Compton-*y*:
Auto-spectrum and cross-correlation with CMB lensing and shear

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collaborators: the many people who contributed to related work in the CMB-S4 Decadal Survey Report; Boris Bolliet; Fiona McCarthy; Nick Battaglia; Enrico Pajer; David Spergel

CMB-S4 Project Meeting
Zoom
6 April 2023

CMB-S4
Next Generation CMB Experiment

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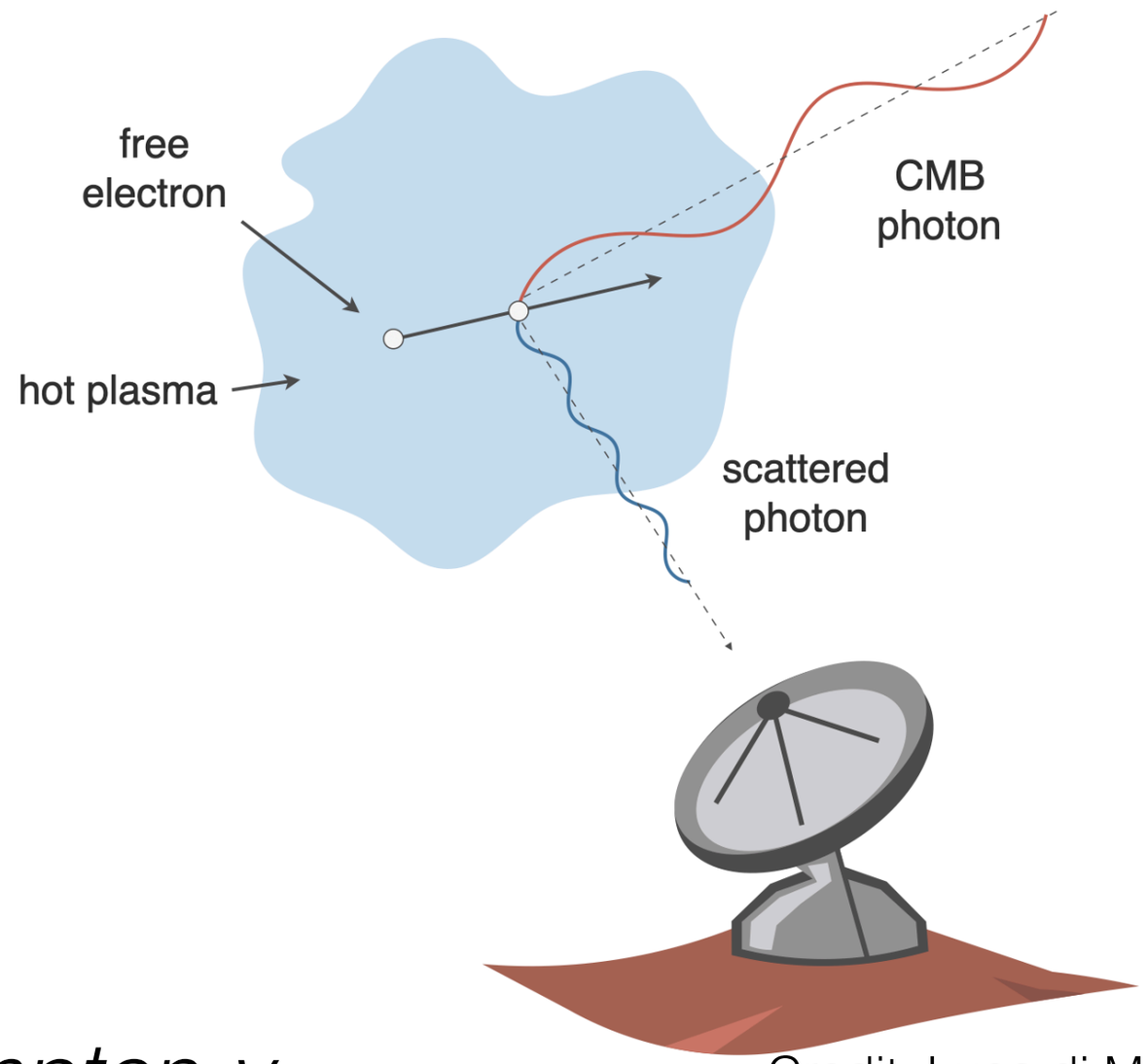
Thermal SZ Effect

Thermal SZ Effect: Change in temperature of CMB photons due to inverse-Compton scattering off hot electrons, most of which are in the intracluster medium (ICM) of galaxy groups/clusters



Credit: Luca di Mascolo

$$\frac{\Delta T_{\rm tSZ}}{T_{\rm CMB}} = g_\nu \frac{\sigma_T}{m_e c^2} \int P_e(\chi) d\chi$$

Compton-y

line-of-sight integral

tSZ spectral function

electron pressure

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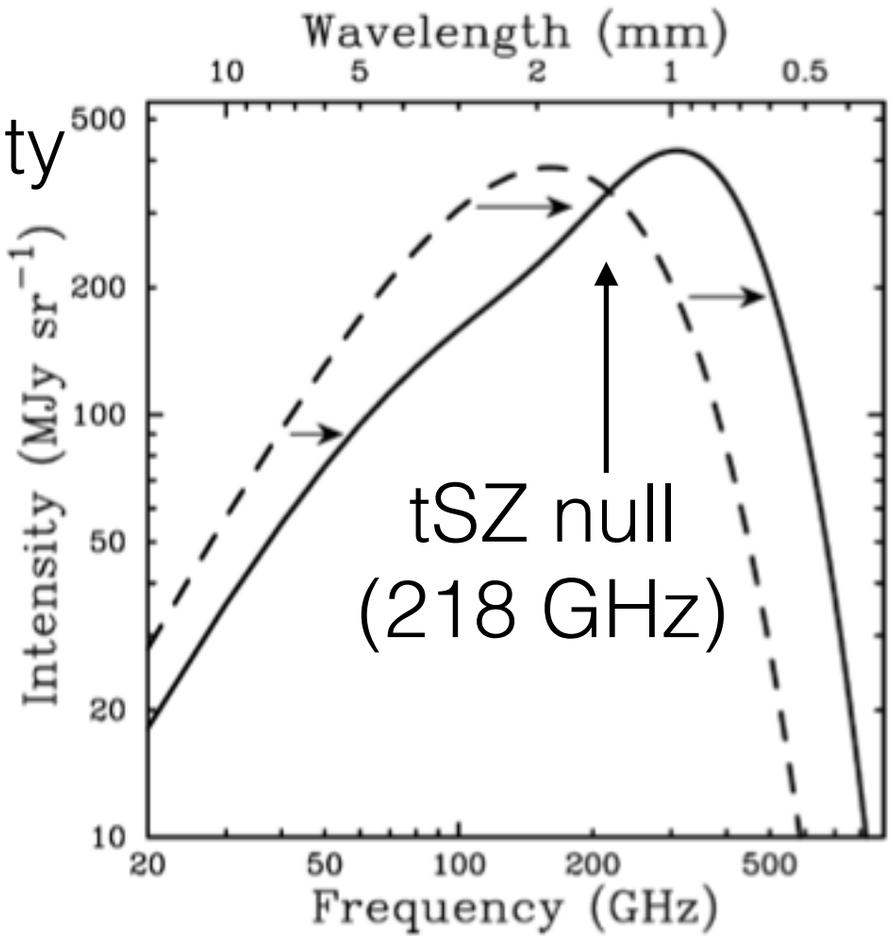
Thermal SZ Effect

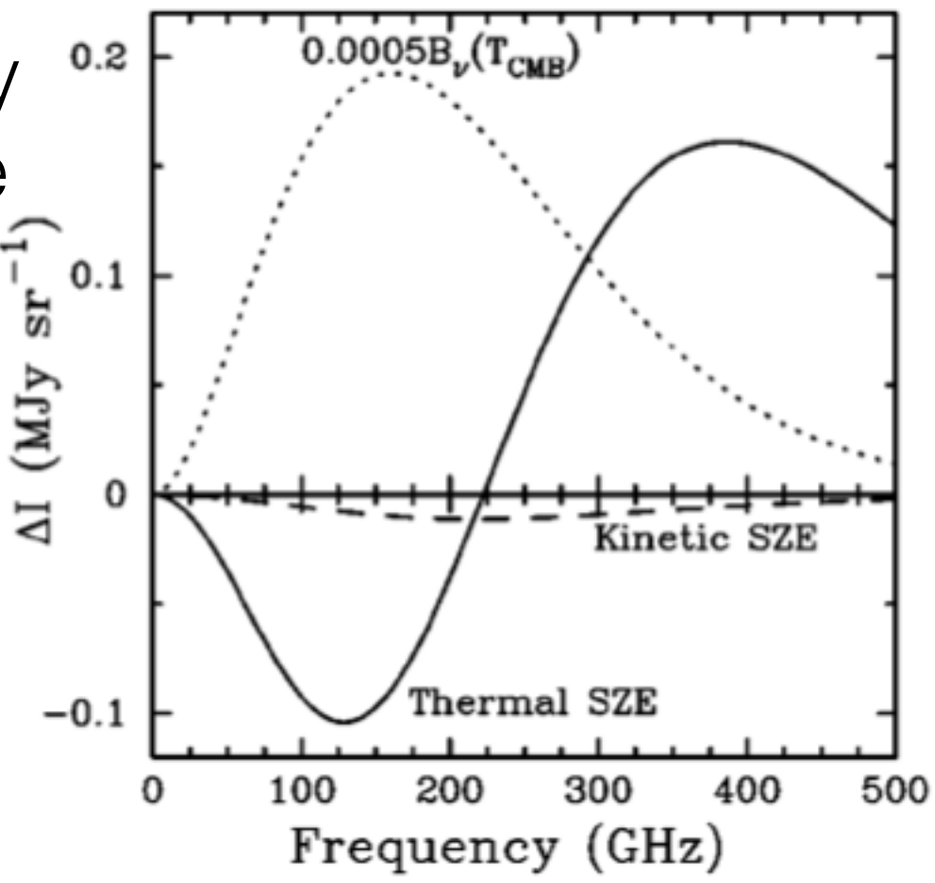
Unique spectral signature

intensity



frequency

intensity change



frequency

Can thus be isolated and mapped using multi-frequency data

Figures: Carlstrom+ (2002)

Matter Mapping with the CMB

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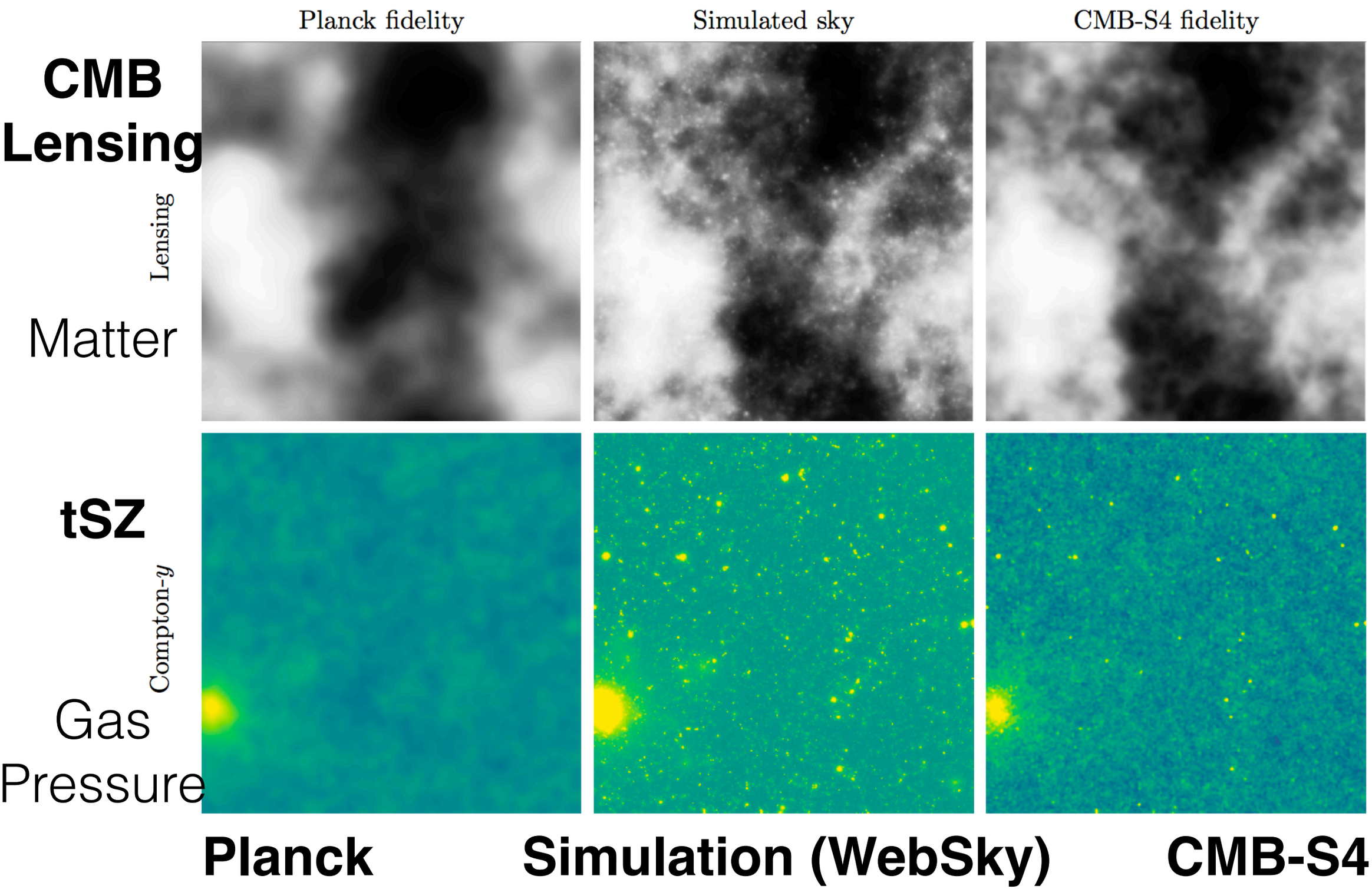

CMB-S4 DSR (2019)

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Beyond Cluster Counts

Thermal SZ Statistics

Probe cosmology and astrophysics:

- tSZ power spectrum [Sievers+ (2013); George+ (2015); Planck+ (2016); Bolliet+ (2018)]
- tSZ skewness / bispectrum [Wilson+ (2012); Crawford+ (2014); Planck+ (2016)]
- tSZ 1-point PDF [JCH+ (2014); Planck+ (2016)]
- tSZ x CMB lensing [JCH & Spergel (2014); McCarthy & JCH (in prep.)]
- tSZ x galaxy lensing [e.g., van Waerbeke+ (2014); Hojjati+ (2016); Gatti+ (2022)]

Probe astrophysics (e.g., AGN feedback):

- tSZ stacking:
  - galaxies [e.g., Hand+ (2011); Planck+ (2013); Greco, JCH+ (2015); JCH+ (2018); …]
  - quasars [e.g., Ruan+ (2015); Crichton+ (2016); Verdier+ (2016); …]
  - clusters [e.g., Plagge+ (2010); Planck+ (2013); …]

Thermal SZ Power Spectrum

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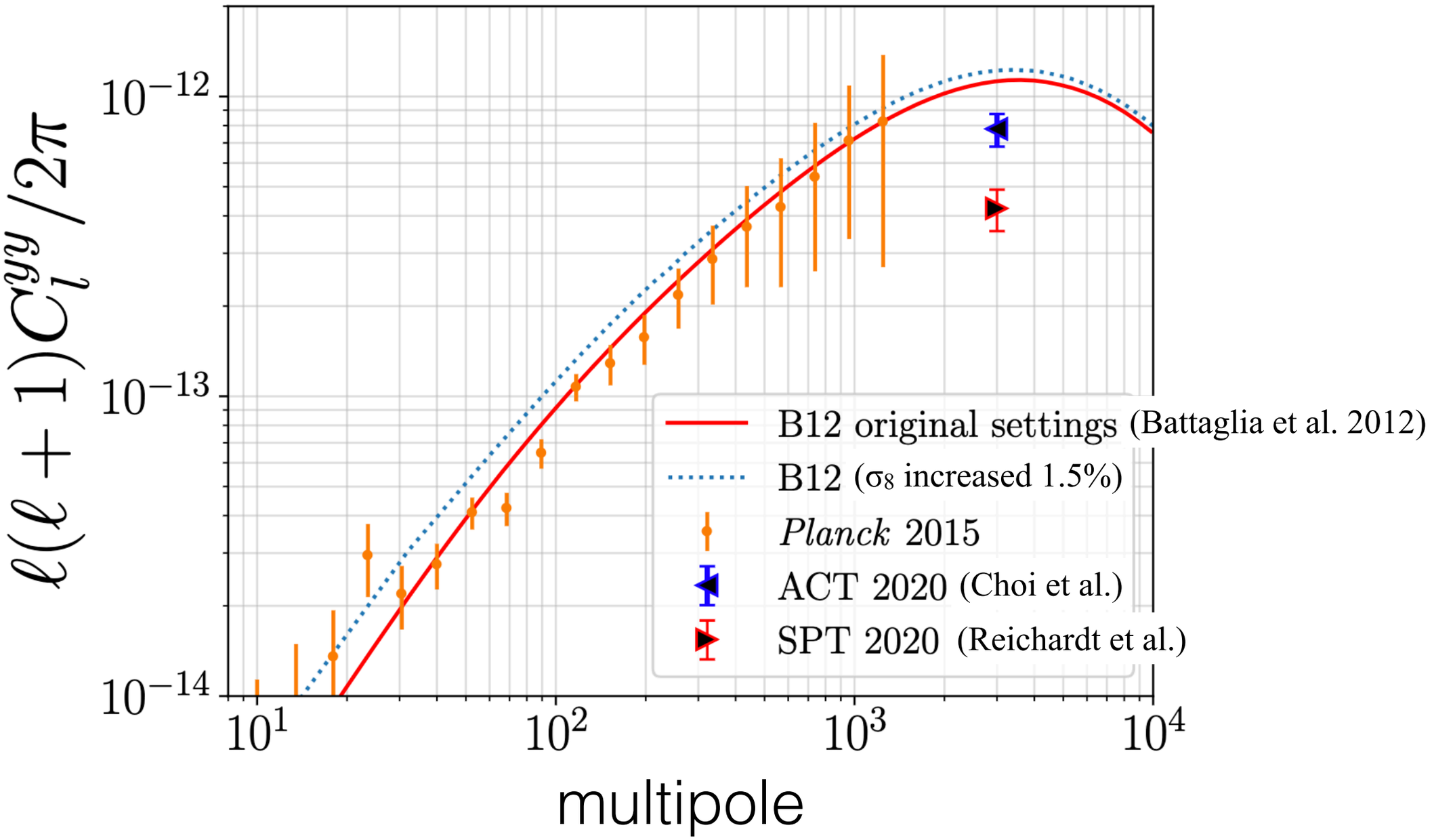
Existing constraints: *Planck* at ell < 1000; ACT/SPT at ell=3000
(inferred by very different techniques)



Kusiak, Surrao, JCH (2023)

CMB-S4: Thermal SZ

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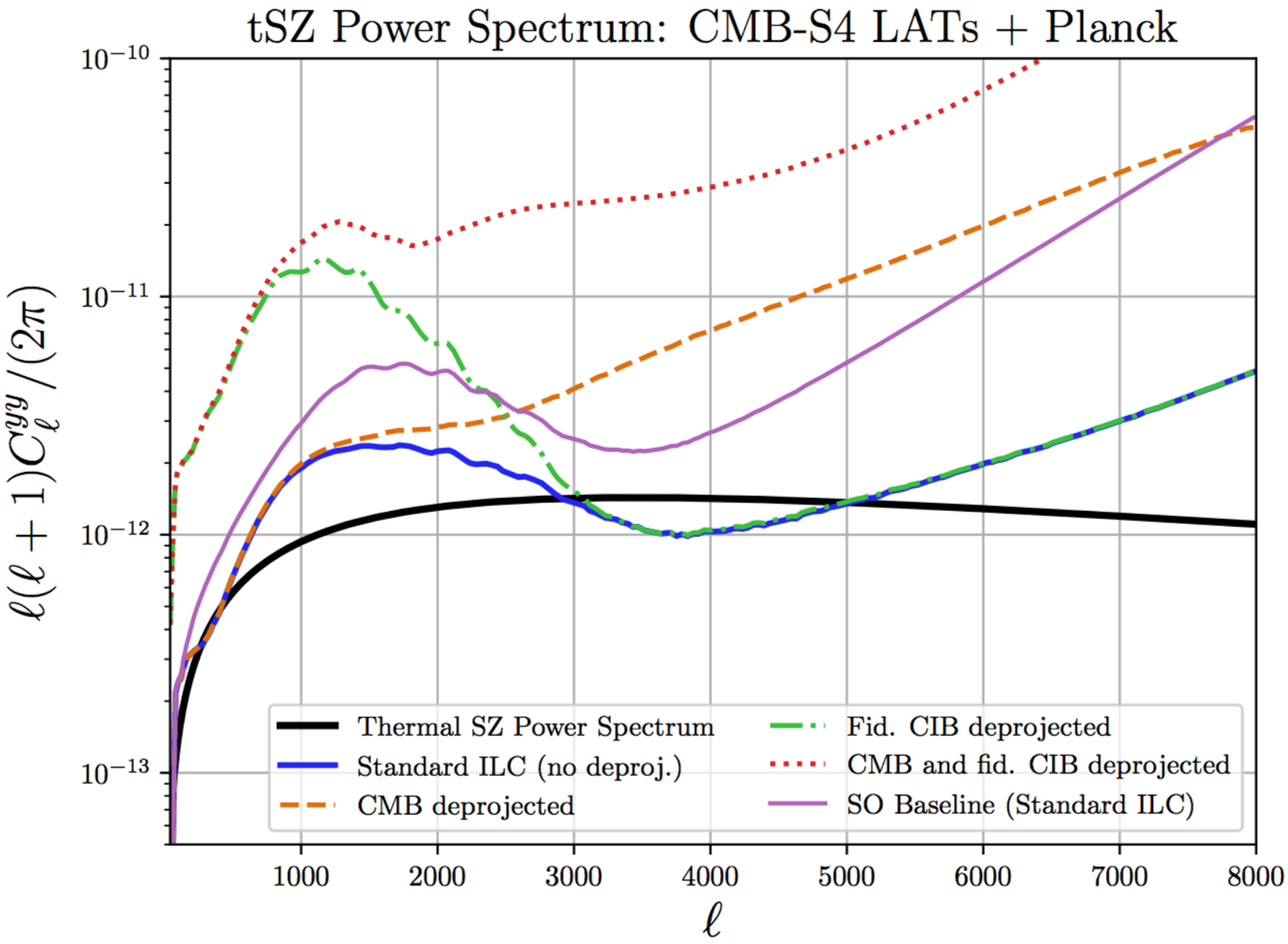
The first experiment to map the diffuse Compton-*y* field to the cosmic-variance limit on any scale (for S4: 3000<ell<5000)



CMB-S4 DSR (2019); see also related work from Srini Raghunathan for PBDR

Origin of the Thermal SZ PS

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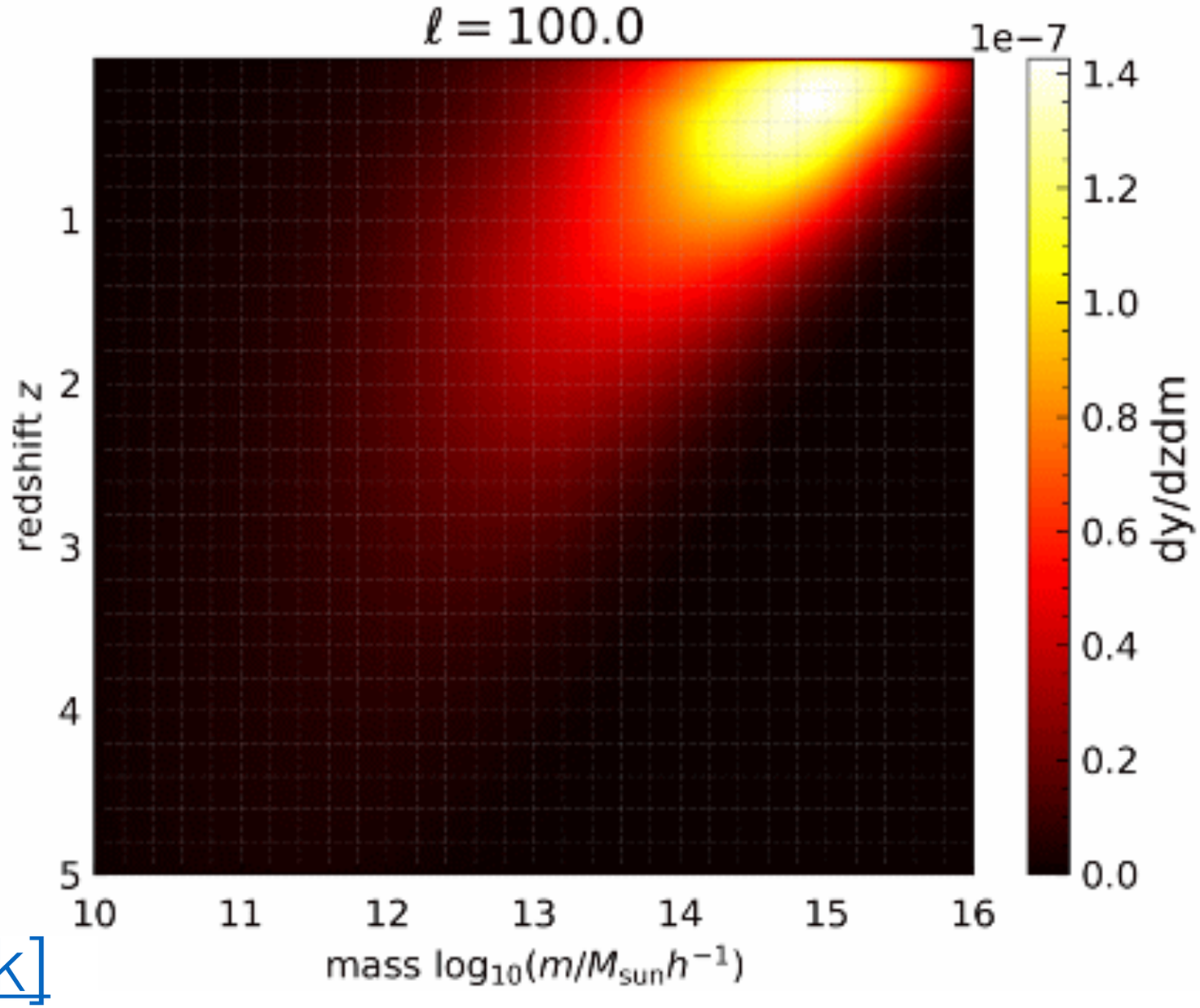
Halo model decomposition in terms of halo mass and redshift



[gif link]

Sensitive probe of both cosmology (~$\sigma_8^{7\text{-}8}$) and gastrophysics

Bolliet et al. (in prep.): computed with CLASS_SZ [https://github.com/CLASS-SZ]

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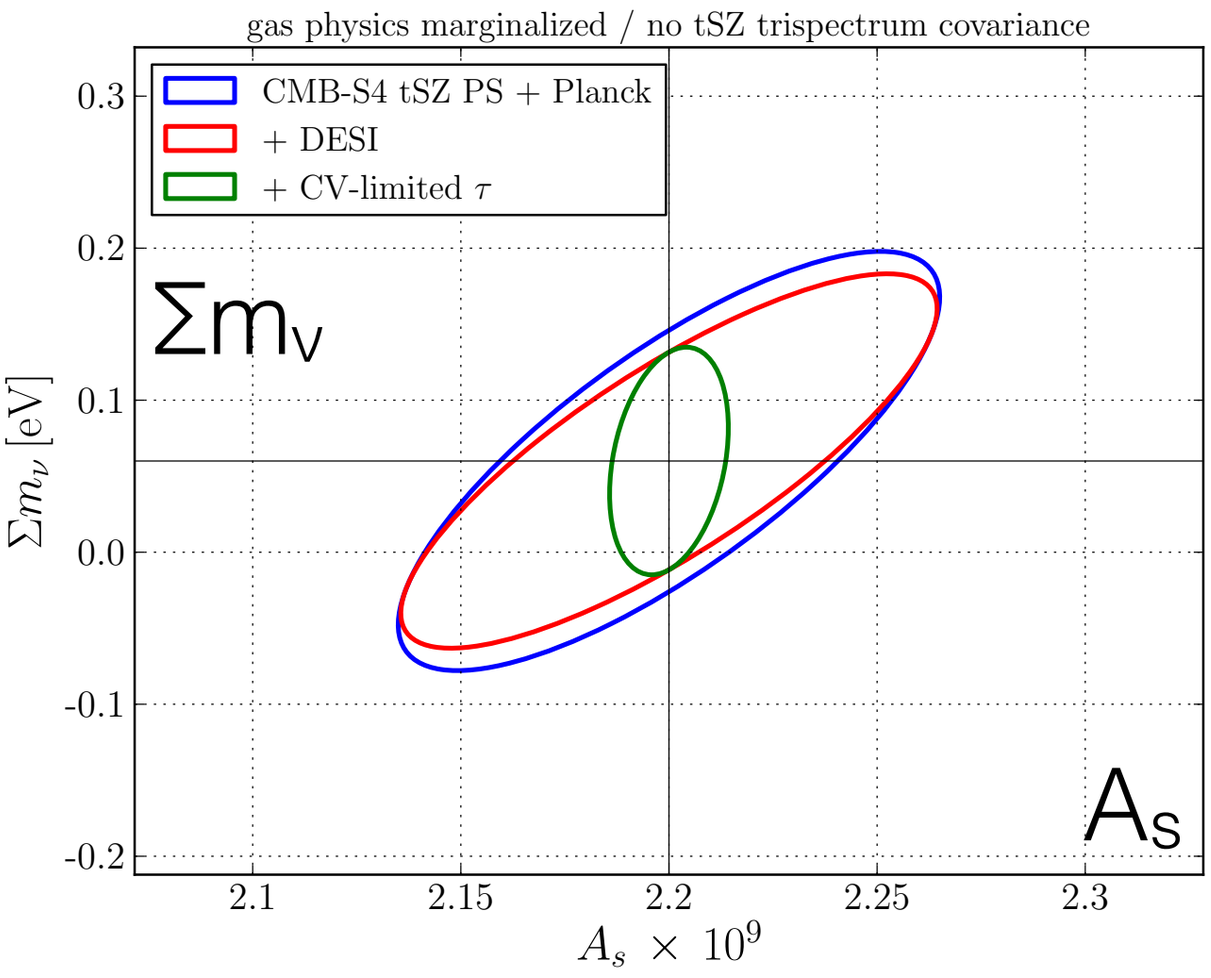
Fisher Forecasts: Σm_ν

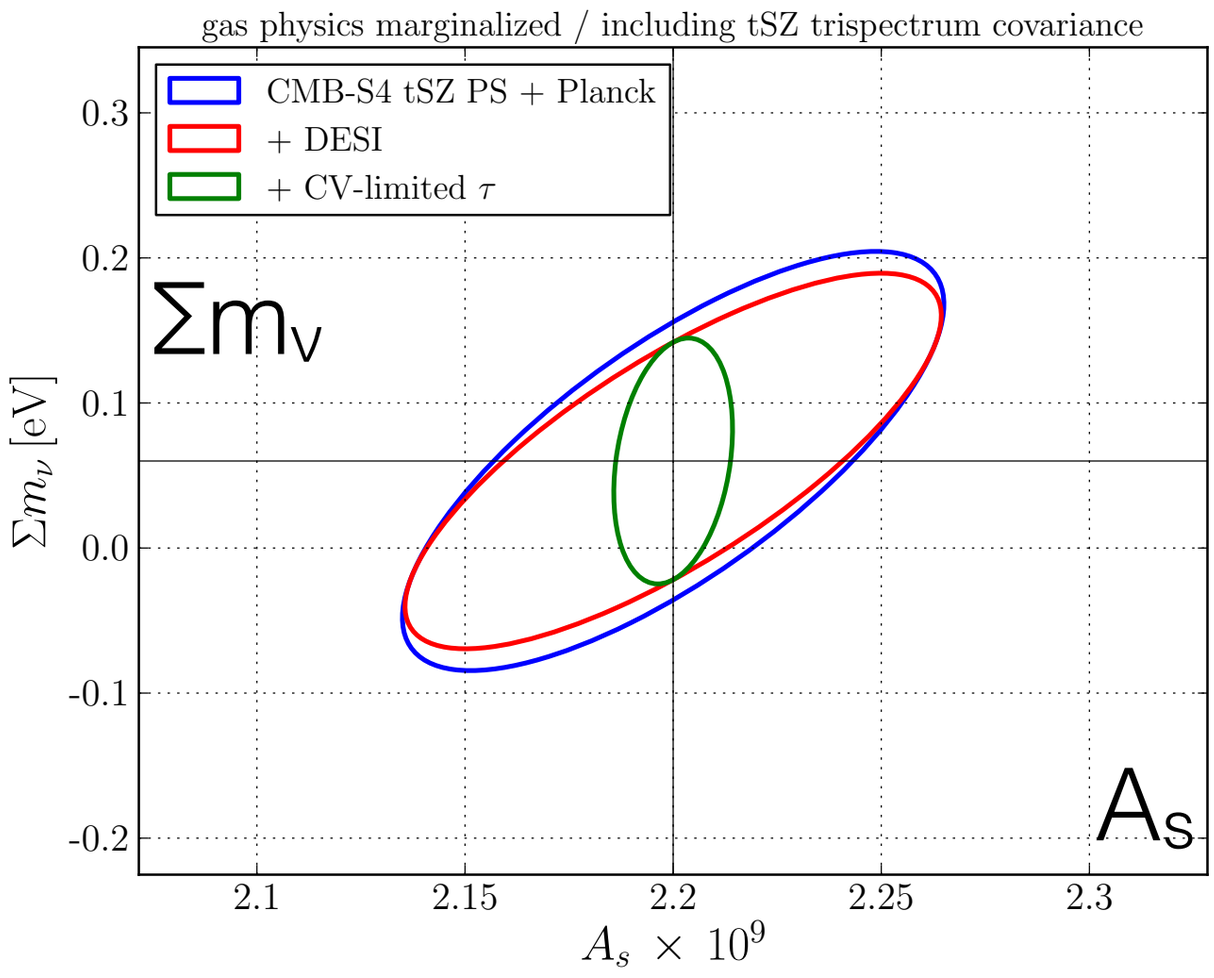
Gas physics marginalized

no tSZ trispectrum in cov.



$\sigma(\Sigma m_\nu) = 91$ meV
$\sigma(\Sigma m_\nu) = 81$ meV
$\sigma(\Sigma m_\nu) = 49$ meV

incl. tSZ trispectrum in cov.



$\sigma(\Sigma m_\nu) = 95$ meV
$\sigma(\Sigma m_\nu) = 85$ meV
$\sigma(\Sigma m_\nu) = 56$ meV

tSZ x CMB Lensing

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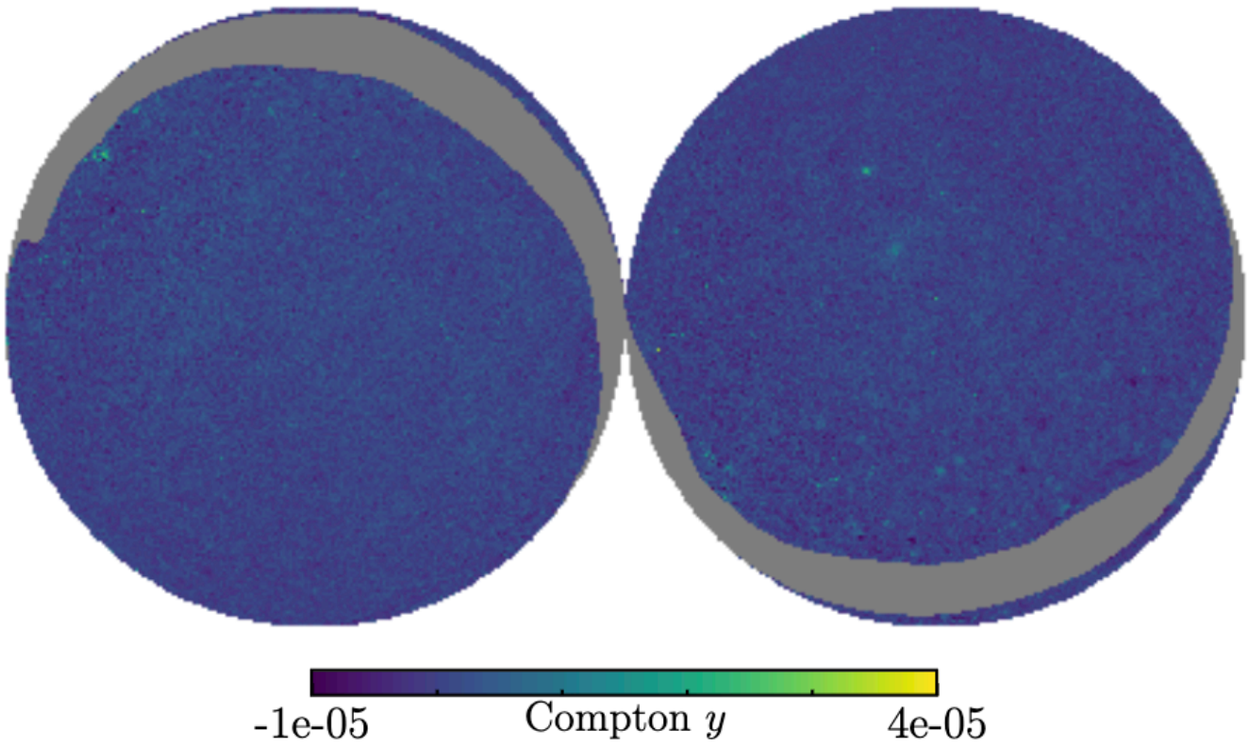
Probe of relationship of hot, ionized gas and matter density

New analysis using Planck NPIPE data



Custom NILC y-maps with tailored CIB cleaning

X

CMB lensing from Planck PR4 maps

Carron+ (2022)

JCH & Spergel (2014); McCarthy & JCH (in prep.)

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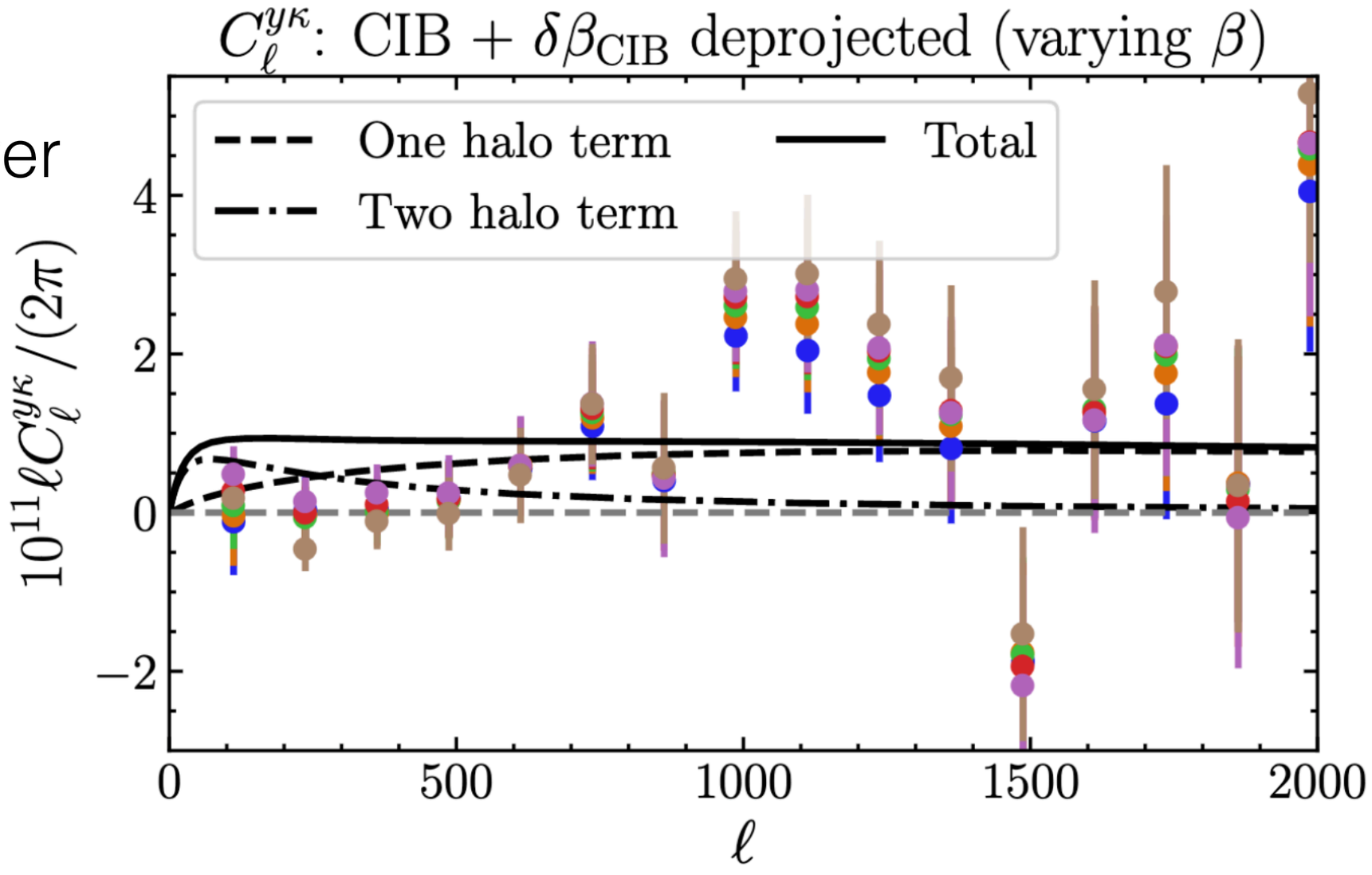
tSZ x CMB Lensing

CIB contamination robustly cleaned using moment-based method

y x κ_{CMB} cross-power



multipole

but the low-ell points fluctuate quite low

McCarthy & JCH (in prep.)

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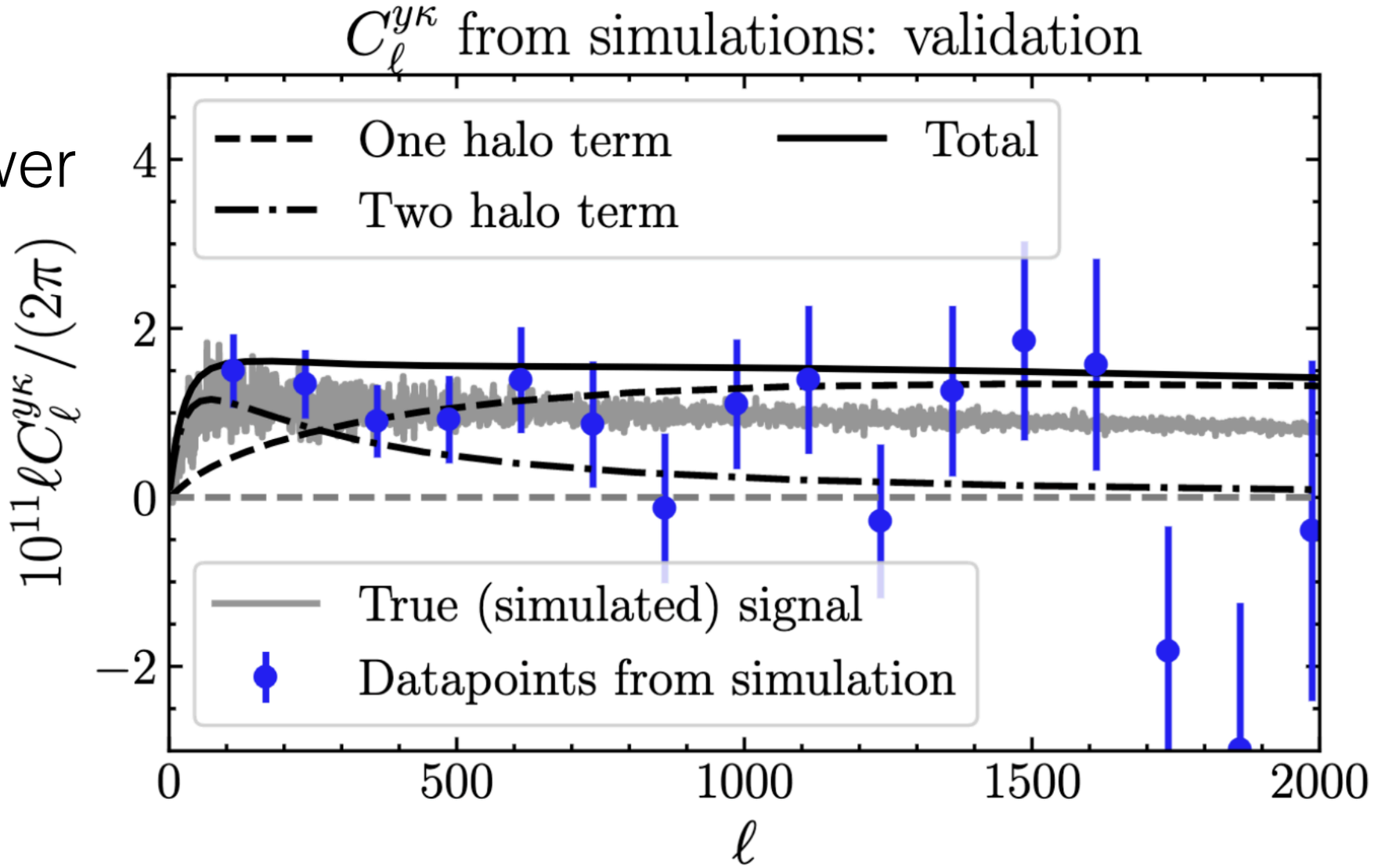
tSZ x CMB Lensing

Validation on Websky simulations (w/ moment-based CIB cleaning)

y x κ_{CMB} cross-power



McCarthy & JCH (in prep.)

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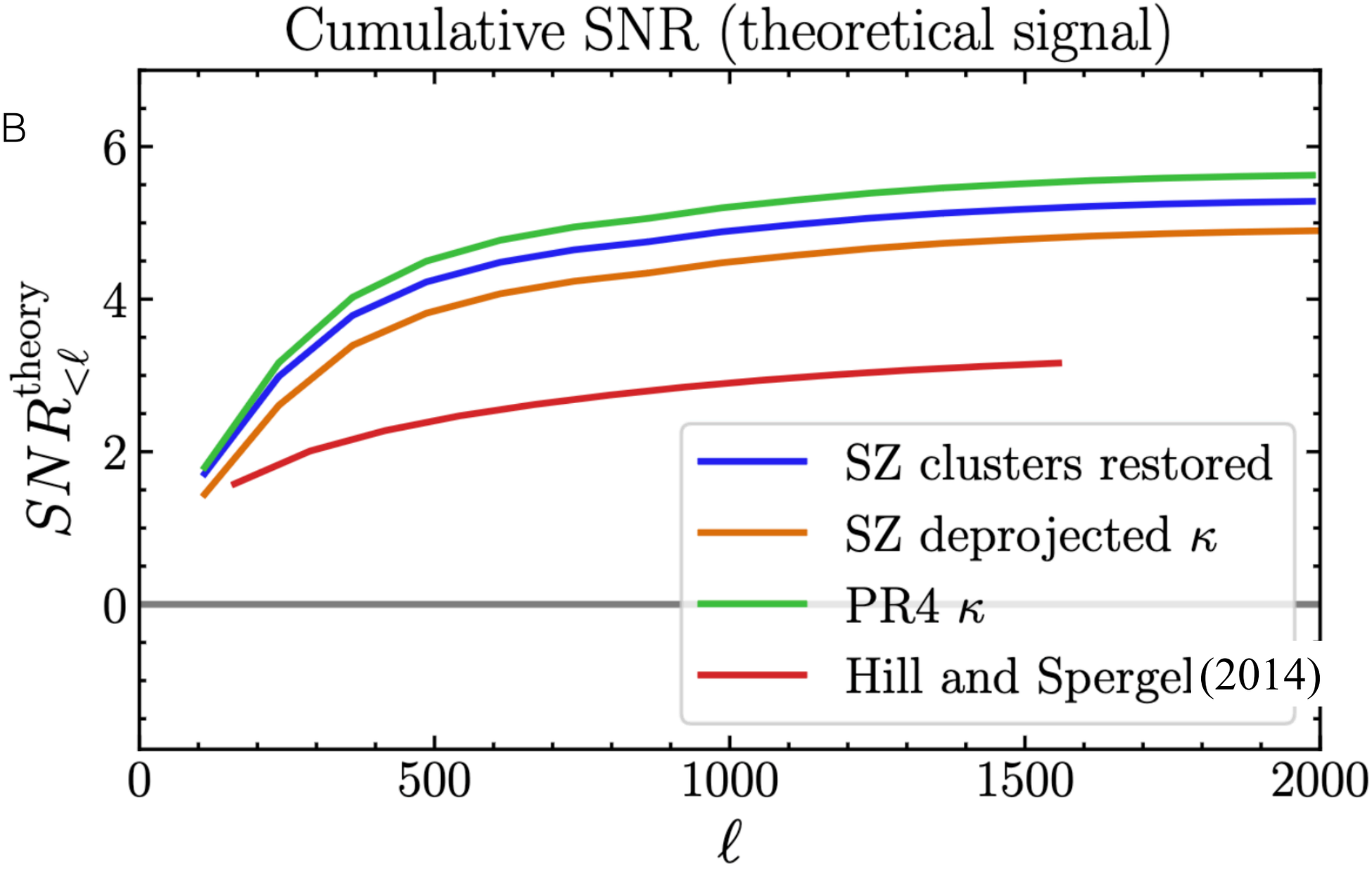
tSZ x CMB Lensing

Significant sensitivity gain over Planck nominal mission analysis

y x κ_{CMB} SNR



multipole

McCarthy & JCH (in prep.)

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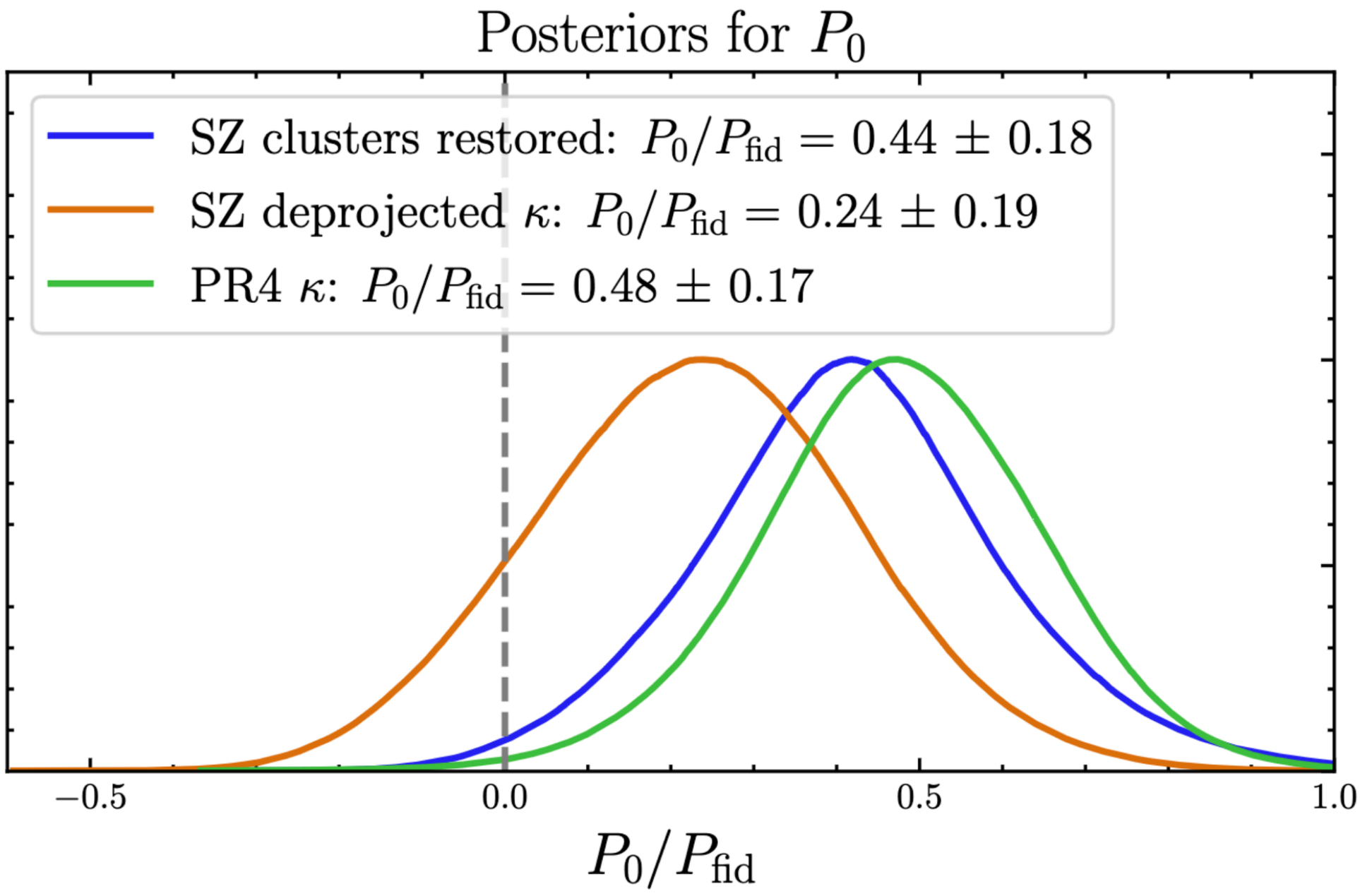
tSZ x CMB Lensing

Probe of ICM gas physics in low-mass, high-z clusters



Here $P_0 = 1$ corresponds to Battaglia+ (2012) ICM model

McCarthy & JCH (in prep.)

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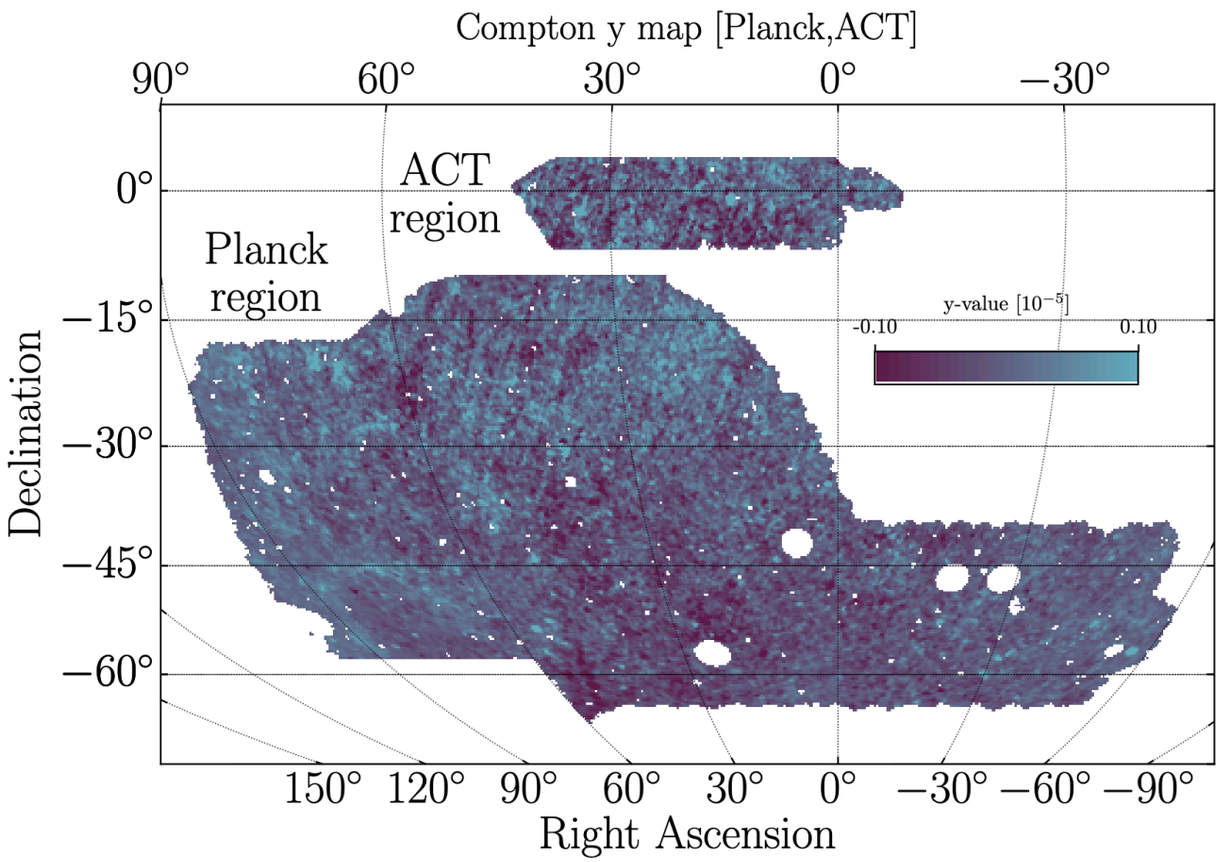
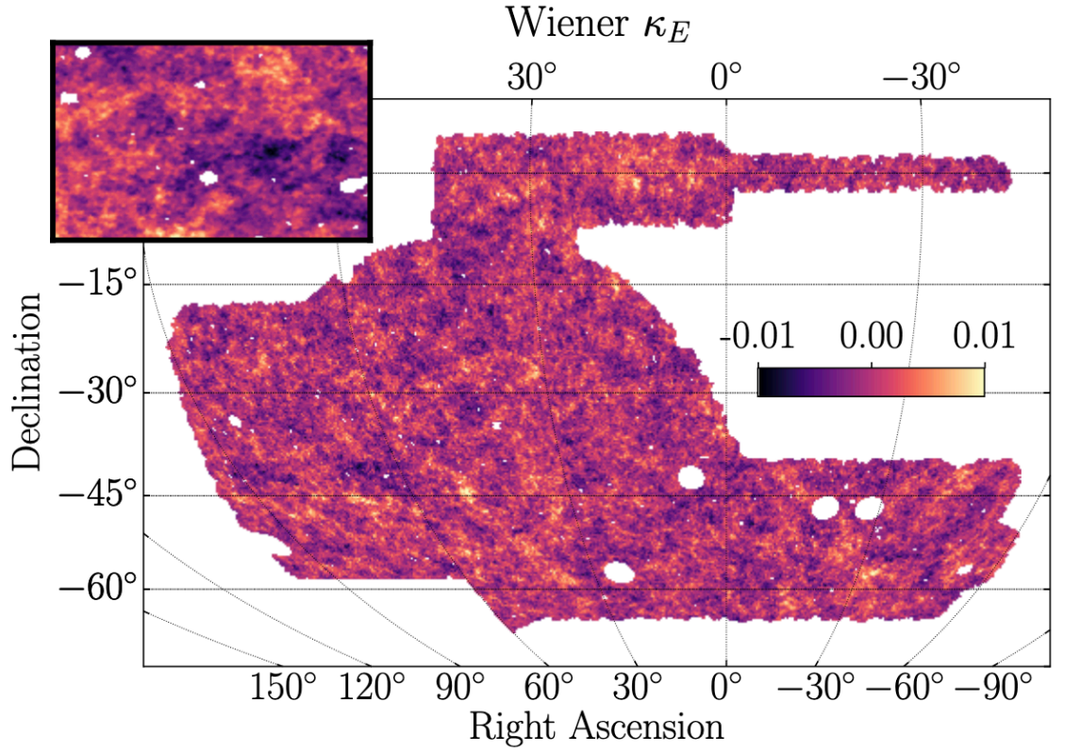
tSZ x Galaxy Lensing

Probe of relationship of hot, ionized gas and matter density

Recent analyses using ACT(+Planck) DR4 y-map x DES KiDS



X



Madhavacheril, JCH, Naess+ (2020)
Planck+ (2016)

DES-Y3

Gatti+ (2022); Pandey+ (2022); Troster+ (2022)

tSZ x Galaxy Lensing

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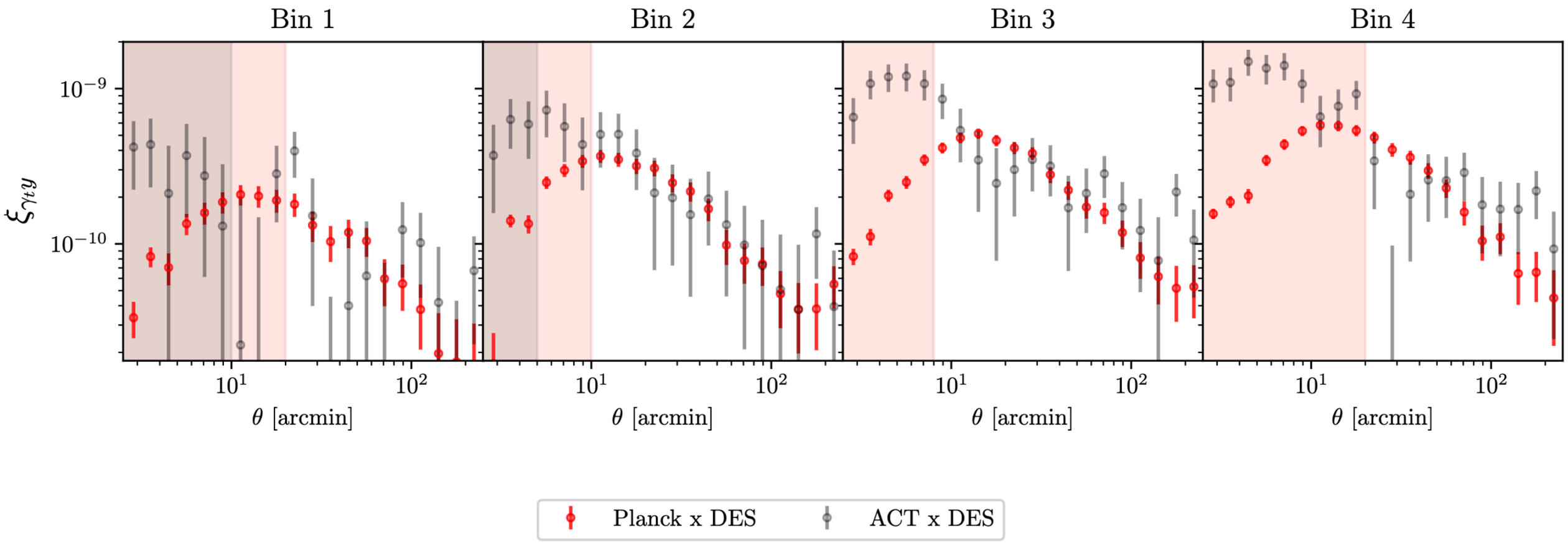
ACT+Planck x DES-Y3: 21σ detection



Gatti+ (2022); Pandey+ (2022)

tSZ x Galaxy Lensing

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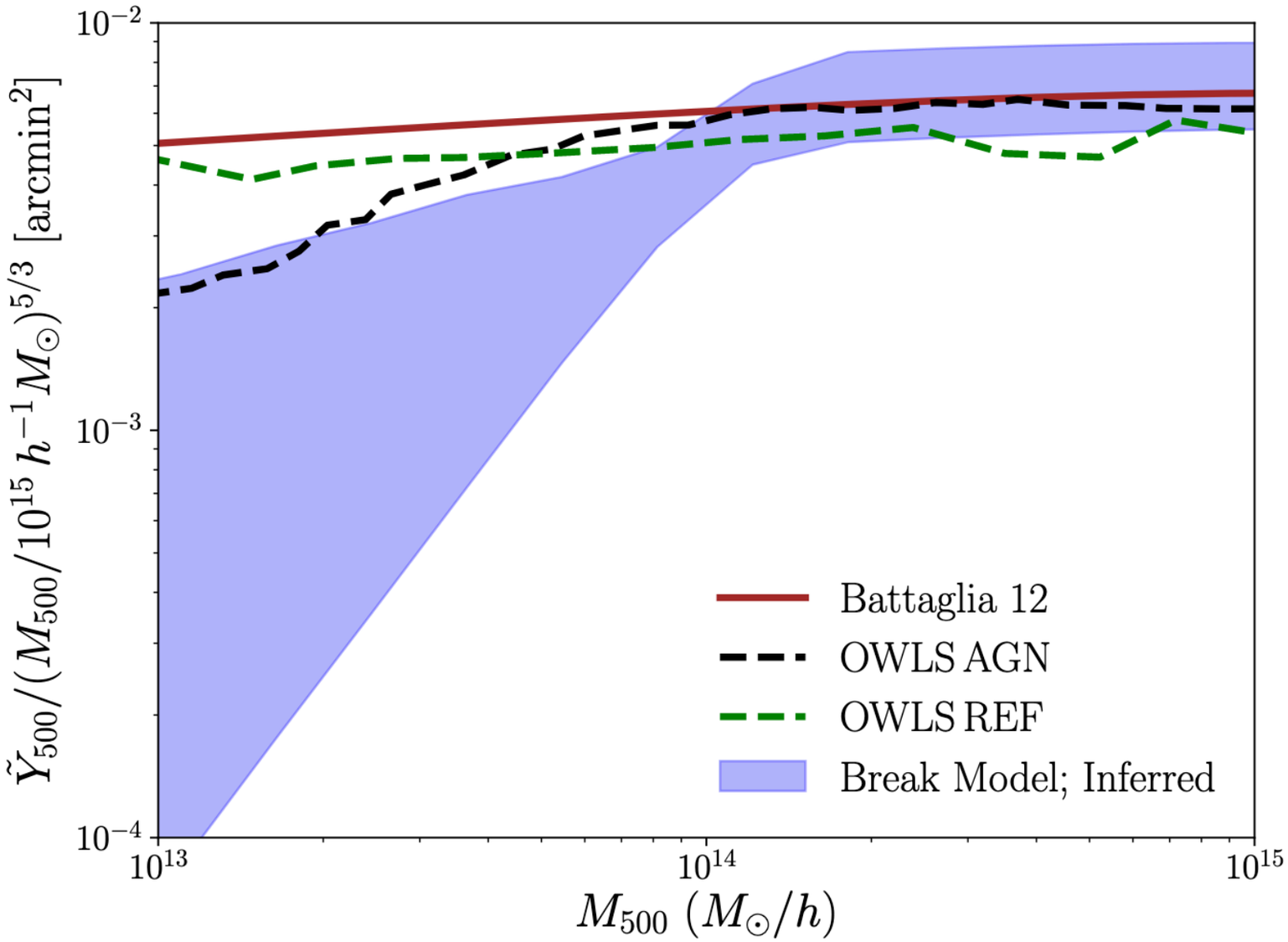
ACT+Planck x DES-Y3: novel constraints on Y-M relation



Gatti+ (2022); Pandey+ (2022)

Forecasts/Outlook

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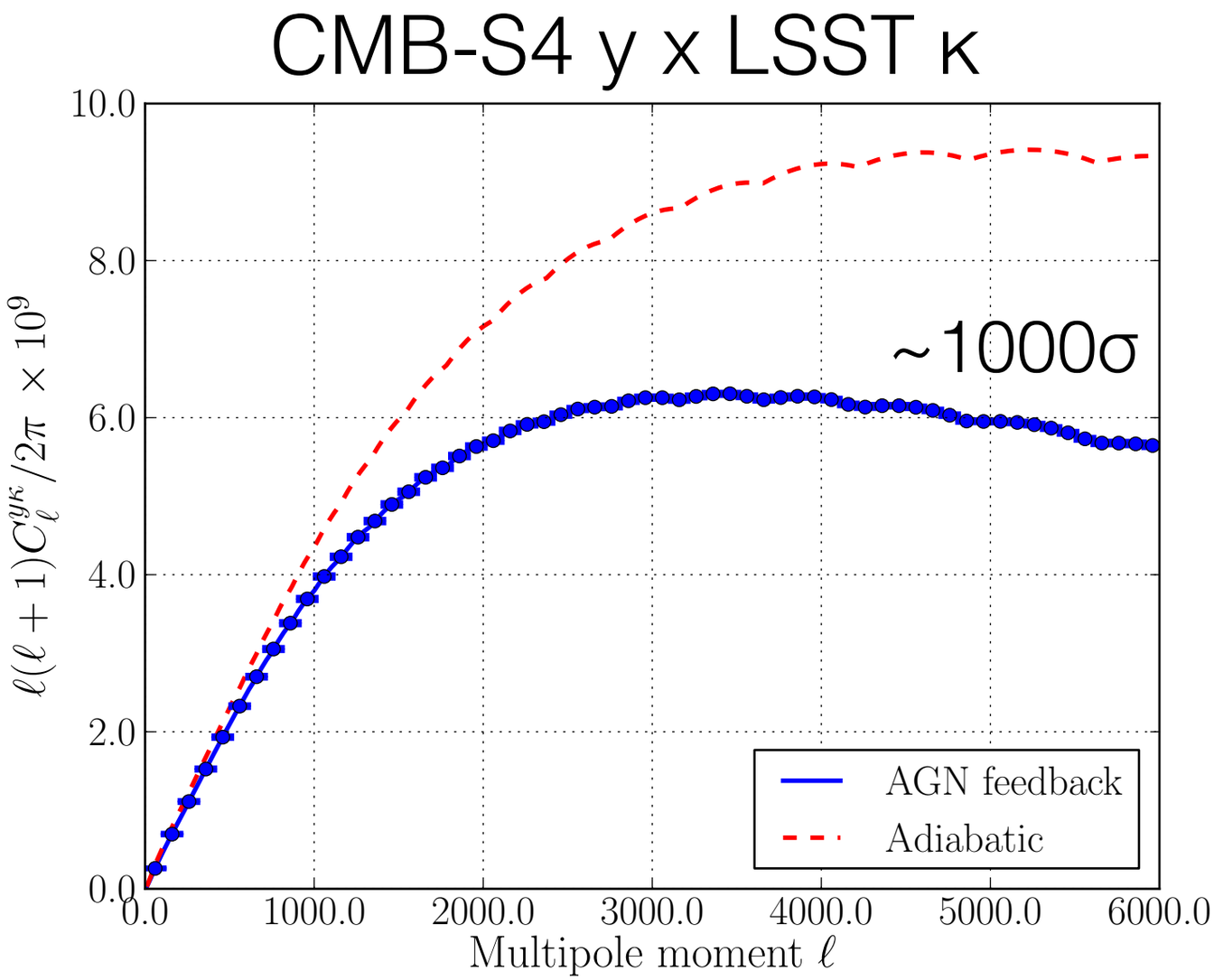
An ancient forecast from the 2016 LSST Brookhaven Cross-Correlation Spectacular



Clearly we won't be short on SNR. But can we robustly clean CIB/radio/etc. to this level? And model the signals across the full range of measured scales? Work to be done

Thanks

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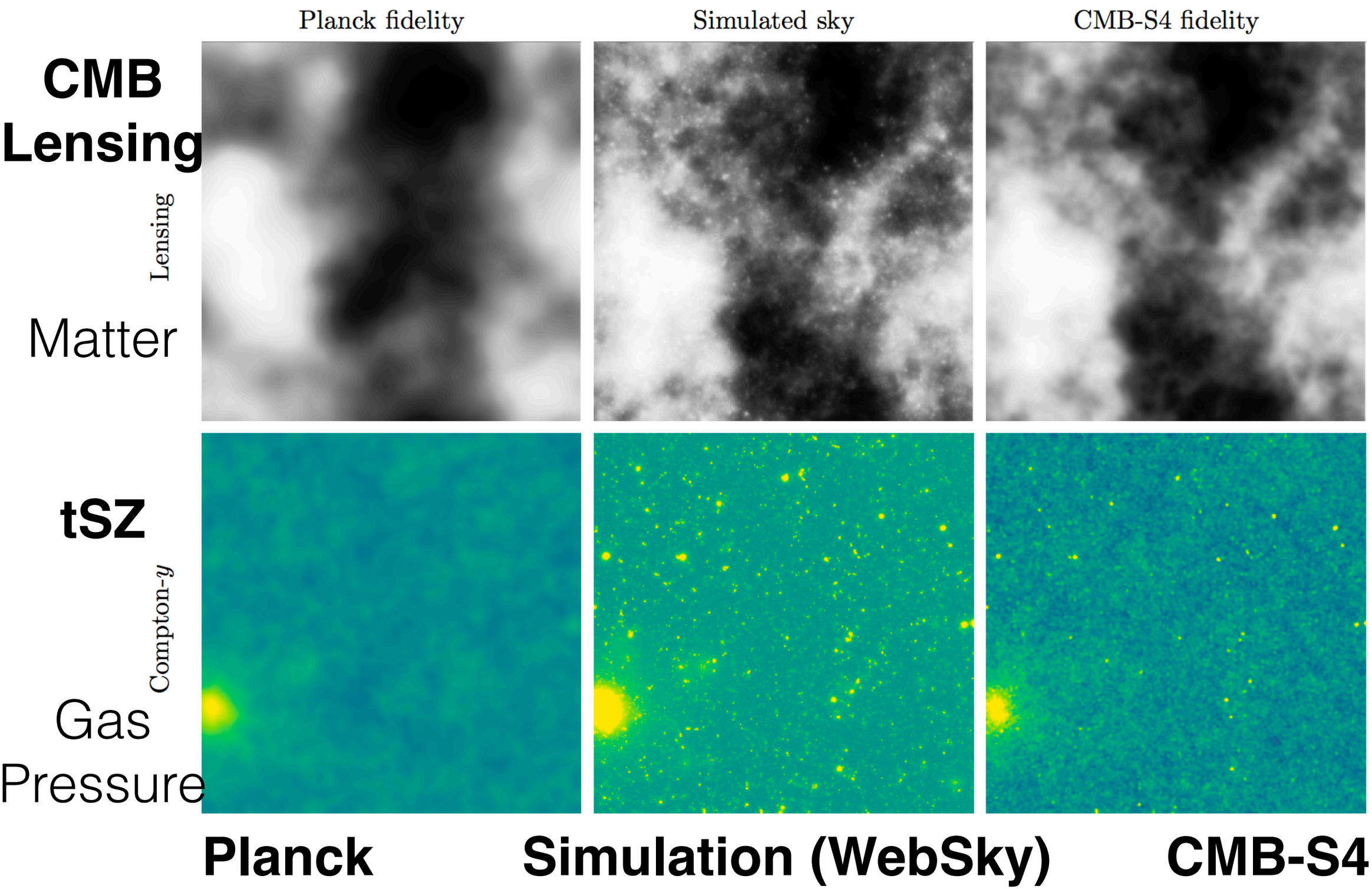

CMB-S4 DSR (2019)