Cosmological analysis with new Planck tSZ map

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Motivation

1, S8 tension?

tSZ effect is sensitive to σ_8 and Ω_m cosmological parameters as $\sigma_8^8\ \Omega_m^3$,

and it can be used to constrain $S_8(=\sigma_8(\Omega_m/0.3)^{0.5})$ parameter.

2, Planck tSZ map has not been updated since 2015 (PR2).

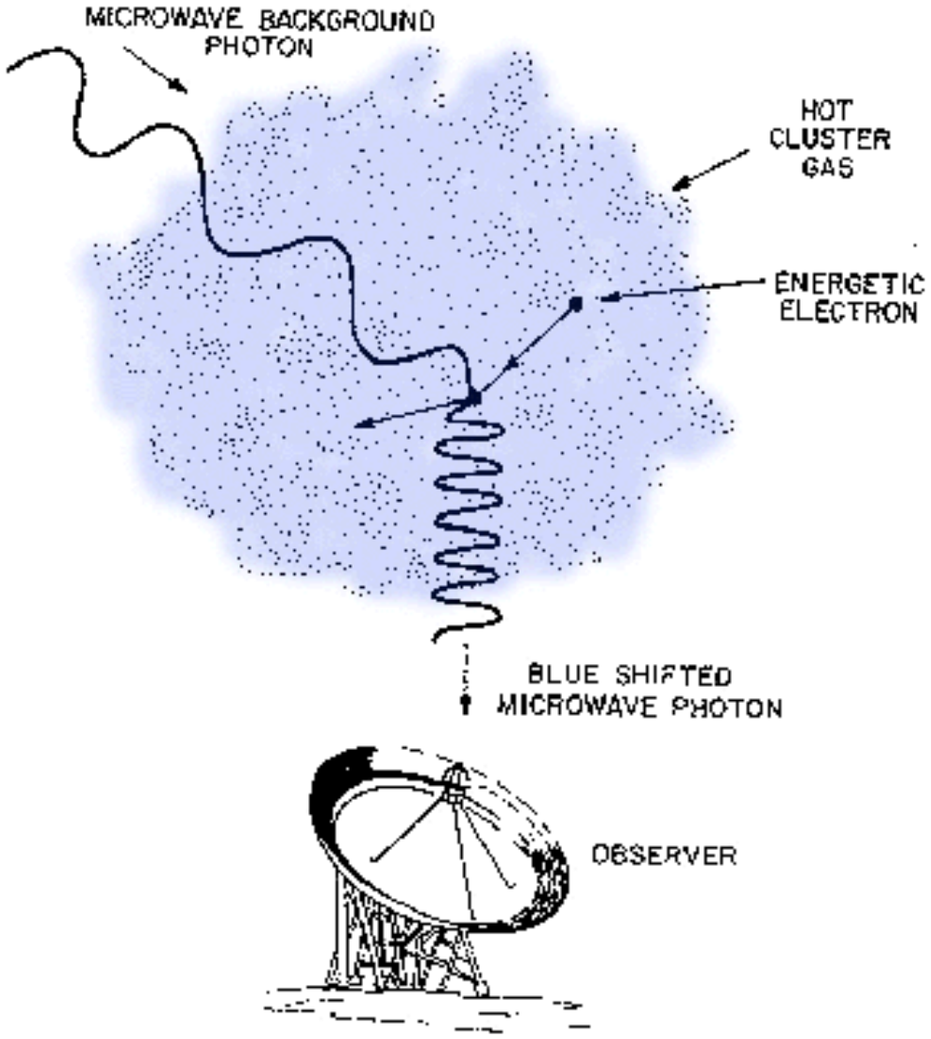
Planck PR4 data (Planck intermediate results. LVII, NPIPE maps) have improvements in temperature maps in terms of

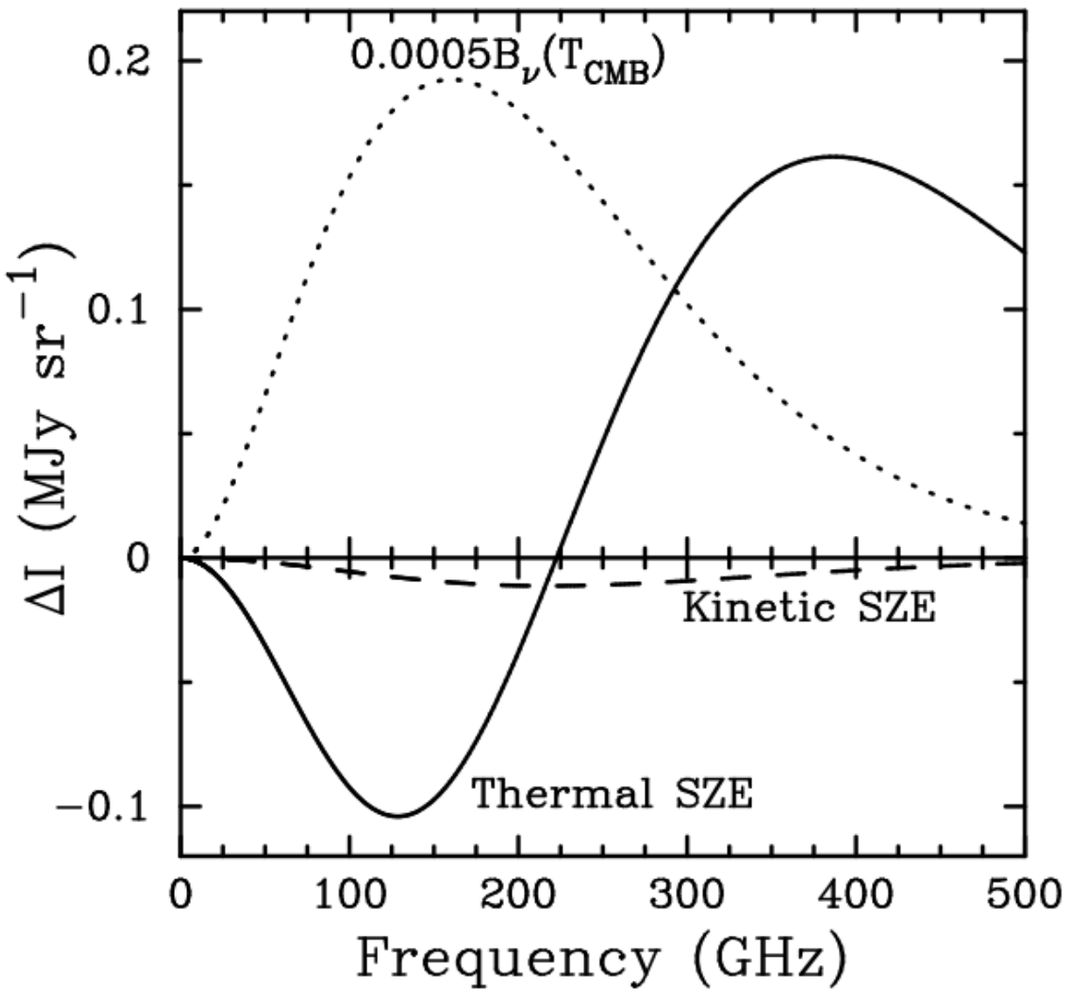
- calibration
- correction of bandpass mismatch at all frequencies
- ~8% more data collected during repointing maneuvers
- etc

These systematic and statistical improvements allow to construct better tSZ map and will provide a unbiased view to cosmological and astrophysical analysis.

Sunyaev-Zel'dovich(SZ) Effect

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



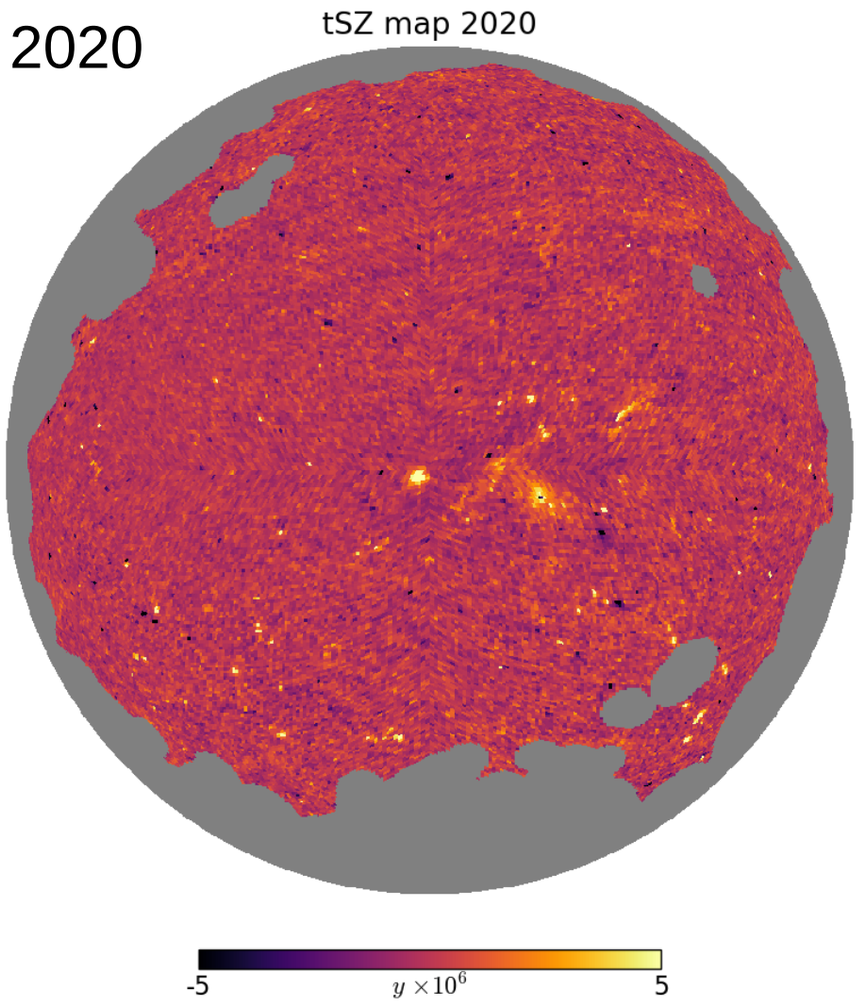


Spectral distortion of the CMB by a galaxy cluster
with T=10 keV, y=1e-4, Vpec=500 km/s (Carlstrom et al 2002)

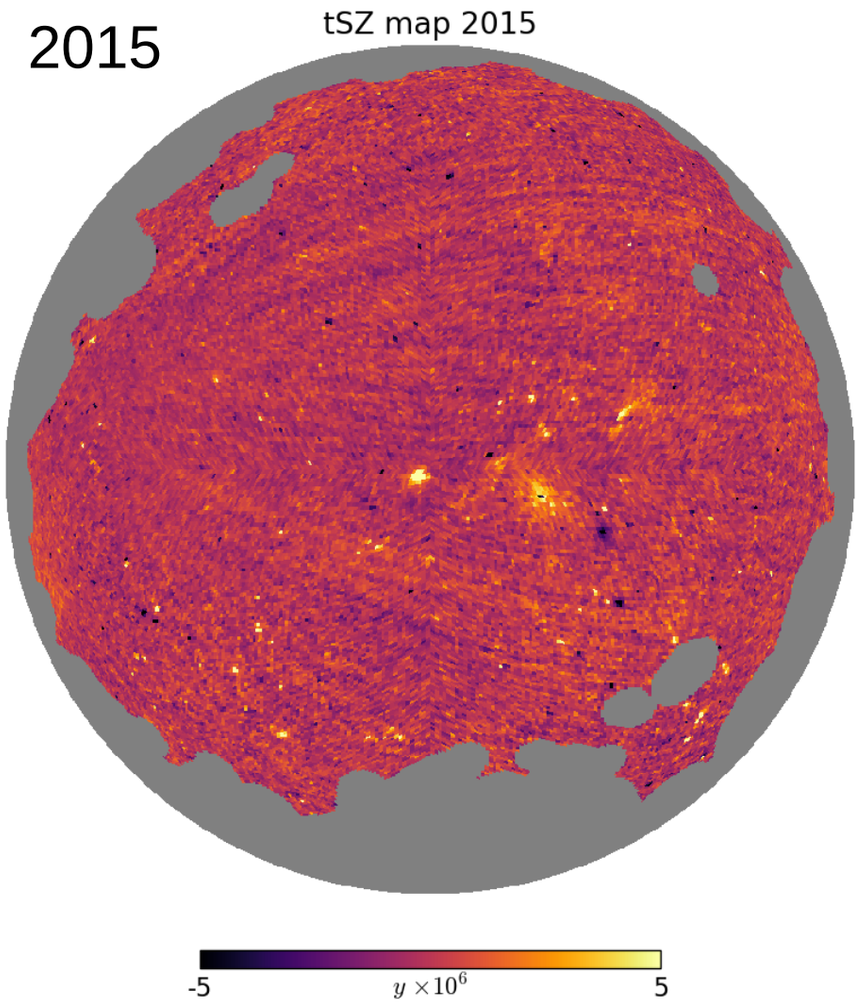
Comparison of tSZ maps

We reconstructed the y-map with 10’ angular resolution using the MILCA algorithm (Hurier et al., 2013) and compared it with the older version in 2015 (Planck 2015 results XXII).

2020



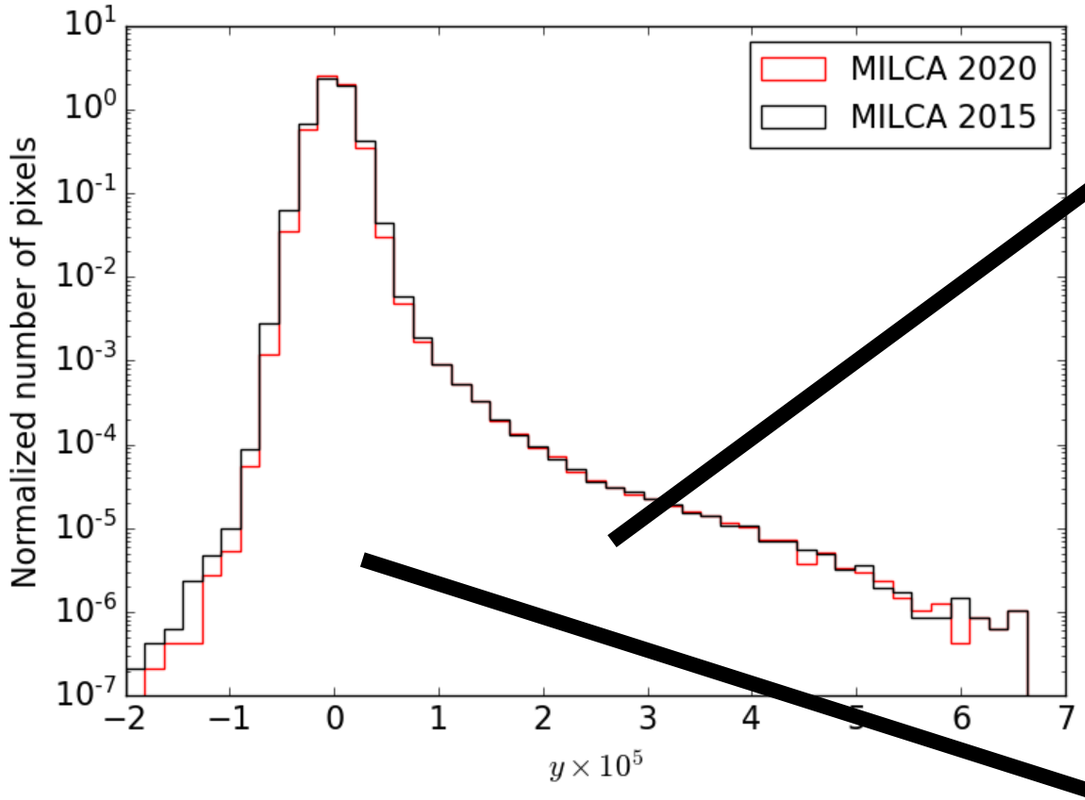
2015



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

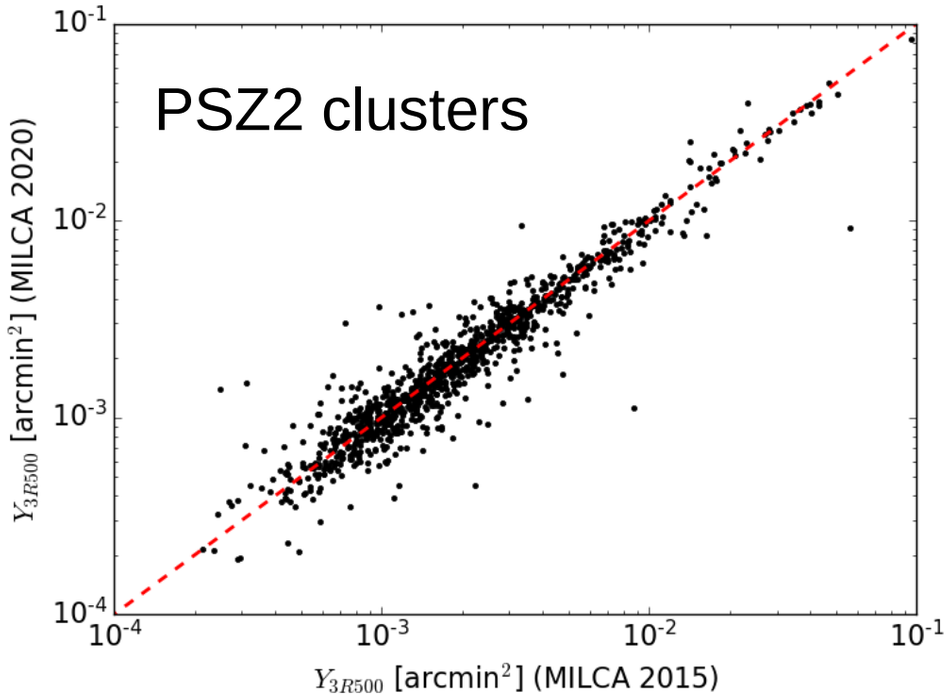
Comparison of tSZ maps (signal and noise)

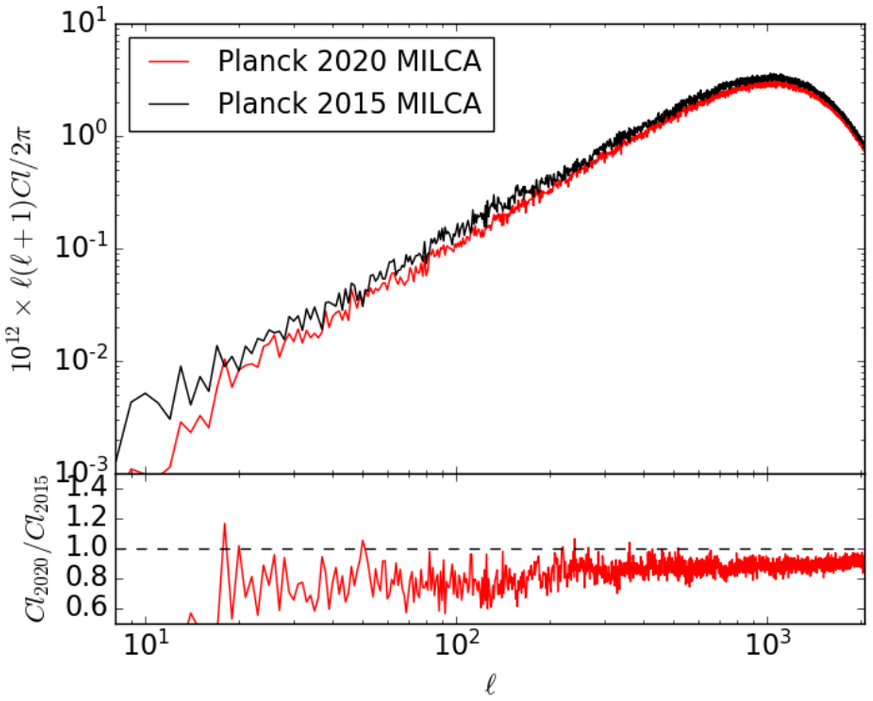
Histogram of the y-maps



Signals

Noises



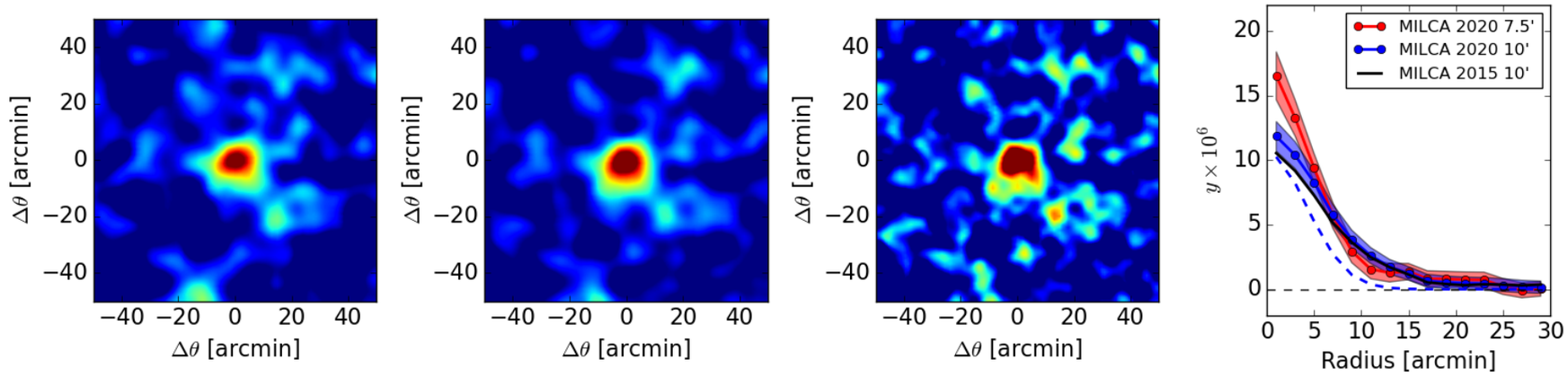


Noise of new y-map is reduced by ~7%.

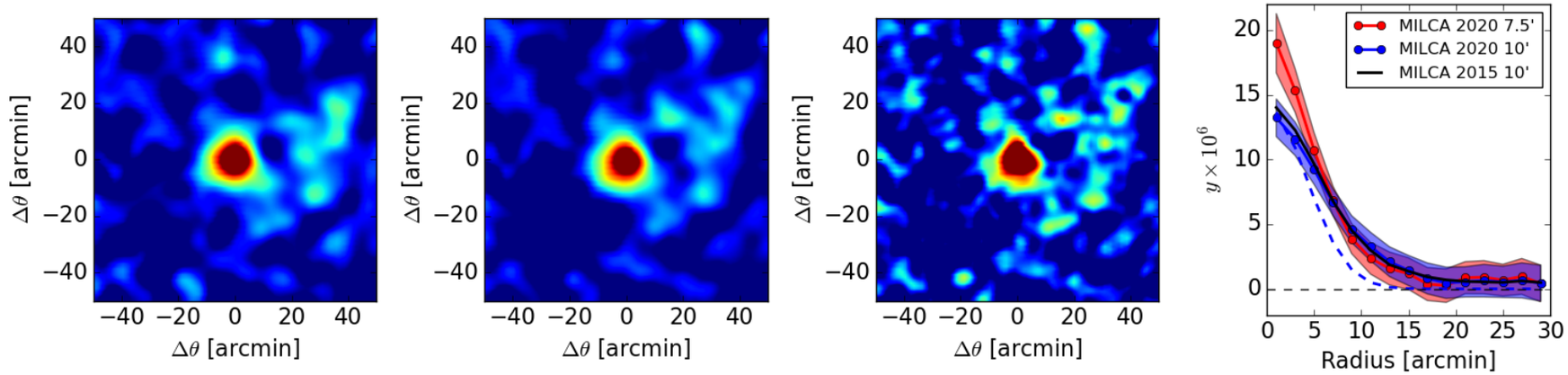
Comparison of tSZ maps (clusters)

2015 (10')　　2020 (10')　　2020 (7.5')

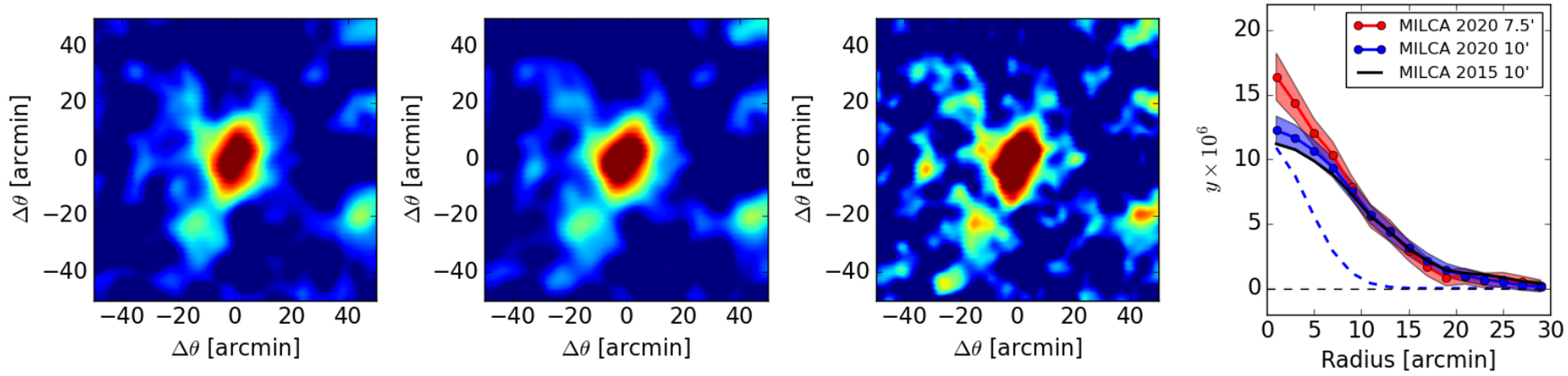
Abell 2397



RXC. J2104.3-4120

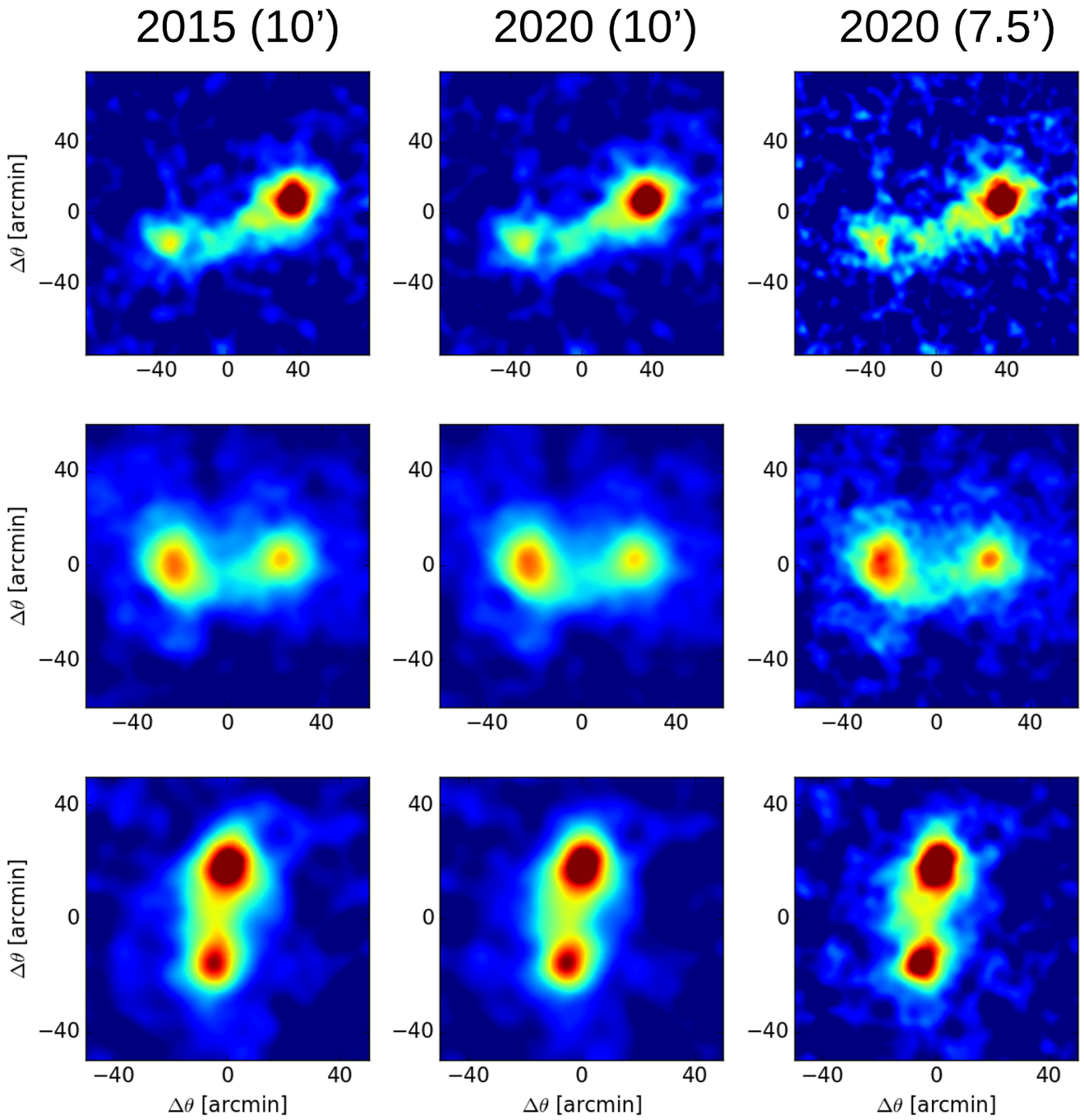


Abell 2593



The tSZ signals in clusters are consistent between 2015 and 2020 y-maps,
and the y-map with a higher angular resolution allows to better probe at small scales.

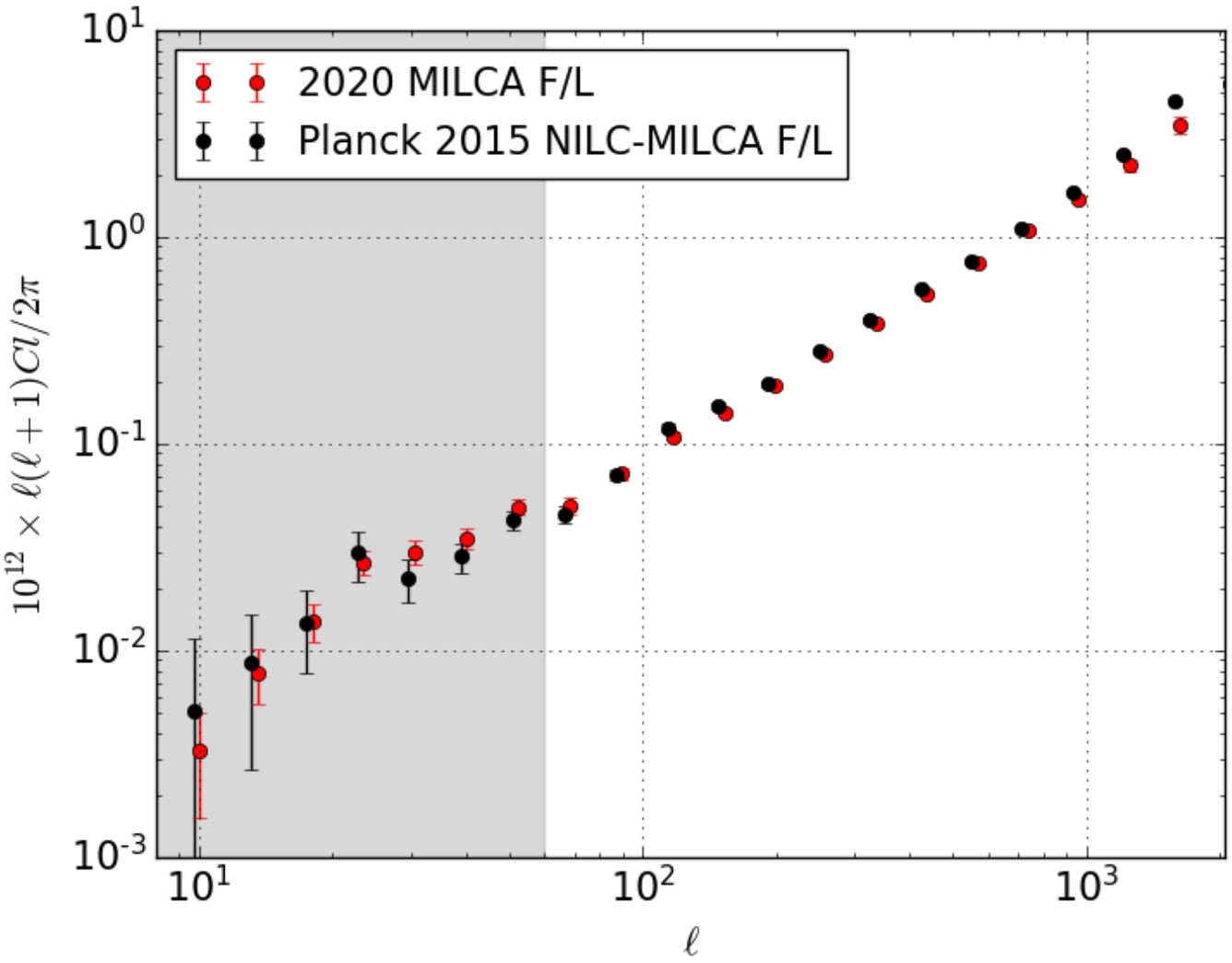
Comparison of tSZ maps (diffuse gas)



The tSZ signals between merging systems are consistent between 2015 and 2020 y-maps, and the y-map with a higher angular resolution allows to probe more detailed structures.

Comparison of power spectrum

For a cosmological analysis,
we made two y-maps with half-period HFI maps, computed their cross-power spectrum, and used it to avoid a bias induced by the noise in the auto-power spectrum.



Our uncertainties are lower. It is probably due to lower noises, minimal survey strips, and our window function that suppresses residual foreground emissions.

Model of tSZ power spectrum

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

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

Halo mass function — y-signal in a halo

$$\tilde{y}_\ell(M,z) = \frac{\sigma_\mathrm{T}}{m_\mathrm{e}c^2} \frac{4\pi r_\mathrm{s}}{\ell_\mathrm{s}^2} \int \mathrm{d}x x^2 \frac{\sin(\ell x/\ell_\mathrm{s})}{\ell x/\ell_\mathrm{s}} P_\mathrm{e}(x,M,z)$$

pressure in a halo

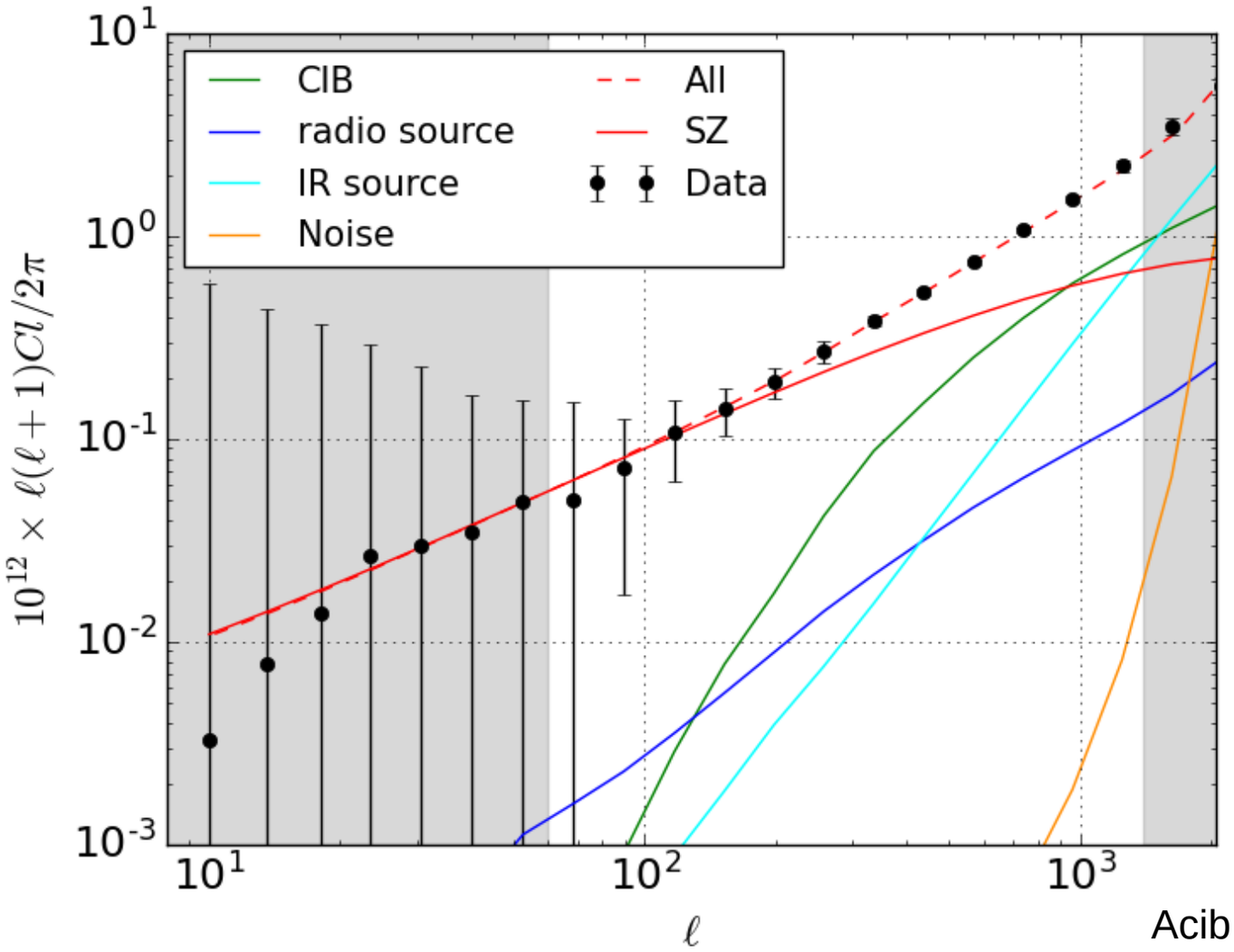
$$\frac{P(r)}{P_{500}} = \mathbb{P}(x) \qquad P_{500} = 1.65 \times 10^{-3} \left[\frac{H(z)}{H_0}\right]^{8/3} \times \left[\frac{(1-b)\, M_{500}}{3 \times 10^{14}\, (h/0.7)^{-1} \mathrm{M}_\odot}\right]^{2/3+\alpha_\mathrm{p}} \left(\frac{h}{0.7}\right)^2 \mathrm{keV\ cm^{-3}}$$

mass bias

Cosmological analysis with MCMC

We included the contamination terms in the y-map and performed a cosmological analysis under ΛCDM with a model of

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

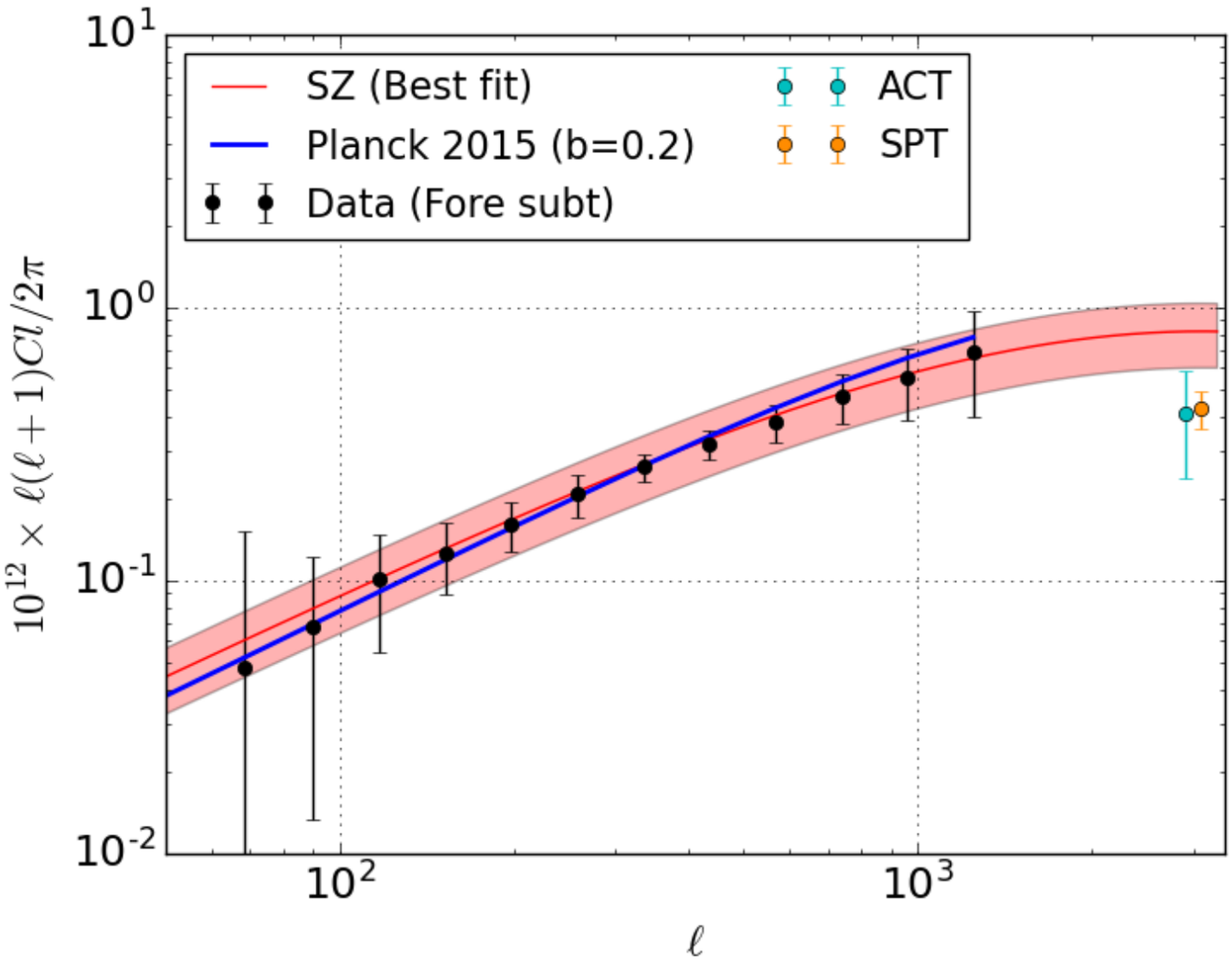


Acib = 0.82±0.16, Air = 1.18±0.34,
Arad = 1.02±0.48, ACN = 1.03±0.47.

tSZ signals dominates our y-map at 60 < ell < 600.

Our best tSZ model

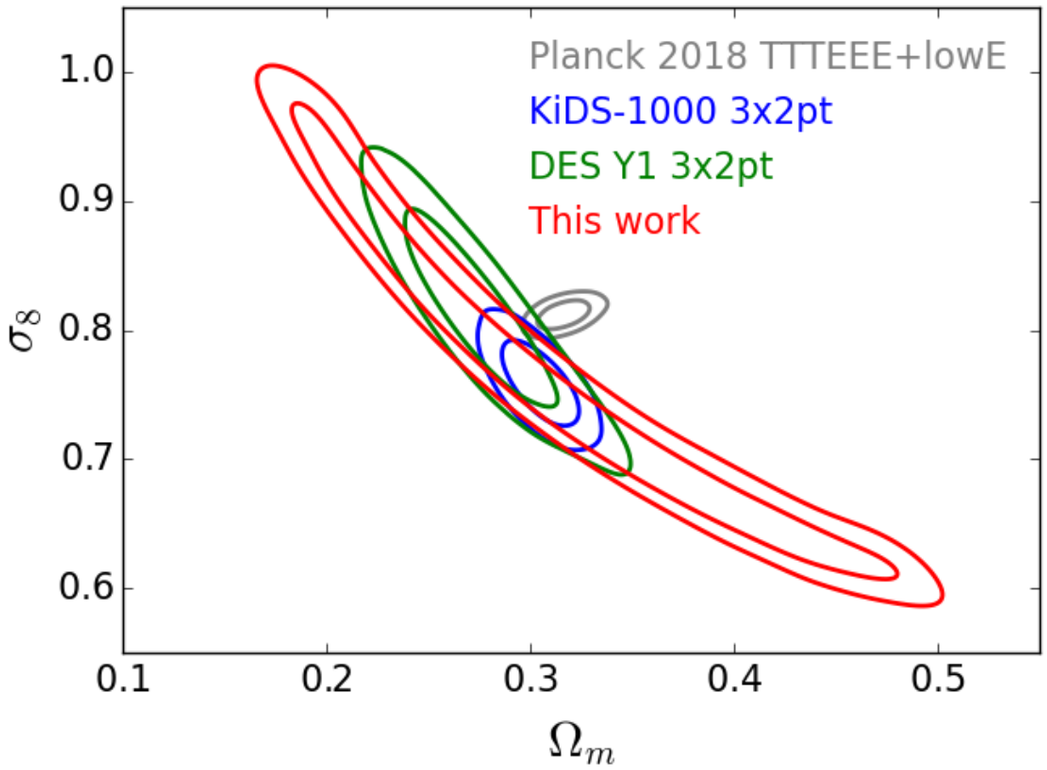
We compared our best tSZ model with previous result from the Planck 2015 as well asl ACT (cyan, Dunkley et al. 2013) and SPT (orange, Reichardt et al. 2021).

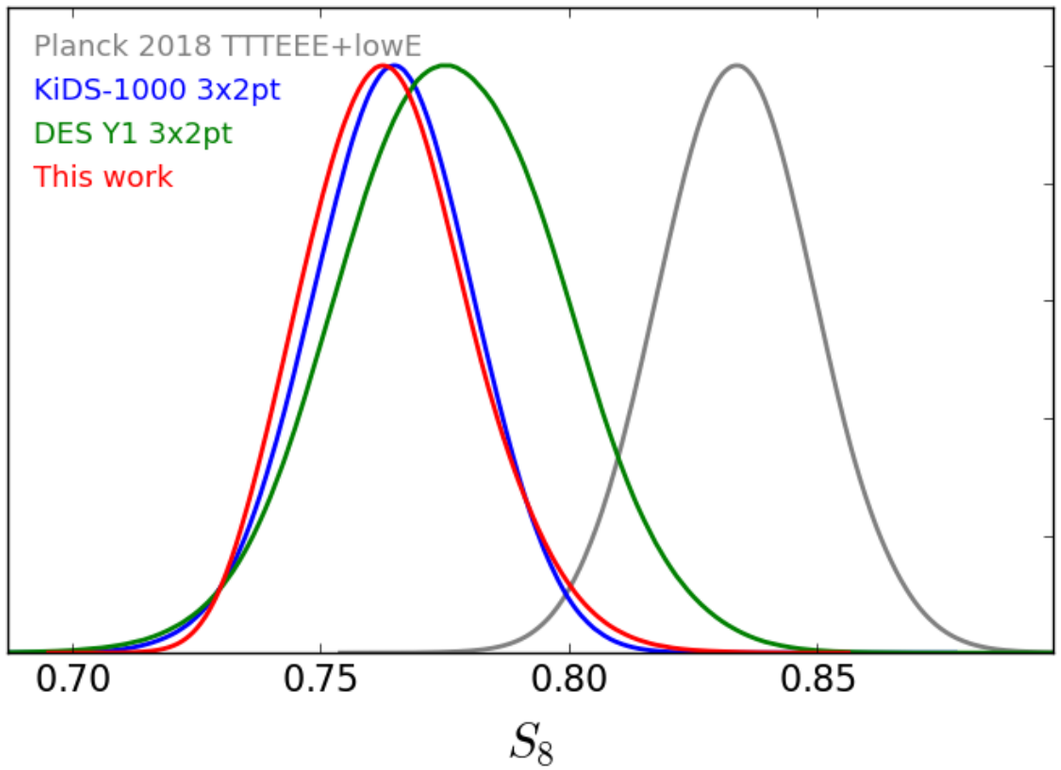


Our model is consistent with Planck 2015 and also with ACT and SPT within 2σ.

Cosmological parameter estimate

We compared our cosmological parameter estimates with the Planck CMB's result as well as KiDS-1000 3x2pt (Heymans et al 2021) and DES Y1 3x2pt results (DES 2018).



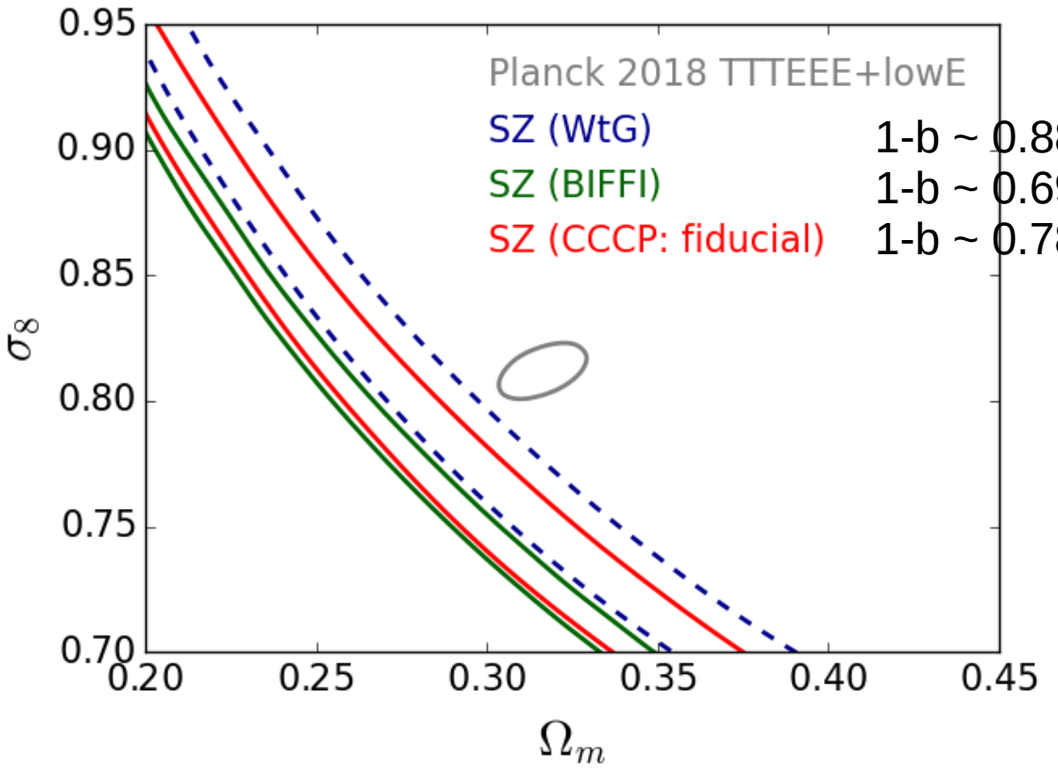


Our result is consistent with the KiDS and DES results.

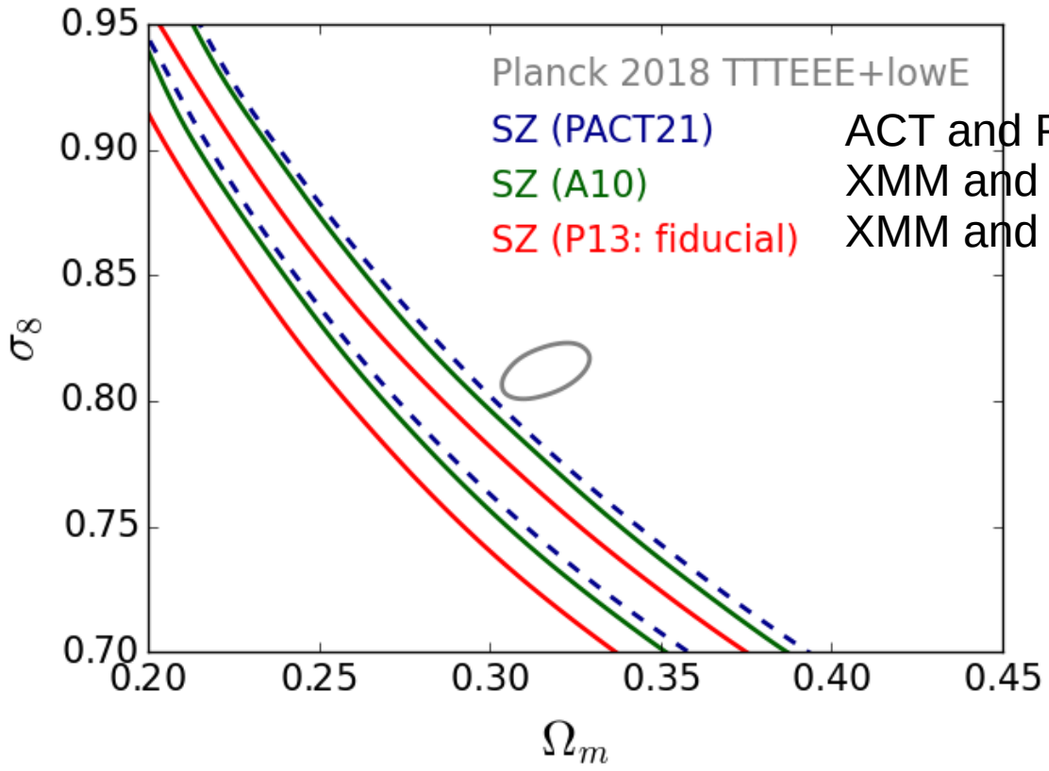
Systematics

We checked systematics in our cosmological analysis
with the tSZ power spectrum analysis..

Different mass bias prior



Different pressure profile model



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.

Summary

- We reconstructed the 10’ and 7.5’ tSZ map using the Planck PR4 data (NPIPE).

  New tSZ map (10’) is improved in terms of noises by ~7% and survey strips.

  New tSZ map (7.5’) allows to probe more detailed structures at small scales.

- Our best tSZ model is consistent with ACT and SPT results within 2σ.

- Our obtained S_8 value is consistent with the DES and KiDS results.

- Our 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.