~~Numerical Simulations of LSS~~

Redshift Anisotropy Maps: A new Cosmological Statistic

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European Research Council
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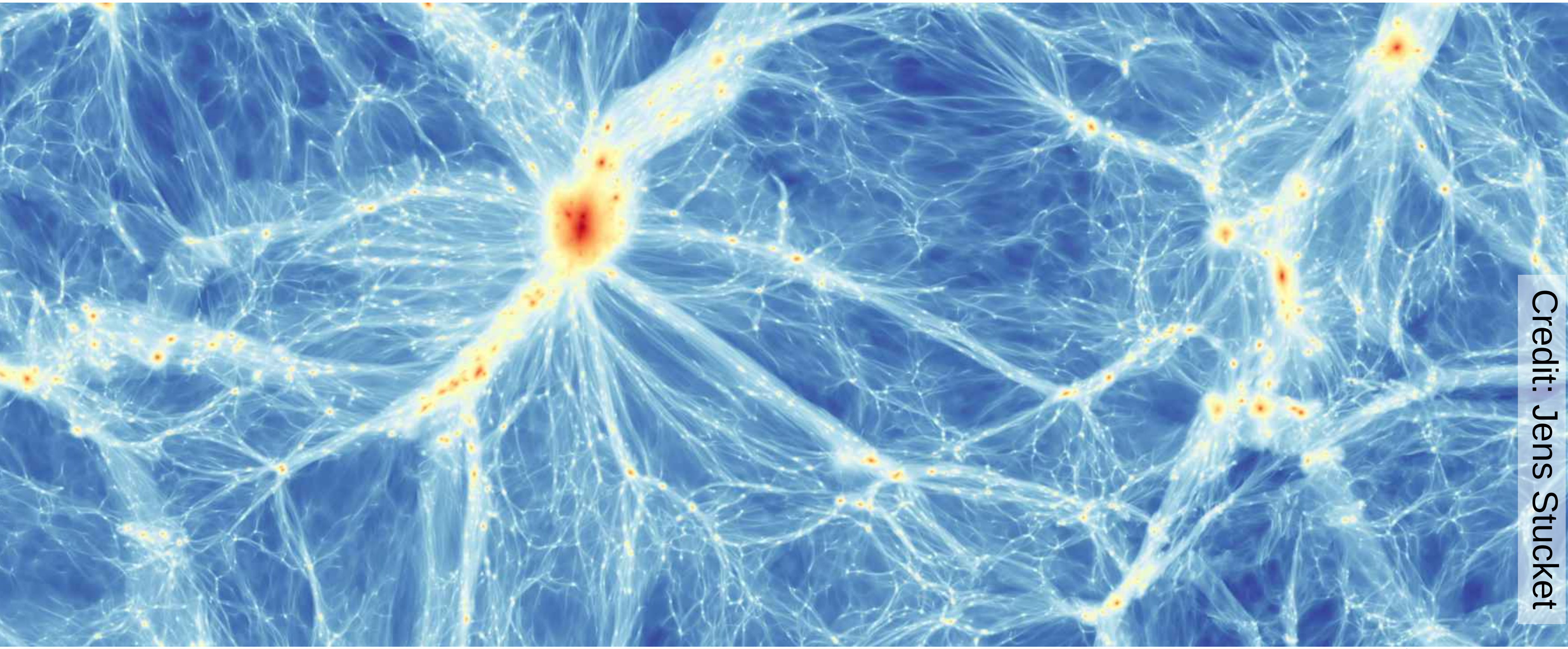
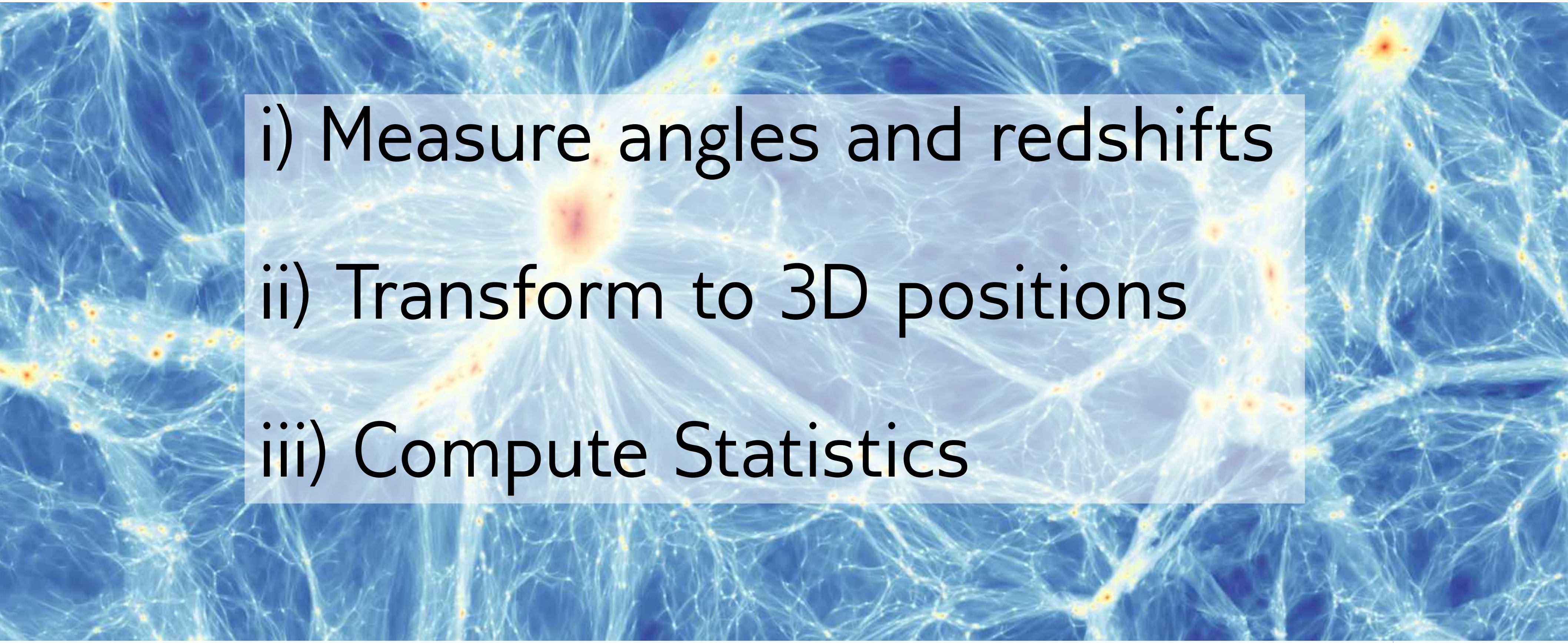


Fundamental Physics



Fundamental Physics

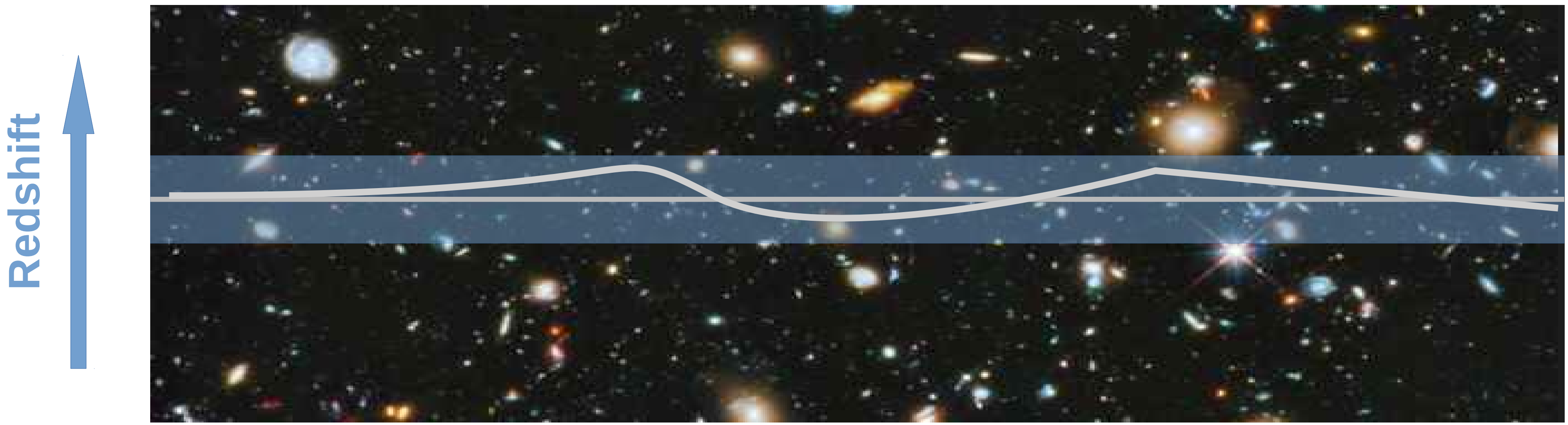
Problems with standard clustering statistics

1. Needs to assume an underlying cosmology and parameters

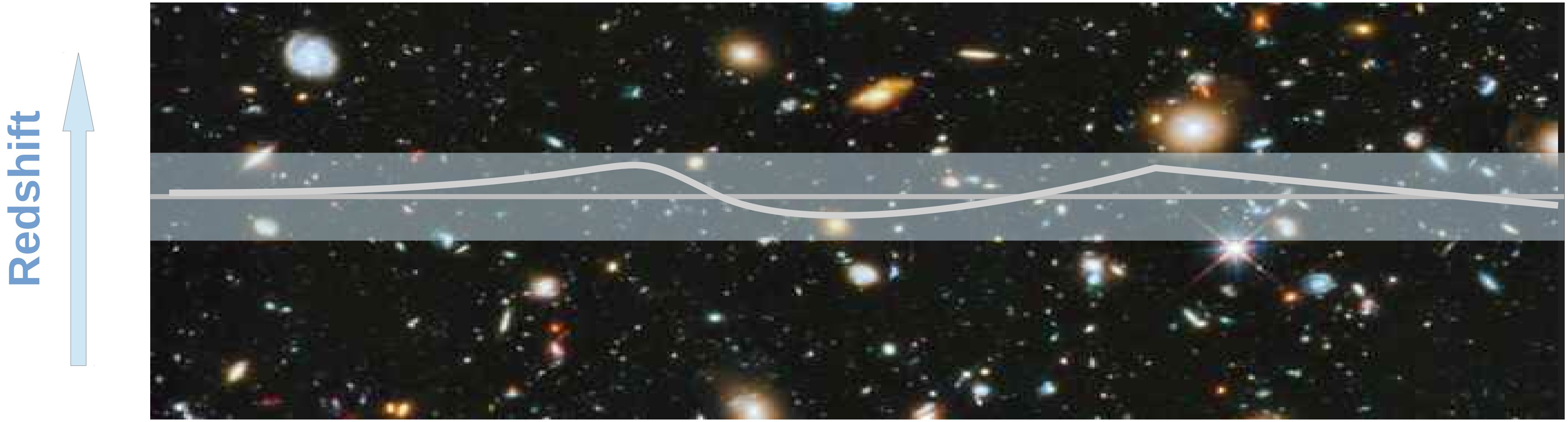
2. Very sensitive to observational systematics

3. Non-tomographic

A new, alternative cosmological statistic



A new, alternative cosmological statistic



i) Dœns't assume any cosmological model

ii) It can be computed in small redshift bins

iii) Insensitive to additive/multiplicative systematics

iv) Highly correlated to the velocity field

1. Theoretical Understanding

Hernandez-Monteagudo et al (submitted)

2. Measurements of Growth

Hurier et al (in prep); Adam et al (in prep)

3. Finding the missing baryons

Chaves-Monteagudo et al (in prep)

A new Cosmological Statistic: Redshift Anisotropy Maps

The redshift anisotropy at a given angular position is a l-o-s integral:

$$\bar{z} + \delta z(\hat{\mathrm{n}}) = \frac{\int d\eta\, \eta^2 \bar{n}(\eta)\big(1 + b_g \delta_{\mathrm{m}}(\eta, \hat{\mathrm{n}})\big)\big(z_H + z_{vlos} + z_\phi\big) W\big(z_H + z_{vlos} + z_\phi;\, \sigma_z\big)}{\int d\eta\, \eta^2 \bar{n}(\eta)\big(1 + b_g \delta_{\mathrm{m}}(\eta, \hat{\mathrm{n}})\big) W\big(z_H + z_{vlos} + z_\phi;\, \sigma_z\big)}$$

A new Cosmological Statistic: Redshift Anisotropy Maps

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Hubble flow (z_H)

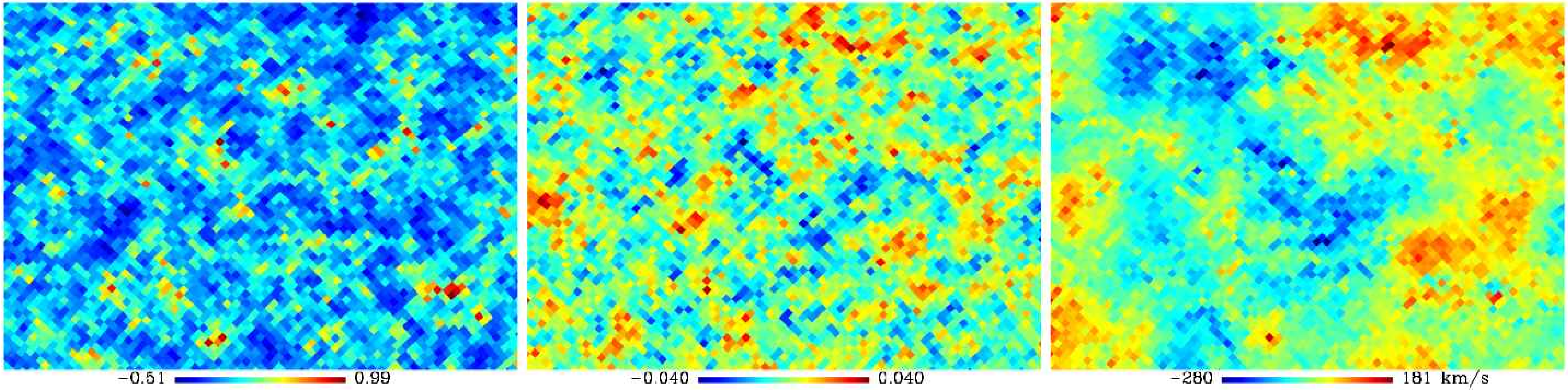
Peculiar Velocities (z_{vlos})

Gravitational Redshifts (z_ϕ)

This can be computed using a simple estimator:

$$\delta z(\hat{\mathrm{n}}) = \sum_j (z_j - \bar{z}) W_j / \sum_j W_j$$

A new Cosmological Statistic: Redshift Anisotropy Maps



Densities

RAMs

Peculiar Velocities

A new Cosmological Statistic: Redshift Anisotropy Maps

Perturbatively (assuming delta & v/sigma_z << 1)

$$\bar{z} + \delta z(\hat{\mathrm{n}}) = \mathcal{F}[z_H] + \mathcal{F}[b_g \delta_{\mathrm{m}} \left(z_H - \mathcal{F}[z_H]\right)]$$
$$+ \mathcal{F}\left[\left(z_\phi + \frac{\mathbf{v}\cdot\hat{\mathrm{n}}}{c}(1+z_H)\right)\left(1 - \frac{d\log W}{dz}(z_H - \mathcal{F}[z_H])\right)\right] + \mathcal{O}(2^{\mathrm{nd}})$$

$$\mathcal{F}[Y] = \frac{\int d\eta\, \eta^2 \bar{n}(\eta) W(z_H;\, \sigma_z) Y(\eta)}{\int d\eta\, \eta^2 \bar{n}(\eta) W(z_H;\, \sigma_z)}$$

A new Cosmological Statistic: Redshift Anisotropy Maps

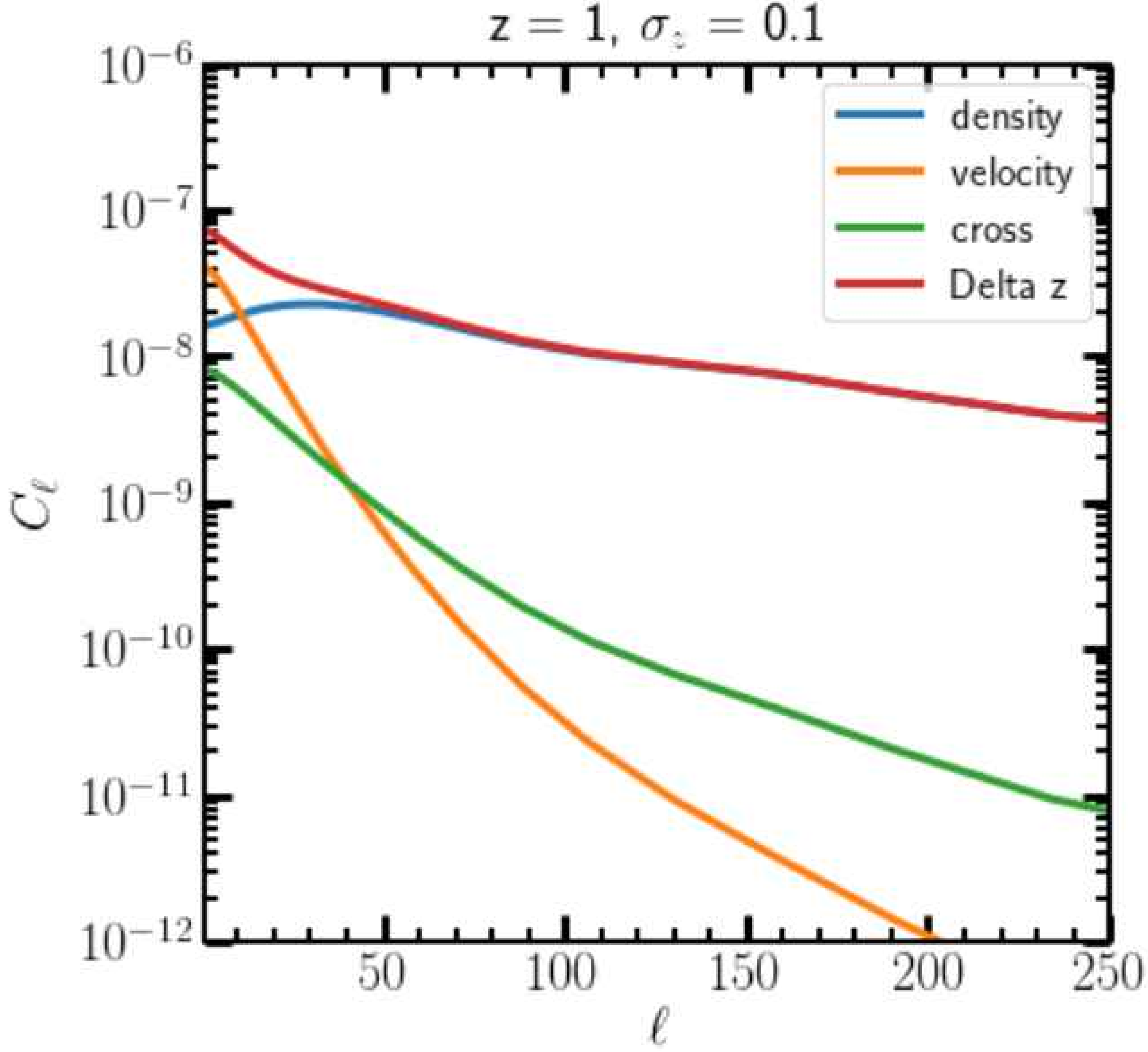
$$\Delta_l^{\delta_{\rm m}} = \int d\eta\, \Sigma(\eta)\, W(z_H;\, \sigma_z) D_{\delta_{\rm m}} \delta z_H\, j_l(k\eta)$$

$$\Delta_l^{vlos} = \int d\eta\, \Sigma(\eta)\, W(z_H;\, \sigma_z) \frac{H(z_H)}{a} \frac{dD_{\delta_{\rm m}}}{dz} (1 - \frac{d\log W}{dz} \delta z_H)\, \frac{j_l'(k\eta)}{k}$$

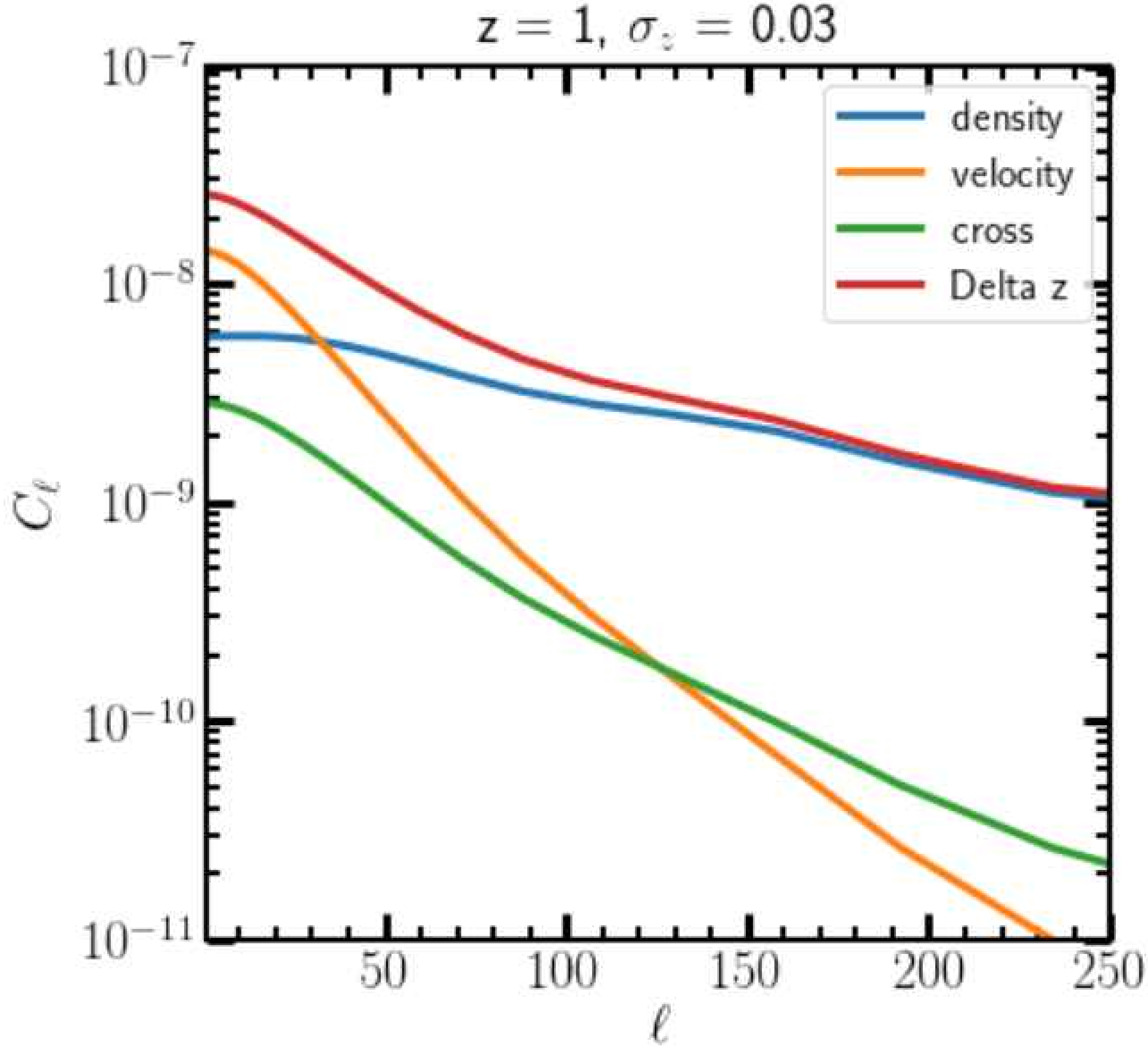
$$C_l^{\alpha,\,\beta} = (2/\pi) \int dk\, k^2 P_{\rm m}(k) \Delta_l^{\alpha}(k) \Delta_l^{\beta}(k)$$

$$C_l^{\delta z,\, \delta z} = b_g^2 C_l^{\delta,\, \delta} + 2 b_g C_l^{\delta,\, vlos} + C_l^{vlos,\, vlos}$$

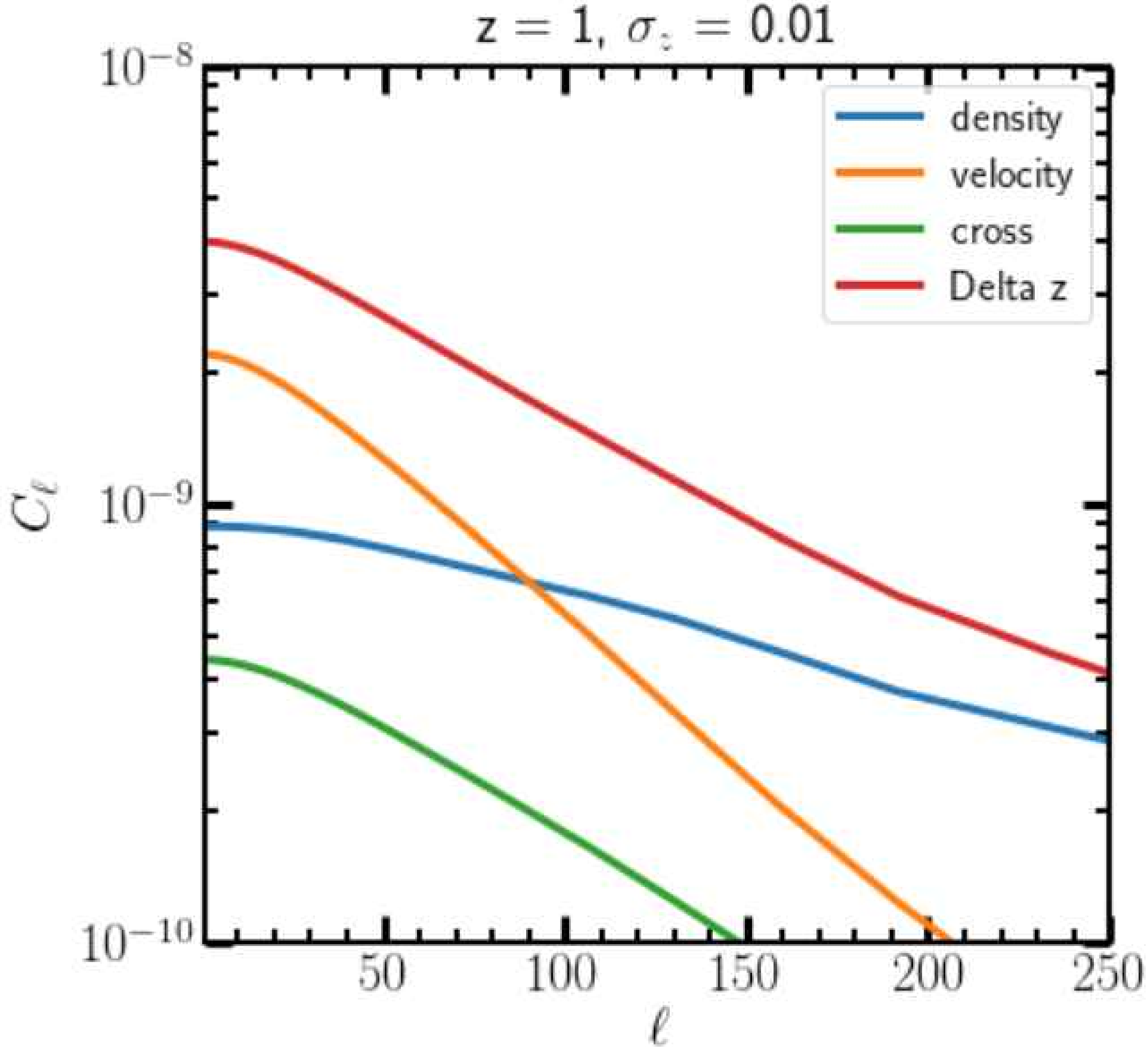
A new Cosmological Statistic: Theoretical understanding



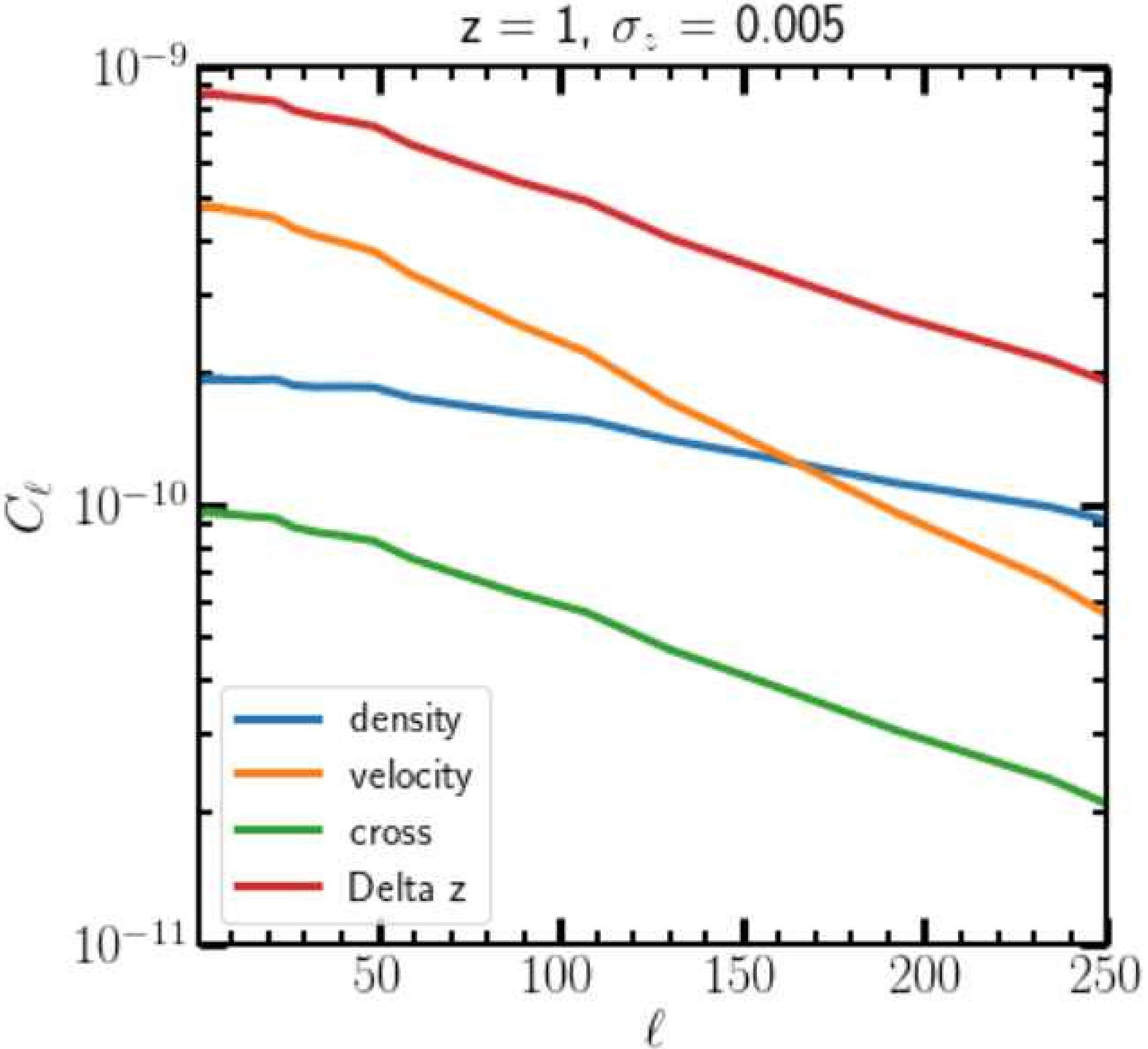
A new Cosmological Statistic: Theoretical understanding



A new Cosmological Statistic: Theoretical understanding

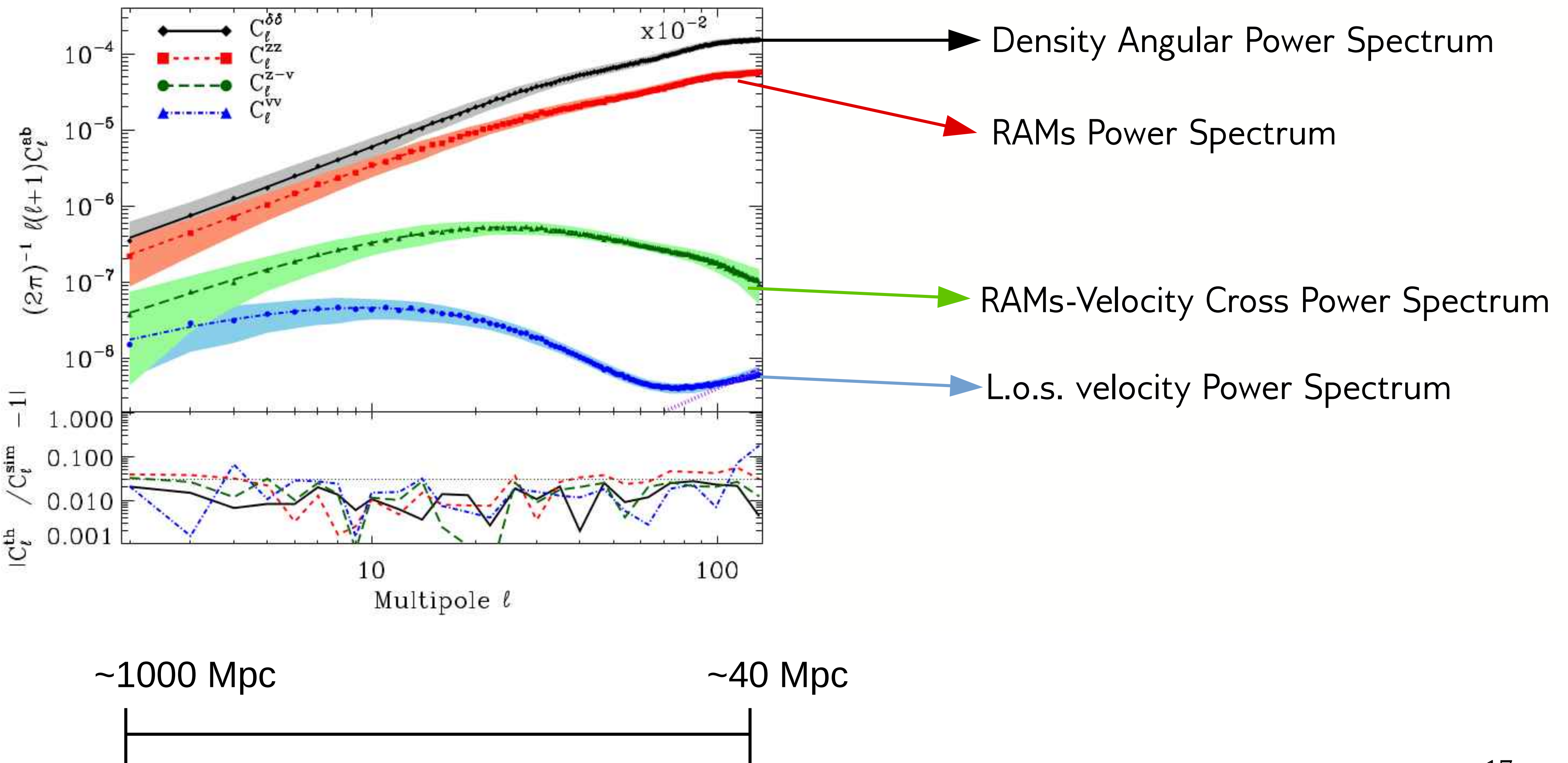


A new Cosmological Statistic: Theoretical understanding



A new Cosmological Statistic: Theoretical understanding

Comparison with DM @ z=0.5 from 1000 COLA Lightcone Mocks



A new Cosmological Statistic: Theoretical understanding

Let's consider the observed number of galaxies under additive (e) and Multiplicative bias (gamma) created by systematic errors:

$$n^{\rm obs}(\mathbf{r}) = \gamma\bar{n}(1 + \delta_g(\mathbf{r}) + \epsilon)$$

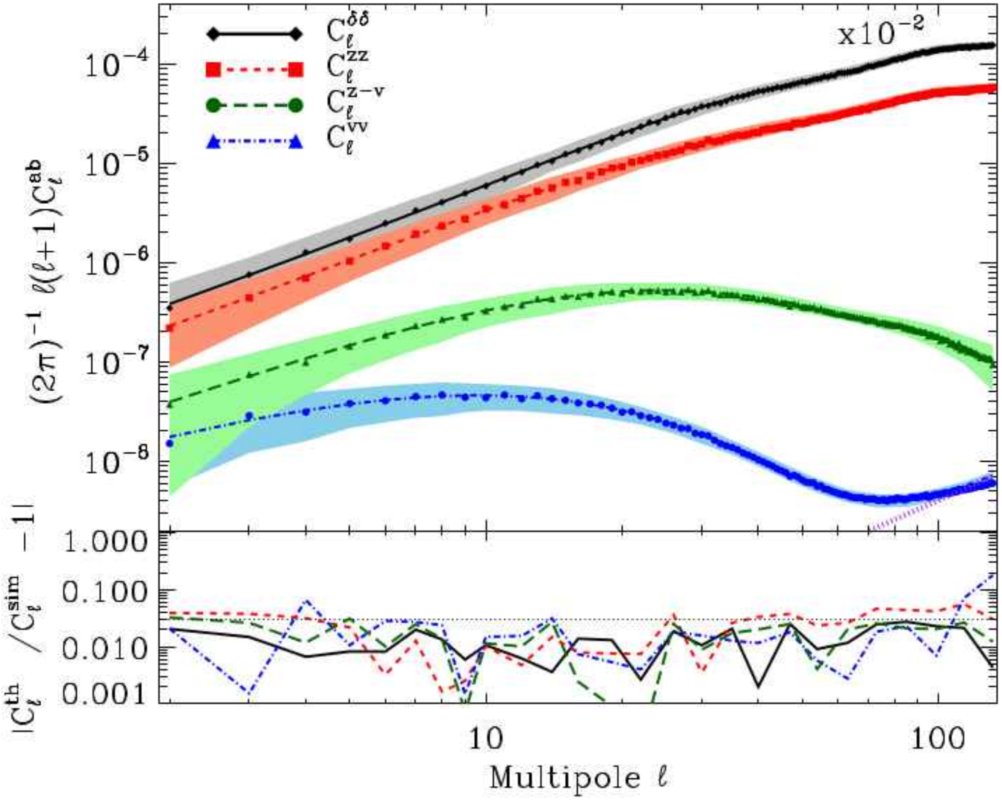
The same errors in the RAMs:

$$(\delta z)^{\rm obs}(\hat{\rm n}) \simeq \delta z(\hat{\rm n}) + \mathcal{F}[\epsilon(z_H - \mathcal{F}[z_H])]$$

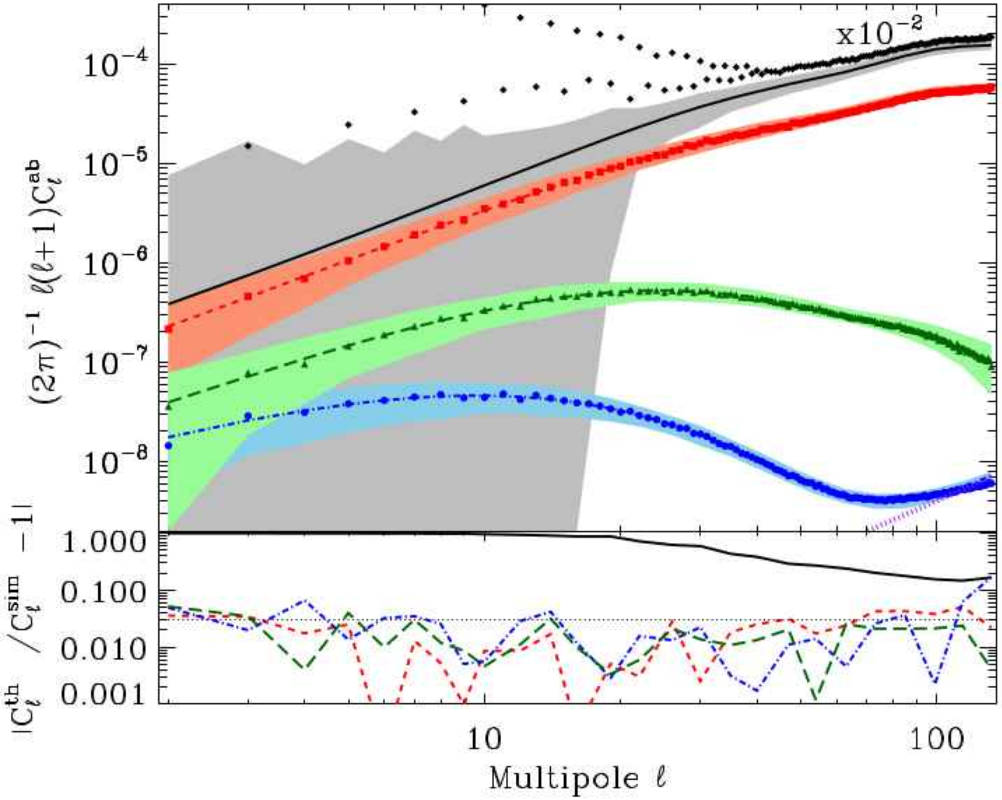
RAMs are formally insensitive to multiplicative biases, and roughly insensitive to additive biases as long as dN/dz is constant over W(z)

A new Cosmological Statistic: Theoretical understanding

No added systematics



With added systematics



~1000 Mpc ~40 Mpc

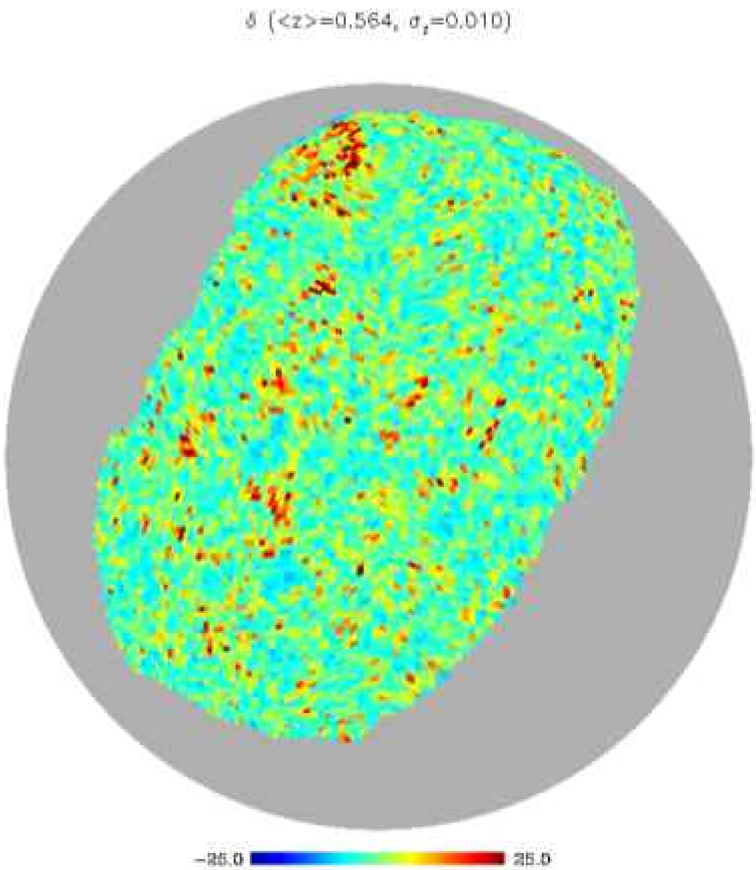
1. Theoretical Understanding

2. Application to data

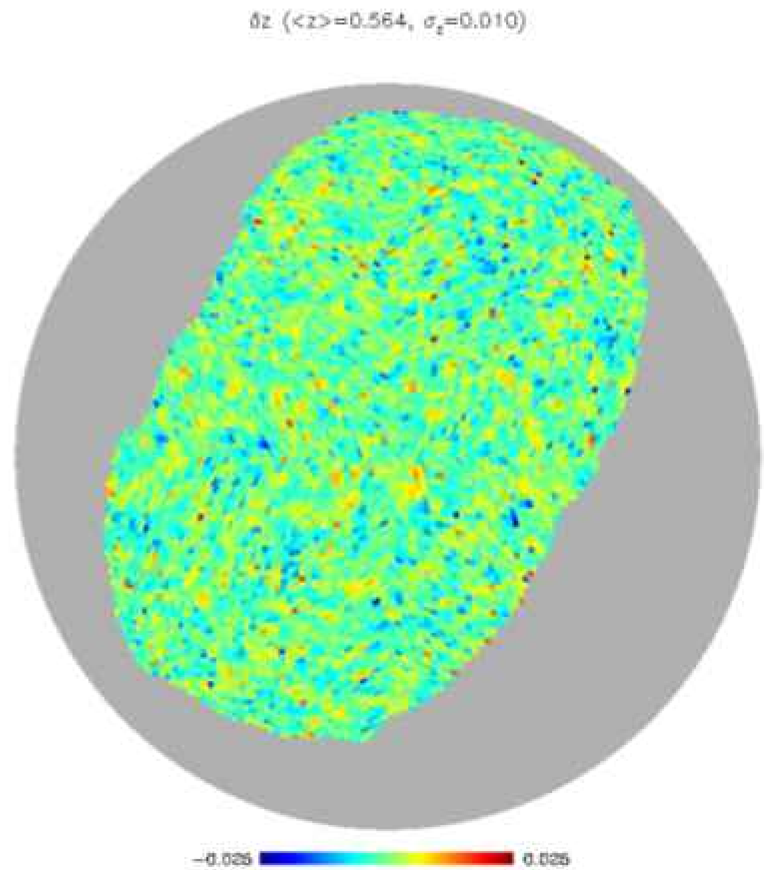
3. Finding the missing baryons

A new Cosmological Statistic: Redshift Anisotropy Maps

Analysis of 1.3 million galaxies in DR13



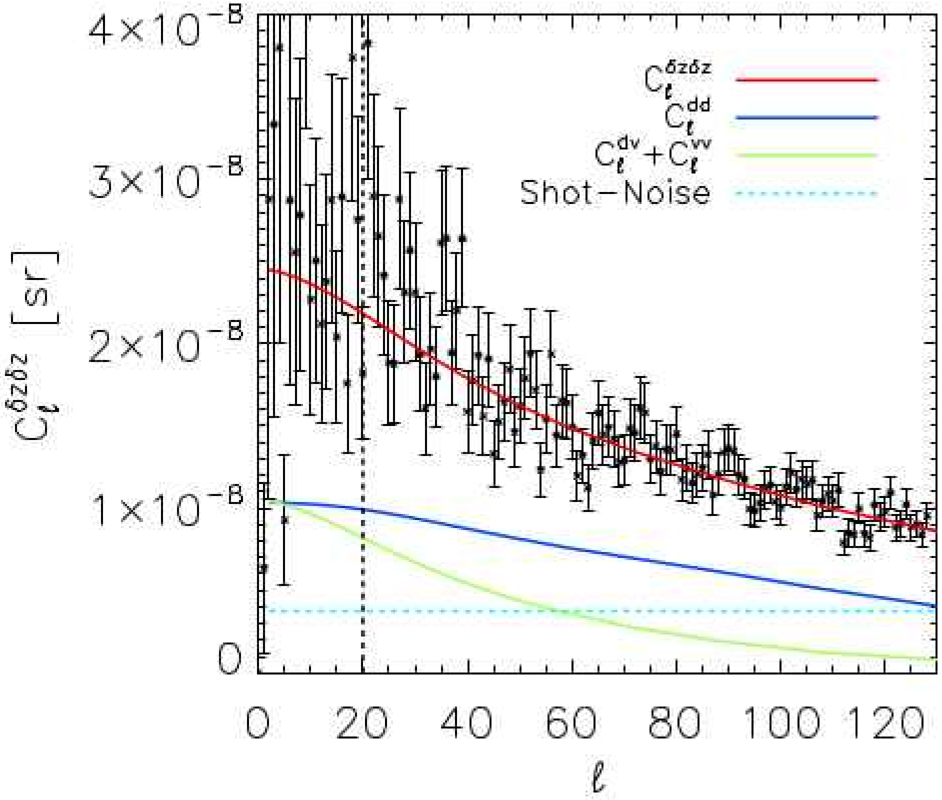
Densities

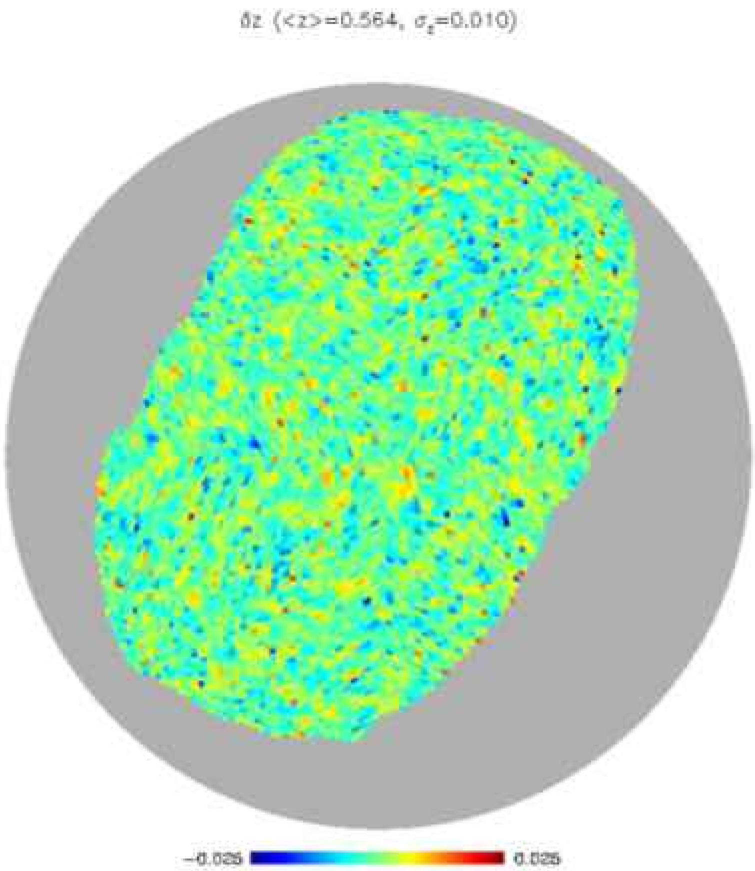


RAMs

A new Cosmological Statistic: Redshift Anisotropy Maps

HealPix tesselation with 0.84 deg^2 pixel

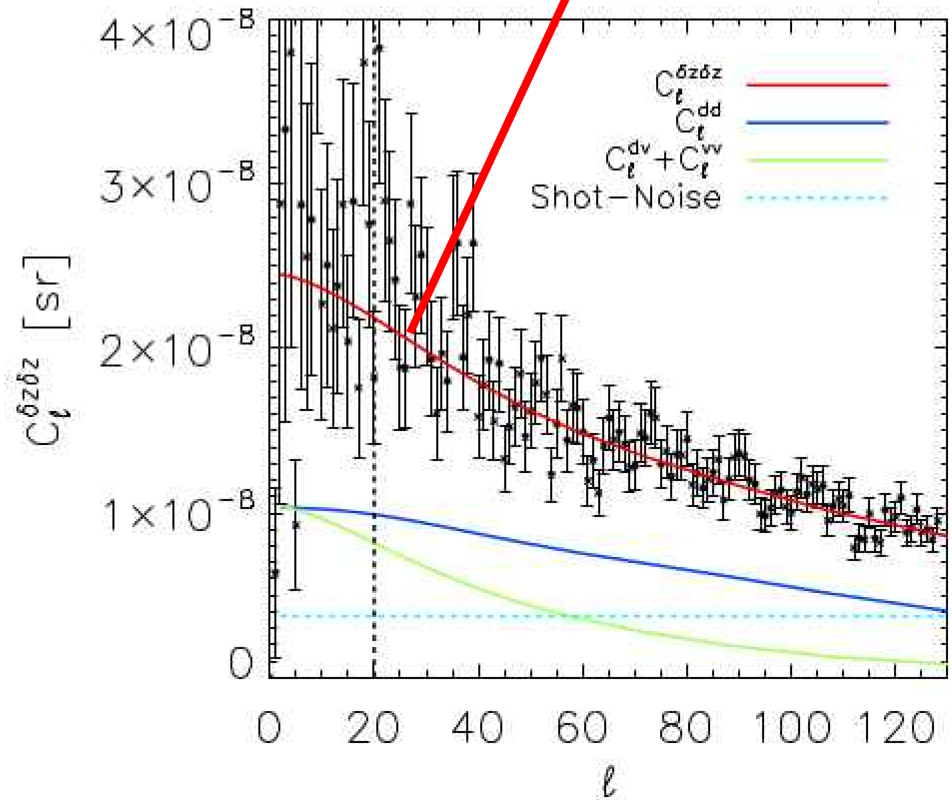




RAMs

A new Cosmological Statistic: Redshift Anisotropy Maps

$$C_\ell^{\delta z,\delta z} = \sigma_8^2 \left(b_g^2 C_\ell^{\rm dd} + 2 b_g f C_\ell^{\rm dv} + f^2 C_\ell^{\rm vv} \right) + {\rm SN}_z$$



Constrains on the Growth rate and Amplitude of fluctuations

Cosmological Constraints from Redshift Anisotropy Maps

i) LOWZ & CMASS in DR12 - DR13

ii) 51 redshift bins, with $\sigma_z = 0.01$

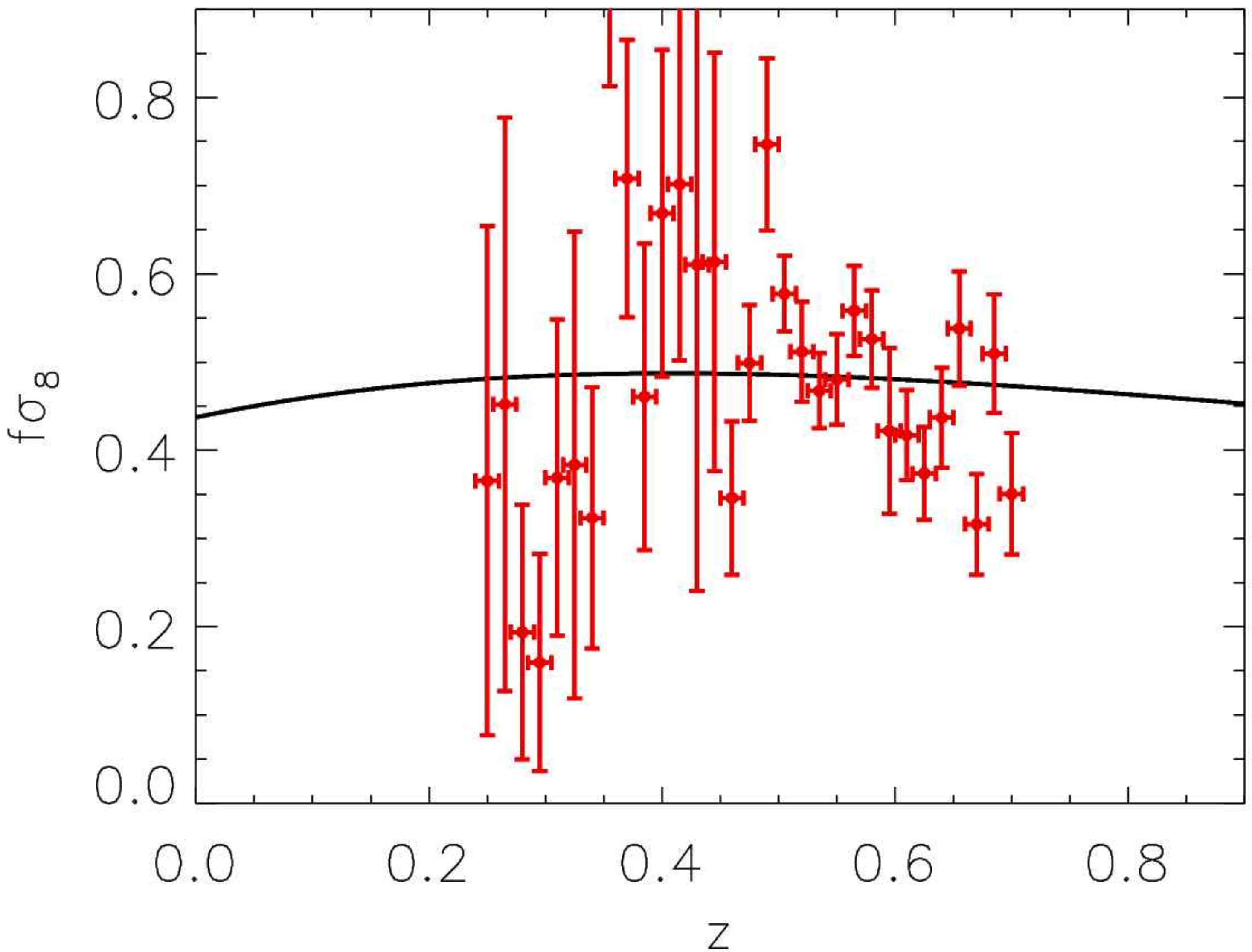
iii) Covariance in delta-delta, delta-delta_z, and delta_z-delta_z from PATCHY mocks

iv) We fit for $\{b\ \sigma_8$, $f\ \sigma_8$, SN_z, $Sn_{delta}\}$

v) Adopt Planck (TT, TE, EE), BAO, SNe Likelihoods for other cosmological parameters

Cosmological Constraints from Redshift Anisotropy Maps

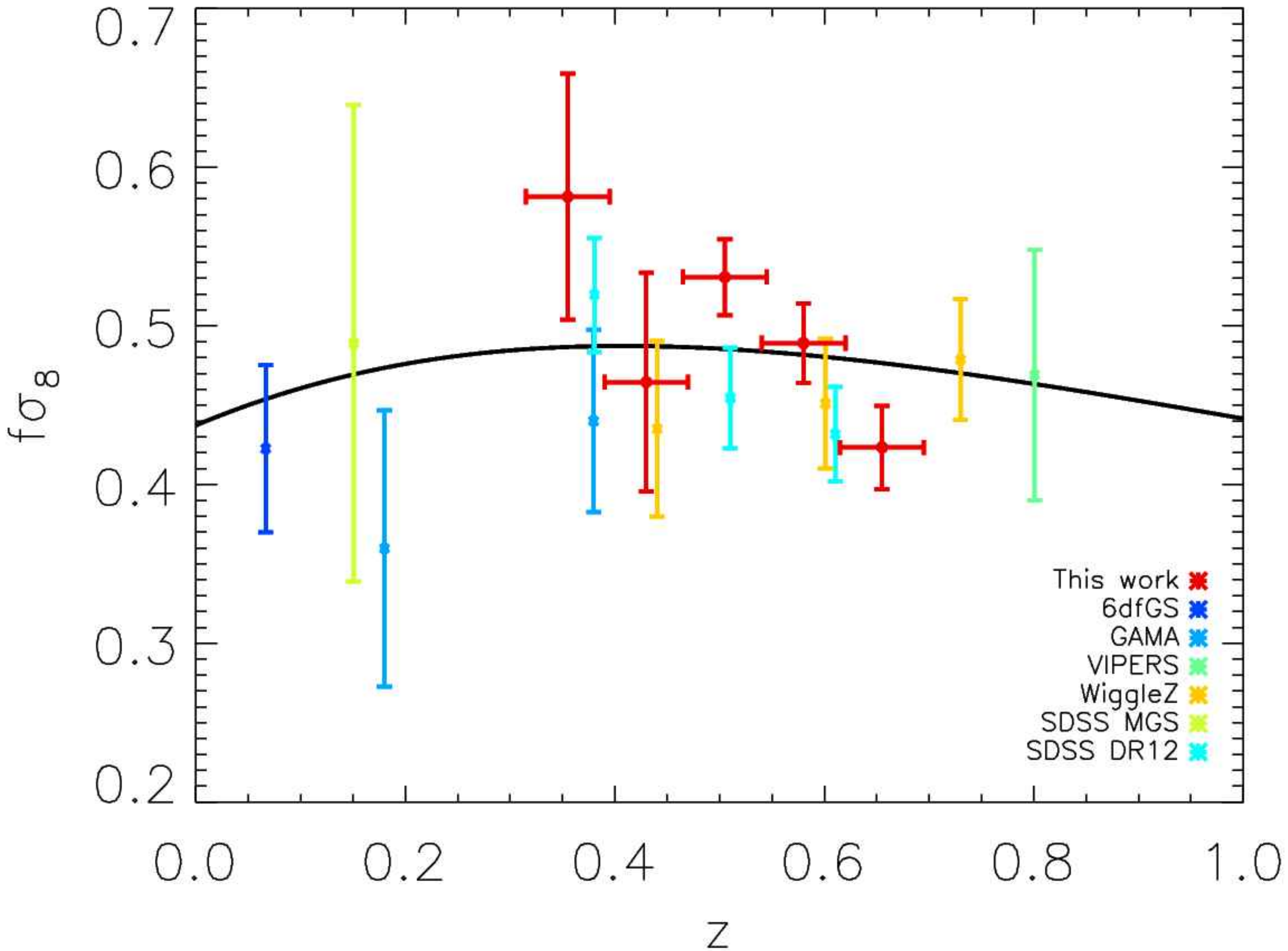
Growth measurement in ~18 independent redshift bins



Cosmological Constraints from Redshift Anisotropy Maps

A 2.8% measurement of the growth rate: $f\sigma_8$ = 0.478 \pm 0.013

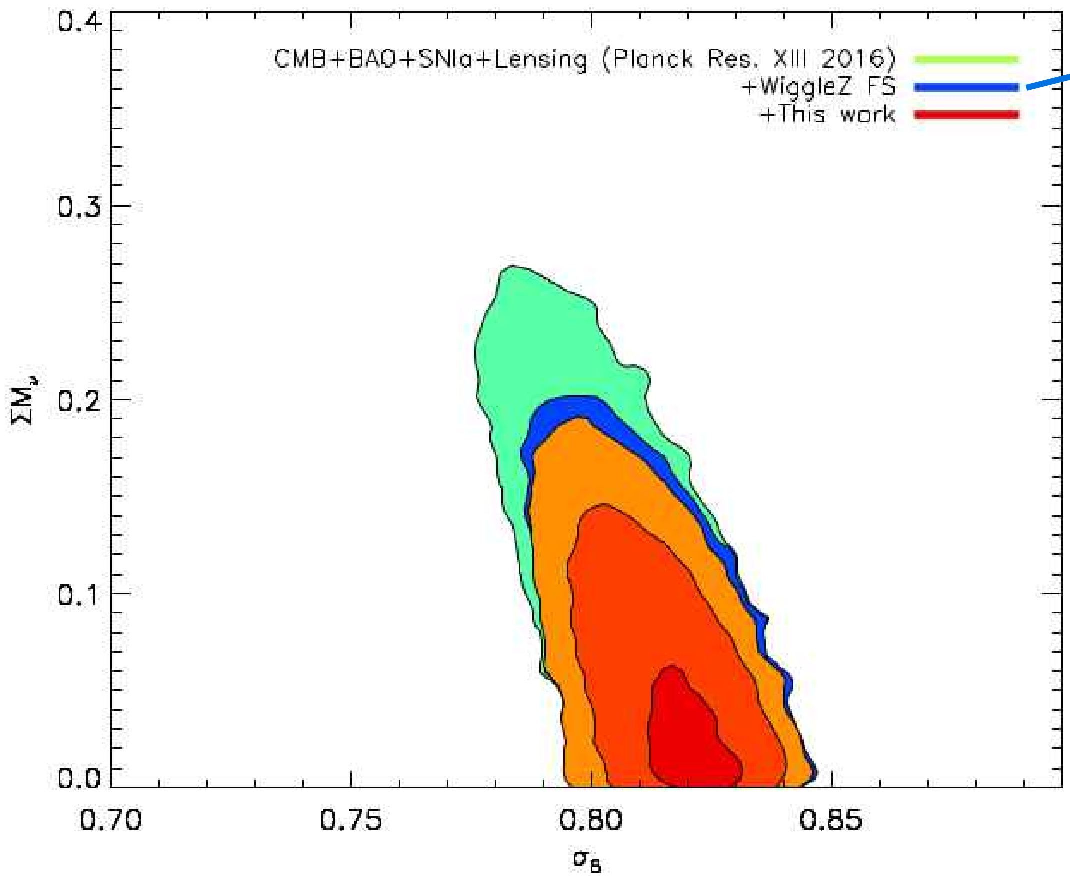
A 9% measurement of growth-rate index: γ = 0.505 \pm 0.045



Cosmological Constraints from Redshift Anisotropy Maps

One of the strongest cosmological constraints so far on massive Neutrinos (improvement of 25% over Alam et al)

$\sum m_\nu < 0.13$ eV at 95% confidence level



WiggleZ P(k) used Only down to k < 0.1 h/Mpc

1. Theoretical Understanding

2. Application to data

3. Finding the missing baryons

Finding the missing baryons with Redshift Anisotropy Maps

Thomson scattering of free-electrons and CMB photons creates secondary anisotropies in the observed CMB temperature fluctuations:

$$\frac{\Delta T_{\mathrm{kSZ}}(\hat{n})}{T_{\mathrm{CMB}}} = -\sigma_T \int \mathrm{d}l\, n_e \left(\frac{\mathbf{v} \cdot \hat{n}}{c} \right)$$

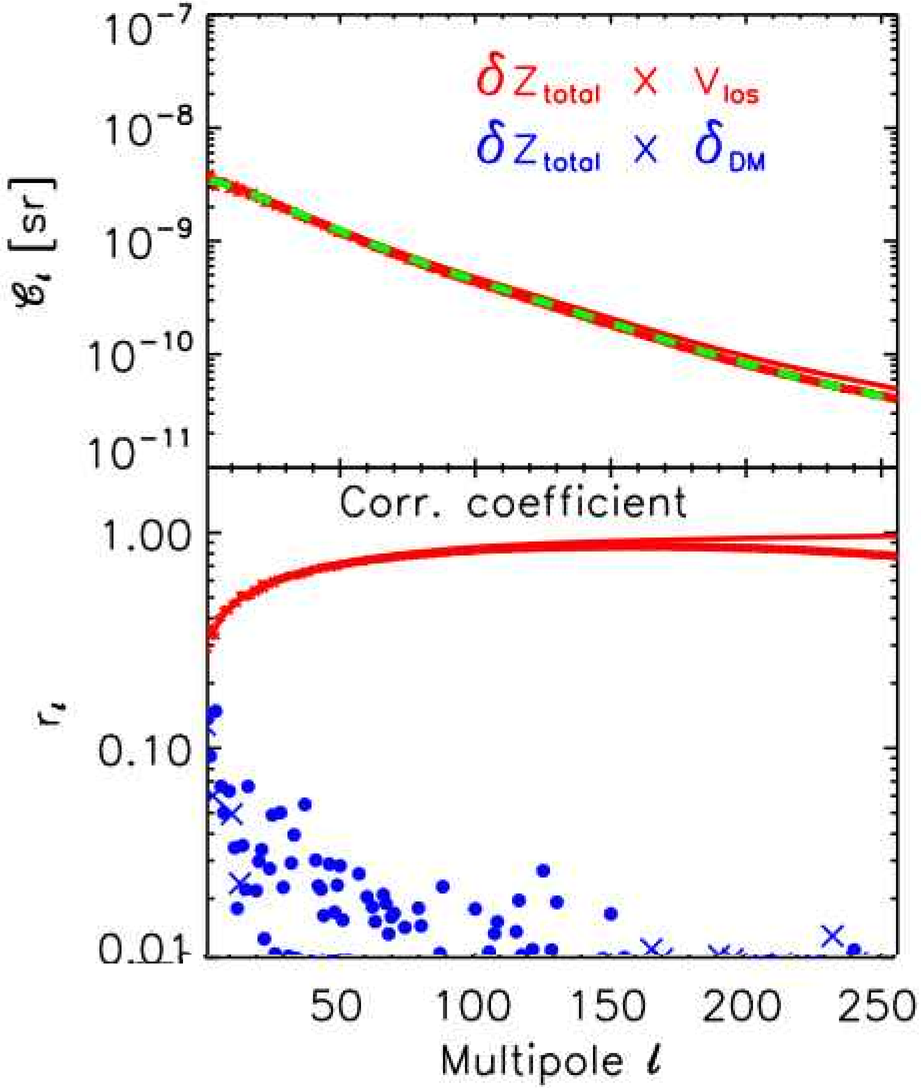
The kSZ is not sensitive to the temperature of the gas, only depends on its Momentum.

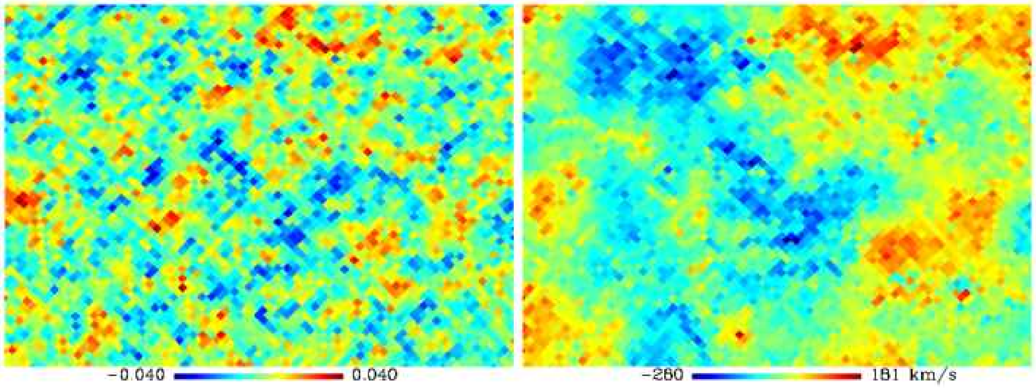
Unfortunately, kSZ << tSZ << primordial fluctuation.

However, the kSZ could be detected through x-correlation with the velocity field

Finding the missing baryons with Redshift Anisotropy Maps

RAMs are a proxy for the velocity field





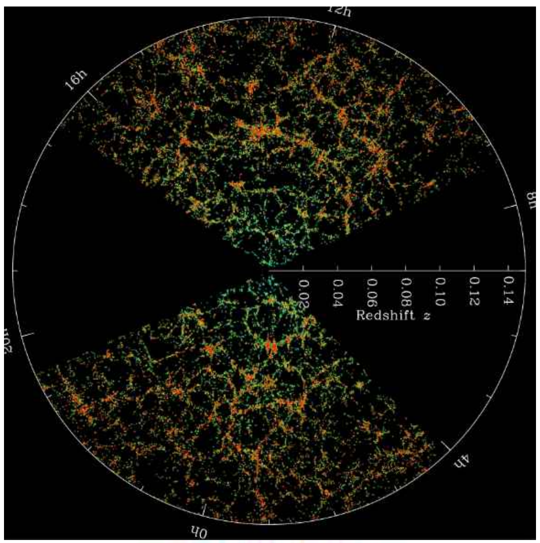
RAMs

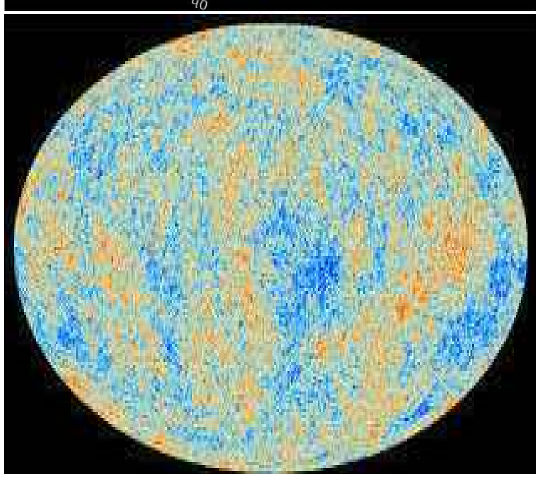
Peculiar Velocities

$$C_\ell^{\mathrm{kSZ}-z} = -\tau_{\mathrm{AP}}(\theta_{\mathrm{AP}})C_\ell^{v-z}$$

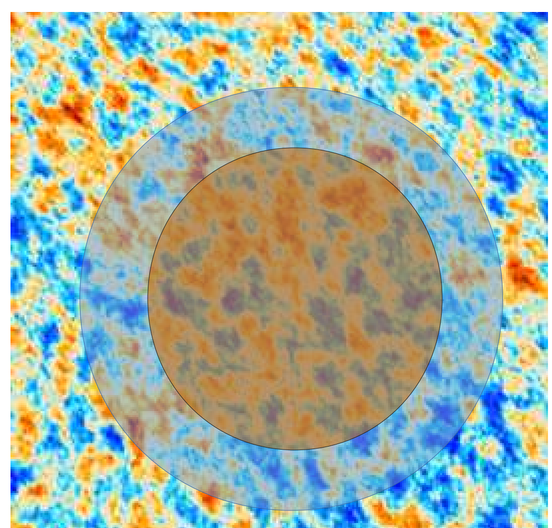
Finding the missing baryons with Redshift Anisotropy Maps

Our sample consists of ~1.3 million galaxies and ~500k quasars, and 4 Planck Temperature maps





Sample	Range	$\langle b \rangle$	$\langle M_h \rangle [10^{13} h^{-1} M_\odot]$
6dF-GAL	all	1.48	3.5
DR12-GAL	$z < 0.43$	2	5.2
DR12-GAL	$z > 0.43$	''	$10^{1.46(1+z)-1.86}$
DR14-QSO	$z < 1.8$	$0.3(1+z)^2 + 0.6$	0.6
DR14-QSO	$1.8 < z < 3$	''	$10^{-0.84(1+z)+2.17}$
DR14-QSO	$z > 3$	''	$10^{0.2(1+z)-1.10}$

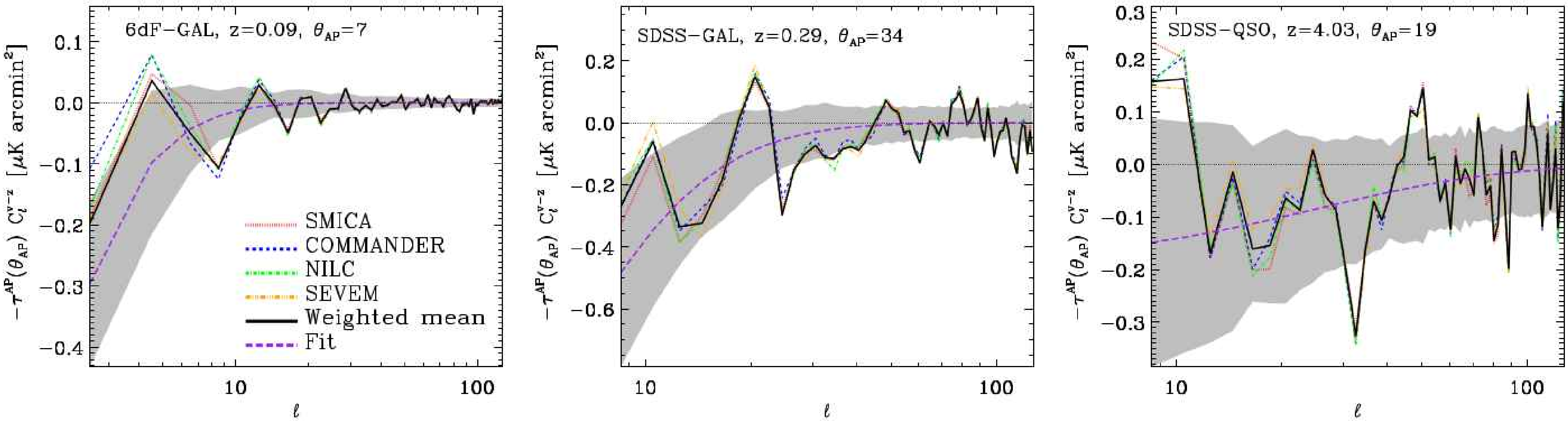


foreground-cleaned maps:

SMICA
COMMANDER
SEVEM
NILC

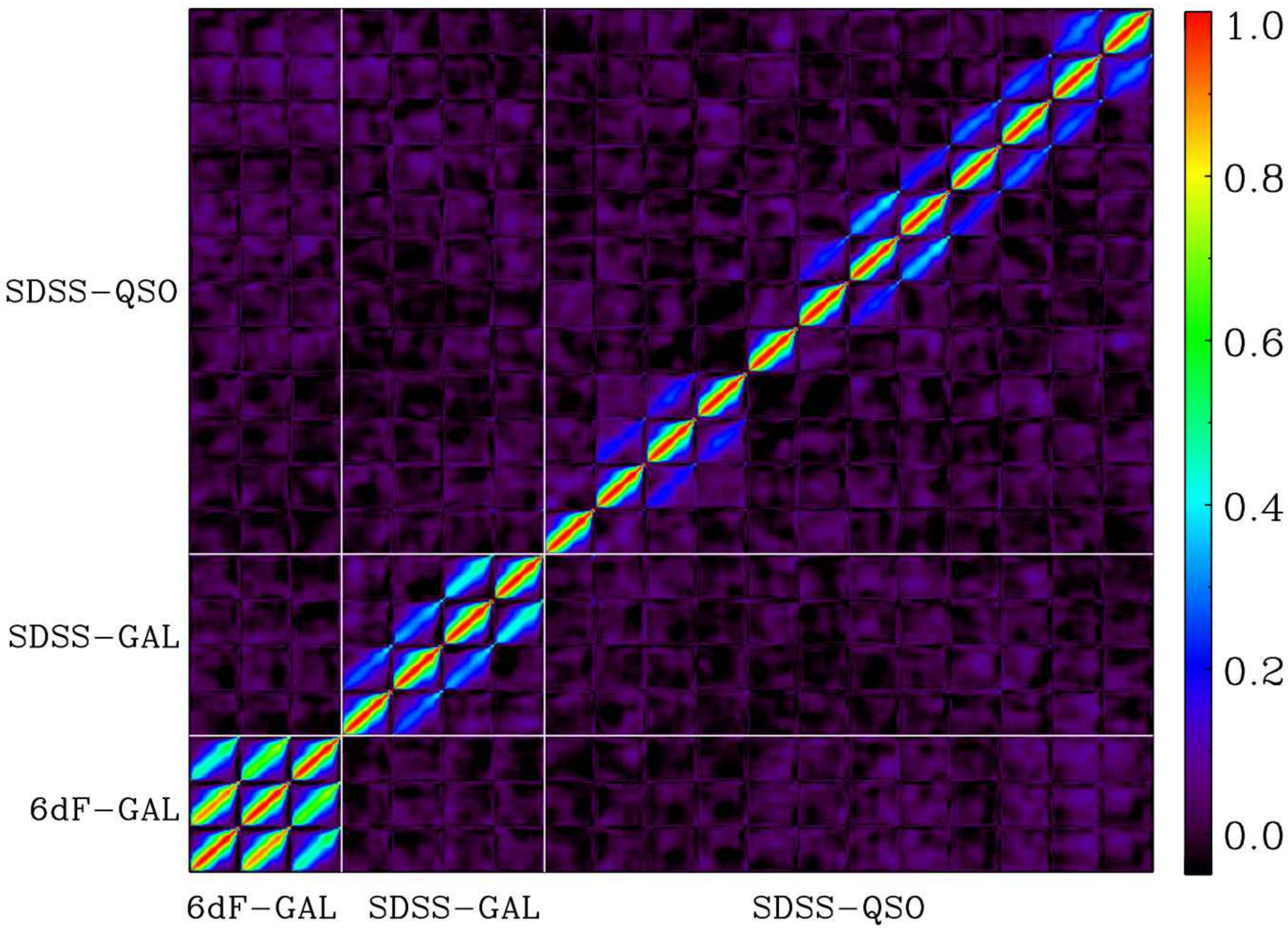
Finding the missing baryons with Redshift Anisotropy Maps

$$C_\ell^{\mathrm{kSZ}-z} = -\tau_{\mathrm{AP}}(\theta_{\mathrm{AP}}) C_\ell^{v-z}$$

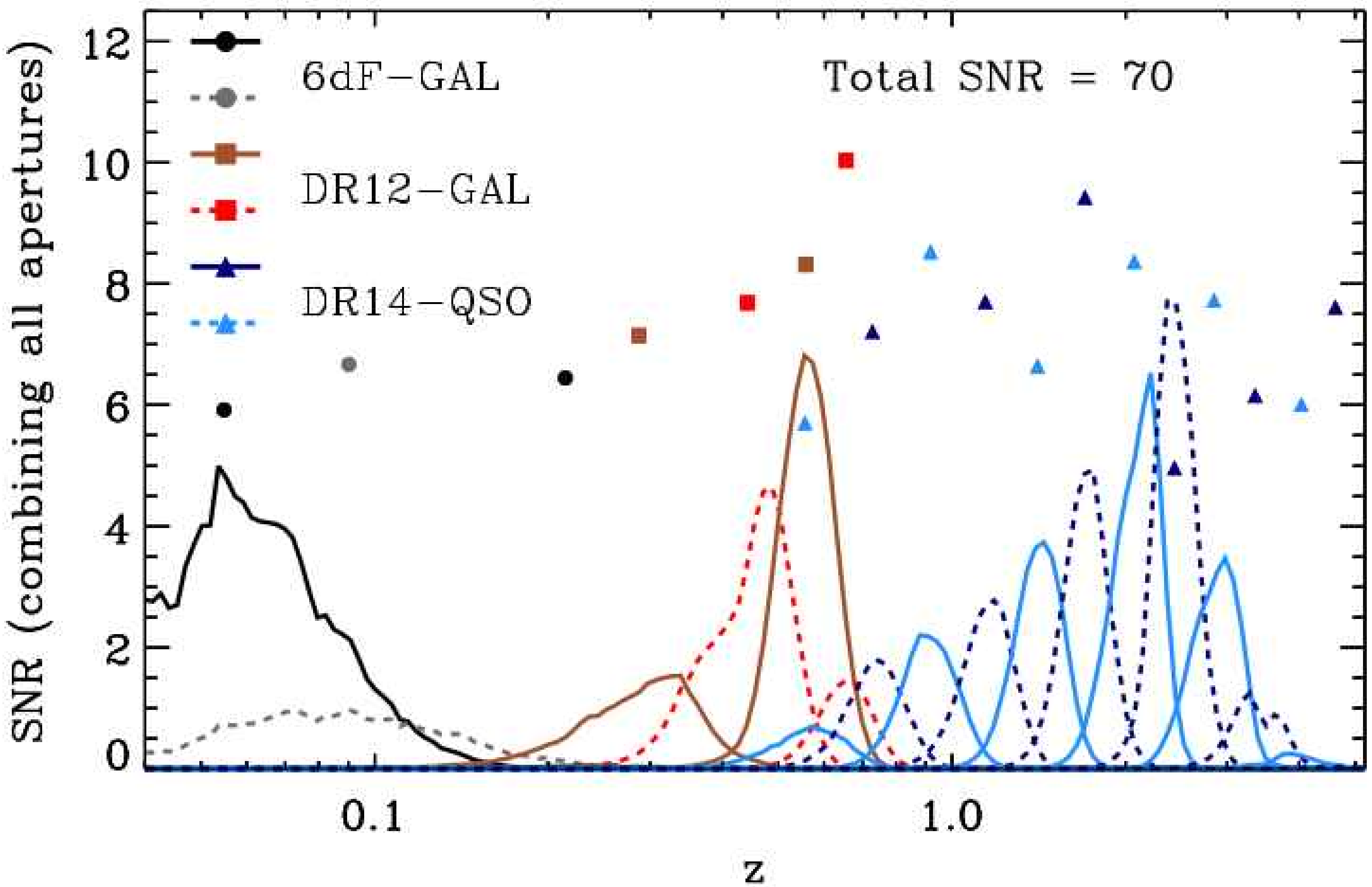


2736 Angular power spectra:
4 maps, 19 redshift bins, 36 apertures

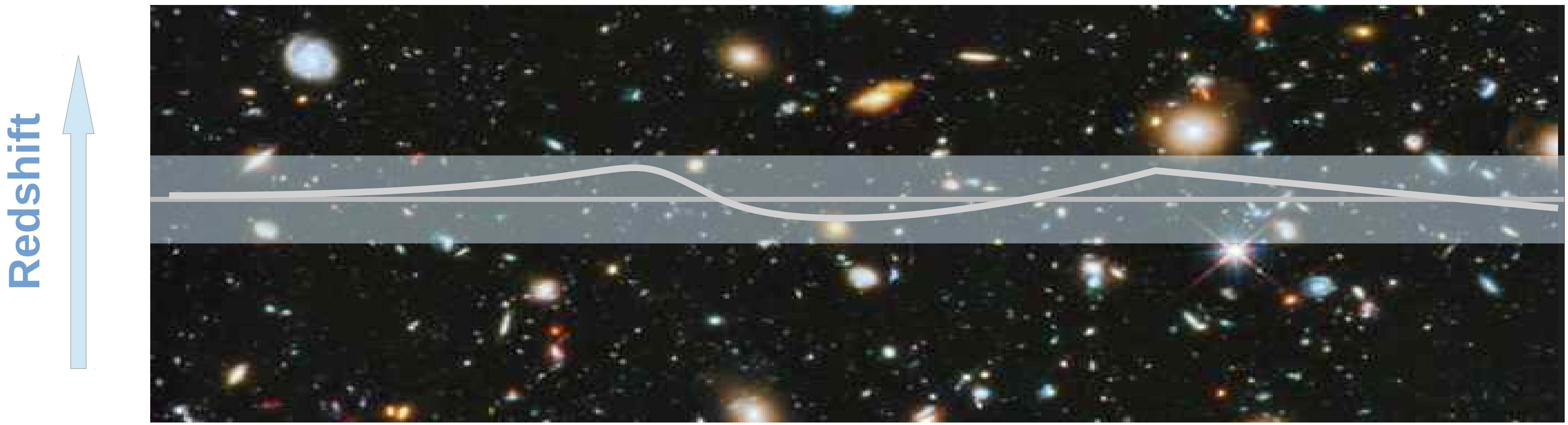
Finding the missing baryons with Redshift Anisotropy Maps



Finding the missing baryons with Redshift Anisotropy Maps



Summary
RAMs: a promising cosmological tool



i) Dœns't assume any cosmological model
ii) It can be computed in small redshift bins
iii) Insensitive to additive/multiplicative systematics
iv) Highly correlated to the velocity field

Application to data leads to strong cosmological inferences and helps in the quest for missing baryons