Precision Cosmology with Large-Scale Structure Surveys

The Effective Field Theory of Large-Scale Structure applied to SDSS-BOSS data

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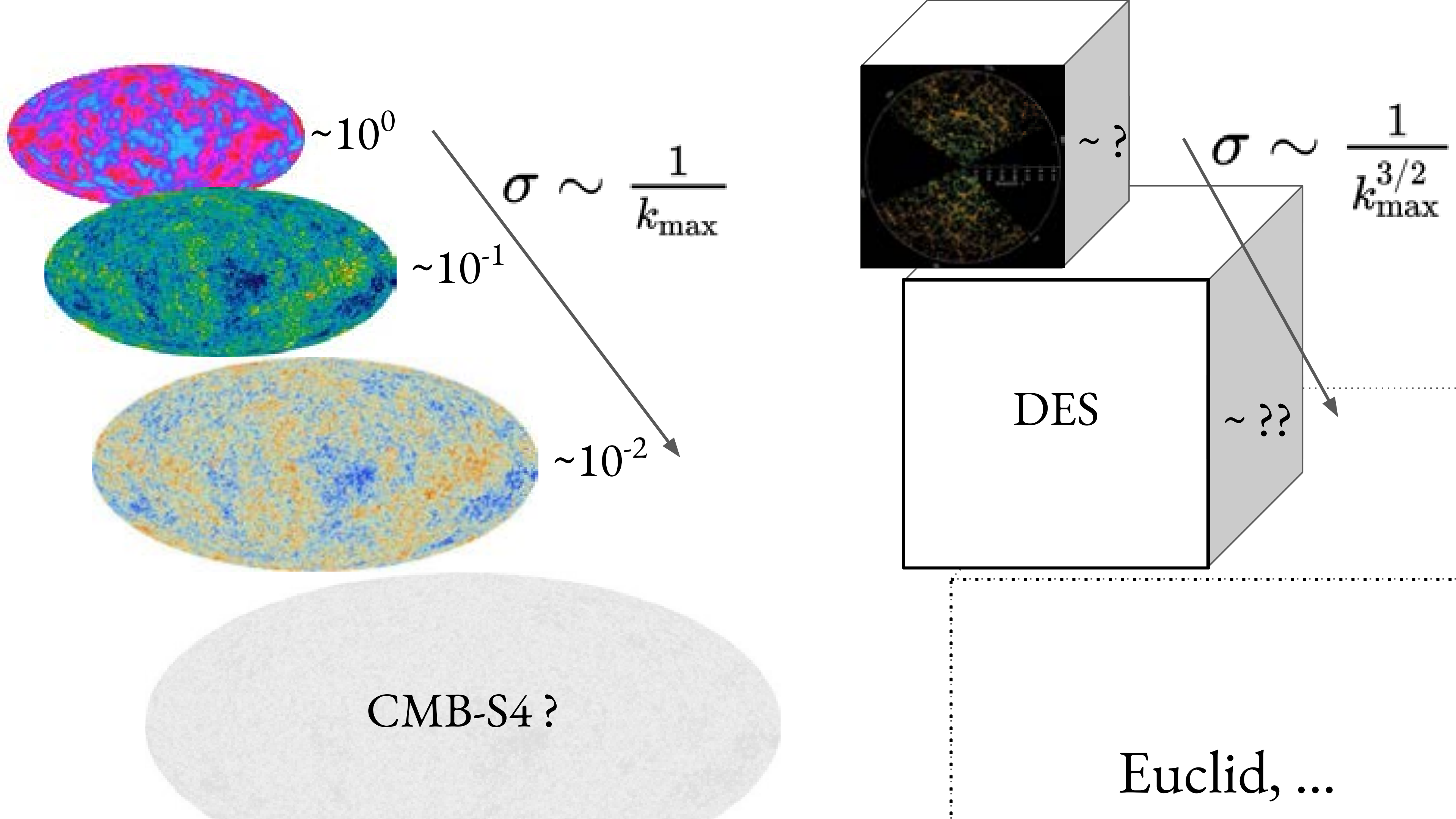
@2019 CCNU - cfa @USTC Junior Cosmology Symposium

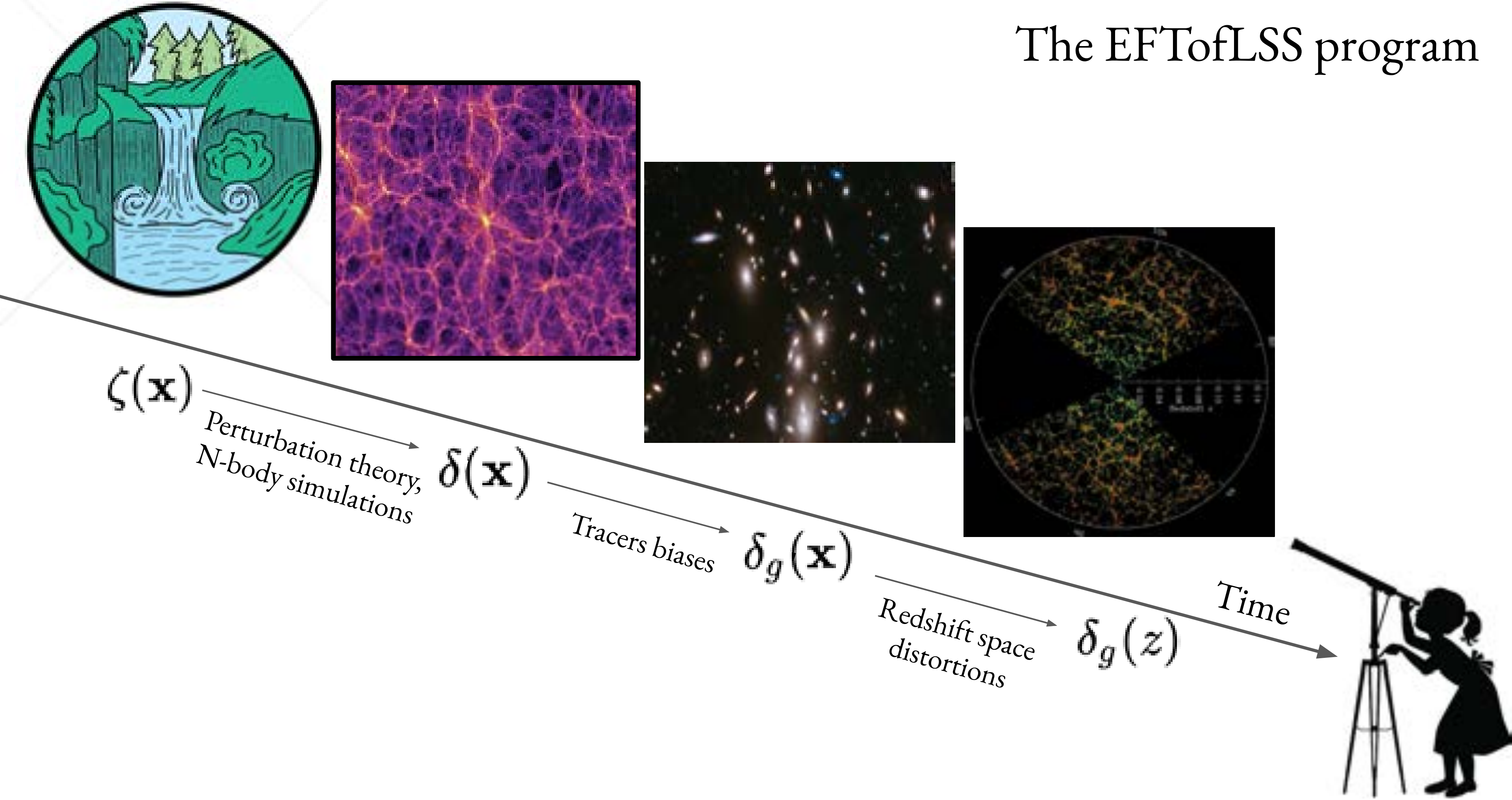
Pierre Zhang

@Particle Cosmology Group @Department of Astronomy @USTC



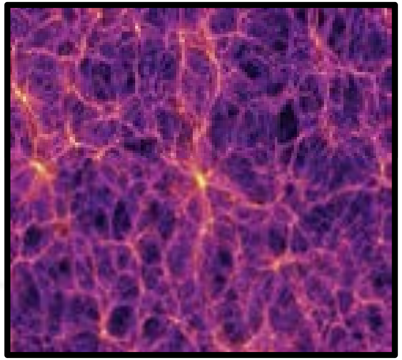
~10^0
~10^-1
~10^-2
$\sigma \sim \frac{1}{k_{\rm max}}$
CMB-S4 ?
~ ?
DES
~ ??
$\sigma \sim \frac{1}{k_{\rm max}^{3/2}}$
Euclid, ...

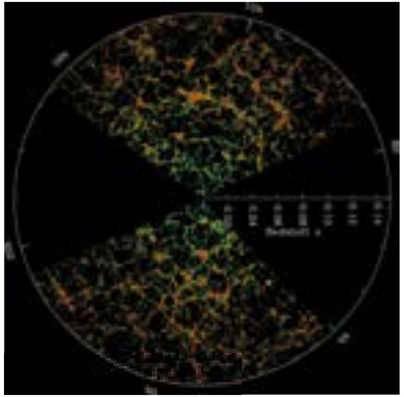
The EFTofLSS program



The EFTofLSS program

- Slide inspired from a talk of E. Pajer





$\zeta(\mathbf{x})$ → Perturbation theory, N-body simulations → $\delta(\mathbf{x})$ → Tracers biases → $\delta_g(\mathbf{x})$ → Redshift space distortions → $\delta_g(z)$

Time

Cosmology recipe

Start with vanilla: ΛCDM

Evolve the fields δ, v ...

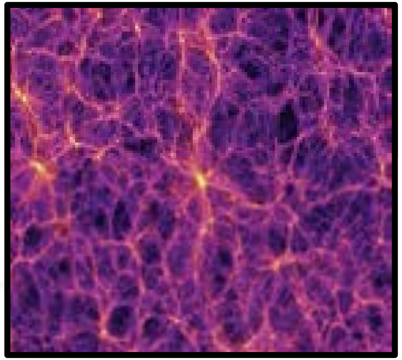
Add biasing and redshift space distortions

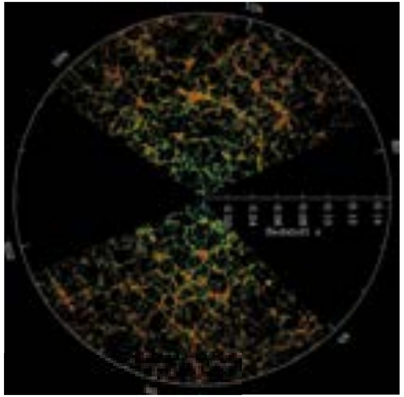
Compute correlation functions

Compare with observations

“Cosmology in one slide”

slide inspired from a talk of E. Pajer





$\zeta(\mathbf{x})$ → Perturbation theory, N-body simulations → $\delta(\mathbf{x})$ → Tracers biases → $\delta_g(\mathbf{x})$ → Redshift space distortions → $\delta_g(z)$

Time

Cosmology recipe

Start with vanilla: ΛCDM

Evolve the fields δ, v ...

Add biasing and redshift space distortions

Compute correlation functions

Compare with observations

Start over with your favorite ingredients: f_{NL}, warm DM, ~~GR~~ ...

I. EFTofLSS “Effective Field Theory of Large-Scale Structure”

Building LSS observables from first principles

II. Redshift Surveys Data Analysis

Extracting cosmological information from LSS

III. Results

SDSS-BOSS data analysis results

with G. d’Amico, J. Gleyzes, N. Kokron, D. Markovic, L. Senatore, F. Beutler, H. Gil Marin

I. EFTofLSS

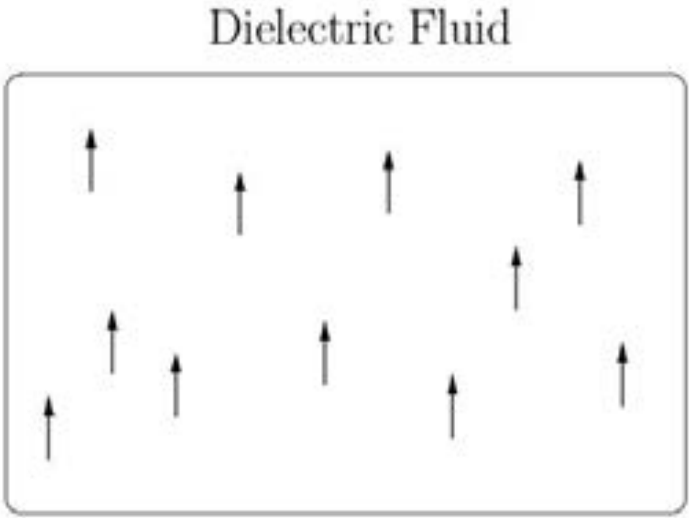
Building LSS observables from first principles

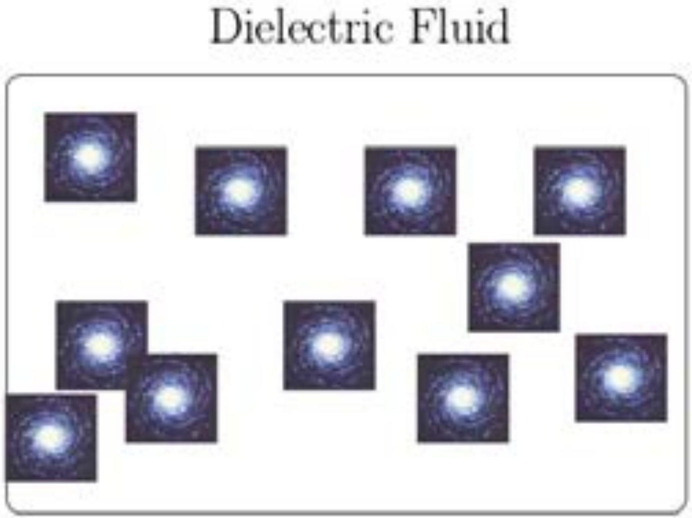
EFTofLSS and Dieletric Materials

slide inspired from a talk of L. Senatore

Dielectric Materials Theory:
massless spin-1 object (light) interacting with composite objects (atoms)

EFTofLSS:
massless spin-2 object (gravity) interacting with composite objects (galaxies)





One slide of equations

$$\dot{\delta}_\ell + \frac{1}{a}\partial_i((1+\delta_\ell))v^i_\ell) = 0\ ,$$

Dark matter

$$\dot{v}^i_\ell + H v^i_\ell + \frac{1}{a}v^j_\ell \partial_j v^i_\ell + \frac{1}{a}\partial_i \phi_\ell = \int^t dt' \ \left[c_{s,1}(t,t')\, \delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')\right.$$
$$\left. + c_{s,2}(t,t')\, \delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \dots \right]$$

Energy + momentum conservation equations in Newton gravity for the long-wavelength modes (most general parametric form)

One slide of equations

Solved perturbatively with a *finite* number of *counterterms* at each perturbative *order*

Dark matter

$$\delta_\ell(\vec{k},t) = \sum_n \delta_\ell^{(n)}(\vec{k},t)$$

$$\dot{\delta}_\ell + \frac{1}{a}\partial_i((1+\delta_\ell))v_\ell^i) = 0 \, ,$$

$$\dot{v}_\ell^i + H v_\ell^i + \frac{1}{a} v_\ell^j \partial_j v_\ell^i + \frac{1}{a}\partial_i \phi_\ell = \int^t dt' \; [c_{s,1}(t,t')\, \delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + c_{s,2}(t,t')\, \delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \dots]$$

One slide of equations

$$\dot{\delta}_\ell + \frac{1}{a}\partial_i((1+\delta_\ell))v_\ell^i) = 0 \, ,$$

Dark matter

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$$\dot{v}_\ell^i + H v_\ell^i + \frac{1}{a} v_\ell^j \partial_j v_\ell^i + \frac{1}{a}\partial_i \phi_\ell = \int^t dt' \; [c_{s,1}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + c_{s,2}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \ldots]$$

$$\delta_{\ell,g}(\vec{x},t) = \int^t dt' \; [\bar{c}_1(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + \bar{c}_2(t,t')\,\partial_i v_\ell^i(x_{\rm fl}(\vec{x},t,t'),t')^2 + \bar{c}_3(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \ldots]$$

Galaxies

Expressed as coefficient-weighted combinations of the underlying DM

One slide of equations

Dark matter

$$\dot{\delta}_\ell + \frac{1}{a}\partial_i((1+\delta_\ell))v^i_\ell) = 0\,,$$

$$\delta_\ell(\vec{k},t) = \sum_n \delta^{(n)}_\ell(\vec{k},t)$$

$$\dot{v}^i_\ell + H v^i_\ell + \frac{1}{a} v^j_\ell \partial_j v^i_\ell + \frac{1}{a}\partial_i \phi_\ell = \int^t dt'\ \left[c_{s,1}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')\right.$$
$$\left. + c_{s,2}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \dots\right]$$

Galaxies

$$\delta_{\ell,g}(\vec{x},t) = \int^t dt'\ \left[\bar{c}_1(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')\right.$$
$$\left. + \bar{c}_2(t,t')\,\partial_i v^i_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \bar{c}_3(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \dots\right]$$

Expressed as coefficient-weighted combinations of the underlying DM

Galaxies in Redshift Space

$$\delta_{\ell,g,r}(\vec{k},t) = \delta_{\ell,g}(\vec{k},t) - i\frac{k_z}{aH} v^z_{\ell,g}(\vec{k},t) + \frac{i^2}{2}\left(\frac{k_z}{aH}\right)^2 [v^z_{\ell,g}(\vec{x},t)^2]_{\vec{k}}$$
$$-\frac{i^3}{3!}\left(\frac{k_z}{aH}\right)^3 [v^z_{\ell,g}(\vec{x},t)^3]_{\vec{k}} - i\frac{k_z}{aH}[v^z_{\ell,g}(\vec{x},t)\delta(\vec{x},t)]_{\vec{k}} + \frac{i^2}{2}\left(\frac{k_z}{aH}\right)^2 [v^z_{\ell,g}(\vec{x},t)^2\delta_{\ell,g}(\vec{x},t)]_{\vec{k}} +$$
$$+\int dt' \left(\frac{aH}{k_{\rm NL}}\right)^2 \left[c_{r,1}(t,t')\delta^{(3)}_D(\vec{k}) + \left(c_{r,2}(t,t') + c_{r,3}(t,t')\frac{k_z^2}{k^2}\right)[\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')]_{\vec{k}}\right] + \dots$$

One slide of equations

Dark matter

$$\dot{\delta}_\ell + \frac{1}{a}\partial_i((1+\delta_\ell))v^i_\ell) = 0\ ,$$

$$\delta_\ell(\vec{k},t) = \sum_n \delta^{(n)}_\ell(\vec{k},t)$$

$$\dot{v}^i_\ell + H v^i_\ell + \frac{1}{a} v^j_\ell \partial_j v^i_\ell + \frac{1}{a}\partial_i \phi_\ell = \int^t dt'\ \left[c_{s,1}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + c_{s,2}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \ldots\right]$$

Galaxies

$$\delta_{\ell,g}(\vec{x},t) = \int^t dt'\ \left[\bar{c}_1(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + \bar{c}_2(t,t')\,\partial_i v^i_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \bar{c}_3(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \ldots\right]$$

Galaxies in Redshift Space

$$\delta_{\ell,g,r}(\vec{k},t) = \delta_{\ell,g}(\vec{k},t) - i\frac{k_z}{aH} v^z_{\ell,g}(\vec{k},t) + \frac{i^2}{2}\left(\frac{k_z}{aH}\right)^2 [v^z_{\ell,g}(\vec{x},t)^2]_{\vec{k}}$$
$$-\frac{i^3}{3!}\left(\frac{k_z}{aH}\right)^3 [v^z_{\ell,g}(\vec{x},t)^3]_{\vec{k}} - i\frac{k_z}{aH}[v^z_{\ell,g}(\vec{x},t)\delta(\vec{x},t)]_{\vec{k}} + \frac{i^2}{2}\left(\frac{k_z}{aH}\right)^2 [v^z_{\ell,g}(\vec{x},t)^2\delta_{\ell,g}(\vec{x},t)]_{\vec{k}} +$$
$$+\int dt'\left(\frac{aH}{k_{\rm NL}}\right)^2\left[c_{r,1}(t,t')\delta^{(3)}_D(\vec{k}) + \left(c_{r,2}(t,t') + c_{r,3}(t,t')\frac{k_z^2}{k^2}\right)[\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')]_{\vec{k}}\right] + \ldots$$

One slide of equations

$$\dot{\delta}_\ell + \frac{1}{a}\partial_i((1+\delta_\ell))v^i_\ell) = 0\,,$$

$$\delta_\ell(\vec{k},t) = \sum_n \delta_\ell^{(n)}(\vec{k},t)$$

Bottom line:

$$\dot{v}^i_\ell + H v^i_\ell + \frac{1}{a} v^j_\ell \partial_j v^i_\ell + \frac{1}{a}\partial_i \phi_\ell = \int^t dt' \; [c_{s,1}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + c_{s,2}(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \dots]$$

Correlation functions of galaxies in redshift space

$$\delta_{\ell,g}(\vec{x},t) = \int^t dt' \; [\bar{c}_1(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t') + \bar{c}_2(t,t')\,\partial_i v^i_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \bar{c}_3(t,t')\,\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')^2 + \dots]$$

= Linear (bias-weighted) combination of DM correlation functions

$$\delta_{\ell,g,r}(\vec{k},t) = \delta_{\ell,g}(\vec{k},t) - i\frac{k_z}{aH} v^z_{\ell,g}(\vec{k},t) - \frac{i^2}{2}\left(\frac{k_z}{aH}\right)^2 [v^z_{\ell,g}(\vec{x},t)^2]_{\vec{k}} - \frac{i^3}{3!}\left(\frac{k_z}{aH}\right)^3 [v^z_{\ell,g}(\vec{x},t)^3]_{\vec{k}} - i\frac{k_z}{aH}[v^z_{\ell,g}(\vec{x},t)\delta(\vec{x},t)]_{\vec{k}} + \frac{i^2}{2}\left(\frac{k_z}{aH}\right)^2 [v^z_{\ell,g}(\vec{x},t)^2 \delta_{\ell,g}(\vec{x},t)]_{\vec{k}} + \int dt' \left(\frac{aH}{k_{\rm NL}}\right)^2 \left[c_{r,1}(t,t')\delta_D^{(3)}(\vec{k}) + \left(c_{r,2}(t,t') + c_{r,3}(t,t')\frac{k_z^2}{k^2}\right)\right][\delta_\ell(x_{\rm fl}(\vec{x},t,t'),t')]_{\vec{k}} + \dots$$

+ Finite number of counterterms

EFTofLSS observables

Galaxies power spectrum in redshift space:

$$
\begin{aligned}
P_g(k,\mu) = {} & Z_1(\mu)^2 P_{11}(k) \\
& + 2\int d^3q\; Z_2(\boldsymbol{q}, \boldsymbol{k}-\boldsymbol{q}, \mu)^2 P_{11}(|\boldsymbol{k}-\boldsymbol{q}|)P_{11}(q) + 6 Z_1(\mu) P_{11}(k) \int d^3q\; Z_3(\boldsymbol{q}, -\boldsymbol{q}, \boldsymbol{k}, \mu) P_{11}(q) \\
& + 2 Z_1(\mu) P_{11}(k) \left(c_{\rm ct}\frac{k^2}{k_{\rm M}^2} + c_{r,1}\mu^2 \frac{k^2}{k_{\rm M}^2} + c_{r,2}\mu^4 \frac{k^2}{k_{\rm M}^2} \right) + \frac{1}{\bar{n}_g}\left(c_{\epsilon,1} + c_{\epsilon,2}\frac{k^2}{k_{\rm M}^2} + c_{\epsilon,3} f\mu^2 \frac{k^2}{k_{\rm M}^2} \right).
\end{aligned}
$$

EFTofLSS observables

Galaxies power spectrum in redshift space:

linear power spectrum

1-loop

$$P_g(k,\mu) = \underline{Z_1(\mu)^2 P_{11}(k)}$$
$$+ \underline{2\int d^3q\, Z_2(\mathbf{q},\mathbf{k}-\mathbf{q},\mu)^2 P_{11}(|\mathbf{k}-\mathbf{q}|)P_{11}(q) + 6Z_1(\mu)P_{11}(k)\int d^3q\, Z_3(\mathbf{q},-\mathbf{q},\mathbf{k},\mu)P_{11}(q)}$$
$$+ 2Z_1(\mu)P_{11}(k)\left(c_{ct}\frac{k^2}{k_M^2} + c_{r,1}\mu^2\frac{k^2}{k_M^2} + c_{r,2}\mu^4\frac{k^2}{k_M^2}\right) + \frac{1}{\bar{n}_g}\left(c_{\epsilon,1} + c_{\epsilon,2}\frac{k^2}{k_M^2} + c_{\epsilon,3} f\mu^2\frac{k^2}{k_M^2}\right).$$

Galaxies kernels in redshift space:

composed of density and velocity kernels

functions of 4 bias parameters at the 1-loop

$$Z_1(\mathbf{q}_1) = K_1(\mathbf{q}_1) + f\mu_1^2 G_1(\mathbf{q}_1) = b_1 + f\mu_1^2, \quad (6$$

$$Z_2(\mathbf{q}_1,\mathbf{q}_2,\mu) = K_2(\mathbf{q}_1,\mathbf{q}_2) + f\mu_{12}^2 G_2(\mathbf{q}_1,\mathbf{q}_2) + \frac{1}{2}f\mu q\left(\frac{\mu_2}{q_2}G_1(\mathbf{q}_2)Z_1(\mathbf{q}_1) + \text{perm.}\right),$$

$$Z_3(\mathbf{q}_1,\mathbf{q}_2,\mathbf{q}_3,\mu) = K_3(\mathbf{q}_1,\mathbf{q}_2,\mathbf{q}_3) + f\mu_{123}^2 G_3(\mathbf{q}_1,\mathbf{q}_2,\mathbf{q}_3)$$
$$+ \frac{1}{3}f\mu q\left(\frac{\mu_3}{q_3}G_1(\mathbf{q}_3)Z_2(\mathbf{q}_1,\mathbf{q}_2,\mu_{123}) + \frac{\mu_{23}}{q_{23}}G_2(\mathbf{q}_2,\mathbf{q}_3)Z_1(\mathbf{q}_1) + \text{cyc.}\right),$$

where here $\mu = \mathbf{q}\cdot\hat{\mathbf{z}}/q$, $\mathbf{q} = \mathbf{q}_1 + \cdots + \mathbf{q}_n$, and $\mu_{i_1\ldots i_n} = \mathbf{q}_{i_1\ldots i_n}\cdot\hat{\mathbf{z}}/q_{i_1\ldots i_n}$, $\mathbf{q}_{i_1\ldots i_m} = \mathbf{q}_{i_1} + \cdots + \mathbf{q}_{i_m}$

EFTofLSS observables

Galaxies power spectrum in redshift space:

linear power spectrum

1-loop

$$P_g(k,\mu) = \underline{Z_1(\mu)^2 P_{11}(k)}$$
$$+ 2\int d^3q\, Z_2(\boldsymbol{q}, \boldsymbol{k}-\boldsymbol{q}, \mu)^2 P_{11}(|\boldsymbol{k}-\boldsymbol{q}|)P_{11}(q) + 6Z_1(\mu)P_{11}(k)\int d^3q\, Z_3(\boldsymbol{q}, -\boldsymbol{q}, \boldsymbol{k}, \mu)P_{11}(q)$$
$$+ 2Z_1(\mu)P_{11}(k)\left(c_{\rm ct}\frac{k^2}{k_{\rm M}^2} + c_{r,1}\mu^2\frac{k^2}{k_{\rm M}^2} + c_{r,2}\mu^4\frac{k^2}{k_{\rm M}^2}\right) + \frac{1}{\bar{n}_g}\left(c_{\epsilon,1} + c_{\epsilon,2}\frac{k^2}{k_{\rm M}^2} + c_{\epsilon,3}f\mu^2\frac{k^2}{k_{\rm M}^2}\right).$$

counterterms

EFTofLSS observables

Galaxies power spectrum in redshift space:

linear power spectrum

1-loop

$$P_g(k,\mu) = \underline{Z_1(\mu)^2 P_{11}(k)}$$
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$$+ 2Z_1(\mu)P_{11}(k)\left(c_{\rm ct}\frac{k^2}{k_{\rm M}^2} + c_{r,1}\mu^2\frac{k^2}{k_{\rm M}^2} + c_{r,2}\mu^4\frac{k^2}{k_{\rm M}^2}\right) + \frac{1}{\bar{n}_g}\left(c_{\epsilon,1} + c_{\epsilon,2}\frac{k^2}{k_{\rm M}^2} + c_{\epsilon,3} f\mu^2\frac{k^2}{k_{\rm M}^2}\right).$$

counterterms

1 dark matter counterterm:
Renormalization the 1-loop

~

Higher derivative term:
Encloses spatial extension of galaxies

2 redshift-space counterterms:
Renormalization of velocity operators

EFTofLSS observables

Galaxies power spectrum in redshift space:

linear power spectrum

1-loop

$$P_g(k,\mu) = Z_1(\mu)^2 P_{11}(k)$$
$$+ 2\int d^3q\, Z_2(\mathbf{q}, \mathbf{k}-\mathbf{q}, \mu)^2 P_{11}(|\mathbf{k}-\mathbf{q}|)P_{11}(q) + 6Z_1(\mu)P_{11}(k)\int d^3q\, Z_3(\mathbf{q}, -\mathbf{q}, \mathbf{k}, \mu)P_{11}(q)$$
$$+ 2Z_1(\mu)P_{11}(k)\left(c_{\rm ct}\frac{k^2}{k_{\rm M}^2} + c_{r,1}\mu^2\frac{k^2}{k_{\rm M}^2} + c_{r,2}\mu^4\frac{k^2}{k_{\rm M}^2}\right) + \frac{1}{\bar{n}_g}\left(c_{\epsilon,1} + c_{\epsilon,2}\frac{k^2}{k_{\rm M}^2} + c_{\epsilon,3} f\mu^2\frac{k^2}{k_{\rm M}^2}\right).$$

counterterms

stochastic terms

Function of 10 free 'EFT' parameters:

- 4 galaxies biases
- 3 counterterms
- 3 stochastic terms

II. Redshift Surveys Data Analysis

Extracting cosmological information from LSS

Analysis pipeline

$$\{A_s\,,\Omega_m\,,h\}$$

Decomposition in bias-independent parts:

$$P_g(k,z) = \sum_n \mu^{2\alpha_n} f(z)^{\beta_n} b_{i_n}(z)^{\gamma_n} b_{j_n}(z)^{\delta_n} D(z)^{2\rho_n} P_n(k) \ ,$$

Analysis pipeline

Decomposition in bias-independent parts:

$$P_g(k,z) = \sum_n \mu^{2\alpha_n} f(z)^{\beta_n} b_{i_n}(z)^{\gamma_n} b_{j_n}(z)^{\delta_n} D(z)^{2\rho_n} P_n(k) \ ,$$

Decomposition in multipoles with Alock-Paszynski effect:

$$P_n^\ell(k^{\rm ref}) = \frac{2\ell+1}{2q_\parallel q_\perp^2} \int_{-1}^{1} d\mu^{\rm ref}\, \mu(\mu^{\rm ref})^{2\alpha_n} P_n\left(k(k^{\rm ref},\mu^{\rm ref})\right) \mathcal{P}_\ell(\mu^{\rm ref}) \ ,$$

$$k = \frac{k^{\rm ref}}{q_\perp}\left[1+(\mu^{\rm ref})^2\left(\frac{1}{F^2}-1\right)\right]^{1/2},$$

$$\mu = \frac{\mu^{\rm ref}}{F}\left[1+(\mu^{\rm ref})^2\left(\frac{1}{F^2}-1\right)\right]^{-1/2},$$

$$q_\perp = \frac{D_A(z_{\rm eff})H(z=0)}{D_A^{\rm ref.}(z_{\rm eff})H^{\rm ref}(z=0)}, \qquad q_\parallel = \frac{H^{\rm ref}(z_{\rm eff})/H^{\rm ref}(z=0)}{H(z_{\rm eff})/H(z=0)}.$$

where $F = q_\parallel / q_\perp$.

AP parameters are not free in our analysis

Analysis pipeline

Decomposition in bias-independent parts:

$$P_g(k,z) = \sum_n \mu^{2\alpha_n} f(z)^{\beta_n} b_{i_n}(z)^{\gamma_n} b_{j_n}(z)^{\delta_n} D(z)^{2\rho_n} P_n(k) \ ,$$

Decomposition in multipoles with Alock-Paszynski effect:

$$P_n^\ell(k^{\mathrm{ref}}) = \frac{2\ell+1}{2q_\parallel q_\perp^2} \int_{-1}^{1} d\mu^{\mathrm{ref}} \, \mu(\mu^{\mathrm{ref}})^{2\alpha_n} P_n\left(k(k^{\mathrm{ref}}, \mu^{\mathrm{ref}})\right) \mathcal{P}_\ell(\mu^{\mathrm{ref}}) \ ,$$

Application of the window functions (in Fourier space):

$$P_\ell^{(\mathrm{EFT})\,(W)}(k) = W_{\ell,\ell'}(k,k') \cdot P_{\ell'}^{(\mathrm{EFT})}(k) \ ,$$

$$W(k,k')_{\ell,\ell'} = \frac{2}{\pi}(-i)^\ell i^{\ell'} k'^2 \int ds \, s^2 \, j_\ell(ks) \, Q_{\ell,\ell'}(s) \cdot j_{\ell'}(k's) \ .$$

III. Results

SDSS-BOSS data analysis results

Tests against simulations

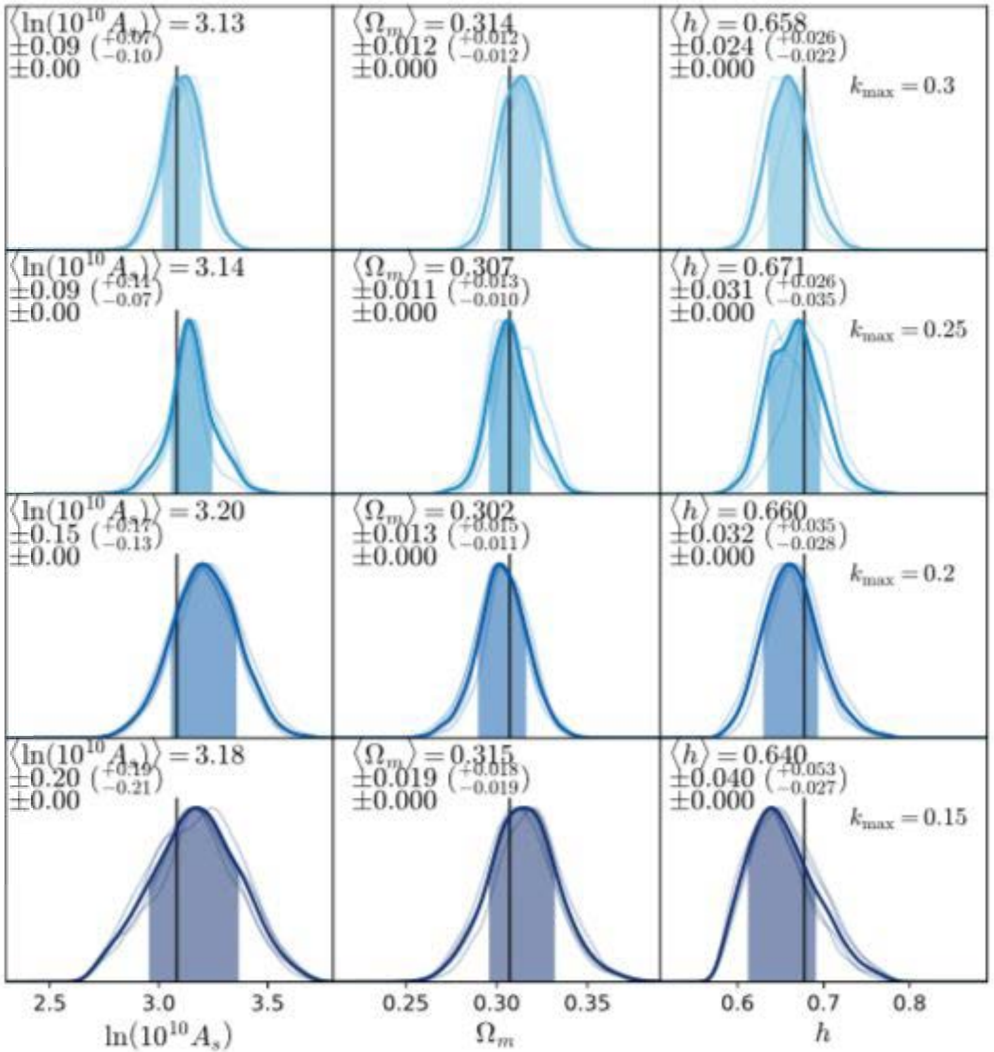
SDSS 'challenge' boxes

~ 4 times the effective volume of SDSS-BOSS CMASS sample

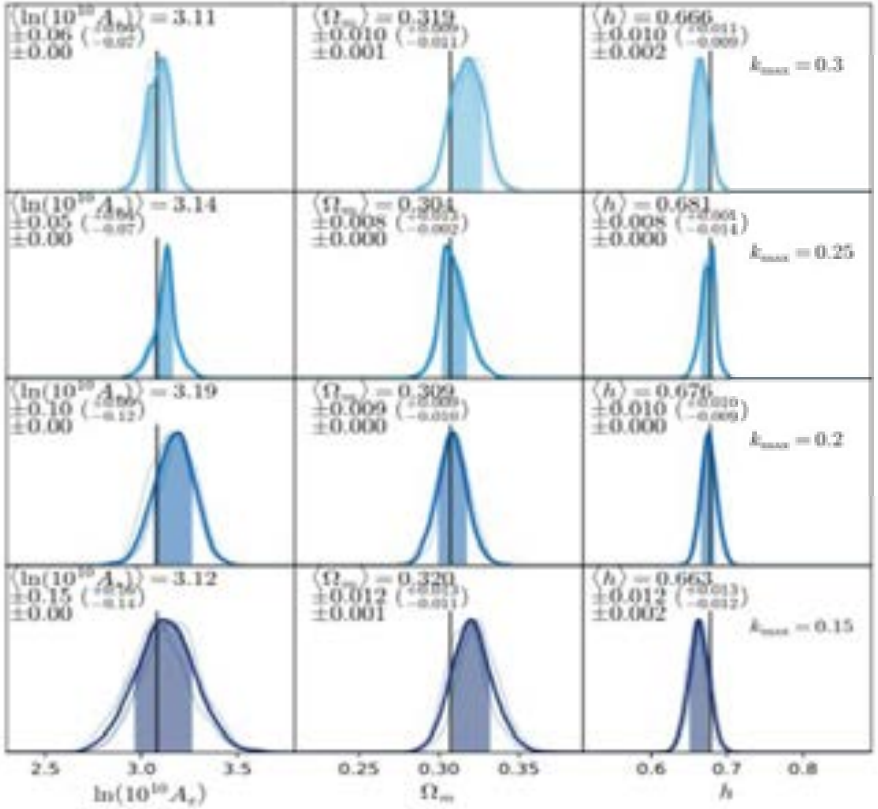
No theory-systematics detected

within 1-sigma statistical fluctuations of the simulation

Error bars shrinking with kmax



Application of CMB sound horizon prior

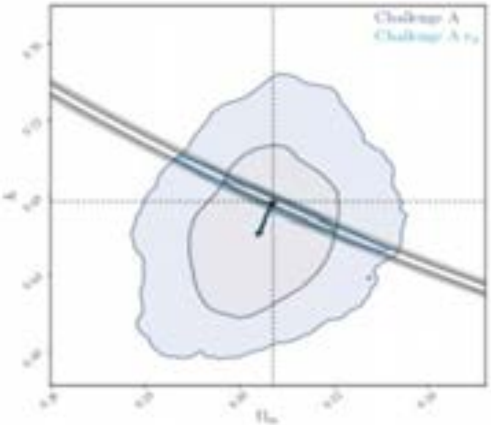


$$r_d = \int_{z_d}^{\infty} \frac{c_s(z)}{H(z)} dz, \qquad c_s^2(z) = \frac{c^2}{3}\left[1 + \frac{3}{4}\frac{\rho_b(z)}{\rho_\gamma(z)}\right]^{-1}$$

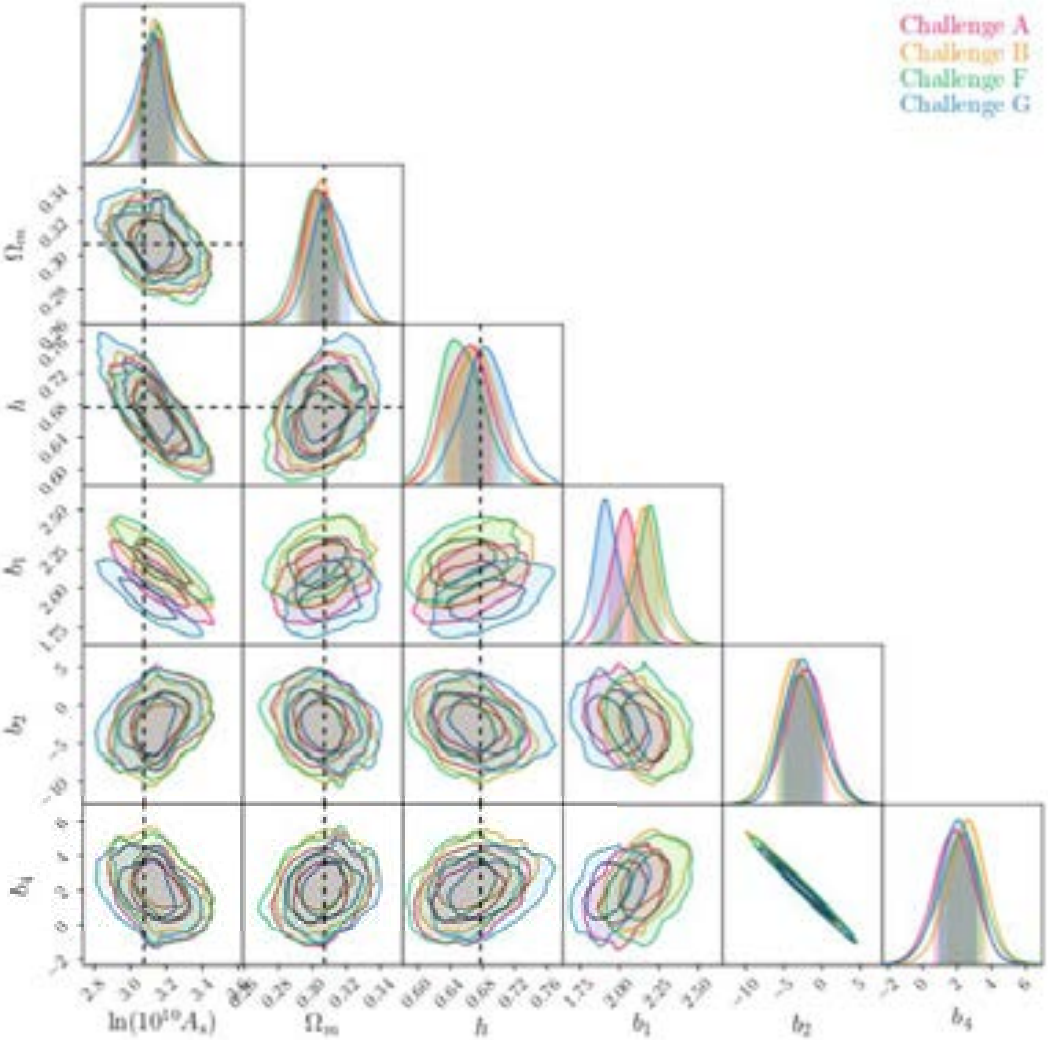
Reduction of statistical errors

~ {35, 20, 62} %

Theory-systematic errors decreased



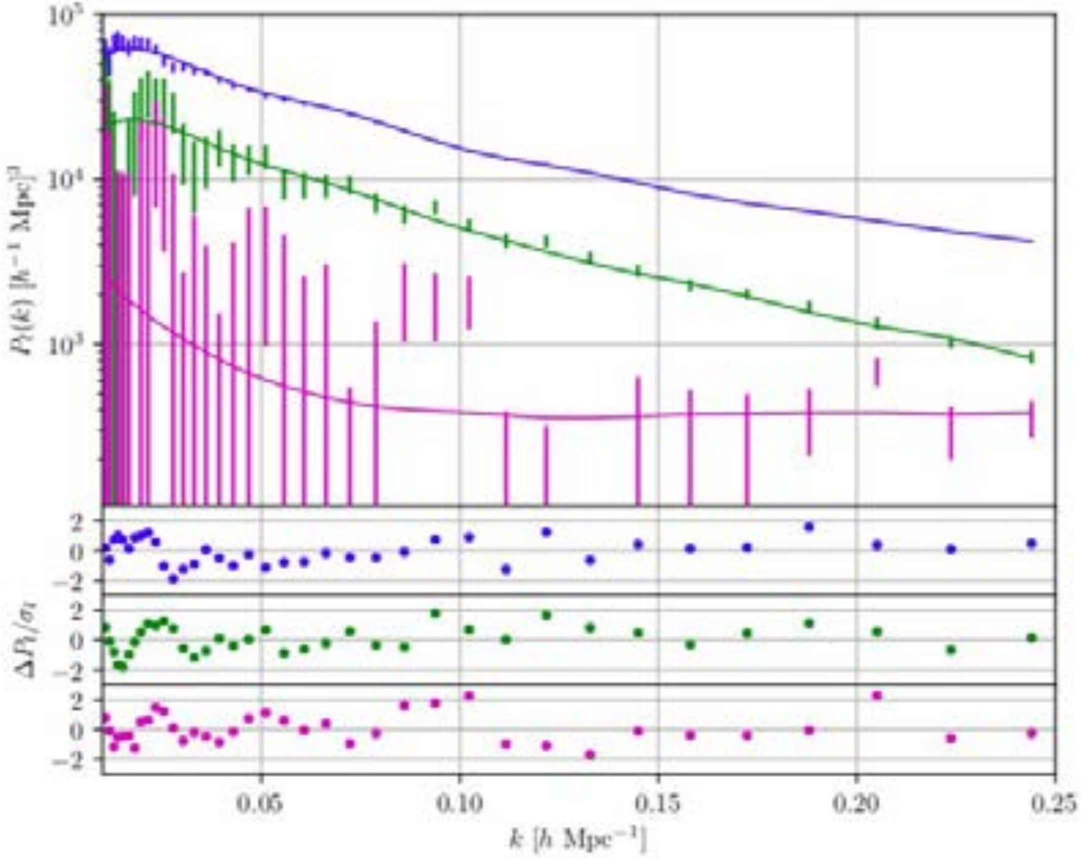
Tests against simulations



Contour plot

Different HOD models differ on linear bias b1

SDSS-BOSS NGC CMASS



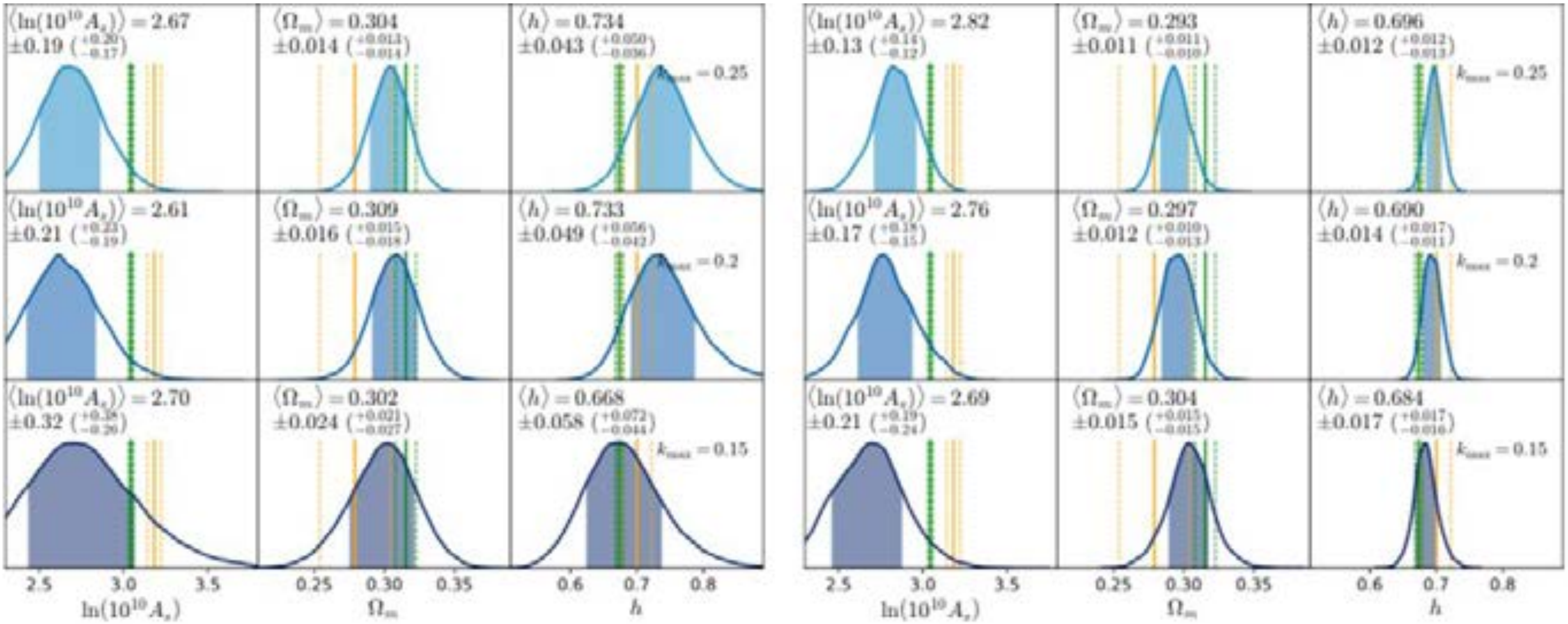
min χ^2/d.o.f. ~ 106/ 100

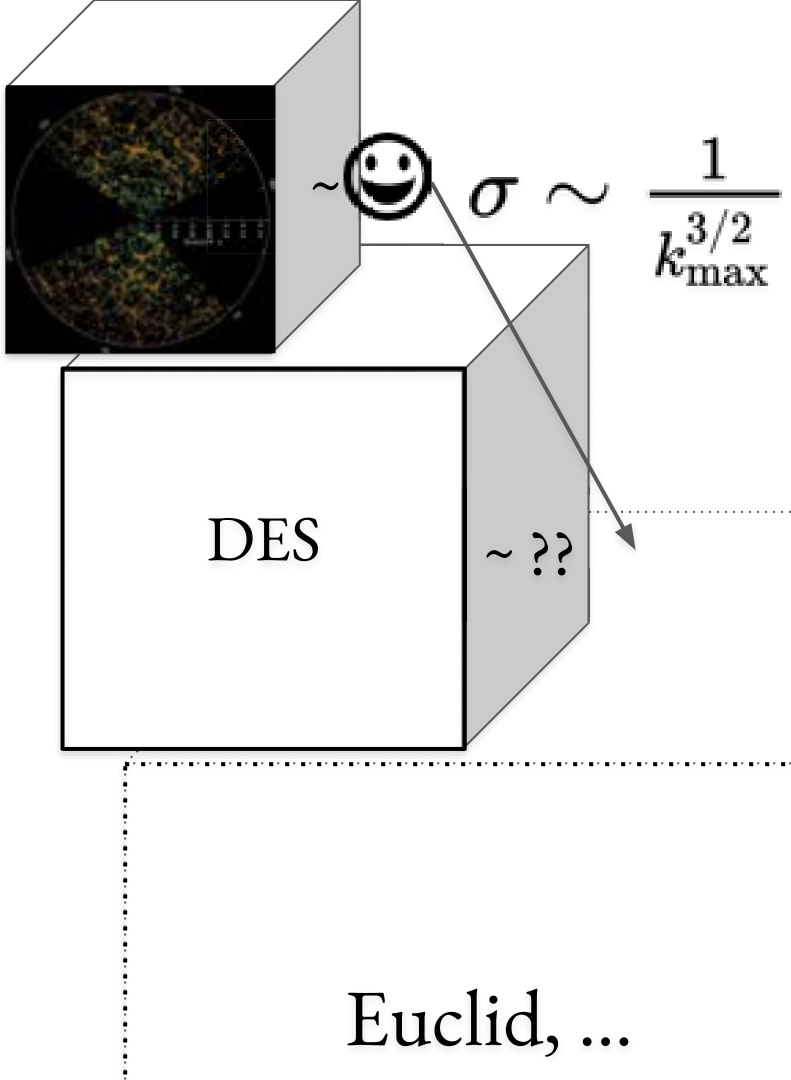
p-value: 0.32

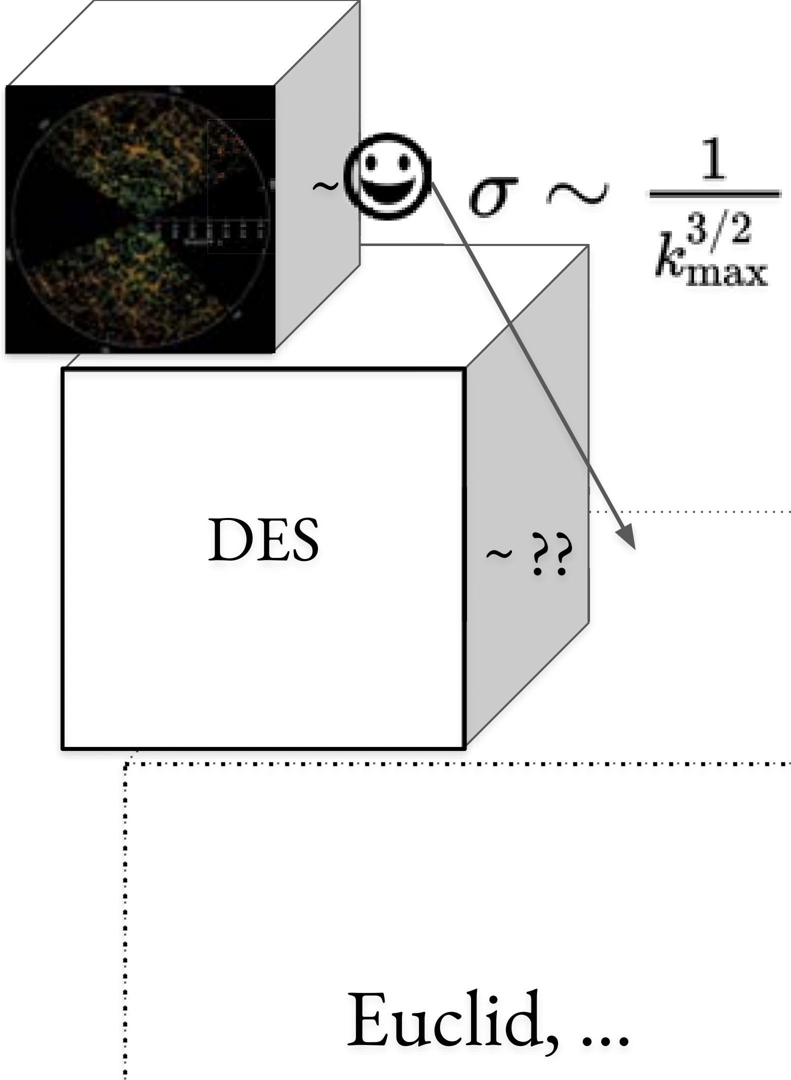
SDSS-BOSS NGC CMASS

$\{A_s, \Omega_m, h\}$ measured ~ 15%, 5%, 5%

with CMB sound horizon prior: 14%, 3.8% and 1.9%

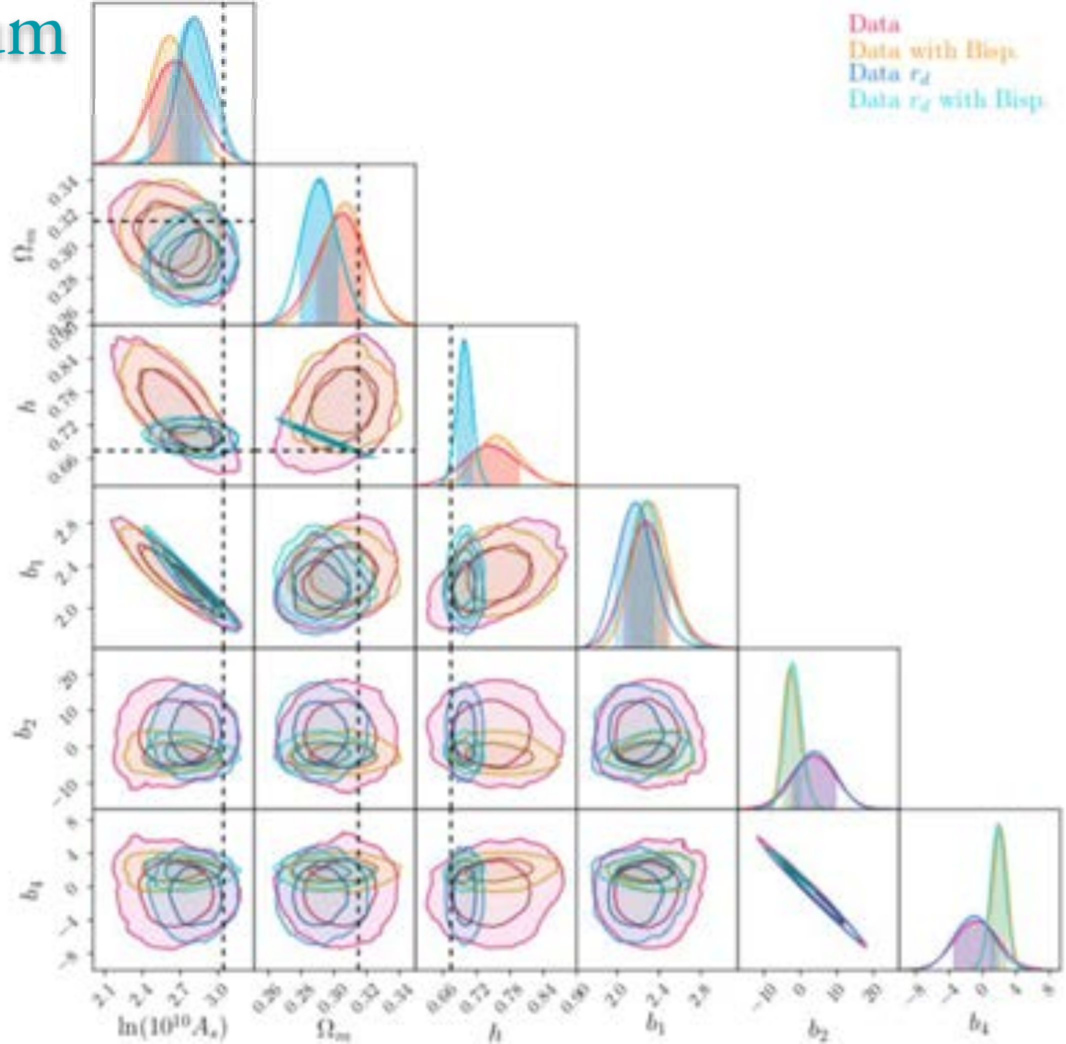



~
$\sigma \sim \frac{1}{k_{\max}^{3/2}}$
DES
~ ??
Euclid, ...



Thanks for your attention !

Inclusion of the bispectrum



10% increase in constraints

Last two-decades approach: BAO extraction and RSD

Baryon Acoustic Oscillations   Redshift-Space Distortions

BAO extraction: ‘wiggle’ - ‘non-wiggle’ separation

> broad-band signal not analyzed

> non-smooth features in the primordial spectrum missed

> degeneracy $H_0 - \Omega_m$

RSD > degeneracy $f\sigma_8$

> Input from either CMB (‘inverse-cosmic ladder’) or SNe (‘cosmic ladder’) necessary to break degeneracies

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Information loss

Introduction of systematics

Non-independent measurements

No probe of baryons-to-matter fraction, etc.

*To be totally fair: redshift tomographic measurements also can do

Can we do better with the EFTofLSS?