

COSMOLOGY WITH MASSIVE NEUTRINOS

COSMOLOGY FROM HOME, JUNE 2021

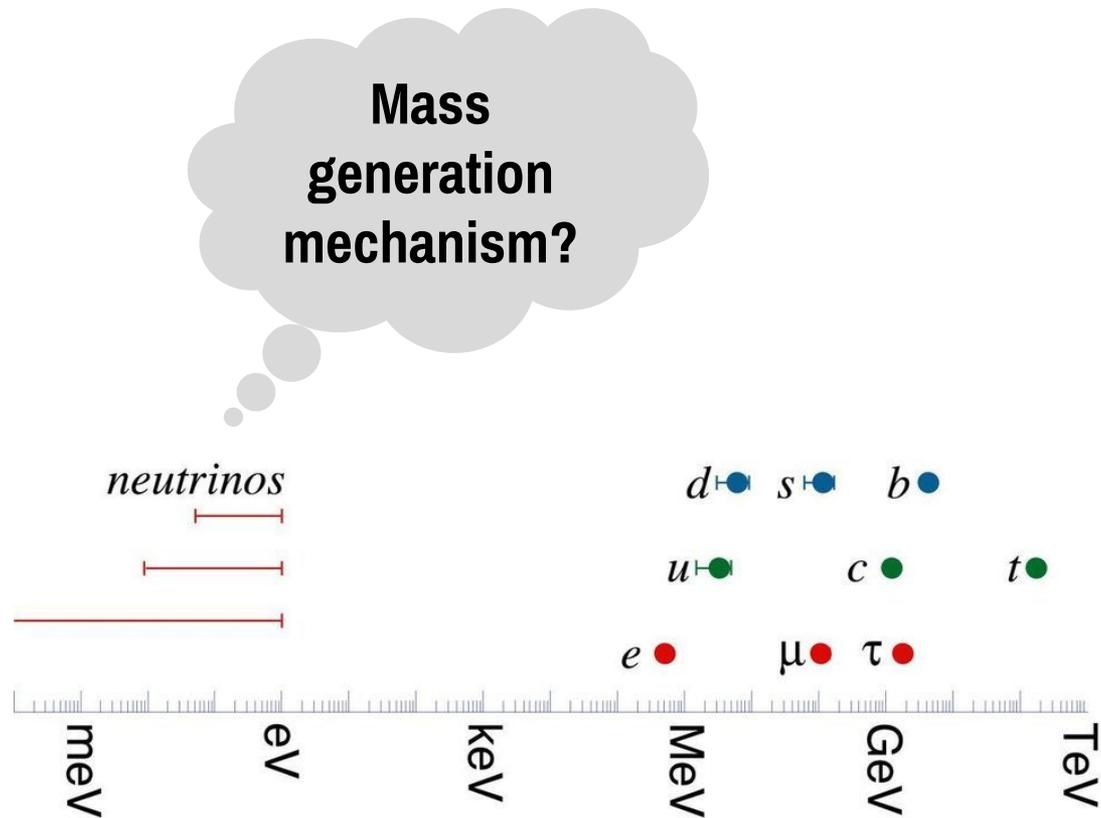
Jia Liu

University of California, Berkeley



BERKELEY CENTER *for*
COSMOLOGICAL PHYSICS

Masses of Standard Model Fermions



PARTICLE EXPERIMENT

Current

$$m_{\nu e}^{\text{eff}} < 1.1 \text{ eV}$$

KATRIN (2019, 90% CL)

Future Sensitivity

0.2 eV

KATRIN 2023

COSMOLOGY

Current

$$\Sigma m_{\nu} < 0.12 \text{ eV}$$

Planck (2018, 95% CL)

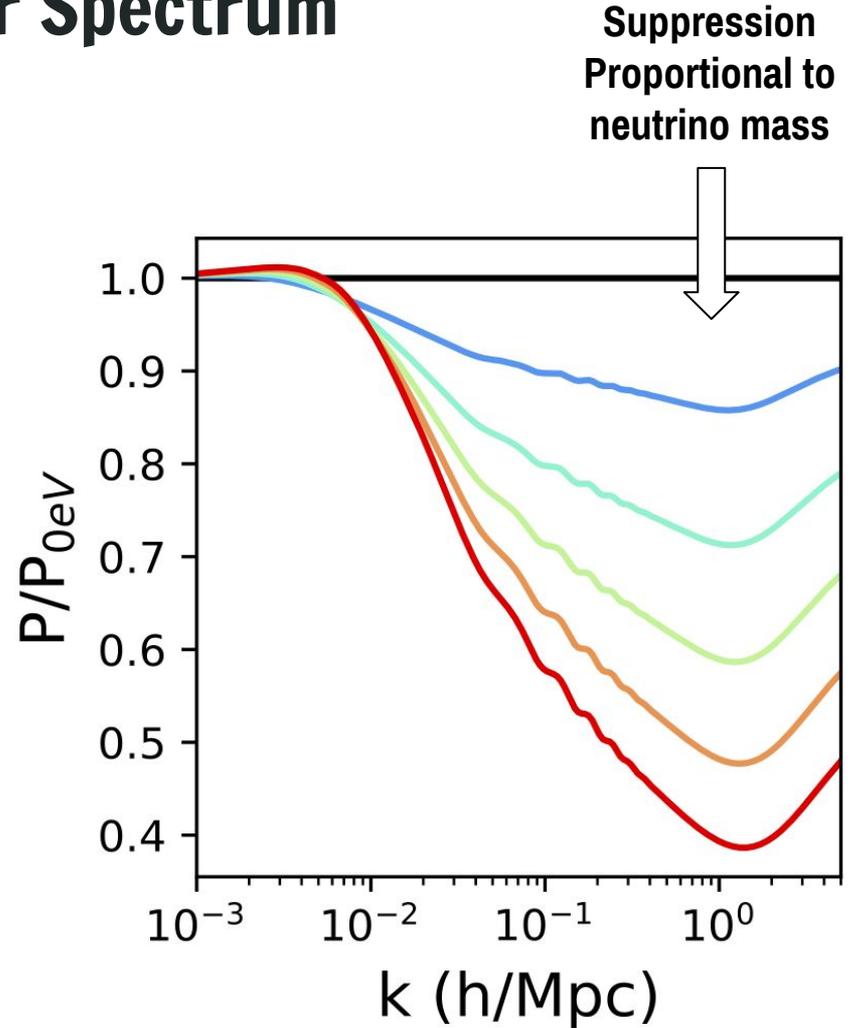
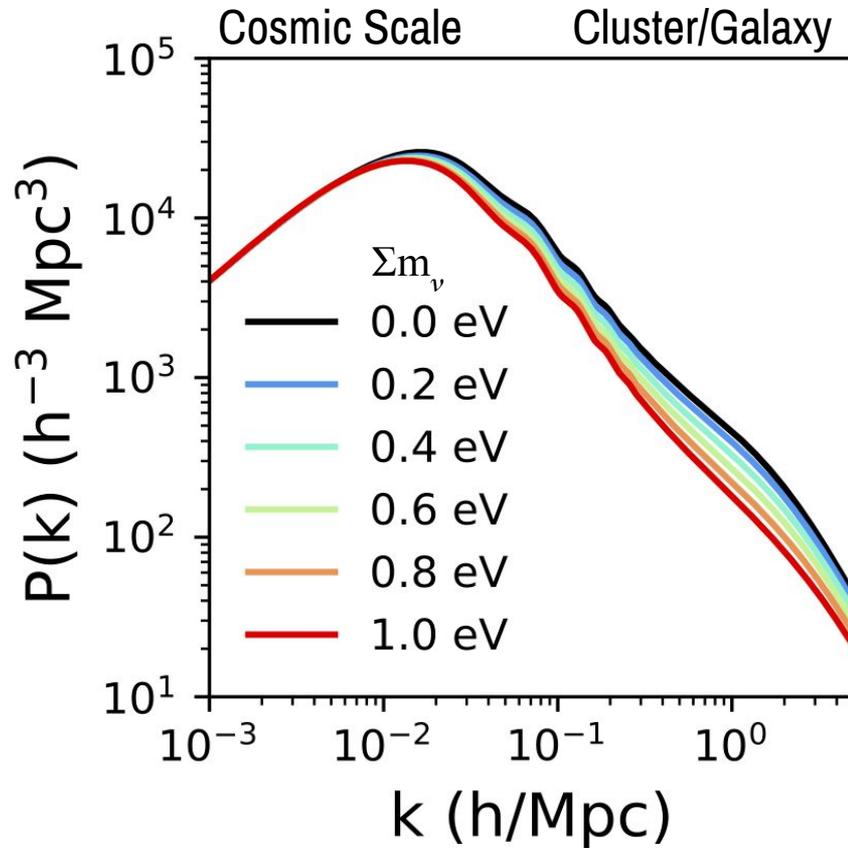
Future Sensitivity

0.03 eV

LSST / SO / CMB-S4 / DESI

Normal Ordering: $\Sigma m_{\nu} > 0.06 \text{ eV}$

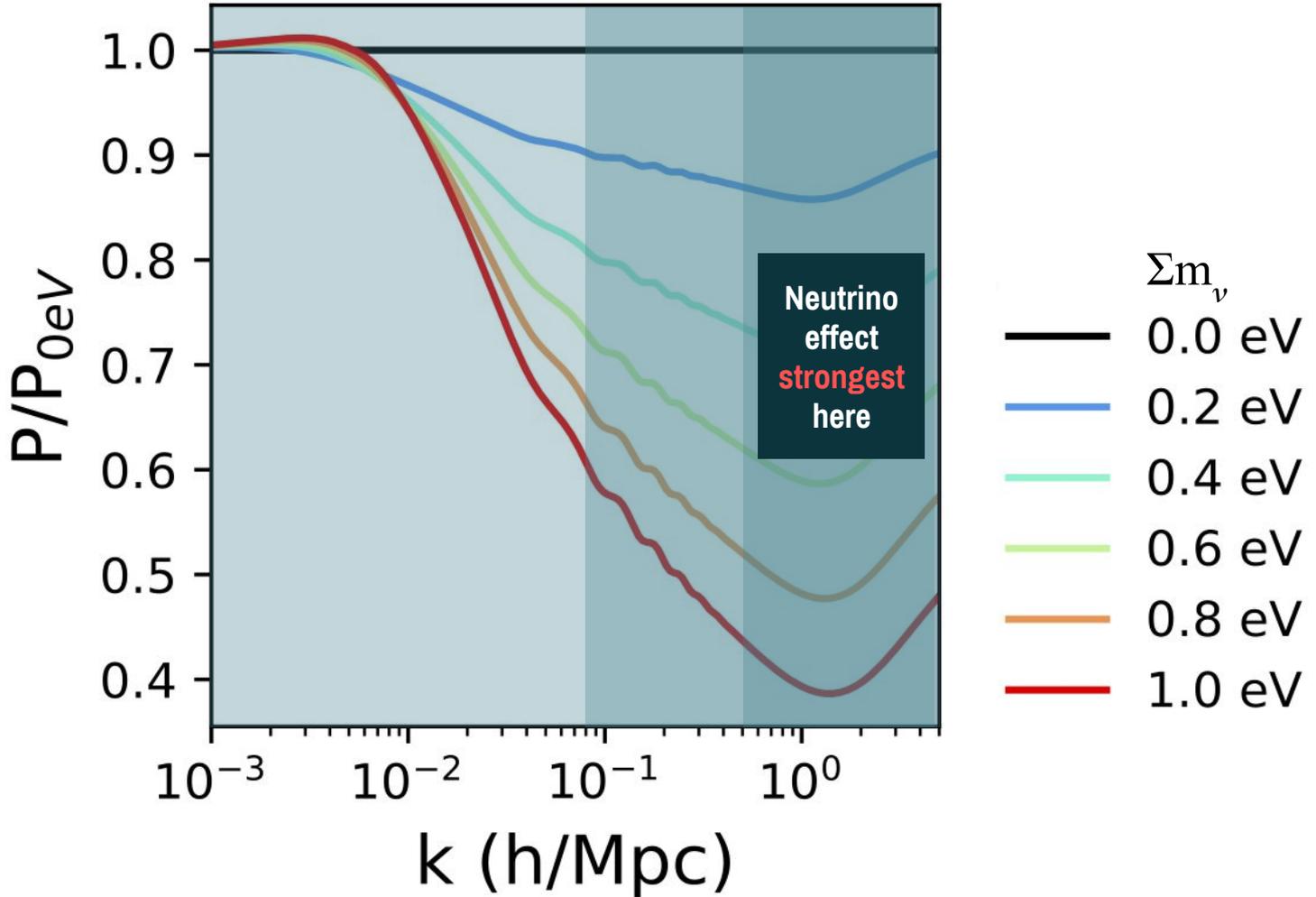
Matter Power Spectrum



Highly Nonlinear: Numerical Simulations

Mildly Nonlinear: Pert. Theory

Linear Theory



MassiveNuS

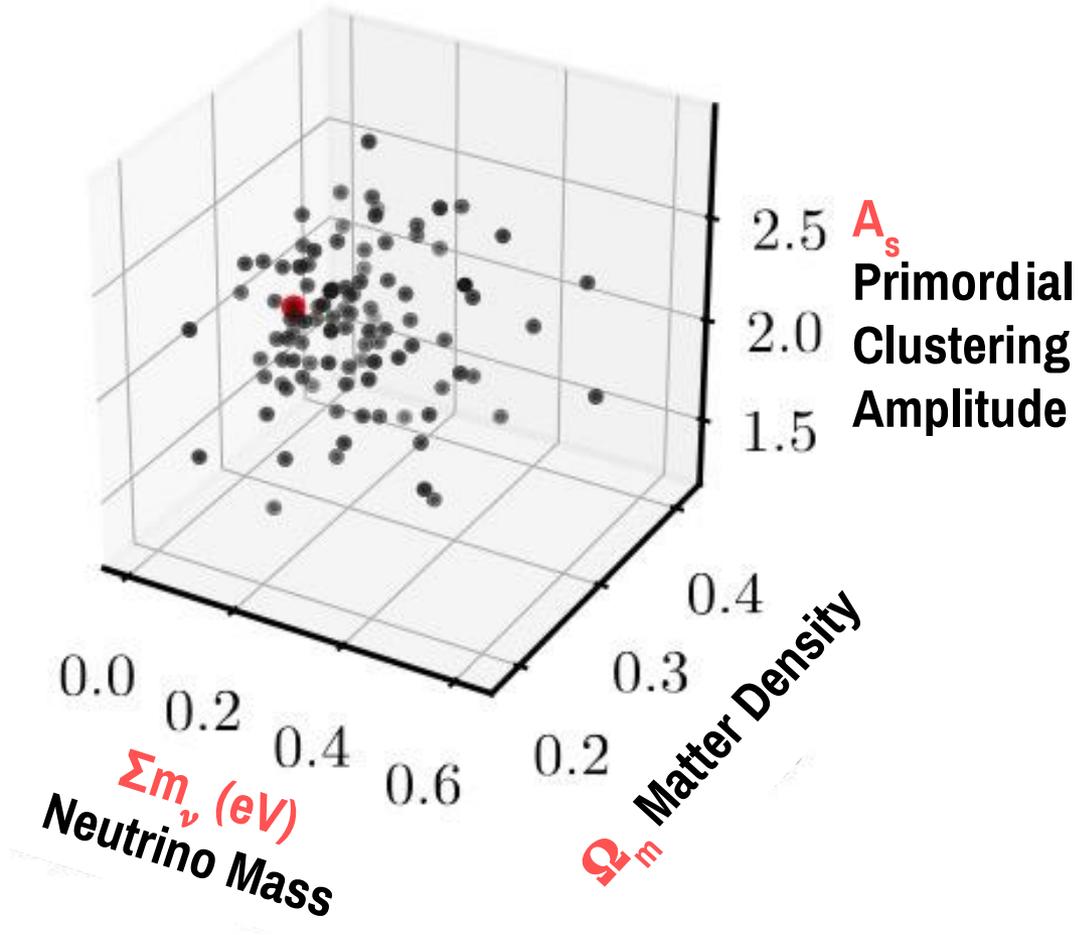
Cosmological massive neutrino simulations (JL et al. 2018)



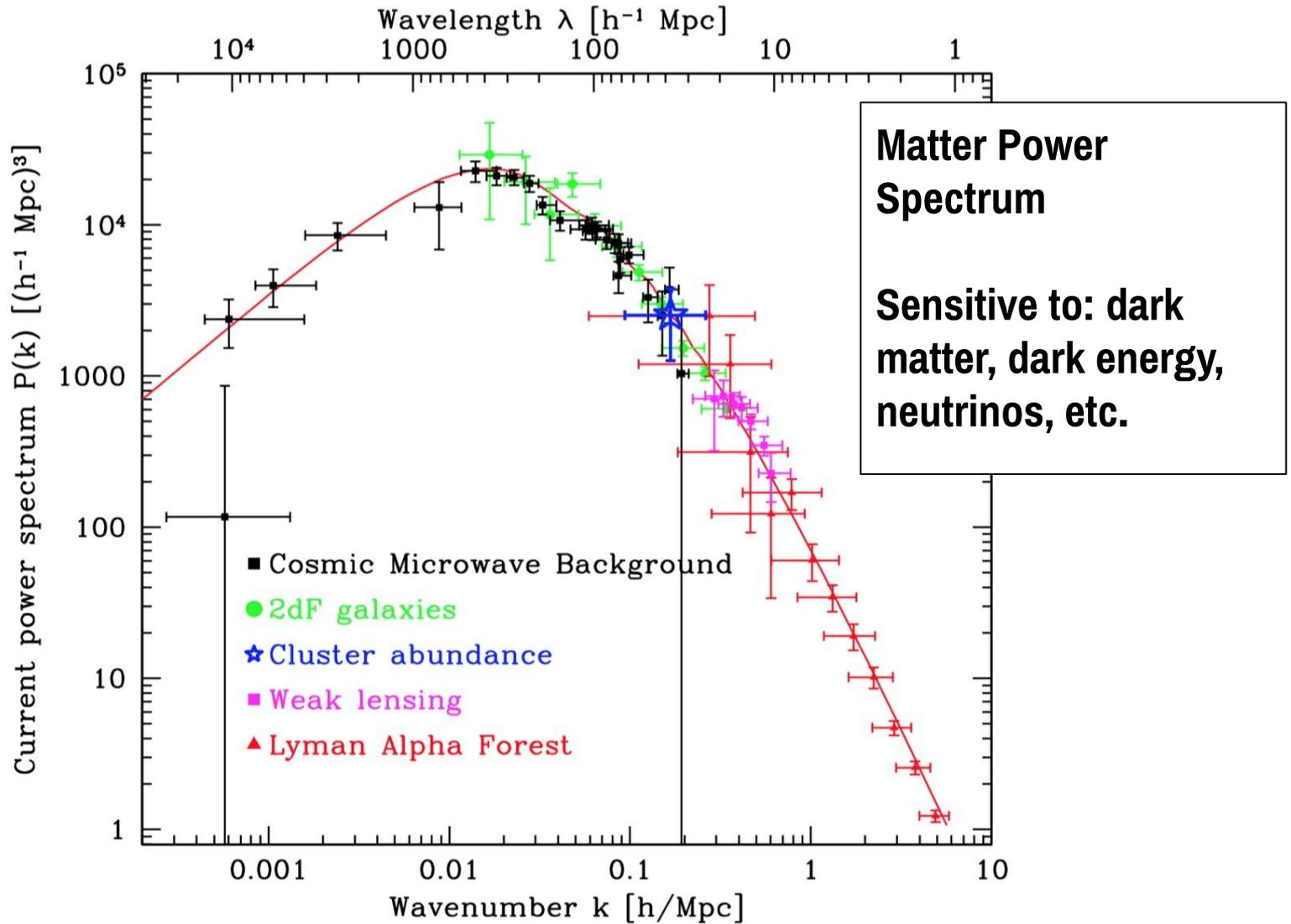
100 high resolution simulations with varying neutrino masses

300TB data (20TB public)
Particles, halo catalogues, merger trees, weak lensing, CMB lensing

Available at:
<http://www.columbialensing.org/>

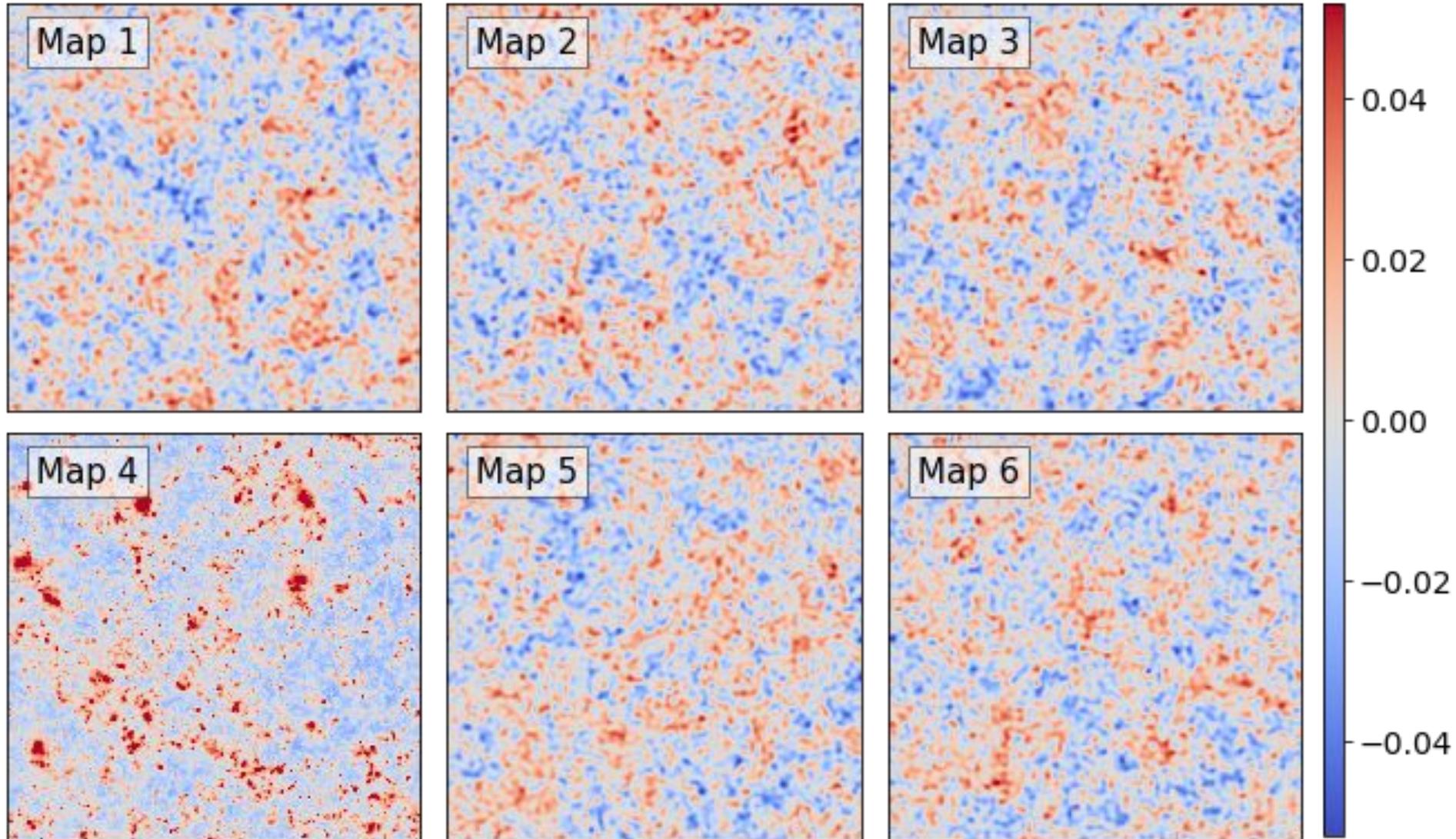


Power Spectrum: Only Complete for Gaussian Fields



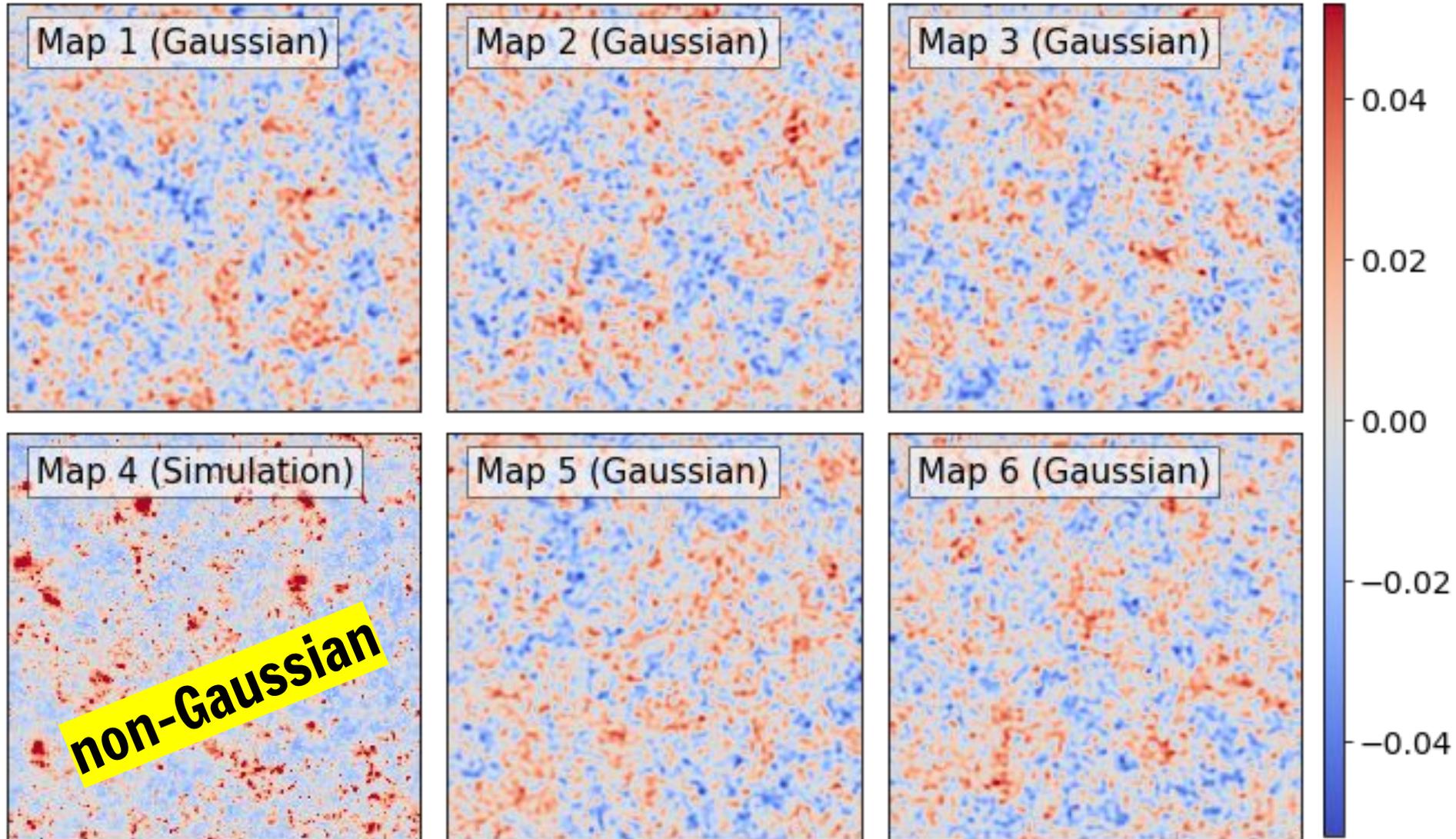
Dark Matter Distribution: Highly Non-Gaussian

color: projected overdensity



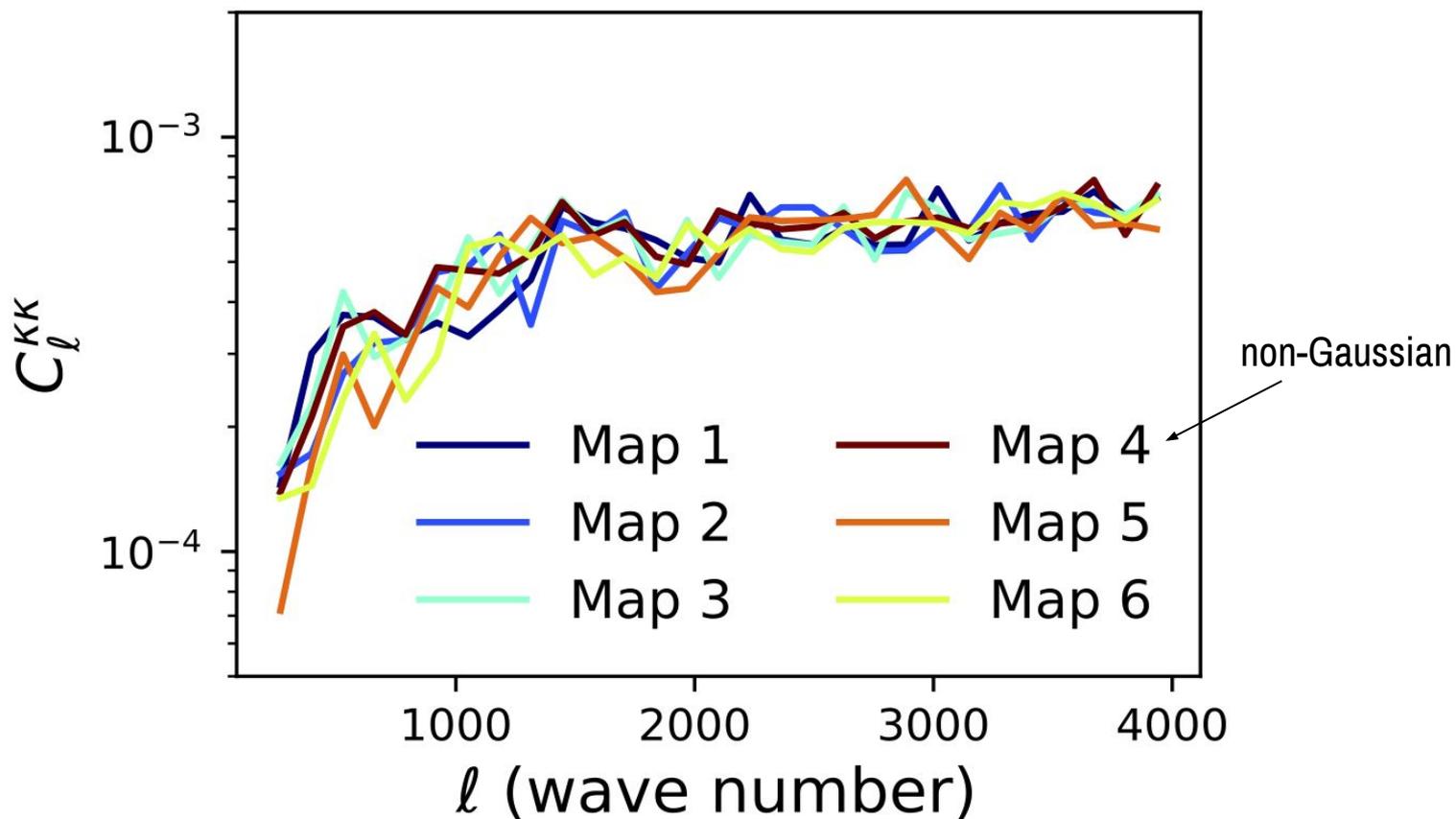
Dark Matter Distribution: Highly Non-Gaussian

color: projected overdensity



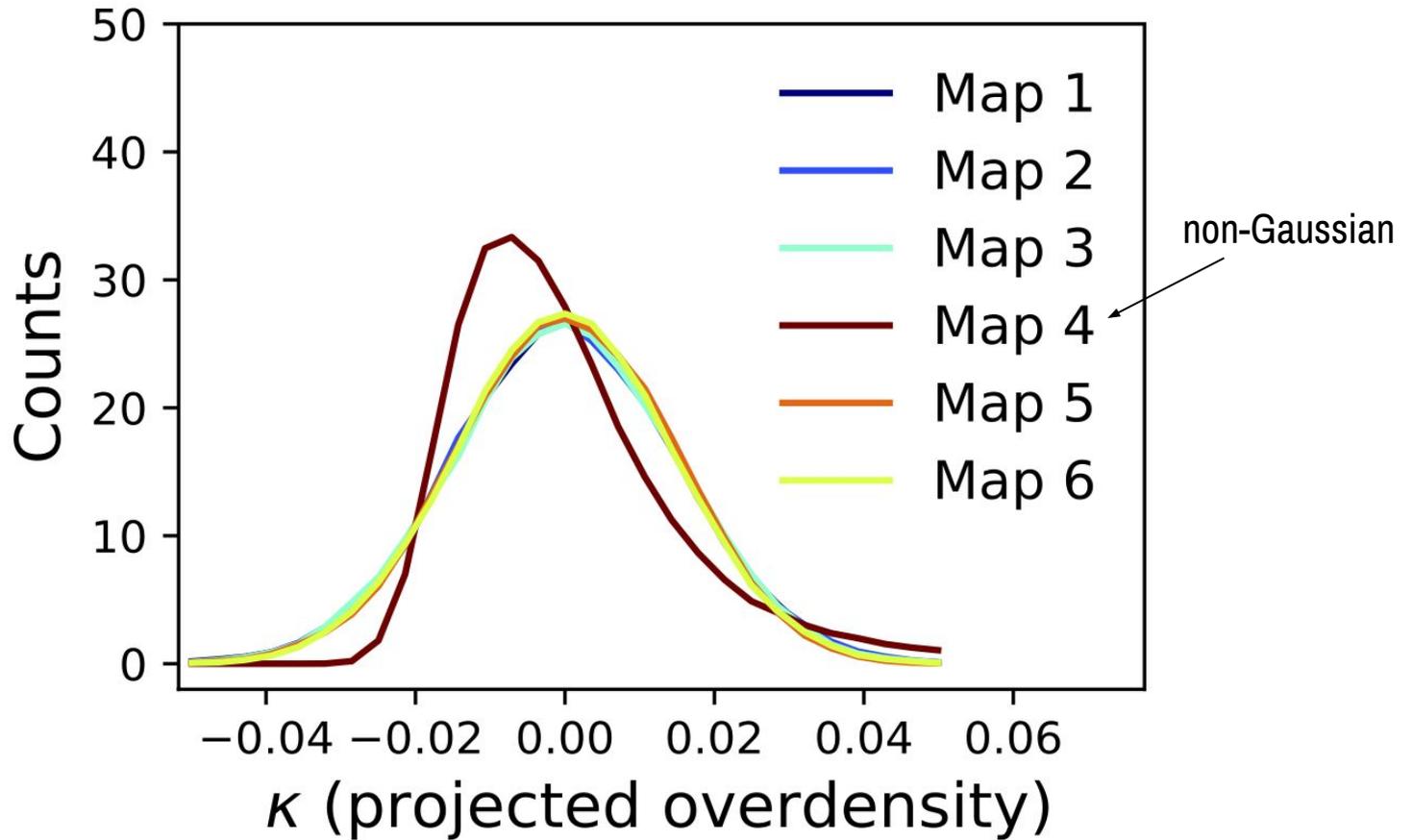
Lensing Power Spectrum

Does not capture non-Gaussian Information

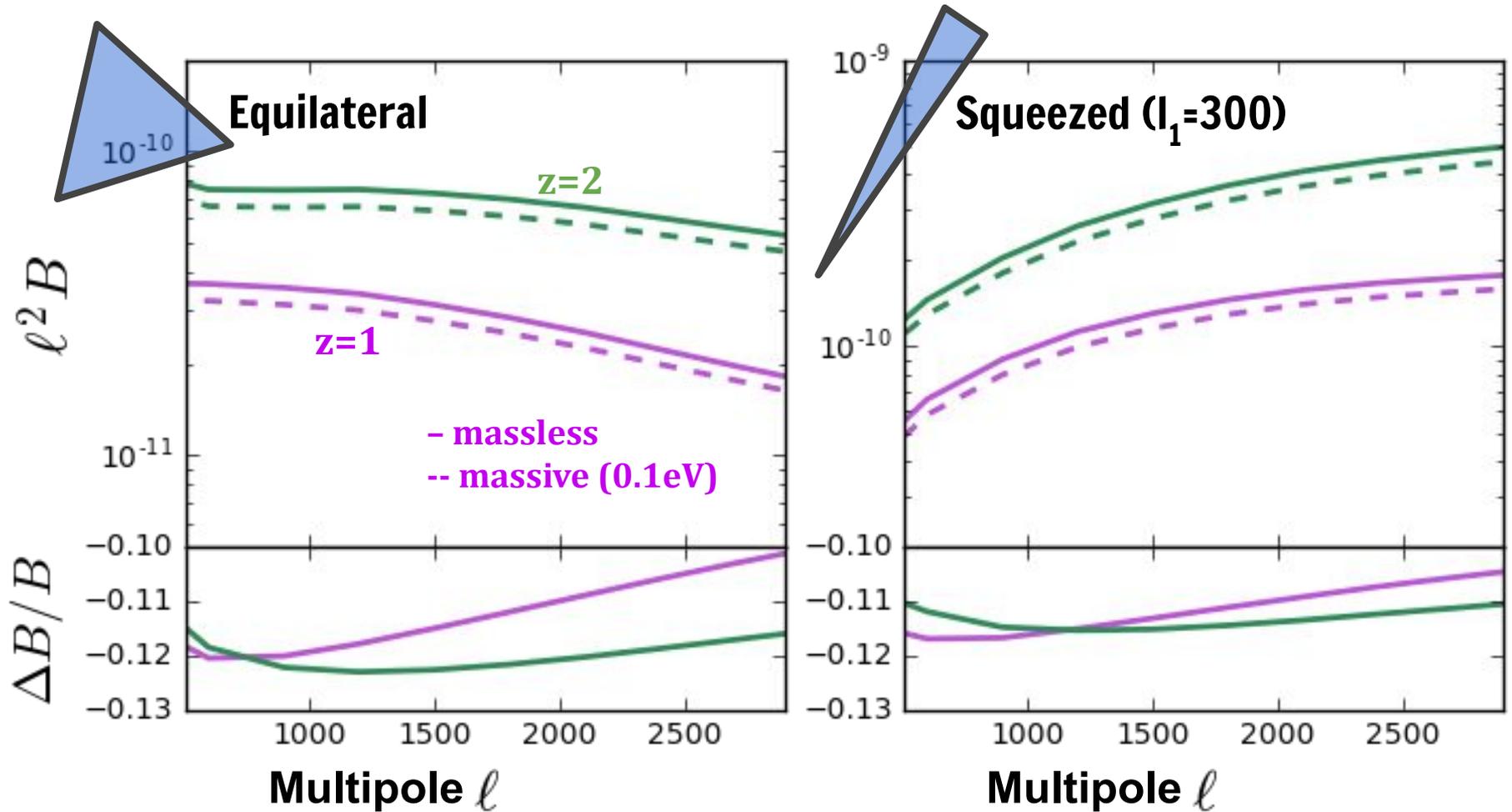


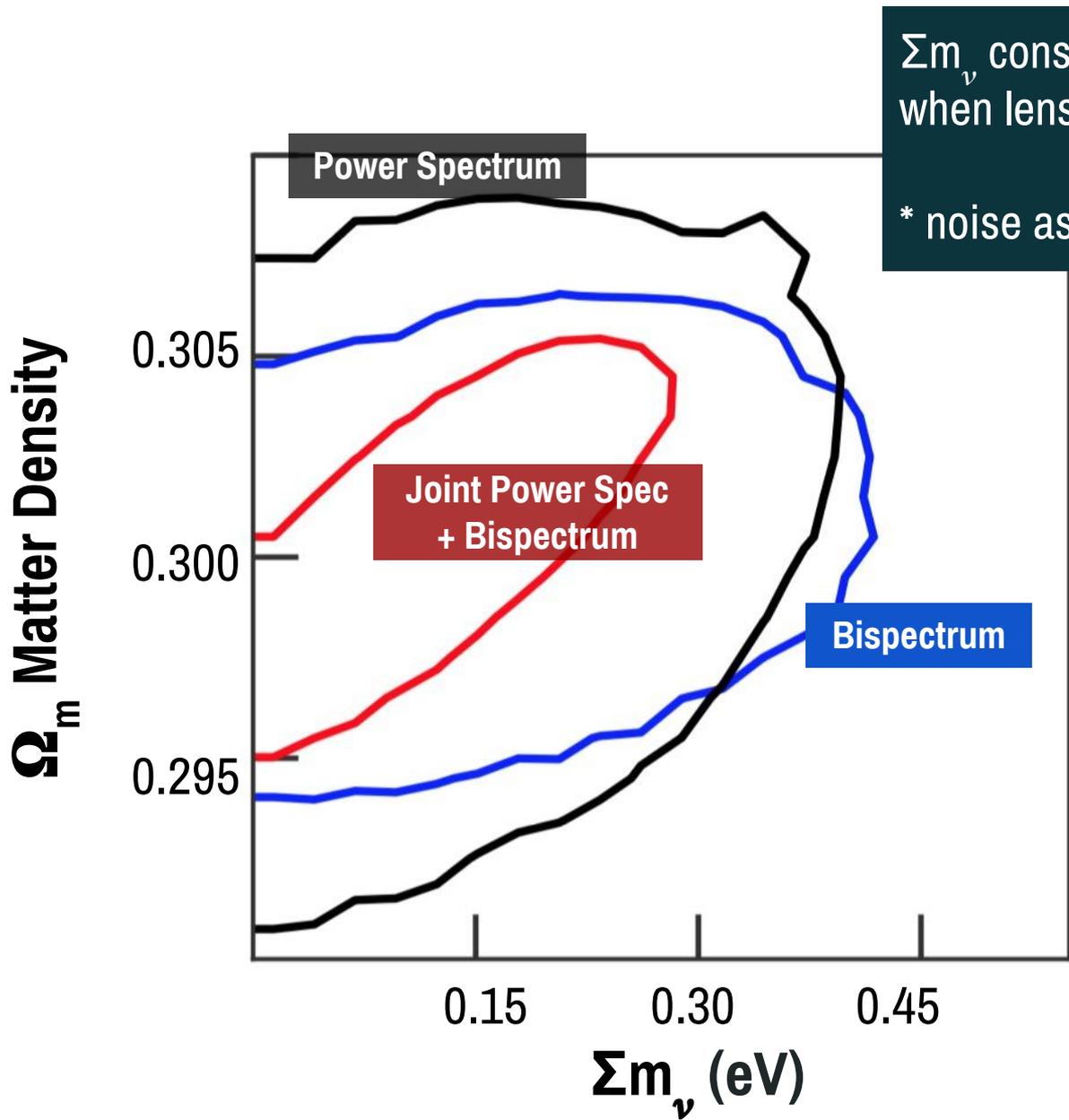
Histogram of All Pixel Values (PDF)

Sensitive to non-Gaussian Information



Extracting non-Gaussian information with **Bispectrum**



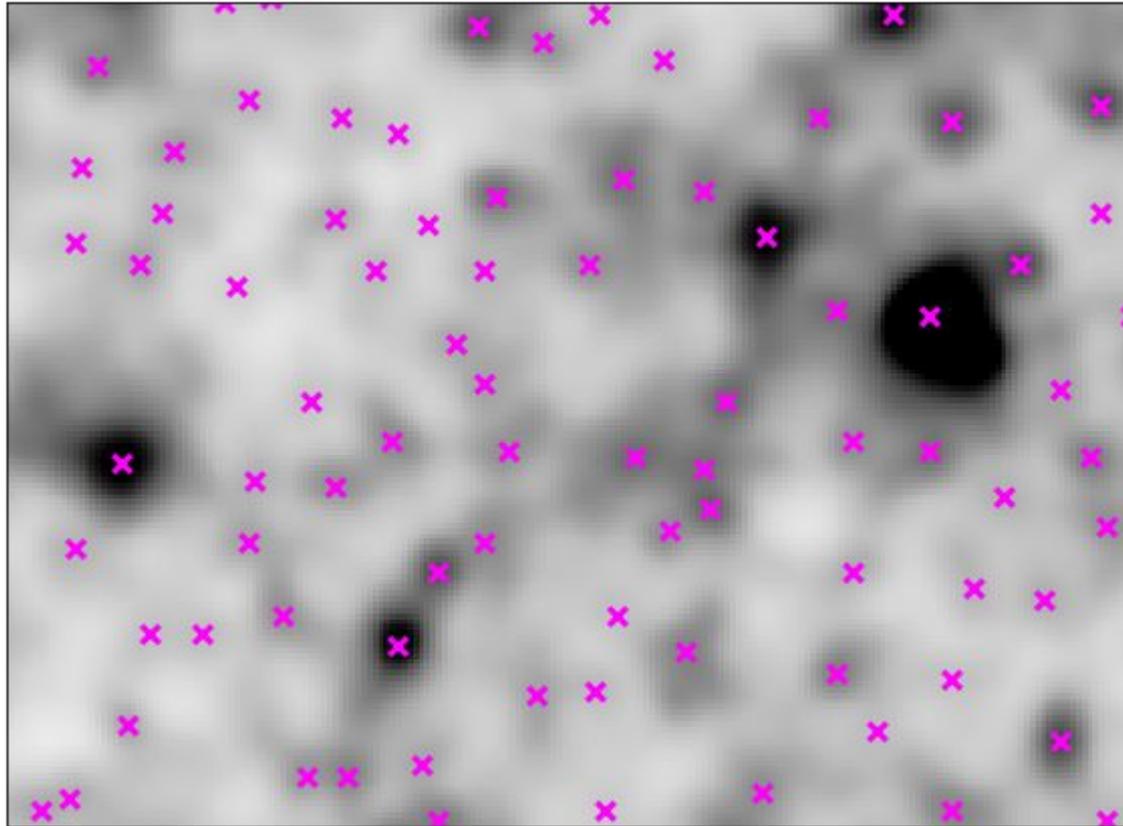


Σm_ν constraint **30% tighter** when lensing bispectrum added.
* noise assumption: LSST

Coulton, JL+2019



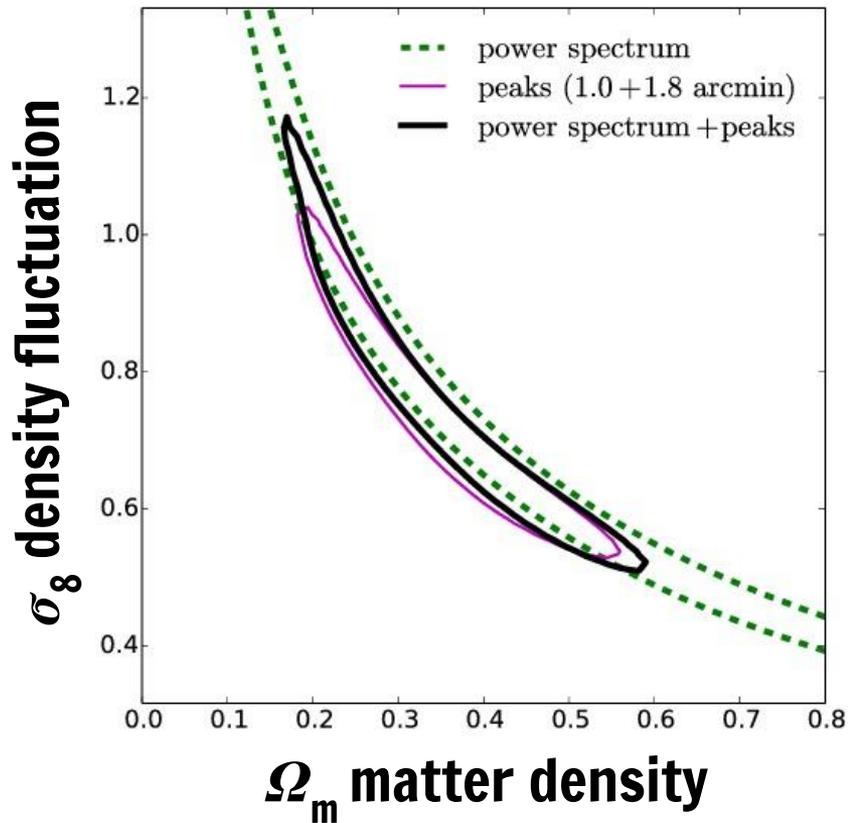
A Promising non-Gaussian Statistic: Peak Counts



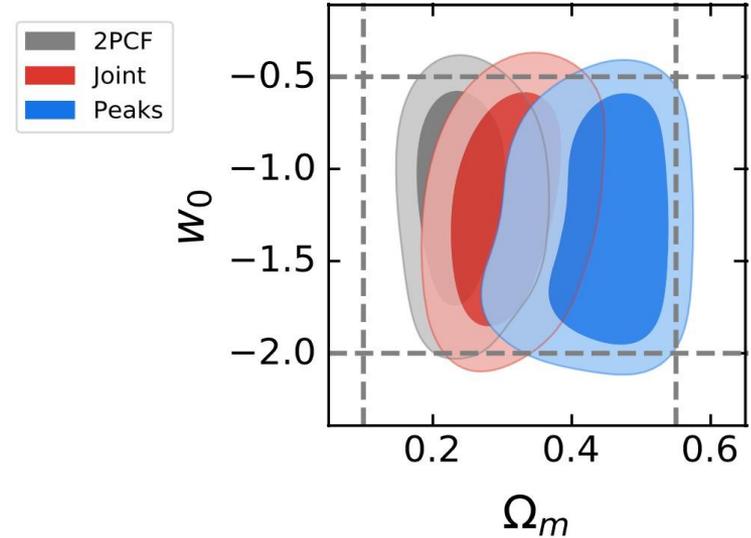
Weak lensing peaks are local maxima that are typically associated with the massive halos in the universe.

Cosmological Constraint with Peak Counts

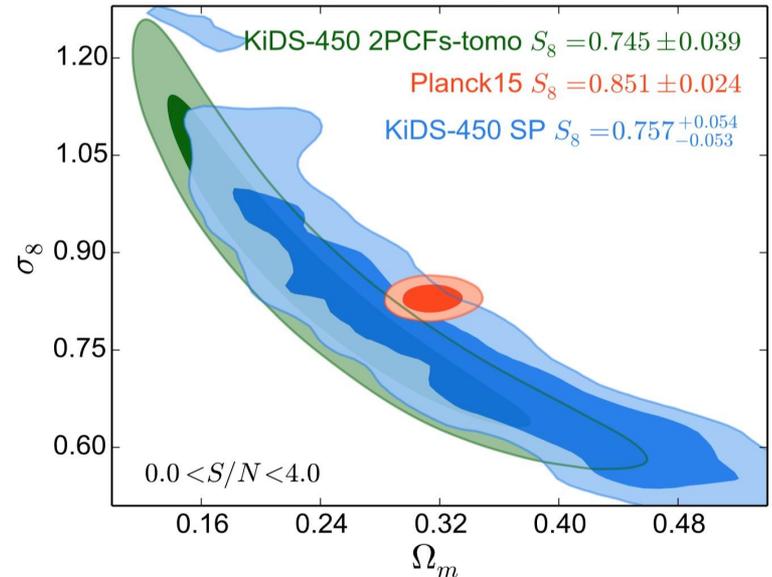
[CFHTLenS] JL+2015



[DES Y1] Harnois-Deraps+2020

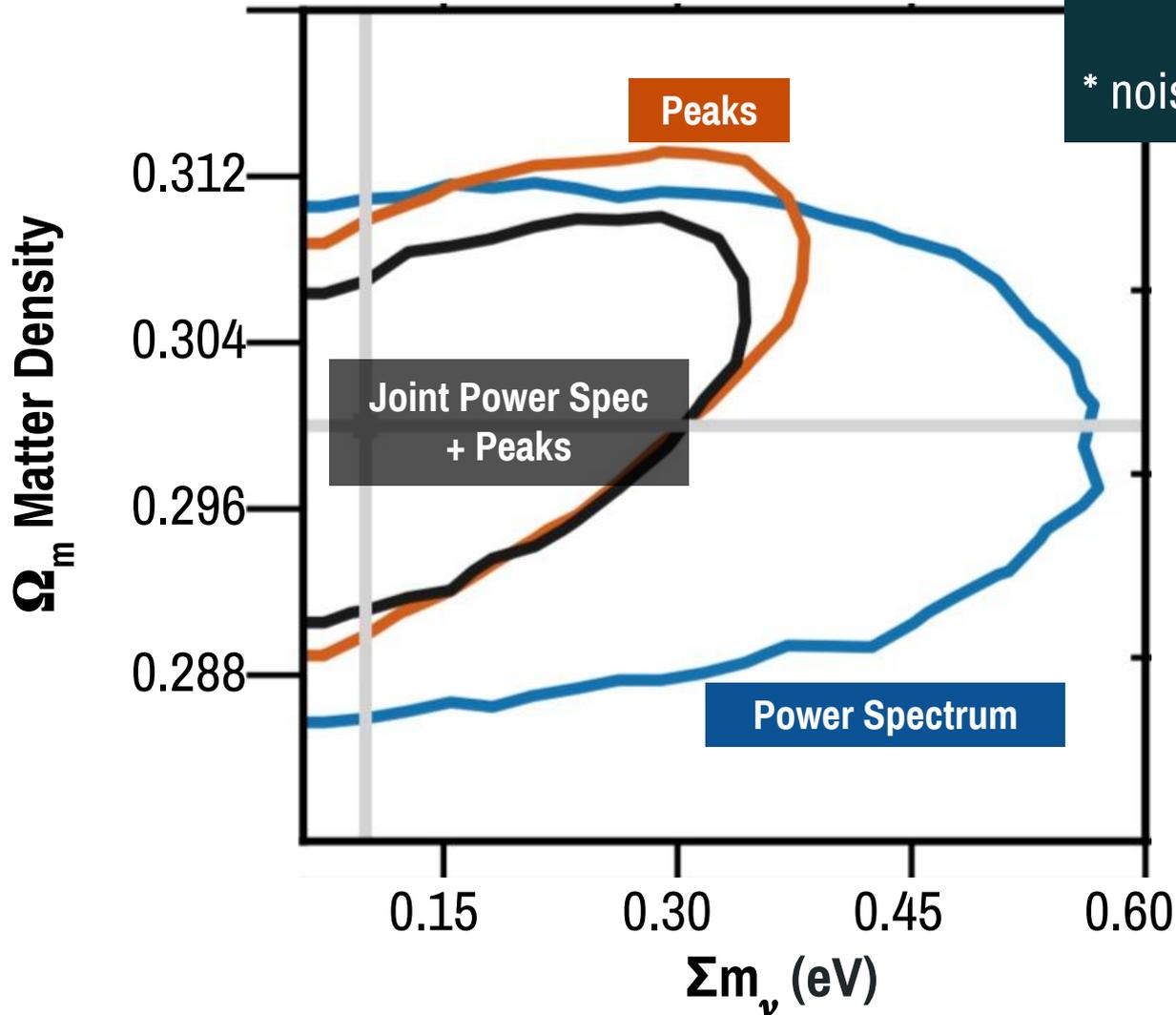


[KiDS-450] Martinet+2017

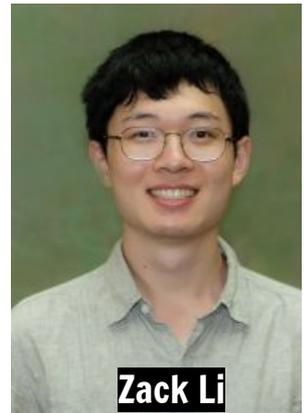


Σm_ν constraint **40% tighter**
using lensing peaks alone.

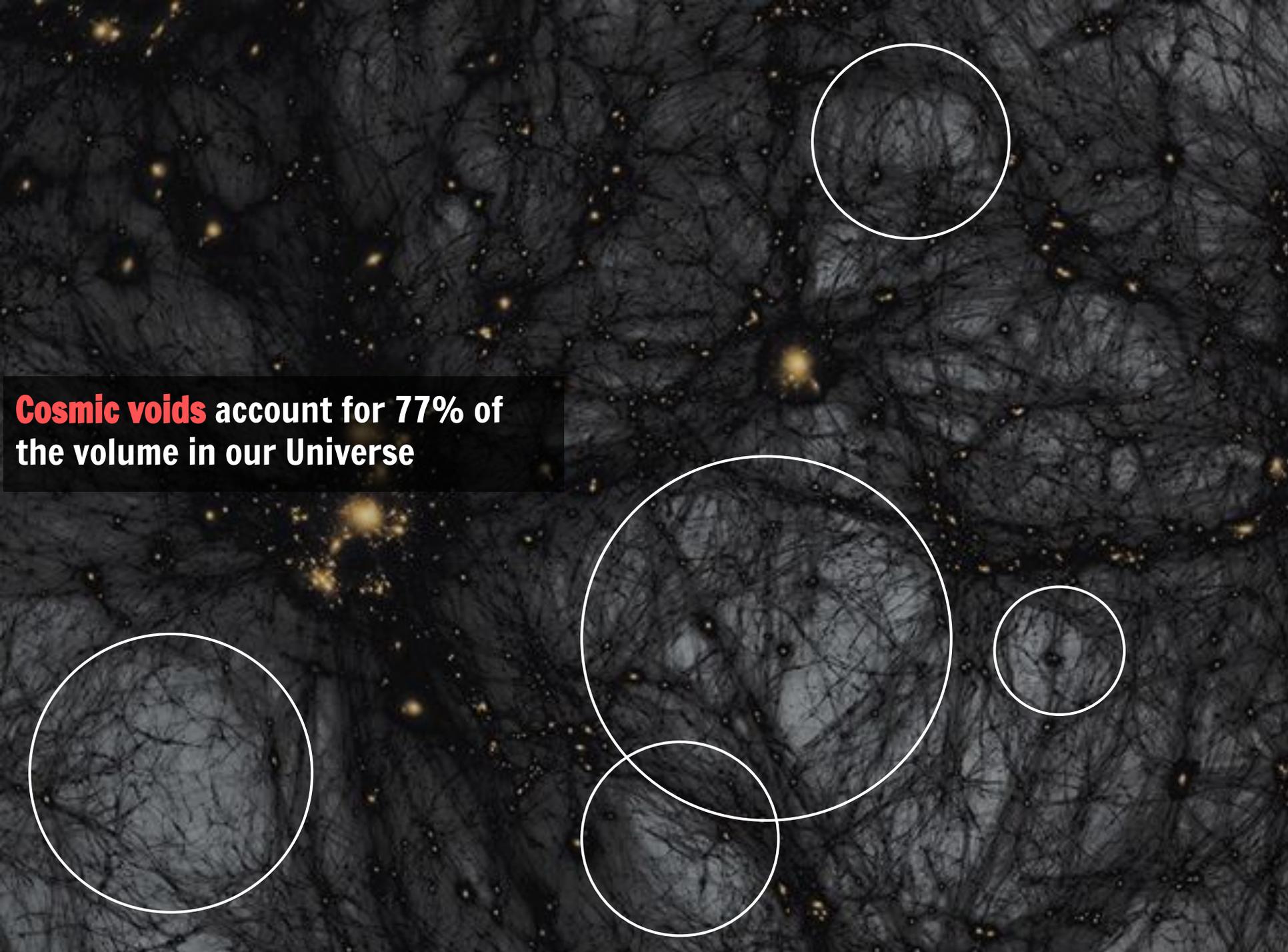
* noise assumption: LSST



Li, JL+2019

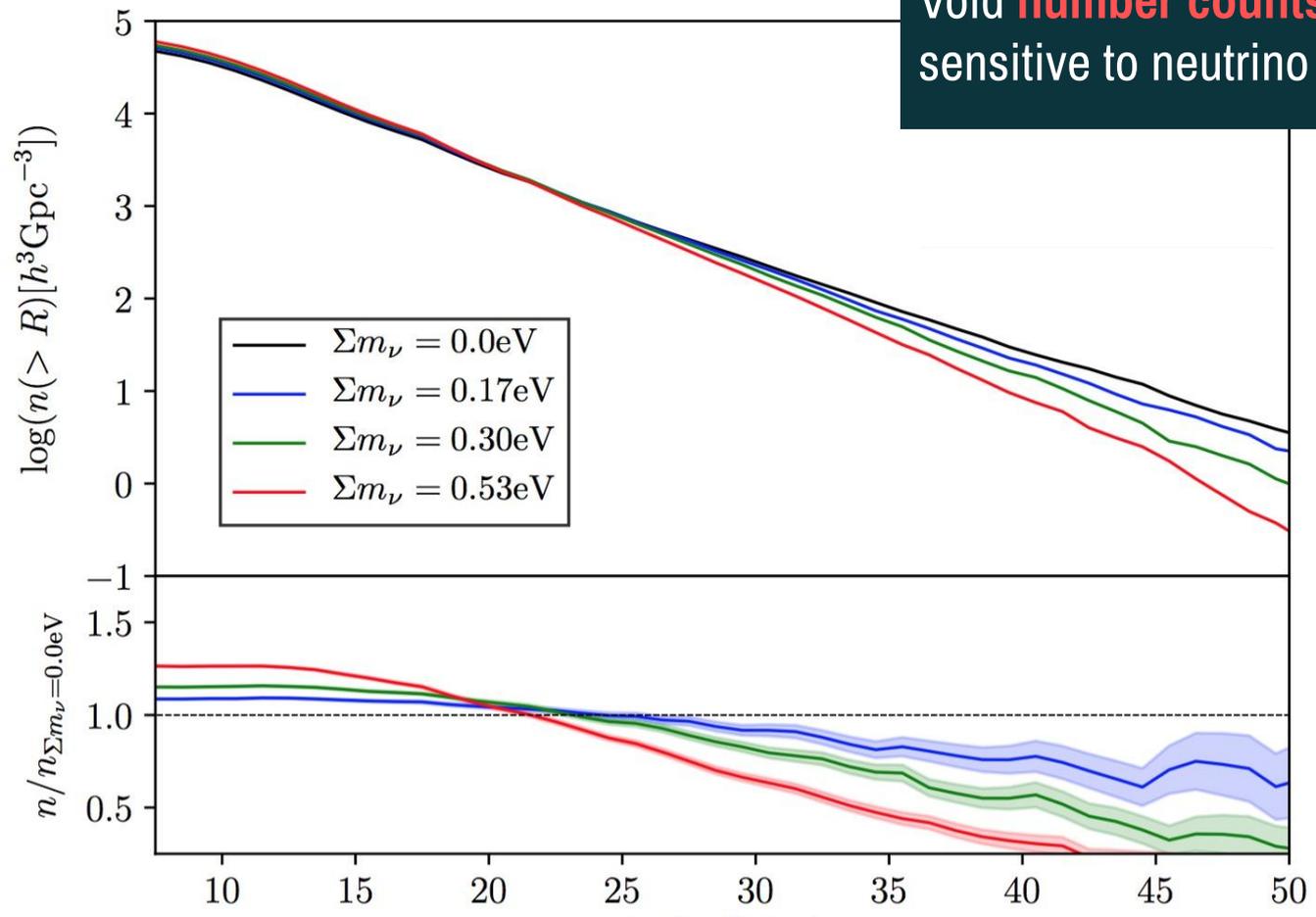


Cosmic voids account for 77% of the volume in our Universe



Void **number counts** and **clustering** are sensitive to neutrino mass

Void Count



Kreisch, Pisani,
Carbone, JL+2019

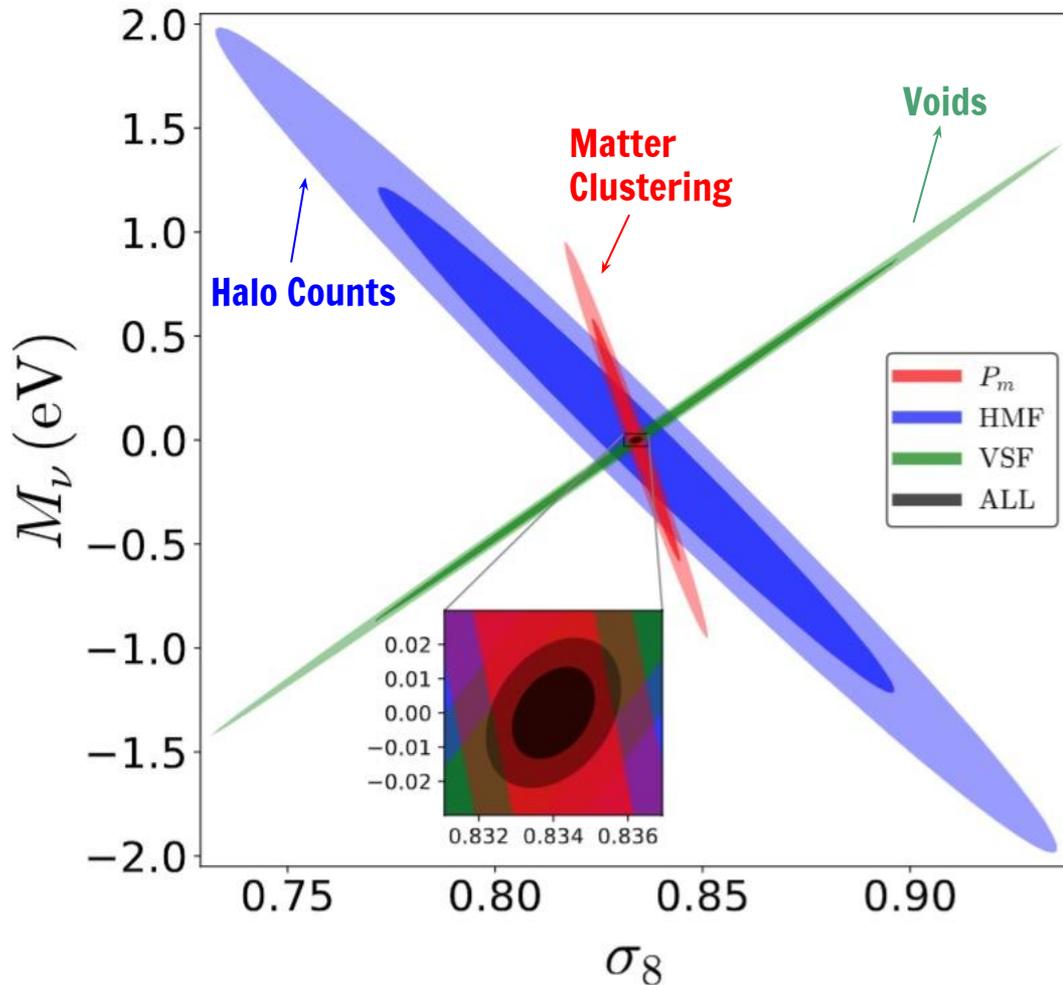


Ratio

Void size (Mpc/h)

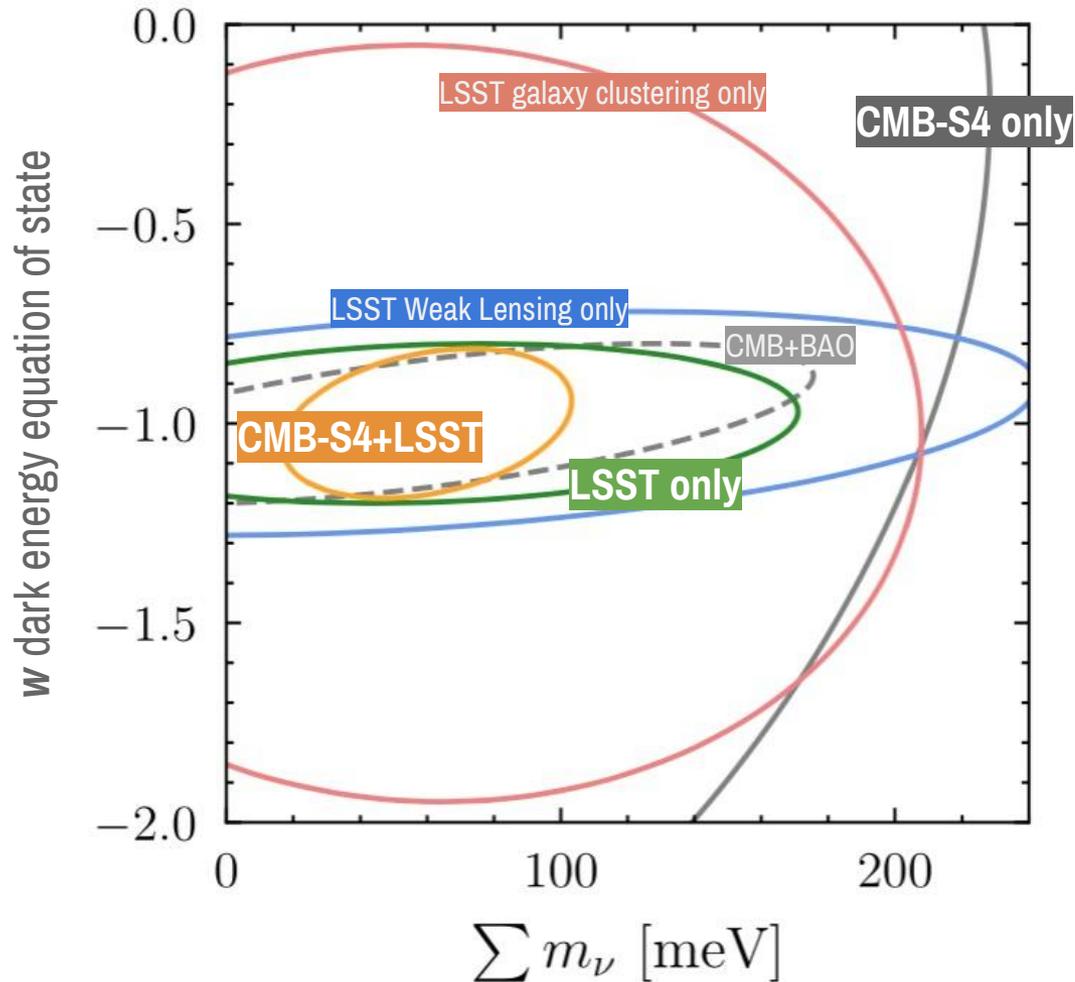
Combining the power spectrum with **voids** and **halos** has the potential to significantly improve neutrino mass constraints.

Bayer+(JL) 2021



Volume = 1 (Gpc/h)^3
Based on 23,000
Quijote simulations

The Power of Joint Analysis

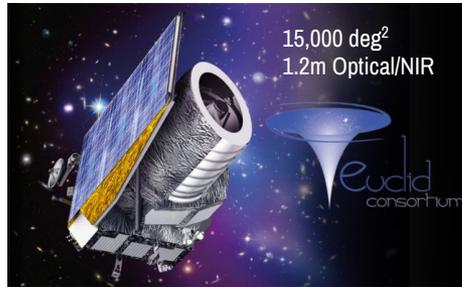
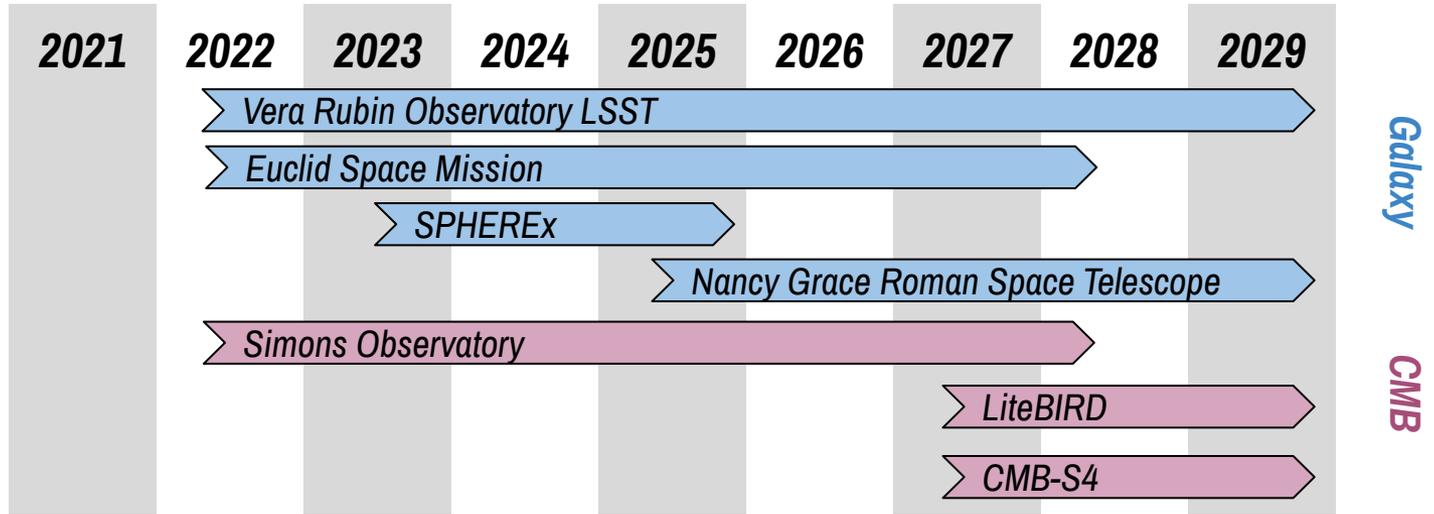


Mishra-Sharma, Alonso, Dunkley 2018

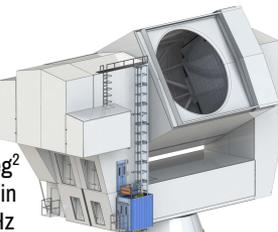
* 10 cosmological parameters: 6 Λ CDM parameters + M_ν , w_0 , w_a , curvature

* Marginalized over the usual systematics (baryons, IA, multiplicative shear bias, photo-z, galaxy bias)

Upcoming Large-Scale Structure and CMB Surveys



16,000 deg²
6μK-arcmin
27-280GHz



Summary

Massive Neutrinos

Have high potential to lead to (yet another!)
breakthrough in physics in the next decade

Accurate Modeling of Nonlinear Scales

Is the key for significant improvement from cosmology

Joint Analysis

Is the only way to reach discovery

Questions? jialiu@berkeley.edu