kSZ velocity reconstruction:

Current measurements with ACT DR6 and near-future measurements with Simons Observatory

Fiona McCarthy

arXiv:2511.15701; 2410.06229 (JCAP 2025); work in prep

*with **ACT collaboration**, incl./+ Anton Baleato Licanzos, Anthony Challinor, Carmen Embil Villagra, Simone Ferraro, Boryana Hadzhiyska, Matthew Johnson, Guanming Liang, Blake Sherwin, ++*

UNIVERSITY OF CAMBRIDGE

BCCP/Cosmology Seminar
10th March 2026

Overview

Introduction

LCDM; Open questions; inflation; primordial non-Gaussianity

The kSZ effect

kSZ velocity reconstruction

Background; first measurements; C_L^{vv}; CMB datasets

Analysis with ACT+DESILS

Results from McCarthy et al 2025 a+b; Other progress in the field; Foregrounds

Forecasts for Simons Observatory(+LSST)

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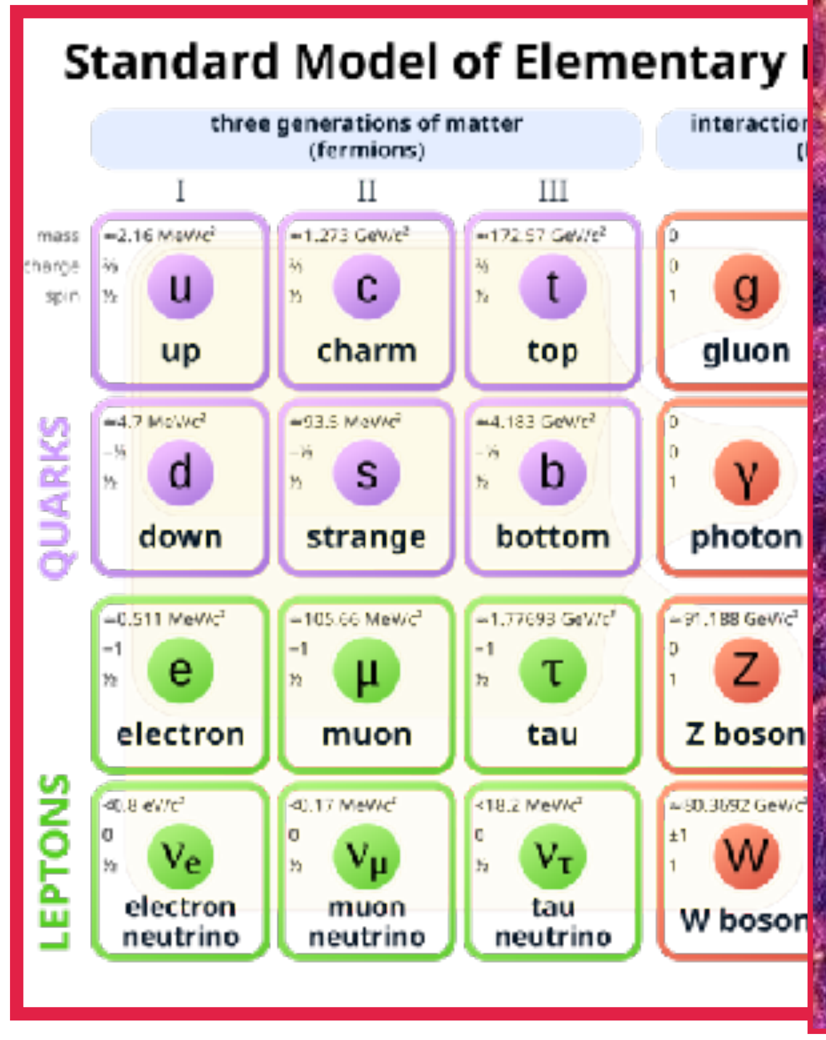
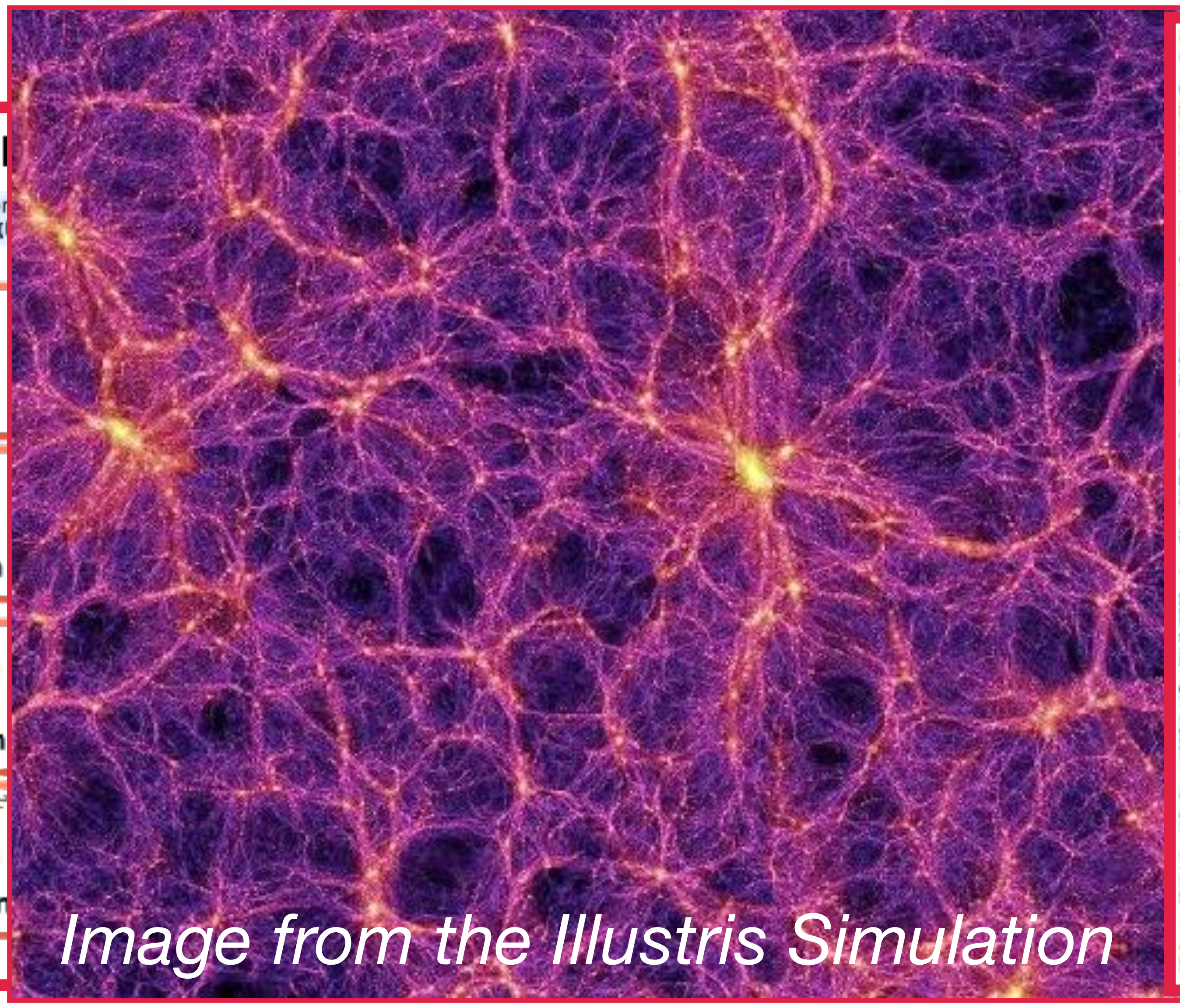
The standard cosmological model: ΛCDM

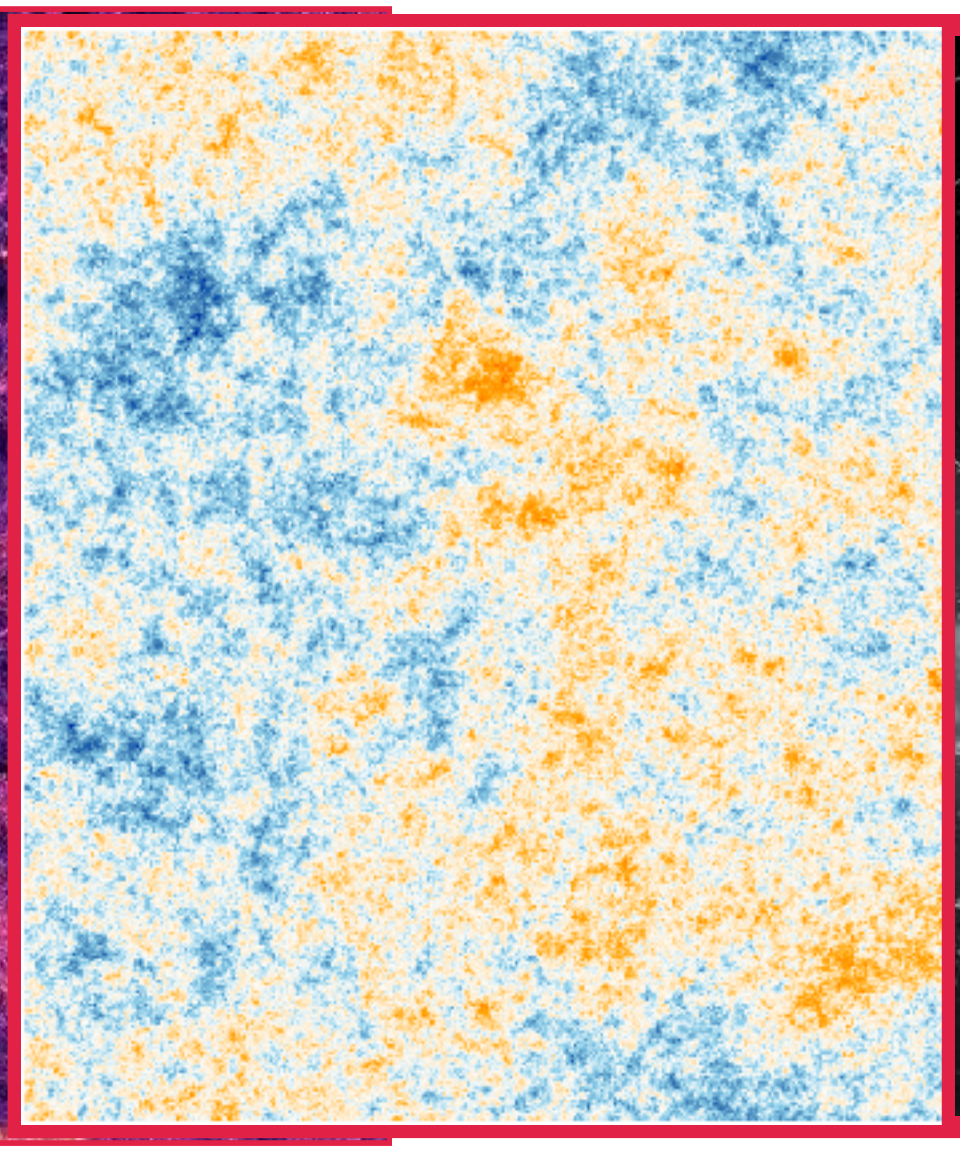
- Framework: Standard Model + Cold Dark Matter (CDM) + cosmological constant Λ + initial conditions for perturbations + gravity



Standard Model



The dark sector:
CDM + Λ



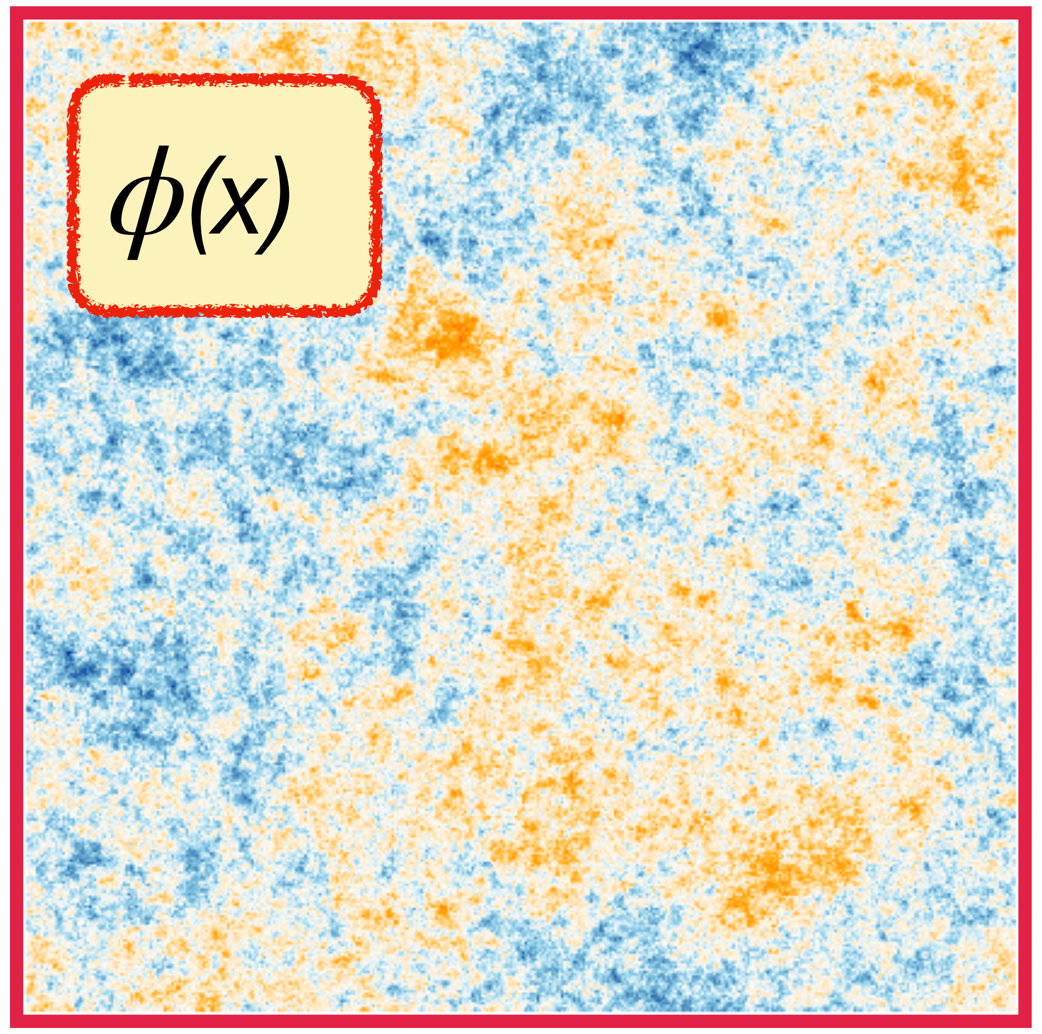
Initial fluctuations

Gravity

Fiona McCarthy, BCCP Seminar, 10th Mar 2026

Open questions: inflation

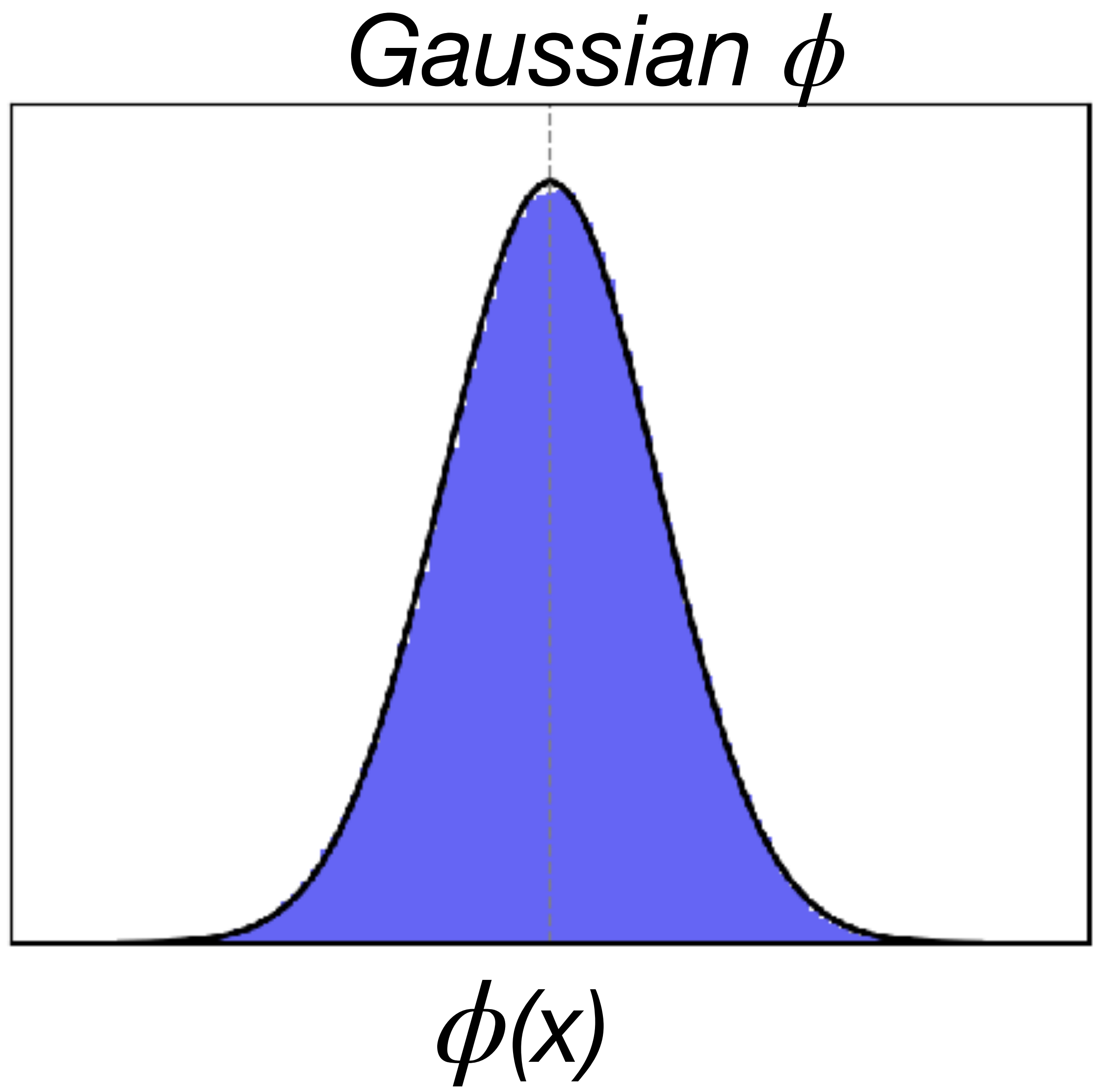
- What caused the initial fluctuations?
  - *What sourced inflation?*
- Probe with **non-Gaussianity** of initial conditions
- **Local** non-Gaussianity

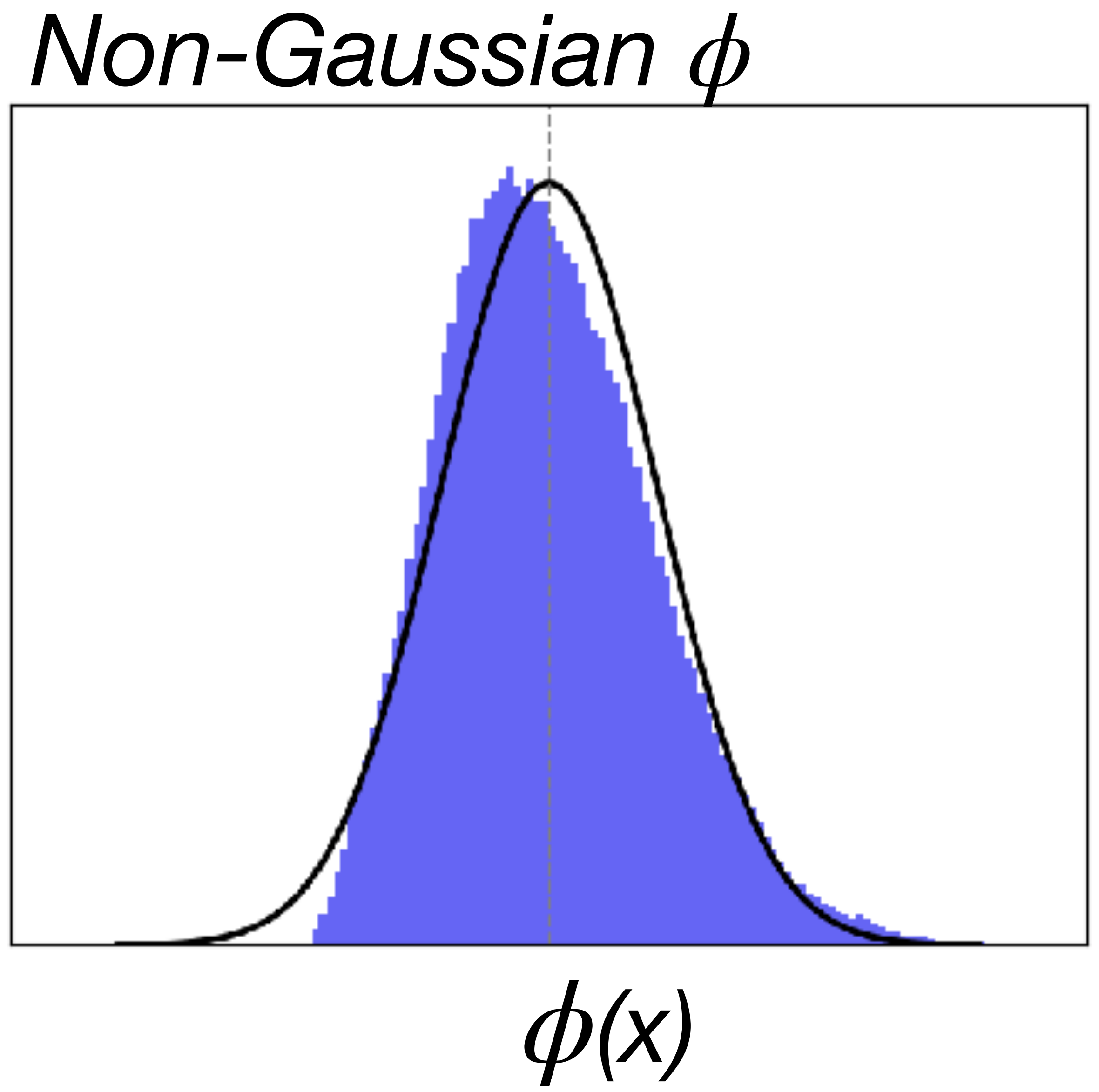


$$\phi = \phi_G + f_{NL}^{\text{loc}} \phi_G^2$$

$f_{NL} \sim 0$: *single field inflation*

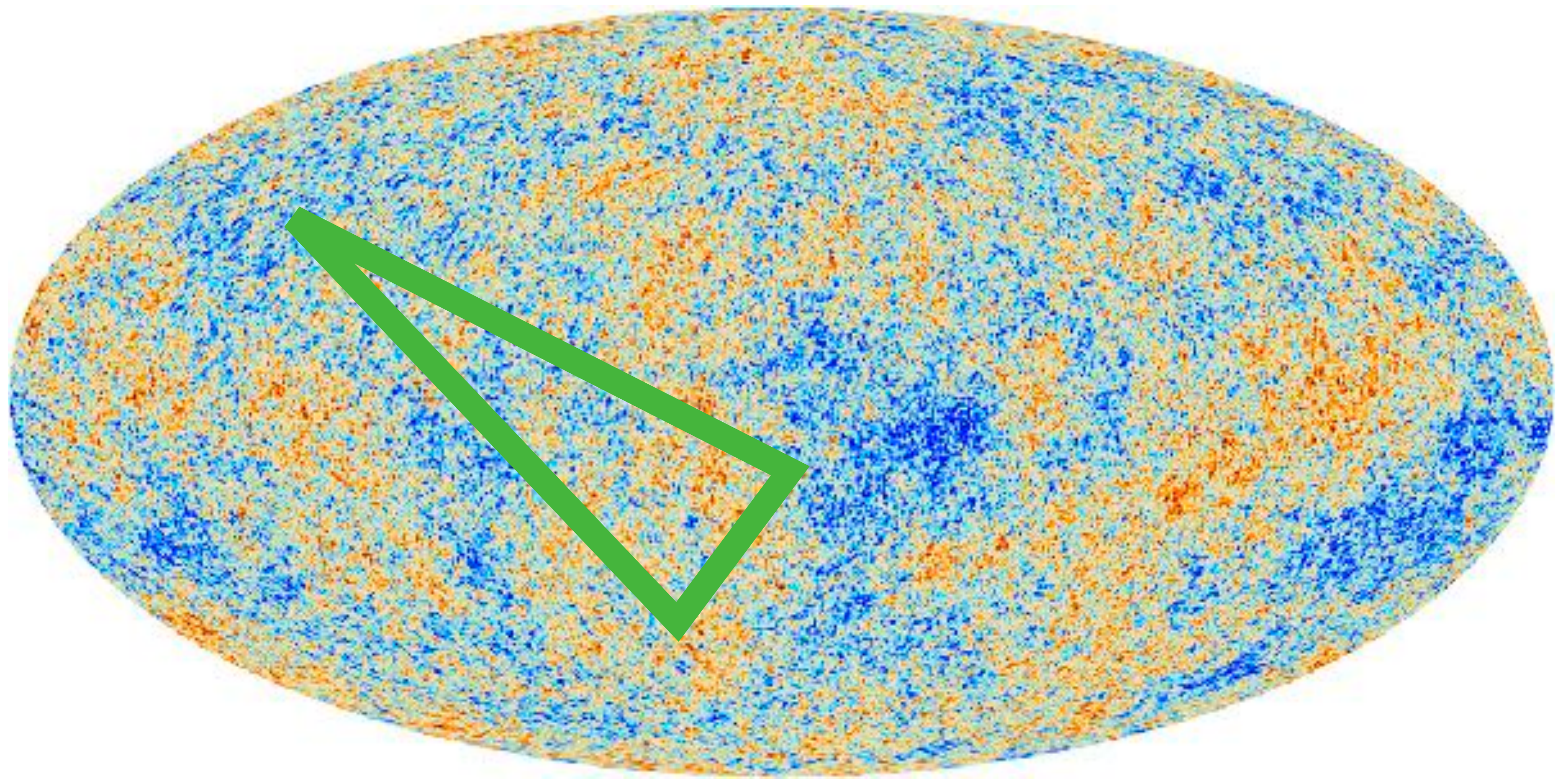
$f_{NL} \sim \mathcal{O}(1)$: *multi field inflation*



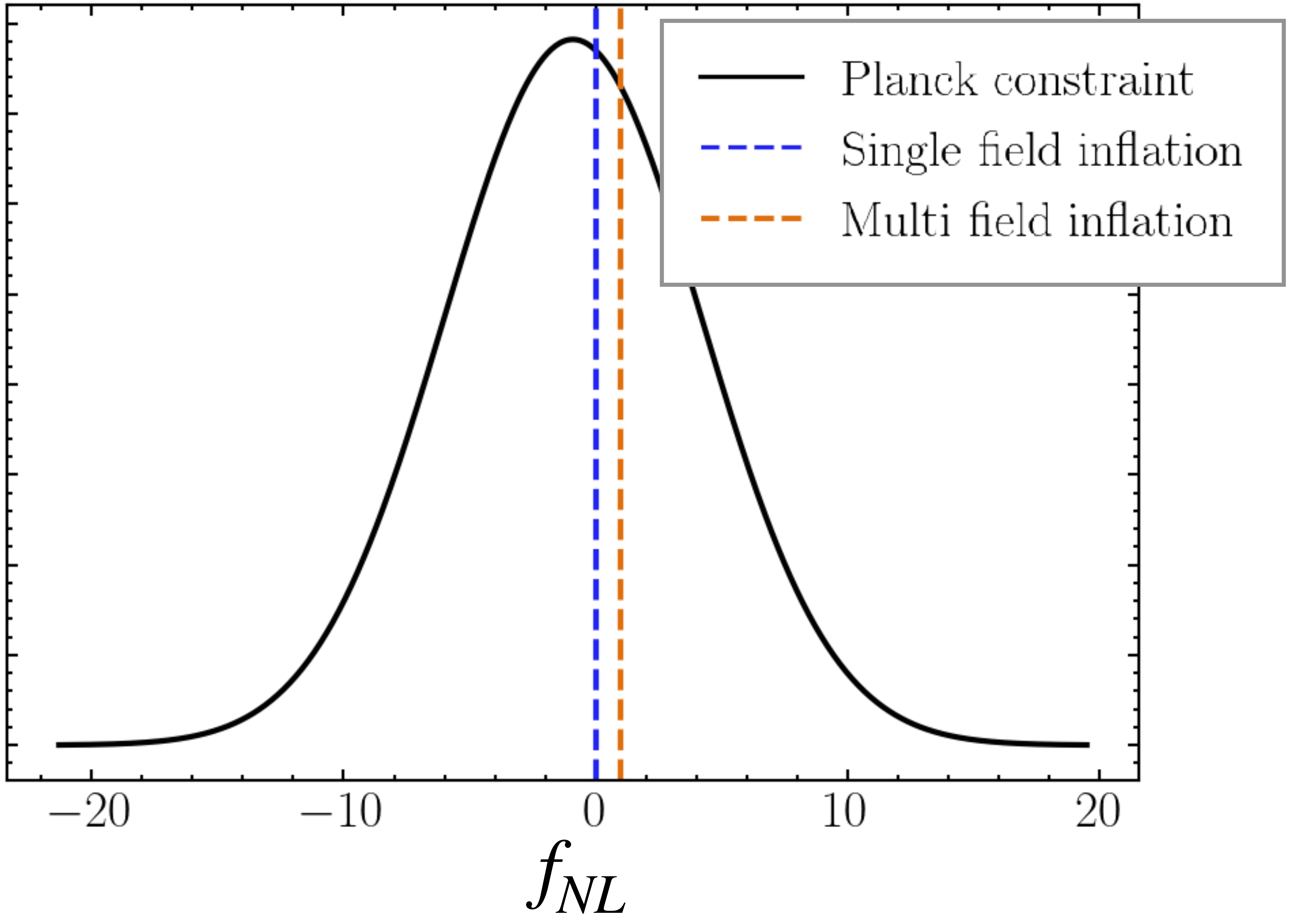


Current constraints

- Current constraints: $f_{NL} = -0.9 \pm 5.1$ (from *Planck* CMB bispectrum)



- There are **not enough modes** in the CMB to get to $\sigma(f_{NL}) < 1$



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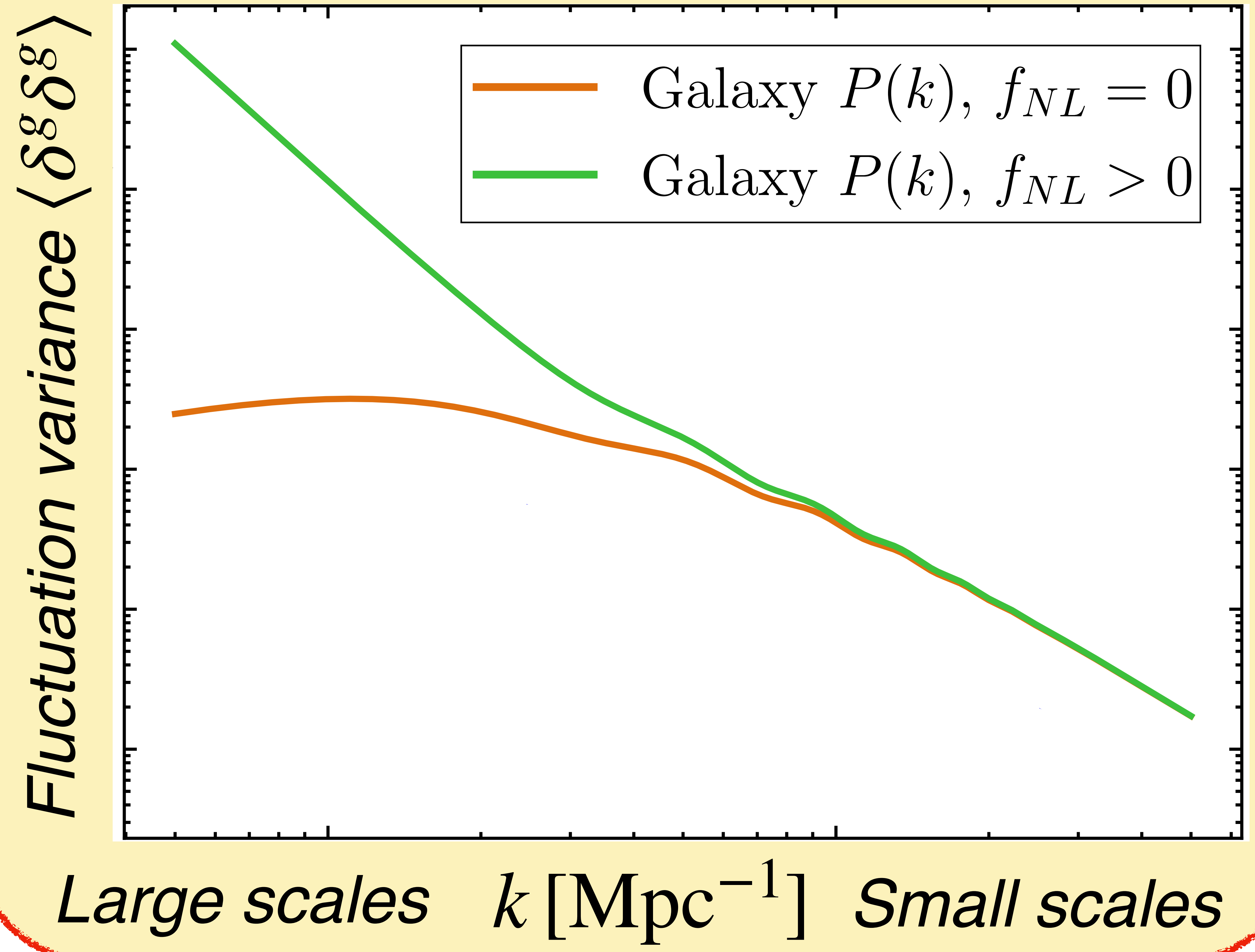
f_{NL} and galaxy clustering

- The best way to constrain f_{NL} is the **large-scale galaxy distribution**

$$\langle \delta^g(k)\delta^g(k)\rangle \equiv P_{gg}(k) = b^2 P_{mm}(k)$$

- In presence of non-zero $f_{\rm NL}$, **galaxies cluster differently on large scales** (Dalal et al 2007)

$$P_{gg}(k) \sim \left(b\left(1+\frac{f_{NL}}{k^2}\right)\right)^2 P_{mm}(k)$$



- Large-scale galaxy surveys are attempting to reach $\sigma(f_{NL}^{\rm loc}) < 1$
- Tightest constraints from DESI: $f_{NL} = -3.6^{+9.0}_{-9.1}$, Chaussidon et al 2025

Large-scale challenges

- Galaxy clustering is sensitive to f_{NL} on large scales

$$b^{NG} \sim b^{G}(1 + \frac{f_{NL}}{k^2})$$

(Dalal et al 2008)

- Clustering is hard to measure on large scales for (at least) two reasons: **cosmic variance** and **additive systematics.**

- Cosmic variance:

$$\sigma(P_{gg}(k)) \propto \frac{P_{gg}(k)}{k} + \frac{1}{k\bar{n}}$$

- Systematics:

$$\hat{P}_{gg}(k) = P_{gg}(k) + P_{NN}(k)$$

- kSZ measurement can help with both.

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Additive systematics are problematic on large scales

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CMB-electron scattering

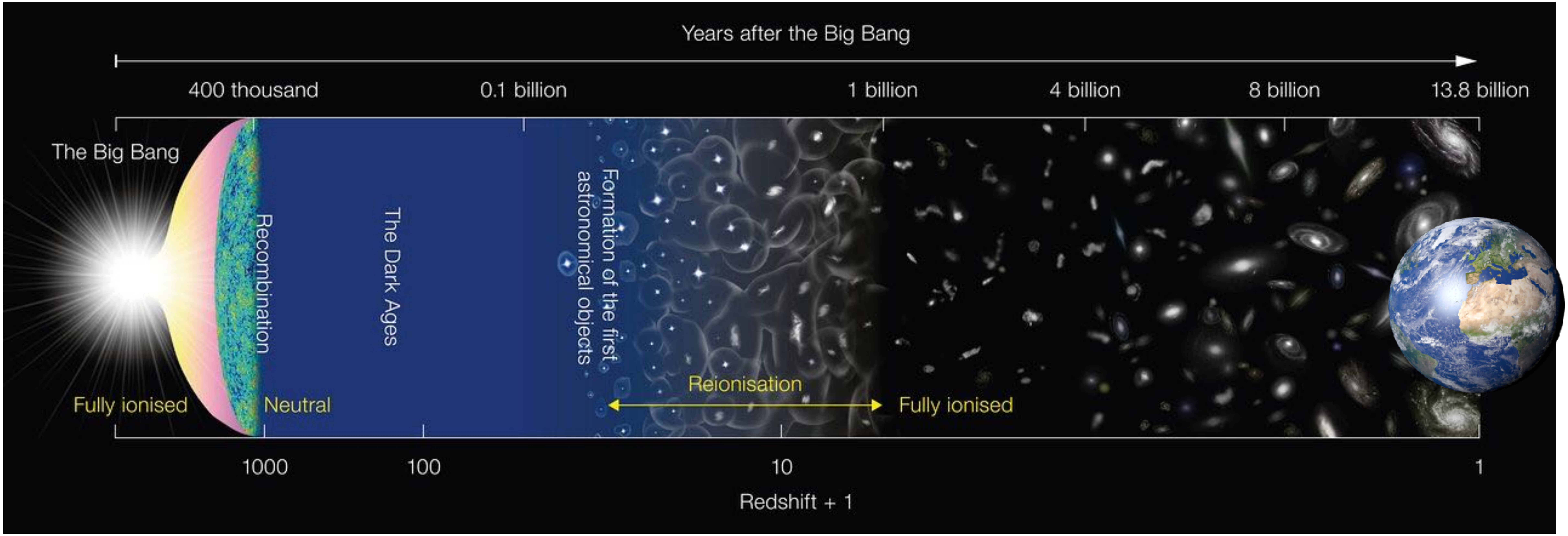
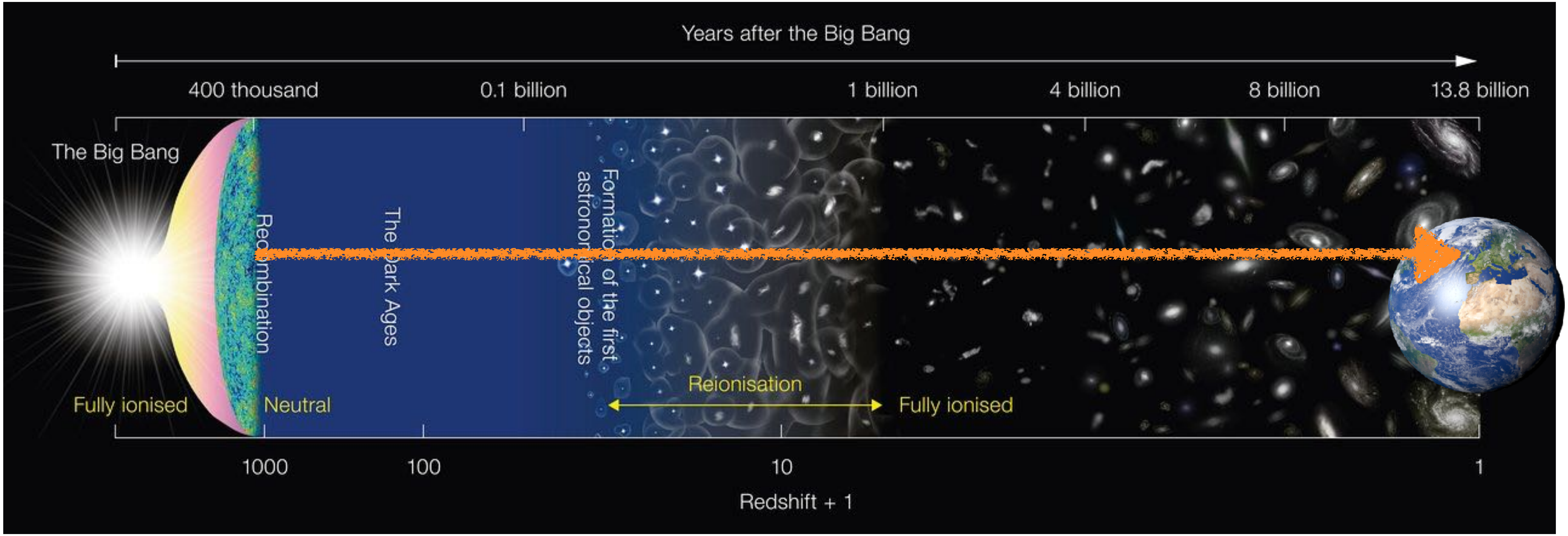


Figure from ESO

CMB-electron scattering



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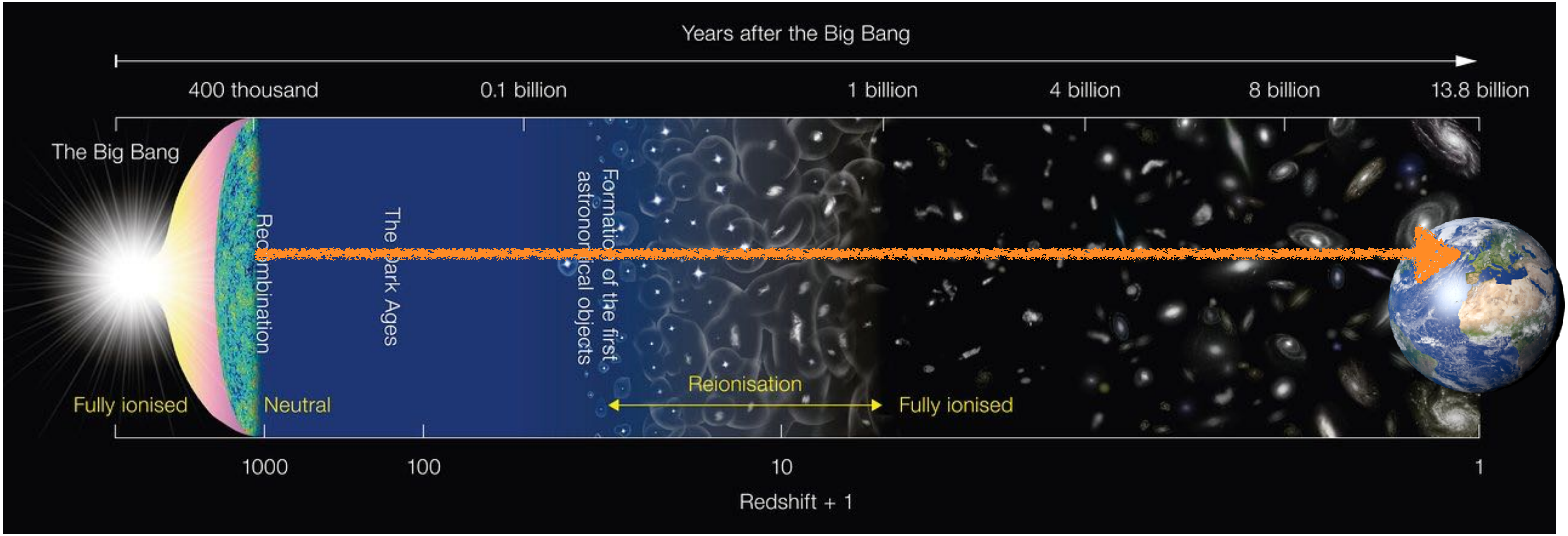
CMB-electron scattering

- At $z \sim 10 - 6$, Hydrogen was ionized



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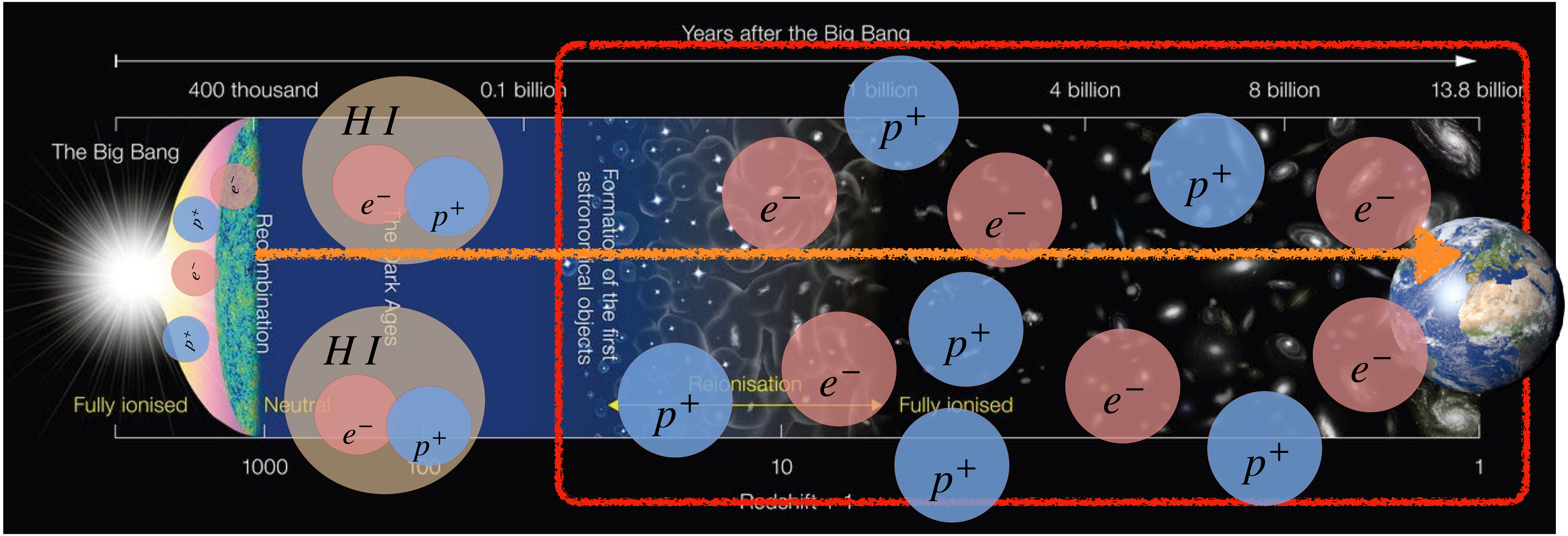


Figure from ESO

CMB-electron scattering

- At $z \sim 10 - 6$, Hydrogen was ionized
  - The CMB photons could scatter again: **Sunyaev—Zel'dovich effect**

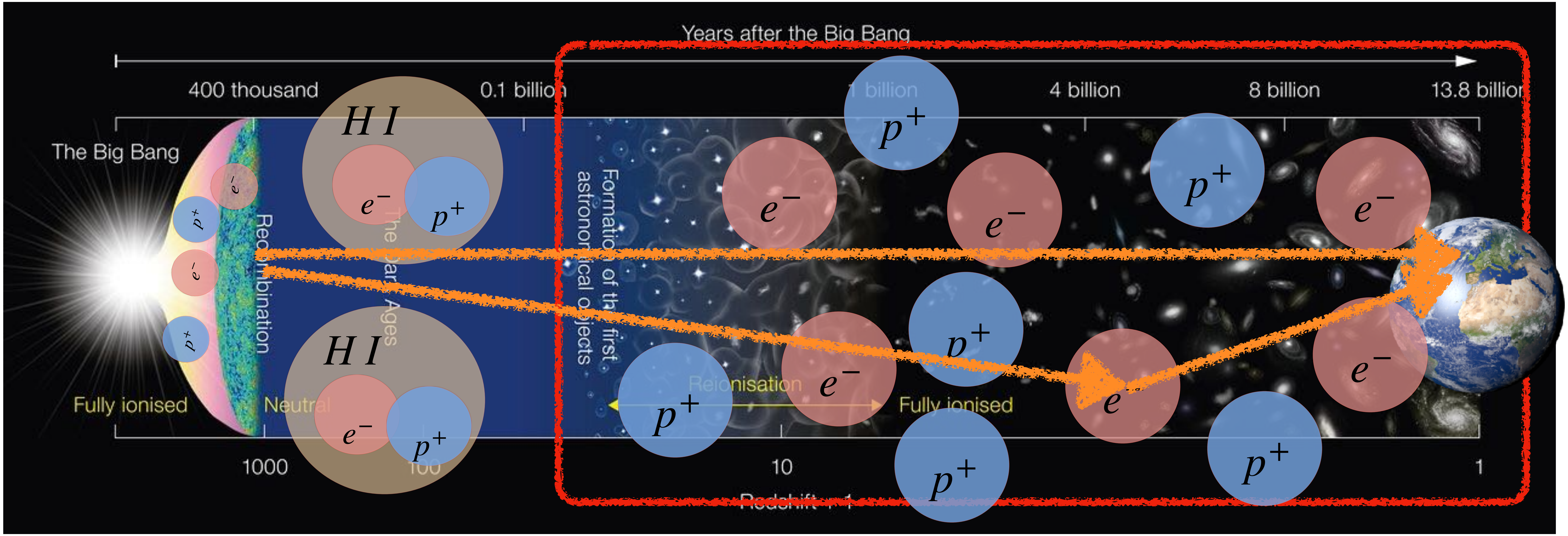
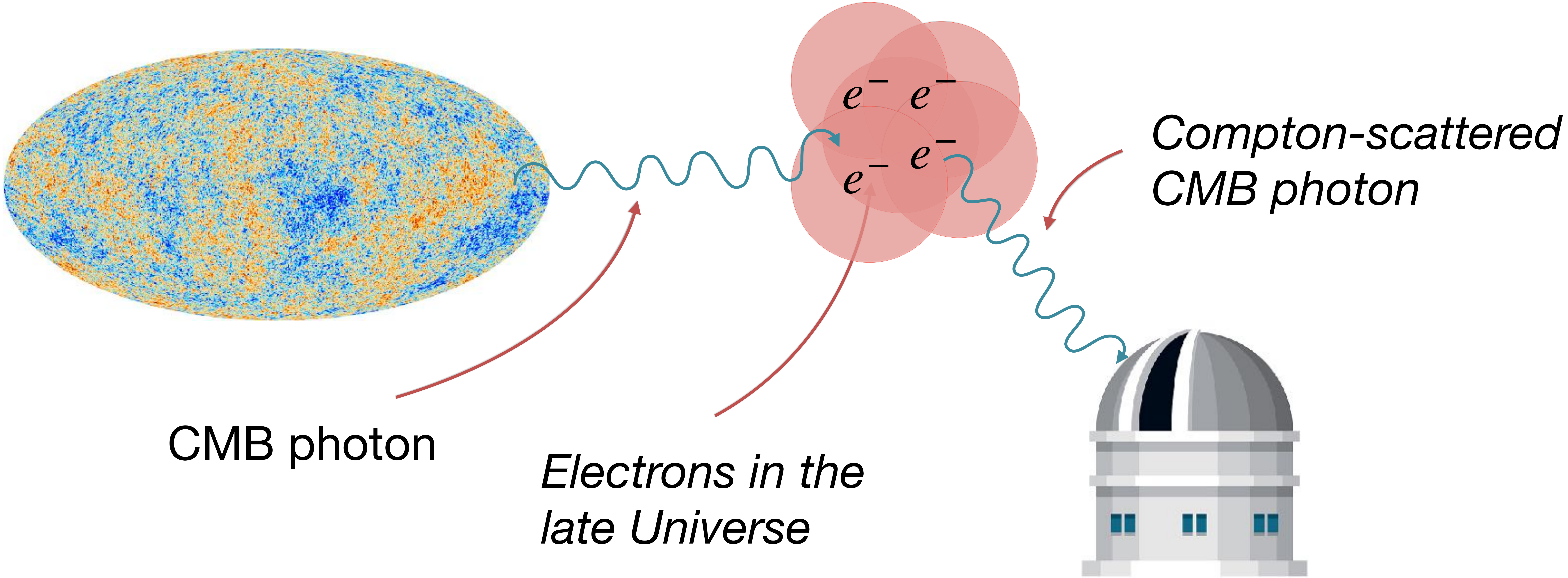


Figure from ESO

The Sunyaev-Zel'dovich (SZ) effect

- We can use the CMB light to "see" late-Universe electrons!



- New probes of electron distribution, thermodynamics, and **bulk motion**

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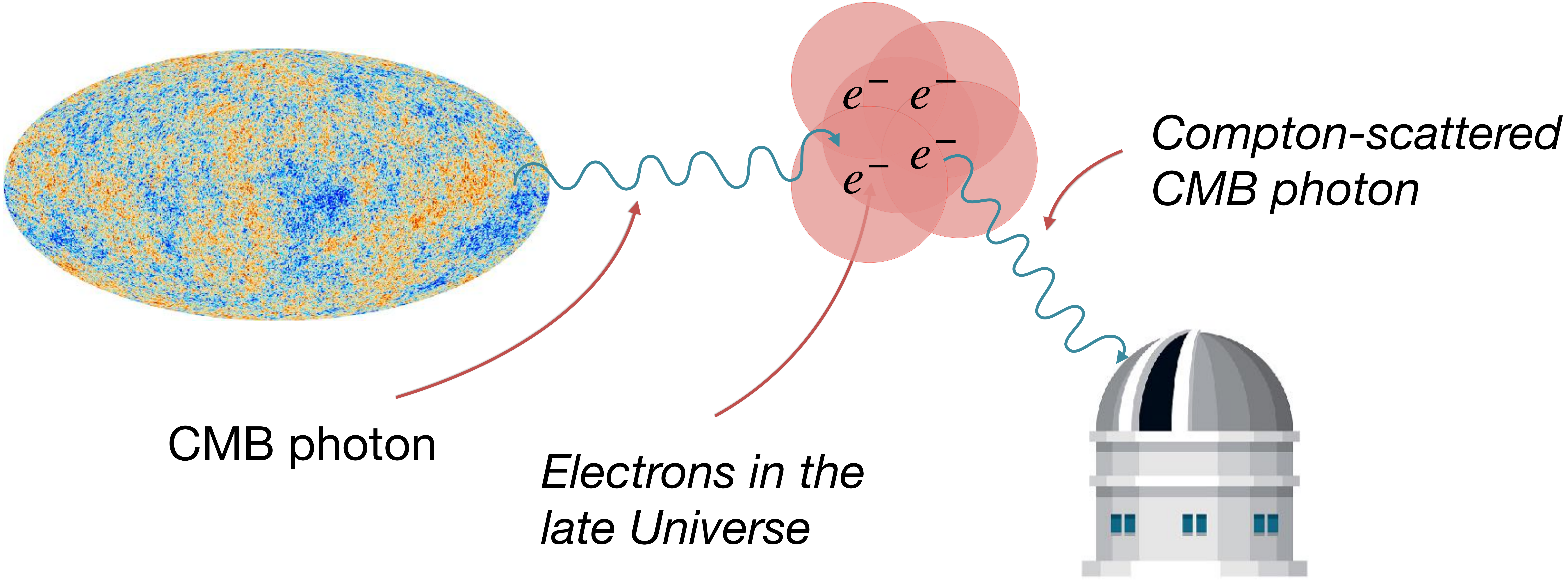

- New probes of electron distribution, thermodynamics, and **bulk motion**

Kinematic SZ (kSZ) effect

- Temperature signal sourced by **velocity** and **electron density**
- New probes of electron distribution, thermodynamics, and **bulk motion**

$$\frac{\Delta T(\hat{n})}{T} = \int d\chi v^{\mathrm{radial}}(\chi, \hat{n}) \frac{\partial \tau}{\partial \chi}(\chi, \hat{n})$$

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$\frac{d\tau}{d\chi}$ = *differential optical depth*

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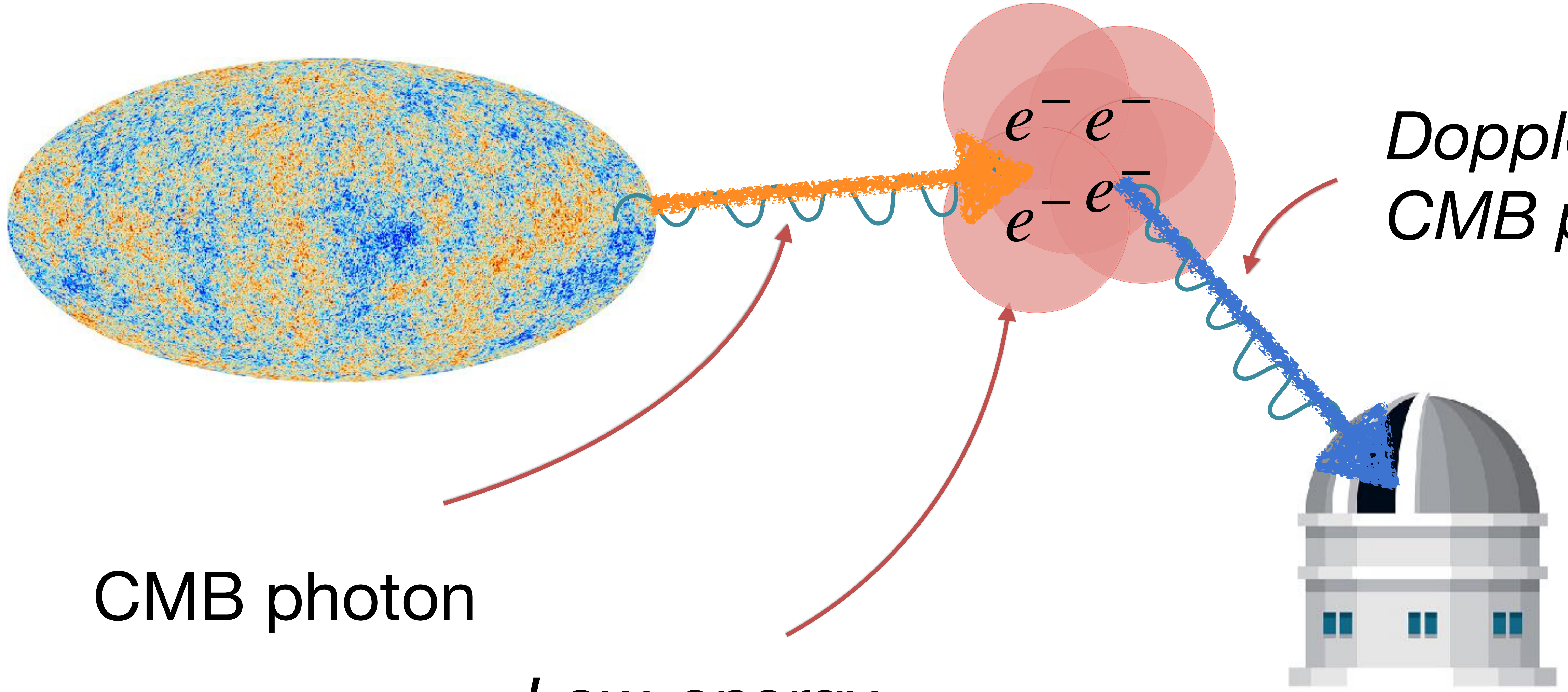
- If we “know” velocity we can probe **small-scale electron distribution** (eg kSZ velocity-weighted stacking)
- If we “know” electron distribution we can probe **large-scale velocity** (eg kSZ tomography)
- Lots of interesting non-Gaussian effects in this signal! Can also probe **reionisation** (see Smith & Ferraro 2017 and Ferraro & Smith 2018)

KSZ and velocity measurements



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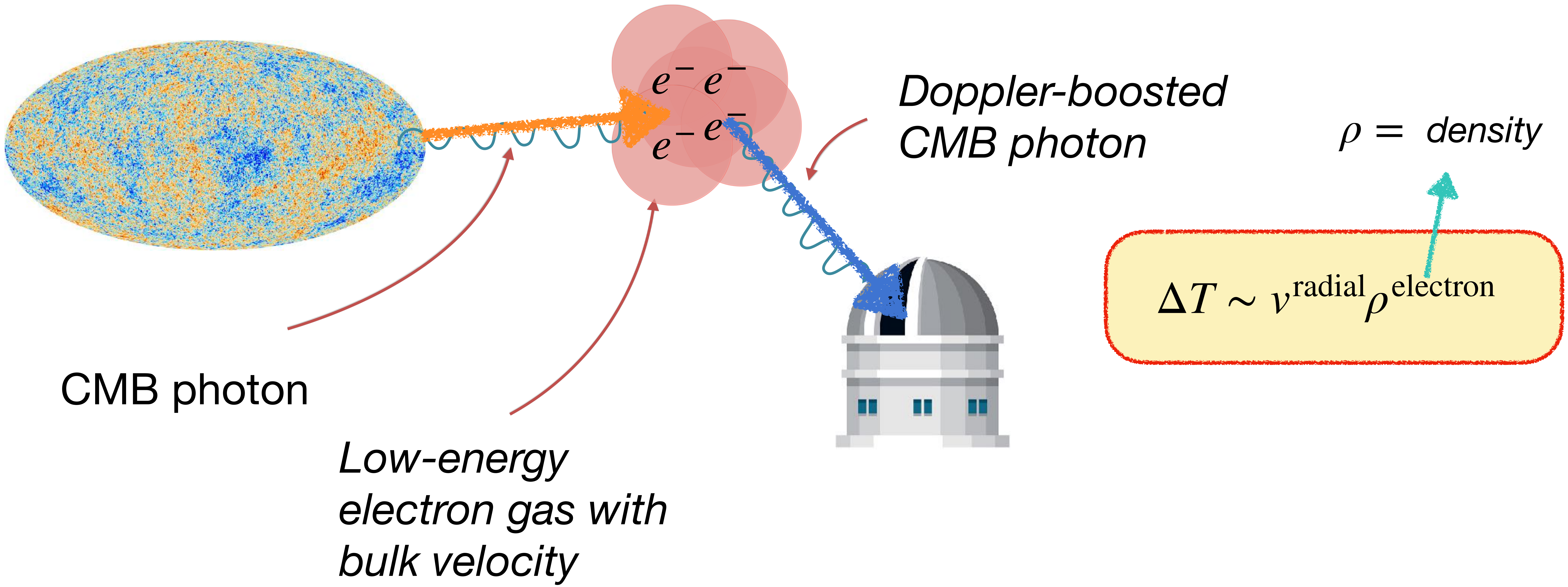

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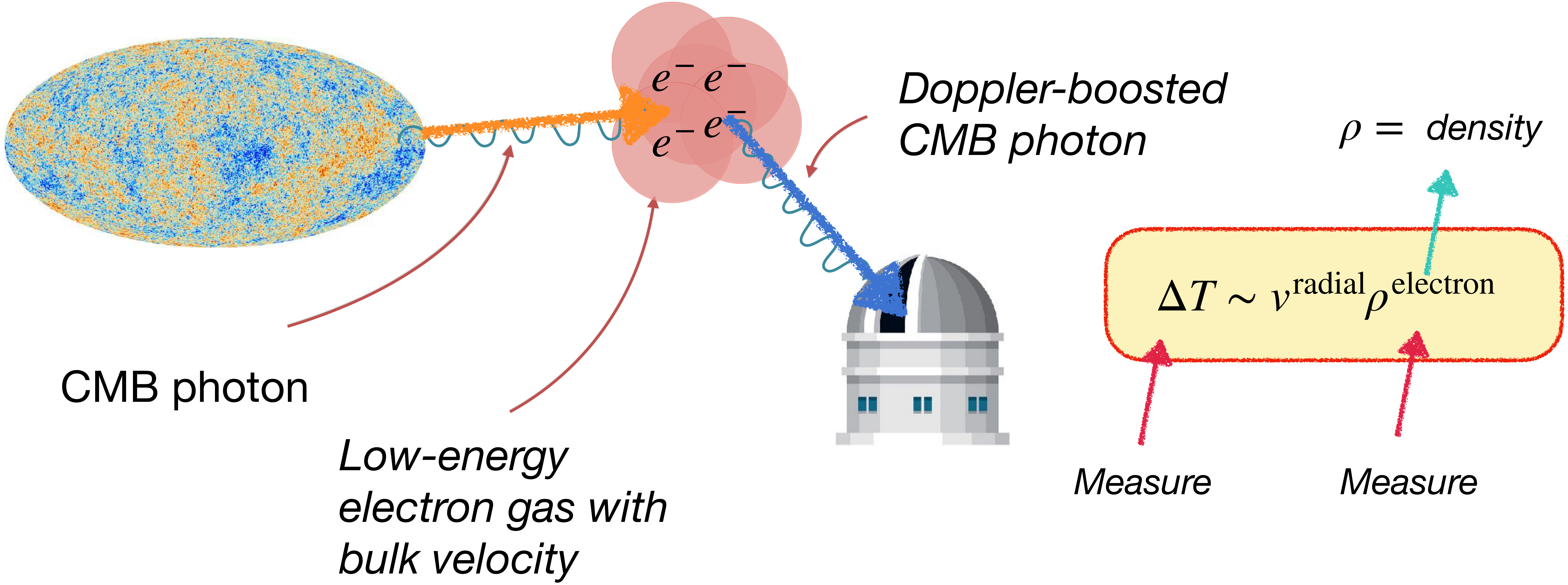

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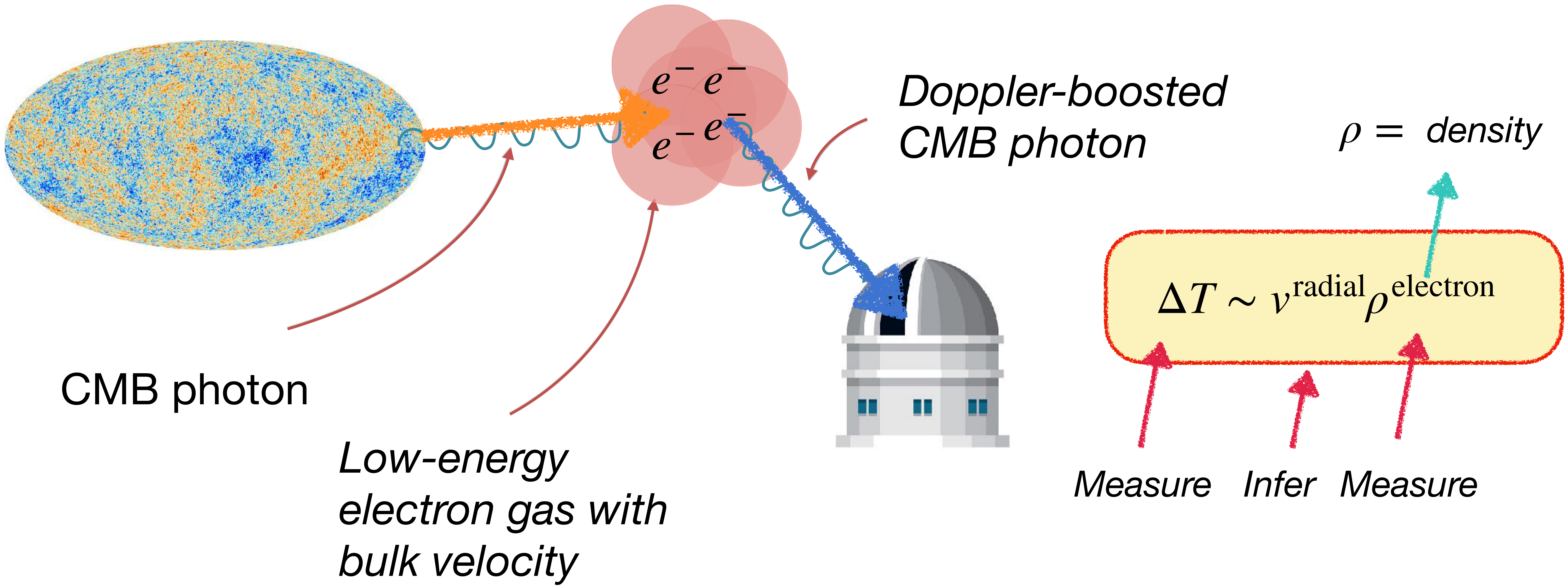

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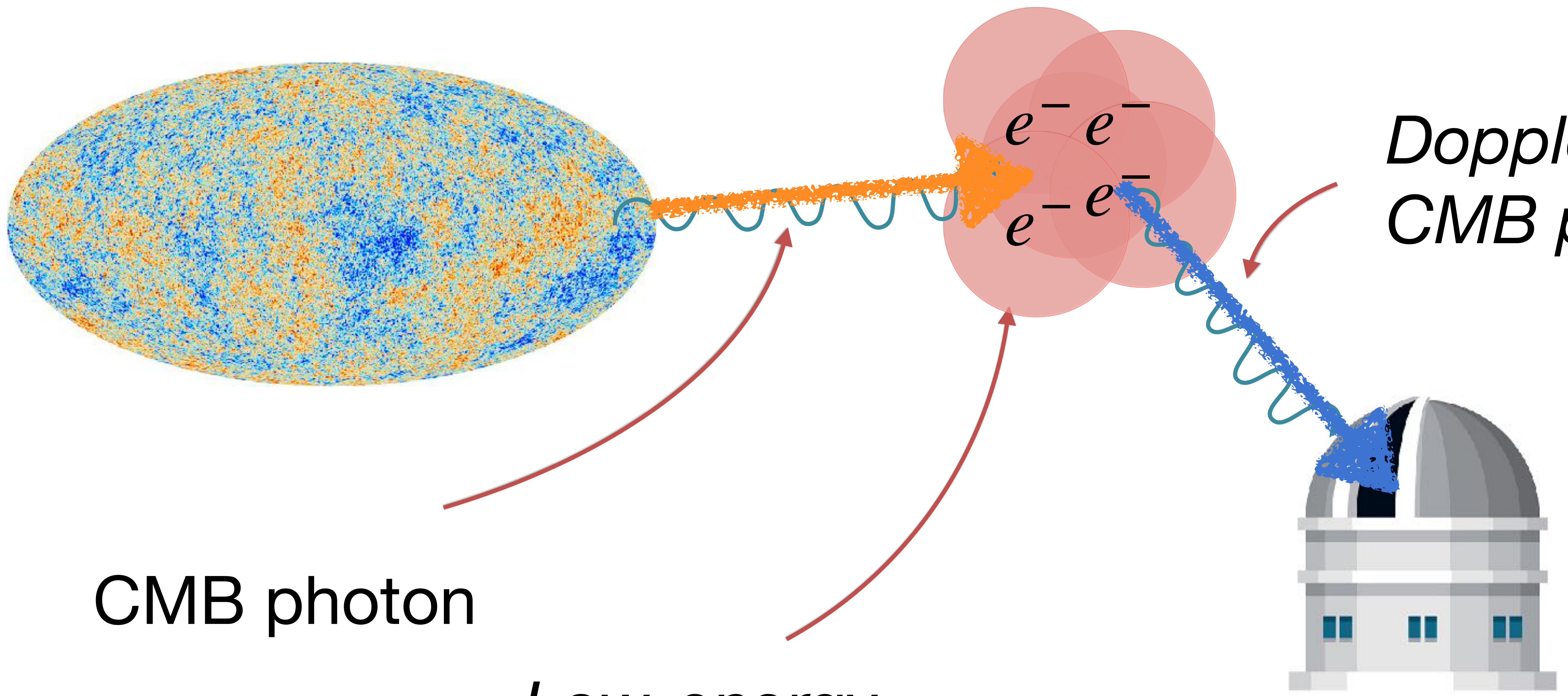

Doppler-boosted CMB photon

CMB photon

Low-energy electron gas with bulk velocity

$\rho =$ *density*

$$\Delta T \sim v^{\text{radial}} \rho^{\text{electron}}$$

Measure *Infer* *Measure*

*Complication! Electrons are hard to measure so measure **galaxies** instead*

- See *Deutsch et al 2017; Smith et al 2018; Cayuso et al (incl FMcC) 2023; Conteras, FMcC, Johnson 2023; Kvasiuk and Munchmeyer 2023*

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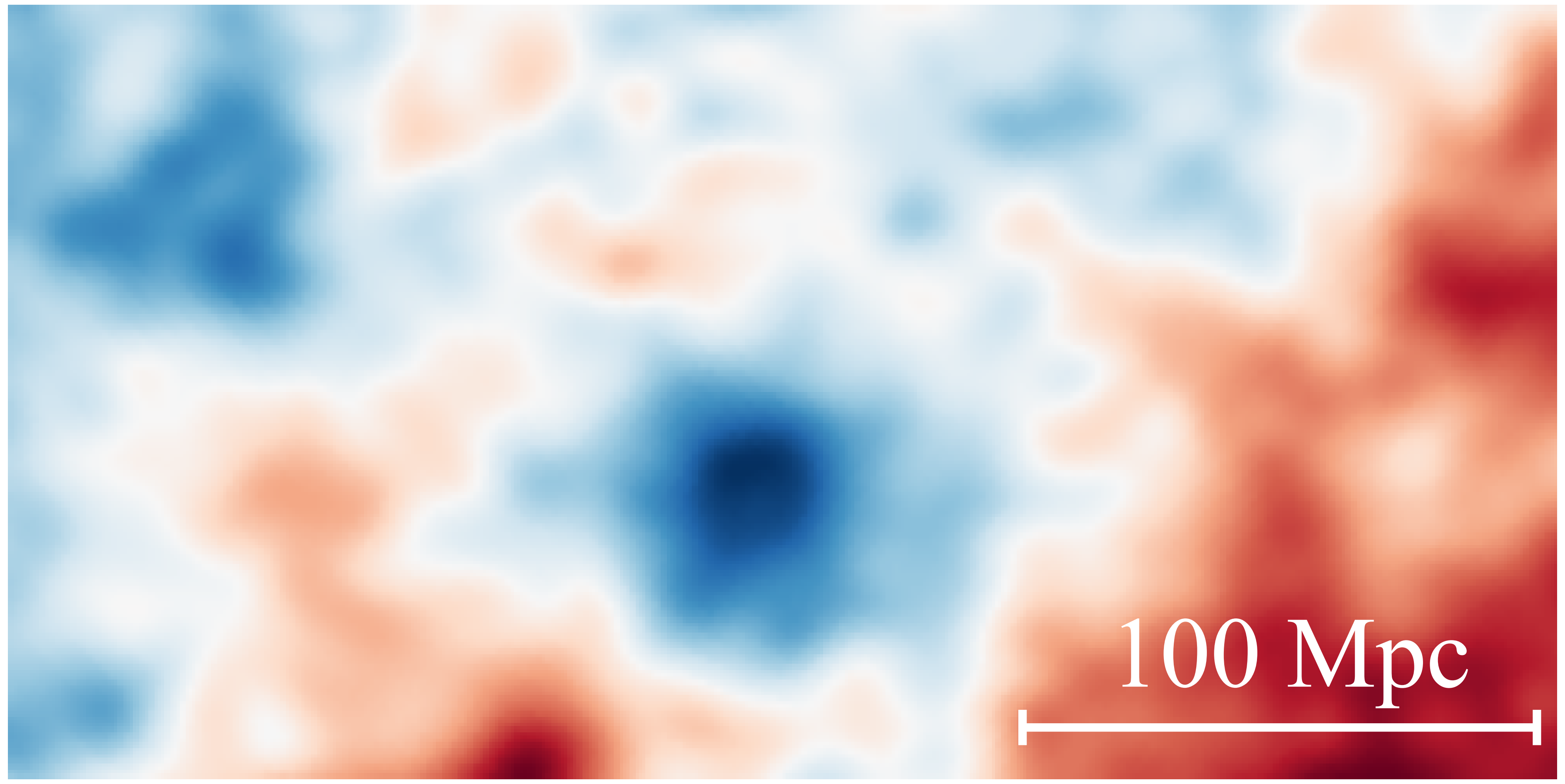
kSZ Velocity Reconstruction

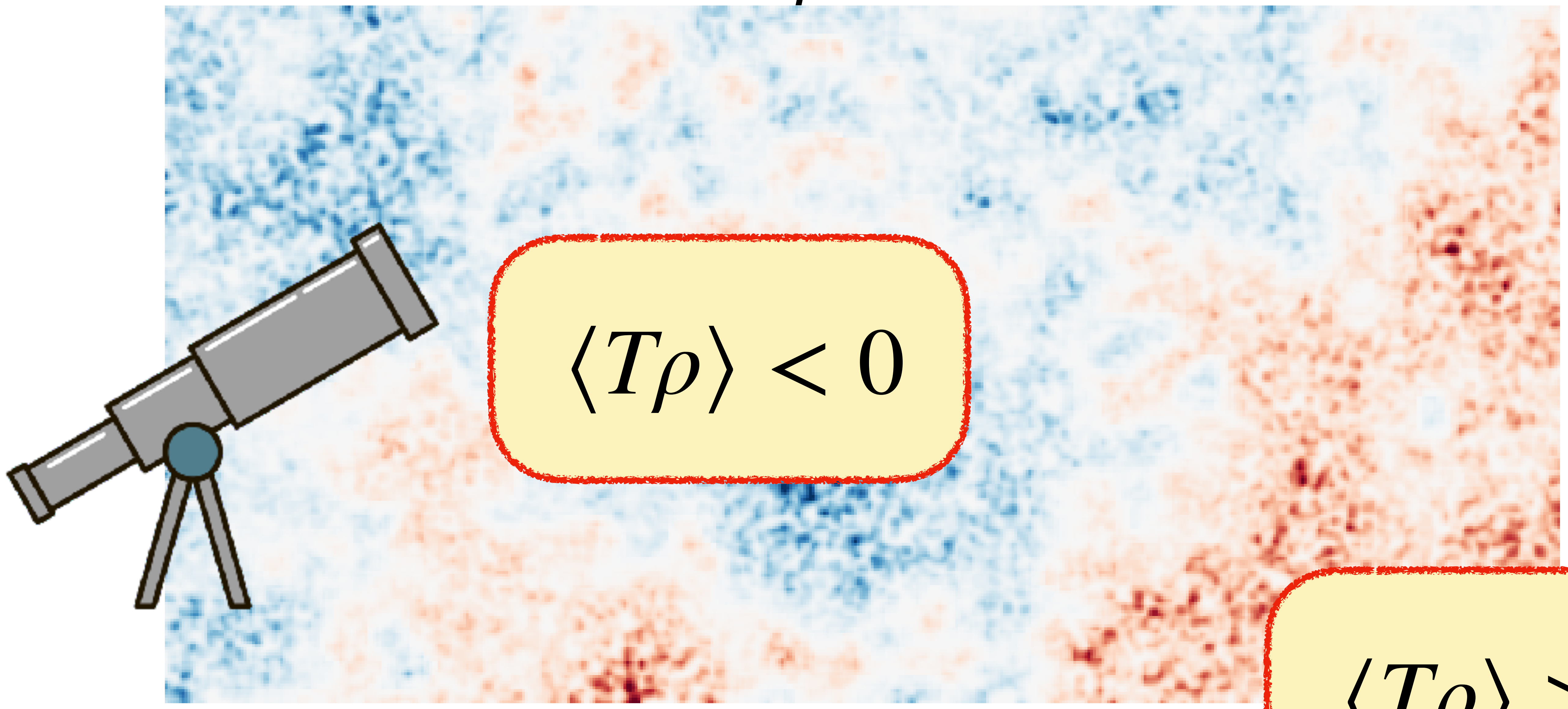
Cosmological radial velocity field v



$T \sim v \times \rho$

$v \sim \frac{T}{\rho}$

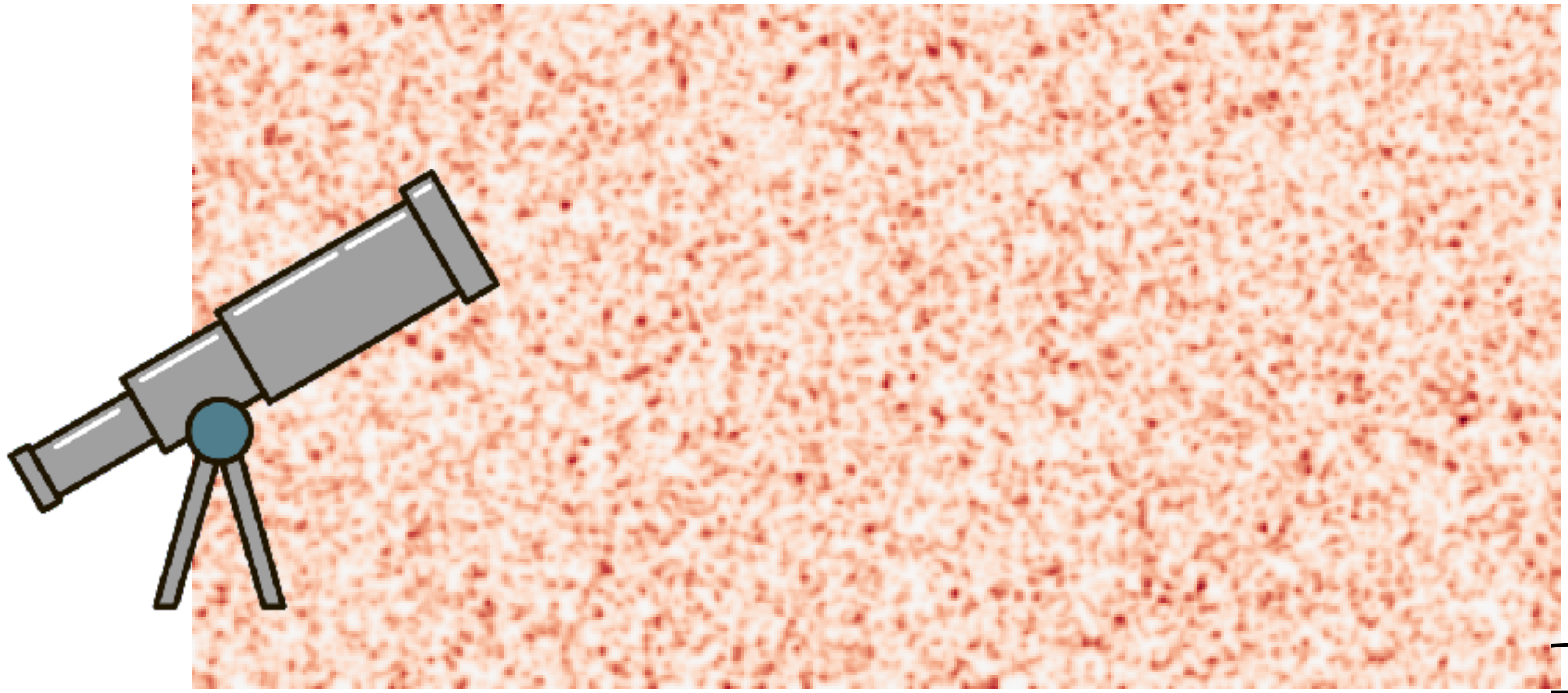
kSZ temperature T



$\langle T\rho \rangle < 0$

$\langle T\rho \rangle > 0$

Electron / galaxy distribution ρ



1 Mpc

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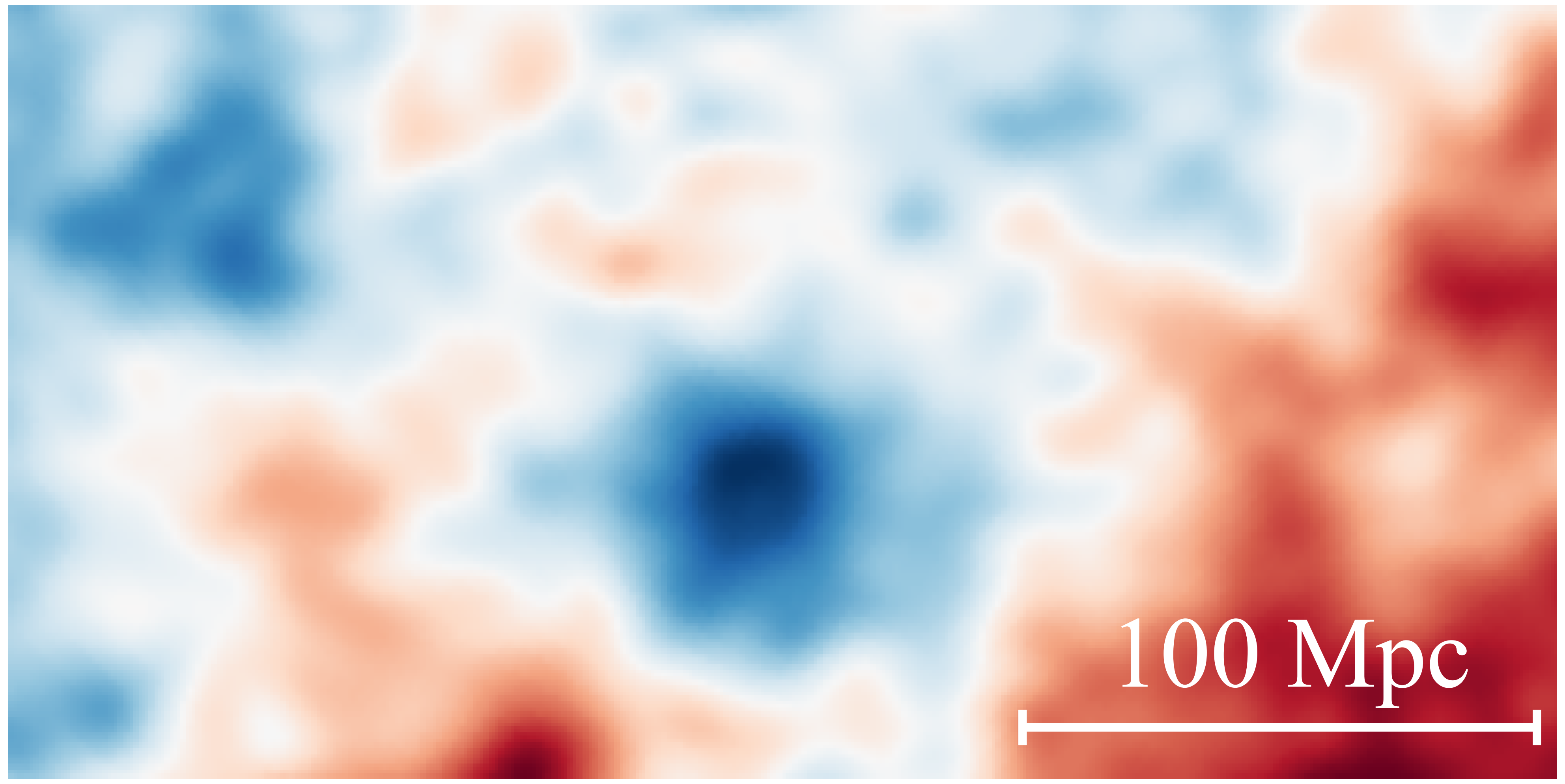

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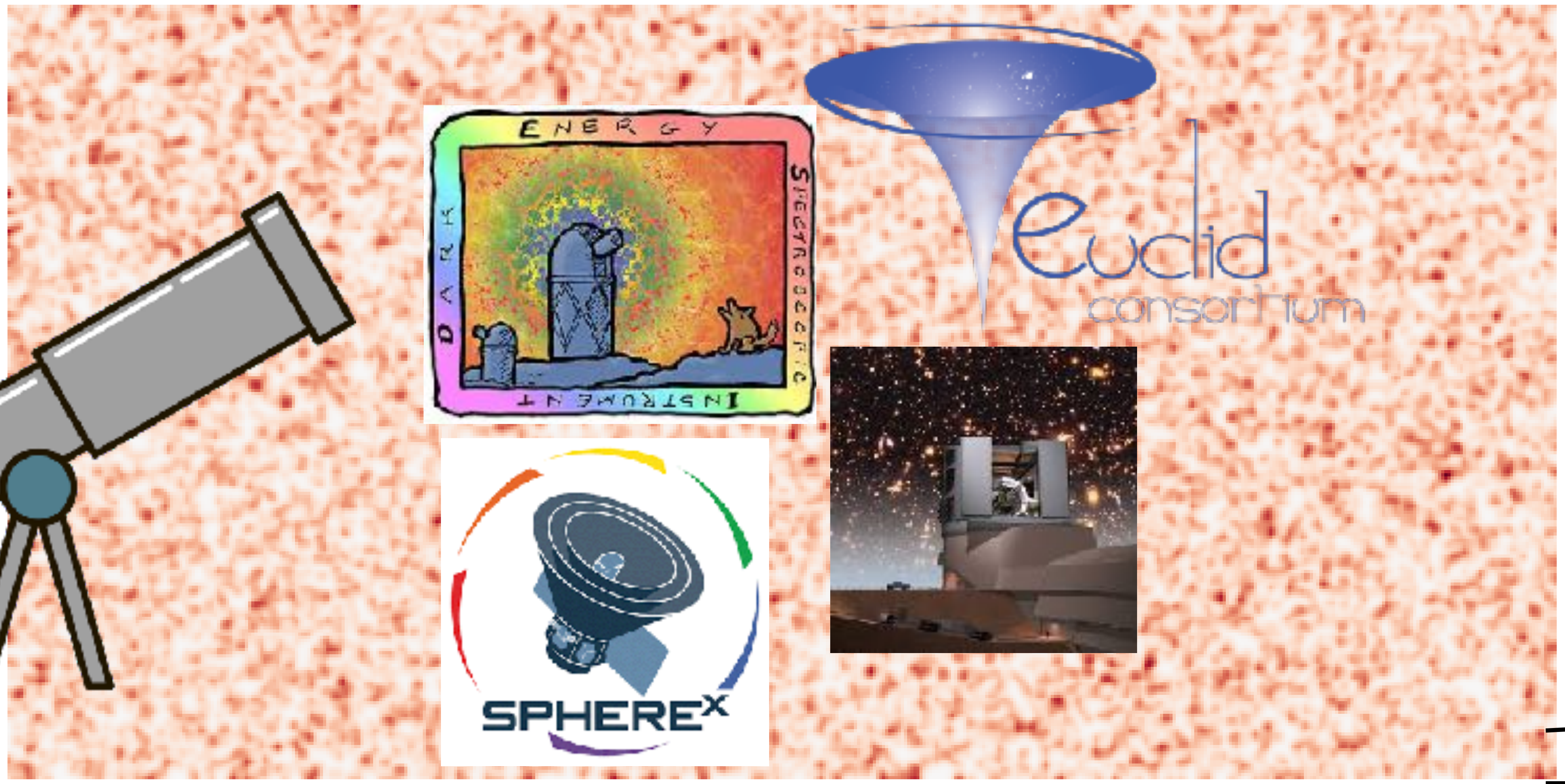

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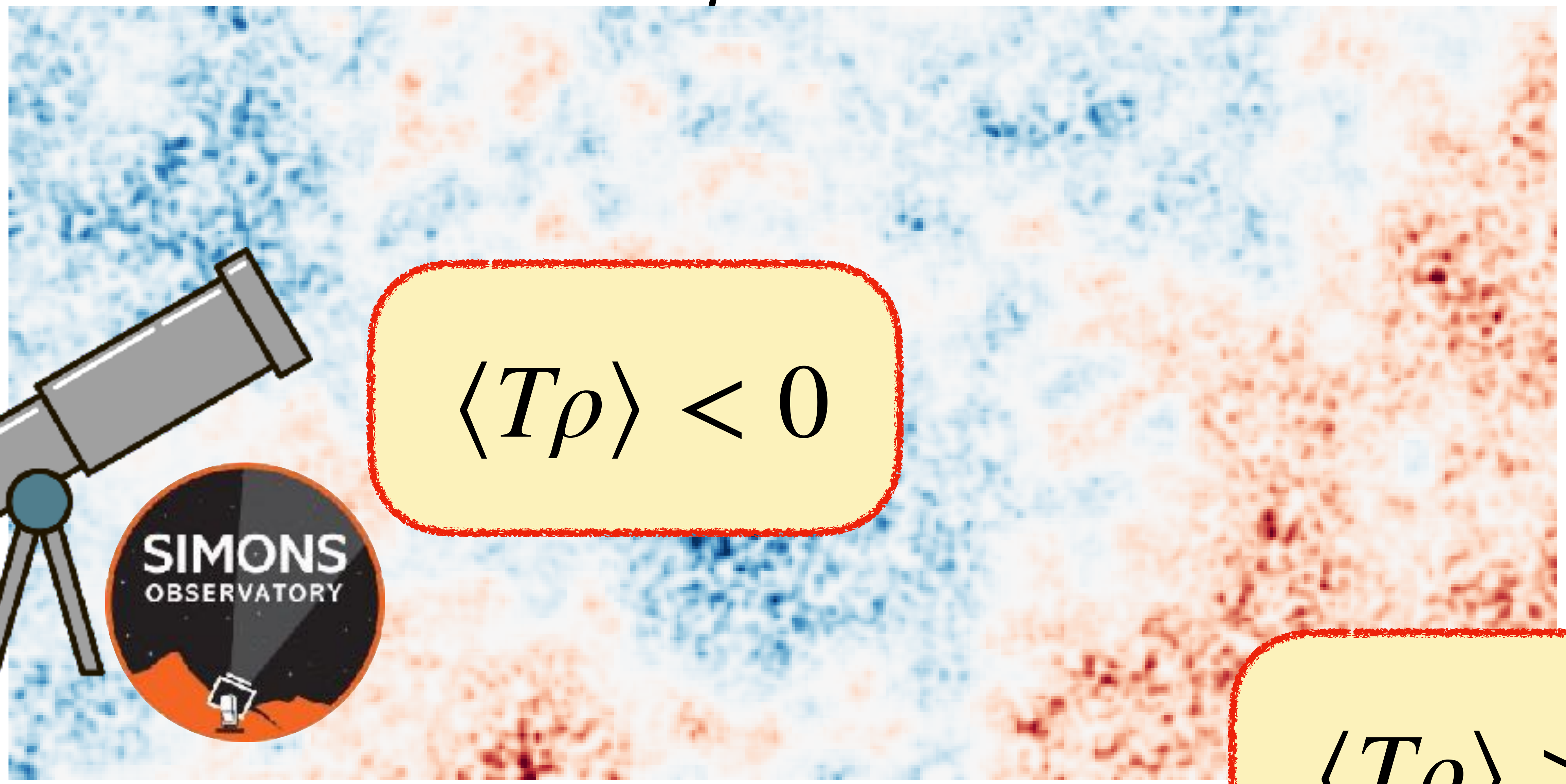


$\langle T\rho \rangle < 0$

$\langle T\rho \rangle > 0$

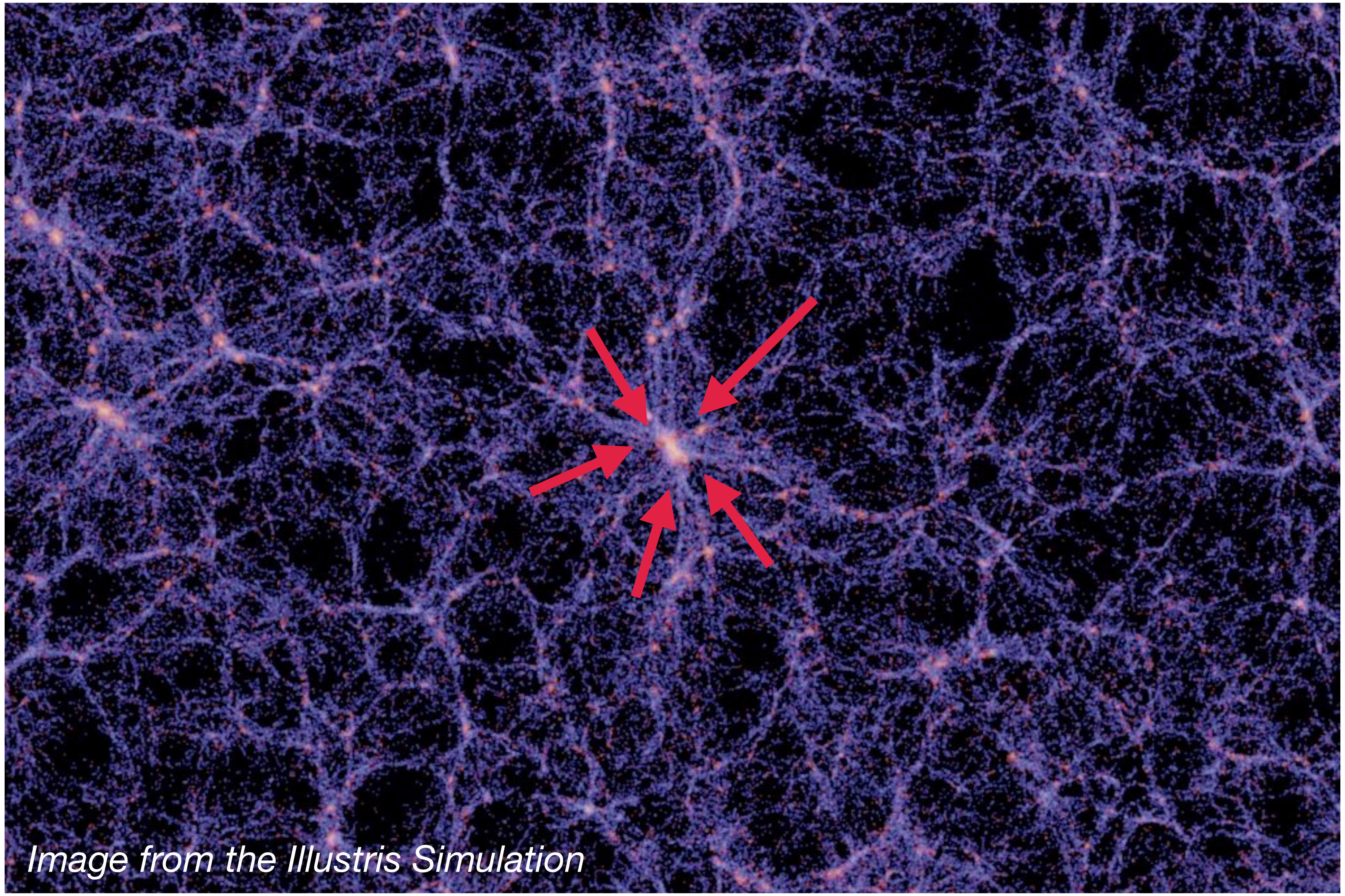
1 Mpc

First kSZ velocity measurements with ACT+DESILS

FMcC et al 2025a (JCAP)

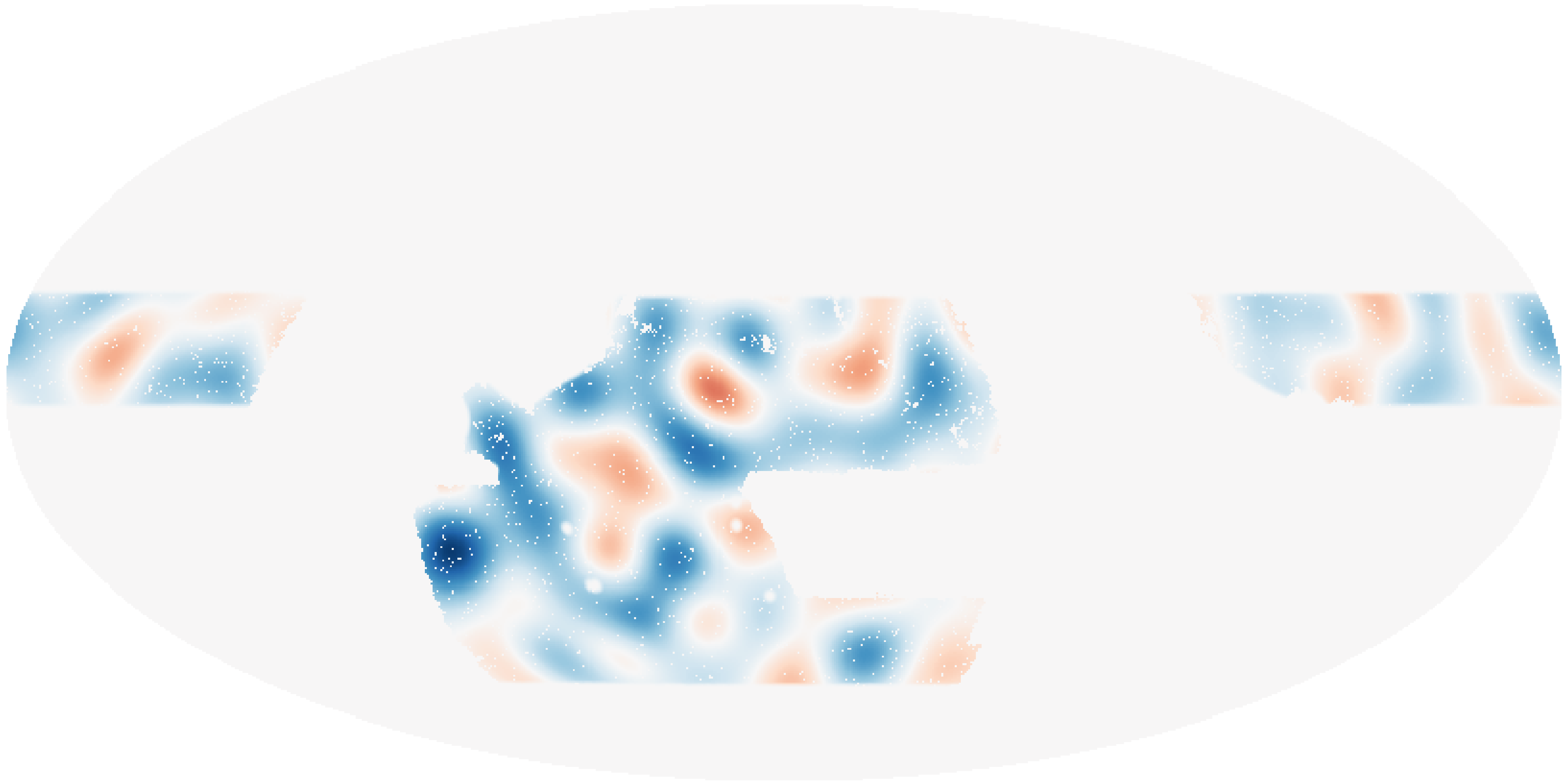
A new large scale probe: **peculiar velocity**

- Velocity tells us about large scale cosmology similar to large scale galaxy surveys!
- New velocity probe is **independent** of previous large scale measurements
- With galaxy surveys, large scales are hard - kSZ velocity **cleaner**

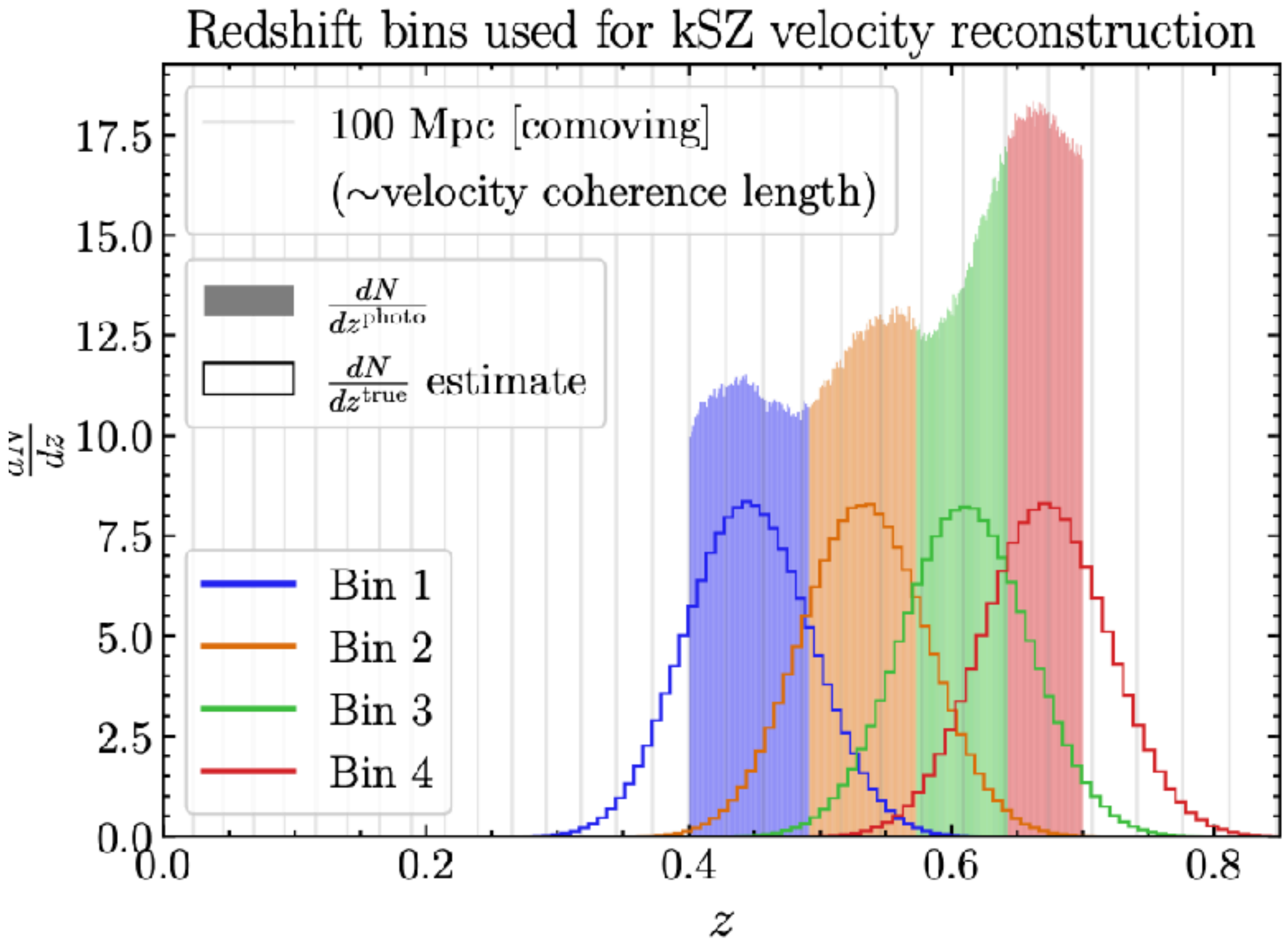


2-Dimensional angular clustering

$z \sim 0.45$
$\alpha = 1$



$$v(\vec{\theta}) = \int dz \frac{dN^\alpha}{dz} v(z, \vec{\theta})$$

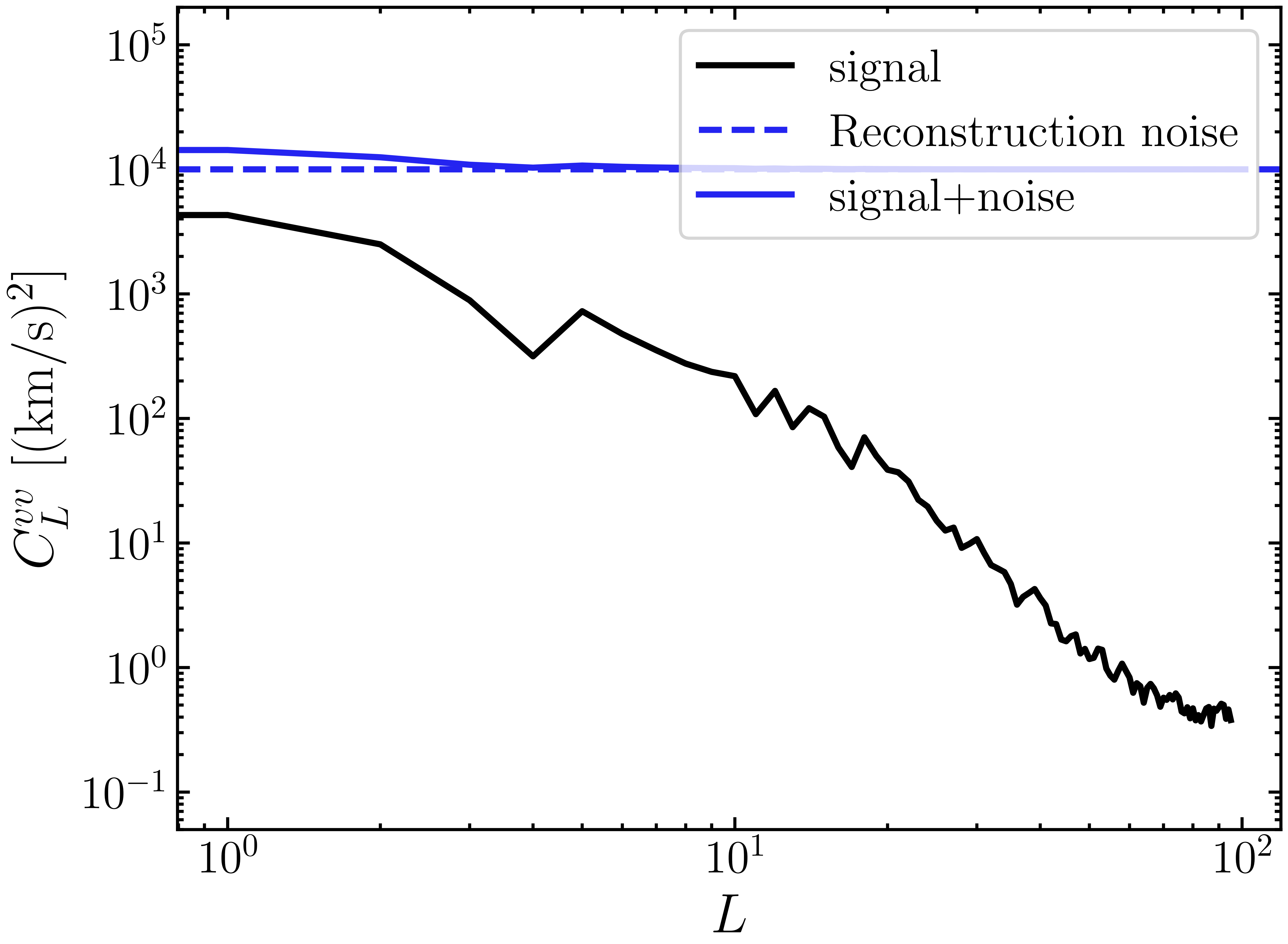


- Angular power spectrum $C_L^{v^\alpha v^\beta}$ quantifies fluctuation variance over angles $L \sim \frac{\pi}{\theta}$

Large-scale v from small-scale g, T

- Large-scale statistical power comes from **better measurement of small scales**

Reconstruction noise from chance correlations in a Gaussian signal



~Planck + unWISE

(See Bloch + Johnson arXiv:2405.00809)

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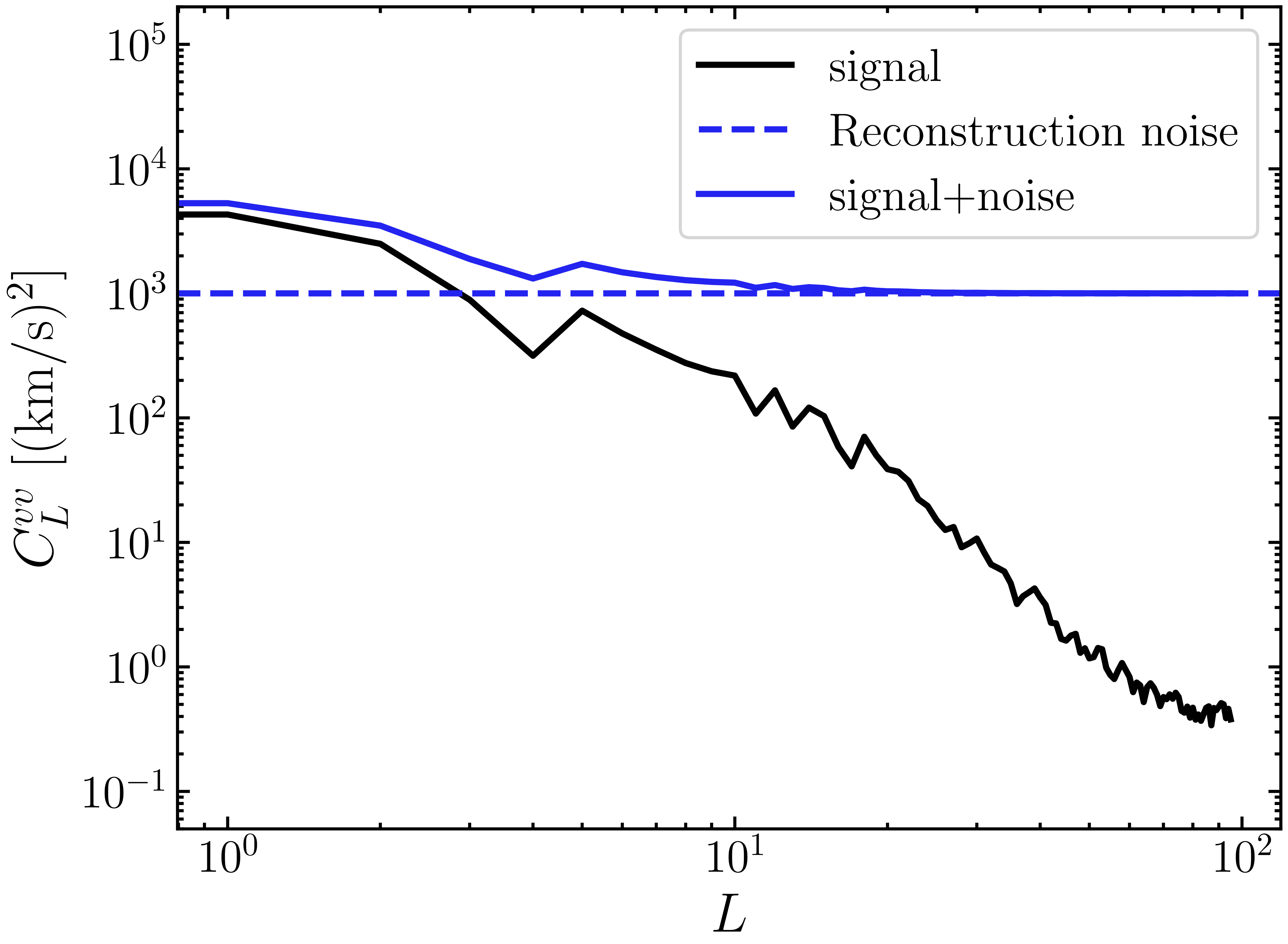

~ACT + DESILS

(See FMcC et al 2025 a+b; Lai et al 2025)

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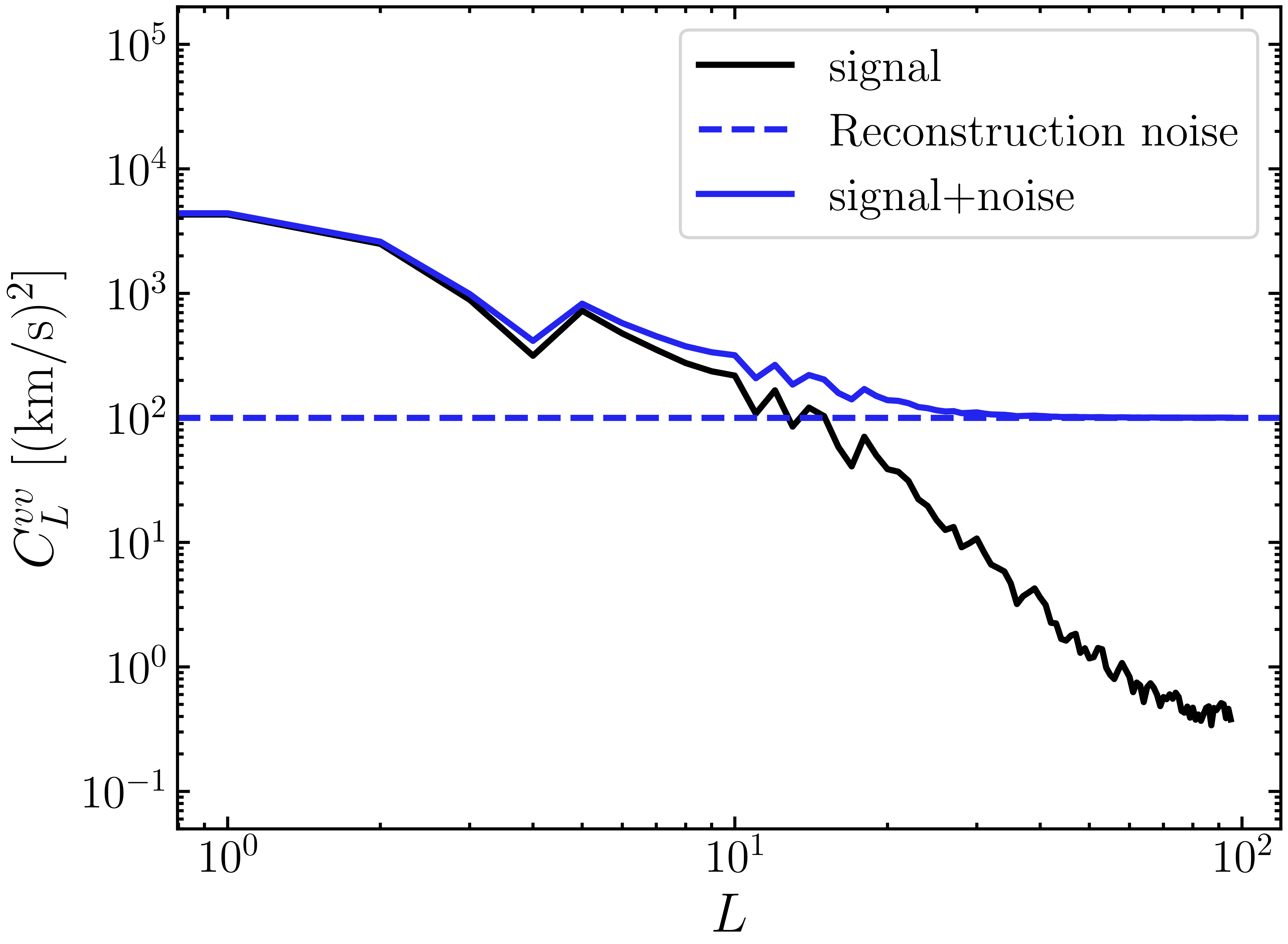
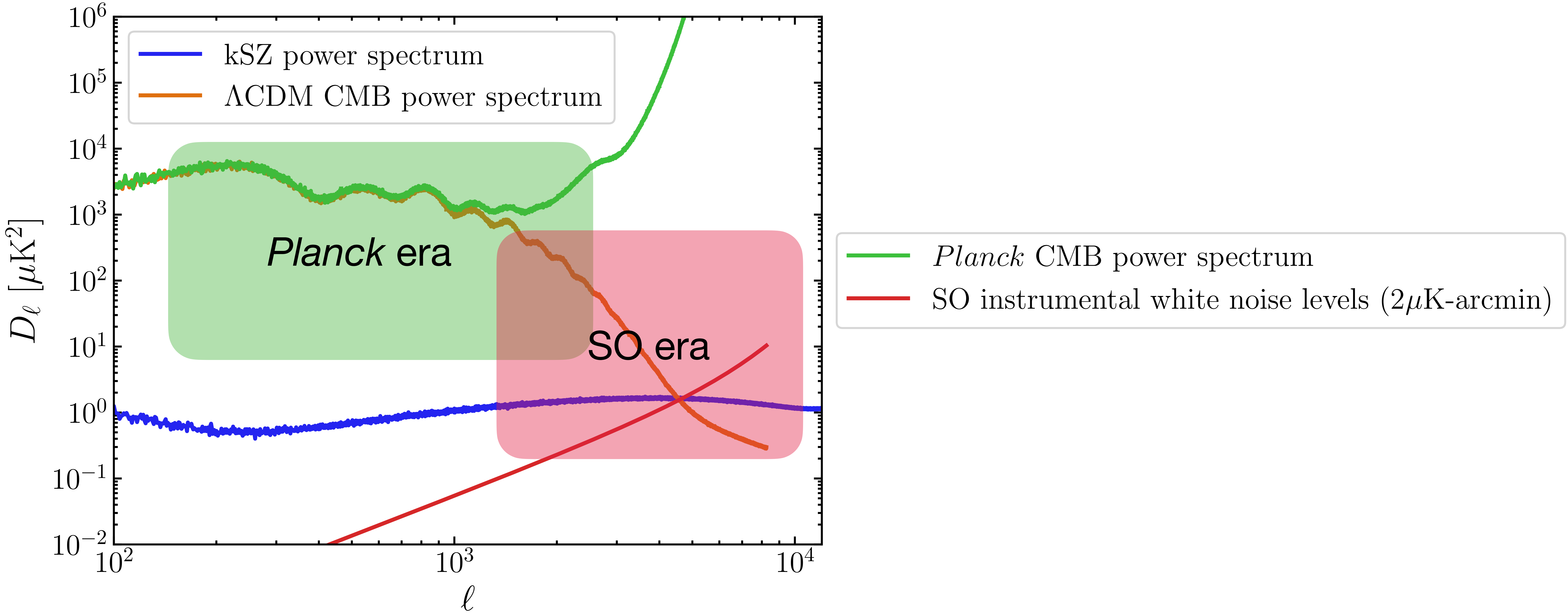


Future experiments!

How to measure kSZ? On **small scales**

- kSZ dominates over primary CMB at $\ell \gtrsim 6000$



- We are measuring the CMB on small scales with ACT and SO!! kSZ measurements will get really good

The Atacama Cosmology Telescope

- Observed from 2007-2022 in the Atacama Desert in Chile
- 90 GHz, 150 GHz, 220 GHz
- DR6, 2025: *maps of the CMB over ~30% of the sky (Naess et al 2025, Coulton et al 2023)*
- Resolution ~ 1 arcmin
- Typical depth $\sim 10\ \mu$K arcmin

Photo Credit: Jon Ward

- Typical kSZ signal: $\sim$ 1 μK over 1 arcmin

SO and kSZ measurements

- kSZ measurements will be more precise (typical depth $\sim 2.5\mu$K-arcmin)
- SO LAT will be a kSZ machine!

FMcC: SO kSZ co-lead with Boryana Hadzhiyska

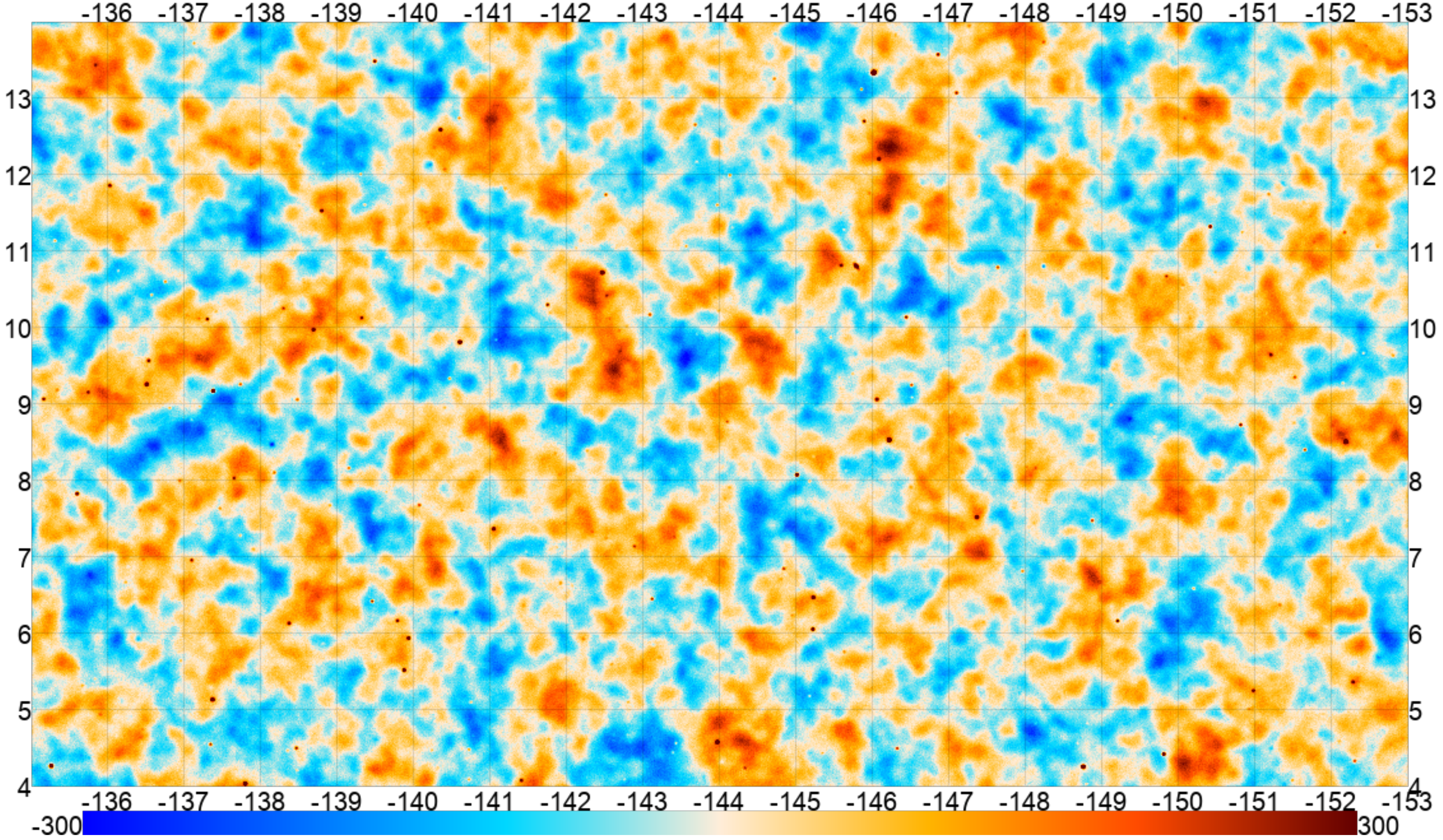
(I also co-lead Foreground WG so please also talk to me about that if interested)

SO Large Aperture Telescope

Initial SO data

Image credit: SO collaboration

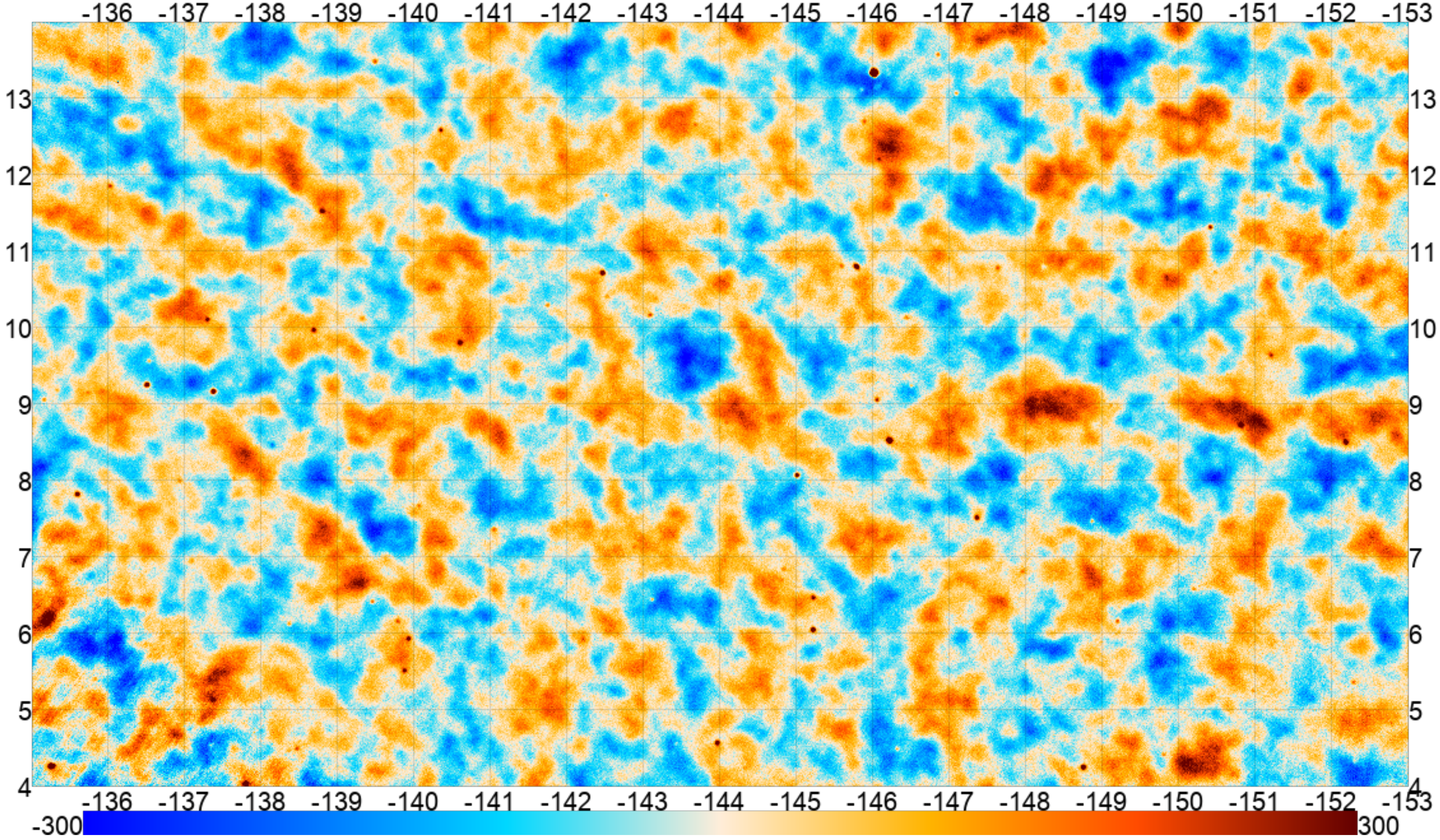
ACT DR6 at 90 GHz (**5 years**)



Initial SO data

Image credit: SO collaboration

SO LAT at 90 GHz (**144 hours**)



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Temperature data: ACT DR6

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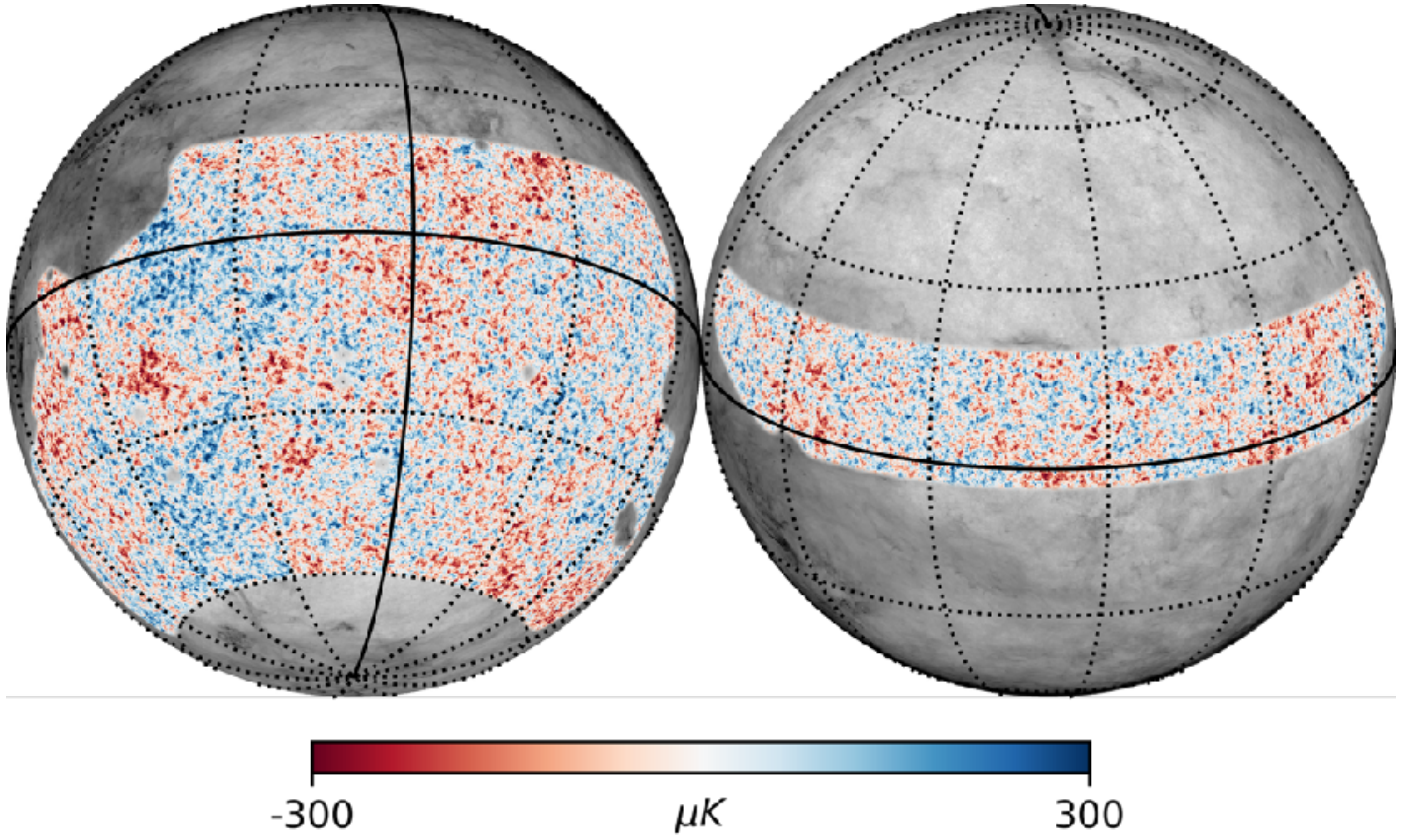
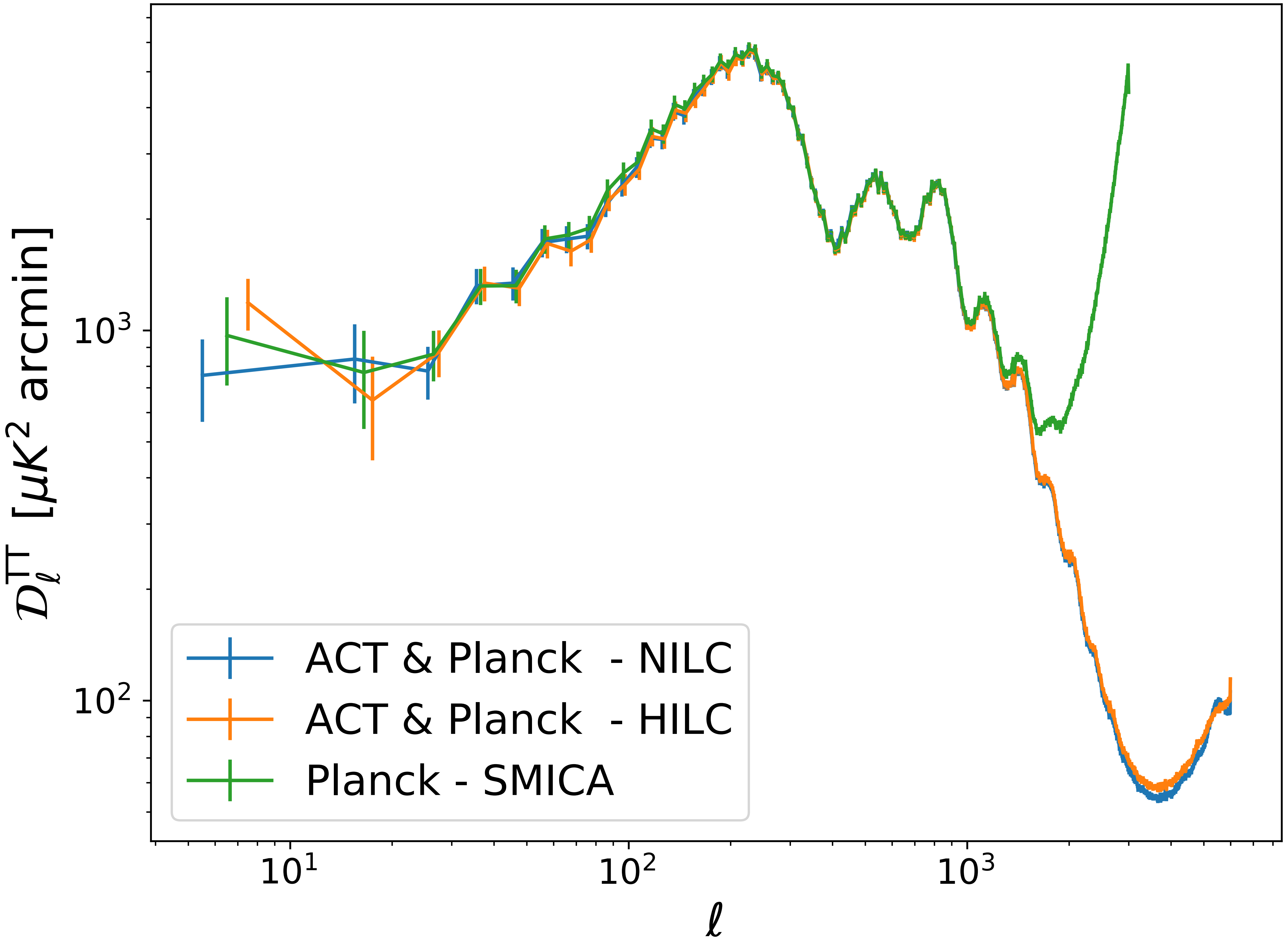
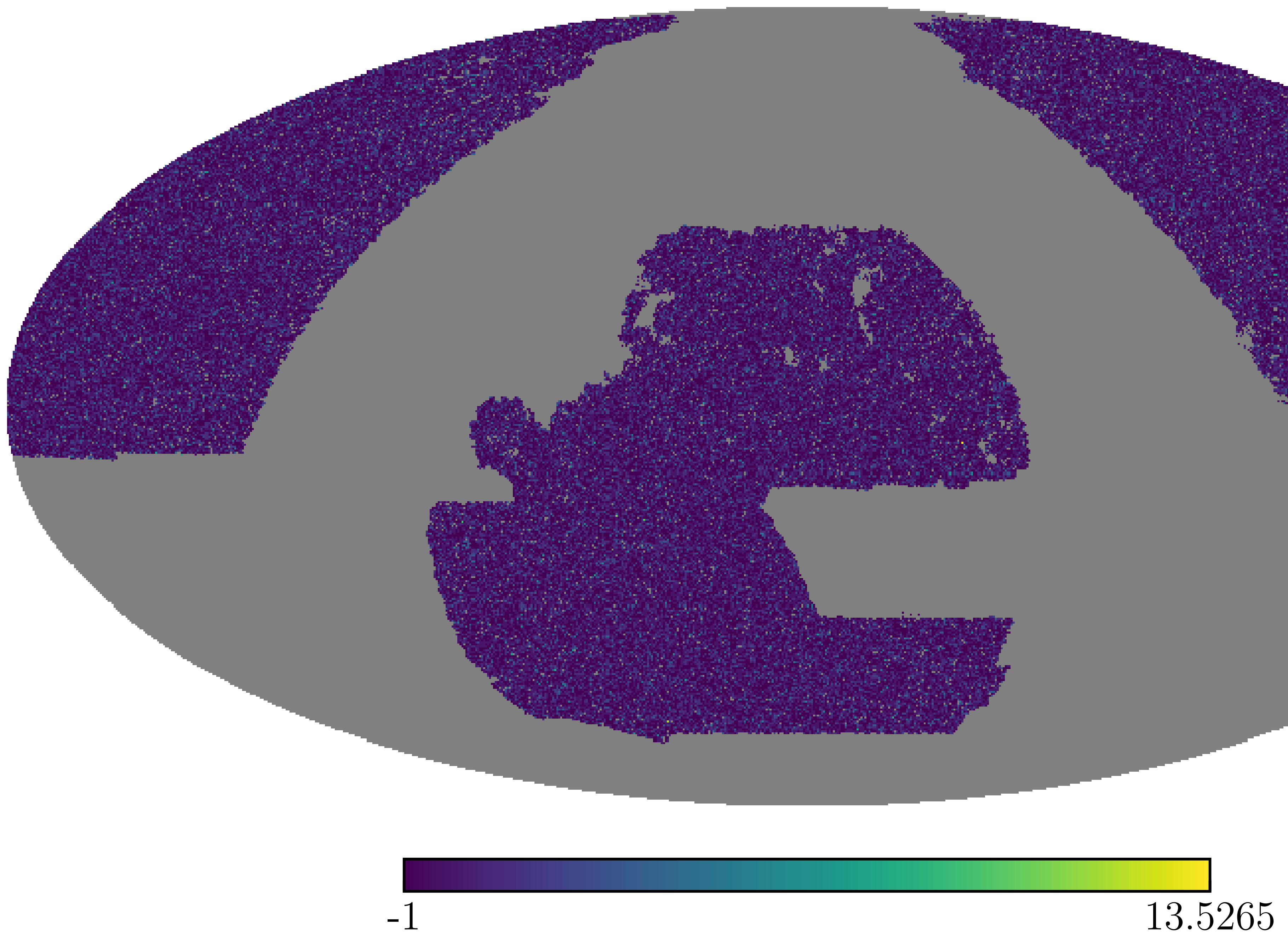


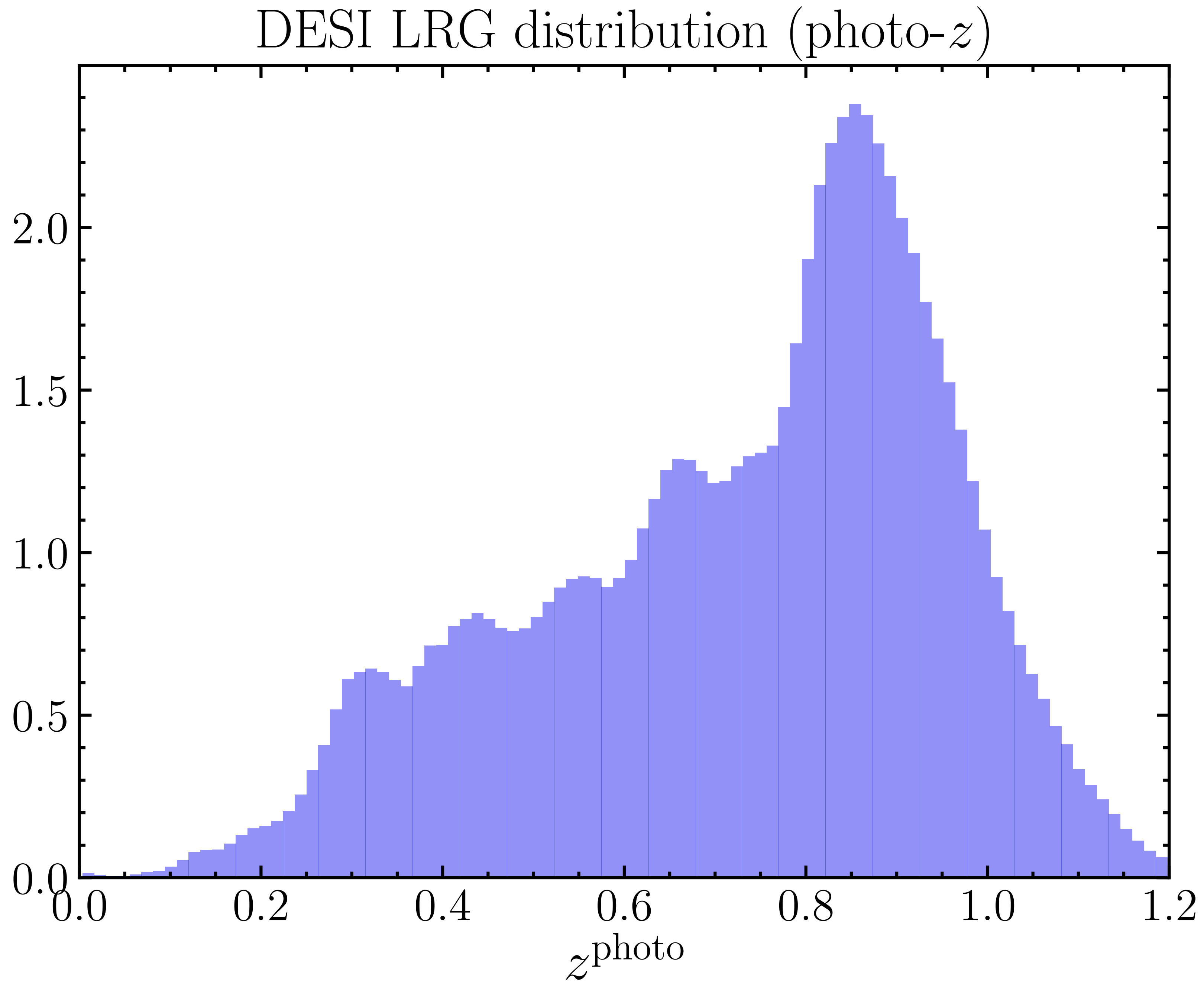


Figures from Coulton et al 2023

Galaxy data: DESILS

- We use the DESI-legacy extended sample from **Zhou et al 2023**





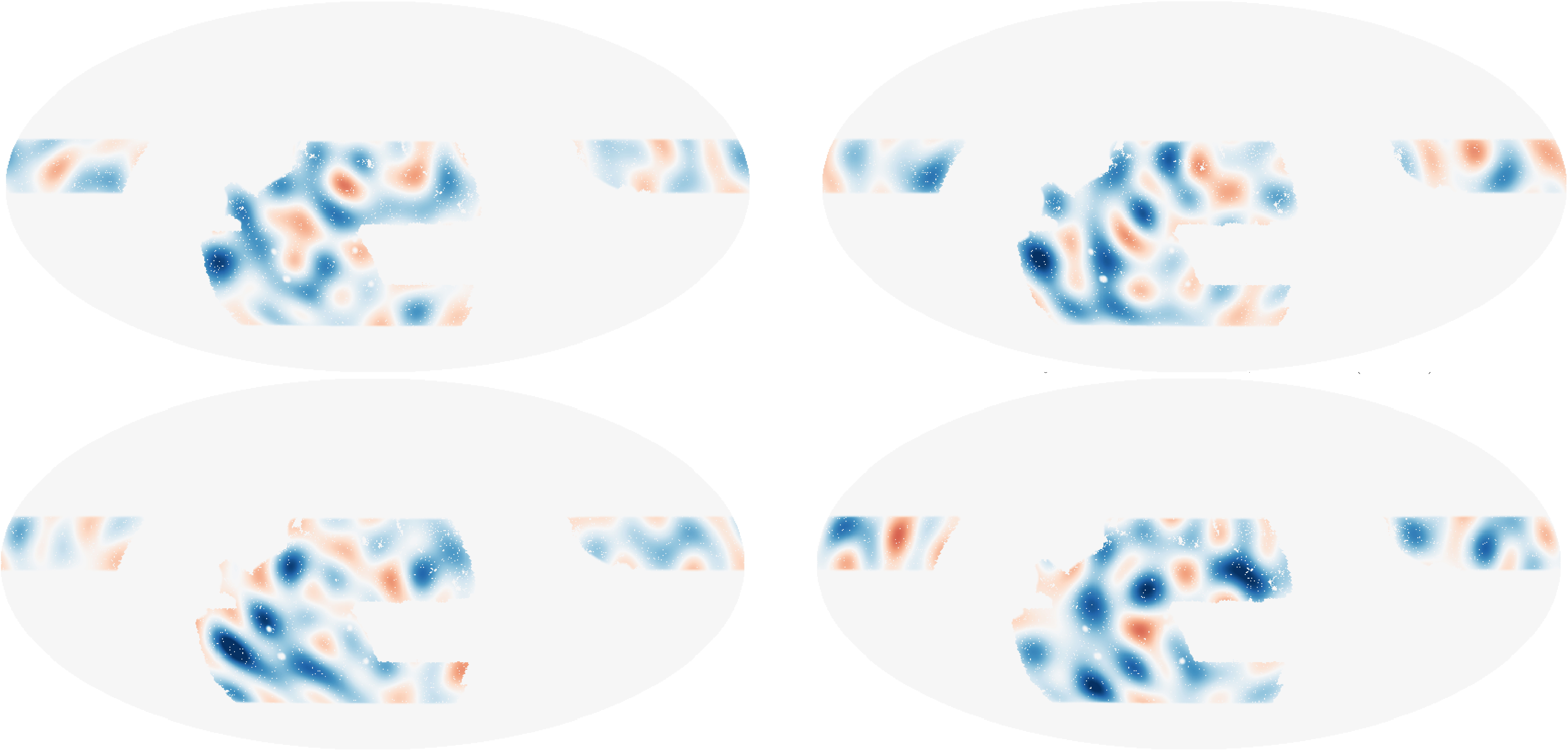
- These are at redshift ~ $0.4 < z < 1$
- Photometric redshift error $\frac{\sigma(z)}{1+z} \sim 0.027$

27,253,833 objects
18,000 square degrees

First kSZ velocity measurements with ACT

$z \sim 0.45$

$z \sim 0.5$



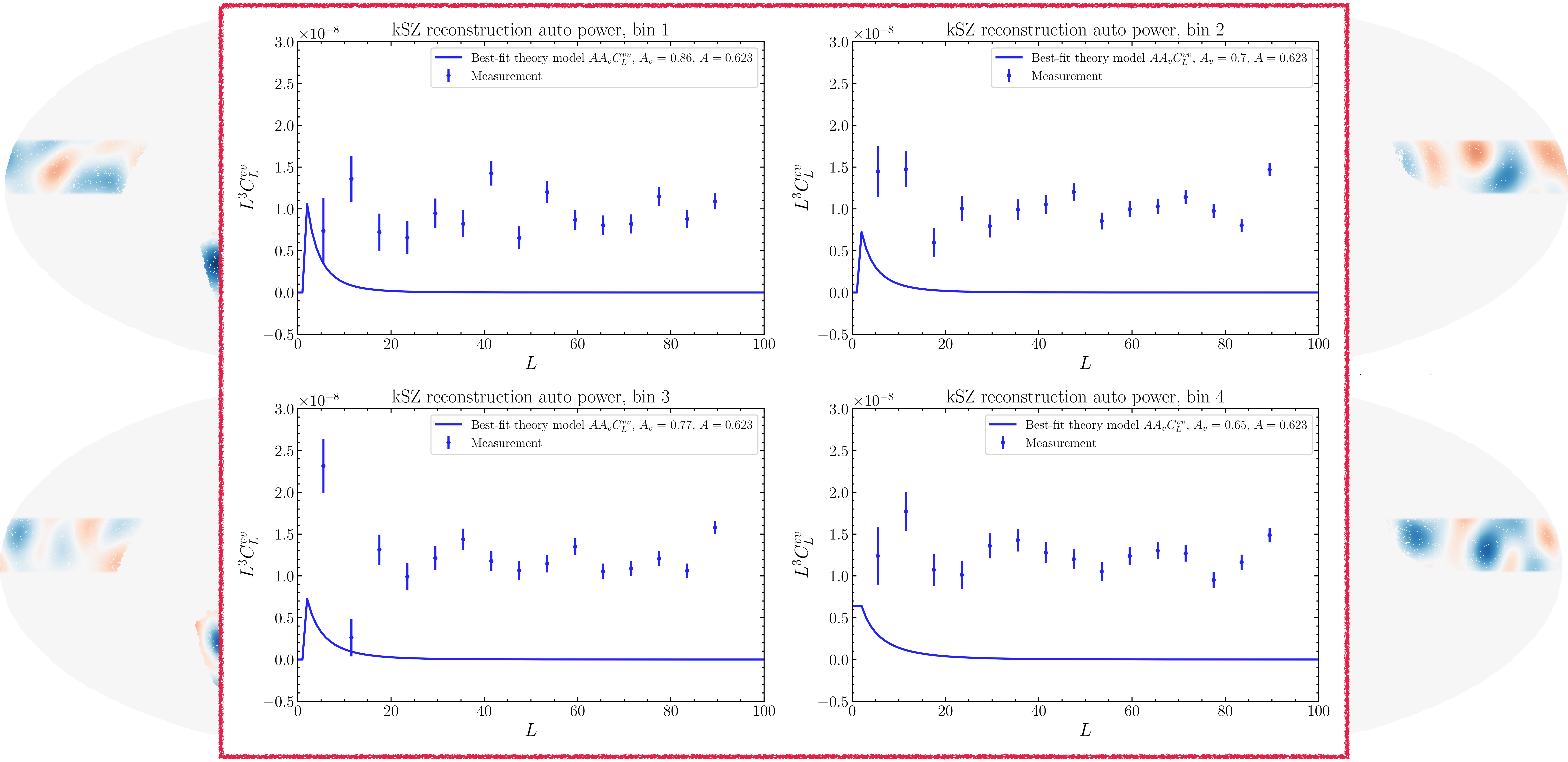
$z \sim 0.6$

$z \sim 0.65$

***FMcC** et al 2025 (JCAP)*

Maps are noise dominated

$z \sim 0.45$ $z \sim 0.5$

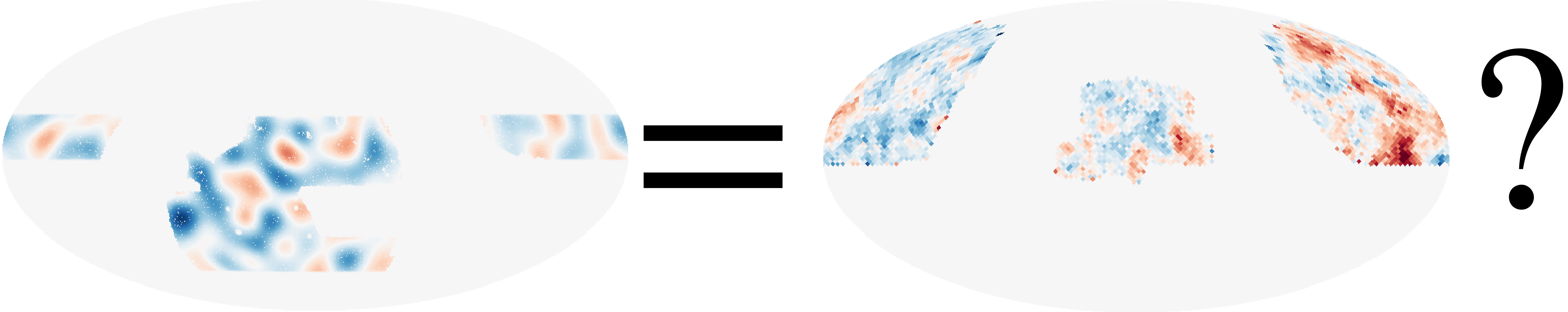


$z \sim 0.6$ $z \sim 0.65$

FMcC *et al 2025 (JCAP)*

Cross-correlation measurement

- Cross correlate with a galaxy survey
- *Currently* less noisy than kSZ estimate - **will not always be the case!**



kSZ-estimated velocity

Indirect velocity estimate from galaxy survey

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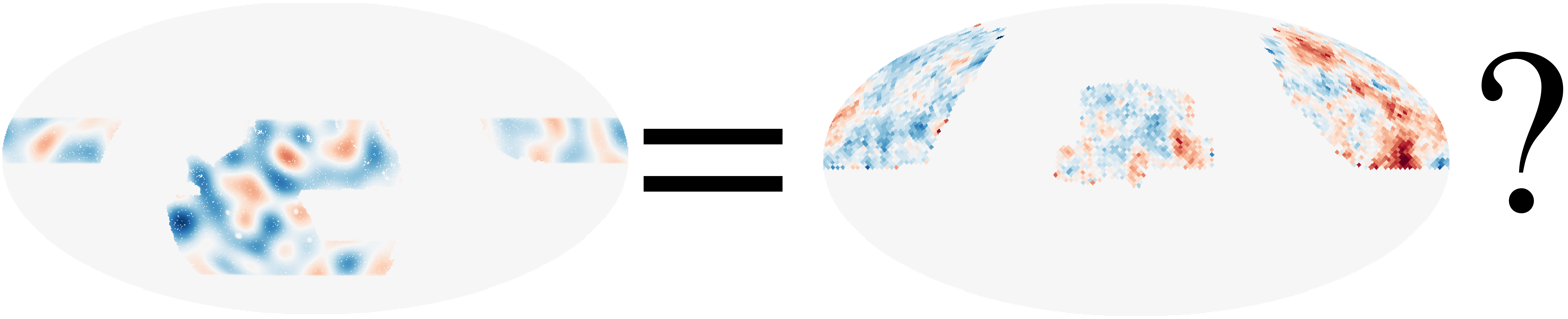

kSZ-estimated velocity

Indirect velocity estimate from galaxy survey

- *FMcC et al 2025a: use SDSS for the indirect estimate (large redshift and $f_{\rm sky}$ overlap penalty)*

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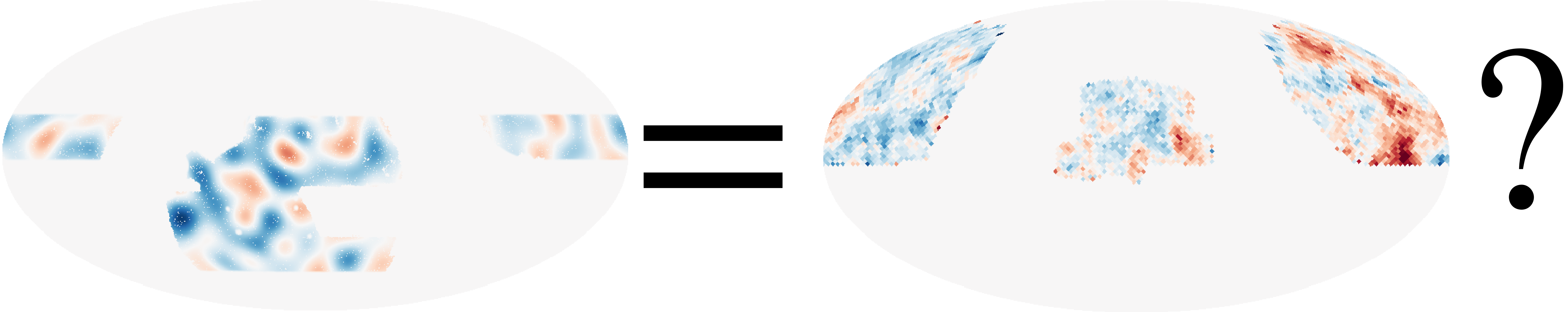


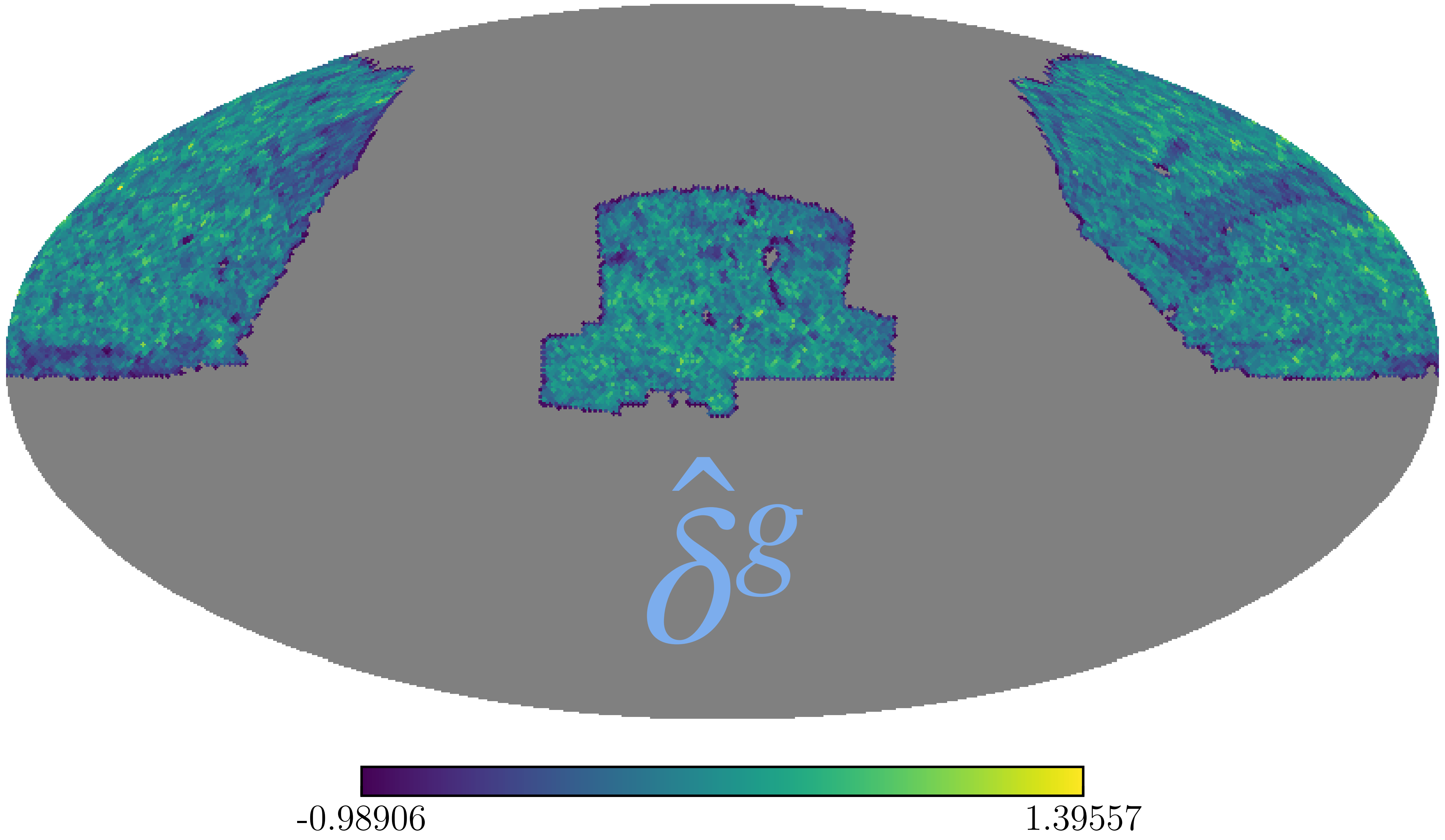
kSZ-estimated velocity

Indirect velocity estimate from galaxy survey

- *FMcC et al 2025a: use SDSS for the indirect estimate (large redshift and $f_{\rm sky}$ overlap penalty)*
- *FMcC et al 2025b: improve SNR by using DESILS for indirect estimate*

Indirect velocity measurement

- Galaxies move in a gravitational field -> **infer the velocity from density** (using GR + continuity equation)
- To differentiate from v^{kSZ} I refer to this as v^{cont}



$$\left\langle v^{\mathrm{kSZ}} v^{\mathrm{external}} \right\rangle ?$$

Continuity equation:

$$-i\vec{k}\cdot\vec{v} - i\vec{k}\cdot\left(v_{||}\hat{n}\right) = -aHf\frac{\delta_g}{b}$$

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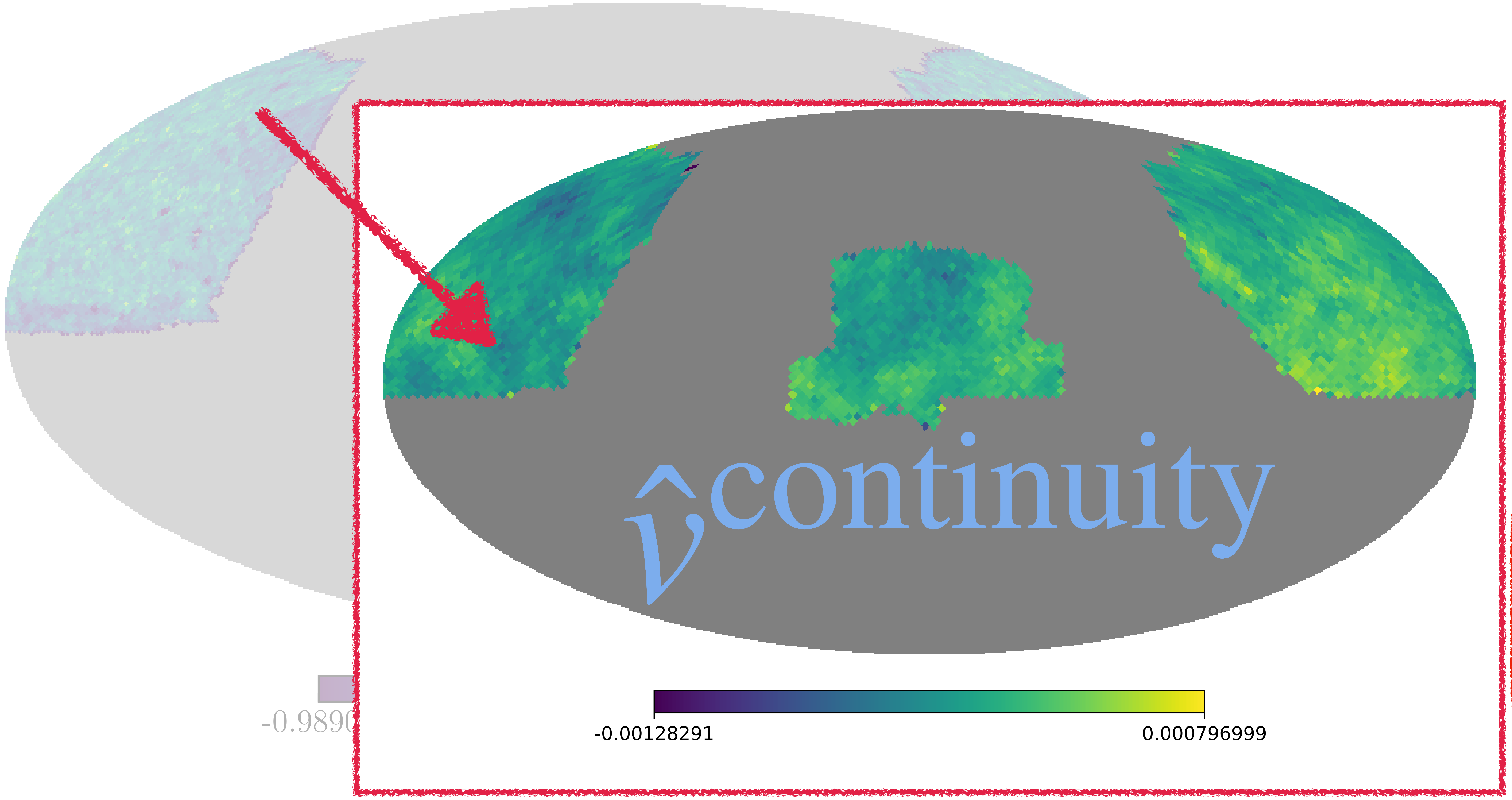


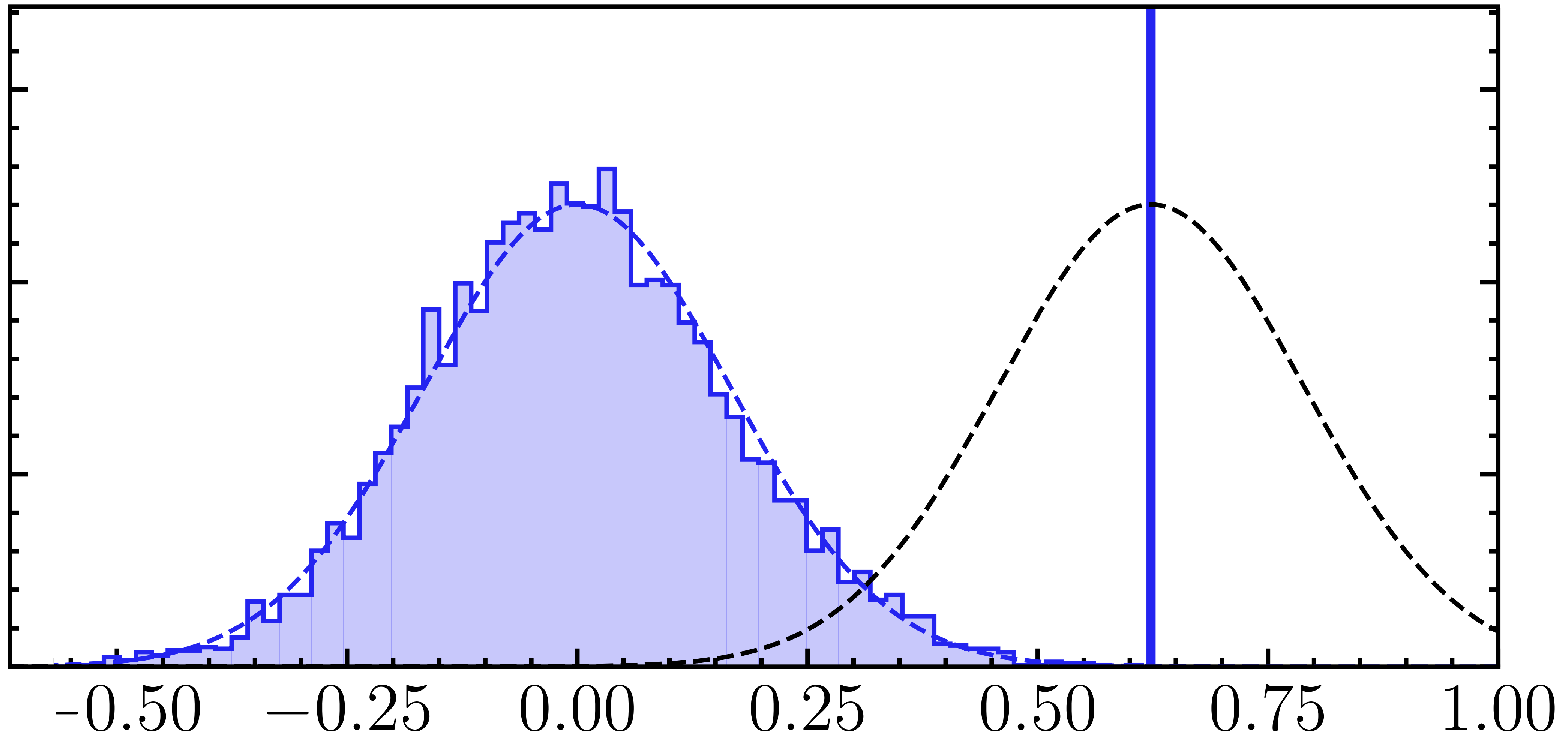
$\left\langle v^{\mathrm{kSZ}} v^{\mathrm{external}} \right\rangle$?

Continuity equation:

$$-i\vec{k}\cdot\vec{v} - i\vec{k}\cdot\left(v_{||}\hat{n}\right) = -aHf\frac{\delta_g}{b}$$

Weak first detection

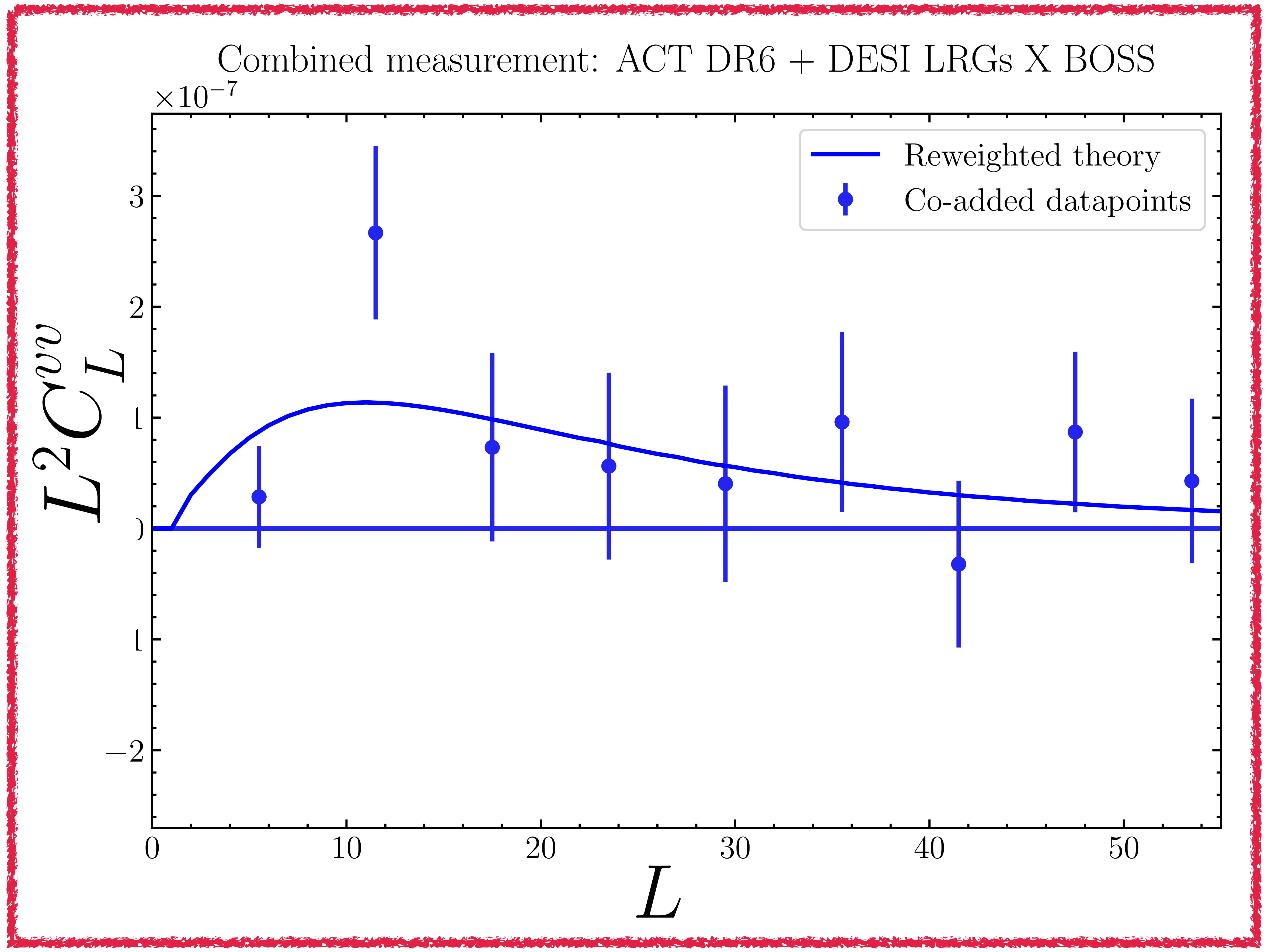
- **FMcC** et al 2025a (ACT-DESILS-SDSS):
  Weak first detection



Signal amplitude b_v

$$\hat{C}_L^{v^{\rm kSZ}v^{\rm cont}} \sim b_v C_L^{vv,\rm fiducial}$$

3.8σ *significant!*



Optical depth bias

- We use **galaxies** to trace **electrons.** There is a modelling step in the velocity estimator

$$v \sim \frac{T}{\delta^e} \xrightarrow{\text{“Galaxies trace electrons”}} \delta^e_\ell = \frac{C^{\tau g}_\ell}{C^{gg}_\ell}\delta^g_\ell$$

- $C^{\tau g}_\ell$ is not perfectly known!! This introduces a bias

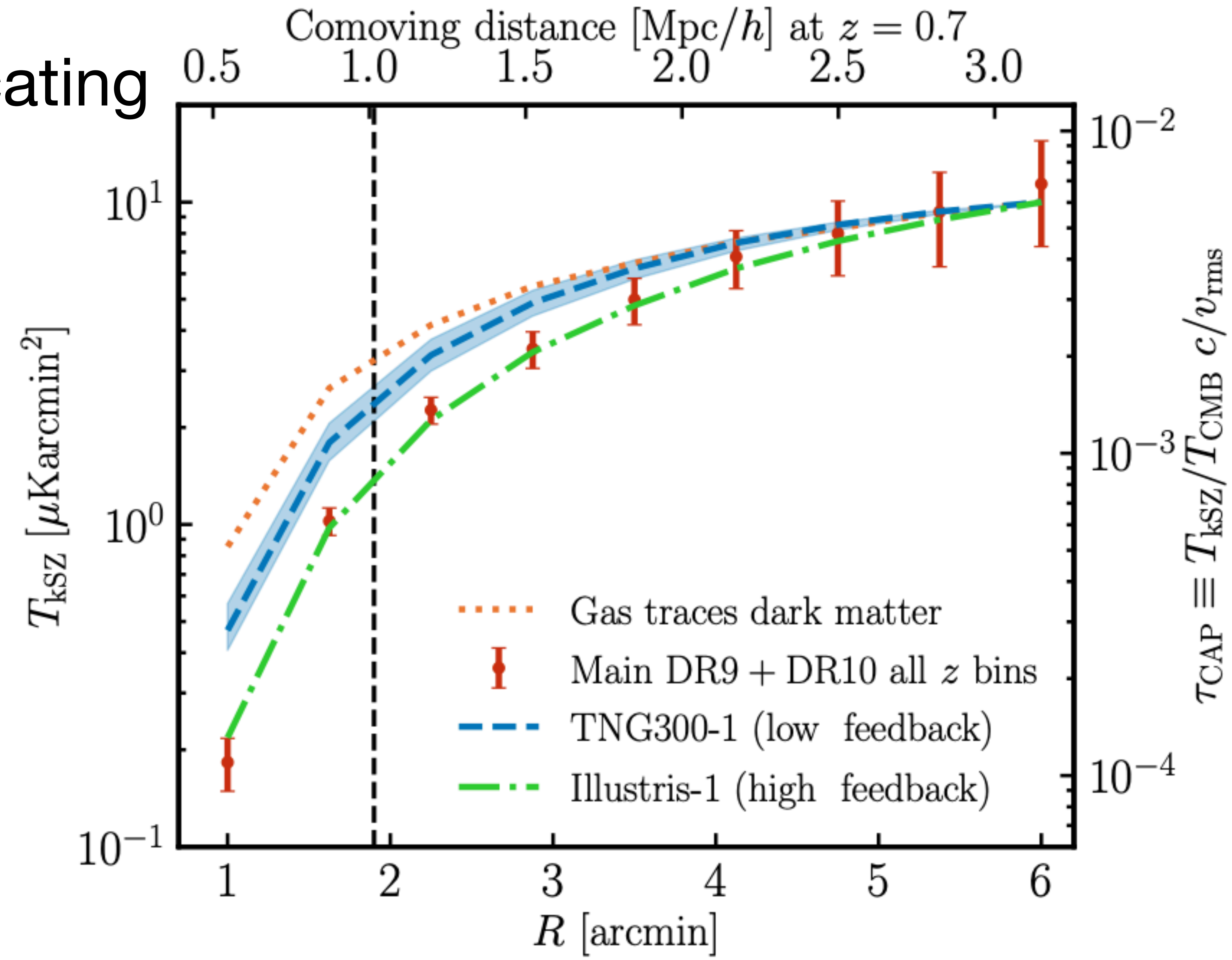
$$v^{\mathrm{k}SZ} = b_v v^{\mathrm{true}} \qquad b_v = b_v(\Delta C^{g\tau}_\ell) \qquad \Delta C^{g\tau}_\ell = C^{g\tau,\mathrm{true}}_\ell - C^{g\tau,\mathrm{assumed}}_\ell$$

- Importantly, b_v is **scale-independent on large scales**

- “Strong feedback” $\implies C^{\tau g}_\ell$ suppressed on scales of interest $\implies b_v < 1,$ weaker signal than expected

“Strong feedback”(?)

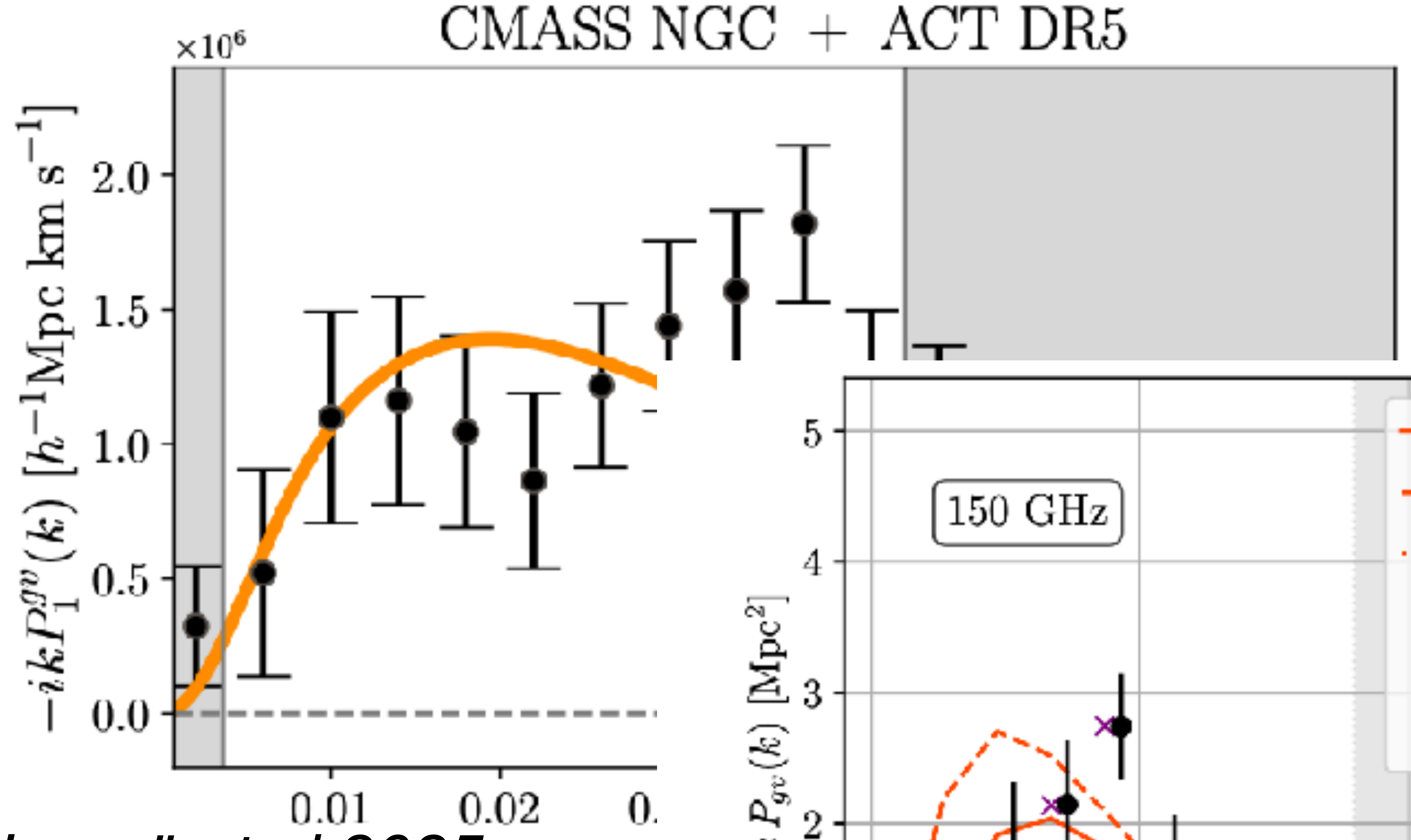
- kSZ **stacking** measurements are indicating suppression in small-scale $C_\ell^{g\tau}$ for DESILS (eg, Hadzhiyska et al 2025)
- I will use the “TNG-300” curve with similar modelling assumptions to Hadzhiyska et al for fiducial theory
- We **expect** $b_v < 1$ (a manifestation of the same signal as Hadzhiyska et al)



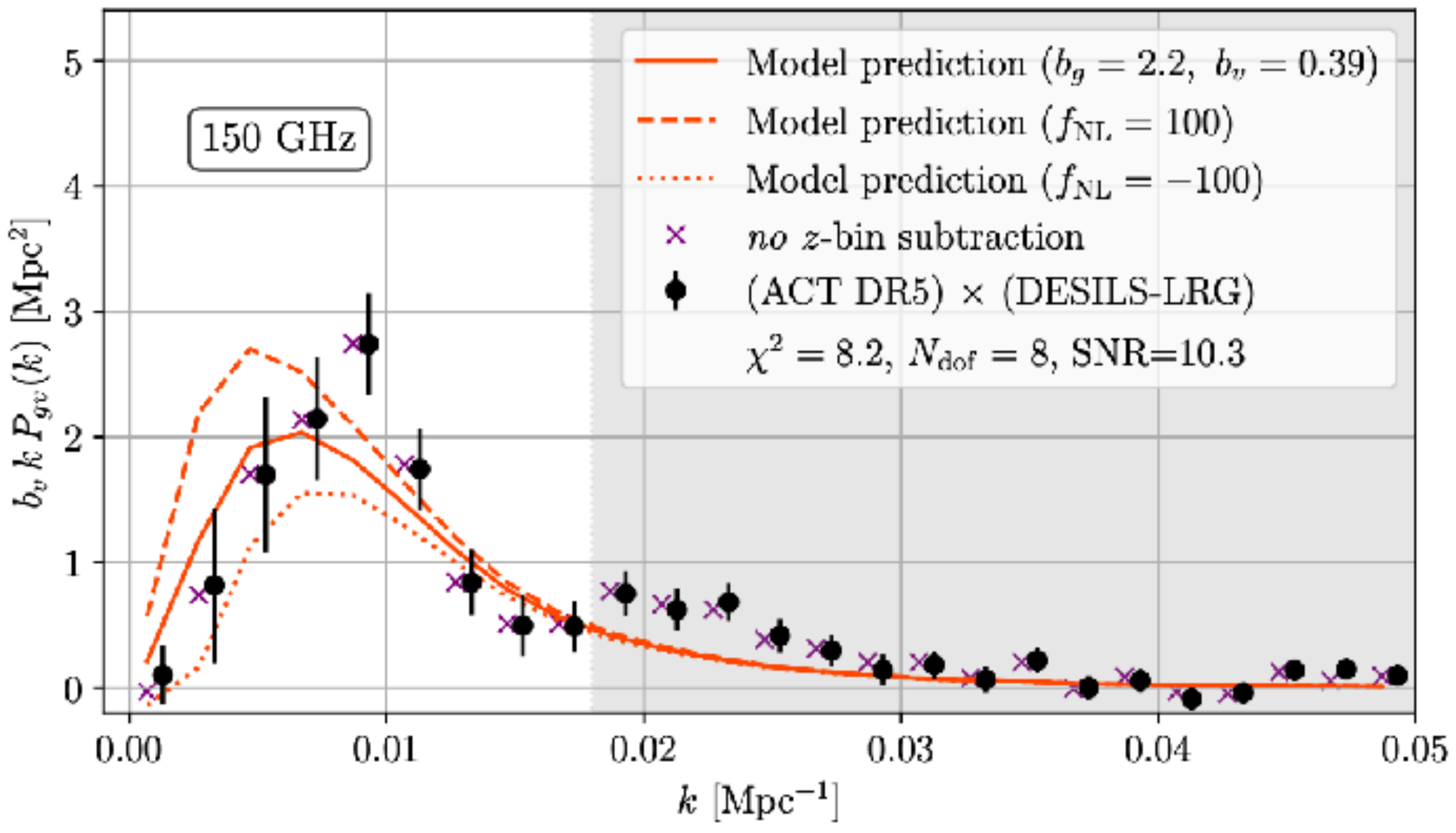
Hadzhiyska et al 2025

Ongoing progress in the field

- Since our first detection, several increasingly high-significance measurements have been made:

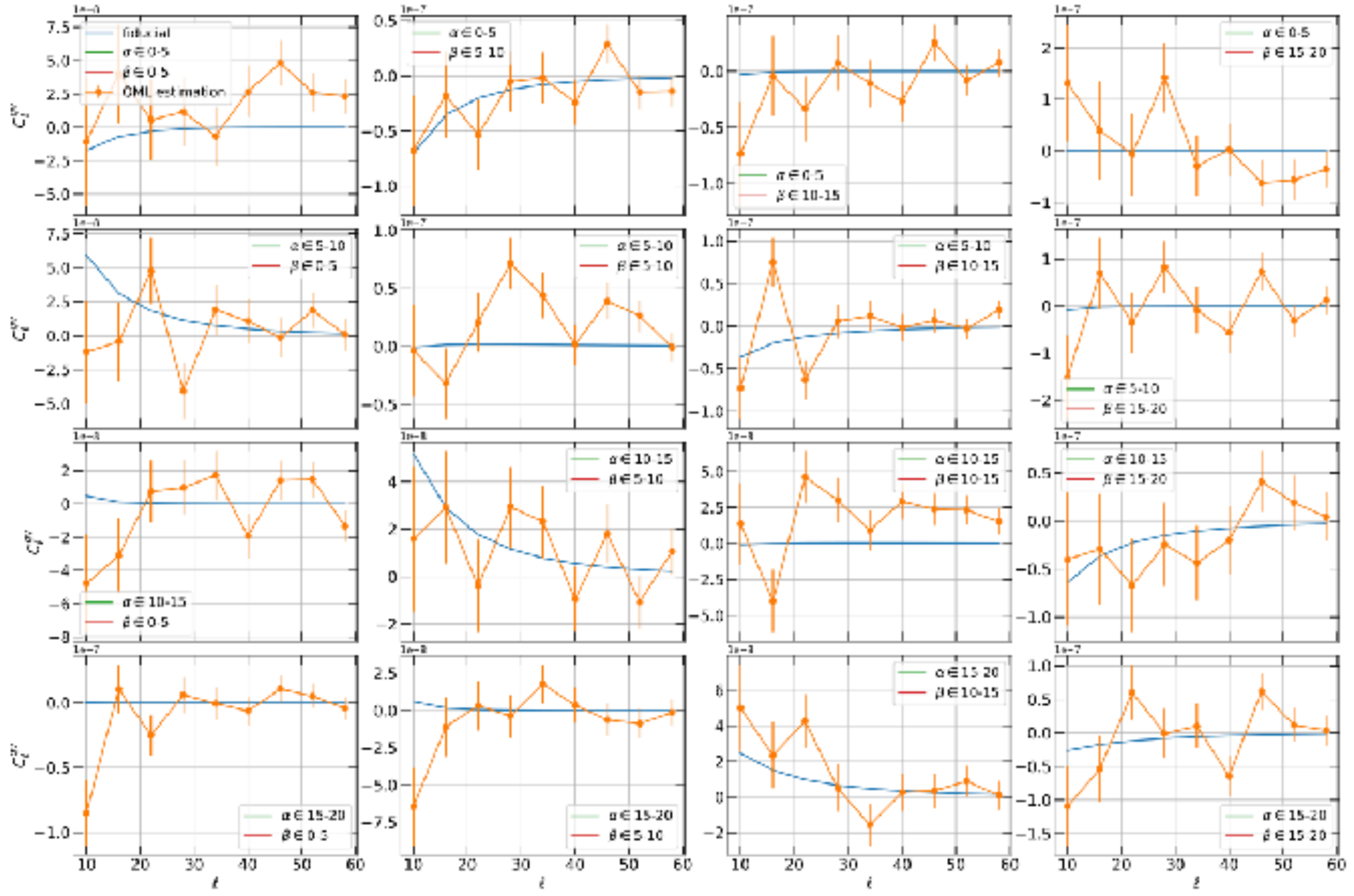


Laguë et al 2025



Hotinli et al 2025

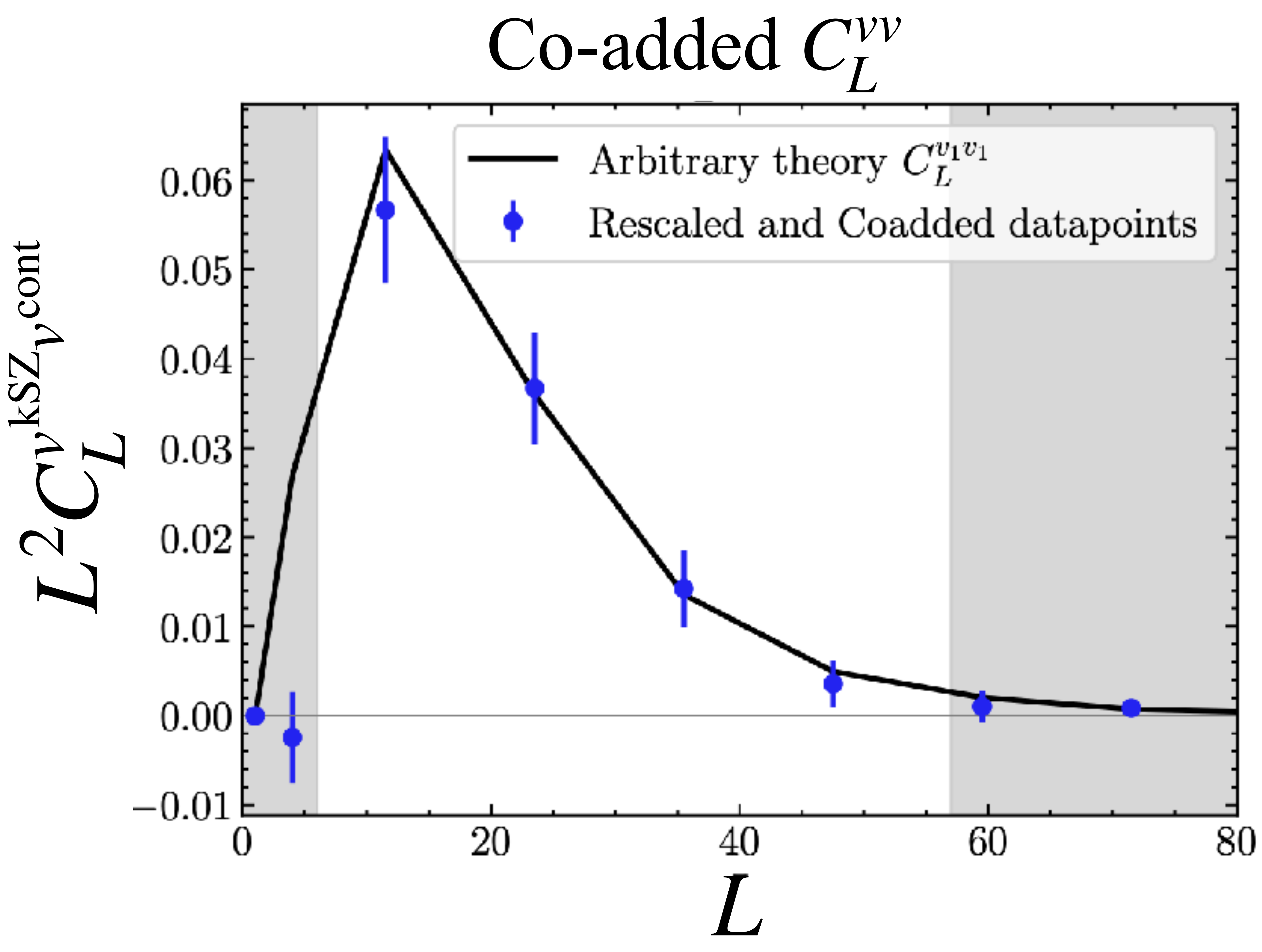
- *Bloch and Johnson 2024:* $\sim 1\sigma$
- *Laguë et al 2025:* $\sim 7\sigma$
- *Hotinli et al 2025:* $\sim 11\sigma$
- *Lai et al 2025:* $\sim 11\sigma$

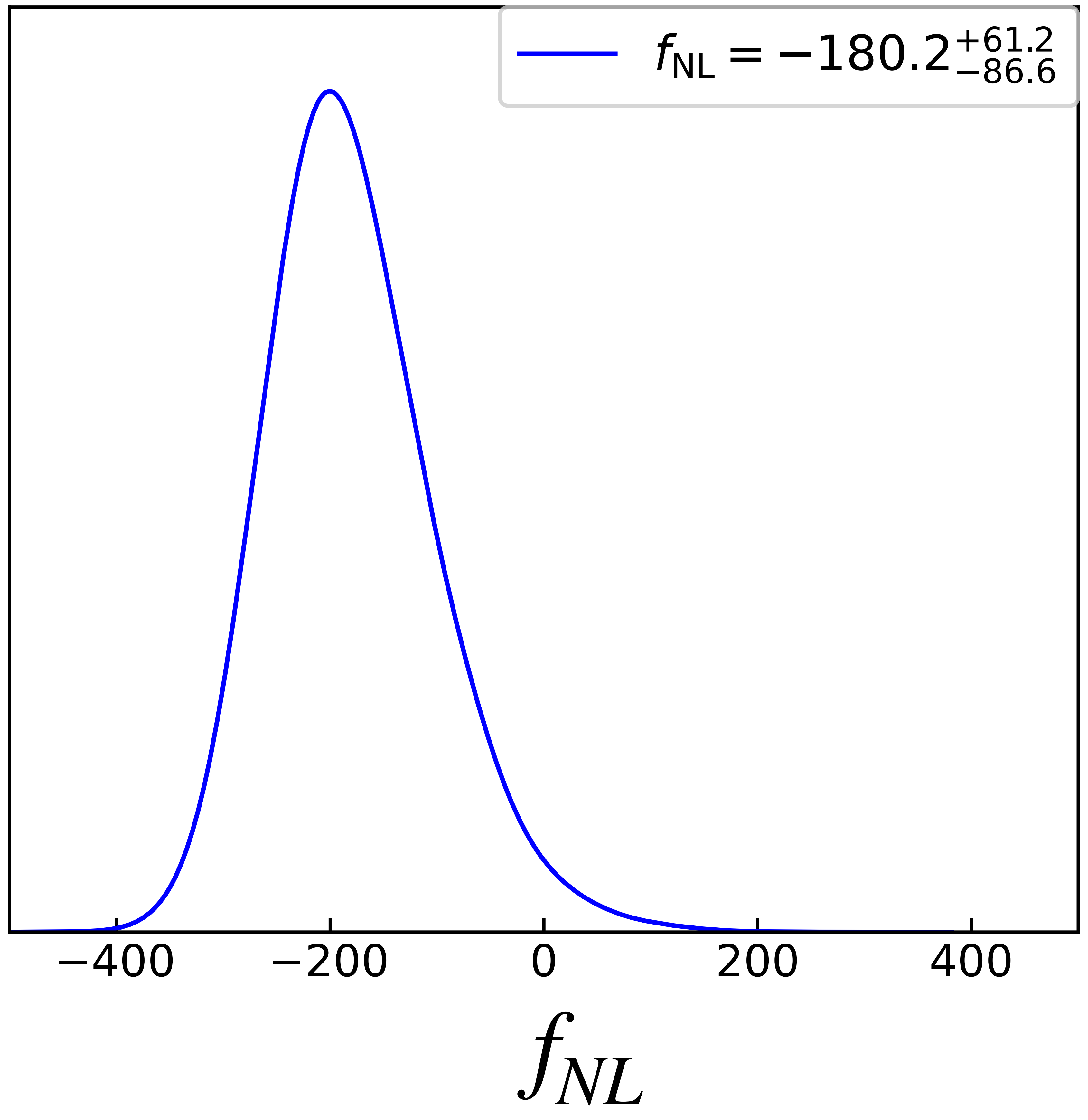


Lai et al 2025

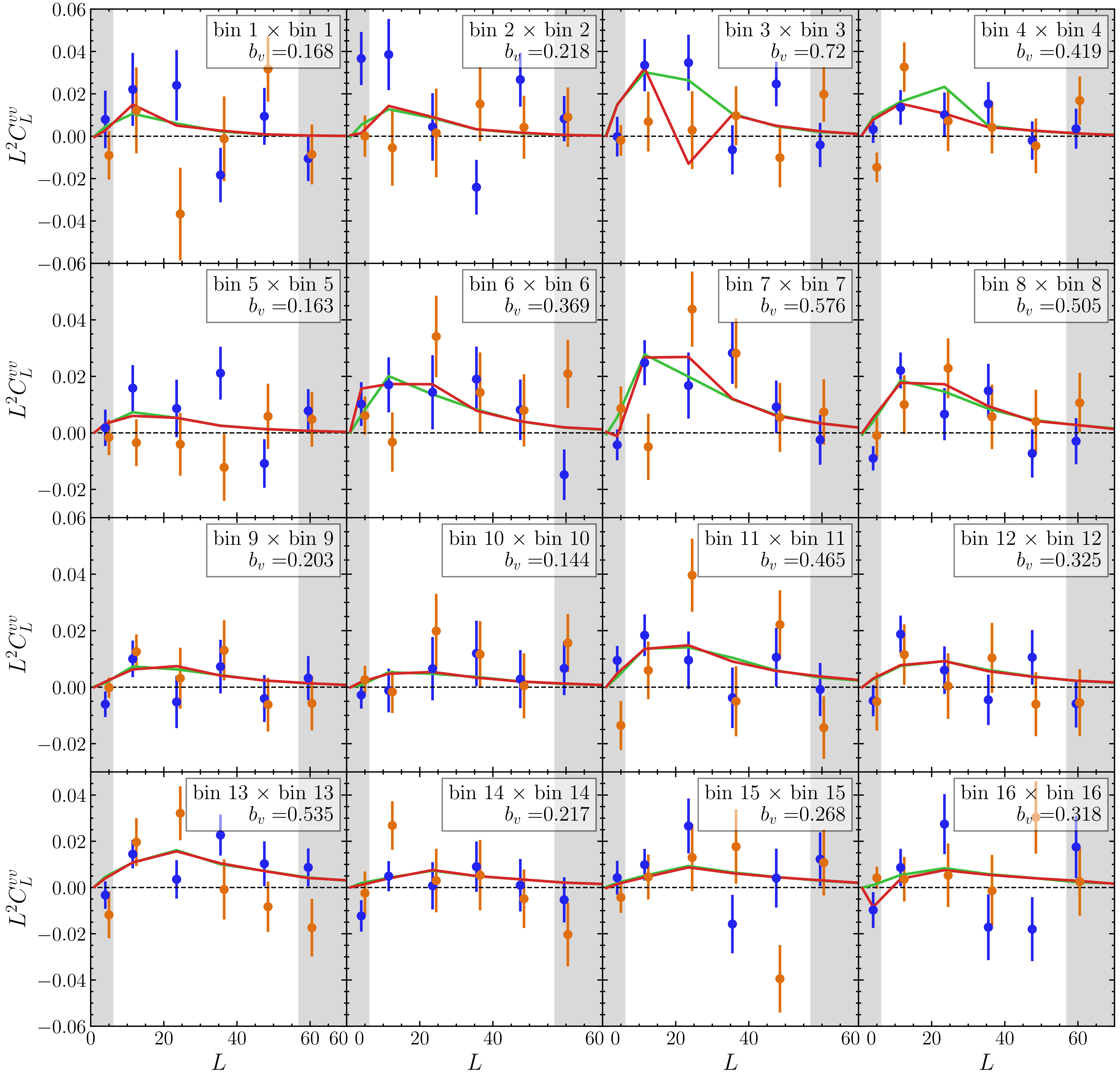
Recent measurement: ACT-DESILS-DESILS

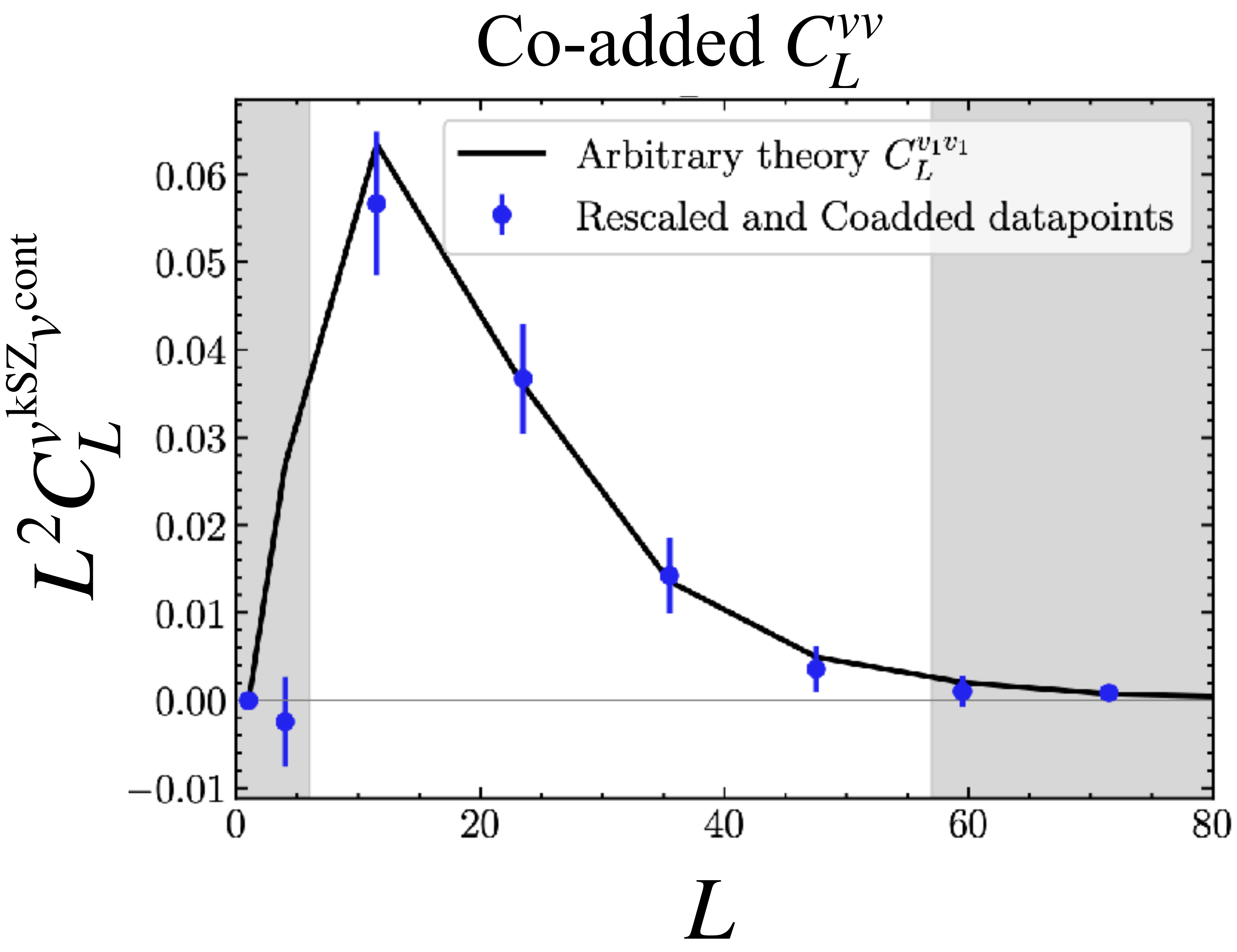
- High-significance measurement of cross-correlation between velocity template and kSZ reconstruction
- Cosmological constraints on f_{NL}





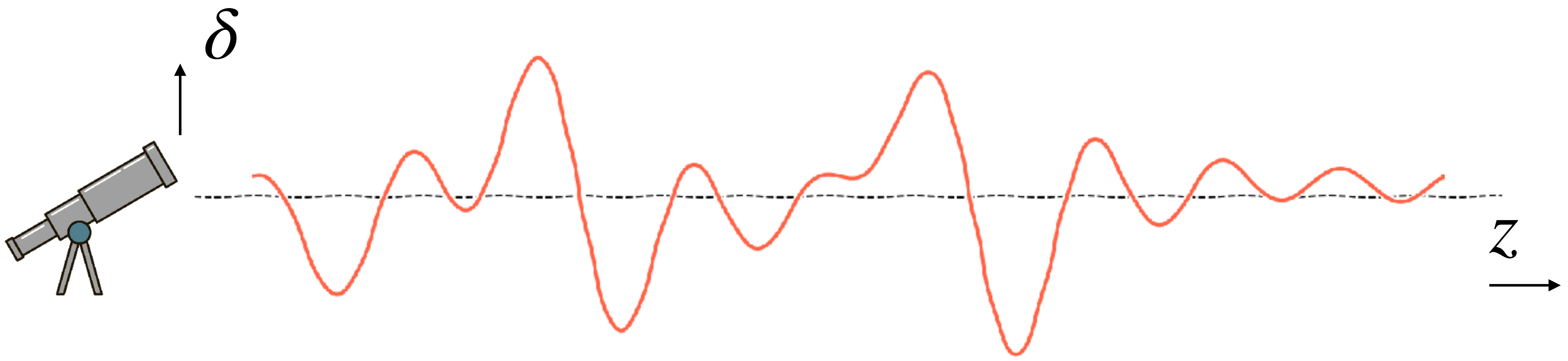
Cross-correlation measurement





Redshift resolution

- Intrinsic signal size depends on redshift resolution
- Wide bin: *radial modes average down*



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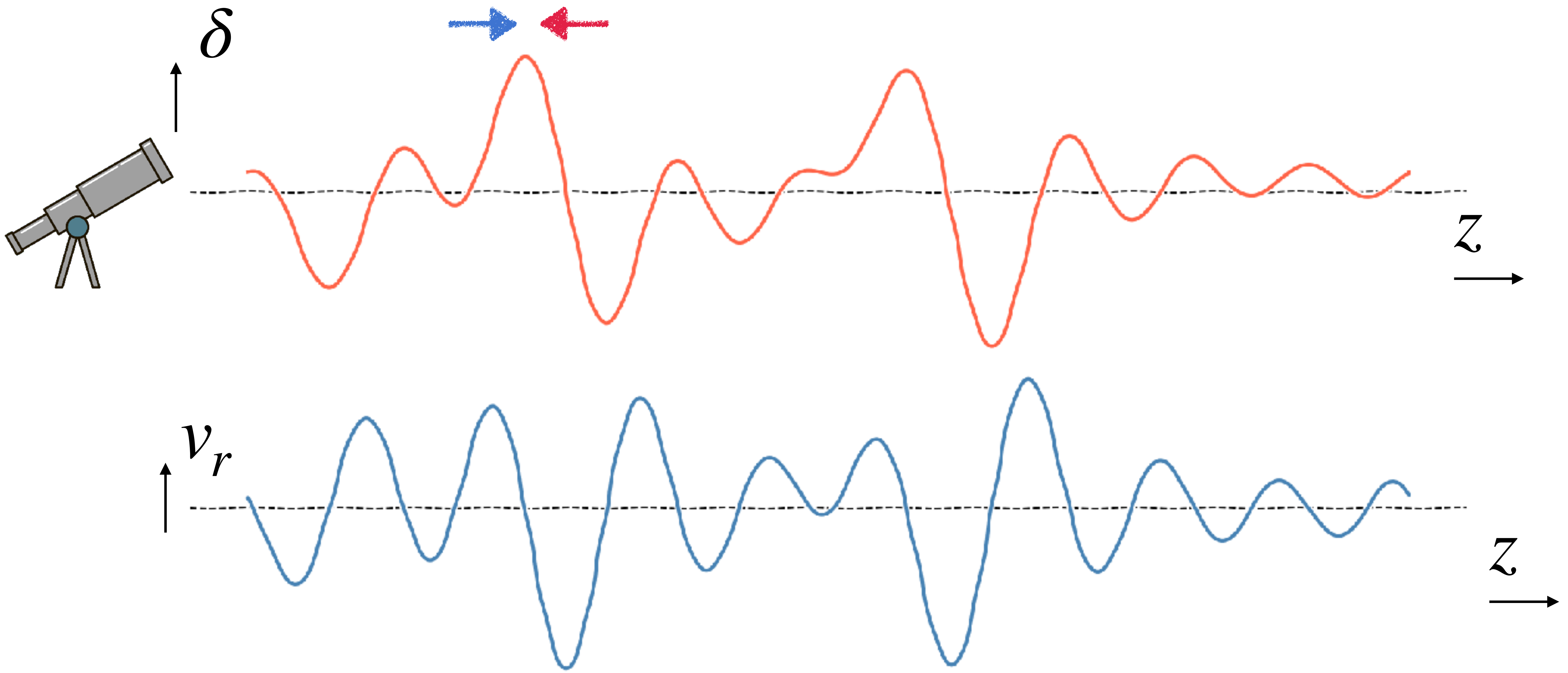

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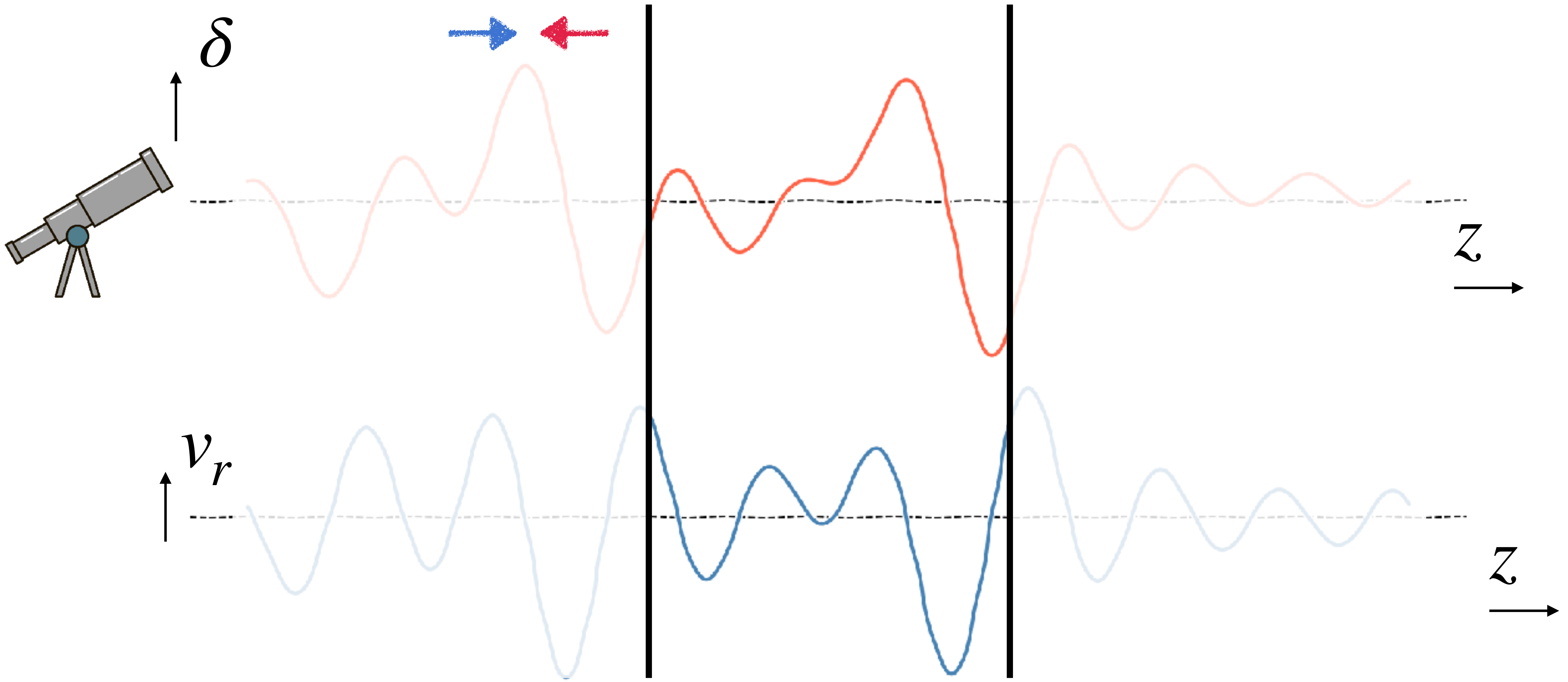

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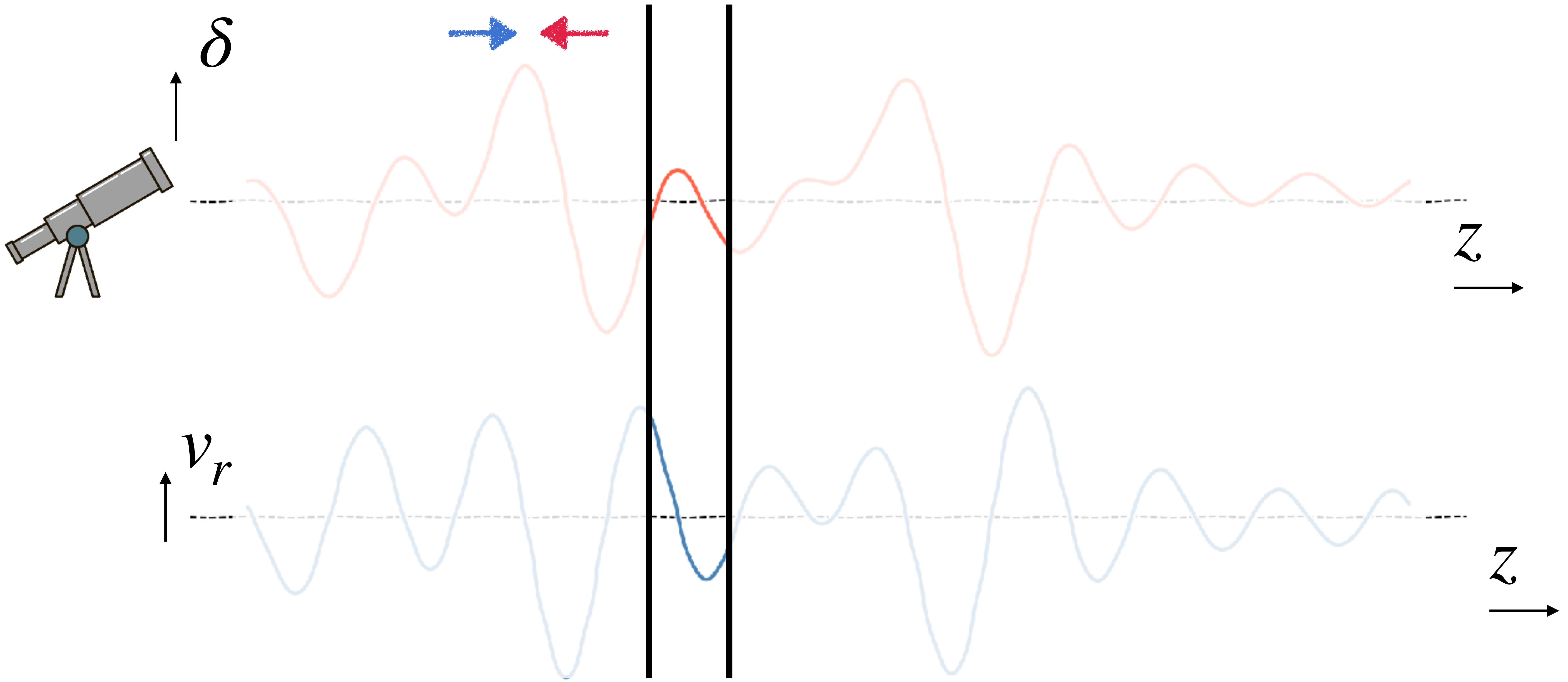

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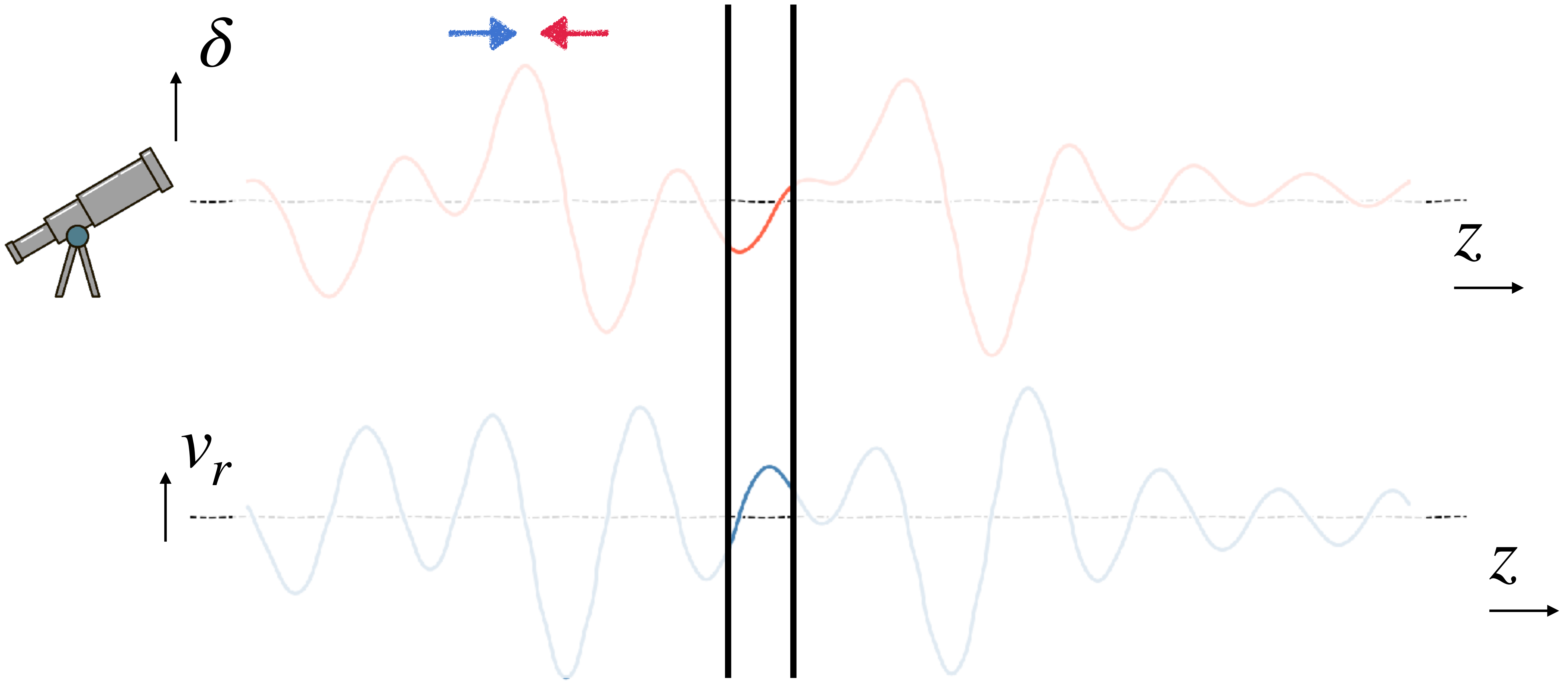
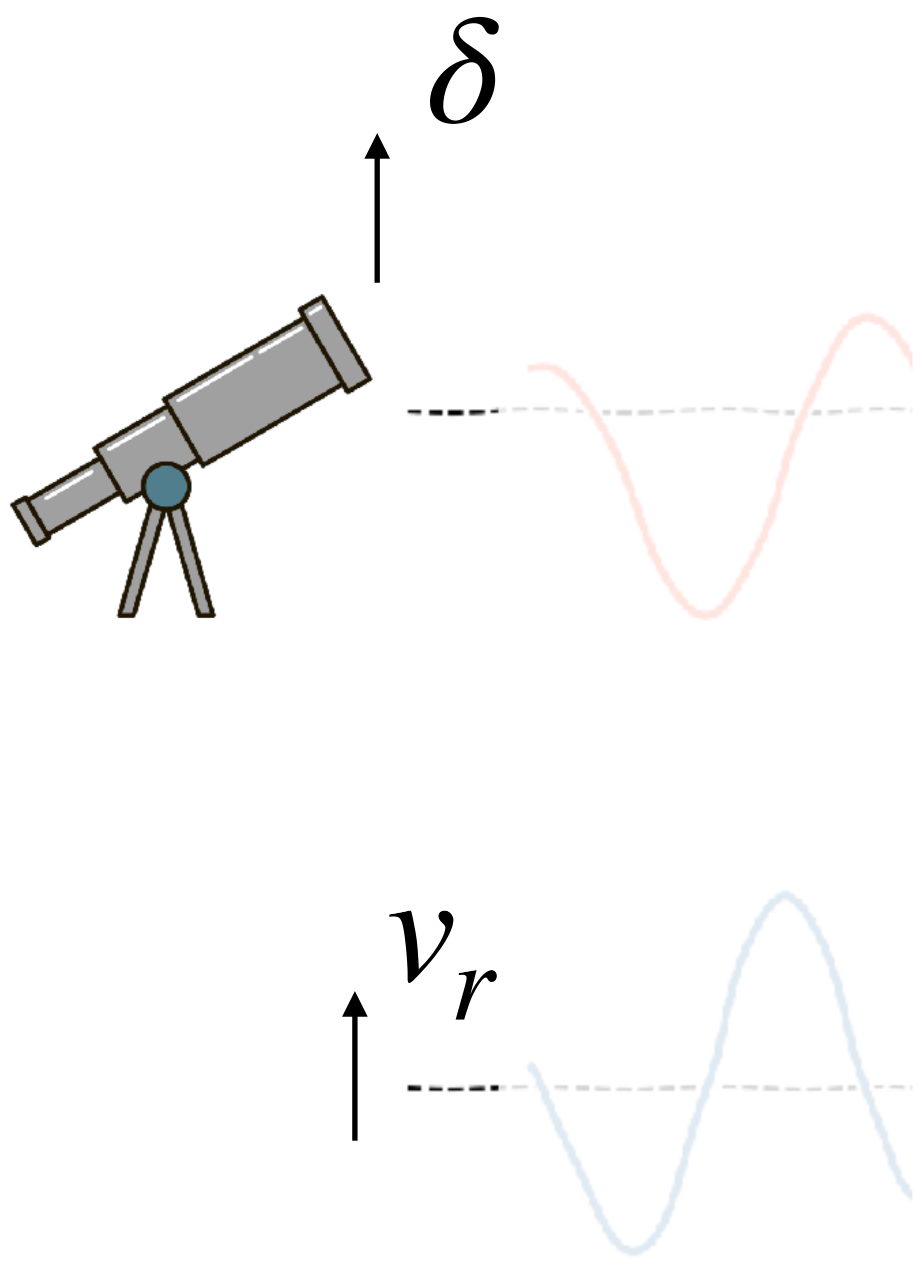
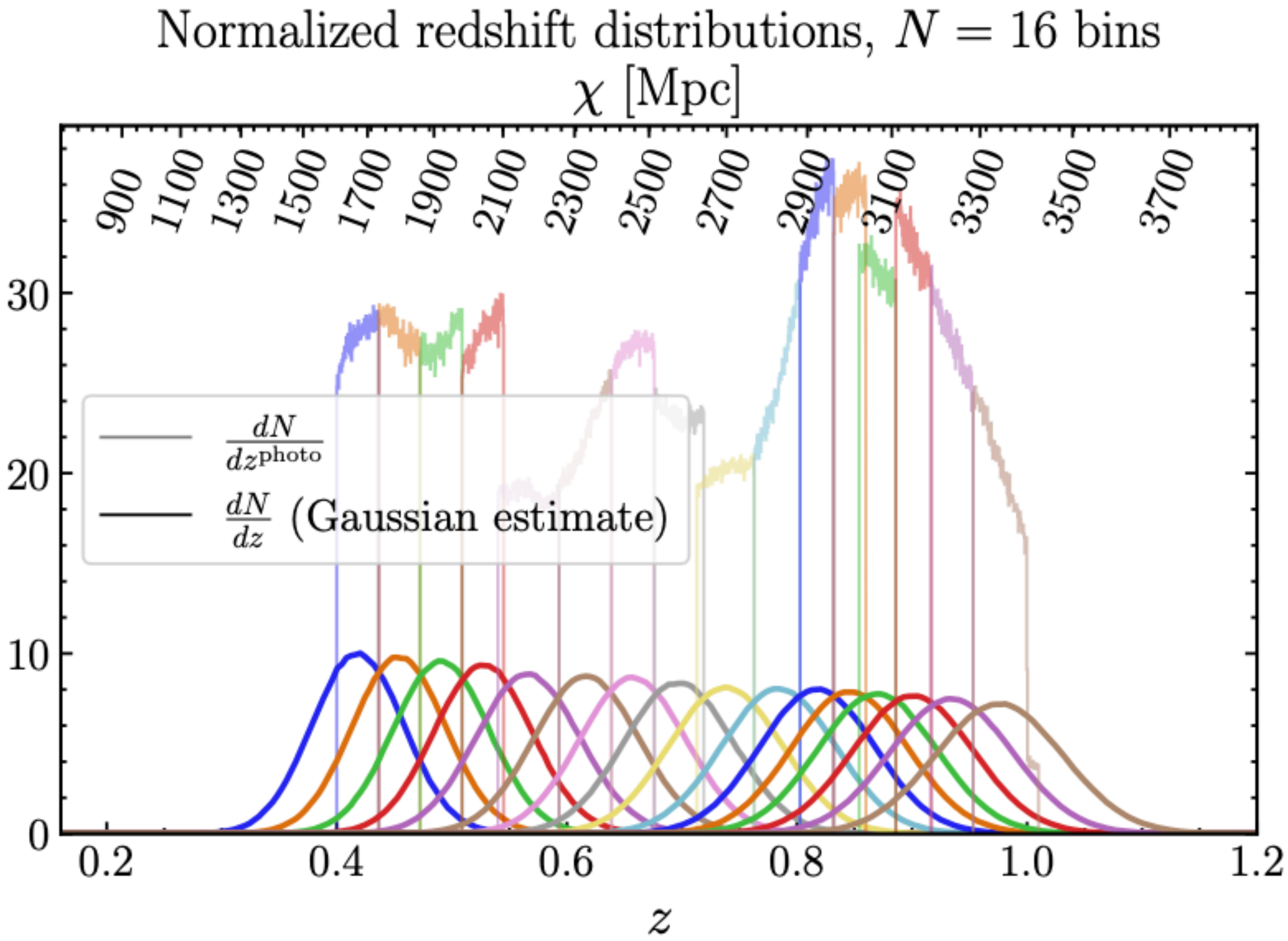


Redshift resolution

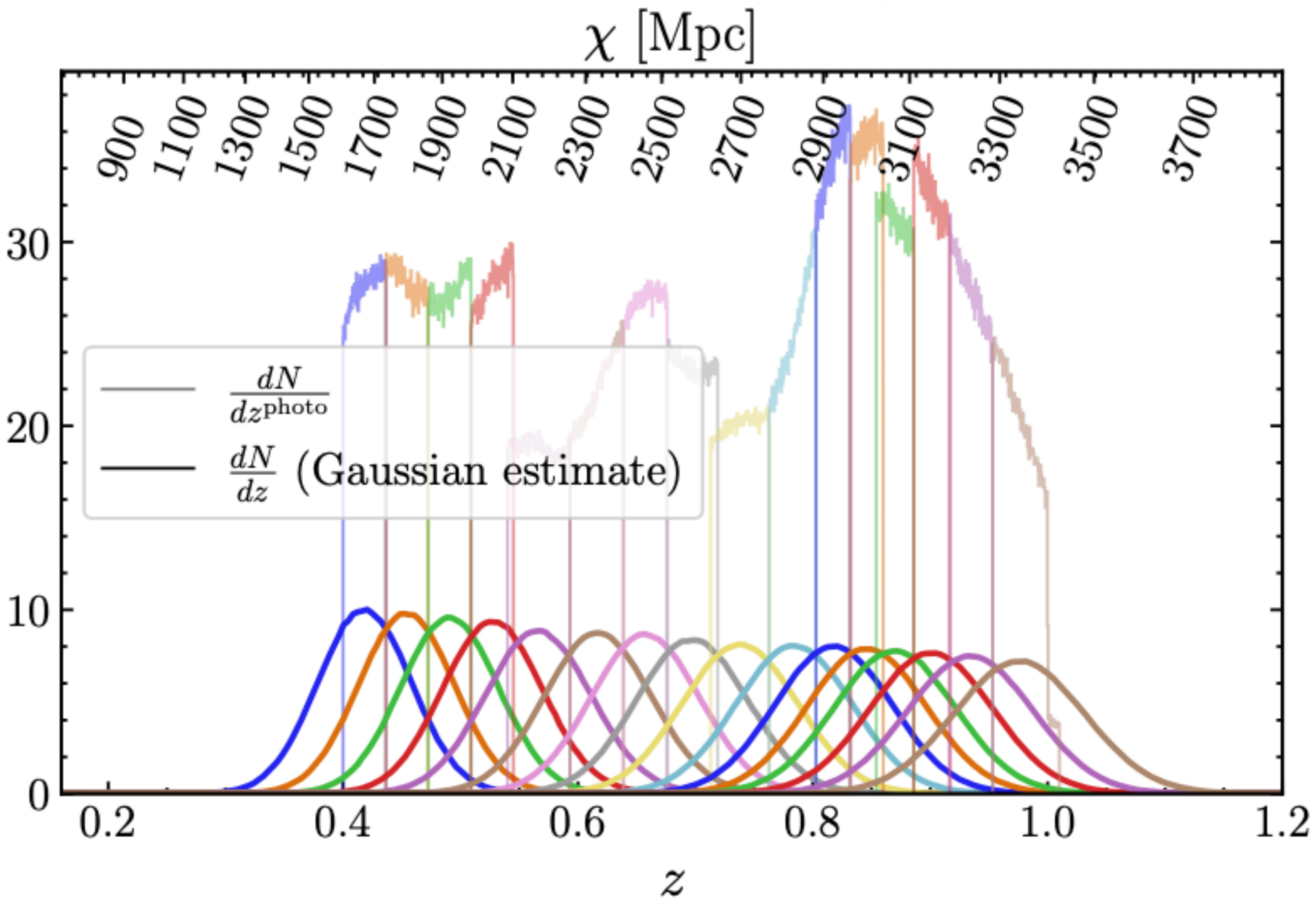
- Intrinsic sig
- Wide bin: *ra*

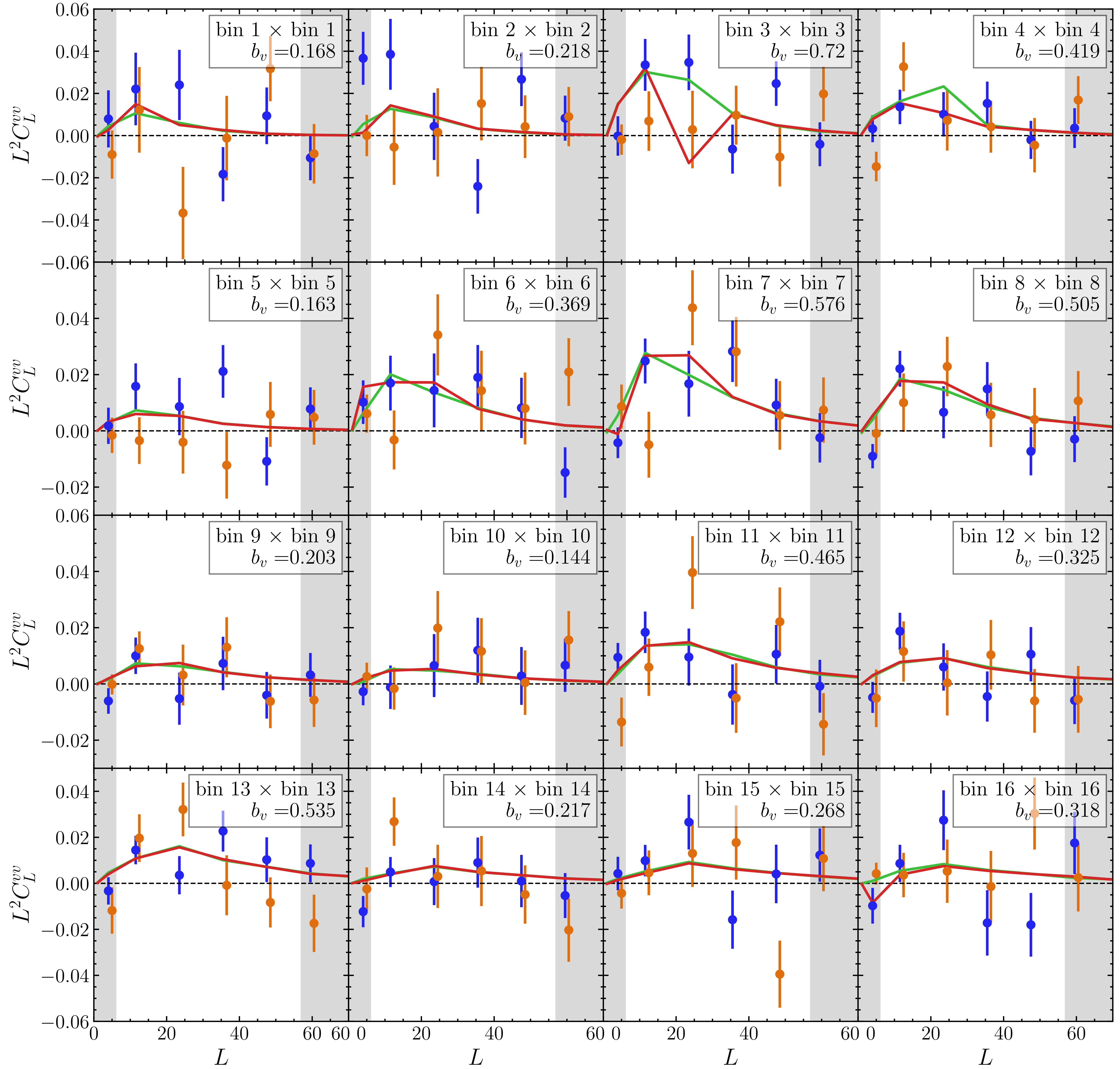




Cross correlation measurement

- Cross correlation between kSZ velocity and continuity equation velocity





Hint of auto measurement

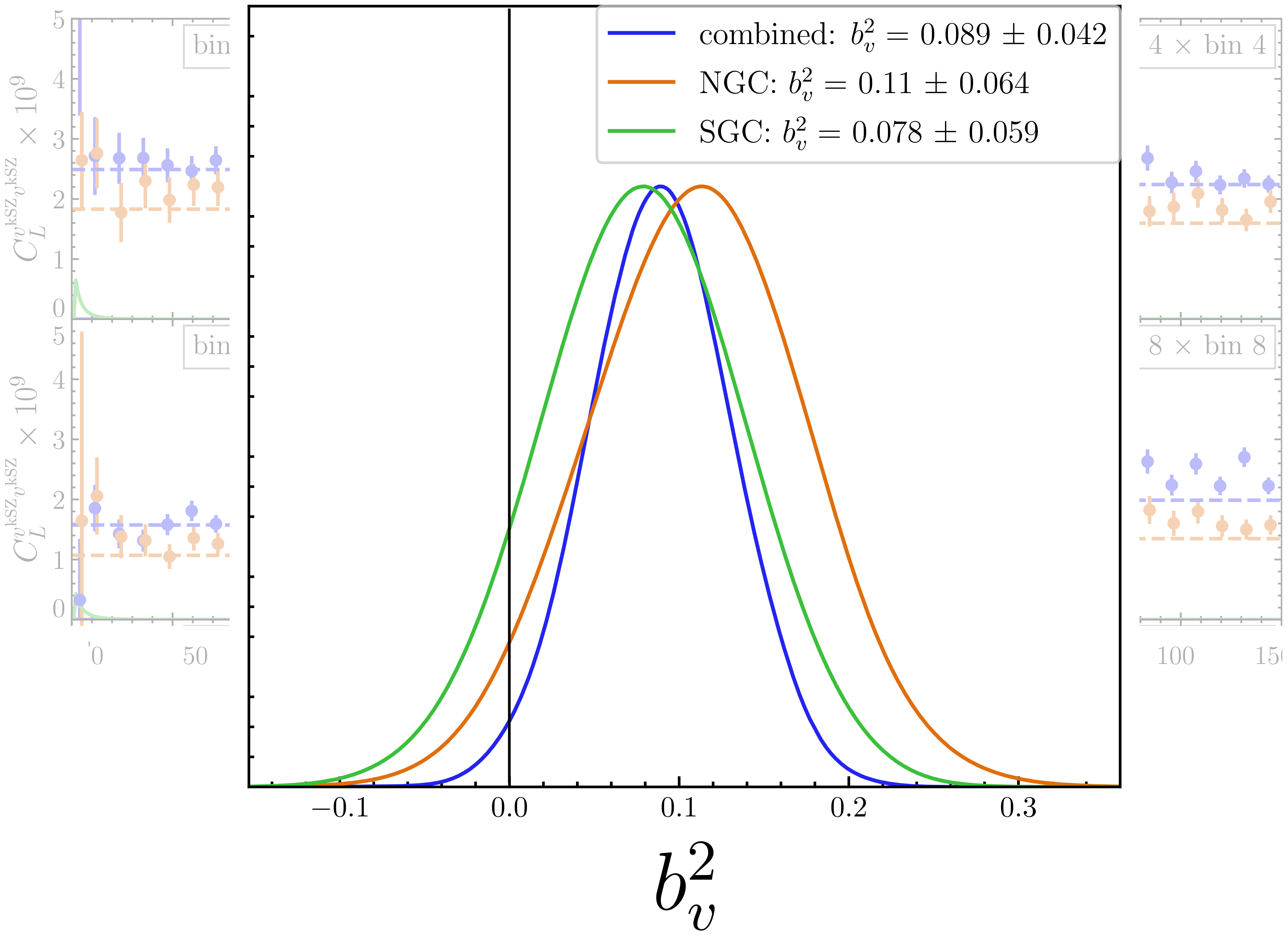
- Auto spectrum of the kSZ velocity C_L^{vv}

Fiona McCarthy, BCCP Seminar, 10th Mar 2026

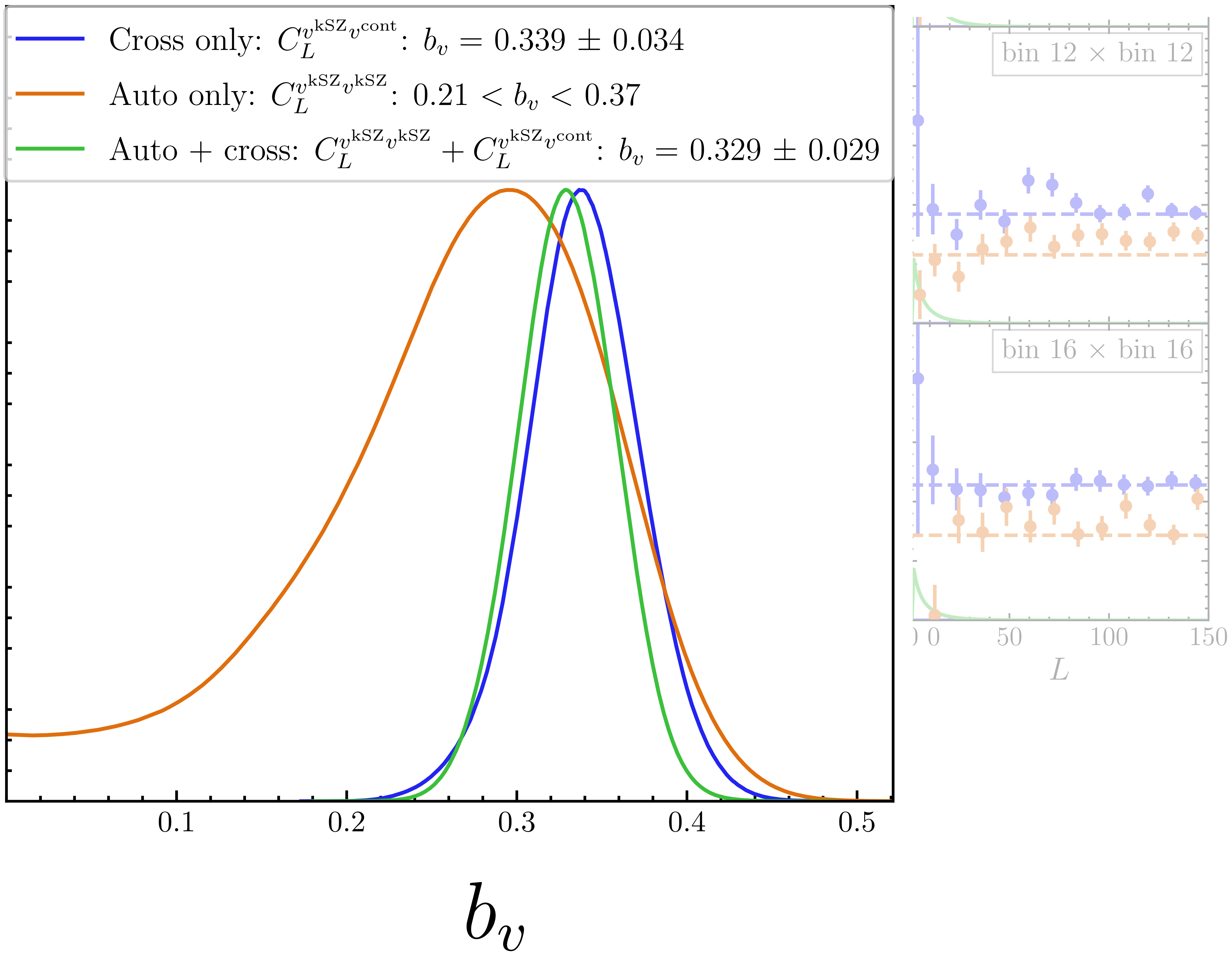
Hint of **consistent** auto measurement

- Amplitude of auto is consistent with the cross

From auto alone

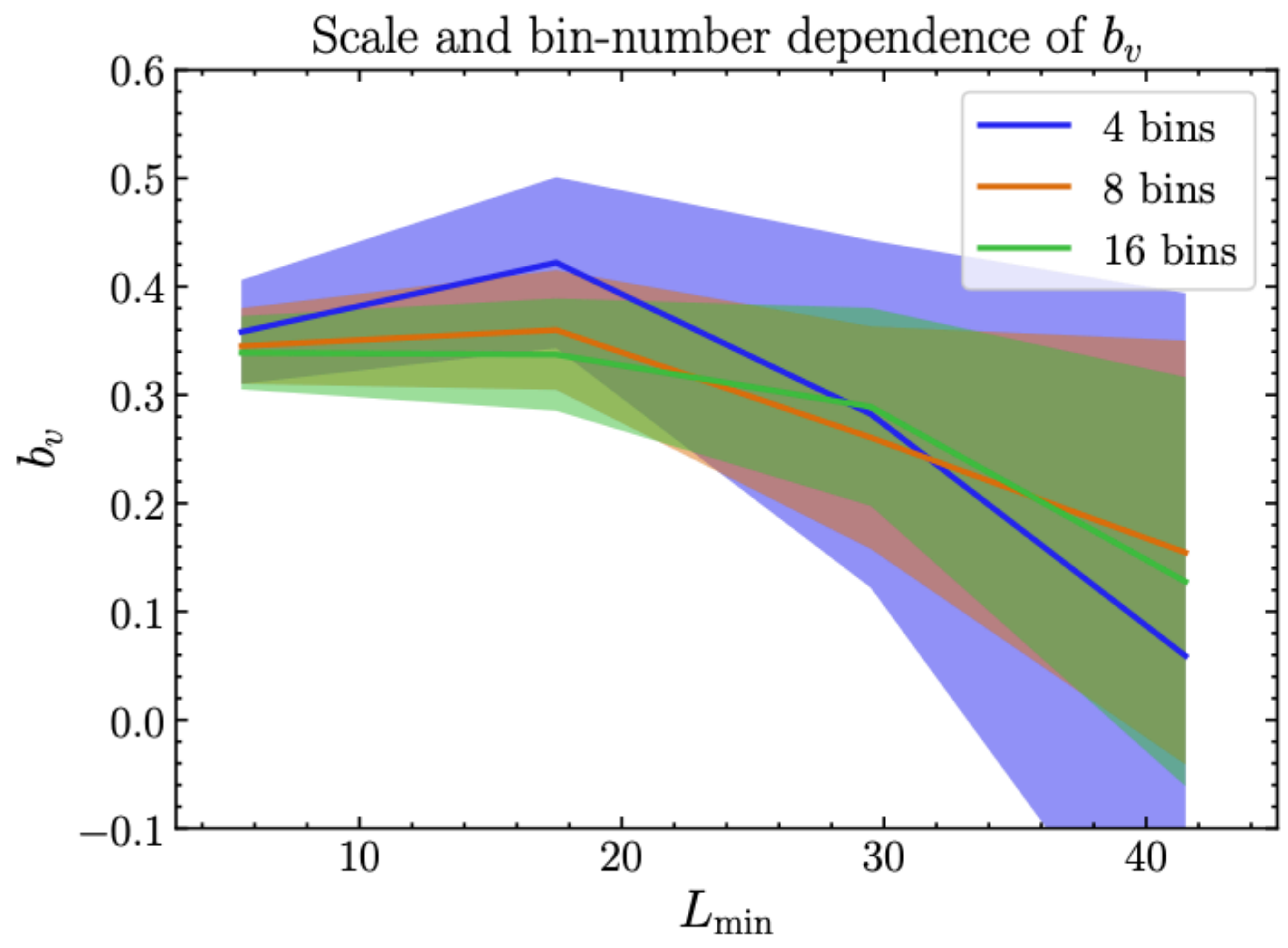


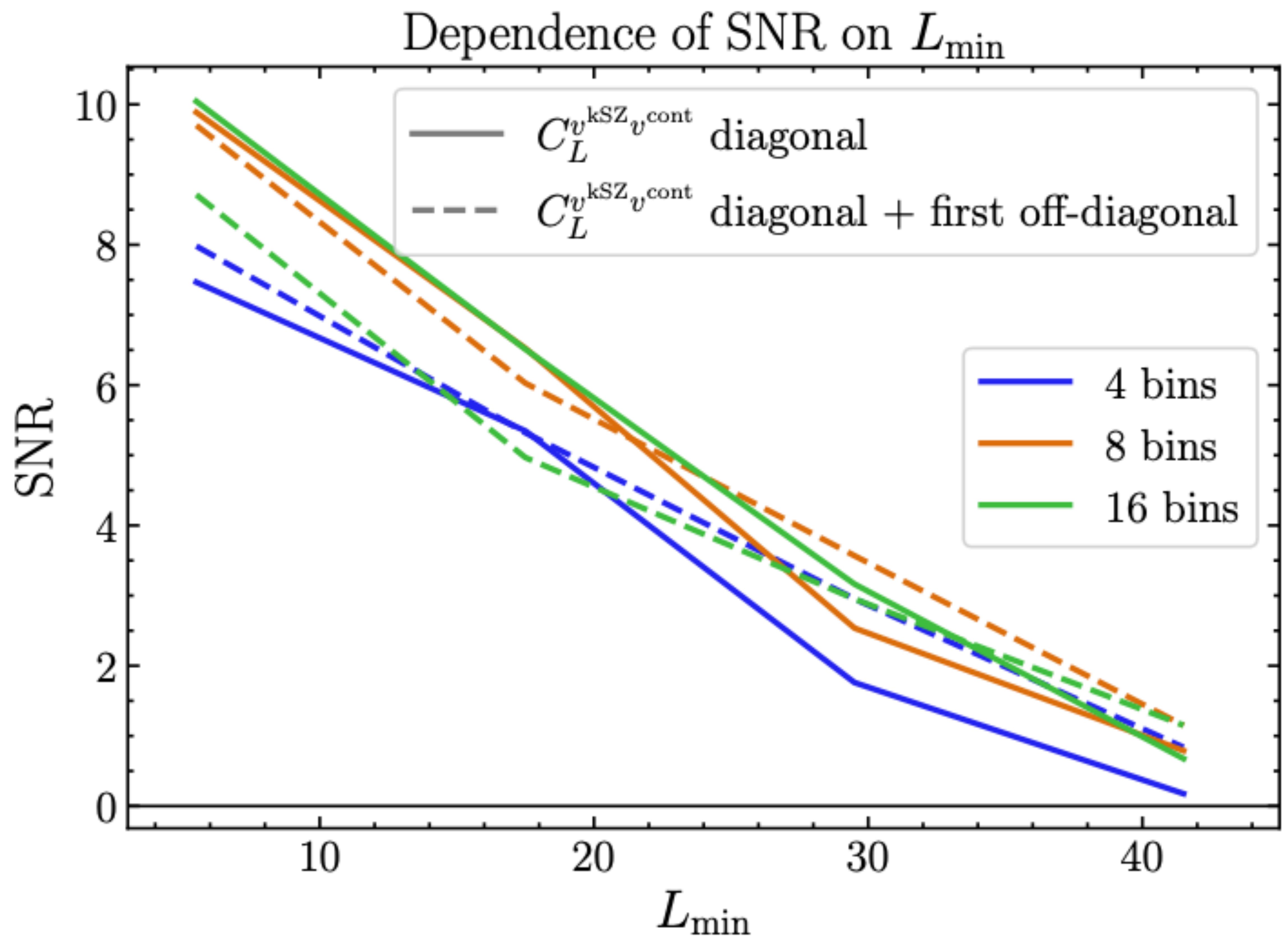
From auto + cross



Scale- and binning dependence

- Most signal-to-noise is at **large scales**
- Increase in SNR with finer binning





Modeling C_L^{vv} for $v_L^{\rm cont}$

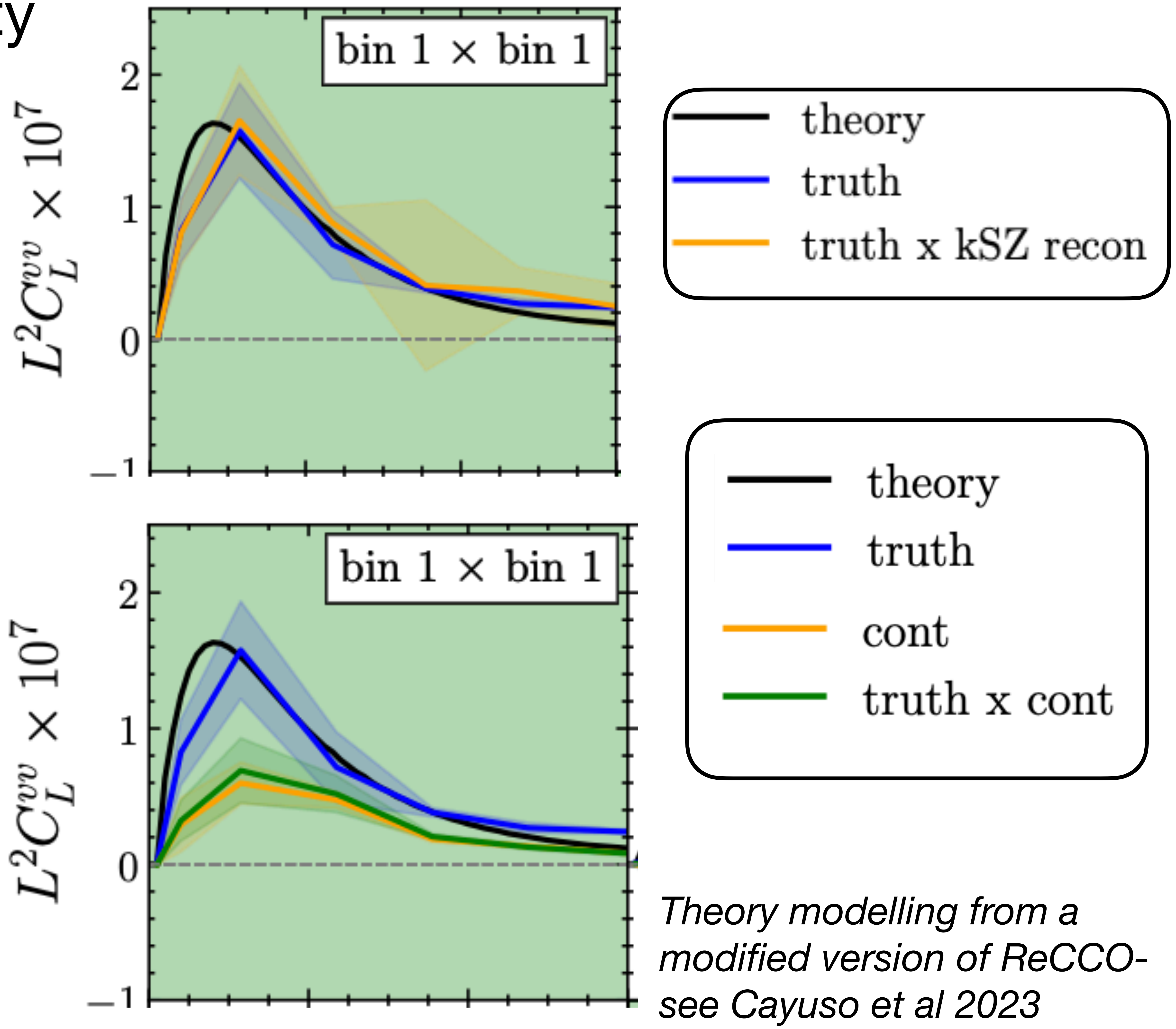
- Within ΛCDM, we can model peculiar velocity

$$v_\alpha(\hat{n}) = \int d\chi W^\alpha(\chi) v_r(\chi, \hat{n}),$$

$$C_L^{v_\alpha v_\beta} = \int d\chi_1 d\chi_2 W^\alpha(\chi_1) W^\beta(\chi_2) \times \int \frac{k^2 dk}{(2\pi)^3} \mathcal{K}_L^v(\chi_1, k) \mathcal{K}_L^v(\chi_2, k) P_{\rm lin}(\chi_1, \chi_2, k),$$

$$\mathcal{K}_L^v(\chi, k) = 4\pi i^L \frac{f(\chi)H(\chi)a(\chi)}{(2L+1)k} \left(L j_{L-1}(k\chi) - (L+1) j_{L+1}(k\chi)\right),$$

- This model works when applied to N-body sims - but $v^{\rm cont}$ is suppressed

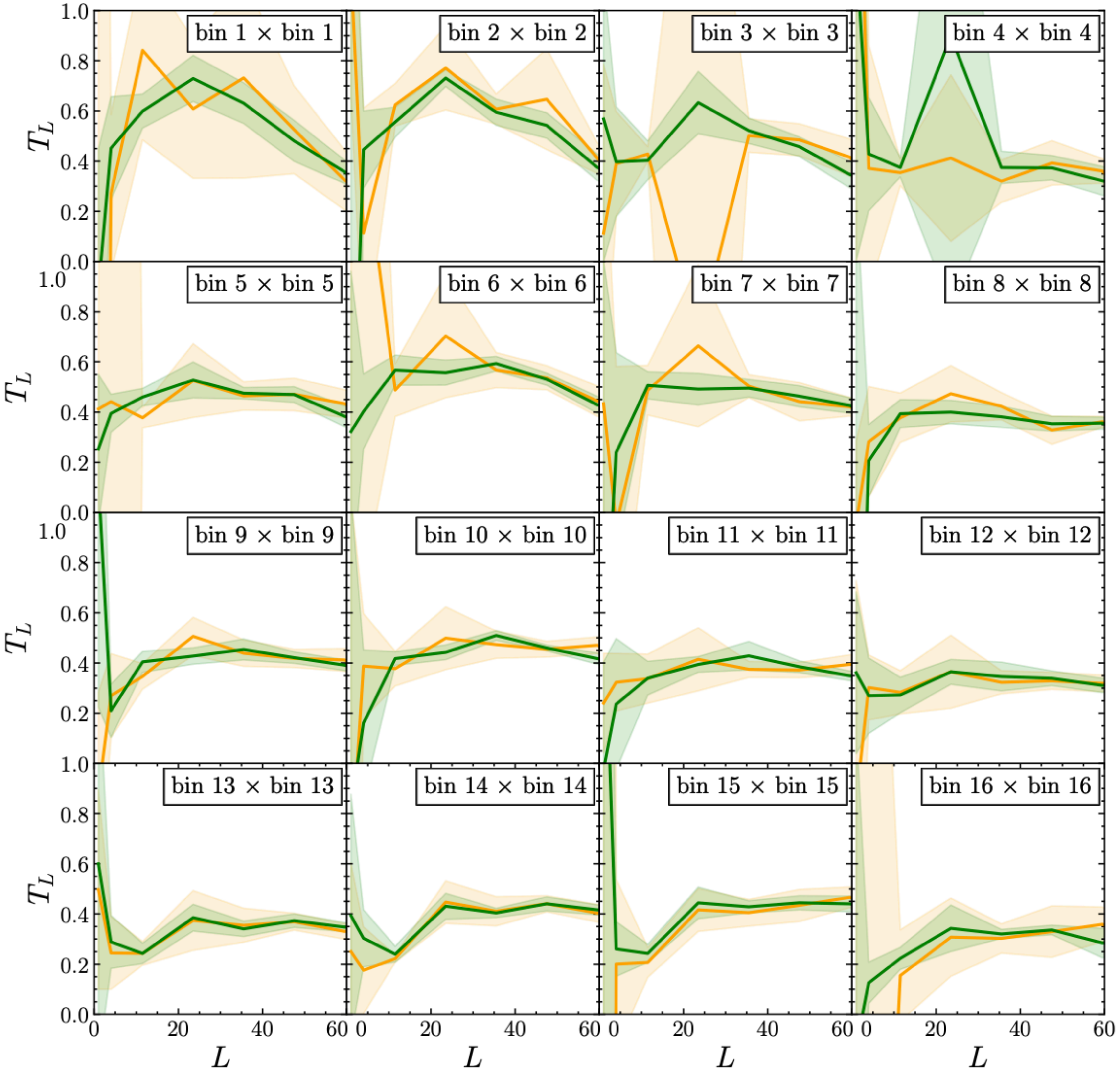


Theory modelling from a modified version of ReCCO- see Cayuso et al 2023 (including FMcC)

Modeling C_L^{vv} for $v_L^{\rm cont}$

- Use N-body+HOD sims (AbacusSummit light cone; see Maksimova et al 2021; Hadzhiyska et al 2022) to calibrate a “transfer function” for $C_L^{vv^{\rm cont}}$

$$C_L^{v^\alpha v^\beta,{\rm cont}} = T_L^{\alpha\beta} C_L^{v^\alpha v^\beta}$$



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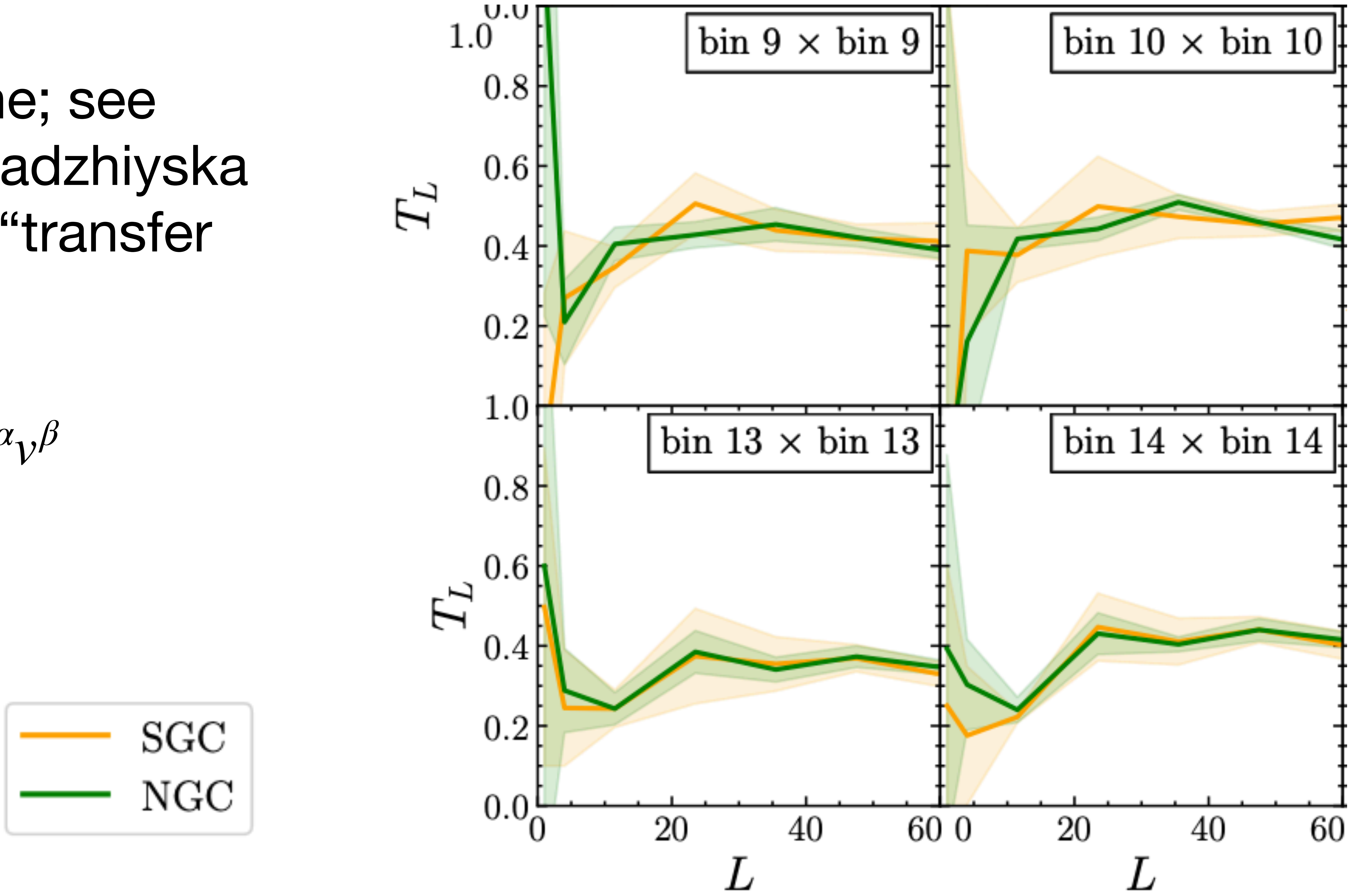
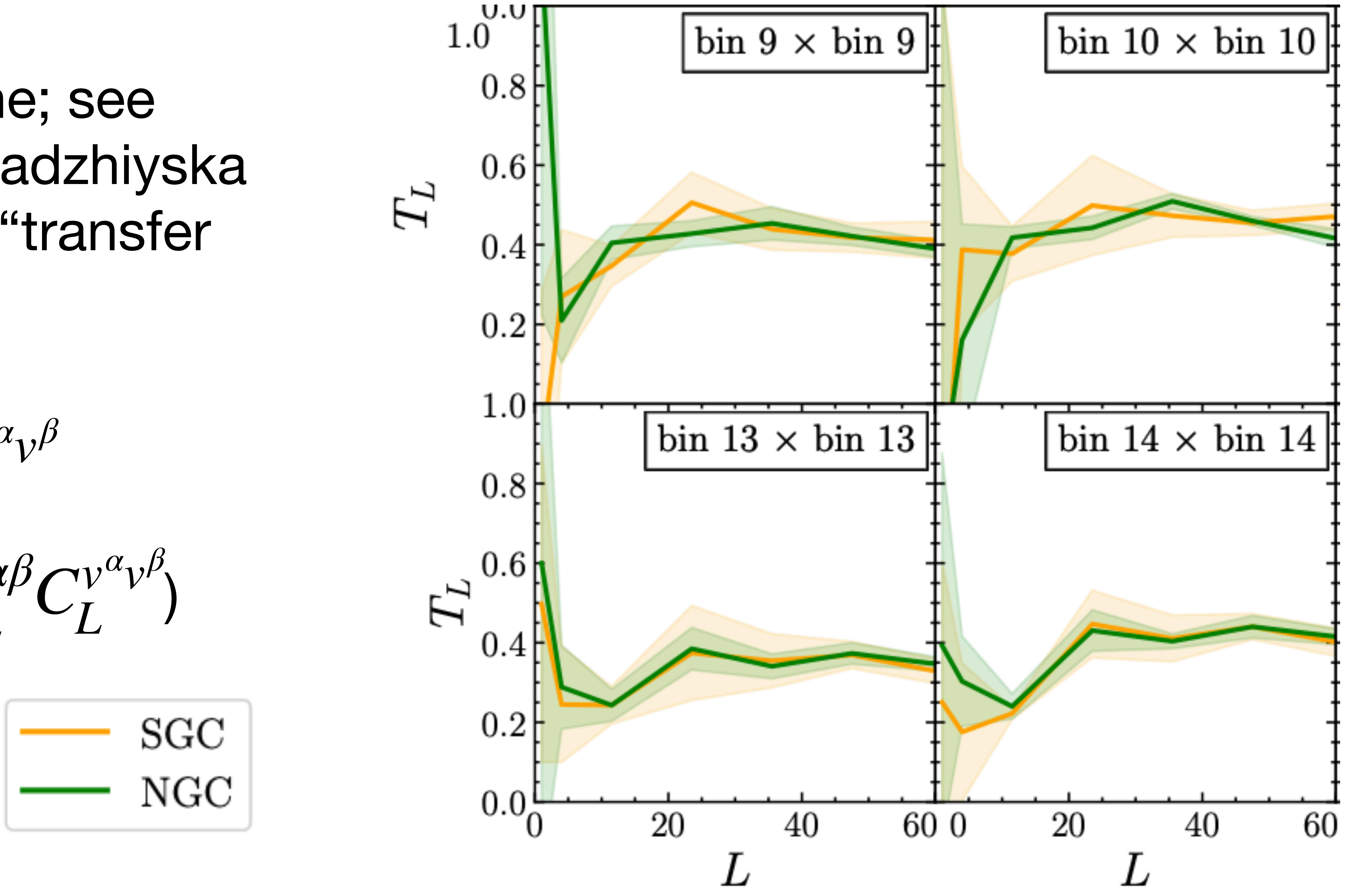


Modeling C_L^{vv} for v_L^{cont}

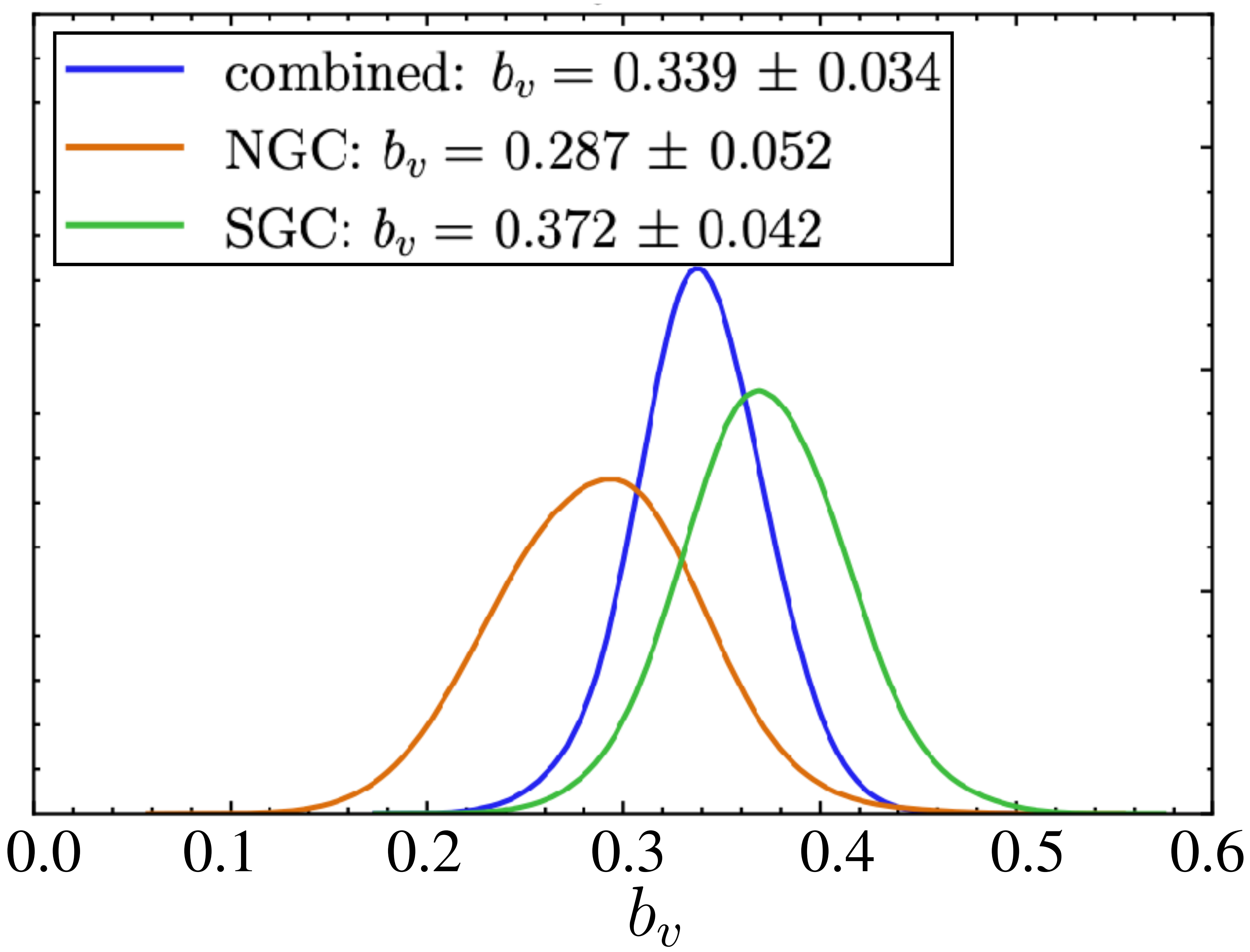
- Use N-body+HOD sims (AbacusSummit light cone; see Maksimova et al 2021; Hadzhiyska et al 2022) to calibrate a "transfer function" for $C_L^{vv^{\mathrm{cont}}}$

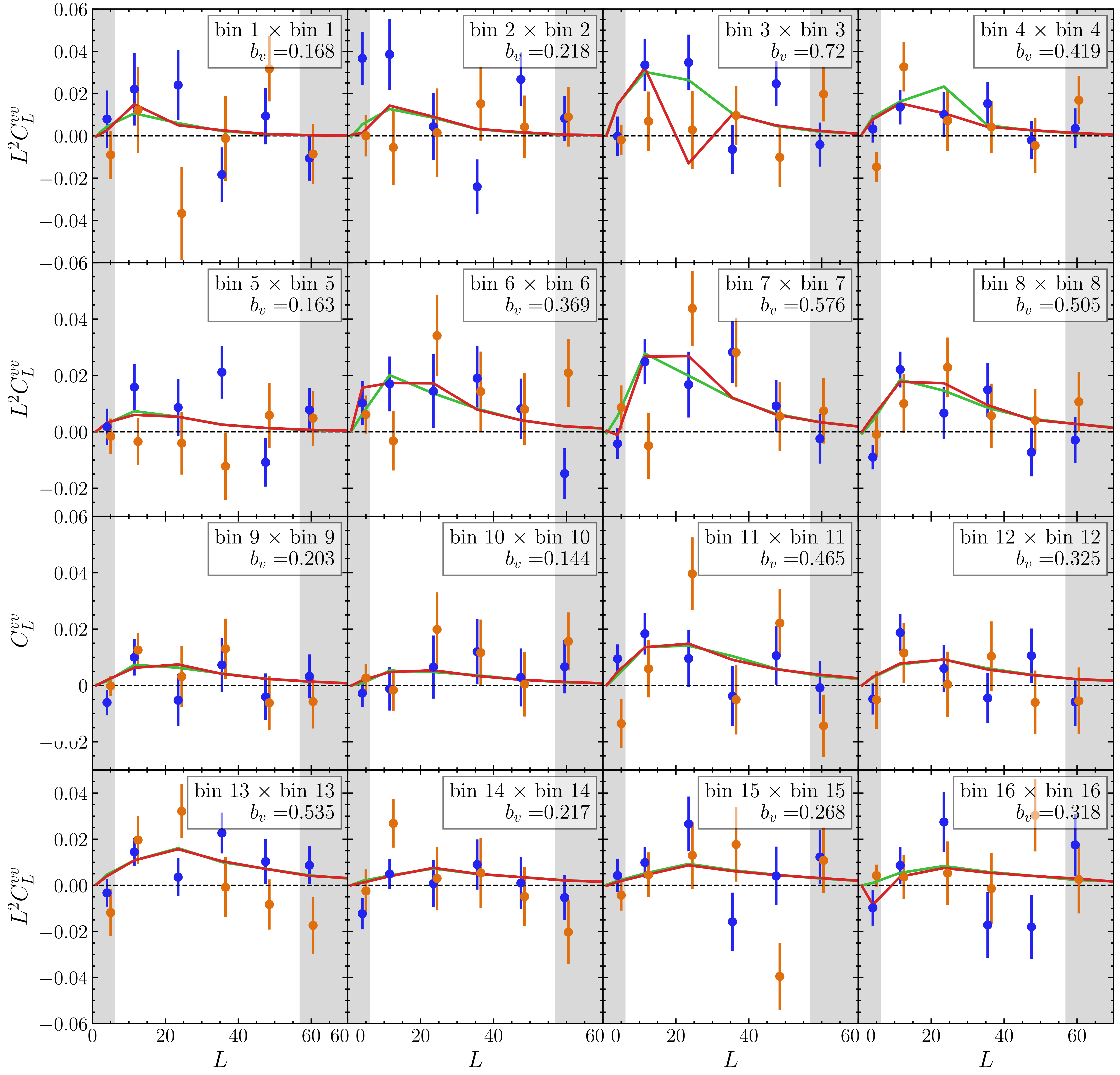
$$C_L^{v^\alpha v^{\beta,\mathrm{cont}}} = T_L^{\alpha\beta} C_L^{v^\alpha v^\beta}$$

(Then $C_L^{v^{\alpha,\mathrm{kSZ}} v^{\beta,\mathrm{cont}}} = b_v^\alpha T_L^{\alpha\beta} C_L^{v^\alpha v^\beta}$)



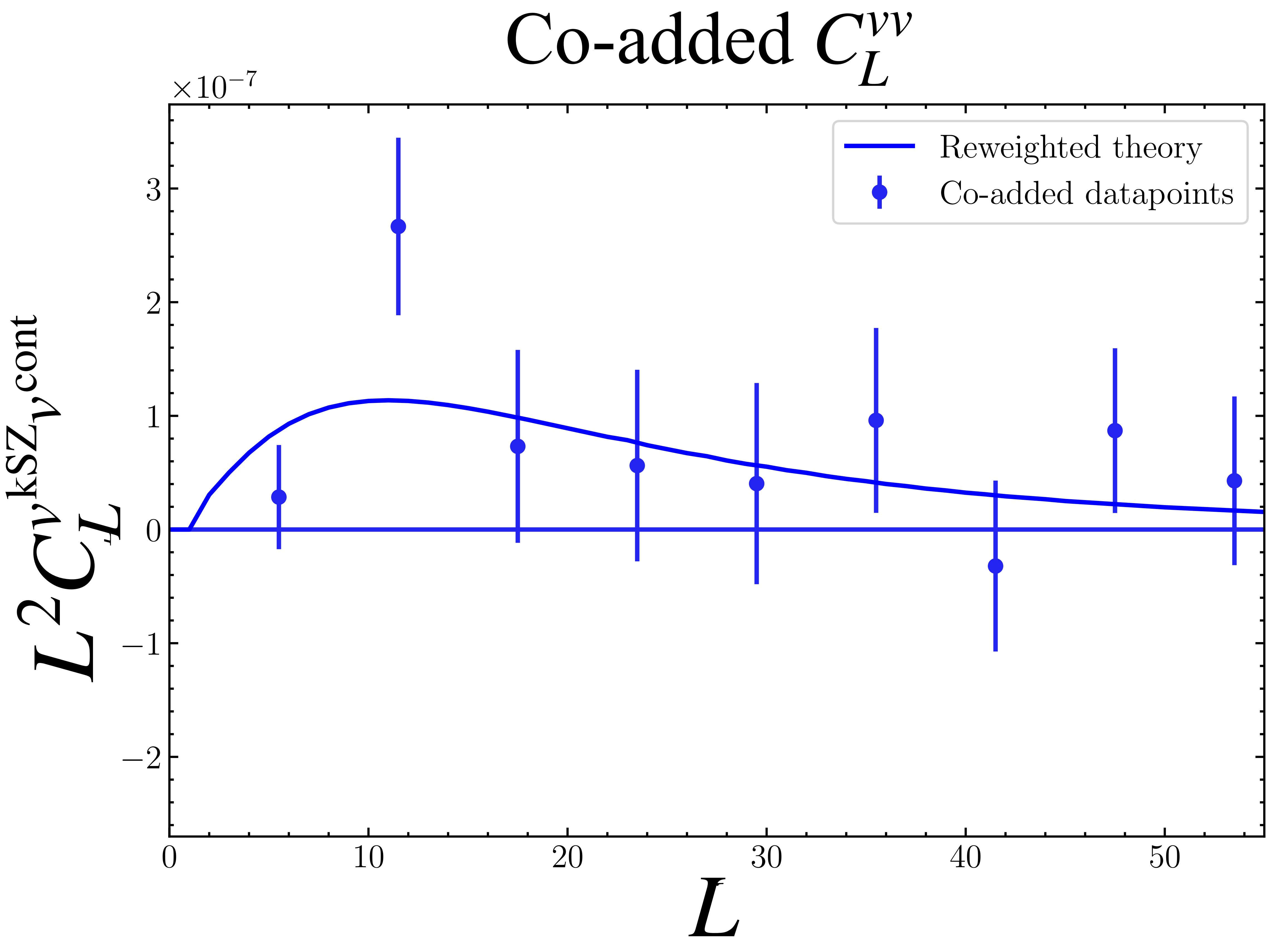
Comparison of model to data



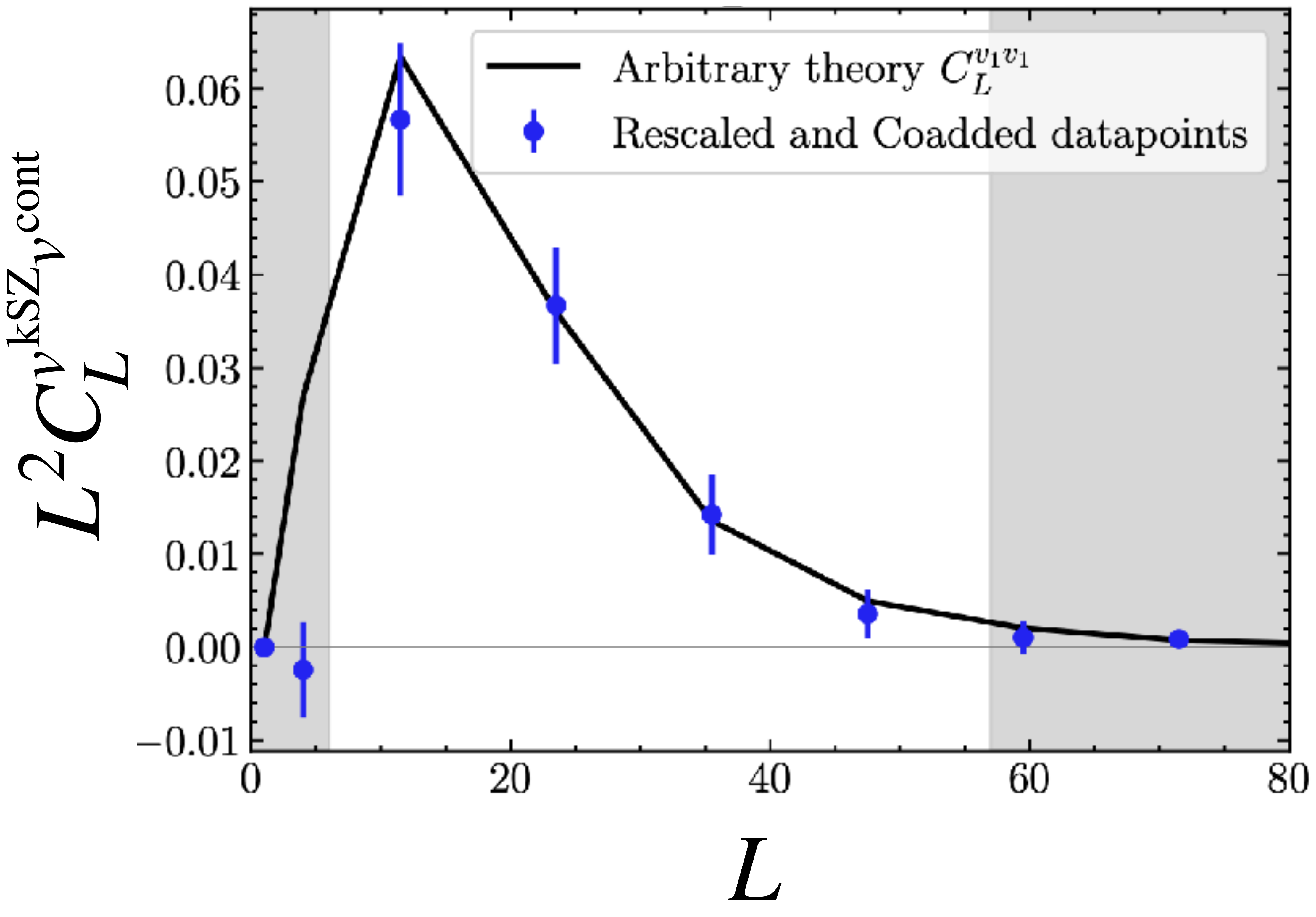


spec	constraint (combined)	SNR	N_{points}	$\chi^2_{\mathrm{min}}\ (b_v^\alpha)$	PTE (b_v^α)
NGC	0.287 ± 0.052	5.53	64	55.49	0.21
SGC	0.372 ± 0.042	8.78	64	55.6	0.21
Joint	0.339 ± 0.034	10.04	128	129.25	0.13

Co-add across redshift bins



1st measurement, 2025a (ACT-DESILS-SDSS)



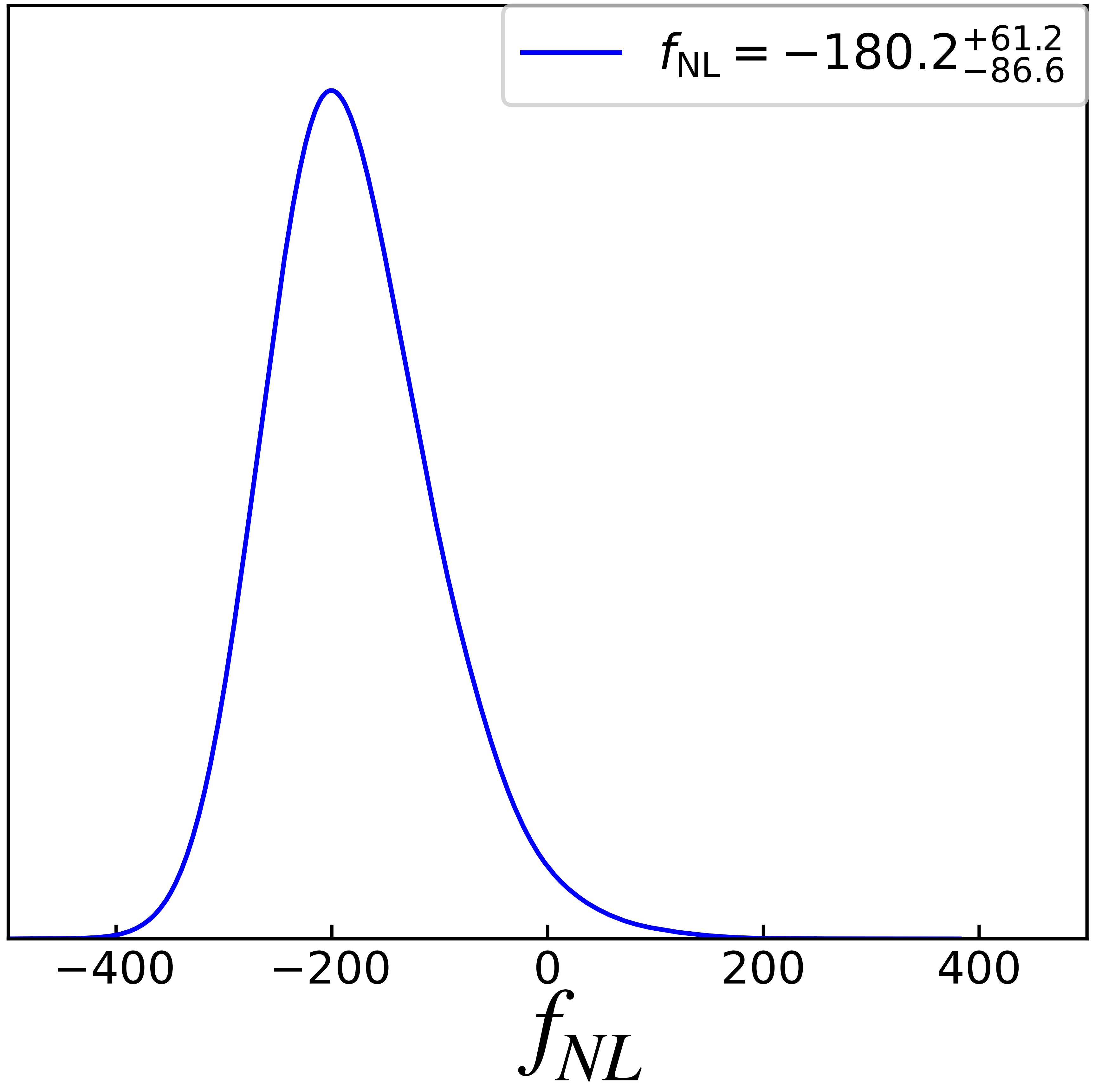
Latest measurement, 2025b (ACT-DESILS-DESILS)

Non-Gaussianity constraint

- $C_L^{v^{\rm cont}v^{\rm kSZ}}$ is sensitive to f_{NL} from b_g

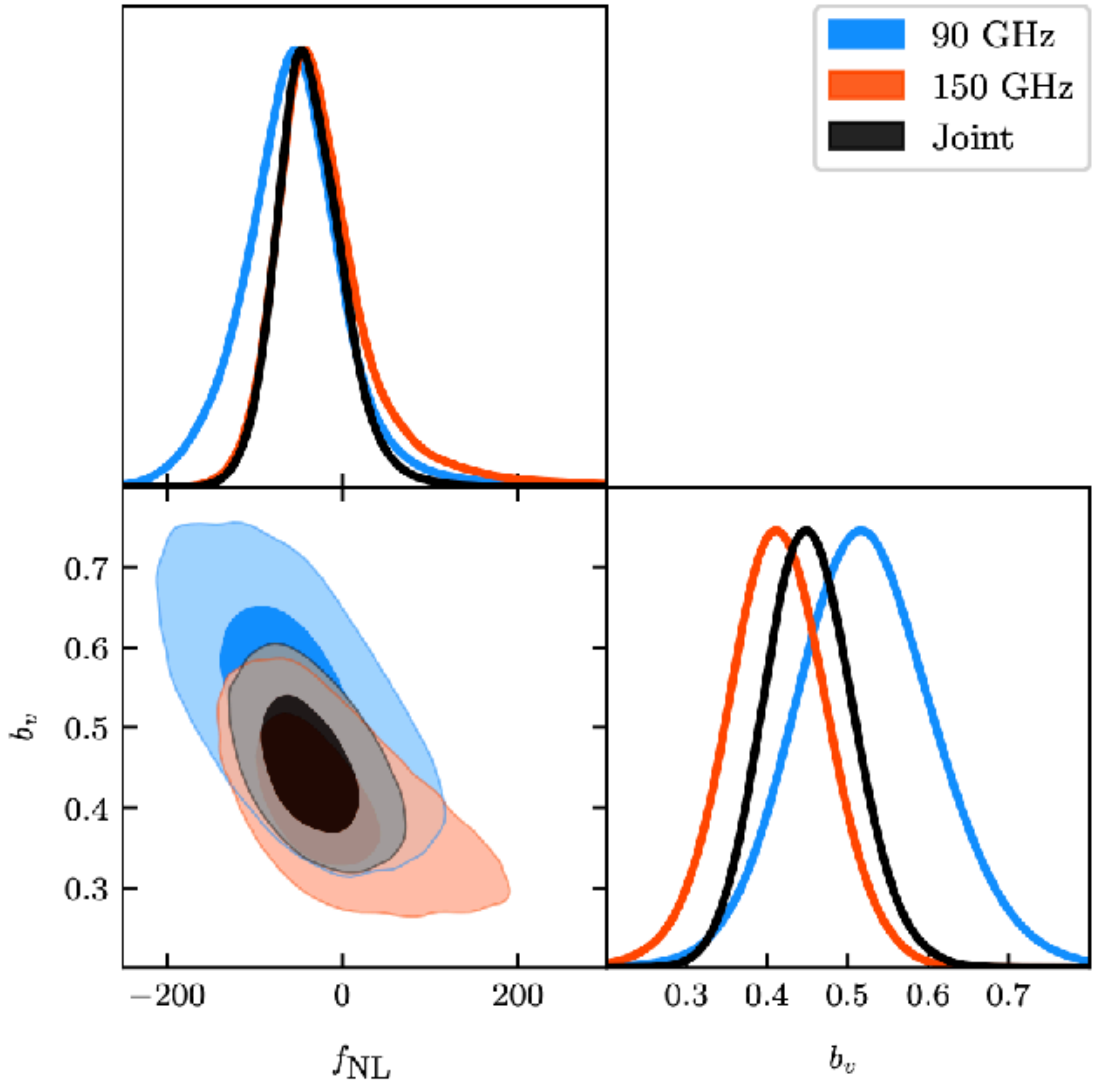
Continuity equation: $-i\vec{k}\cdot\vec{v} - i\vec{k}\cdot\left(v_{||}\hat{n}\right) = -aHf\frac{\delta_g}{b}$

$$v^{\rm cont,true} = \frac{b^{\rm true}}{b^{\rm fid}} v^{\rm cont,estimated}$$

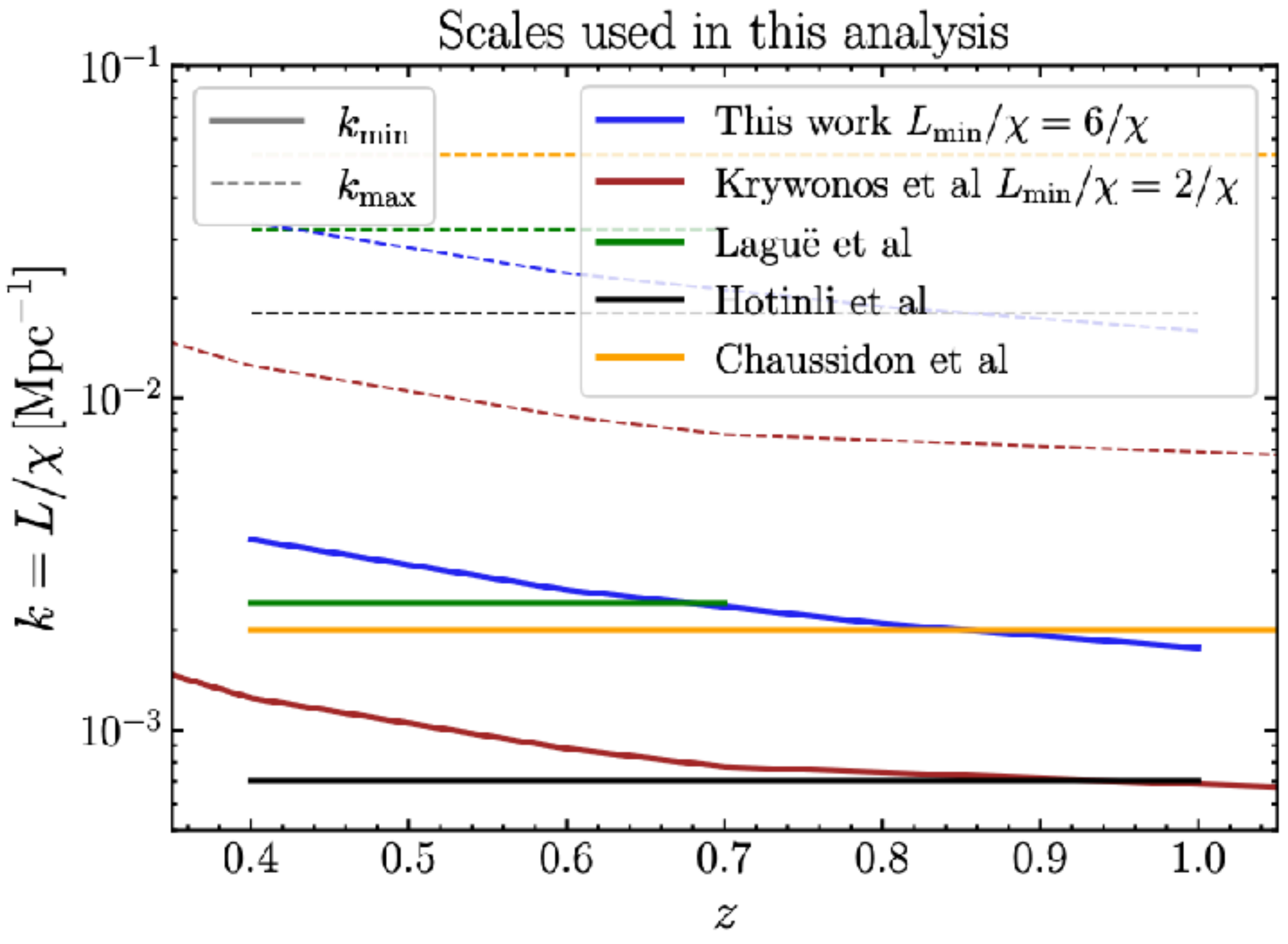


Comparison to other work in 3-D

- See **Hotinli et al 2025:** $f_{NL} = -30^{+40}_{-33}$



- Possible explanation: different scale coverage although **3-D vs 2-D comparison is not a fully solved problem**



Large scale cross-correlation: $C_L^{v^{\mathrm{kSZ}} v^{\mathrm{cont}}}$ or $C_L^{v^{\mathrm{kSZ}} g}$?

- From kSZ, we get $v_L^{\mathrm{kSZ}} \sim T_S \delta_s^g$
- Estimate v^{cont} from the solving the continuity equation on the large-scale galaxies

$$-i\vec{k}\cdot\vec{v} - i\vec{k}\cdot\left(v_{||}\hat{n}\right) = -\,aHf\frac{\delta_g}{b}$$

- Two options: Measure $\left\langle v_L^{\mathrm{kSZ}} \delta_L^g \right\rangle$ ($C_L^{v^{\mathrm{kSZ}} g}$) or $\left\langle v^{\mathrm{kSZ}} v^{\mathrm{cont}} \right\rangle$ ($C_L^{v^{\mathrm{kSZ}} v^{\mathrm{cont}}}$)

Large scale cross-correlation: $C_L^{v^{\mathrm{kSZ}} v^{\mathrm{cont}}}$ or $C_L^{v^{\mathrm{kSZ}} g}$?

- From kSZ, we get $v_L^{\mathrm{kSZ}} \sim T_S \delta_s^g$
- Estimate v^{cont} from the solving the continuity equation on the **large-scale galaxies** δ^g

$$-i\vec{k}\cdot\vec{v} - i\vec{k}\cdot\left(v_{||}\hat{n}\right) = -aHf\frac{\delta_g}{b}$$

- Two options: Measure $\left\langle v_L^{\mathrm{kSZ}} \delta_L^g \right\rangle$ ($C_L^{v^{\mathrm{kSZ}} g}$) or $\left\langle v^{\mathrm{kSZ}} v^{\mathrm{cont}} \right\rangle$ ($C_L^{v^{\mathrm{kSZ}} v^{\mathrm{cont}}}$)

Easy to model and interpret

Much messier to model and interpret (v^{cont} is not perfect)

Large scale cross-correlation: $C_L^{v^{\rm kSZ}v^{\rm cont}}$ or $C_L^{v^{\rm kSZ}g}$?

- From kSZ, we get $v_L^{\rm kSZ} \sim T_S \delta_s^g$
- Estimate $v^{\rm cont}$ from the solving the continuity equation on the **large-scale galaxies** δ^g

$$-i\vec{k}\cdot\vec{v} - i\vec{k}\cdot\left(v_{||}\hat{n}\right) = -aHf\frac{\delta_g}{b}$$

- Two options: Measure $\left\langle v_L^{\rm kSZ}\delta_L^g\right\rangle$ ($C_L^{v^{\rm kSZ}g}$) or $\left\langle v^{\rm kSZ}v^{\rm cont}\right\rangle$ ($C_L^{v^{\rm kSZ}v^{\rm cont}}$)

Easy to model and interpret

Much messier to model and interpret ($v^{\rm cont}$ is not perfect)

- We chose $\left\langle v^{\rm kSZ}v^{\rm cont}\right\rangle$! Why? **Foregrounds not automatically suppressed in** $\left\langle v_L^{\rm kSZ}\delta_L^g\right\rangle \sim \left\langle T_s\delta_s^g\delta_L^g\right\rangle$

Foregrounds in $C_L^{v^{\mathrm{kSZ}}g} \sim \left\langle T_S \delta_S^g \delta_L^G \right\rangle$

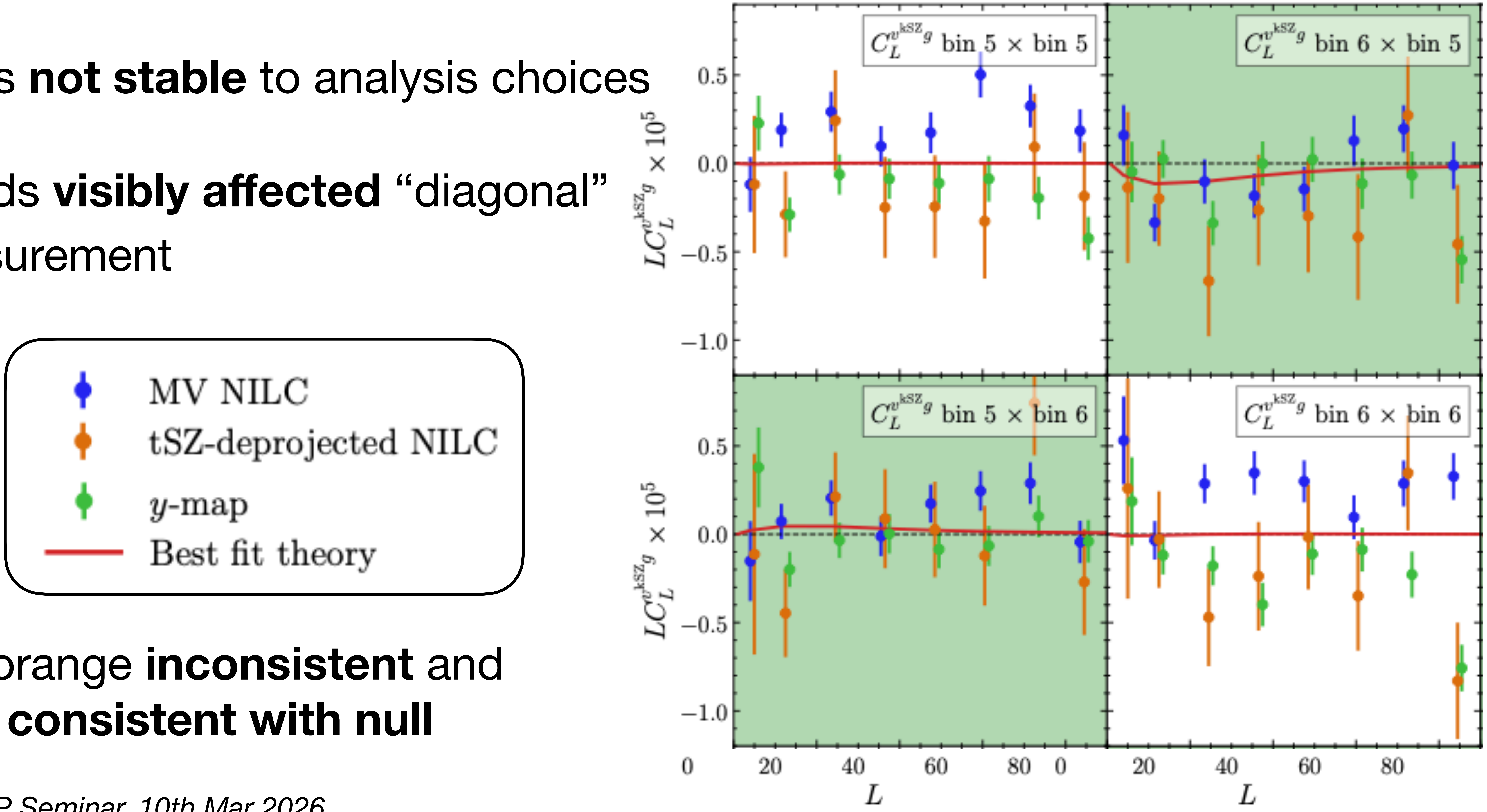
- $\left\langle T_S \delta_S^g \delta_L^g \right\rangle$ contains a foreground contribution

$$T = T^{\mathrm{kSZ}} + FG$$

- Extragalactic foregrounds (eg CIB, tSZ) **are non-Gaussian on small scales and trace the density field**
- $\left\langle FG_s \delta_s^g \delta_L^G \right\rangle \sim \left\langle \delta_s^{\mathrm{CIB}} \delta_s^g \delta_L^G \right\rangle$ - this signal is **non-zero** due to **gravitationally-induced non-Gaussianity of δ**
- These are **suppressed** by the filtering that goes from $\delta_L^g \rightarrow v_r^{\mathrm{cont}}$ ($\delta \rightarrow \hat{n} \cdot \frac{i\vec{k}}{k} \delta$)

Foregrounds in $C_L^{v^{\mathrm{kSZ}}g} \sim \left\langle T_S \delta_S^g \delta_L^G \right\rangle$

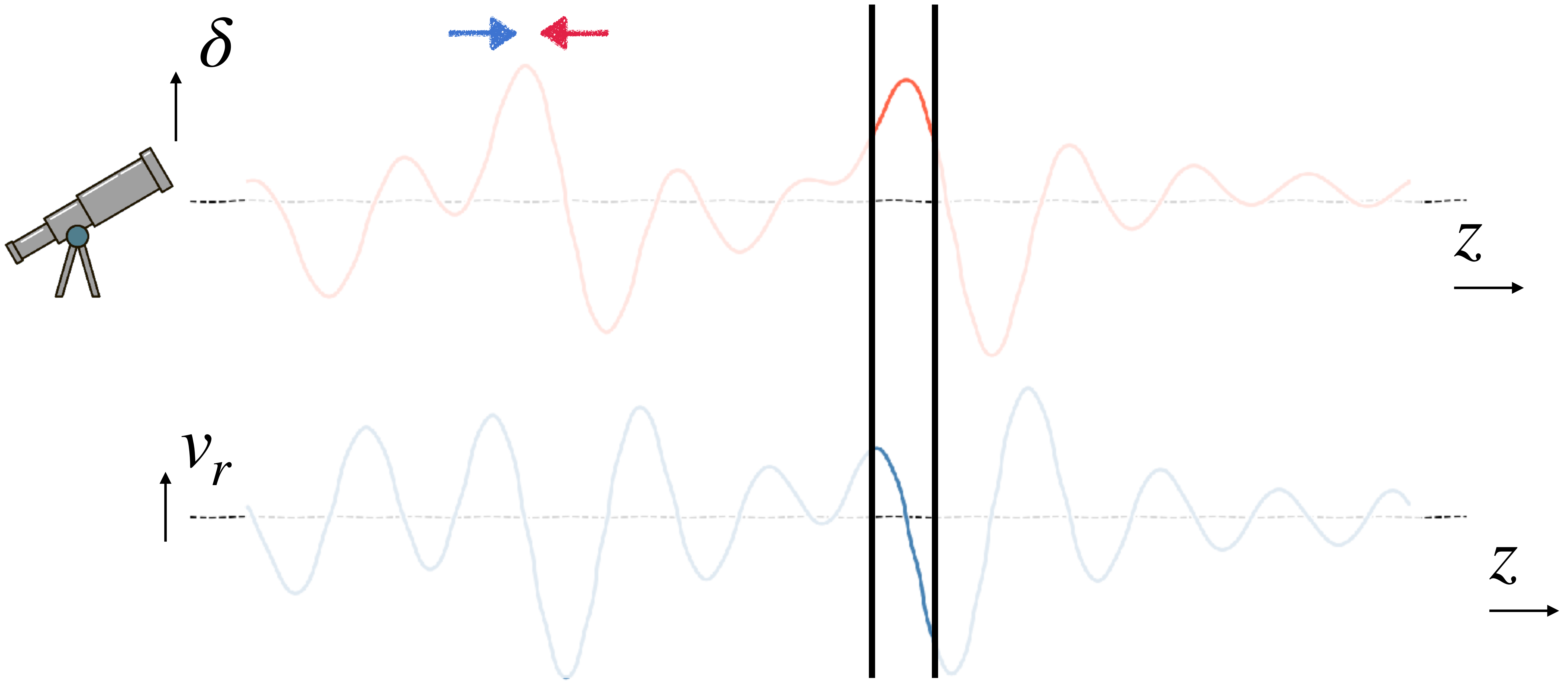
- $C_L^{v^{\mathrm{kSZ}}g}$ was **not stable** to analysis choices
- Foregrounds **visibly affected** “diagonal” $C_L^{g^\alpha v^\alpha}$ measurement



- Blue and orange **inconsistent** and green **not consistent with null**

Redshift resolution and structure

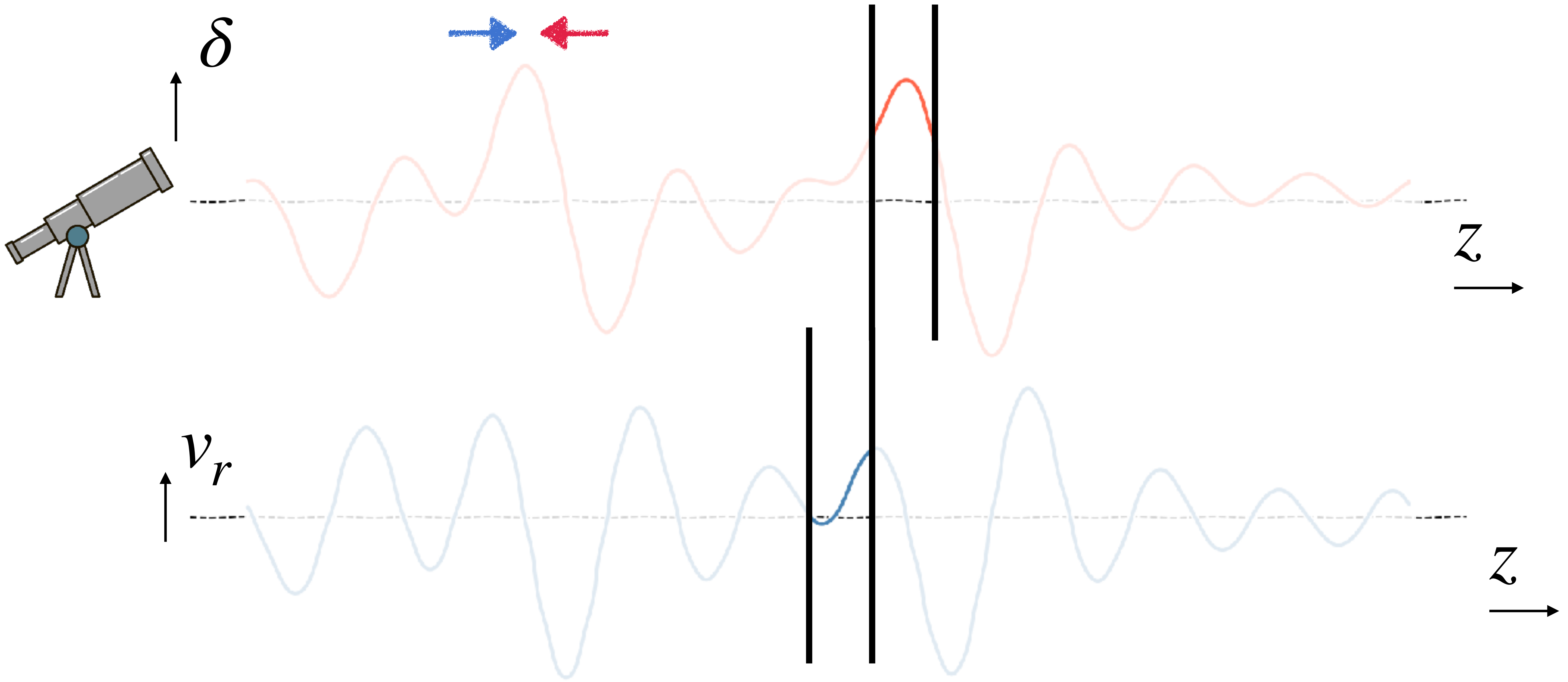
- Velocity and density are **out-of-phase**
- $\langle v^\alpha g^\alpha \rangle = 0$



Redshift resolution and structure

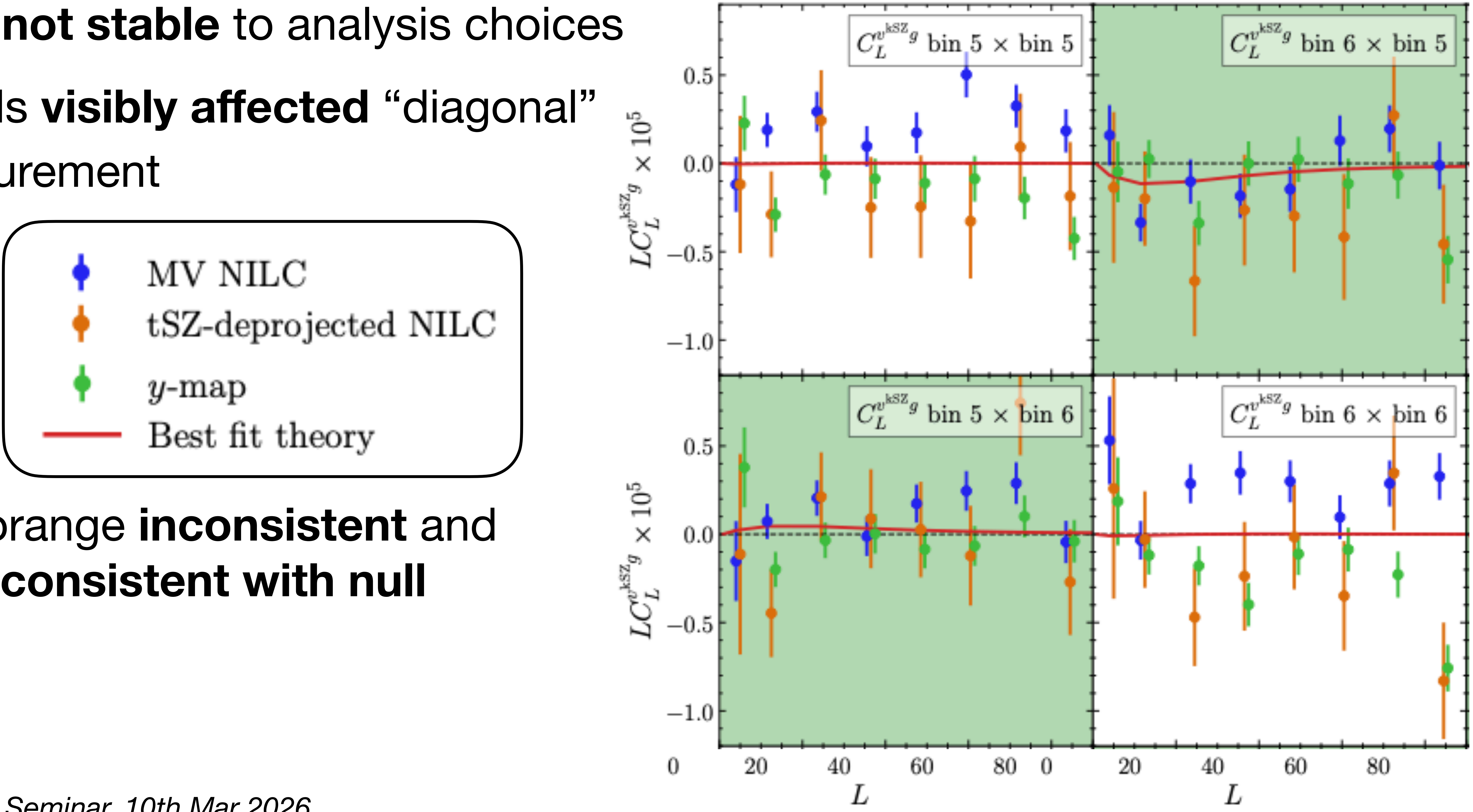
- Velocity and density are **out-of-phase**
- "Off-diagonal" correlations are important

- $\langle v^\alpha g^\alpha \rangle = 0$
- $\left\langle v^\alpha g^{\alpha+1} \right\rangle \neq 0$



Foregrounds in $C_L^{vg} \sim \left\langle T_S \delta_S^g \delta_L^G \right\rangle$

- $C_L^{v^{\mathrm{kSZ}}g}$ was **not stable** to analysis choices
- Foregrounds **visibly affected** "diagonal" $C_L^{g^\alpha v^\alpha}$ measurement



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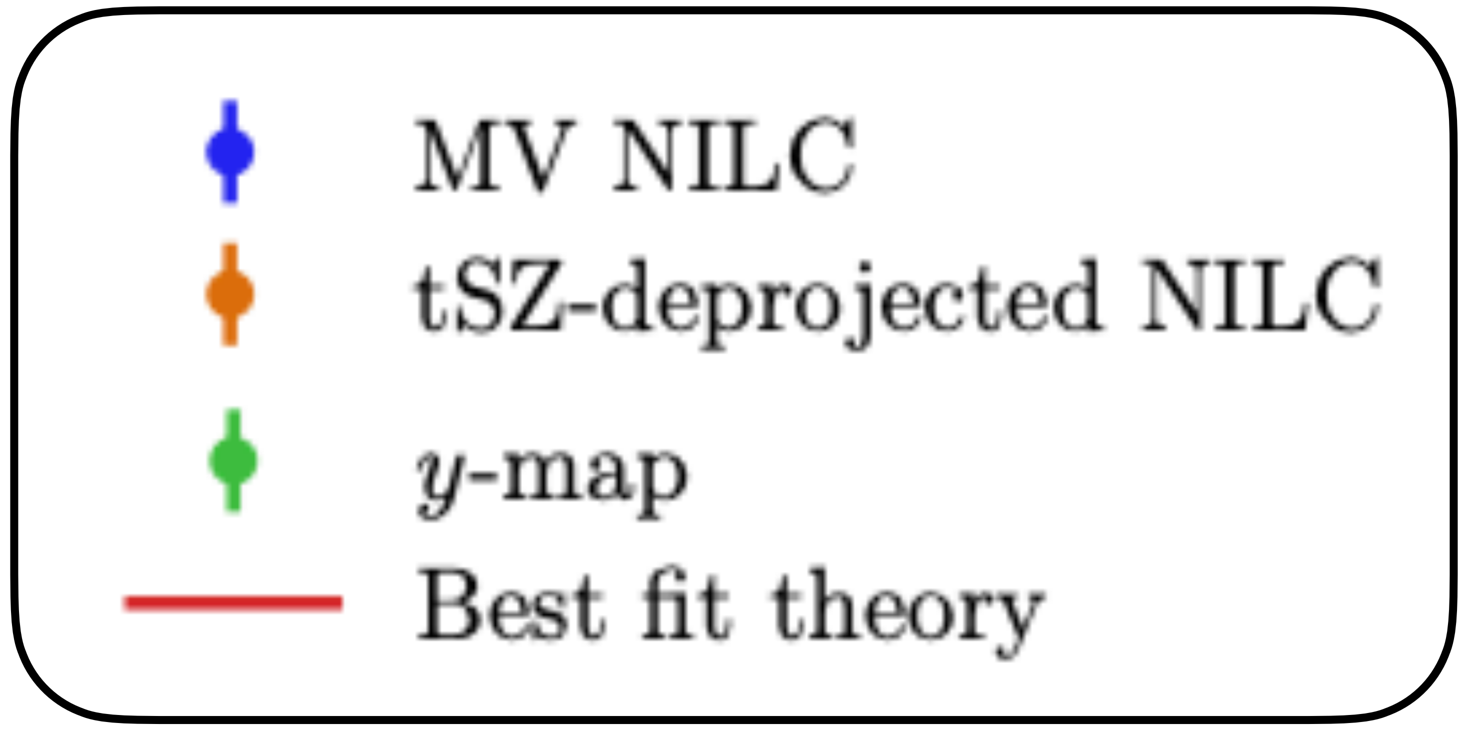

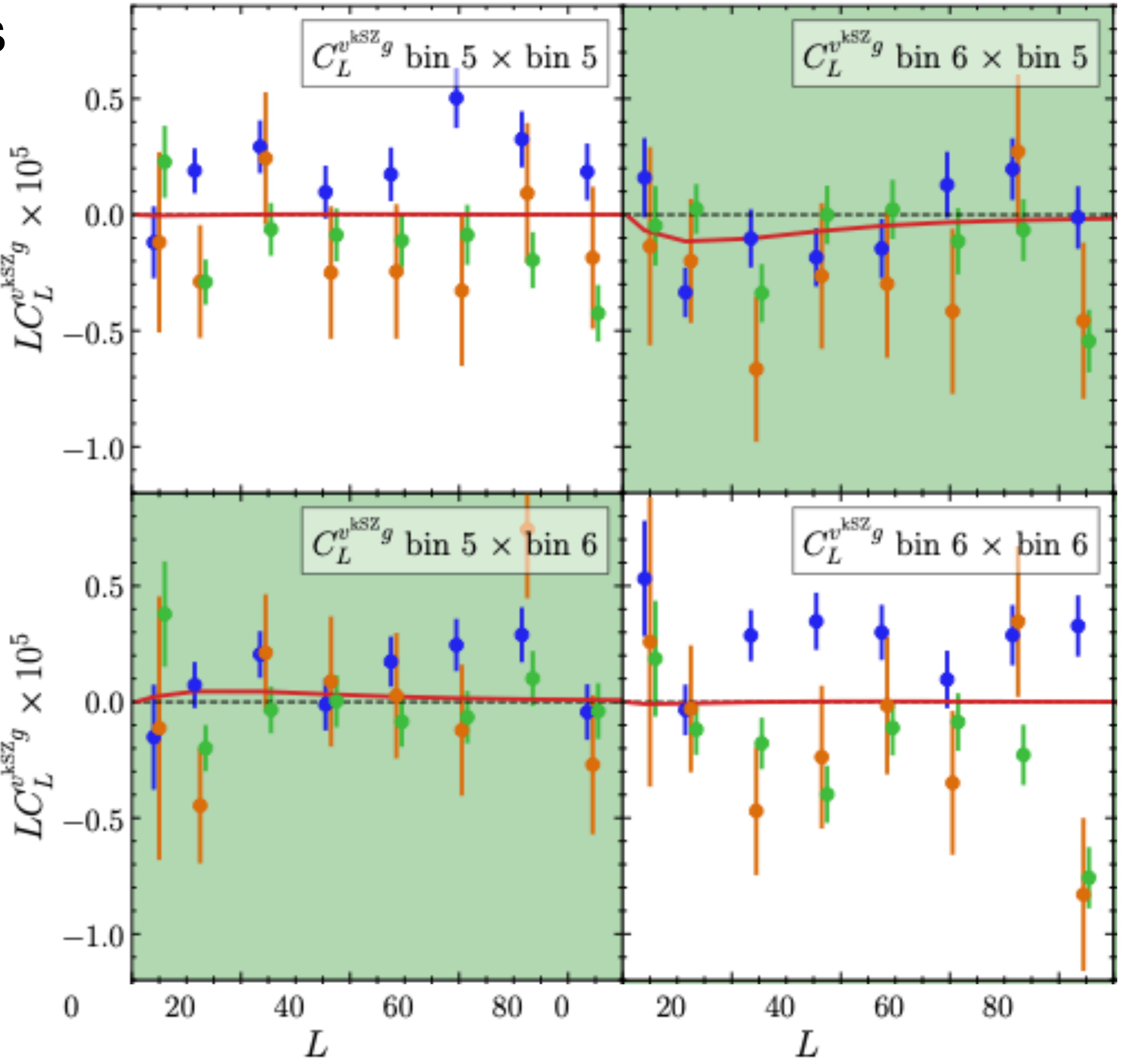

- Blue and orange **inconsistent** and green **not consistent with null**
- One option: use just off-diagonal. But **worried about non-zero redshift overlap**

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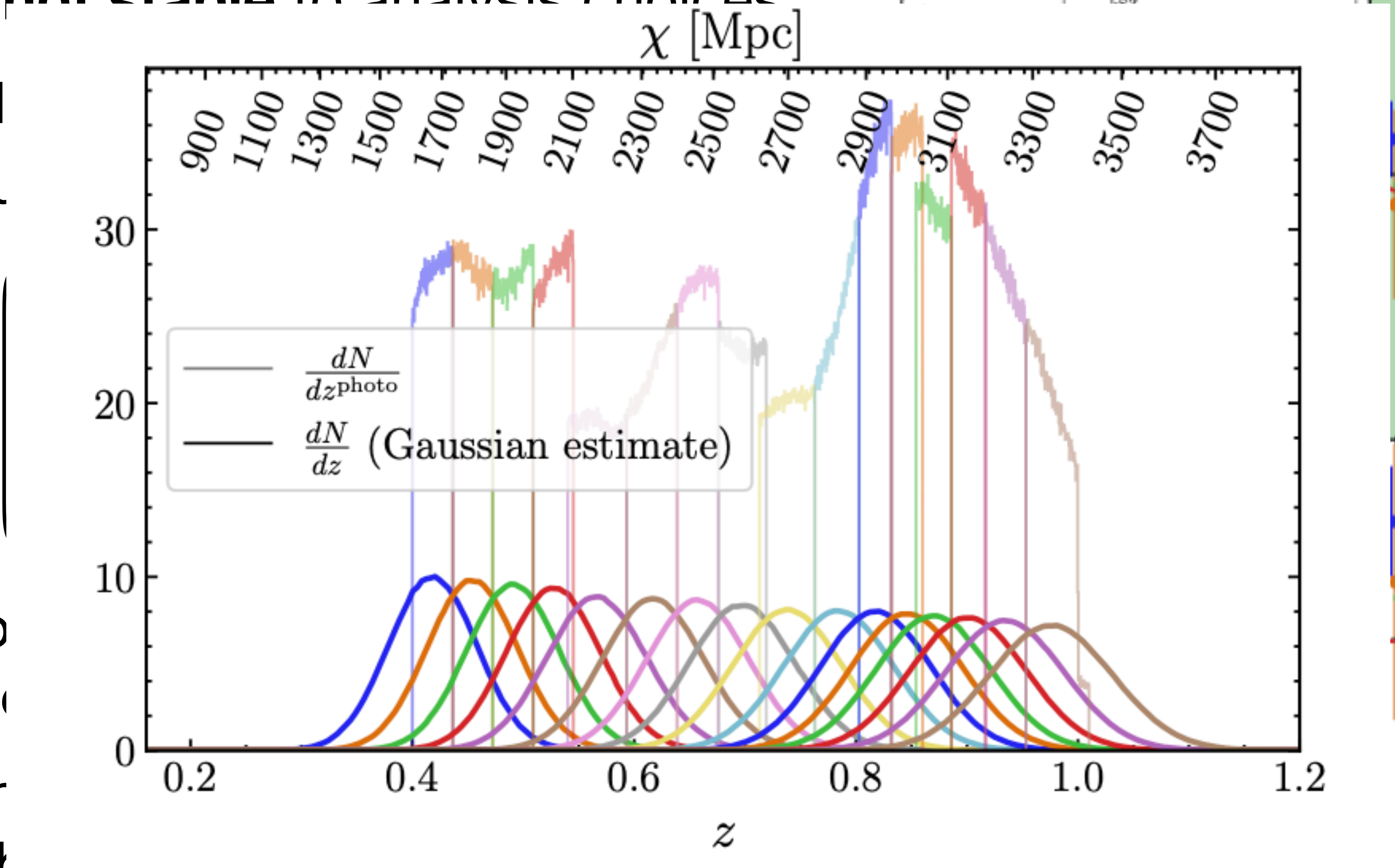

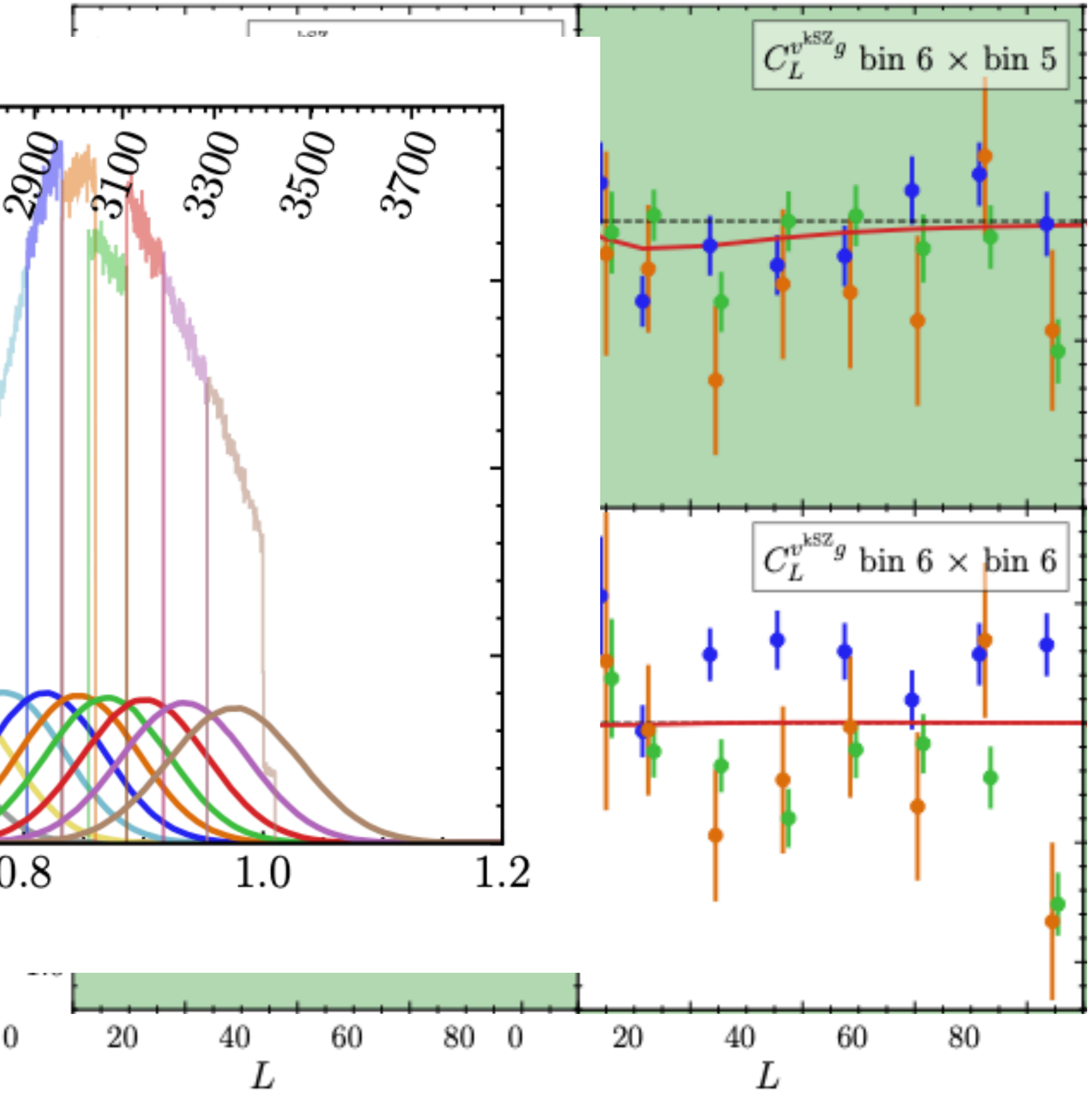

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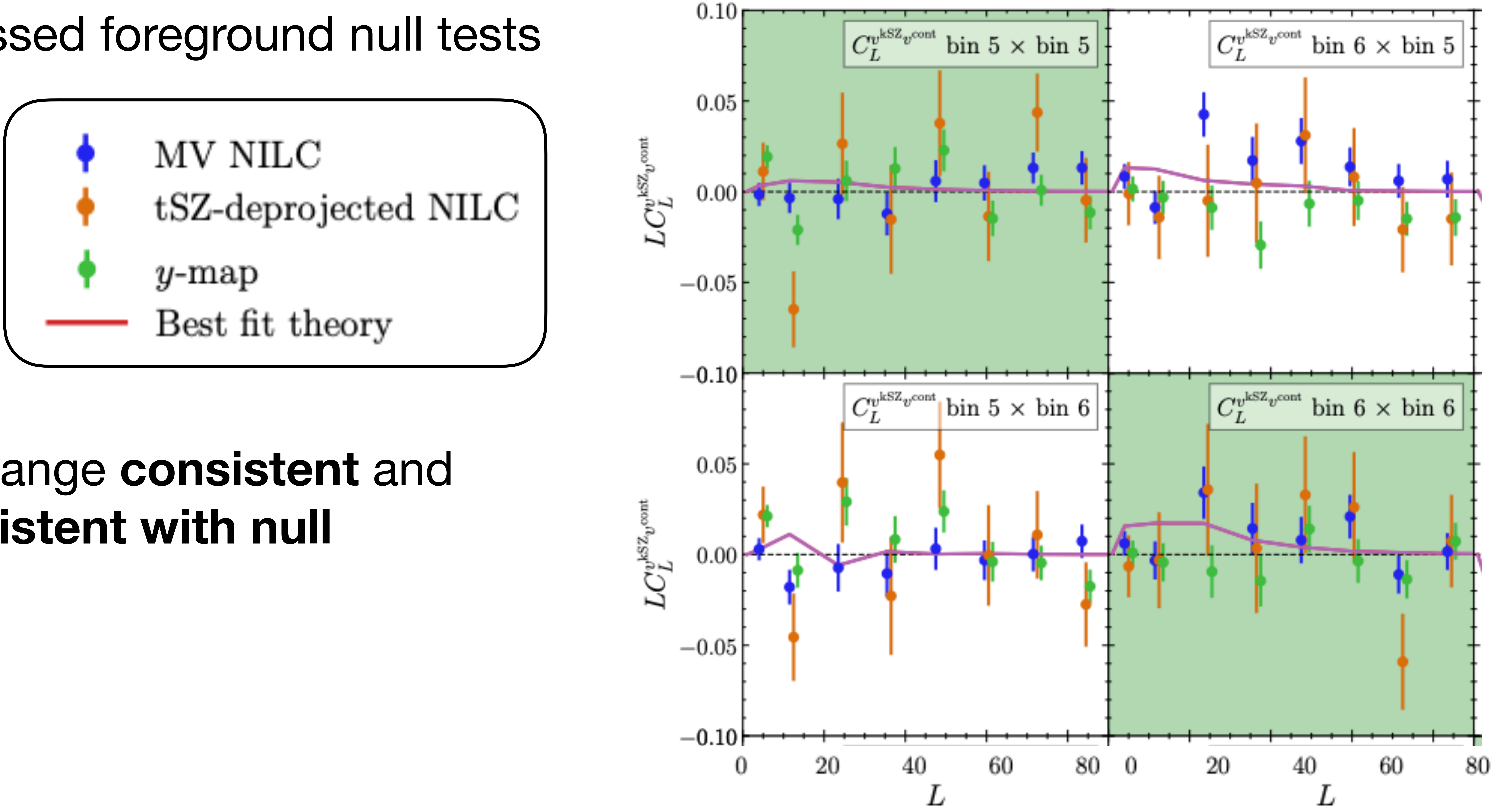
  green **not**
- One optior
  worried ab
  overlap

Foregrounds in $C_L^{vg} \sim \left\langle T_S \delta_S^g \delta_L^G \right\rangle$

- $C_L^{v^{\mathrm{kSZ}} v^{\mathrm{cont}}}$ passed foreground null tests



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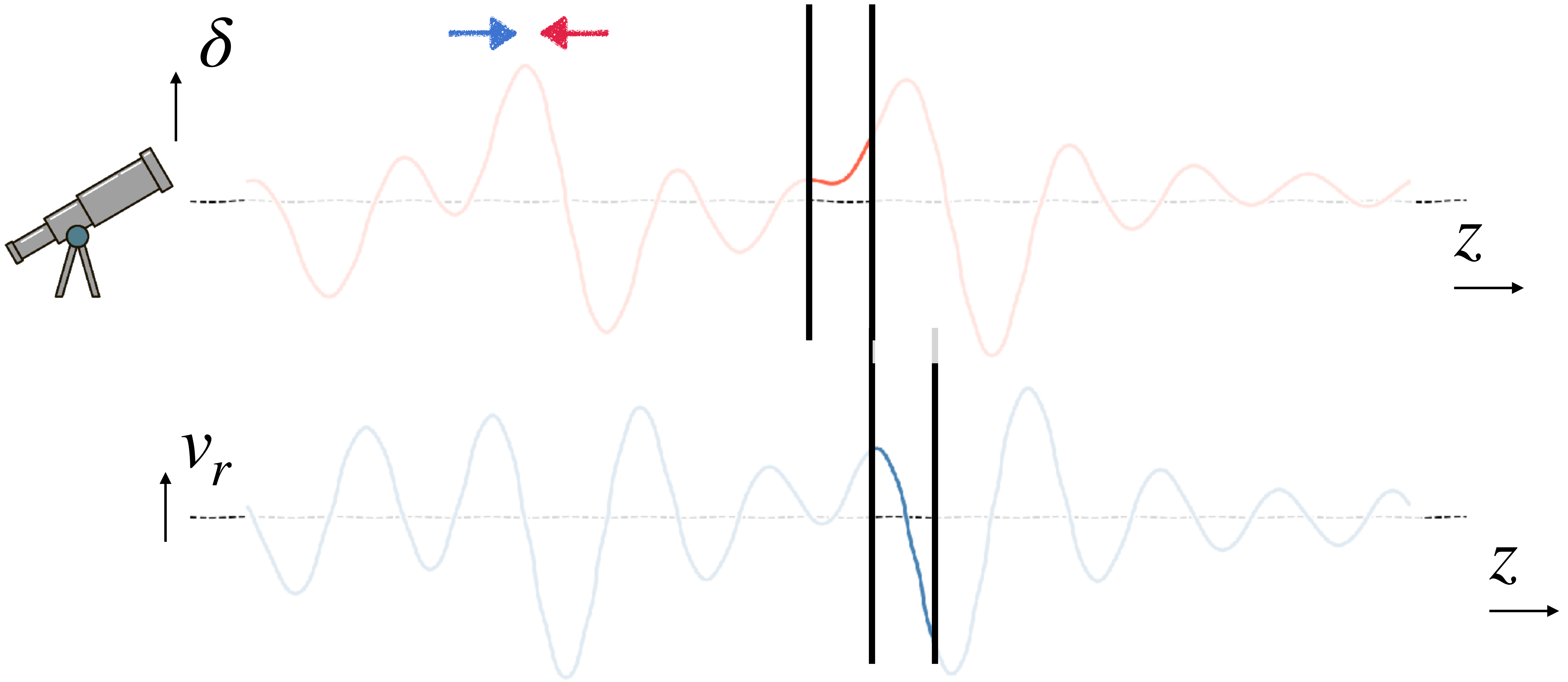
Redshift structure

- Foregrounds and signal display **distinctly different parity properties**
- Neglecting redshift evolution, $\left\langle g^{\alpha} v^{\beta} \right\rangle = - \left\langle g^{\beta} v^{\alpha} \right\rangle$
- For foregrounds, $\left\langle g^{\alpha} FG^{\beta} \right\rangle = \left\langle g^{\beta} FG^{\alpha} \right\rangle$



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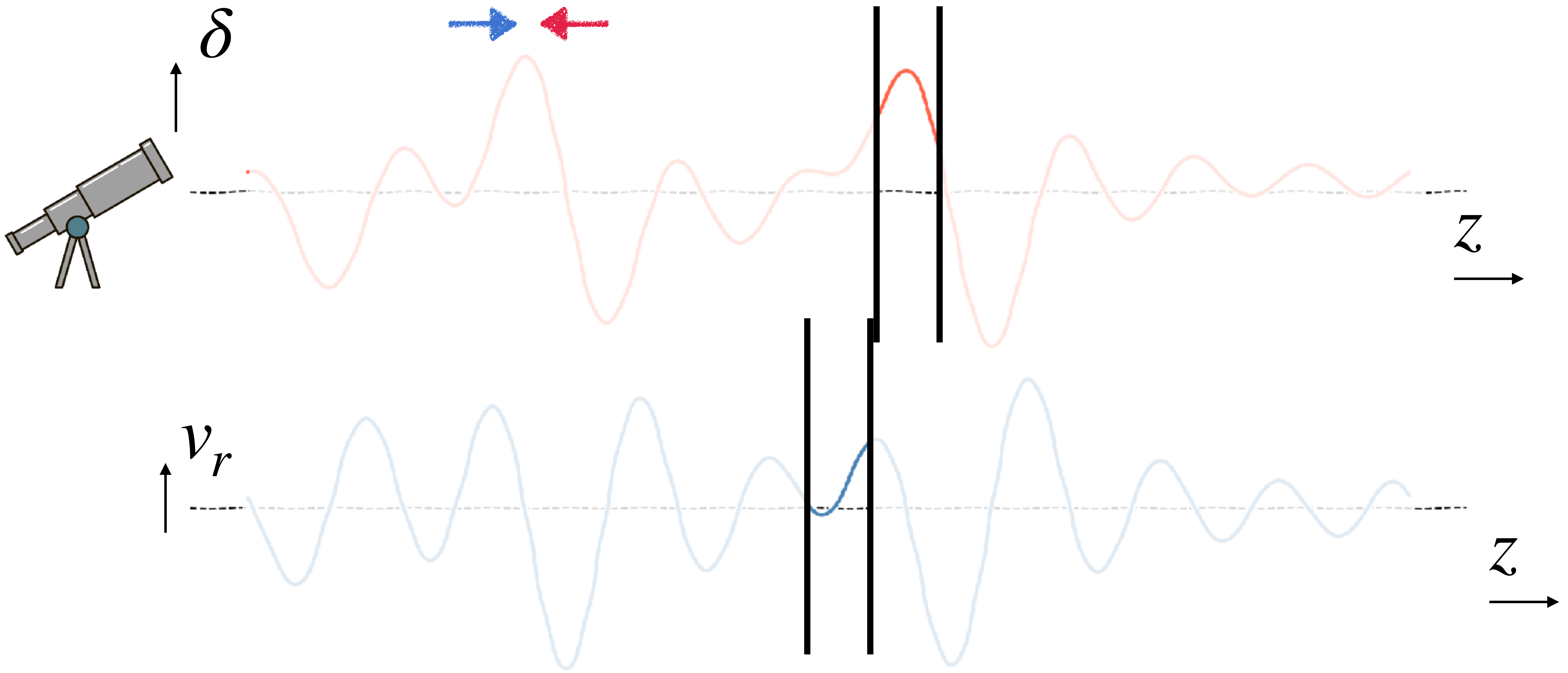
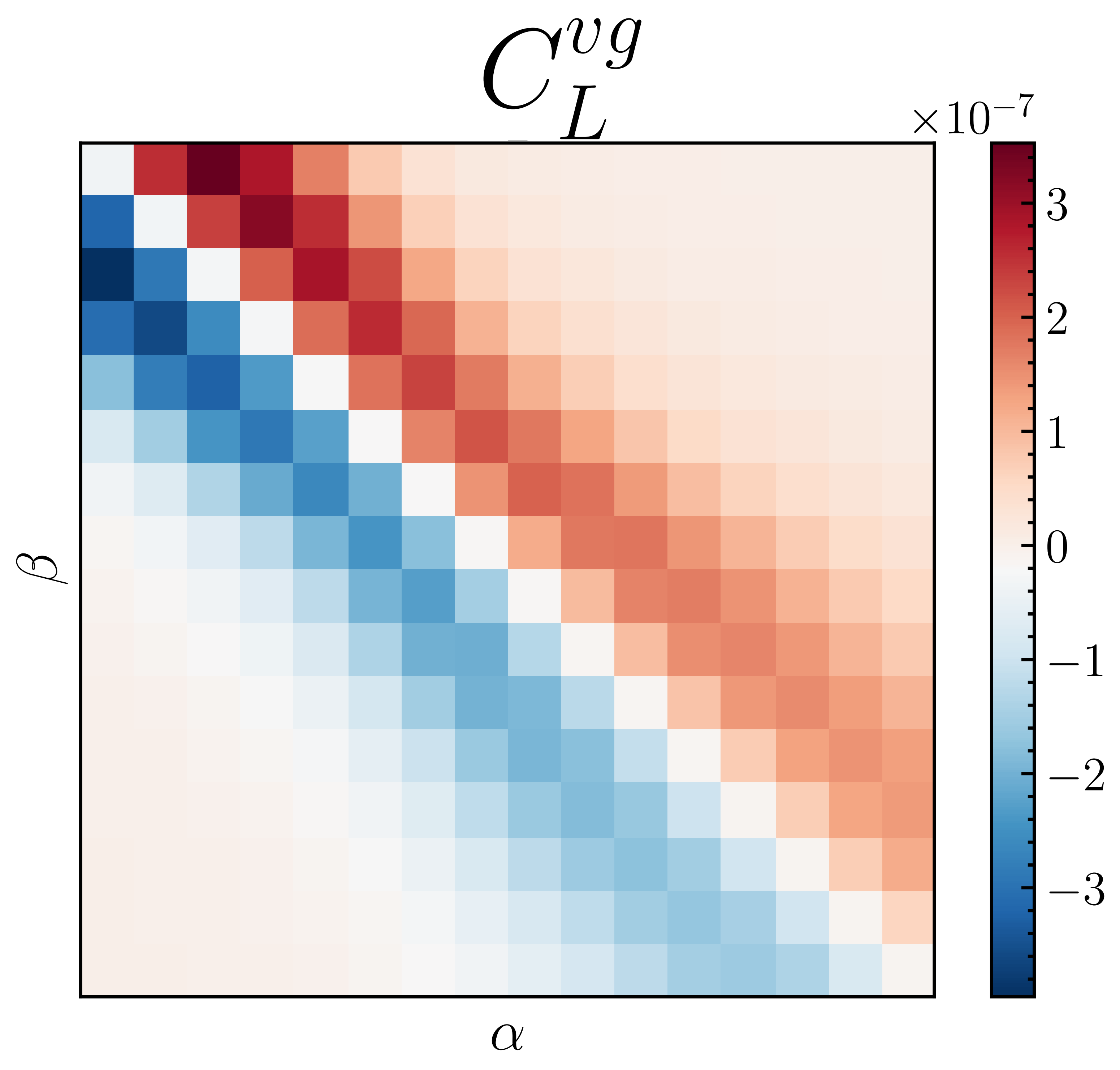
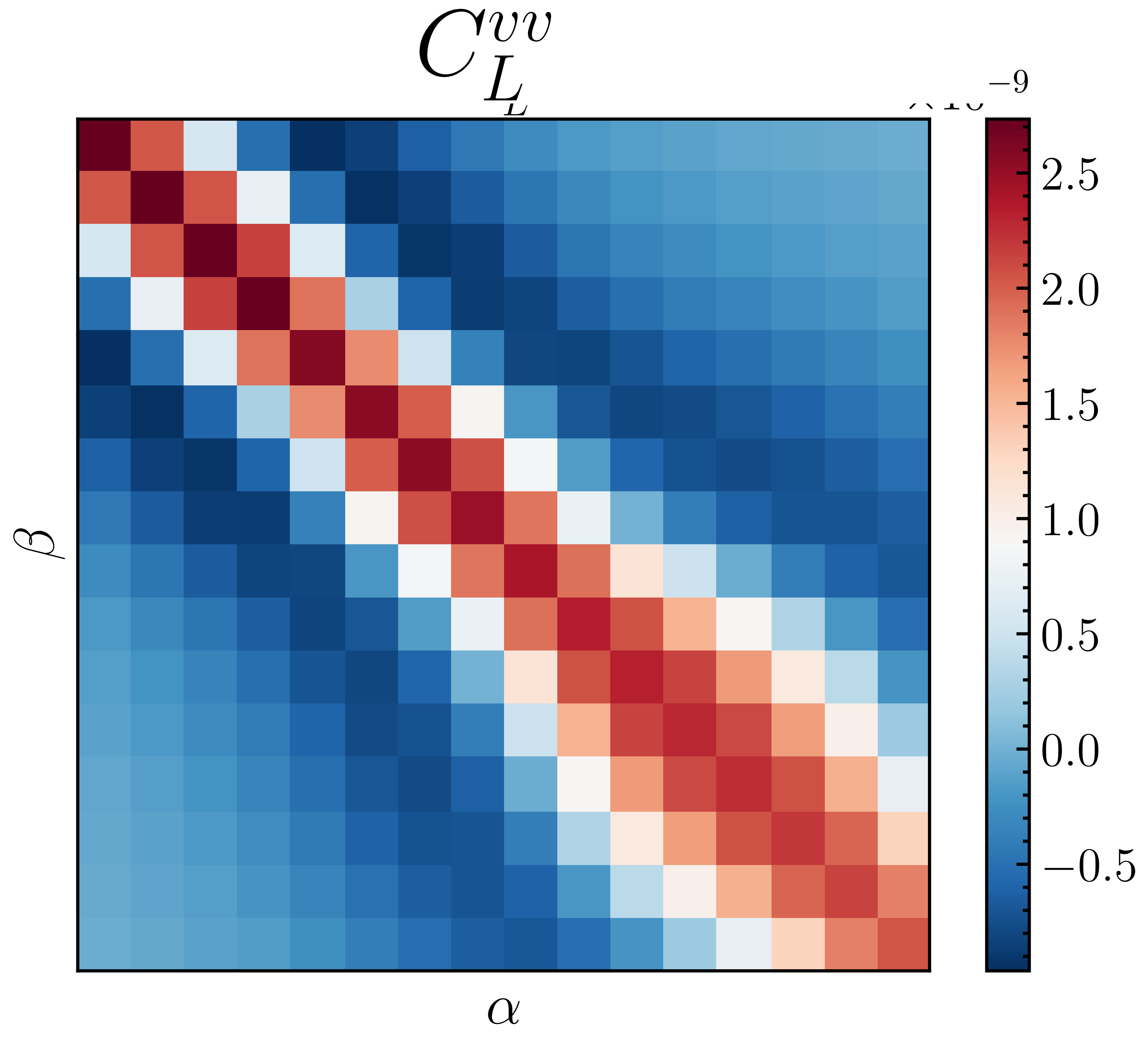


Redshift structure



Antisymmetric in α, β

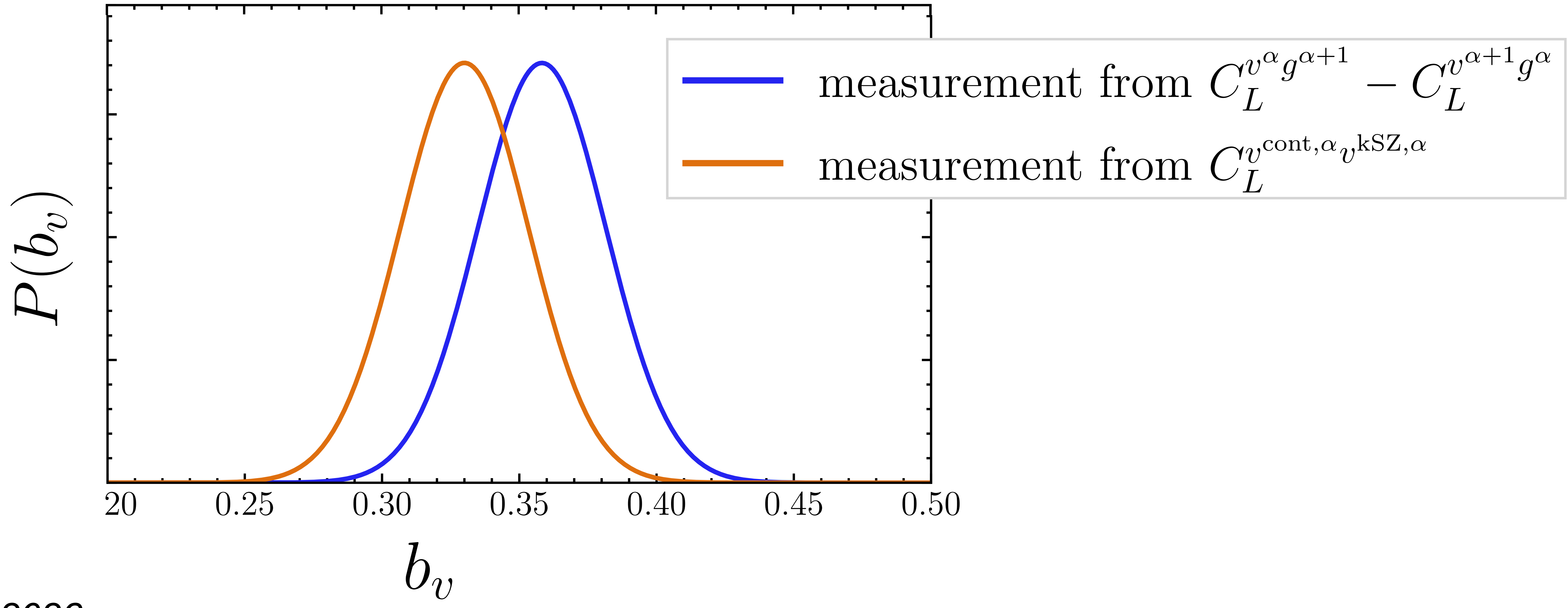


Symmetric in α, β

Foreground mitigation

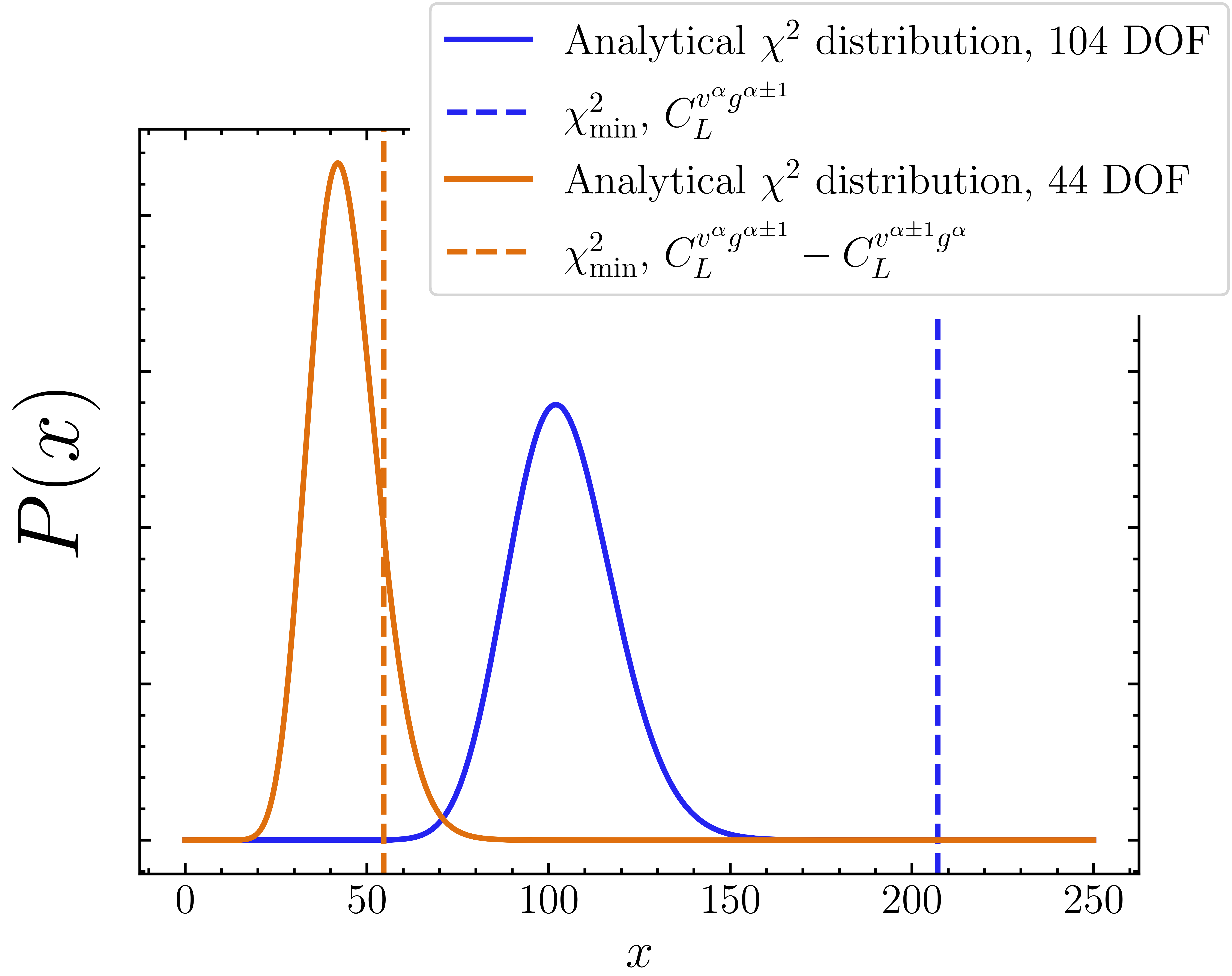
- **Embil Villagra** et al in prep: a study of foreground contamination
- Definition of a **mitigation strategy:** *fit only* $C_L^{v^\alpha g^\beta} - C_L^{v^\beta g^\alpha}$
- Applying this allows us to find a good fit with $C_L^{v^{\rm kSZ}g}$ for the first time

Carmen Embil Villagra



Foreground mitigation

- With antisymmetric combination $C_L^{v^{\alpha,\mathrm{kSZ}}g^{\beta}} - C_L^{v^{\beta,\mathrm{kSZ}}g^{\alpha}}$ we have consistent results
- We find a good fit with $C_L^{v^{\mathrm{kSZ}}g}$ for the first time



Overview

Introduction

LCDM; Open questions; inflation; primordial non-Gaussianity

The kSZ effect

kSZ velocity reconstruction

Background; first measurements; C_L^{vv}; CMB datasets

Analysis with ACT+DESILS

Results from McCarthy et al 2025 a+b; Other progress in the field; Foregrounds

Forecasts for Simons Observatory(+LSST)

Large-scale challenges

- Galaxy clustering is sensitive to f_{NL} on large scales

$$b^{NG} \sim b^G(1 + \frac{f_{NL}}{k^2})$$

Large *scales*

(Dalal et al 2008)

- Clustering is hard to measure on large scales for (at least) two reasons: **cosmic variance** and **additive systematics.**

- Cosmic variance:

$$\sigma(P_{gg}(k)) \propto \frac{P_{gg}(k)}{k} + \frac{1}{k\bar{n}}$$

Largest scales have fundamental CV error even for noiseless measurements

- Systematics:

$$\hat{P}_{gg}(k) = P_{gg}(k) + P_{NN}(k)$$

Additive systematics are problematic on large scales

- kSZ measurement can help with both.

Sample variance cancellation

- kSZ will provide us with a measurement of $P_{mm}(k)$
- Recall statistical error decreases with N samples: $\dfrac{1}{\sqrt{N}}$
- Cosmic variance:

$$\sigma(P_{gg}(k)) \propto \frac{P_{gg}(k)}{k} + \frac{1}{k\bar{n}}$$

Gets very large on large scales - not many modes available.

- Seljak 2008: *sample variance cancellation*: simultaneously measure $P_{mm}(k)$ and $P_{gg}(kk)$

$$P_{gg}(k) = b^2(k)P_{mm}(k) \qquad \Longrightarrow \qquad b^2(k) = \frac{P_{gg}(k)}{P_{mm}(k)}$$

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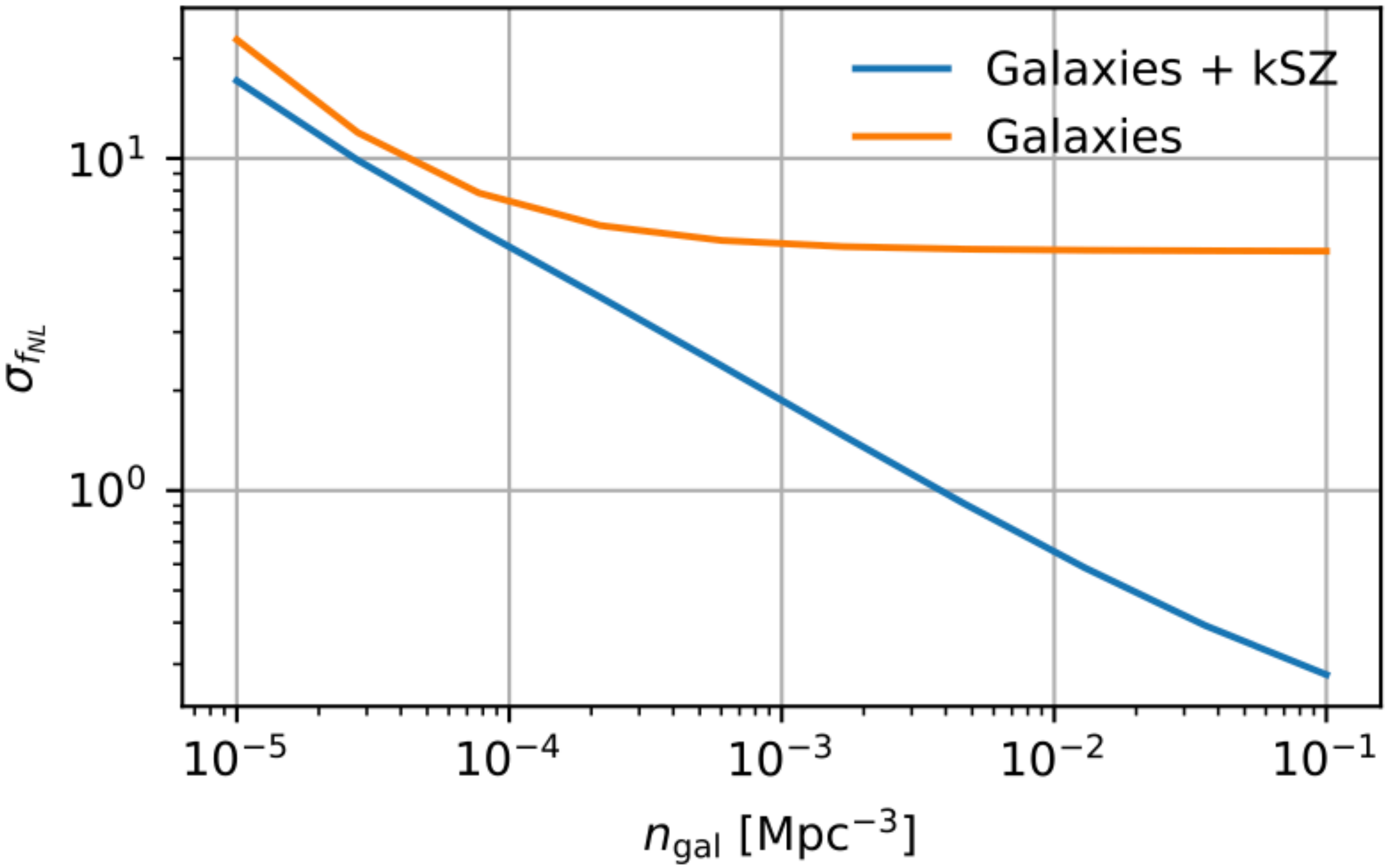
No stochasticity here, cosmic variance cancels out!

$$P_{gg}(k) = b^2(k)P_{mm}(k) \quad \Longrightarrow \quad b^2(k) = \frac{P_{gg}(k)}{P_{mm}(k)}$$

Sample variance cancellation

- Munchmeyer et al 2018: combining kSZ with galaxy survey you can improve constraining power

kSZ combination can bypass fundamental cosmic variance limit!



Plot from Munchmeyer et al 2018

Large-scale systematics

- Galaxy surveys are hard to measure on large scales

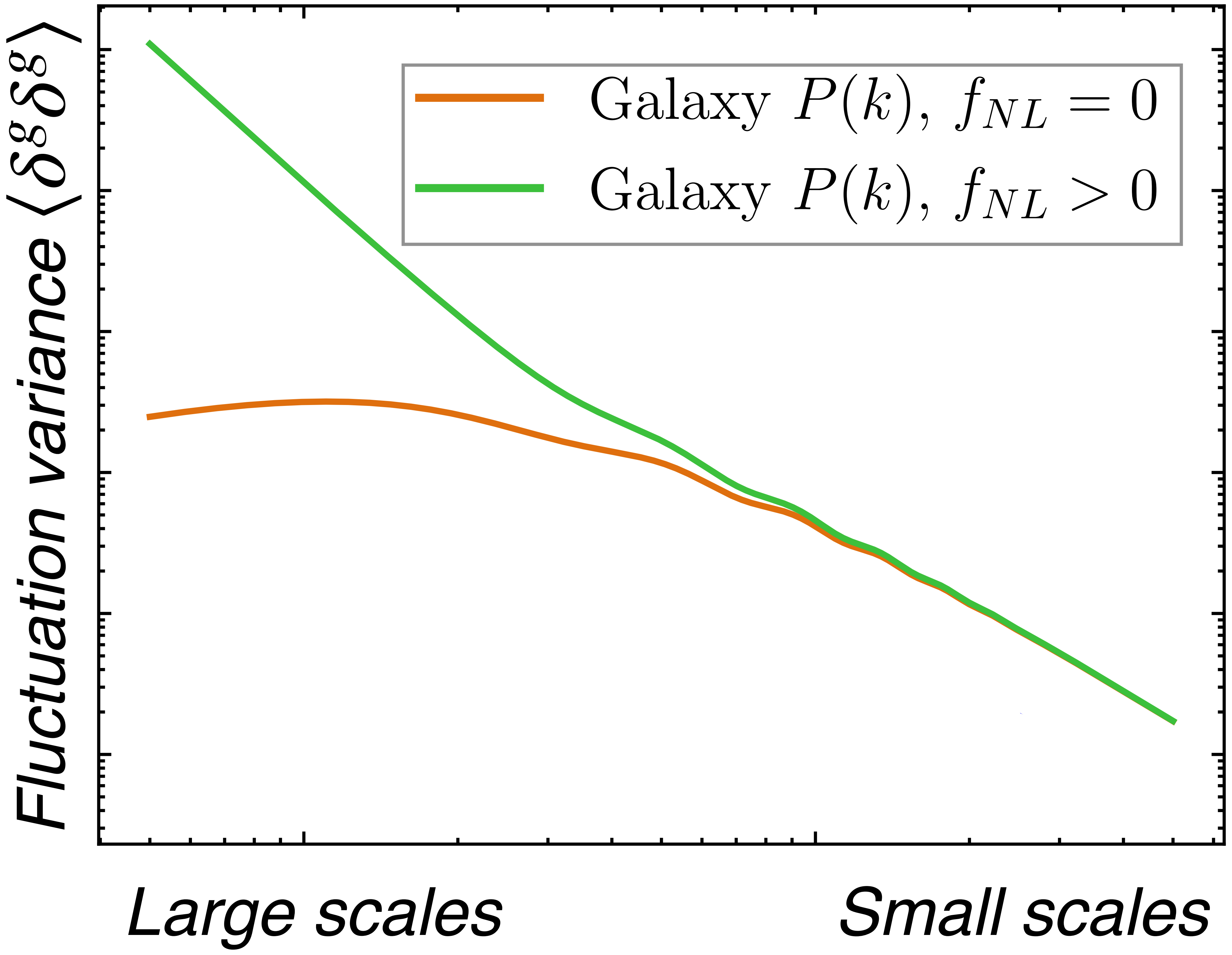
- Systematics:

$$\left\langle \hat{\delta}^g \hat{\delta}^g \right\rangle = \langle \delta^g \delta^g \rangle + \langle ss \rangle$$

$s =$ *Stellar contamination*

$$\hat{\delta}^g = \delta^g + s$$

$\delta^g =$ *galaxy density fluctuation*



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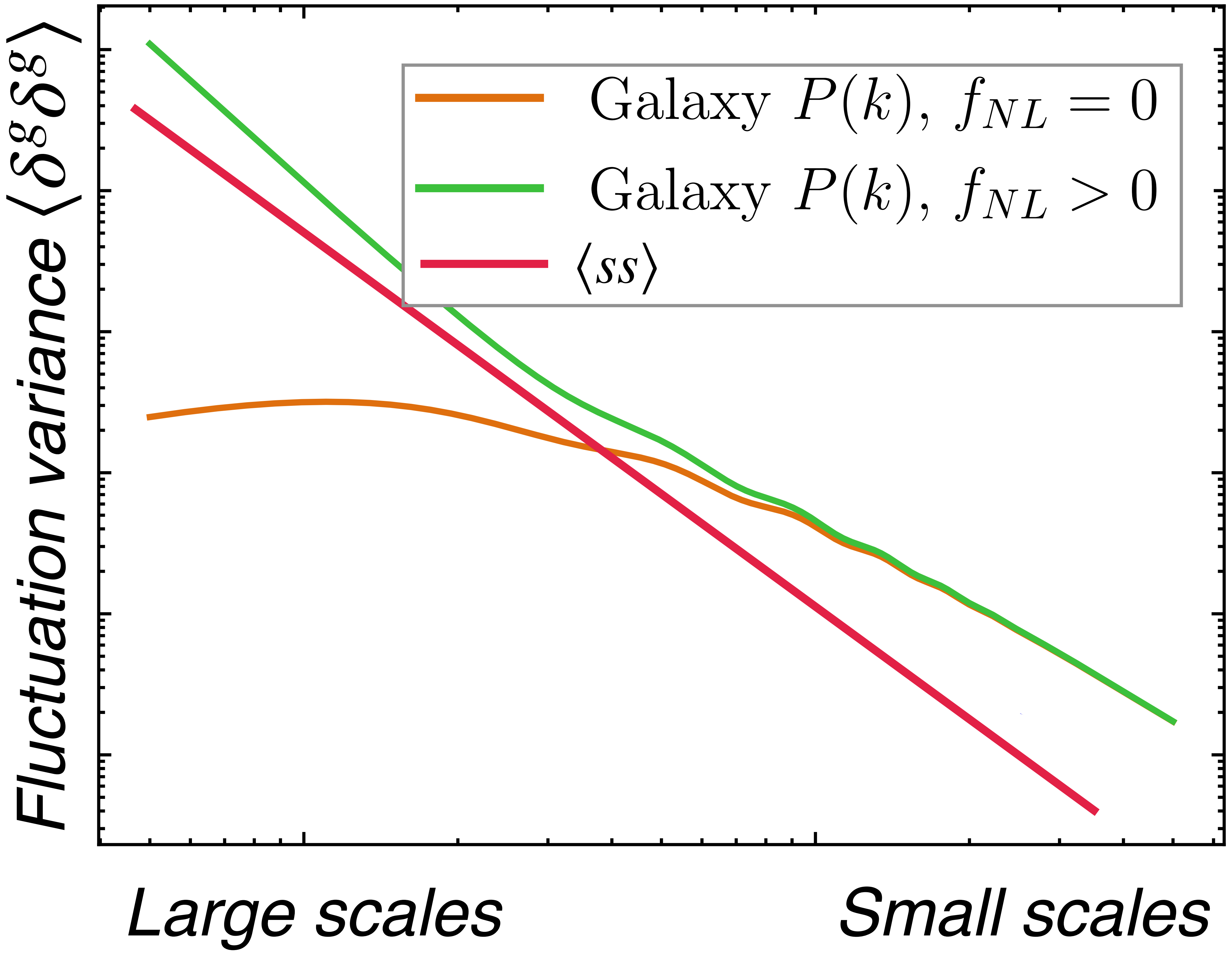

$\langle ss \rangle$ *often looks like the* $f_{\rm NL}$ *signal on large scales!*

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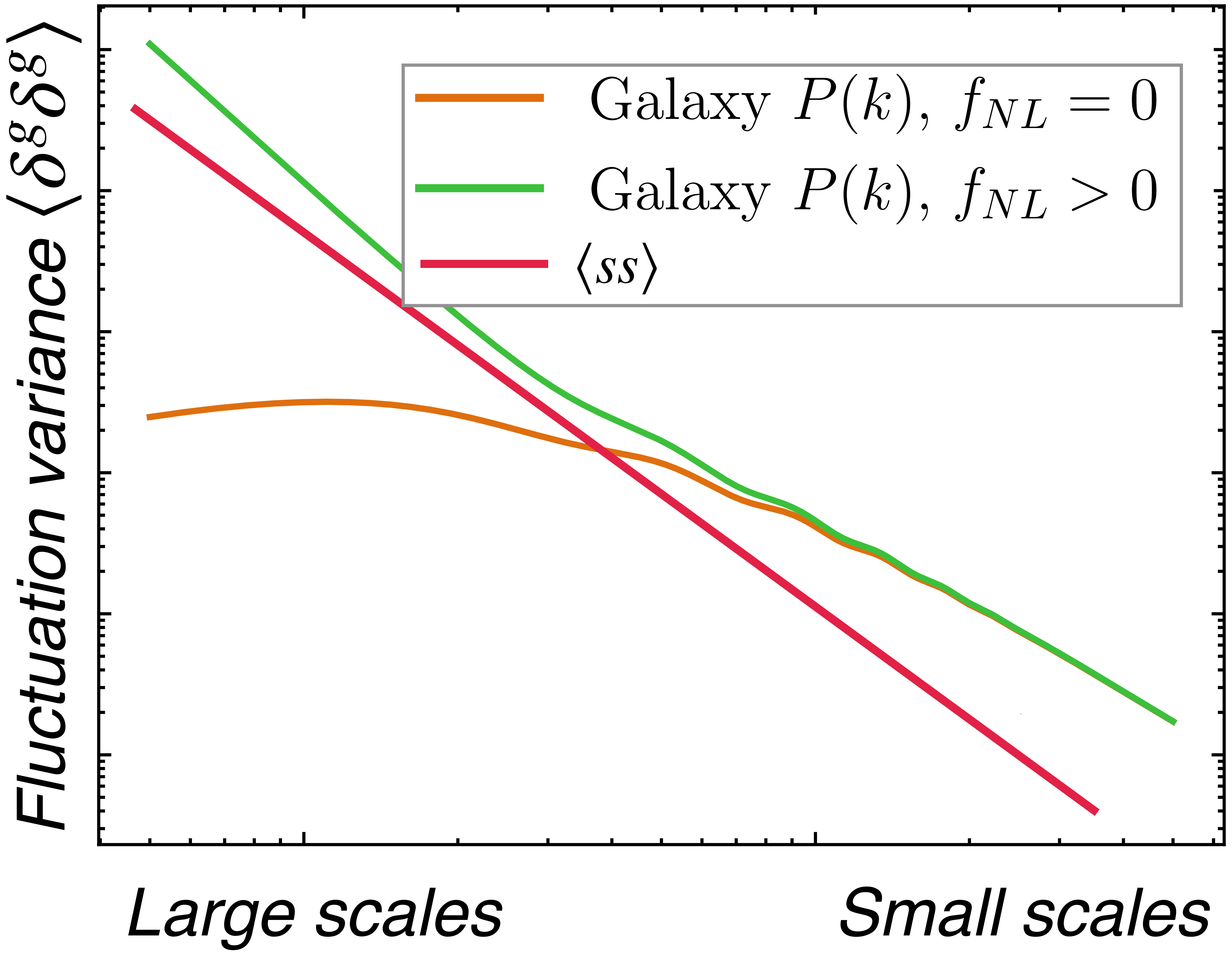

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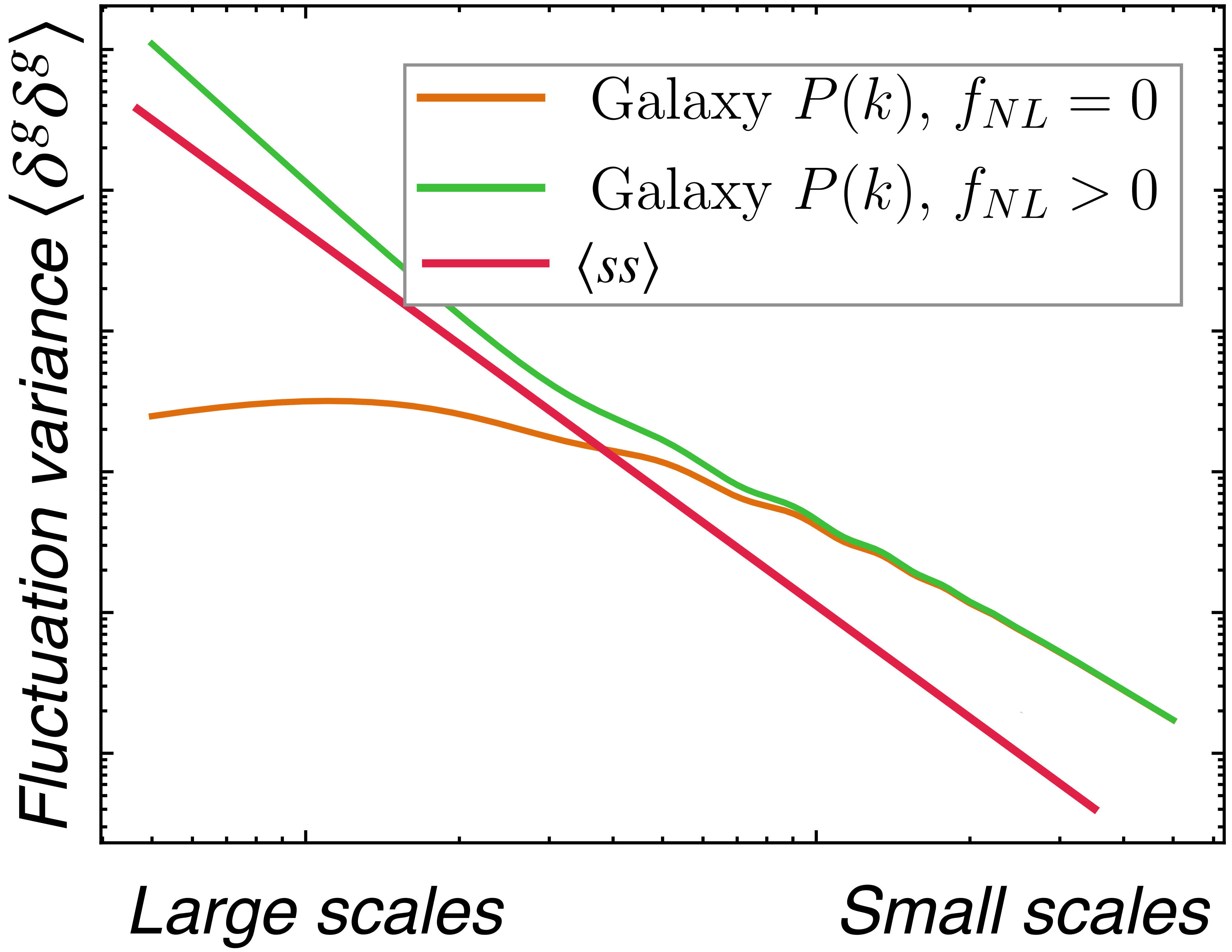

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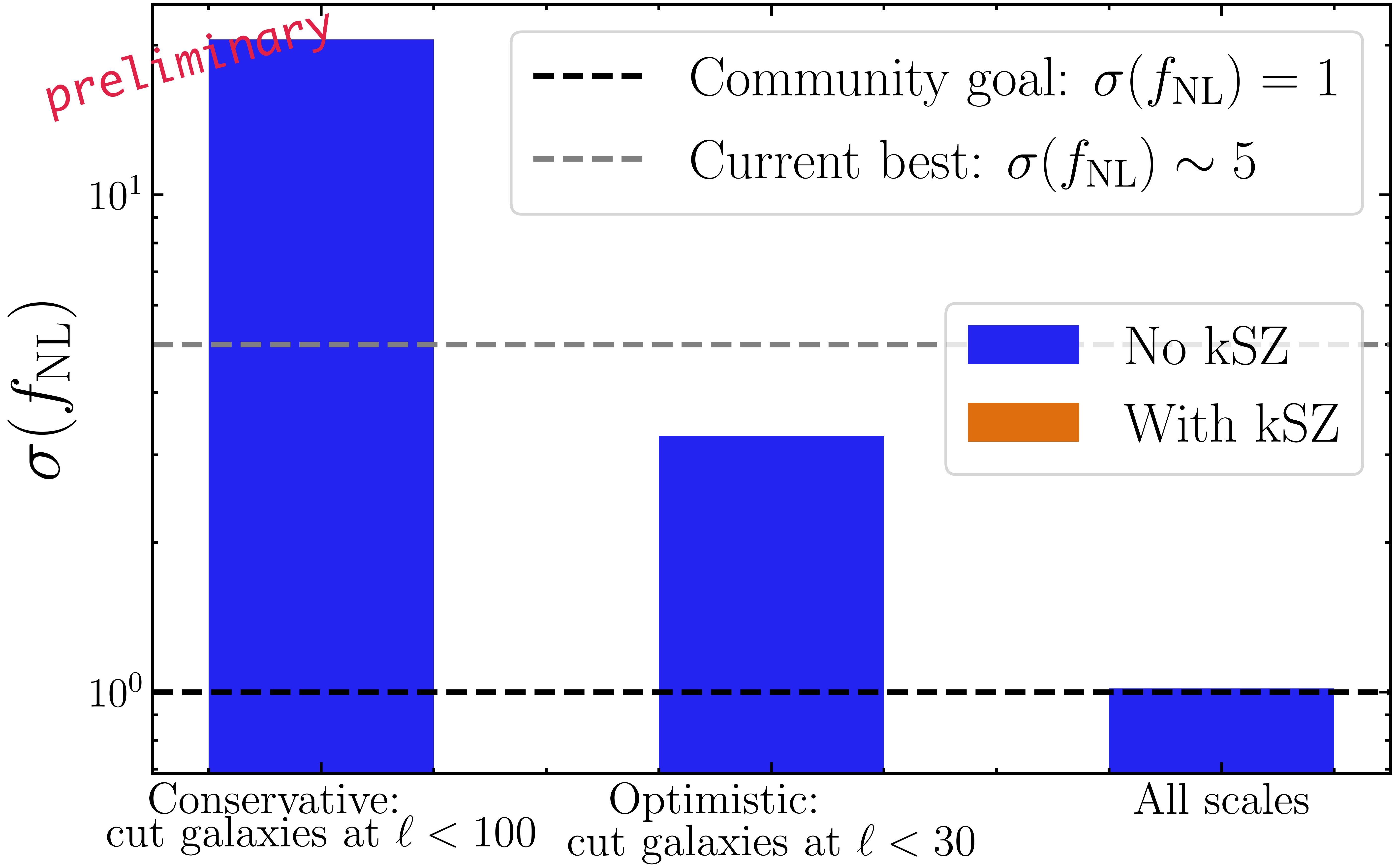
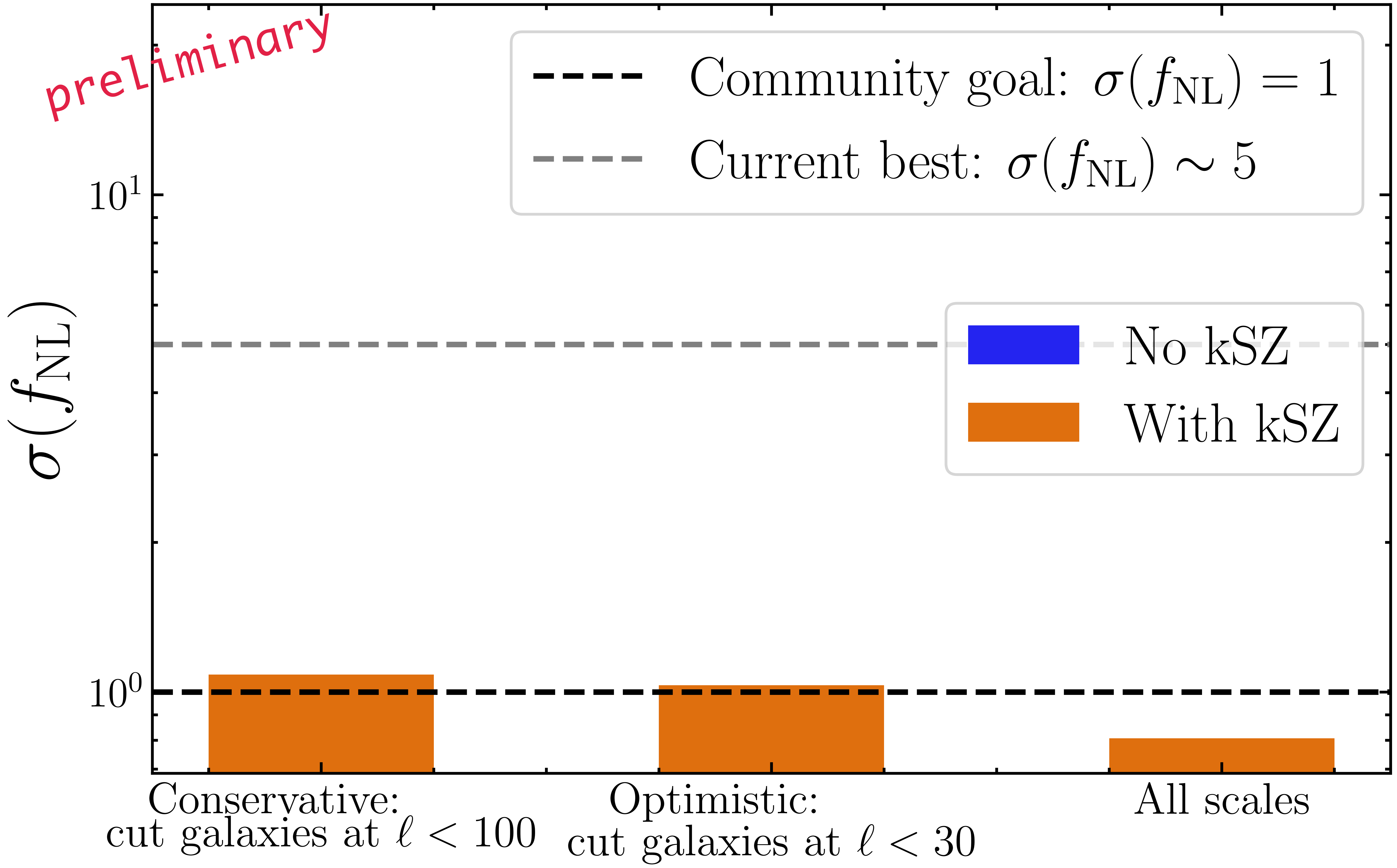
Forecast for SO-LSST



Guanming Liang

*Liang, **FMcC** et al in prep*

Forecast for SO-LSST



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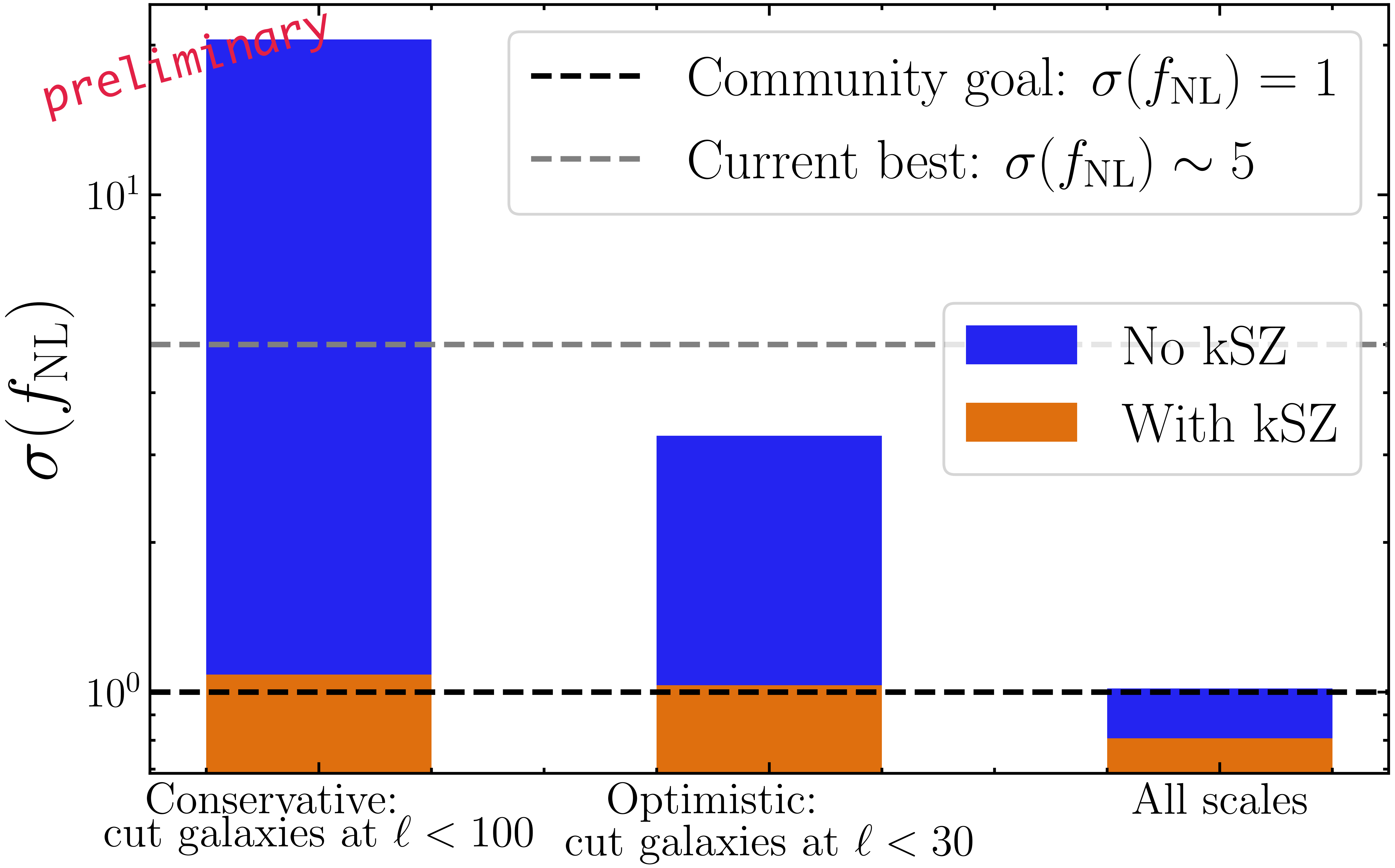


Guanming Liang

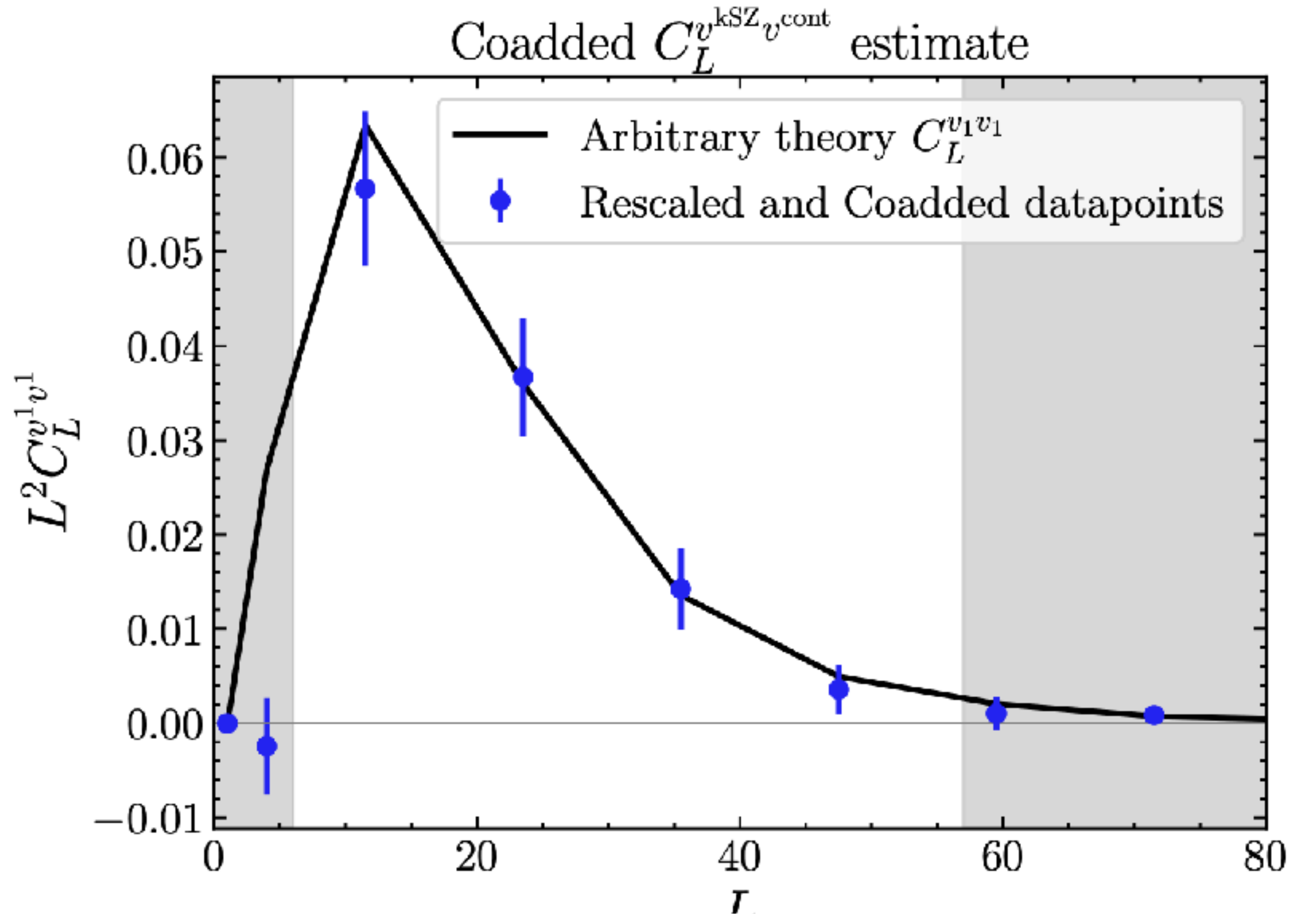
*Liang, **FMcC** et al in prep*

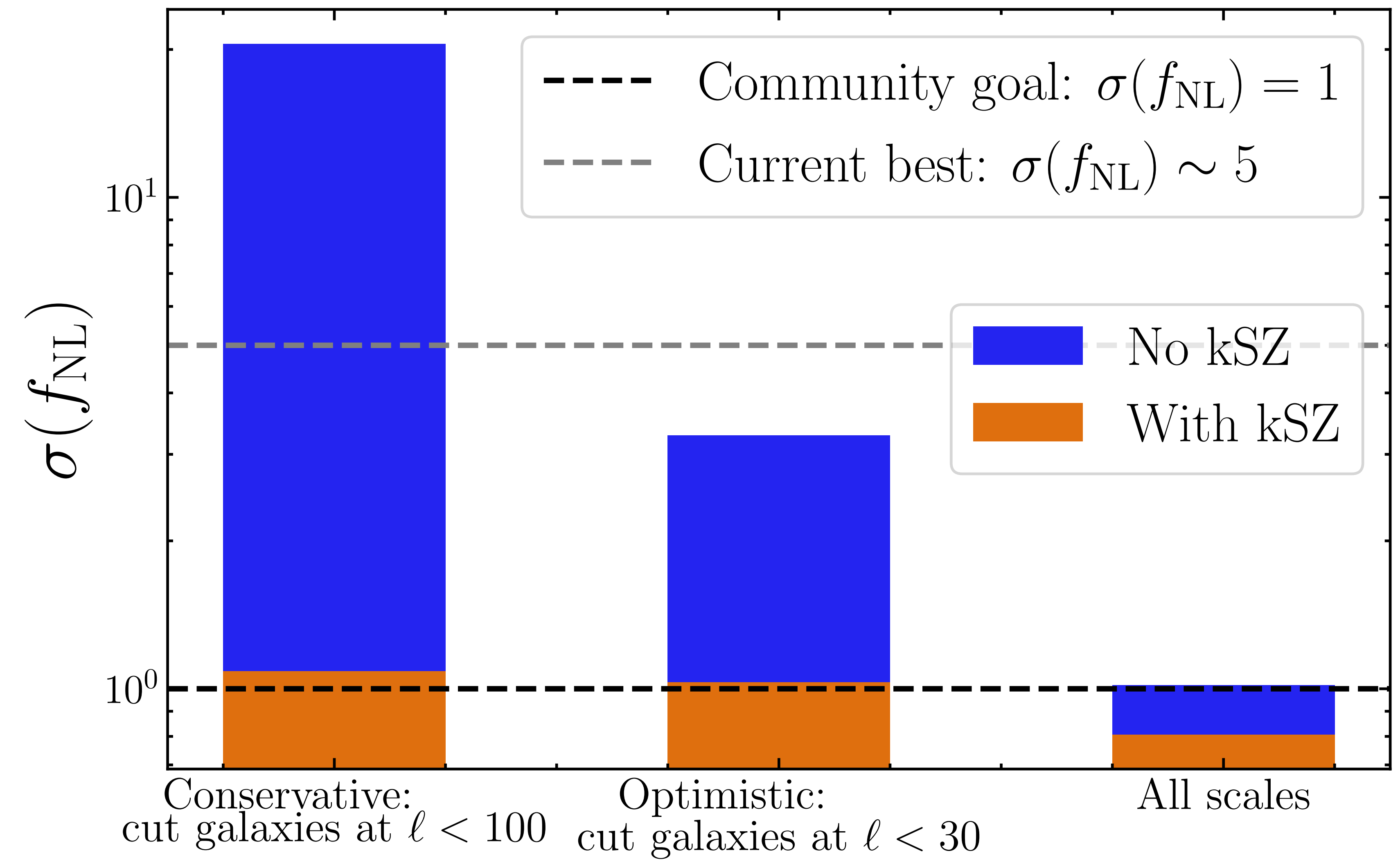
Overview

- Rapid progress in kSZ velocity reconstruction over the last 1.5 years

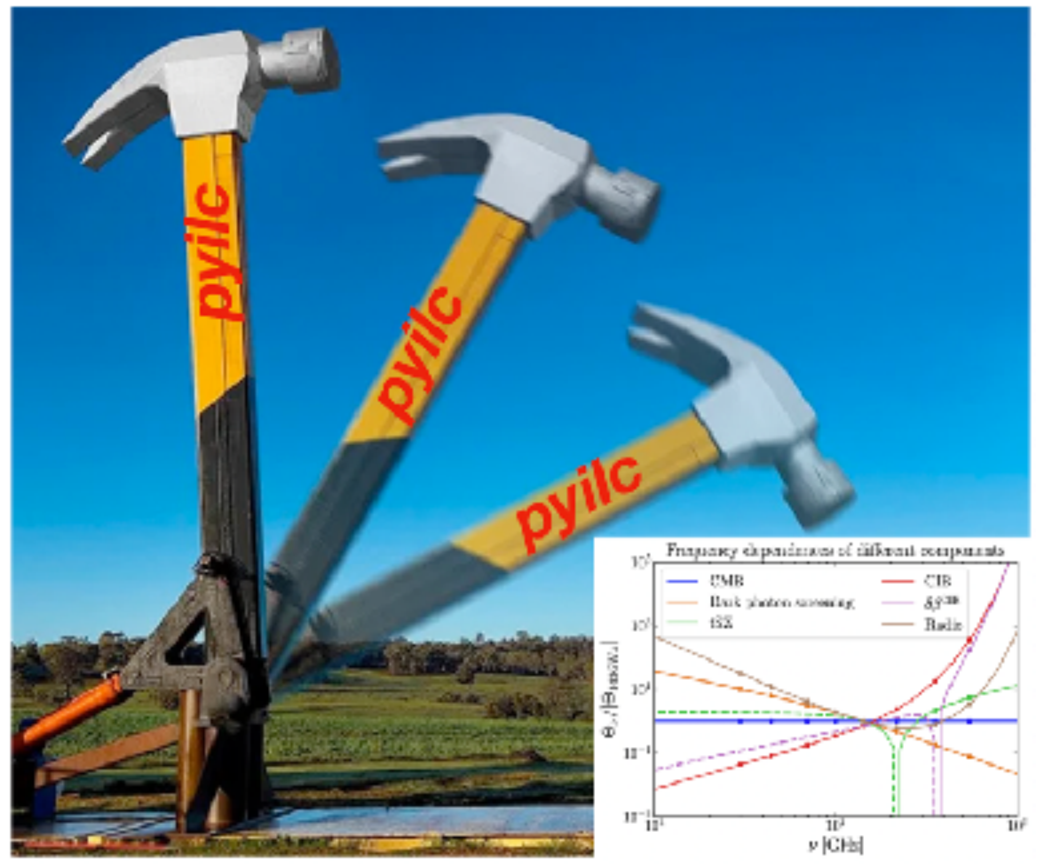
- SO kSZ measurements are coming - this is exciting!

- Competitive f_{NL} constraints **from cross-correlation alone as well as improvements from sample-variance cancellation**



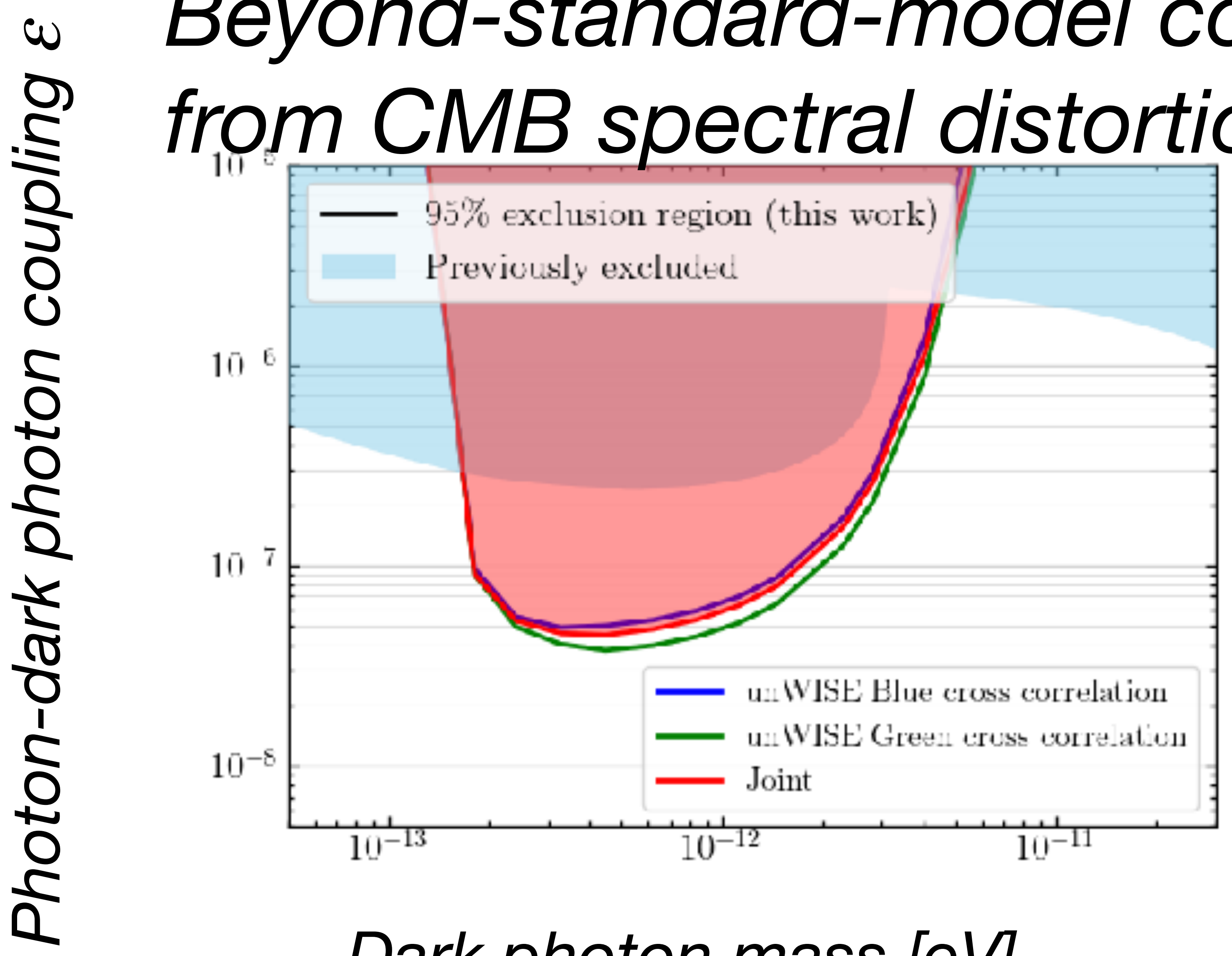


Additional interests

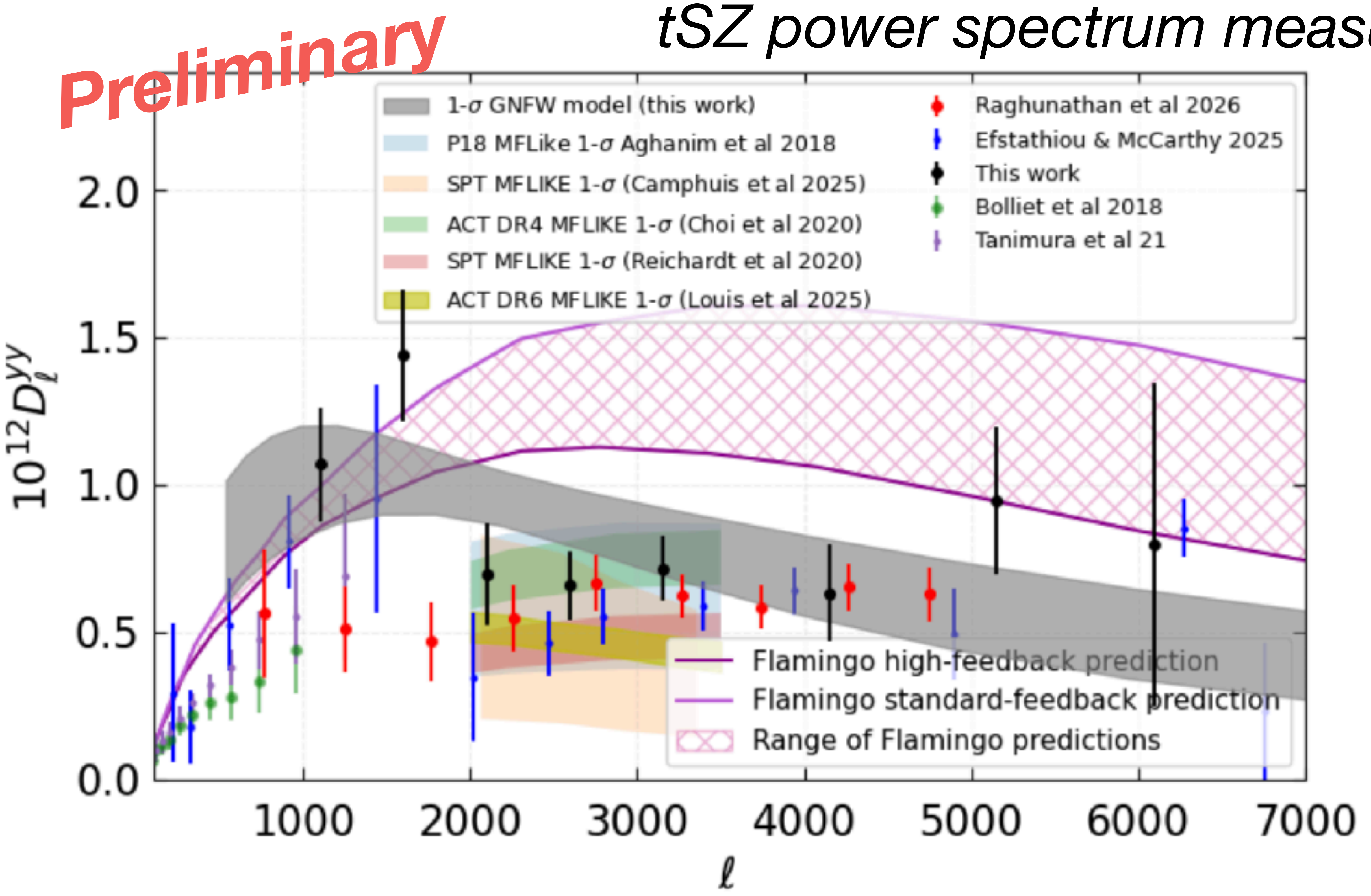


Component separation for CMB surveys (see pyilc)

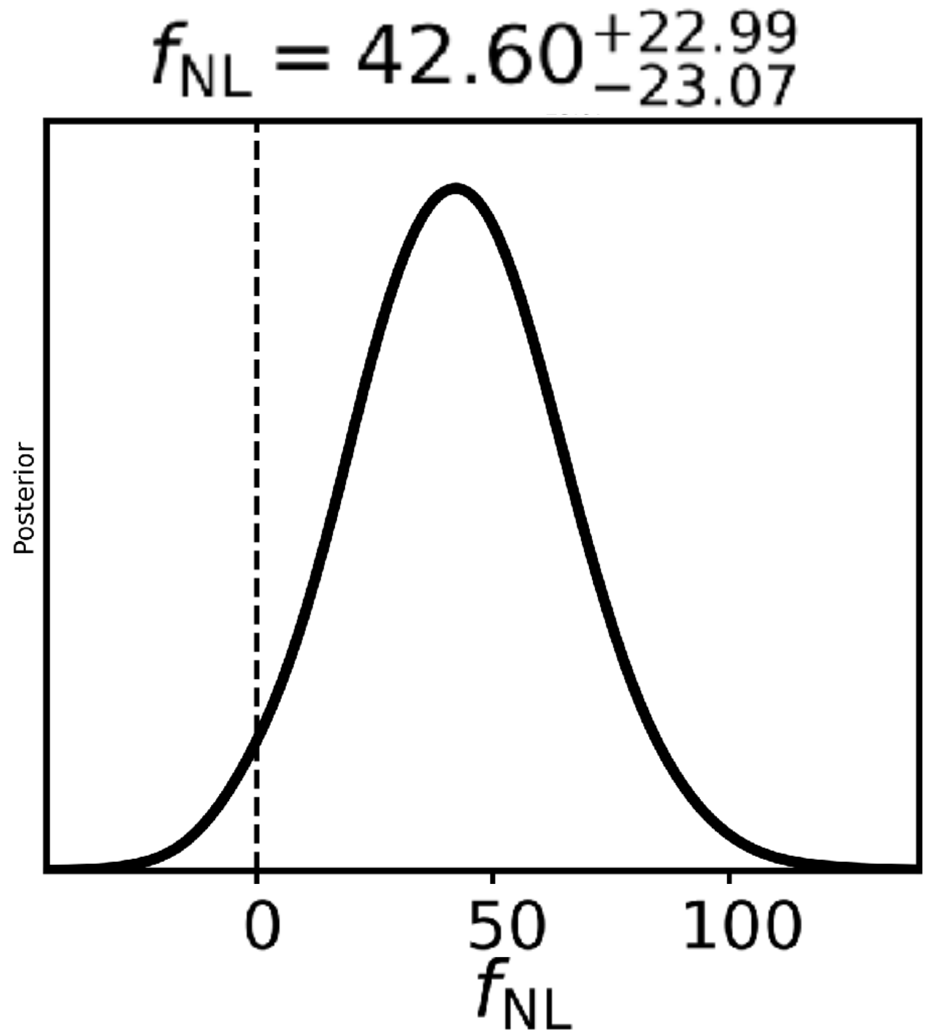
Beyond-standard-model constraints from CMB spectral distortions



tSZ power spectrum measurements

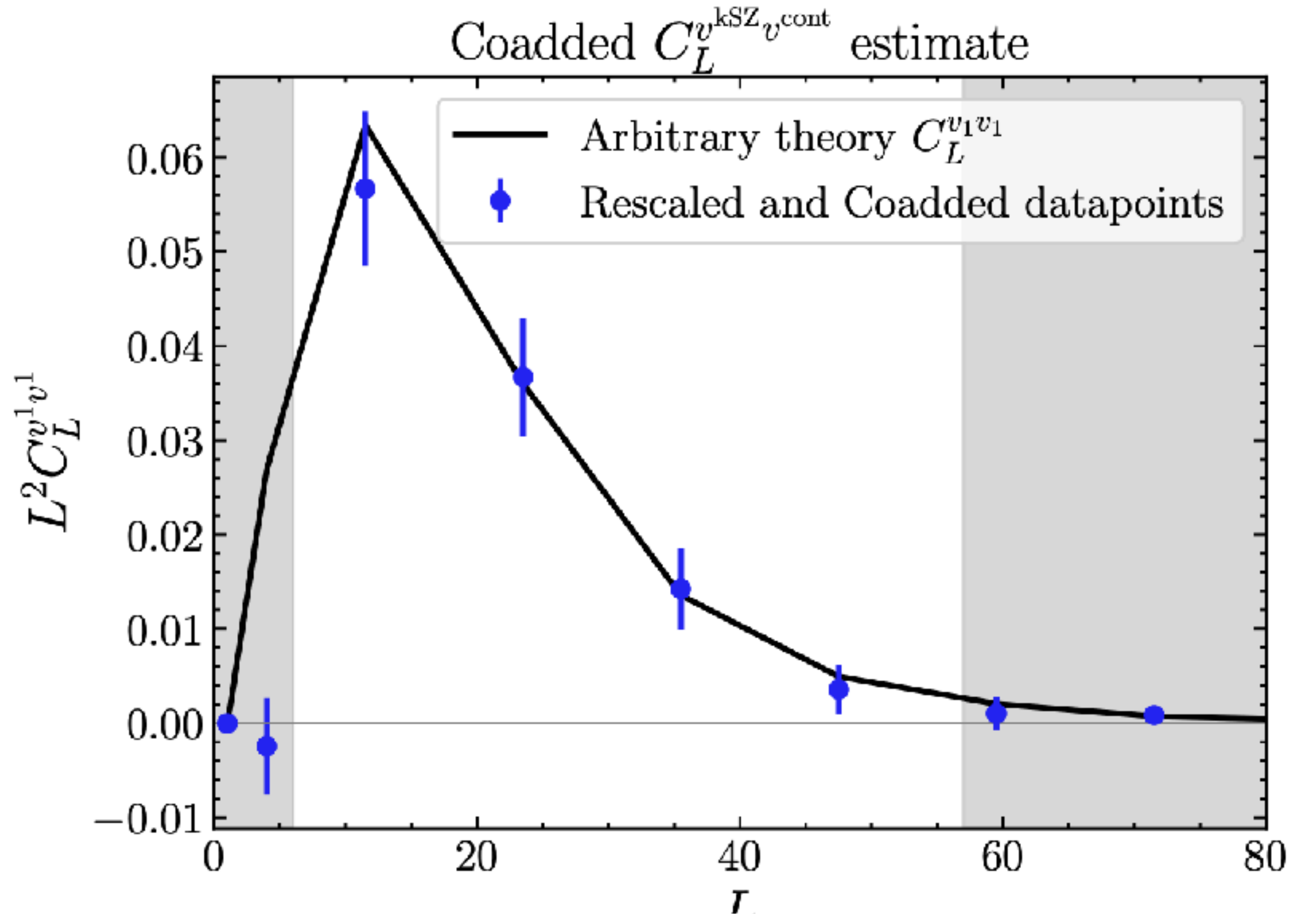


f_{NL} from CMB lensing-CIB cross correlation



Joseph Thornton

Overview



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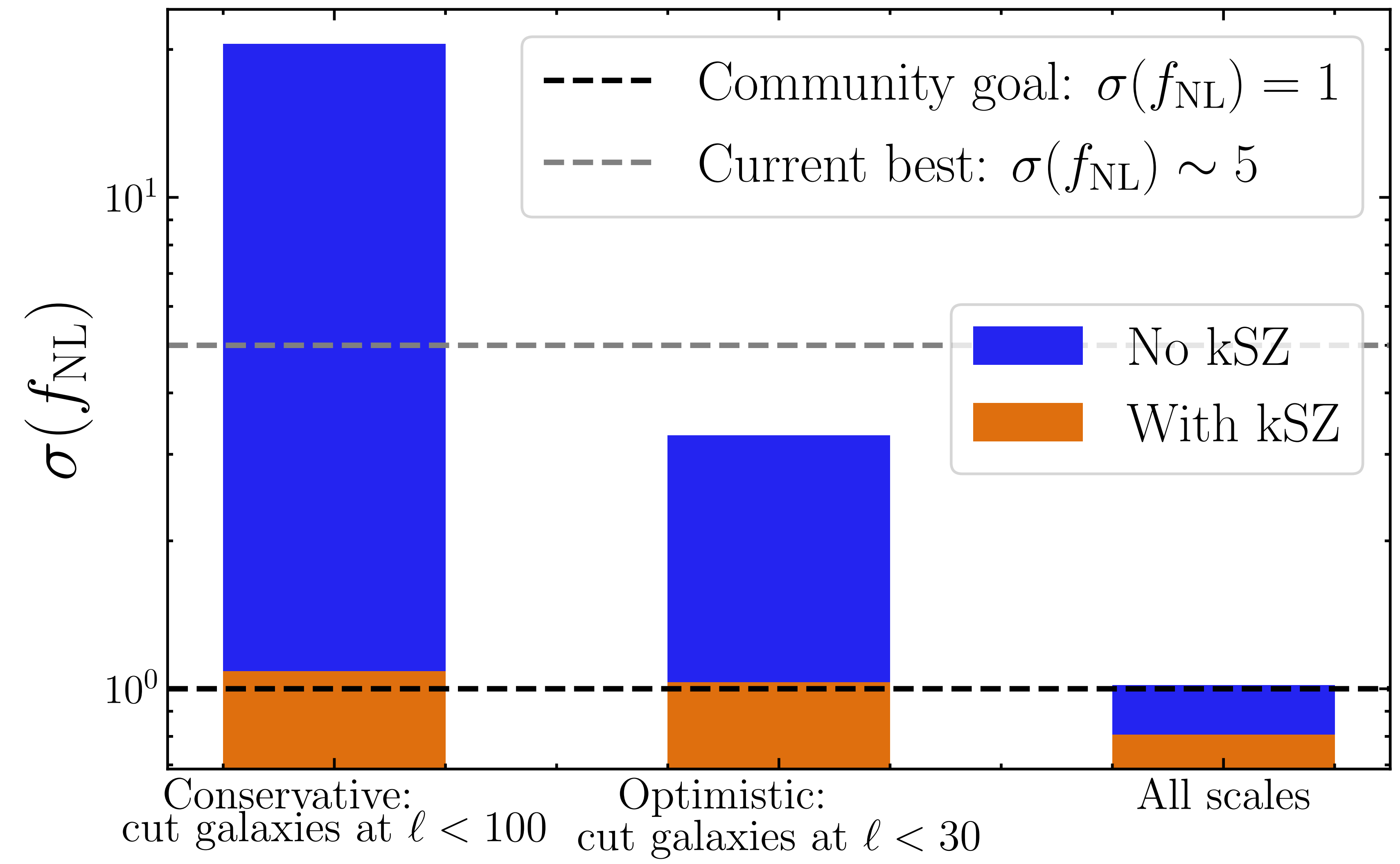
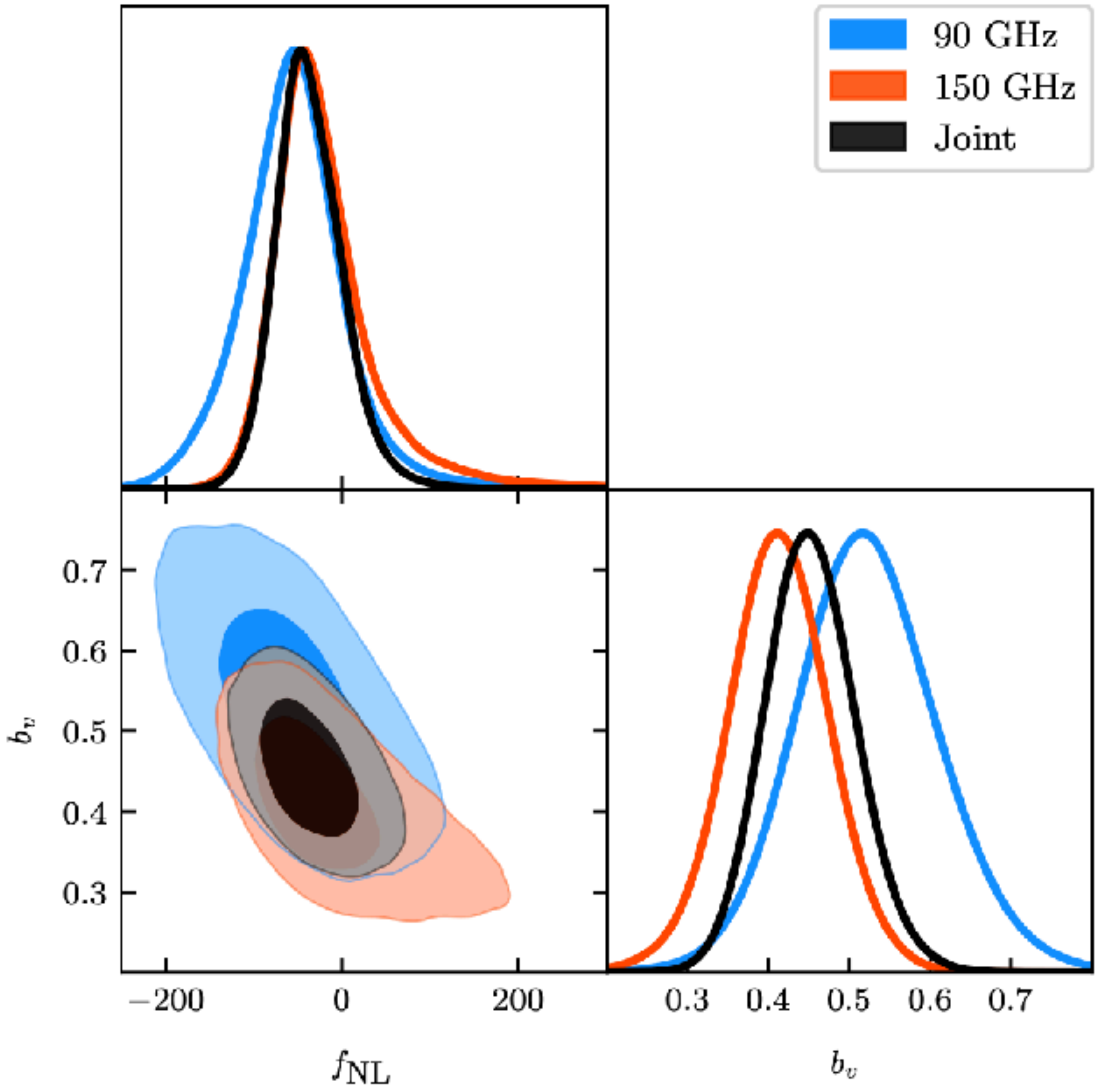


Fiona McCarthy, BCCP Seminar, 10th Mar 2026

Extra slides

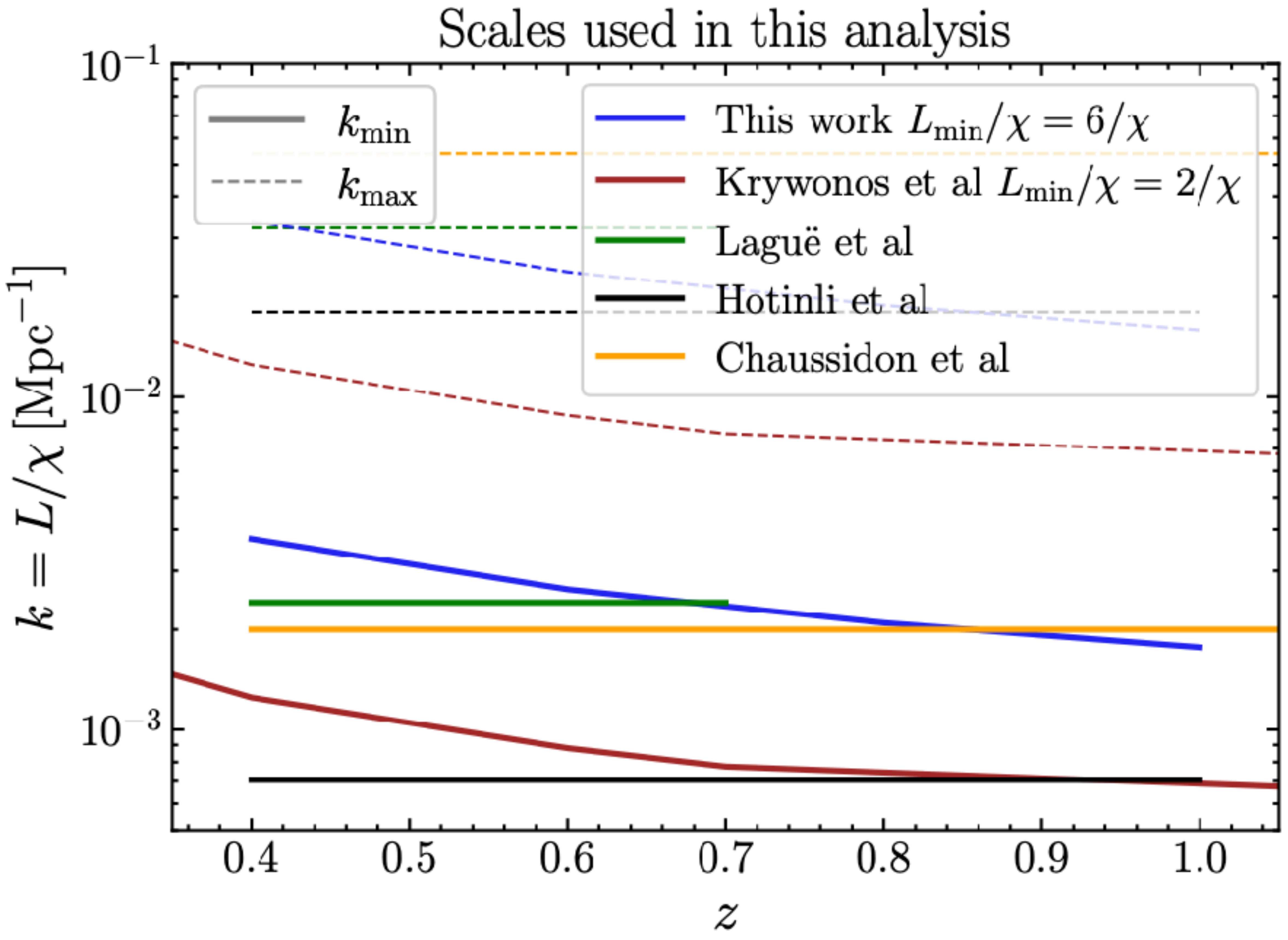
Comparison to 3-D

- See **Hotinli et al 2025:** $f_{NL} = -30^{+40}_{-33}$



Comparison to 3-D

- Possible explanation: different scale coverage although **3-D vs 2-D comparison is not a fully solved problem**



Photometry vs spectroscopy

- With **spectroscopy** we get **very good redshift measurements of galaxies**
  - Work in 3-D. $\vec{x} \rightarrow \vec{k}$
  - Observable is 3-dimensional $P_{vv}(k)$ or $P_{vg}(k)$
- With **photometry** we can get ~ few-percent accuracy on redshifts
  - Work in 2+1-D. $\vec{\theta}, \alpha \rightarrow L, M, \alpha$
  - Observable is 2+1-dimensional $C_L^{v^\alpha v^\beta}$ or $C_L^{v^\alpha g^\beta}$
  - Expect good measurements of **overall redshift distribution**