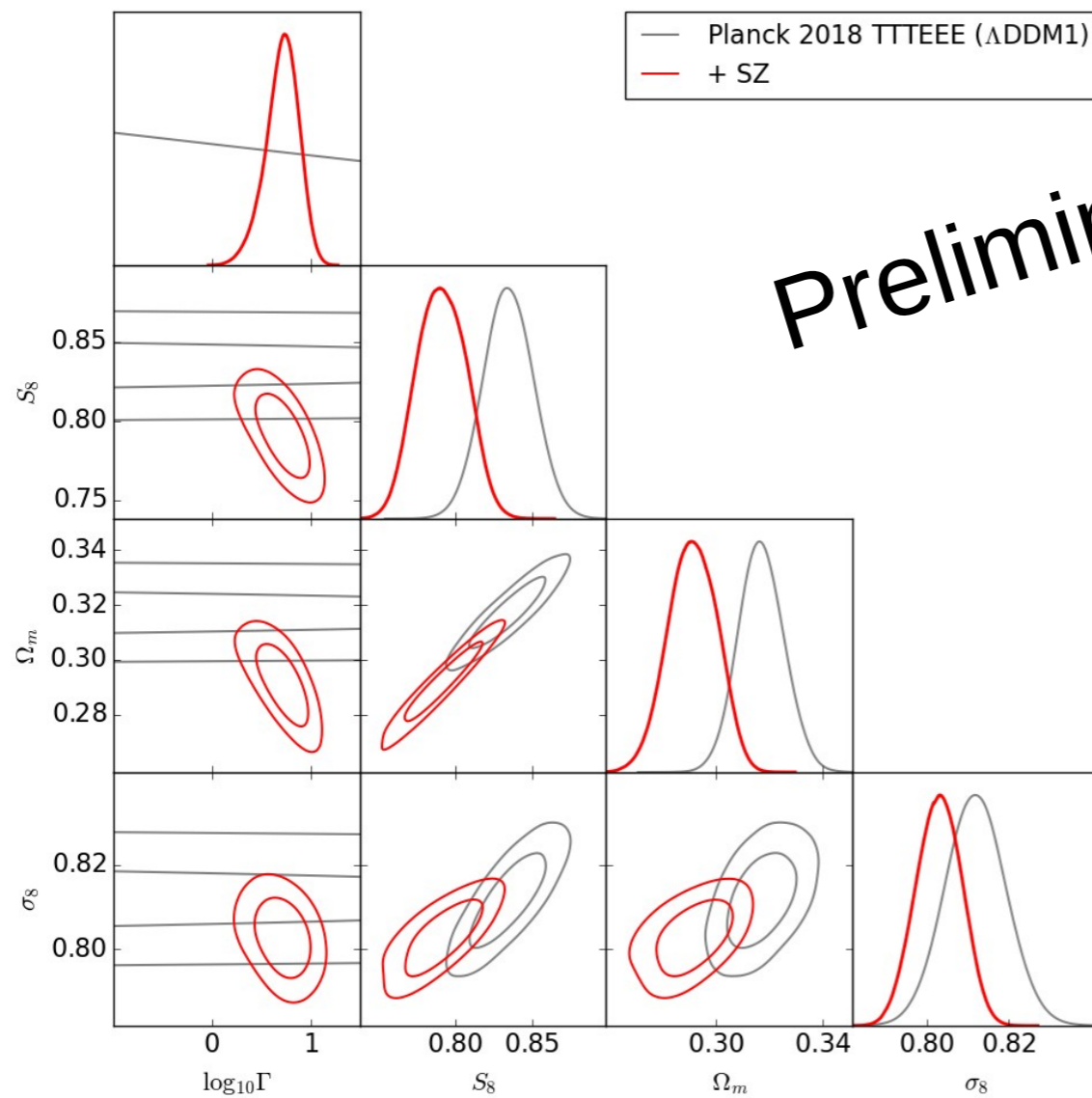


The amplitude and shape of the SZ power spectrum depends on assumed DDM scenarios.

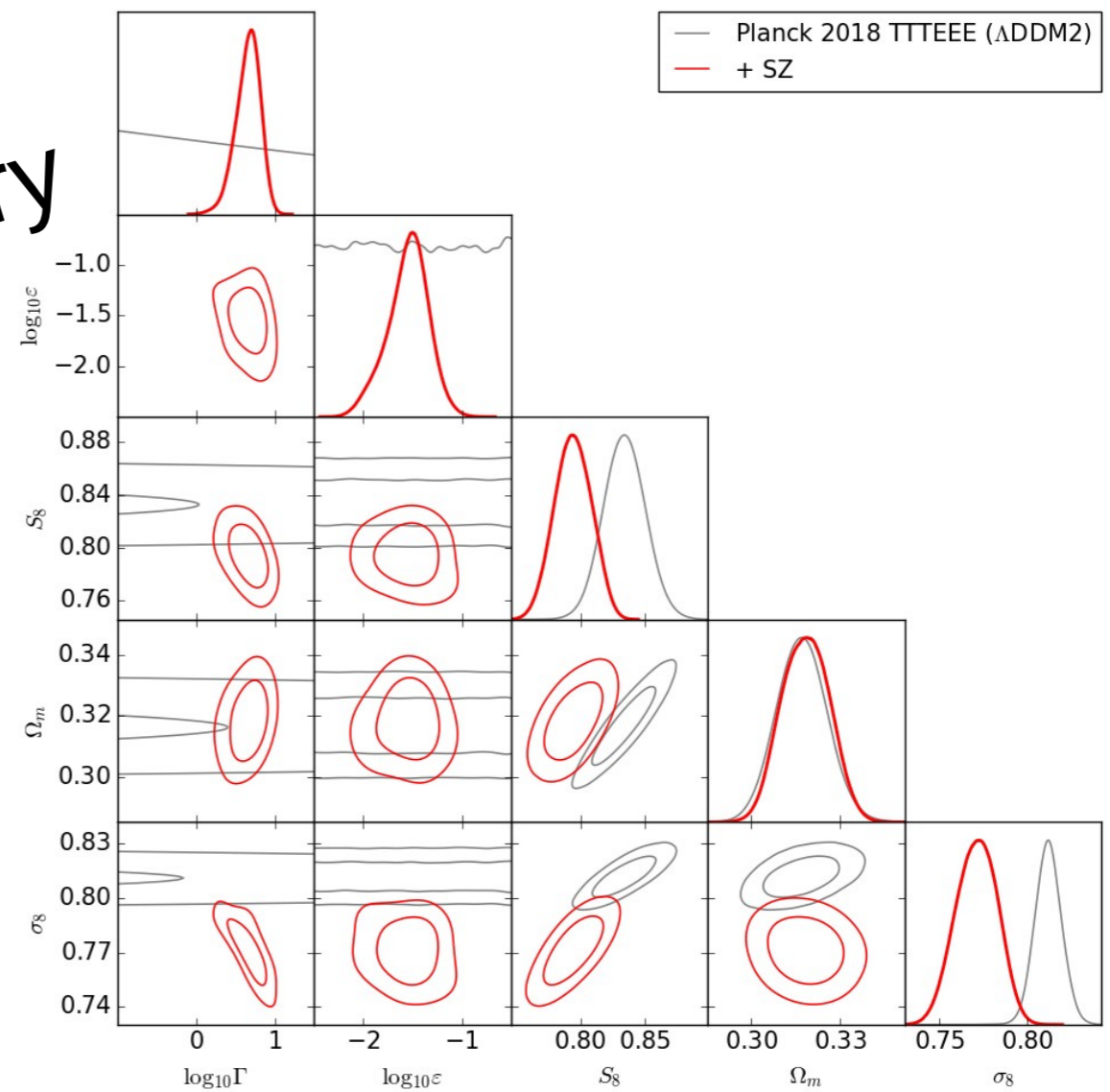
SZ power spectrum in DDM scenario

In DDM1, a lower S_8 value is caused by lower Ω_m .

In DDM2, a lower S_8 value is caused by lower σ_8 .



Preliminary



Summary

- We constructed new SZ map (10') using the latest Planck PR4 data, which is improved in statistics (~7%) and systematics (survey strips).
- Best SZ model is consistent with ACT and SPT results within 2σ .
- **Obtained S_8 value is consistent with the DES and KiDS results.**
- Obtained S_8 value is $S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5} = 0.764^{+0.015}_{-0.018} (stat) {}^{+0.031}_{-0.016} (sys)$ and **consistent with the Planck CMB's $S_8 = 0.830 \pm 0.013$ within 2σ .**

(For future)

- New SZ data from Planck + ACTPol will help to improve statistics and systematics for cosmological analysis.
- The combination of CMB + SZ data will help to constrain the DDM models.