Cosmology and cluster astrophysics with cross-correlations of HSC WL and Planck tSZ

IAP, 12th December 2019
CoSyne: Cosmological Synergies in the upcoming decade

Ken Osato
Institut d'Astrophysique de Paris

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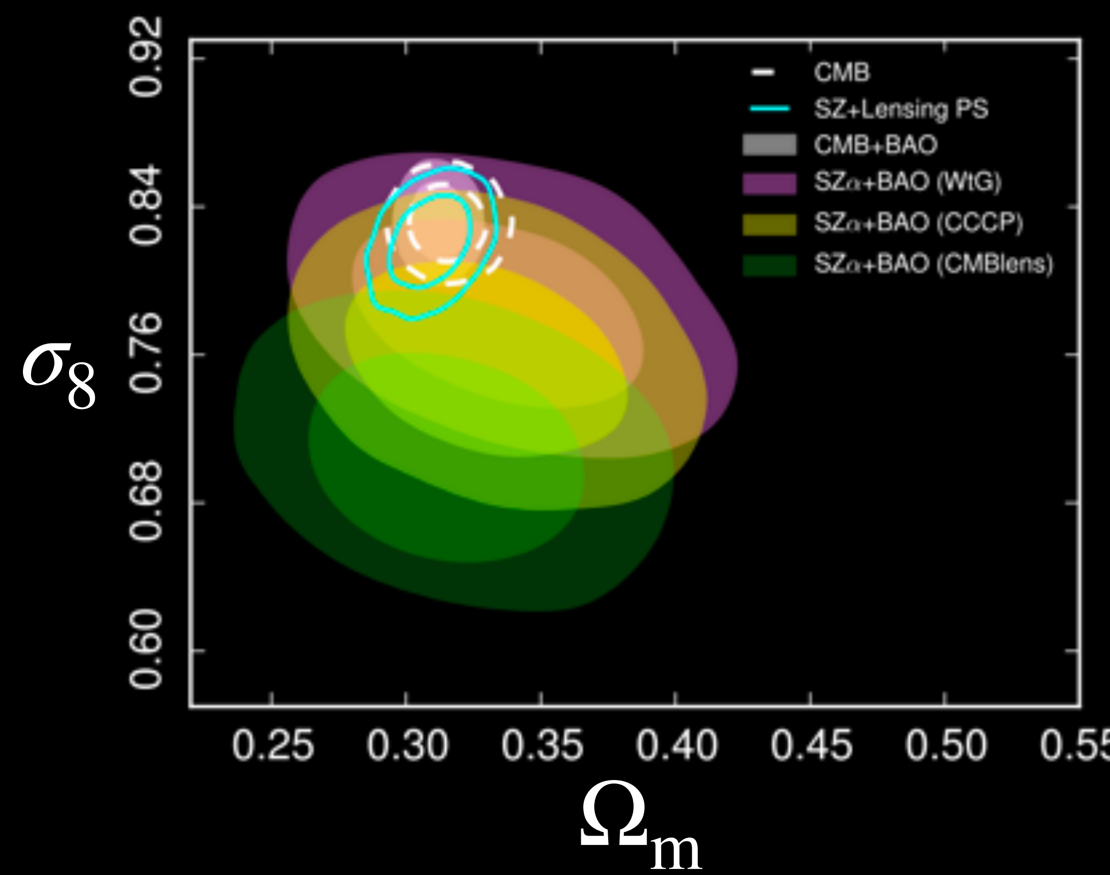
Cluster Cosmology and Astrophysics

Planck col. (2016)

Cluster cosmology

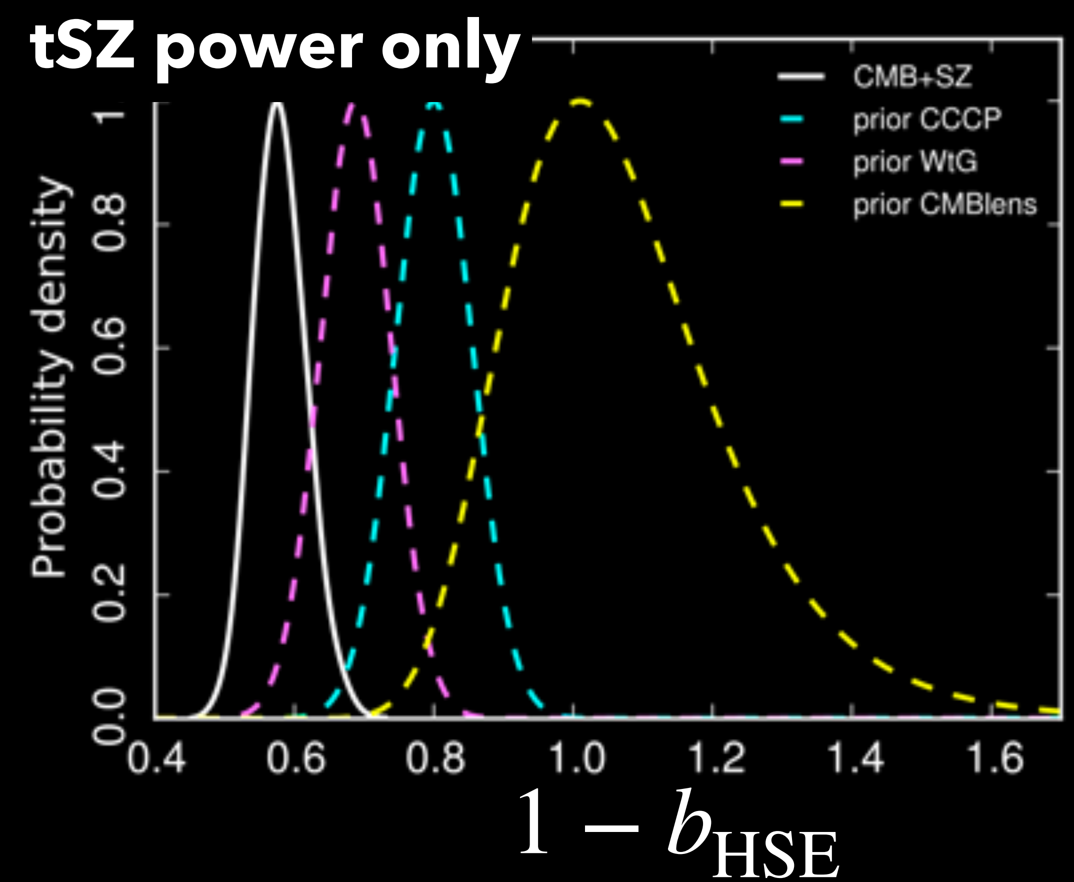
The abundance of clusters and density profile of clusters are powerful probes into dark matter and dark energy.
The accurate mass reconstruction is critical for cluster cosmology.



Non-thermal pressure

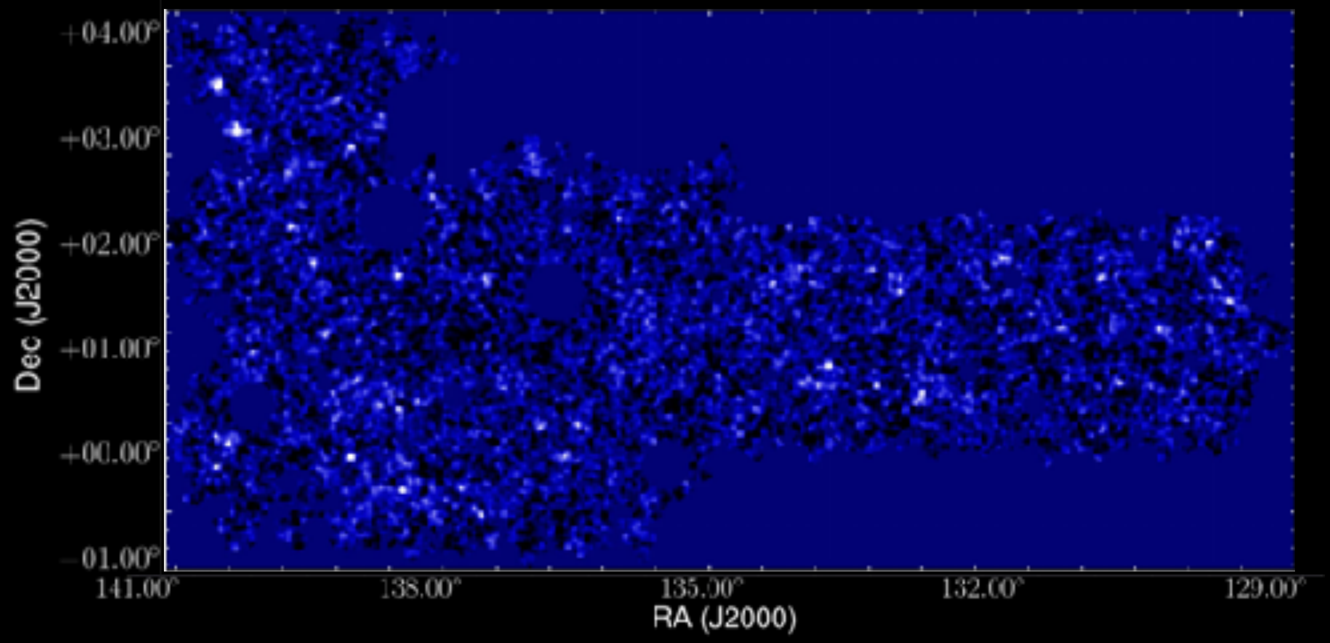
Physical processes other than thermal pressure, e.g., **turbulence**, can also support the self-gravity of galaxy clusters. The mass under hydrostatic equilibrium (HSE) is parameterized as

$$\frac{M_{\rm HSE}}{M_{\rm true}} = 1 - b_{\rm HSE}$$

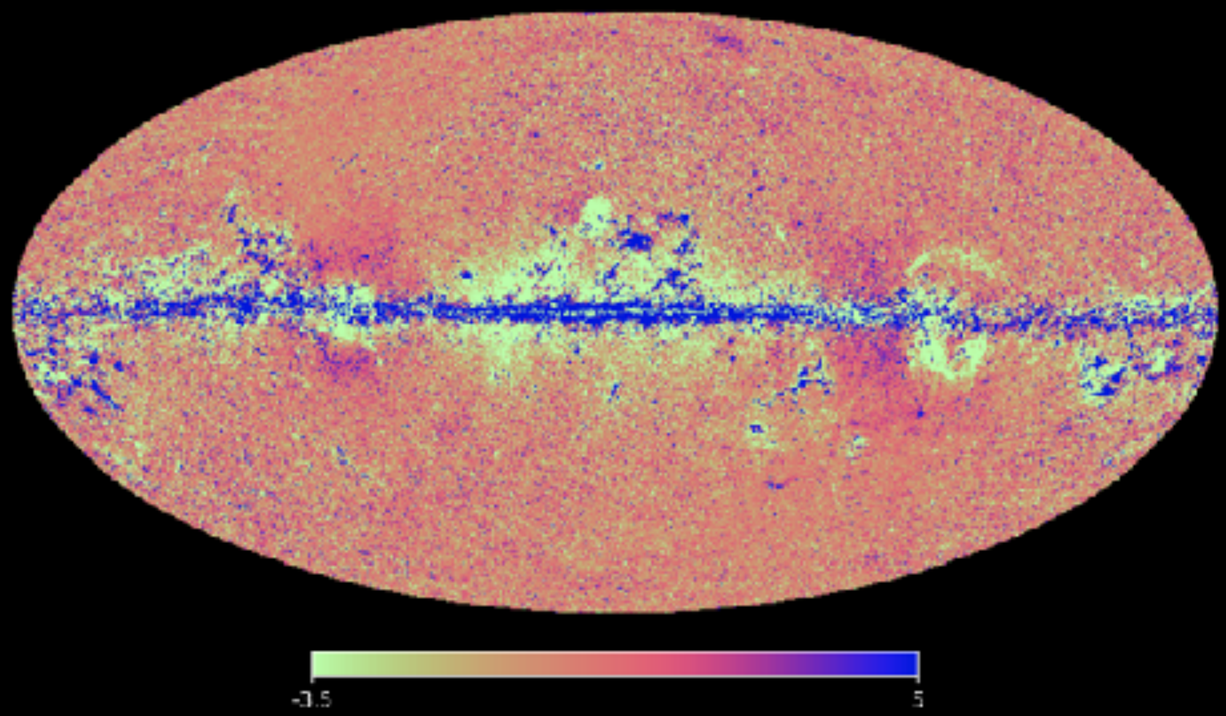


Auto 2pt Correlations

WL



tSZ



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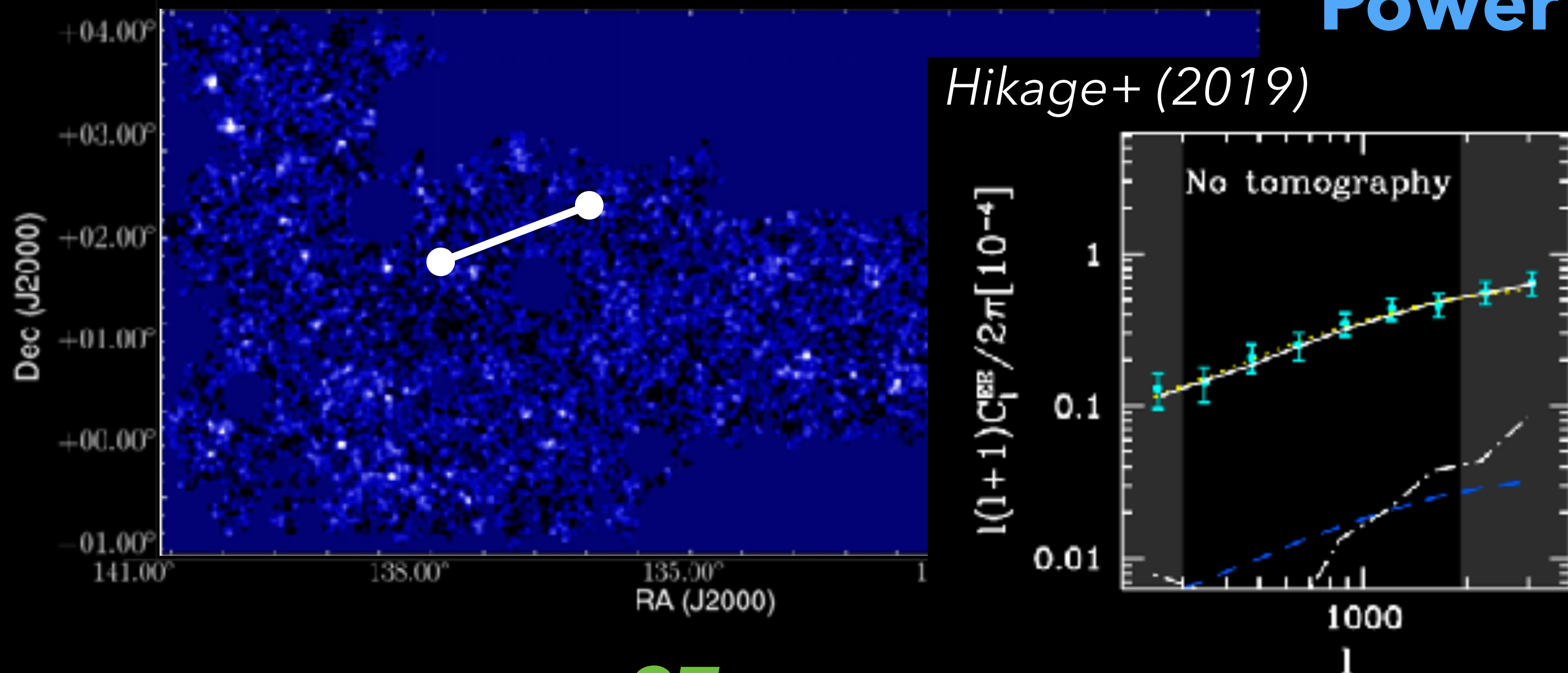
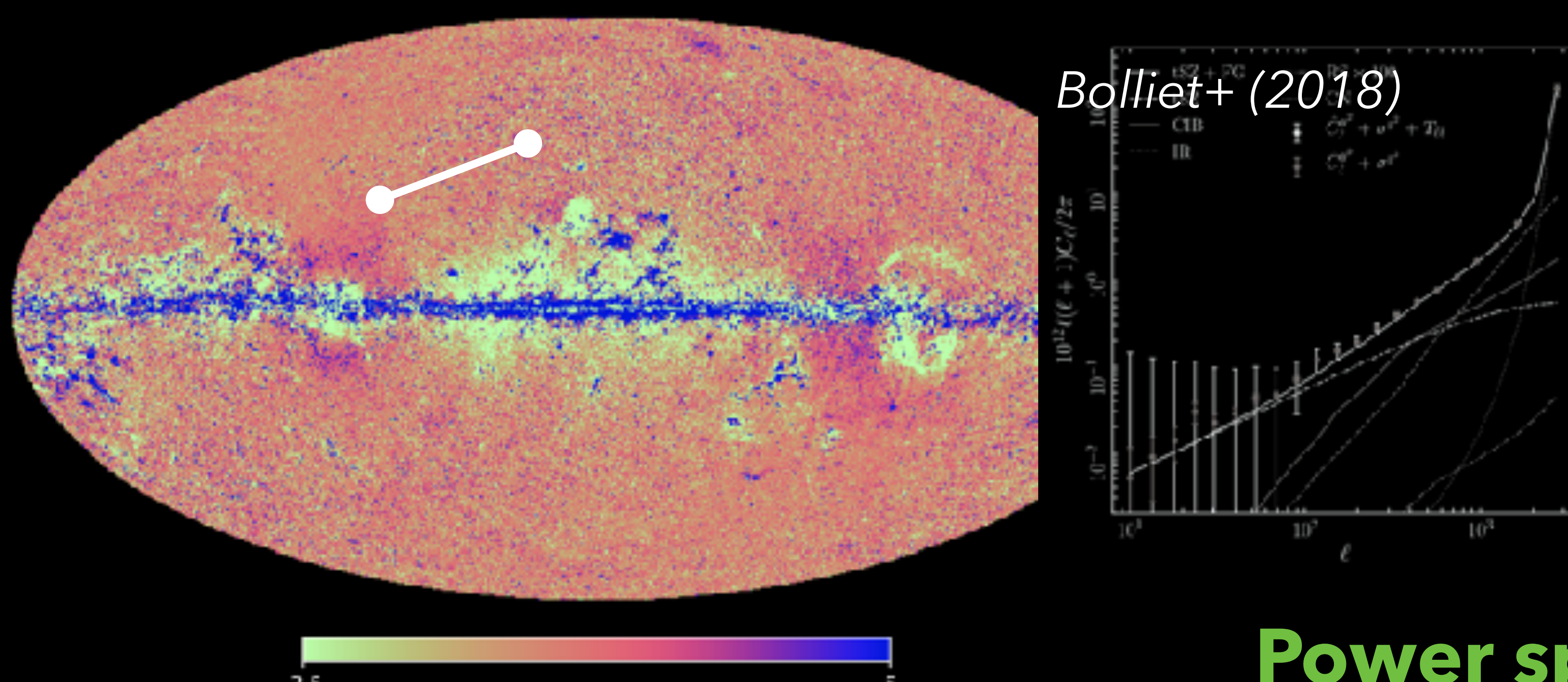


Power spectrum / 2pt correlation

Constraints

tSZ



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Auto 2pt Correlations

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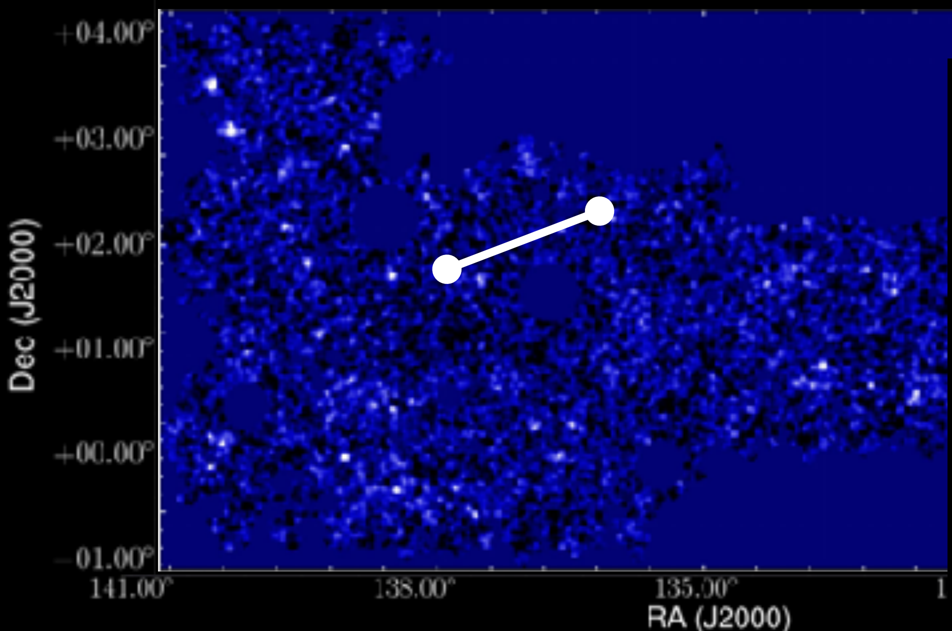
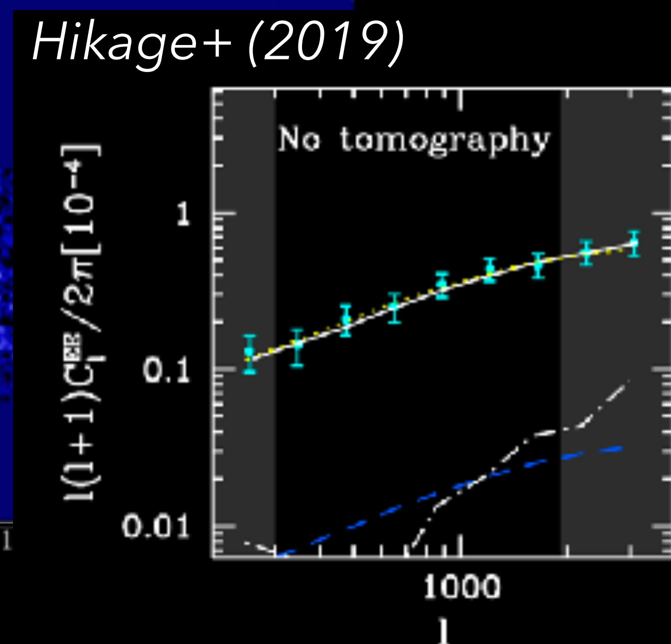




Power spectrum / 2pt correlation

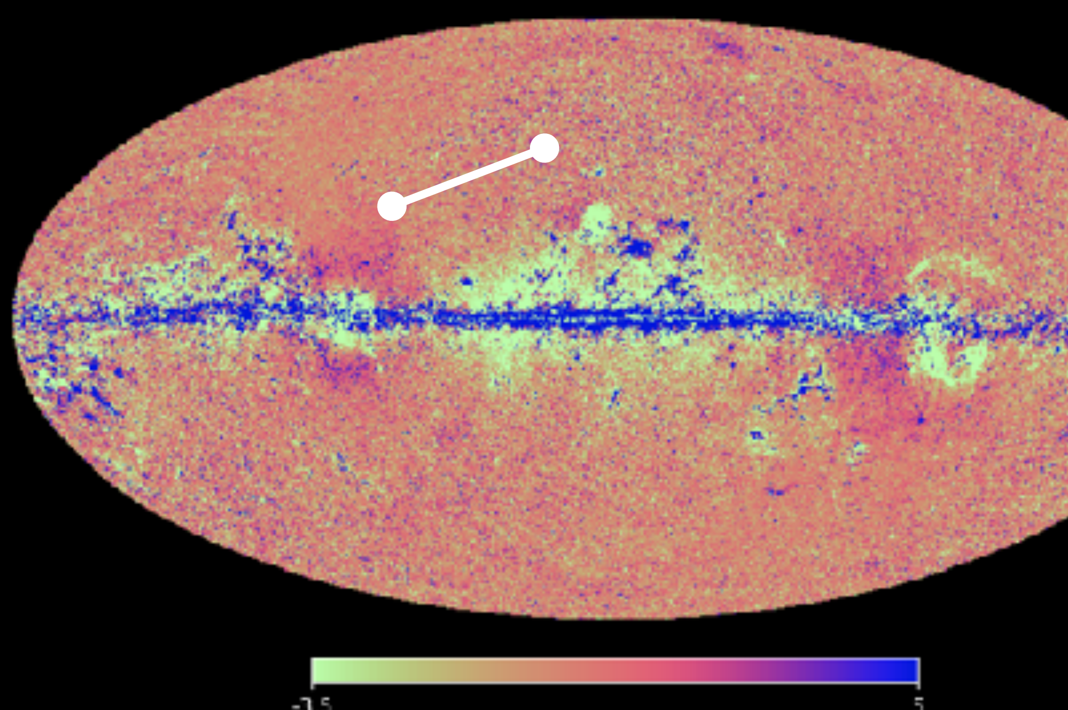
Constraints

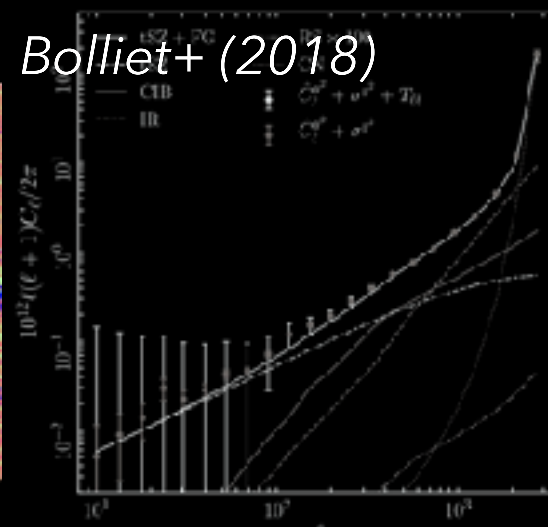
Joint Analysis?

Constraints

Power spectrum / 2pt correlation

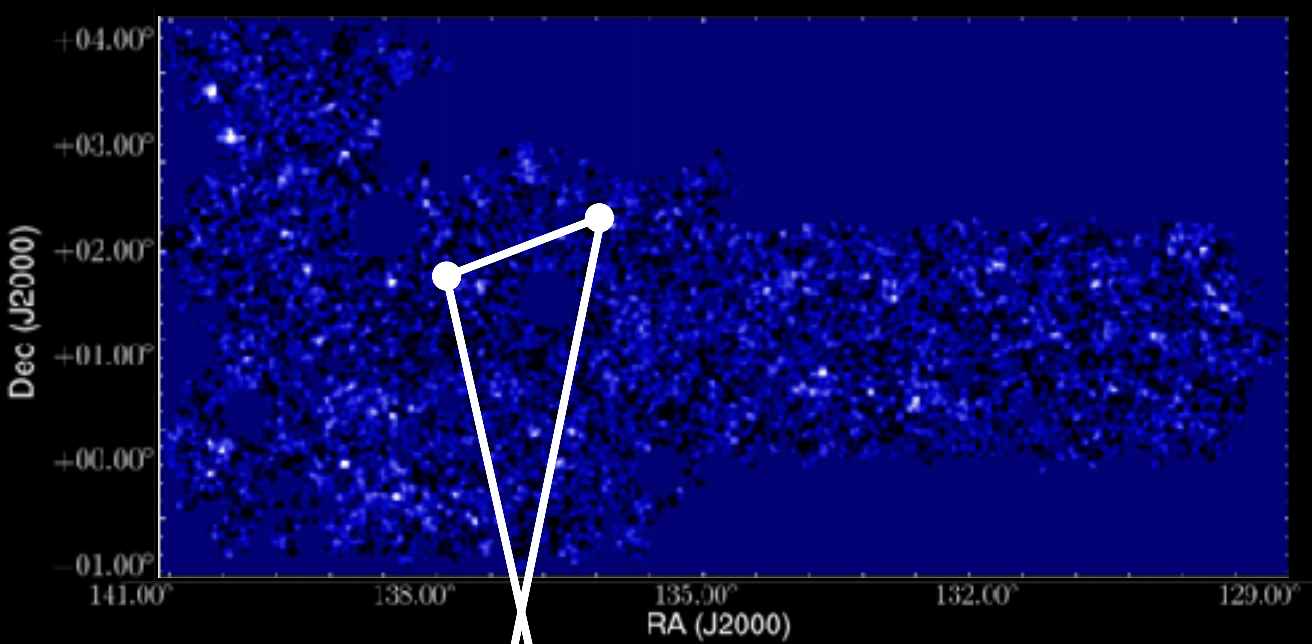
tSZ



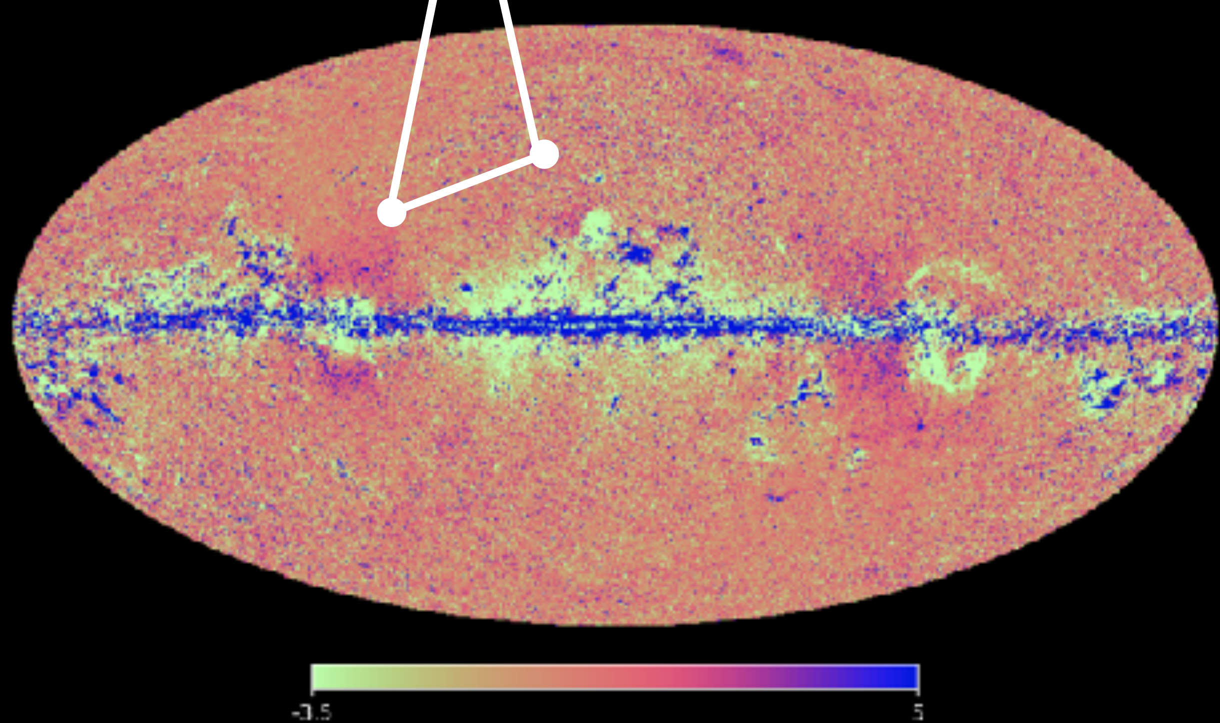


Cross 2pt Correlations

WL



tSZ



Cross-correlations

✦Especially in the case of cross-correlation between ***high S/N*** and *low S/N* observables, the cross-correlation becomes more powerful!

$$\frac{(S/N)^2_{\mathrm{XY}}}{(S/N)^2_{\mathrm{YY}}} \gg 1$$

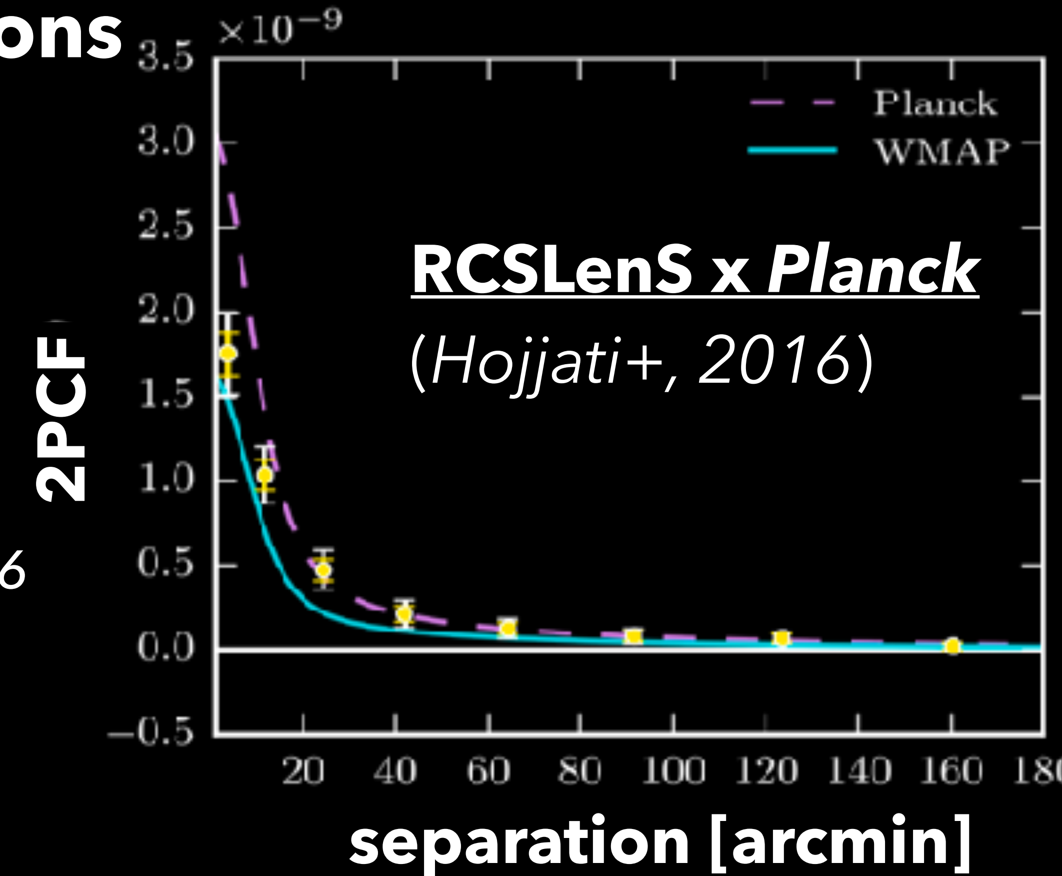
cf.
Battaglia+ (2015)
Makiya+ (2018)

Cross-Correlations of tSZ-WL

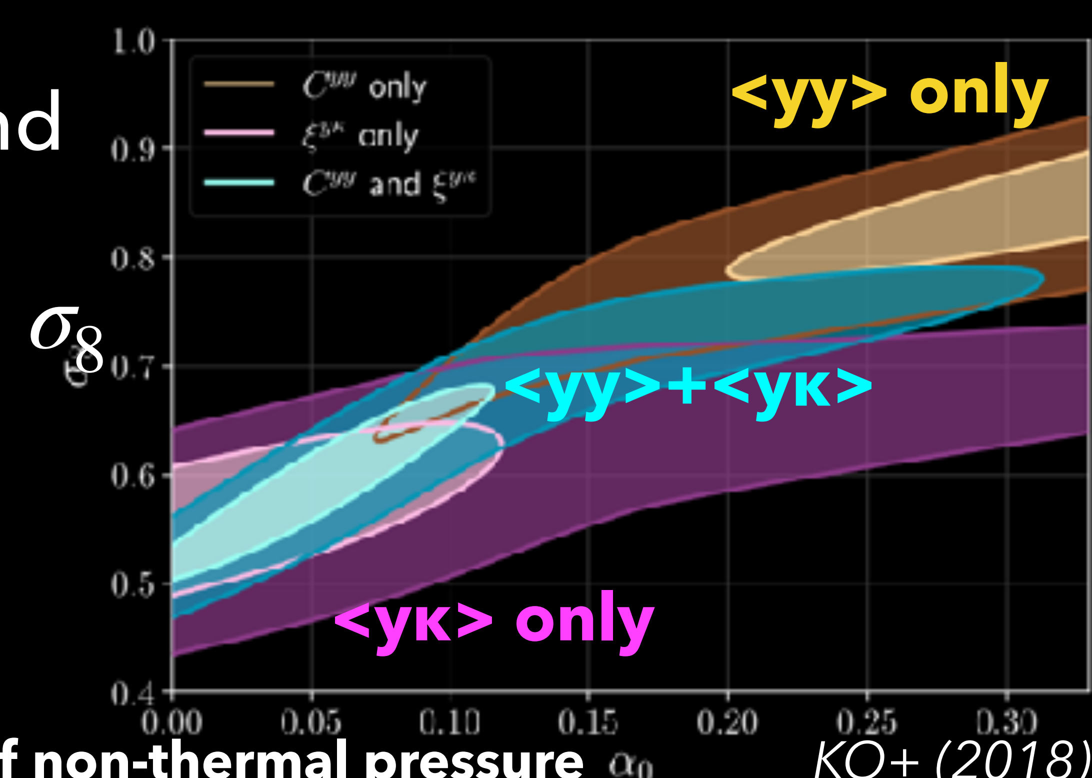
✦**Measurements of tSZ-WL cross-correlations**

The cross-correlation between thermal SZ effect and weak lensing has been measured from *Planck* and CFHTLenS (RCSLenS) data.

cf. van Waerbeke+ 2014, Hojjati+ 2016



➡We can constrain both of cosmological parameters (**cosmology**) and hydrostatic mass bias (**astrophysics**) with tSZ auto-power spectrum and tSZ-WL cross-correlations.



KO+ (2018)

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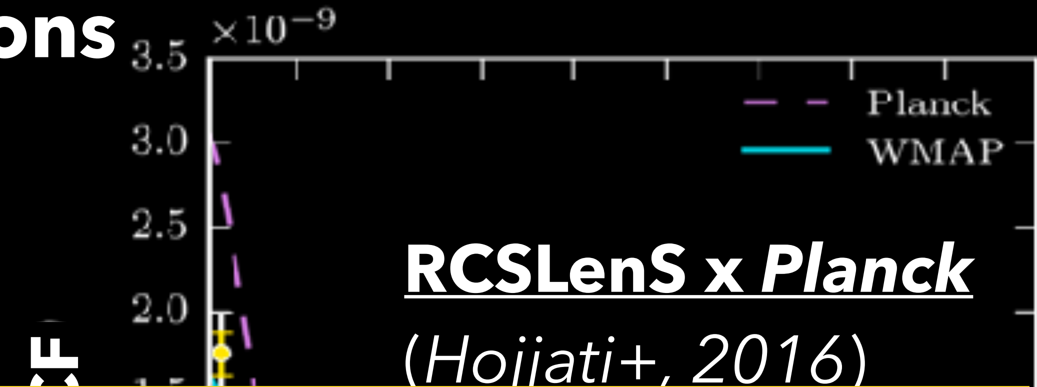
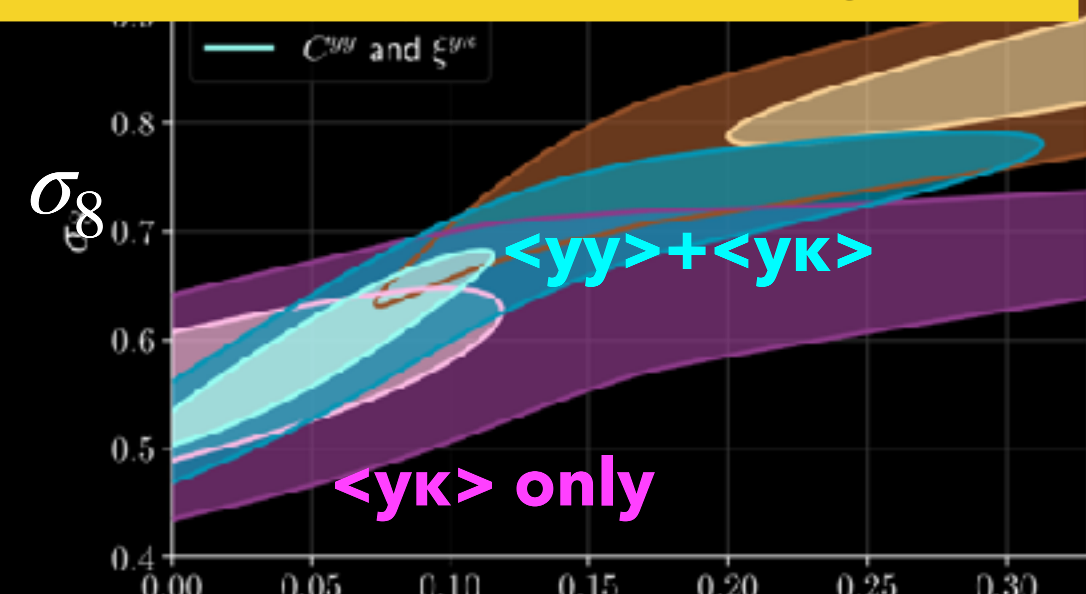


Goal: Constraining cosmological parameters and hydrostatic mass bias parameter with tSZ auto- and tSZ-WL cross-correlations from *Planck* and HSC data.

The low-mass or high-redshift clusters, which are hard to be observed through X-ray or SZ, contribute to the signal.

hydrostatic mass bias (**astrophysics**) with tSZ auto-power spectrum and tSZ-WL cross-correlations.



KO+ (2018)

WL and tSZ data

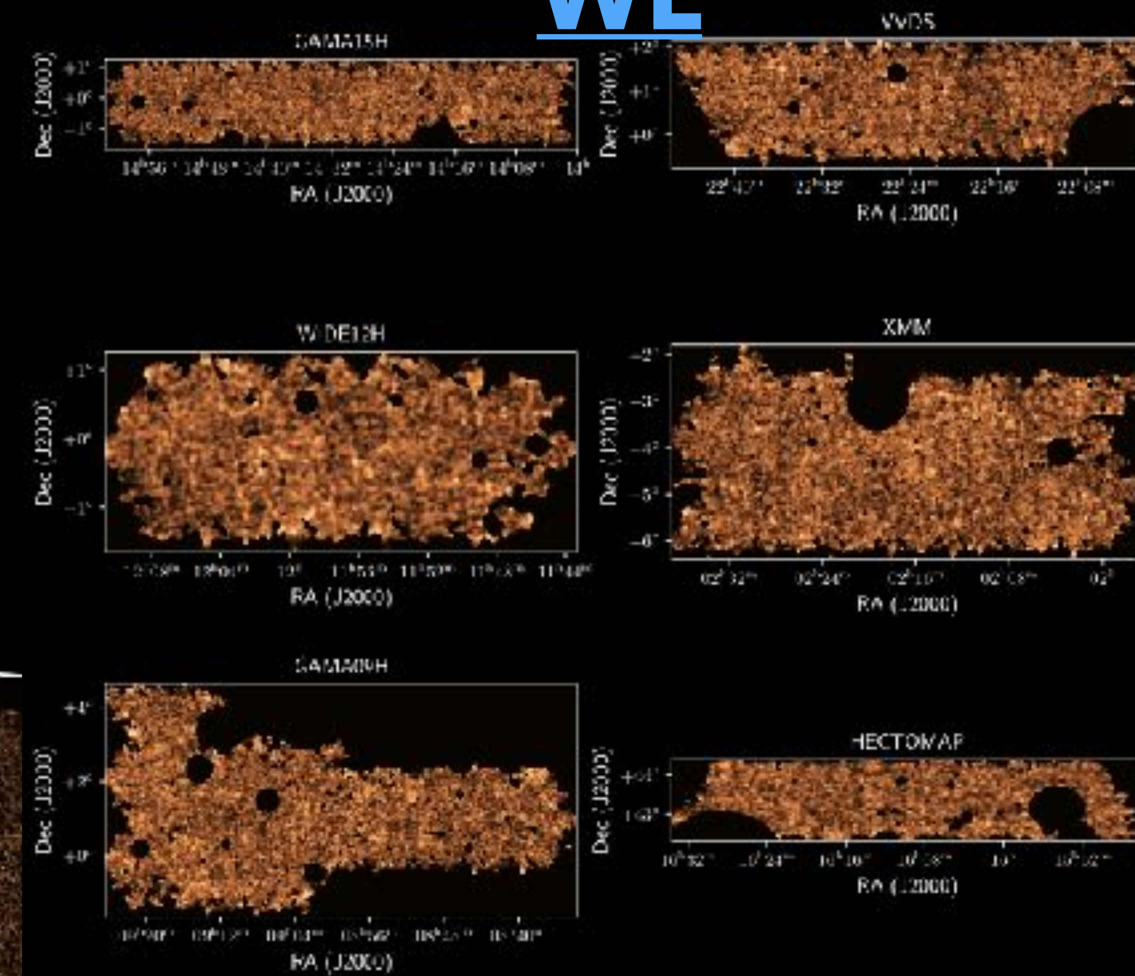
✦**HSC S16A**

Wide and deep WL survey (136.9 deg^2) with mean number density $n_{\rm eff} = 24.6\,{\rm arcmin}^{-2}$ *cf. Mandelbaum+ (2017)*

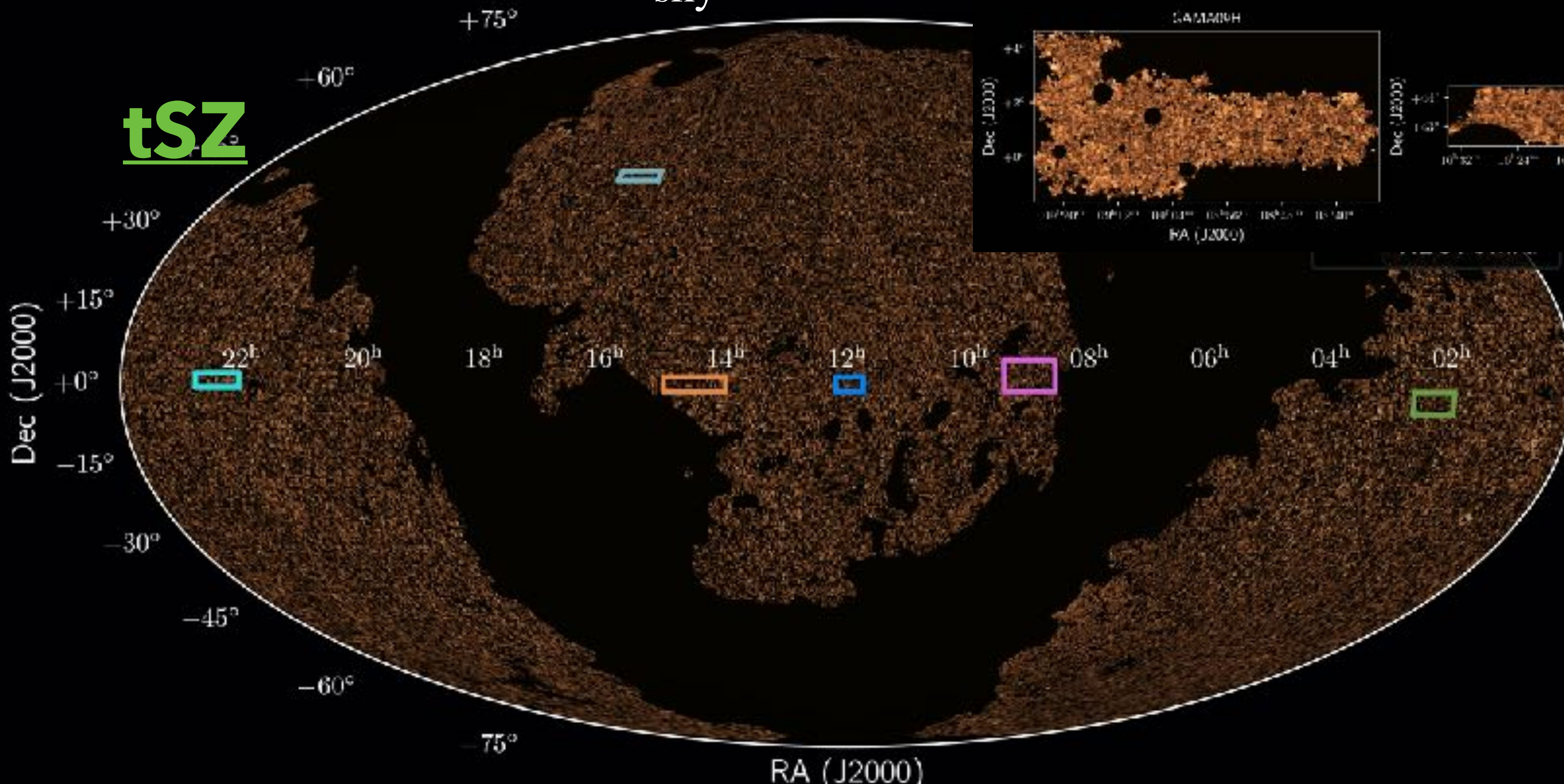
✦***Planck* tSZ map**

constructed from 30 to 857 GHz data. The sky coverage fraction is $f_{\rm sky} = 0.512.$

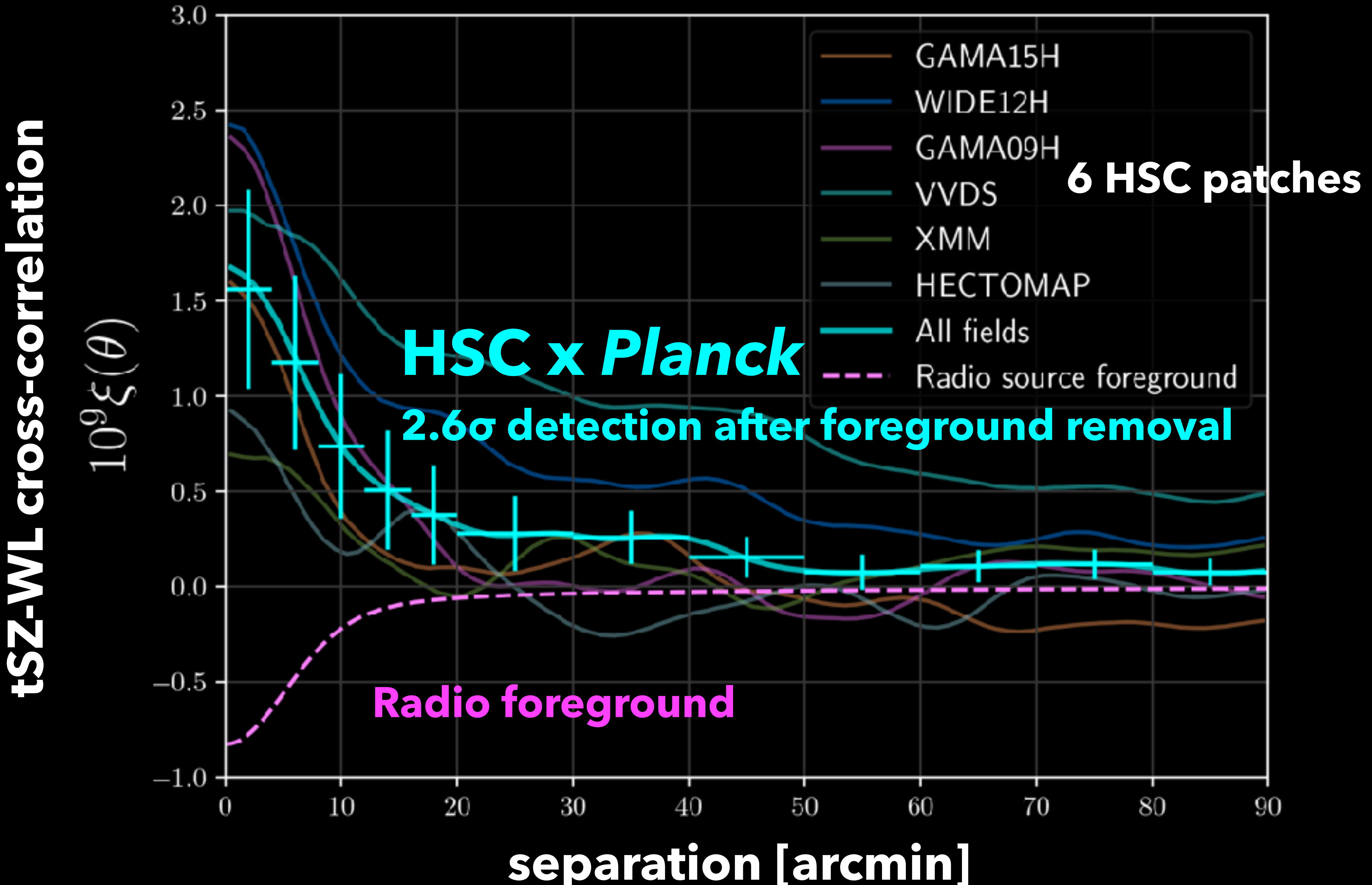
WL



tSZ



Measurements



Analytical Prediction of Signal

- ✦ Theoretical prediction of cross spectra is based on ***halo model***.
- ➡ All matter and gas is associated with halos.

$$C_\ell^{y\kappa} = C_\ell^{y\kappa(1\mathrm{h})} + C_\ell^{y\kappa(2\mathrm{h})}$$

$$C_\ell^{y\kappa(1\mathrm{h})} = \int dz \, \frac{d^2V}{dz d\Omega} \int dM \frac{dn}{dM} y_\ell(M,z) \kappa_\ell(M,z)$$

$$C_\ell^{y\kappa(2\mathrm{h})} = \int dz \, \frac{d^2V}{dz d\Omega} P_\mathrm{m}(k = \ell / D_A, z)$$

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Convergence

➡ Projection of NFW profile

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Convergence
➡ **Projection of NFW profile**

Compton-y
➡ **Projection of *pressure profile***

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Convergence
➡ Projection of NFW profile

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➡ Projection of *pressure profile*

Universal Pressure Profile $P_e(r) = P_{500}\left(\frac{M_{500}^{\mathrm{HSE}}}{3\times10^{14}\,h_{70}^{-1}\,\mathrm{M}_\odot}\right)^{0.12} \frac{P_0}{(c_{500}x)^\gamma[1+(c_{500}x)^\alpha]^{(\beta-\gamma)/\alpha}}$

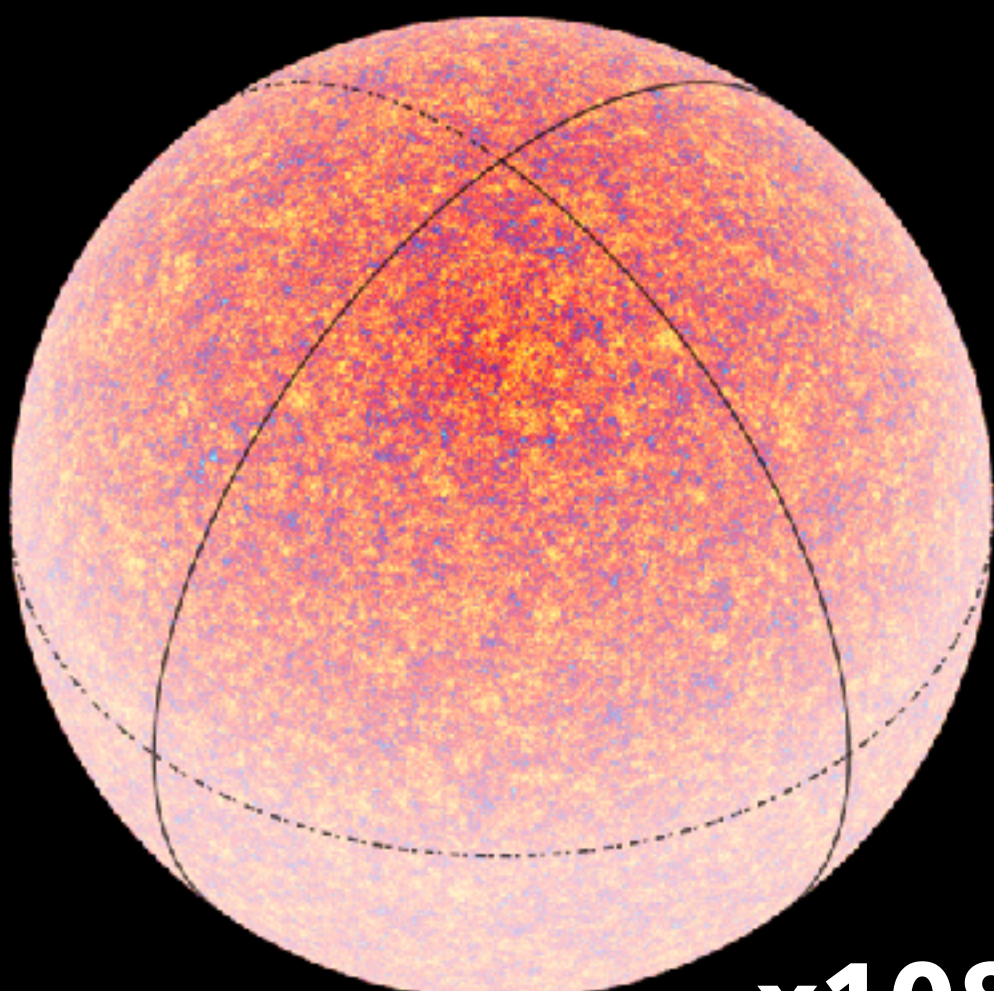
calibrated by 62 SZ clusters by *Planck*

The mass is rescaled with hydrostatic bias $M_{500}^{\mathrm{HSE}} = M_{500}(1-b_{\mathrm{HSE}})$ **x = R/R$_{500}$**

Mock WL and tSZ Maps

✦ ***All-sky simulations***

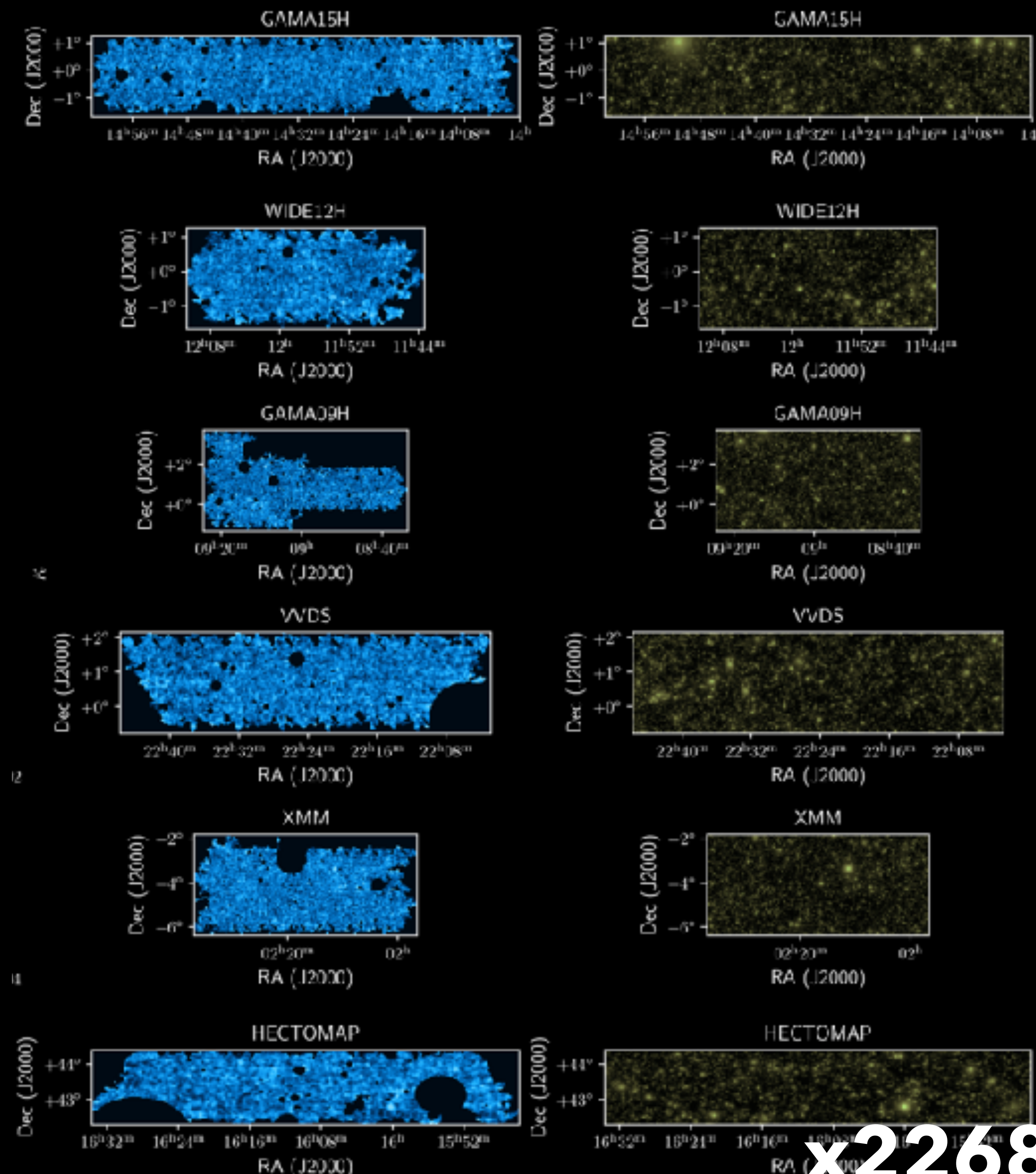
Takahashi+ (2017)
Shirasaki+ (2015)



x108

✦The mock measurements are used to evaluate the covariance matrix.

WL **tSZ**



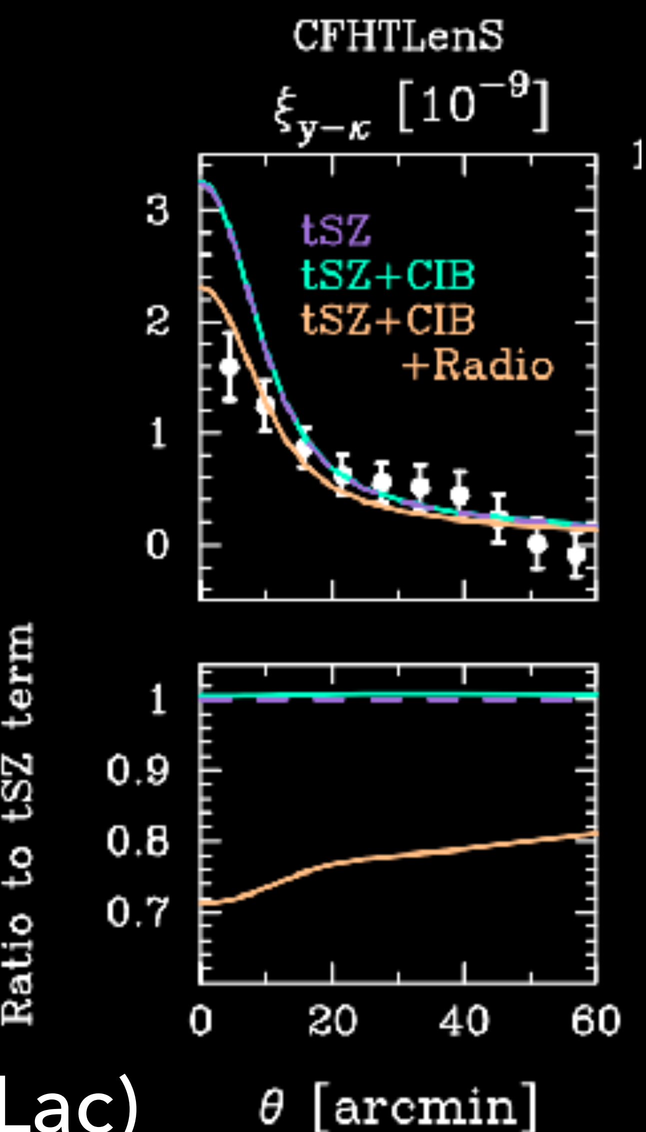
x2268

KO and Nagai (in prep.)

Analysis

- **Data sets**
  1. tSZ auto-power spectrum only
  2. tSZ-WL cross-correlations only
  3. Both of tSZ auto and tSZ-WL cross

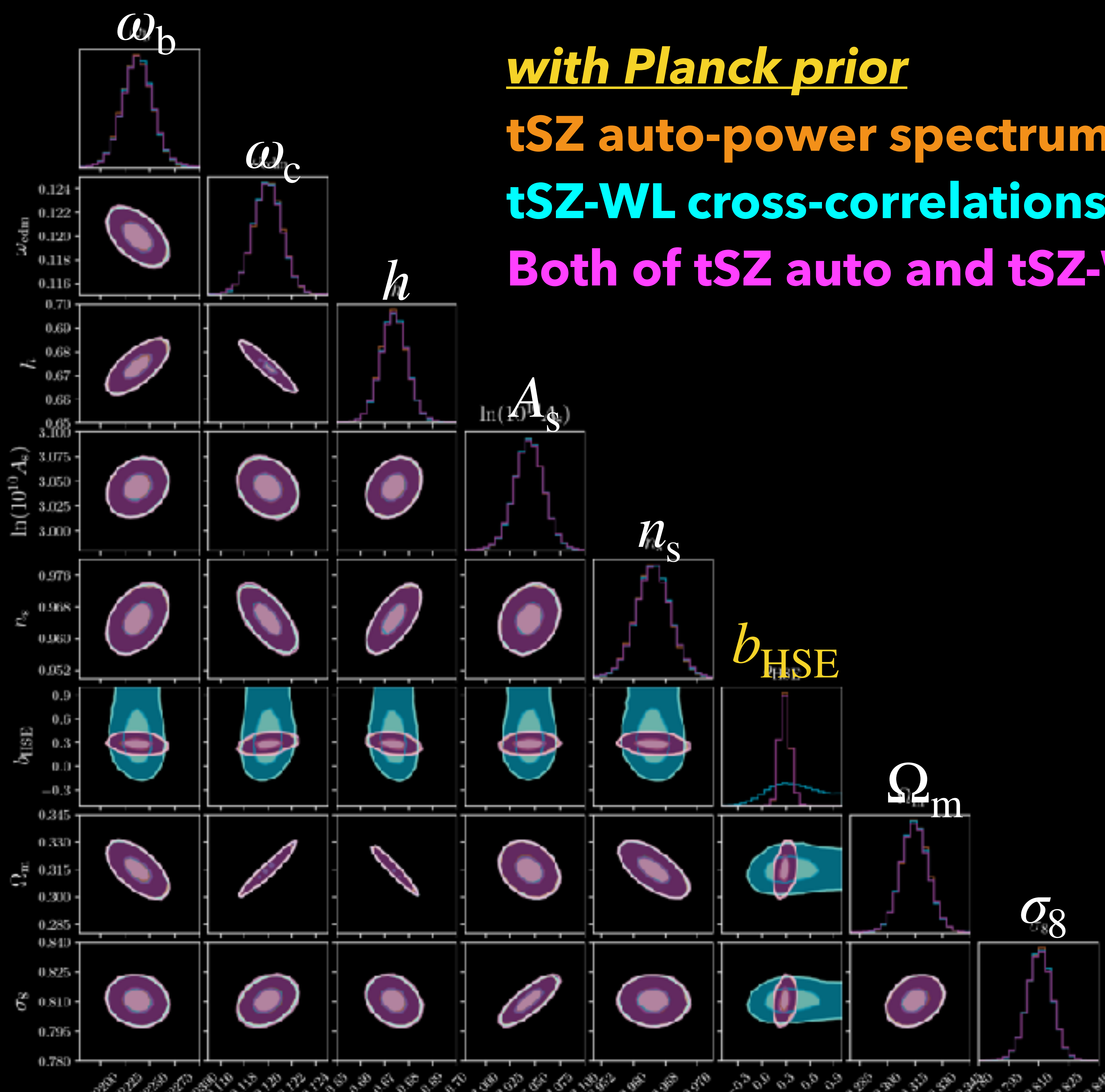
- **Foreground contamination**
  <u>For tSZ auto-power spectrum</u> *Bolliet+ (2018)*
  CIB, IR point sources, radio sources, and correlated noise
  <u>For tSZ-WL cross-correlations</u> *Shirasaki (2019)*
  Radio sources (flat-spectrum radio quasars, BL Lac)



Shirasaki (2019)

- **Priors on cosmological parameters**
  1. combination of low-*z* probes (HSC cosmic shear + JLA SN Ia + BOSS DR12 BAO/RSD)
  2. *Planck* 2018 TT,TE,EE+lowE+lensing

Constraints on Parameters



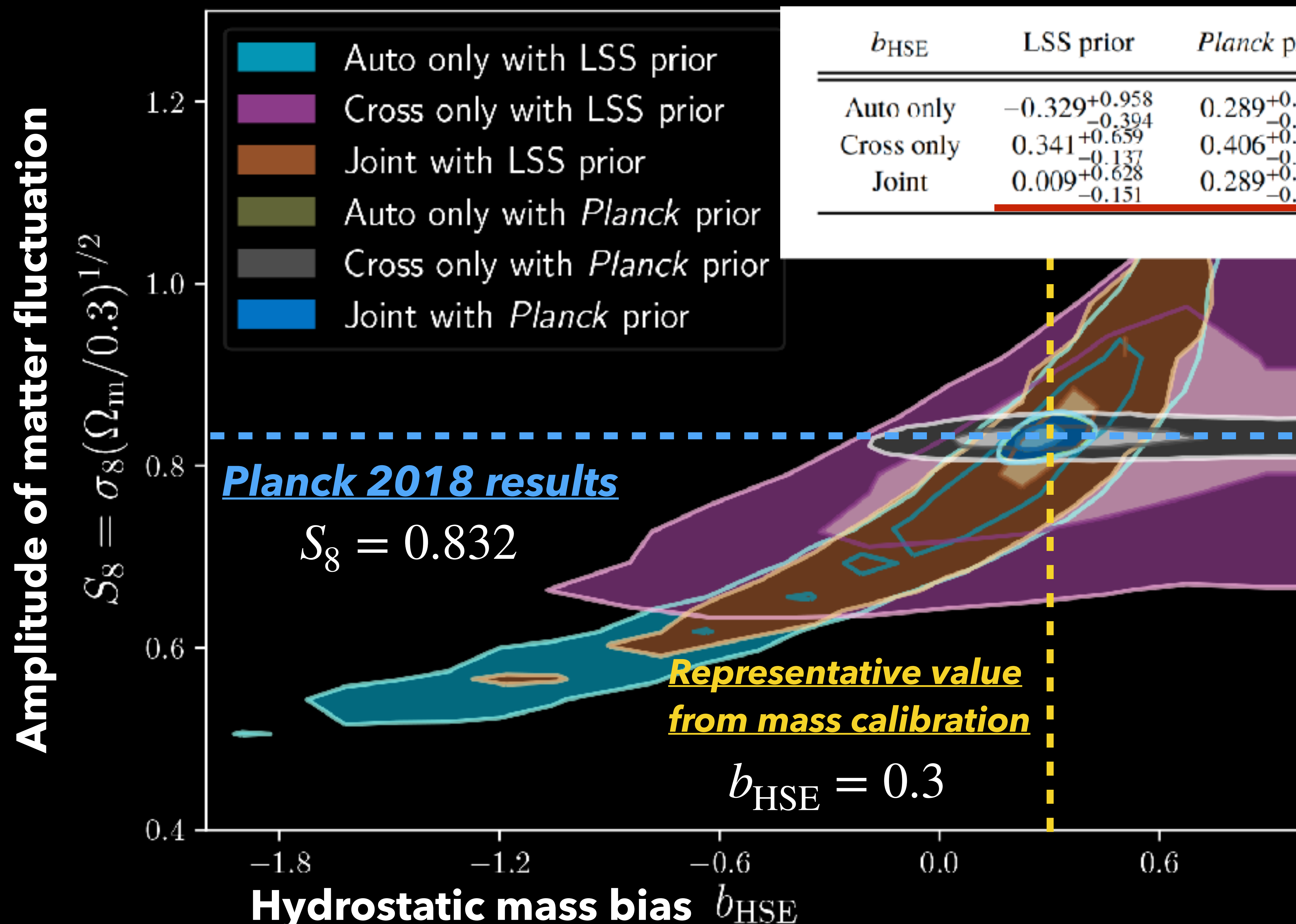
with Planck prior

tSZ auto-power spectrum only

tSZ-WL cross-correlations only

Both of tSZ auto and tSZ-WL cross

Constraints on Amplitude and Mass Bias



$b_{\rm HSE}$	LSS prior	*Planck* prior
Auto only	$-0.329^{+0.958}_{-0.394}$	$0.289^{+0.057}_{-0.074}$
Cross only	$0.341^{+0.659}_{-0.137}$	$0.406^{+0.310}_{-0.366}$
Joint	$0.009^{+0.628}_{-0.151}$	$0.289^{+0.060}_{-0.075}$

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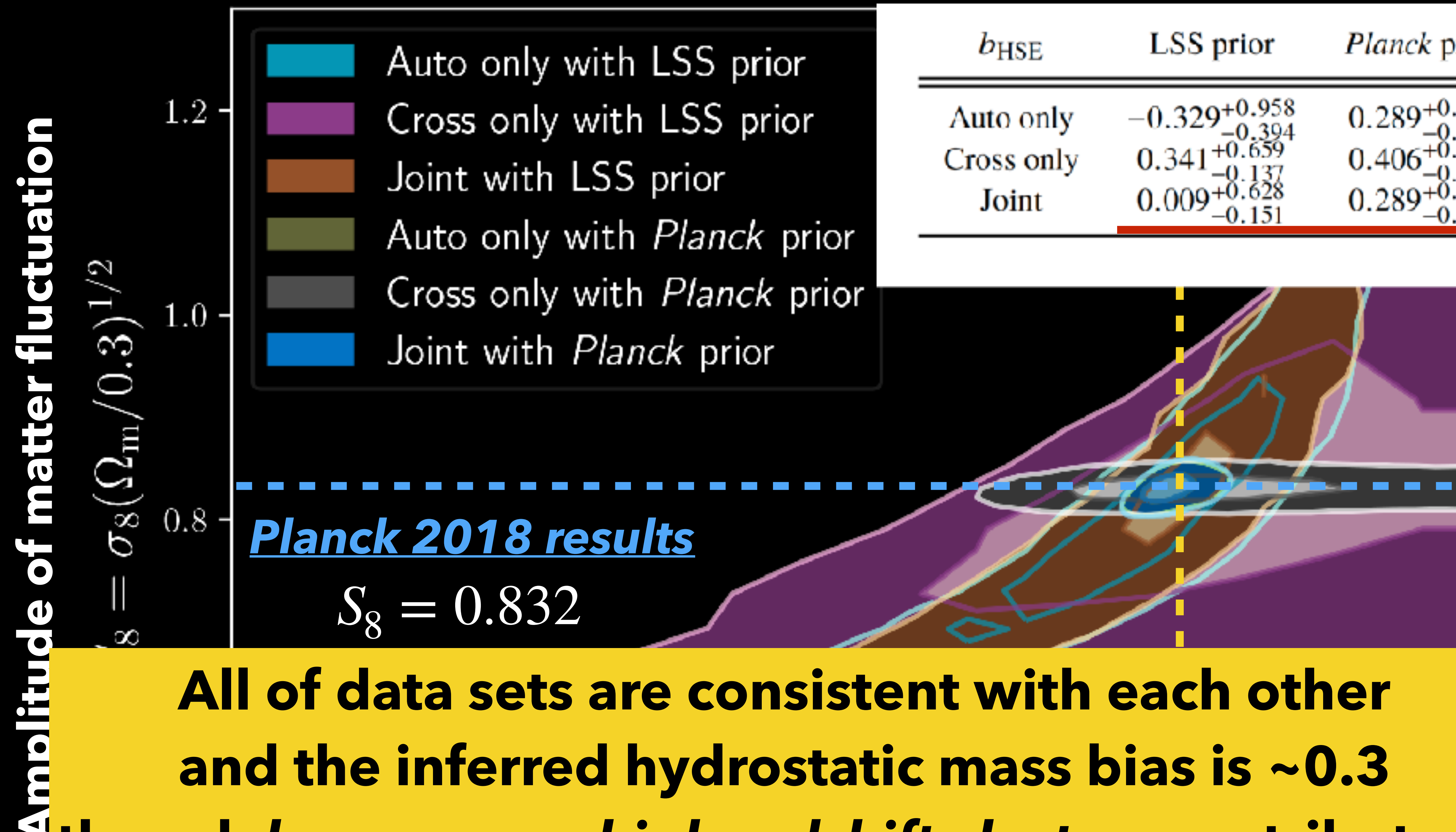

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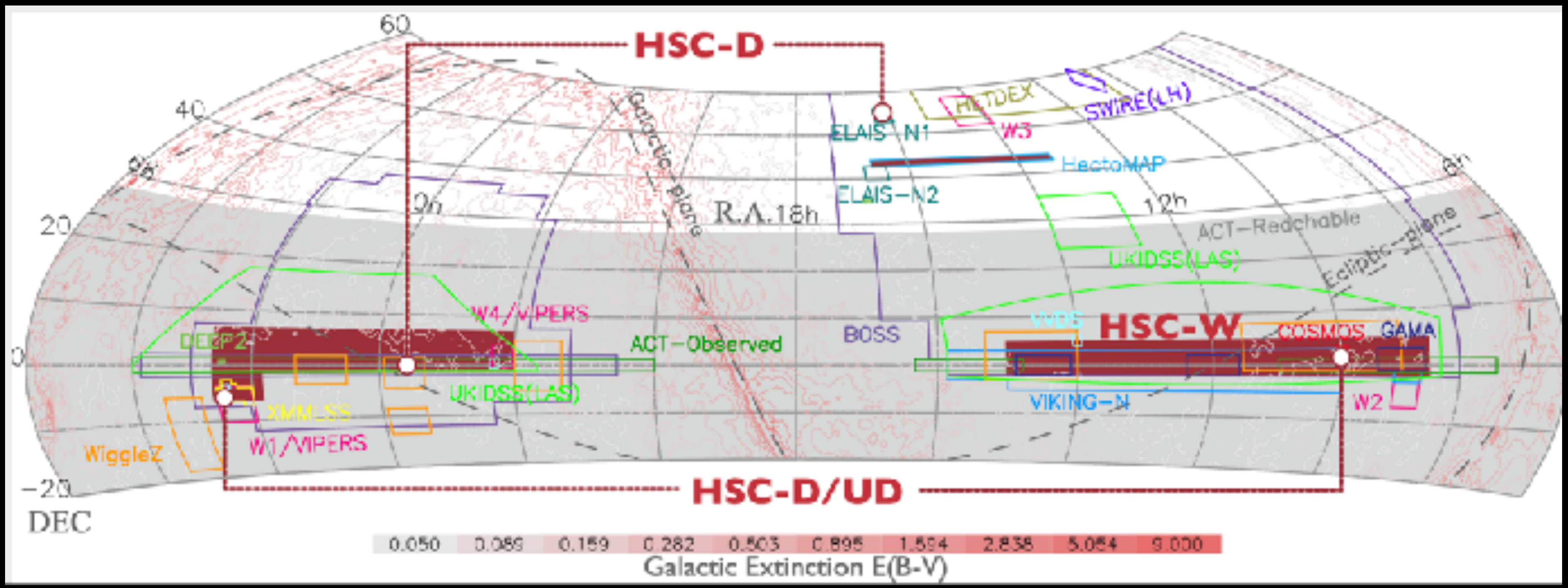
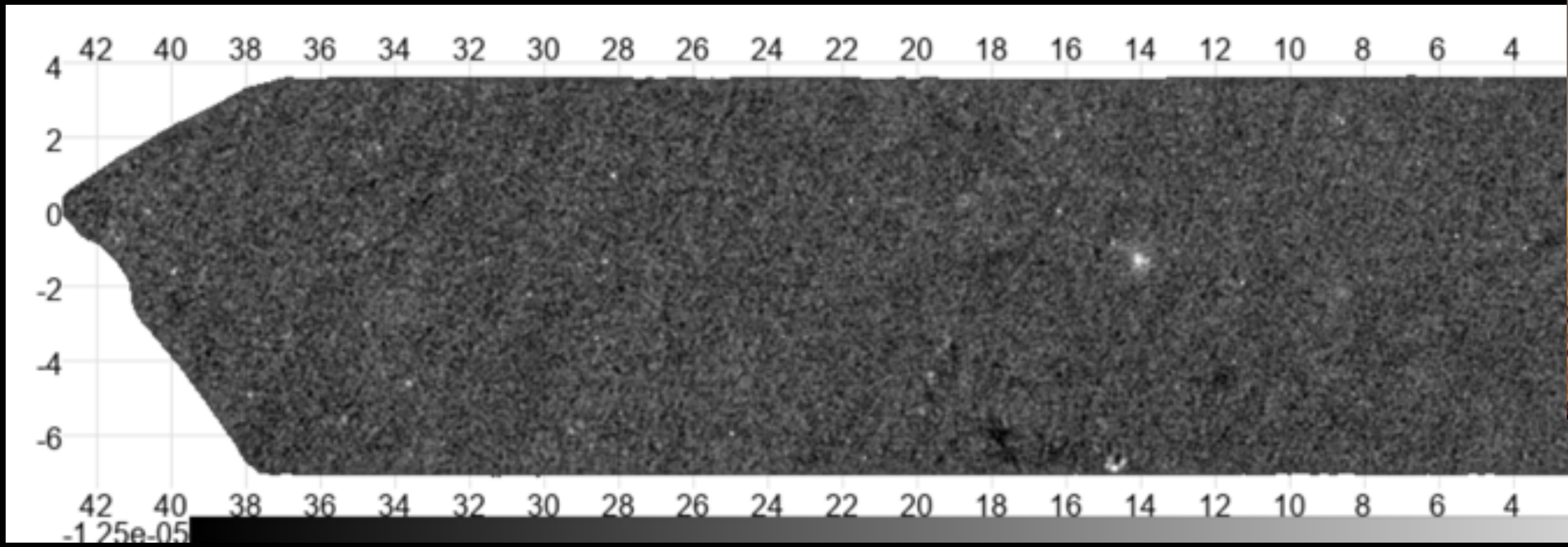
All of data sets are consistent with each other and the inferred hydrostatic mass bias is ~0.3 though *low-mass or high redshift clusters* contribute to the appreciable fraction of tSZ auto-power spectrum and tSZ-WL cross-correlations.

HSC WL x ACT tSZ

✦HSC S18A WL



✦ACTPol Compton-*y* map



Madhavacheril+ (2019)

Summary

- Weak lensing and the thermal Sunyaev-Zel'dovich effect are promising probes into the large-scale structure and thermodynamical properties of intra-cluster medium.

- Cross-correlation is a powerful statistic with high S/N significance provides additional information useful for breaking degeneracy.

- In the joint analysis with tSZ auto-power spectrum and tSZ-WL cross-correlations, the hydrostatic mass bias is inferred as 0.3, which is consistent with mass calibration measurements.

- **HSC is the unique WL survey which can probe into the large-scale structures and cluster astrophysics at high redshifts, and the redshift evolution by tomography.**