Novel results and methods for kSZ velocity reconstruction

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- Primordial non-Gaussianity f_{NL} → scale dependent bias

- Large-scale radial velocity field v_r
  - Lower noise level on large scale
  - Difficult to probe

- Kinetic Sunyeav-Zeldovich (kSZ) effect
  - Secondary CMB anisotropy
  - CMB-LSS cross-correlation → estimates $\hat{v}_r$

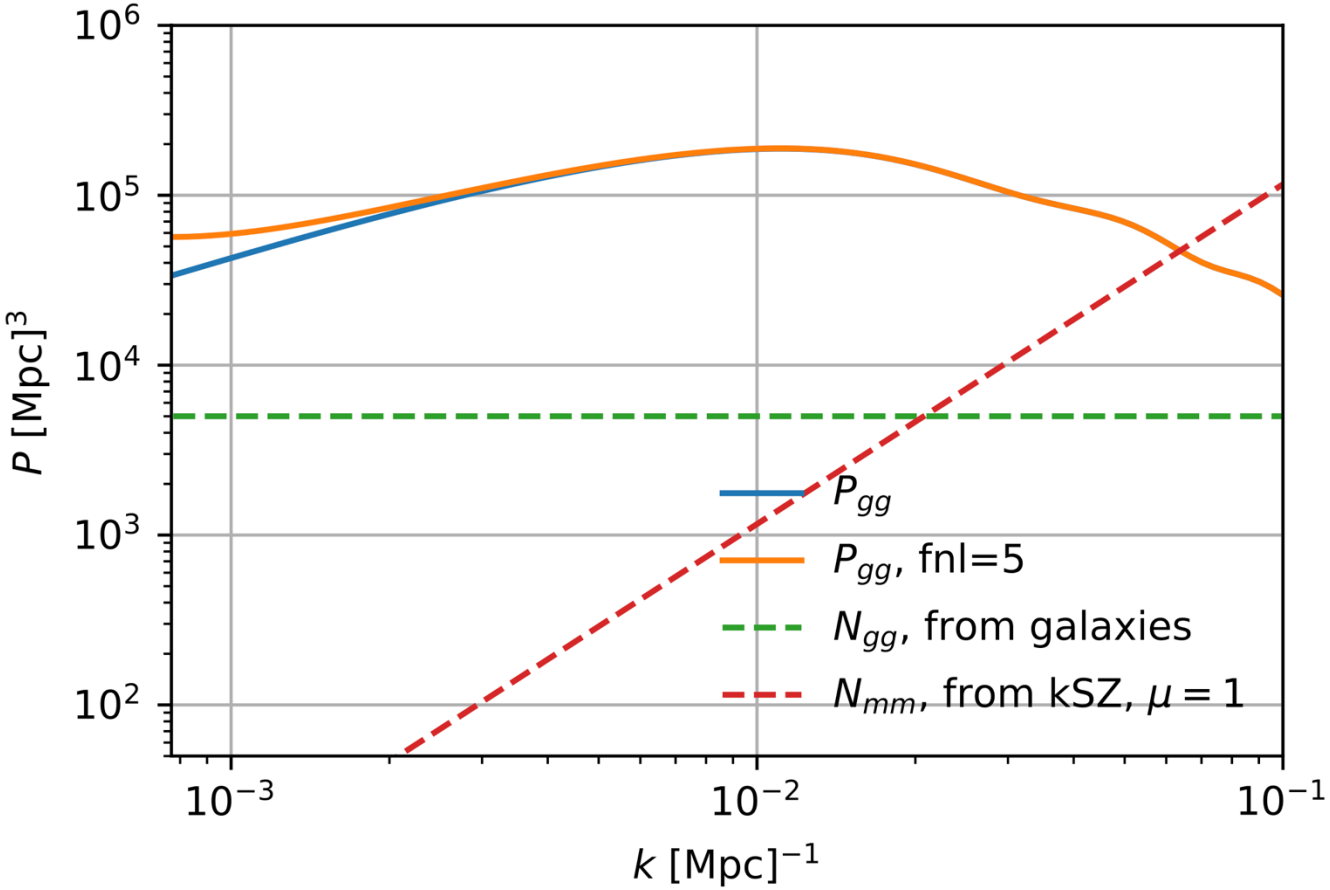
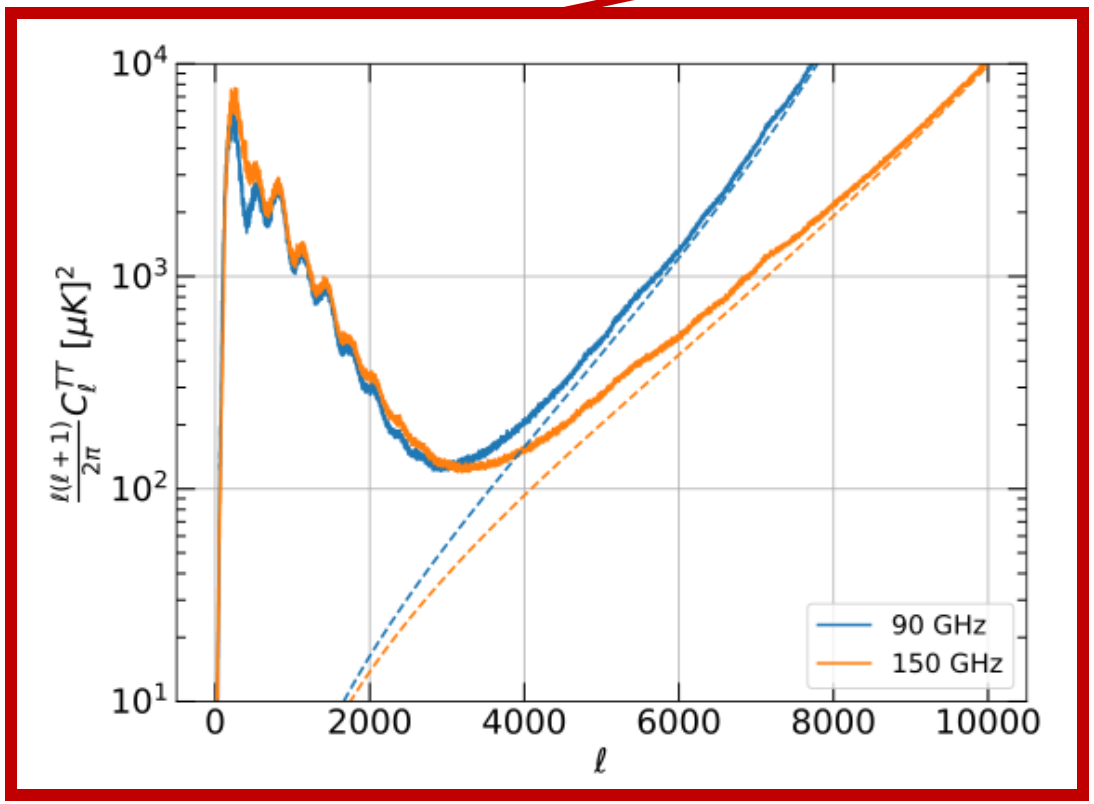


Figure from Münchmeyer et. al., 1810.13424

- Pixel-space, tomographic 2D Quadratic estimator :

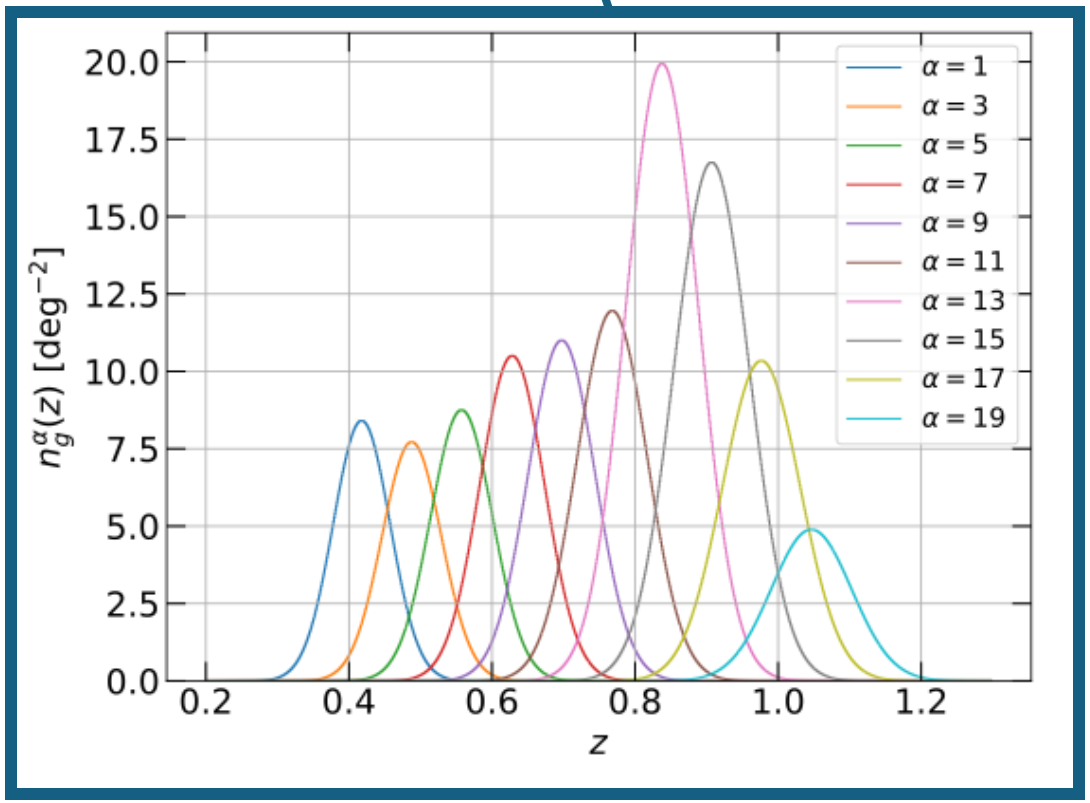
$$\hat{v}_r^{\alpha}(\hat{n}) = -N\ \tilde{T}(\hat{n})\ \tilde{\delta}_g^{\alpha}(\hat{n}) \qquad (1)$$

(Smith et al., 1810.13423, McCarthy et al., 2410.06229, Bloch & Johnson 2405.00809)



ACT DR6: 90 GHz and 150 GHz

Naess et. al., 2503.14451

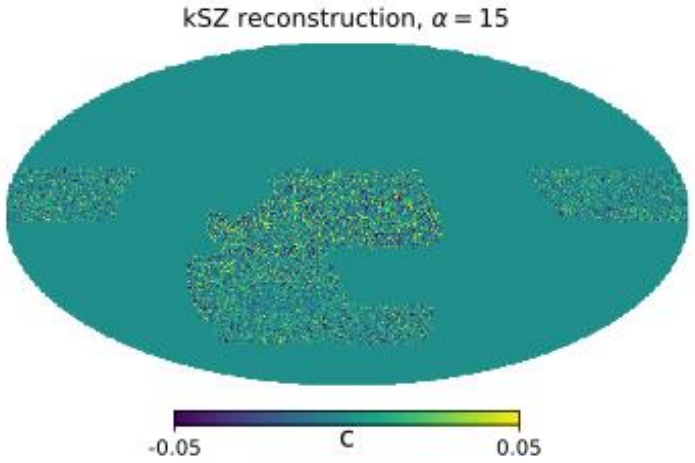


DESI-LS LRG: $z = 0.4$-1.1, 20 bins

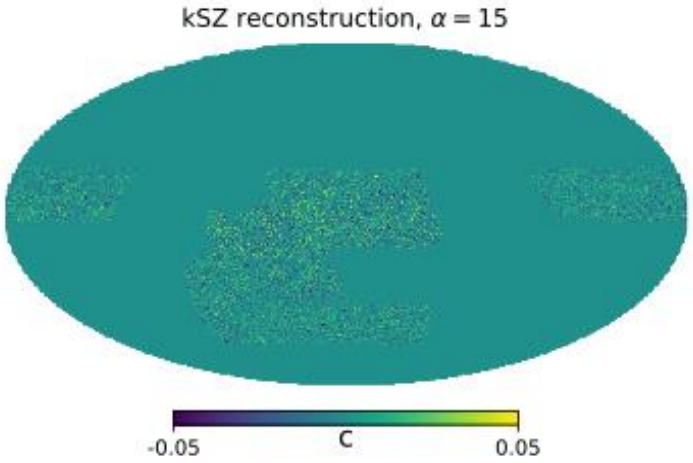
Zhou et. al., 2208.08515

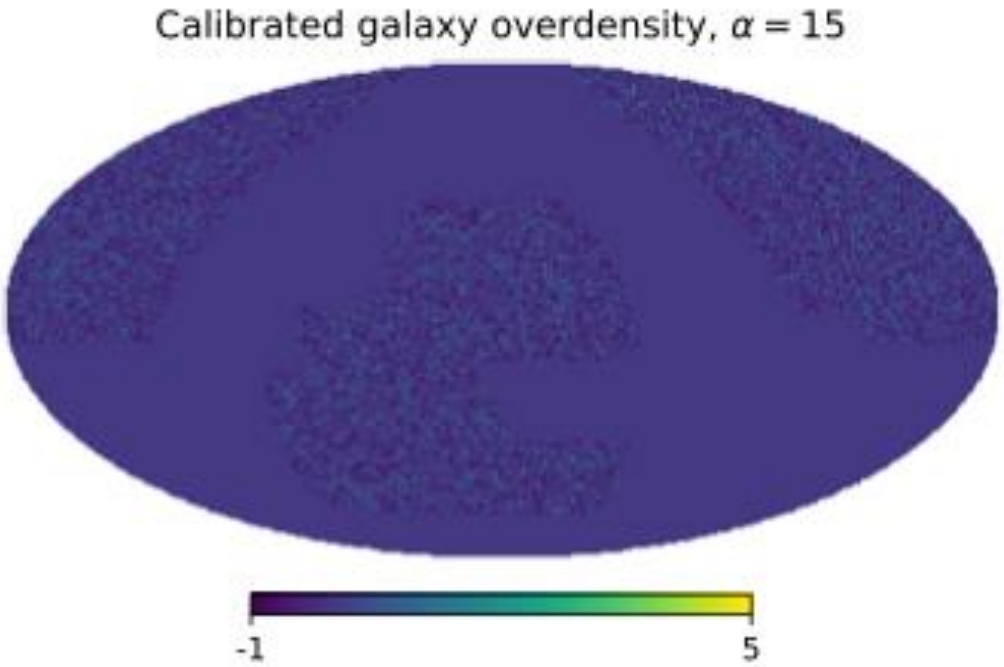
20+20 single-channel velocity maps

$\hat{v}^{\alpha}_{r,\mathrm{f090}}(\hat{n})$



$\hat{v}^{\alpha}_{r,\mathrm{f150}}(\hat{n})$





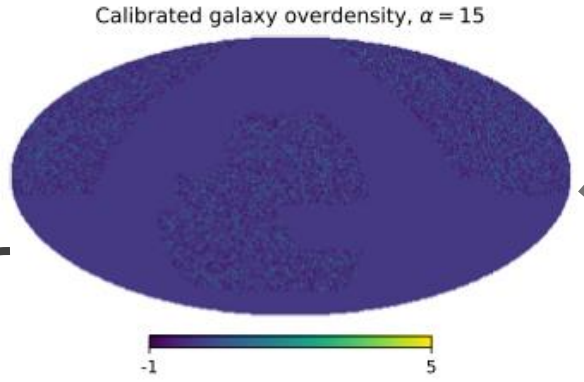
20 coadded velocity maps $\hat{v}^{\alpha}_{r}(\hat{n})$

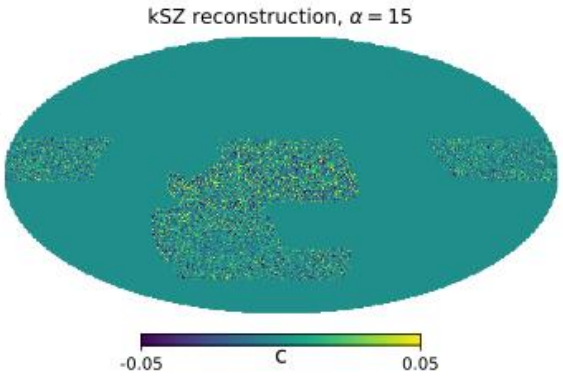
20 galaxy overdensity maps $\hat{\delta}^{\alpha}_{g}(\hat{n})$

Full-sky galaxy-velocity crosspowers estimates $\hat{C}_{\ell}^{g^{\alpha}v^{\beta}}$

- Standard approach: Pseudo-C_ℓ

pair of 2D maps





Coupling matrix M from PyMaster

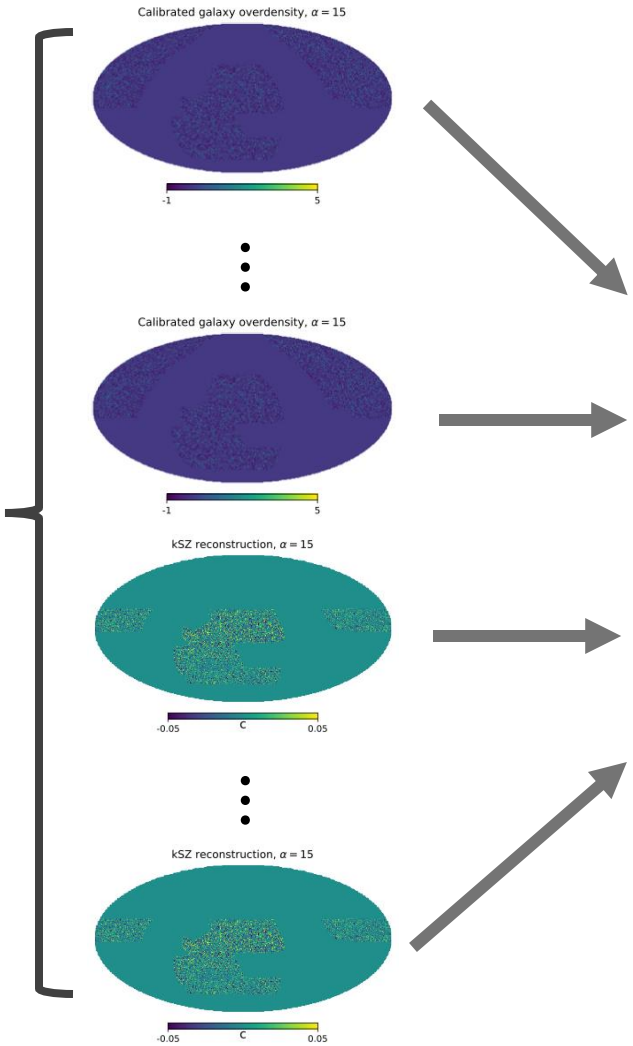
1. Estimate from pseudo-C_ℓ power spectra

2. Repeat for each set of maps

- …… but it is sub-optimal

- Quadratic Maximum Likelihood (QML) (Tegmark, arxiv 9611174, Bilbao-Ahedo, 2104.08528)

2D lightcone projections + 1D redshift bin axis



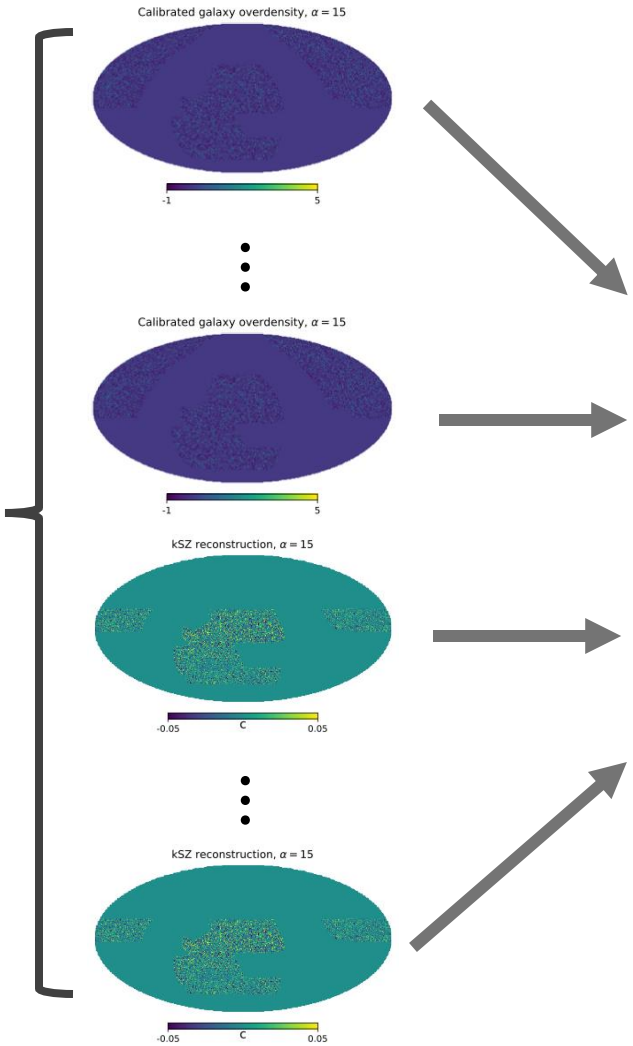
Large covariance matrix $\mathbf{C}$ of dim $\left(n_{\mathrm{pix}} \times n_{\mathrm{field}}\right)^2$

1. $\hat{C}_\ell^{gv}$ estimated from pixels
2. Analytic coupling F between all $\hat{C}_\ell^{gv}$s

- A (2+1)D, pixel-space estimator

- Quadratic Maximum Likelihood (QML), at what cost?

2D lightcone projections + 1D redshift bin axis

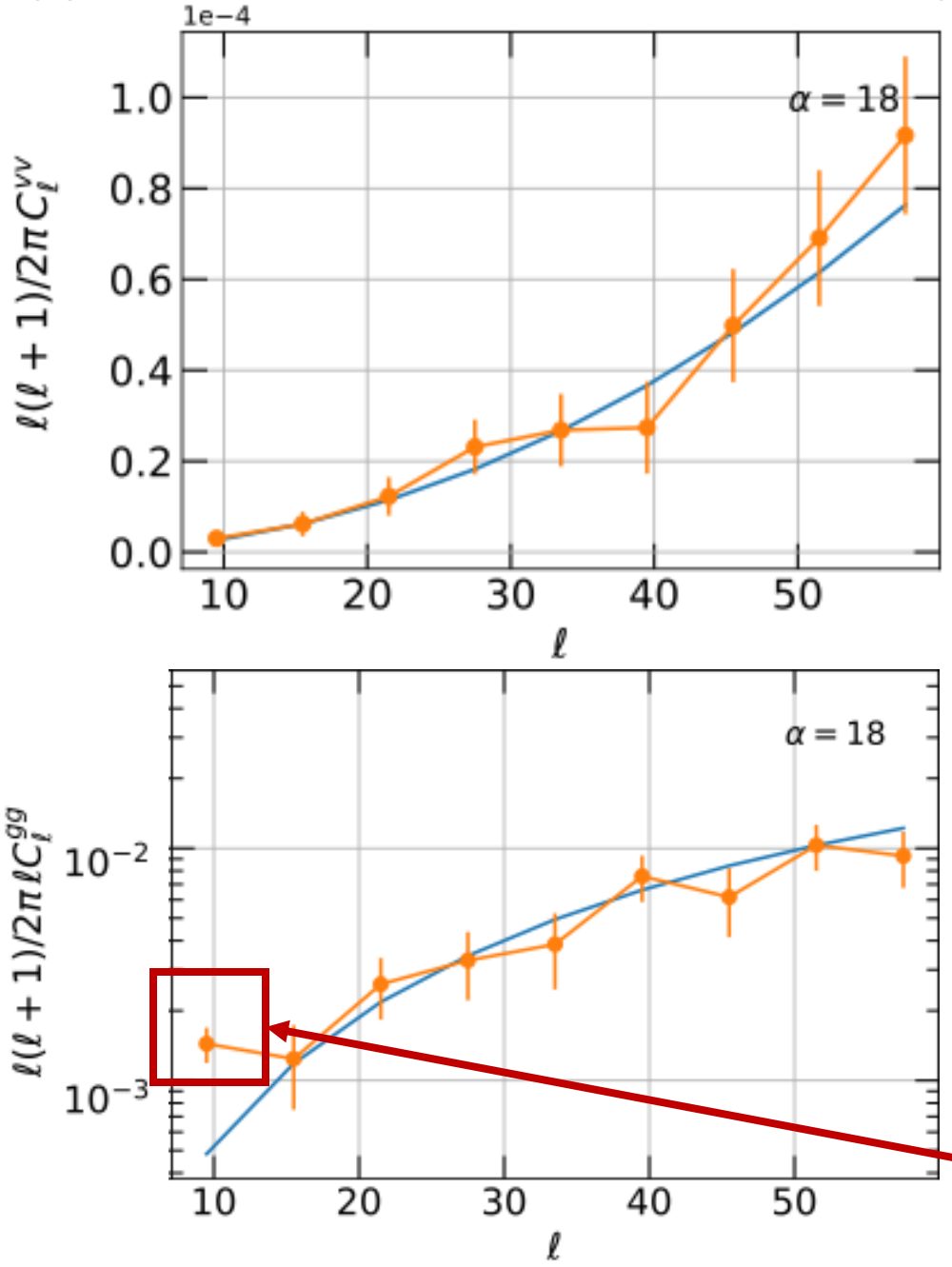


Large covariance matrix $\mathbf{C}$ of dim $\left(n_{\rm pix} \times n_{\rm field}\right)^2$

1. $\hat{C}_\ell^{gv}$ estimated from pixels
2. Analytic coupling F between all $\hat{C}_\ell^{gv}$s

$$O\left(\left(n_{\rm pix} \times n_{\rm field}\right)^3\right) \quad \times \quad O\left(\left(n_{\rm ps} \times n_\ell\right)^2\right)$$

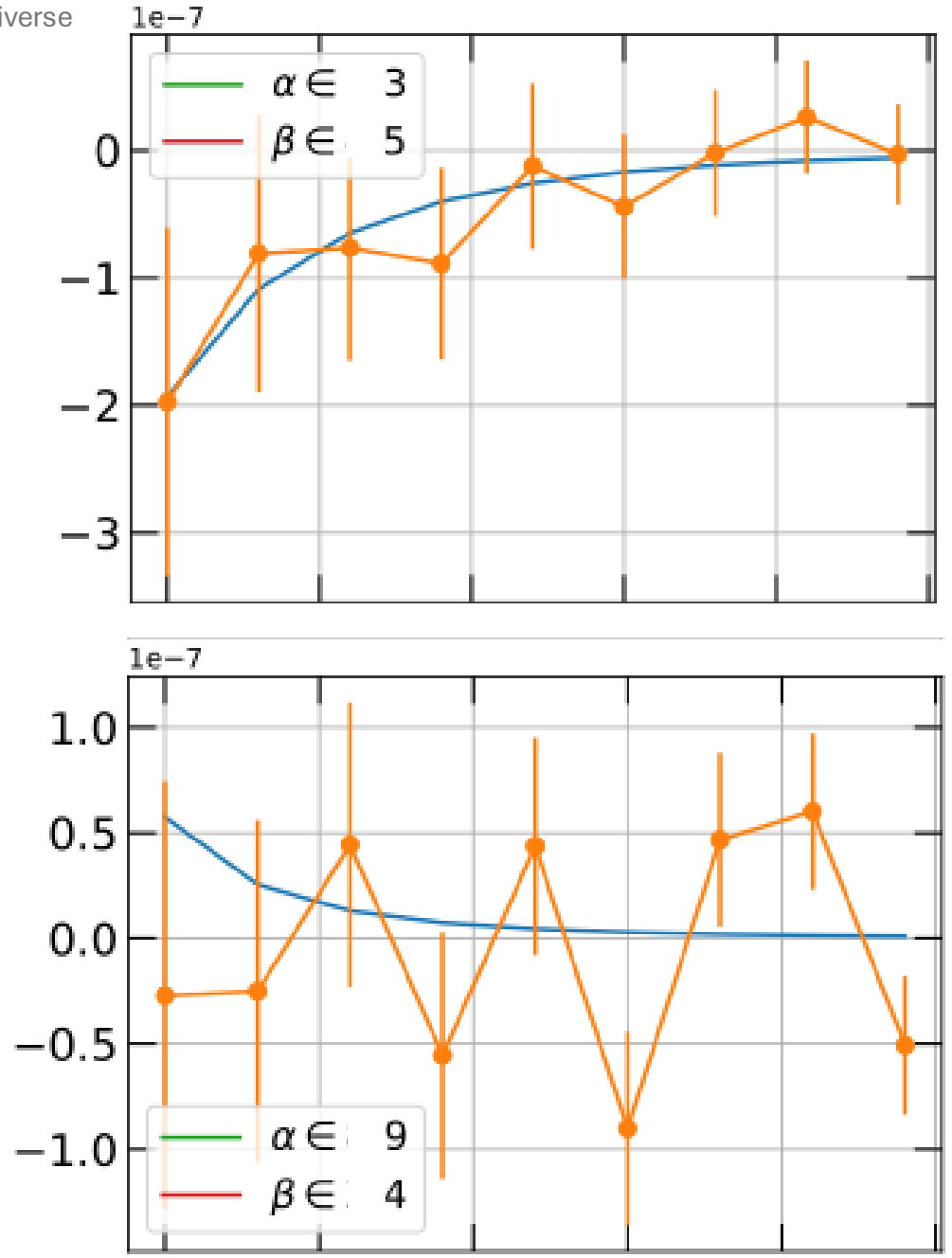
- Highly optimized to ~1 hr on single node for $N_{\rm side} = 32,$ 20+20 fields



- Top: Velocity autopowers $\hat{C}_\ell^{vv,\alpha}$
- Bottom: Galaxy autopowers $\hat{C}_\ell^{gg,\alpha}$
- Bandpower for every 6 modes between $\ell = 7$ and $\ell = 60$
- Fiducials (blue curve) are calculated with PyCCL

Excess on large-scale galaxy power from DESI-LS

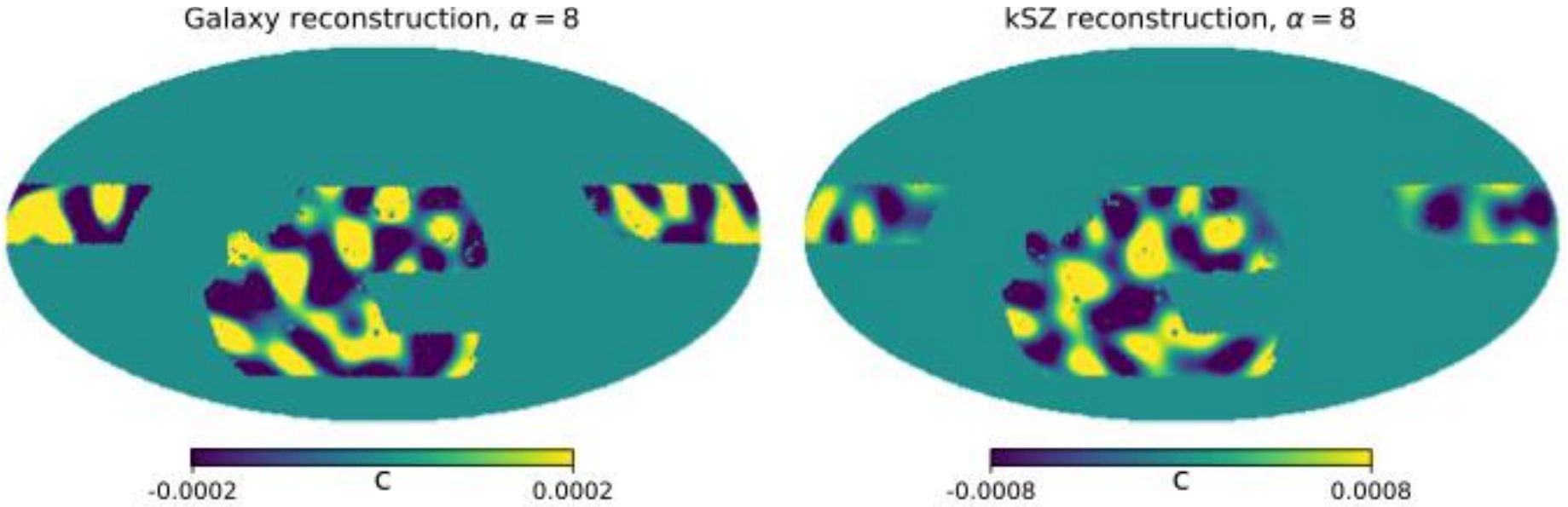
- Velocity-galaxy crosspowers $\hat{C}_\ell^{v^\alpha g^\beta}$
- Signal resides on crosspowers with close redshift bin separation
- Becomes noisier and consistent to zero as the separation grows/becomes zero



- Constrain the kSZ amplitude A, such that $A = 1$ implies a perfect agreement with the Battaglia electron profile (Battaglia, 1607.02442)

- We measured $A \sim 0.4$ at a level of $11.7\ \sigma$

- Same input data with pseudo-C_ℓ pipeline: $A \sim 0.5$ at a level of $6.1\ \sigma$



Final remarks

- We measured the kSZ amplitude $A \sim 0.4$ at a level of $11.7\ \sigma$
  - Achieved with the first attempt in applying QML to the (2+1)D kSZ analysis
  - 20 coadded velocity field (ACT) × 20 galaxy overdensity field (DESI-LS)
  - With highly-optimized pipeline, full estimator can be obtained in ~1hr
  - CMB×Photo. survey is competitive to CMB×Spec. survey
- What's next?
  - Constraints on $f_{\rm NL}$
  - Improve the quality/calibration of the data
  - We get $A \sim 0.4$, can we learn a better profile ? (i.e. with ML, see Kvasiuk et.al., 2411.02496)