

Cosmological Parameter Estimation with Large Scale Structure Observations

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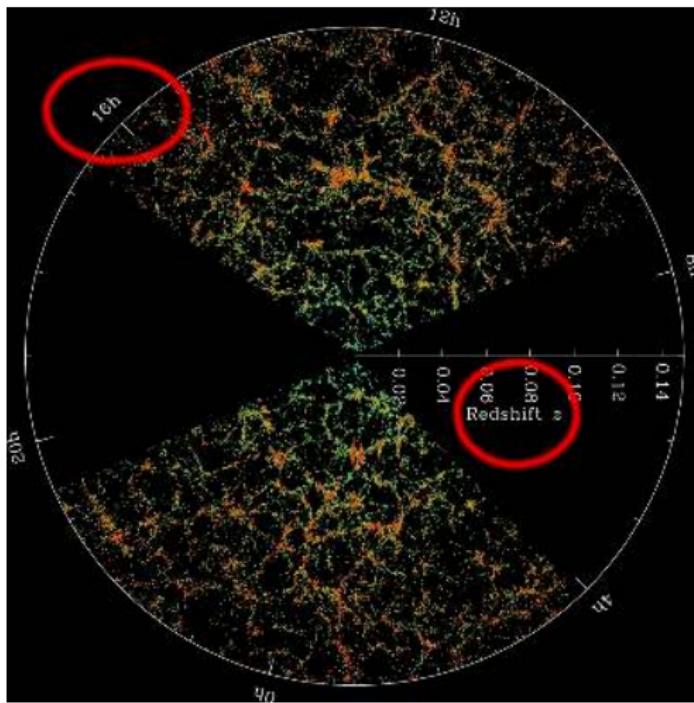
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in collaboration with:

Enea DI DIO, Ruth DURRER, Julien LESGOURGUES
arXiv: 1307.1459, 1308.6186

DAMTP Cambridge, 29 October 2013

Large Scale Structure



SDSS Galaxy Map

Fundamental observable in
a galaxy catalog:

$$\Delta(\mathbf{n}, z) \equiv \frac{N(\mathbf{n}, z) - \langle N \rangle(z)}{\langle N \rangle(z)}$$

Observables in galaxy surveys

Theoretical **perturbation in the number density** of galaxies per redshift bin dz and solid angle $d\Omega$:

$$\Delta(\mathbf{n}, z) = \delta_z(\mathbf{n}, z) + \frac{\delta V(\mathbf{n}, z)}{V(z)} ,$$

- $\delta_z(\mathbf{n}, z) = \frac{\rho(\mathbf{n}, z) - \bar{\rho}(z)}{\bar{\rho}(z)}$
is the density perturbation (per dz and $d\Omega$)
- $V(\mathbf{n}, z) = V(z) + \delta V(\mathbf{n}, z)$
is the physical survey volume (per dz and $d\Omega$)

Observables in galaxy surveys

Linear perturbation theory:

Bonvin & Durrer [arXiv:1105.5280], Challinor & Lewis [arXiv:1105.5292],
Yoo [arXiv:1009.3021]

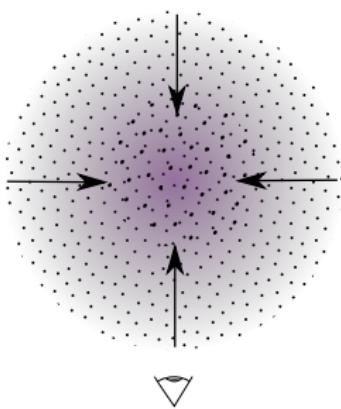
$$\Delta(\mathbf{n}, z) = \underbrace{D_g}_{\text{density}} + \Phi + \Psi + \frac{1}{\mathcal{H}} \left[\Phi' + \underbrace{\partial_r (\mathbf{V} \cdot \mathbf{n})}_{z\text{-distortion}} \right] + \left(\frac{\mathcal{H}'}{\mathcal{H}^2} + \frac{2}{(\tau_0 - \tau_S)\mathcal{H}} \right) \left(\Psi + \mathbf{V} \cdot \mathbf{n} + \int_{\tau_S}^{\tau_0} d\tau (\Phi' + \Psi') \right) + \frac{1}{\tau_0 - \tau_S} \int_{\tau_S}^{\tau_0} d\tau \left[2 - \underbrace{\frac{\tau - \tau_S}{\tau_0 - \tau} \Delta_\Omega}_{\text{lensing}} \right] (\Phi + \Psi)$$

. . . plus galaxy bias, evolution and lensing magnification.

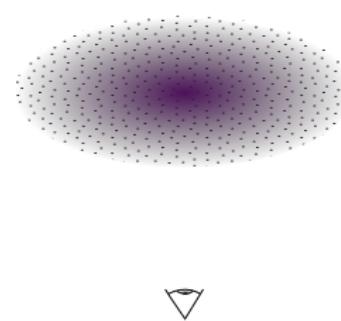
Observables in galaxy surveys

Redshift space distortions:

Real space



Redshift space



Observables in galaxy surveys

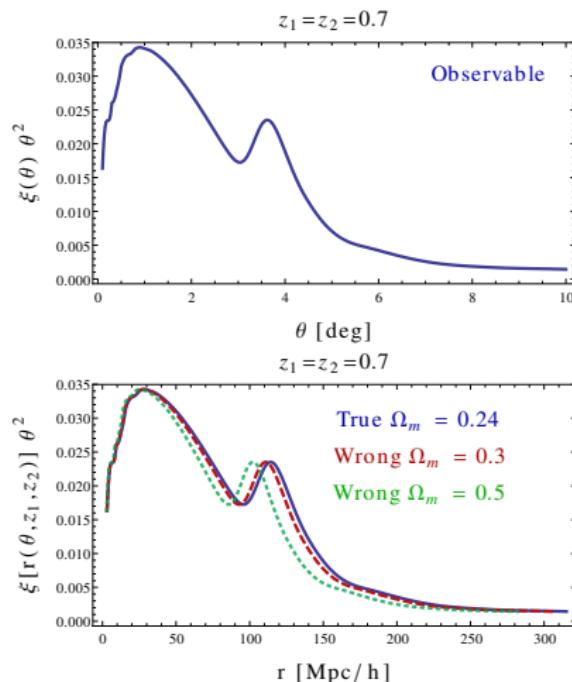
The 2-point correlation function

$$\xi(\theta, z, z') = \langle \Delta(\mathbf{n}, z) \Delta(\mathbf{n}', z') \rangle,$$

$\mathbf{n} \cdot \mathbf{n}' = \cos \theta$, is observable. To convert it into a 3D correlation

$$\theta, z, z' \rightarrow r(\theta, z, z')$$

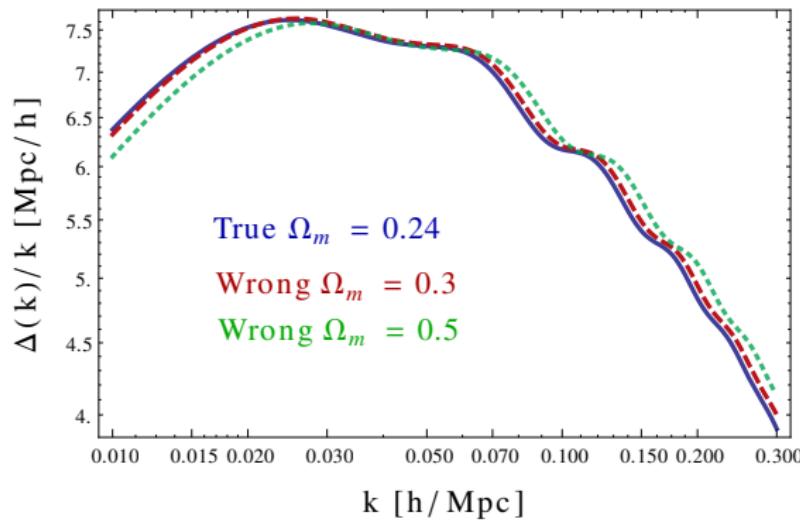
we must assume a cosmology for distances $d(z) = \int_0^z dz'/H(z')$.



Observables in galaxy surveys

3D Power spectrum:

$z = 0$



where $\Delta^2(k) = \frac{k^3 P(k)}{2\pi^2}$

Angular power spectrum

Model independent observables

For fixed z , expand $\Delta(\mathbf{n}, z)$ in spherical harmonics:

$$\Delta(\mathbf{n}, z) = \sum_{\ell m} a_{\ell m}(z) Y_{\ell m}(\mathbf{n}) .$$

Angular power spectrum:

$$C_\ell(z, z') = \langle a_{\ell m}(z) a_{\ell m}^*(z') \rangle ,$$

and correlation function:

$$\xi(\theta, z, z') = \langle \Delta(\mathbf{n}, z) \Delta(\mathbf{n}', z') \rangle = \sum_\ell \frac{2\ell + 1}{4\pi} C_\ell(z, z') P_\ell(\cos \theta) .$$

Fisher matrix

- How well do we expect a given experiment to determine cosmological parameters?

Assuming Gaussian likelihood, for signals $C_\ell(z_i, z_j) \equiv C_\ell^{ij}$ depending on cosmological parameters λ_α and with a given covariance matrix:

$$F_{\alpha\beta} = \sum_\ell \frac{\partial C_\ell^{ij}}{\partial \lambda_\alpha} \frac{\partial C_\ell^{pq}}{\partial \lambda_\beta} \text{Cov}_{\ell,(ij),(pq)}^{-1}$$

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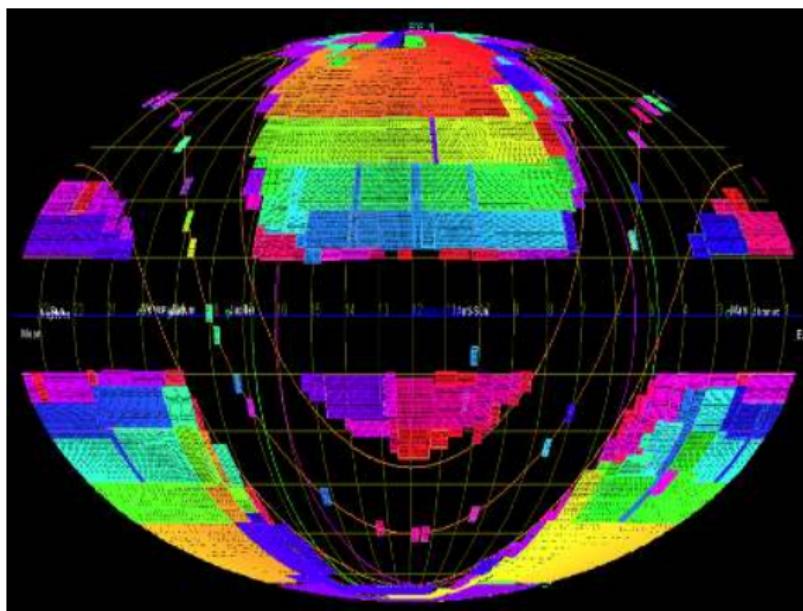
$$F_{\alpha\beta} = \sum_\ell \frac{\partial C_\ell^{ij}}{\partial \lambda_\alpha} \frac{\partial C_\ell^{pq}}{\partial \lambda_\beta} \text{Cov}_{\ell,(ij),(pq)}^{-1}$$

- How to characterize the performance of a method relative to its alternatives?

$$FoM = [\det(F^{-1})]^{-1/2}$$

$$FoM_{fixed} = [\det(\widehat{F}^{-1})]^{-1/2} \quad FoM_{marg.} = [\det(\widehat{F}^{-1})]^{-1/2}$$

Euclid mission (~ 2020)

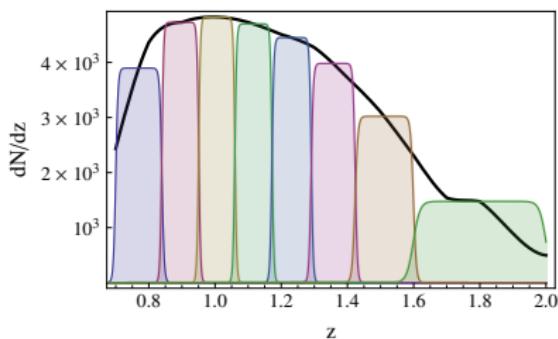


- Wide survey $15,000 \text{ deg}^2$
- z of 10^7 galaxies, photo- z of 10^9 galaxies

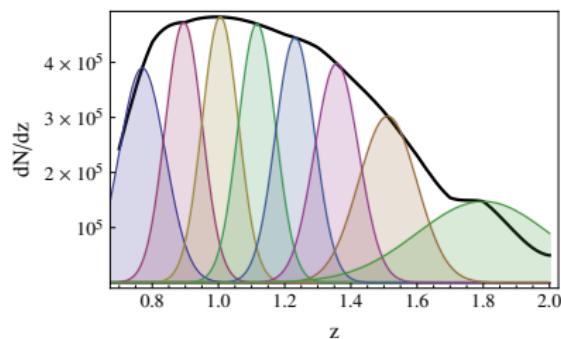
Redshift bins

For real survey, $C_\ell(z_i, z_j) \equiv C_\ell^{ij}$ are computed for bins i, j .

Spectroscopic z (\sim Tophat)



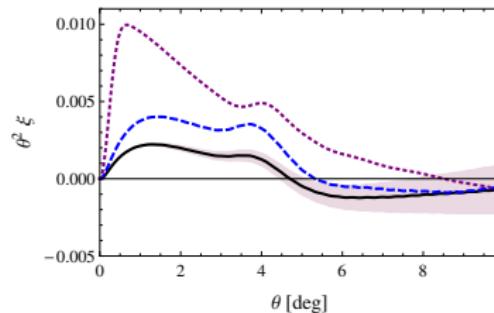
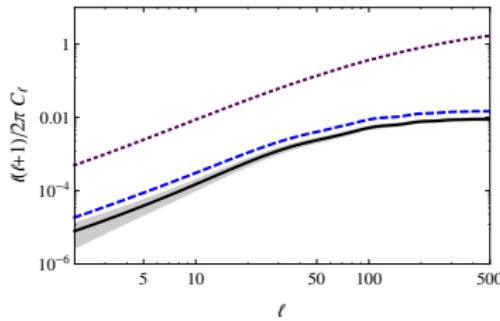
Photometric z (Gaussian)



- dN/dz (black line) for Euclid
- bins with same shot-noise, N_{bin} can vary

Angular power spectrum

The C_ℓ 's are computed with **CAMB SOURCES**¹ or **CLASSgal**².



Auto-correlations at $z=z'=0.55$ (DESspec).

Narrow bin, Spectroscopic $\Delta z = 0.1$, Photo-z $\Delta z = 0.1$

¹<http://camb.info/sources/>

²<http://cosmology.unige.ch/tools/>

Parameter estimation

Spec-z

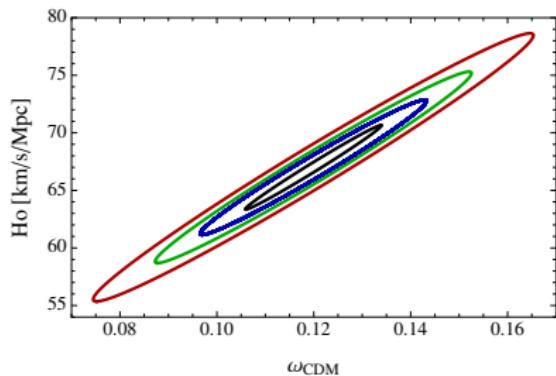
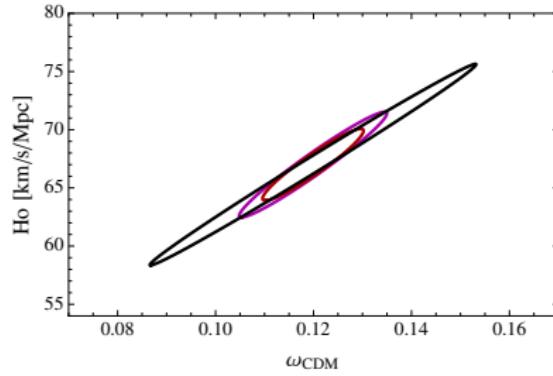


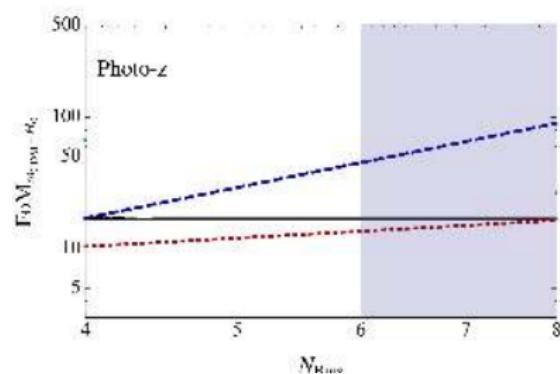
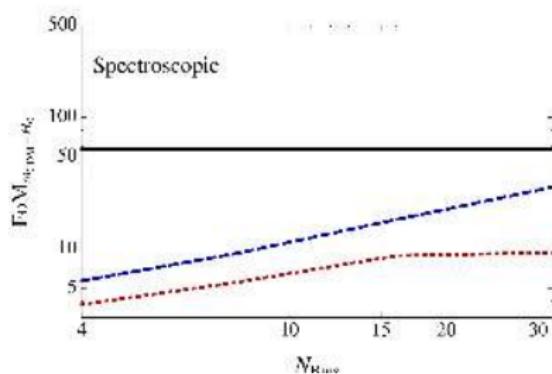
Photo-z



- 4 bins, 8 bins, 16 bins, 32 bins
- black line: 3D analysis with $P(k)$

From Di Dio, FM, Durrer, Lesgourgues 1308.6186

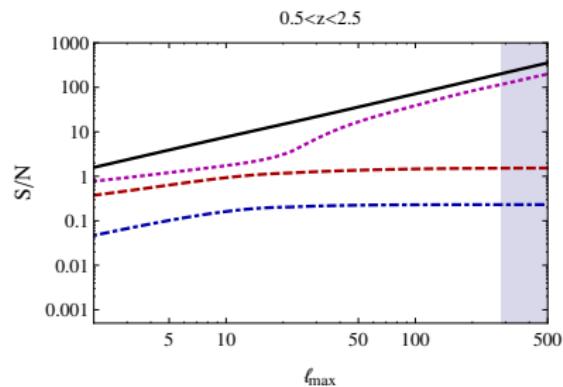
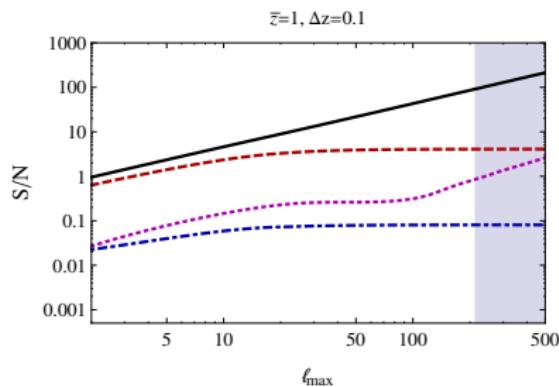
FoM



- black line: 3D analysis with $P(k)$
- only auto-correlations C_ℓ^{ii}
- including cross-correlations C_ℓ^{ij}

From Di Dio, FM, Durrer, Lesgourgues 1308.6186

Signal to Noise



Signal to noise for different contributions:
full C_ℓ , redshift-space distortions, lensing, potential

From Di Dio, FM, Durrer, Lesgourgues 1308.6186

Conclusions

- So far galaxy surveys mainly determined $P(k)$ (or equivalently $\xi(r)$). Easier to measure (less noisy), but require a **fiducial input cosmology** for the conversion:

$$z, z', \theta \rightarrow r(z, z', \theta)$$

- Large and precise surveys like **Euclid** will allow competitive measurements of $C_\ell(z, z')$ and $\xi(\theta, z, z')$
- These spectra are sensitive to the matter distribution (**density**), peculiar velocities (**redshift-space distortions**) and to the perturbations of spacetime geometry (**lensing**)
- The spectra depend sensitively and in several different ways on dark energy (growth factor, distance redshift relation), on galaxy bias, etc.: new estimations of cosmological parameters.