The fully relativistic correlation function for galaxy surveys

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Outline

Galaxy clustering in short

- what galaxy surveys measure:
  1. the energy (frequency) of a photon emitted by a galaxy at redshift z
  2. the direction $\hat{\mathbf{n}}$ in the sky from which this photon originated
- given that at some redshift z we detect on average $\langle N \rangle_\Omega$ galaxies, we define the number counts "overdensity" as:

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

- we can split the contributions to the overdensity as follows:

$$\Delta = \Delta^{\mathrm{den}} + \Delta^{\mathrm{rsd}} + \Delta^{\mathrm{lensing}} + \Delta^{\mathrm{rel}}$$

- largest contributions to 2 point function of Δ come from Δ^{den} and Δ^{rsd}, but $\Delta^{\mathrm{lensing}}$ may be important on large scales

Future galaxy surveys

- DESI, Euclid, SKA, LSST - higher precision and larger survey volumes than ever before
- usual theoretical estimators: $P(k, z_1, z_2)$, $C_\ell(z_1, z_2)$, $\xi(\theta, z_1, z_2)$
  - $P(k)$ - easiest to compute theoretically and observationally, is not gauge invariant, challenging to include integrated effects
  - C_ℓ - easy to compute theoretically, gauge invariant, suitable for photometric surveys, needs many thin redshift bins for optimal information, not easy to extract growth rate f
  - ξ - gauge invariant, easy to get growth rate f, mostly easy to compute, suitable for spectroscopic surveys, covariance is not diagonal and is challenging to include integrated effects in it
- codes: CAMB $[P(k), C_\ell]$, CLASS $[P(k), C_\ell]$, **COFFE**[1] $[\xi]$

[1] https://www.github.com/JCGoran/coffe/

Applications

- goal: estimate impact of lensing and rel. effects on future spectroscopic surveys
- method used: Fisher matrix analysis
- surveys considered: SKA II, DESI
- estimator: multipoles of 2 point correlation function, $\xi_L(\bar{z}, r)$

Signal-to-noise (SNR) ratio

- we define
$$\xi^{\text{total}} = \xi^{\text{std}} + A\,\xi^{\text{effect}}$$
where effect $\in \{\text{lensing}, \text{rel.}\}$, and
$$\xi^{\text{std}} \equiv \langle (\Delta^{\text{den}} + \Delta^{\text{rsd}})(\Delta^{\text{den}} + \Delta^{\text{rsd}}) \rangle_\Omega$$
- define $\text{SNR} \equiv \sqrt{F}$, where F denotes the Fisher matrix, and A is the only free parameter

Signal-to-noise (SNR) ratio (cont.)

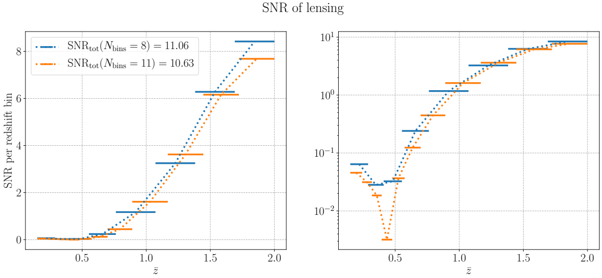

Figure: SNR of lensing for SKA II on linear (left) and logarithmic (right) scales

- lensing has quite a large cumulative SNR (~ 10), while for DESI it appears to be negligible
- rel. effects <u>negligible</u> for both (~ 0.35 for SKA II, ~ 0.65 for DESI)

Cosmological parameters - constraints and bias

Table: Parameters used for the Fisher matrix analysis as well as their fiducial values

name	$\omega_{\rm cdm}$	$\omega_{\rm b}$	h	n_s	$\log_{10}(10^{10} A_s)$	b_0
θ_i	0.1186	0.02226	0.6781	0.9677	3.062	1.0

Cosmological parameters - constraints and bias (cont.)

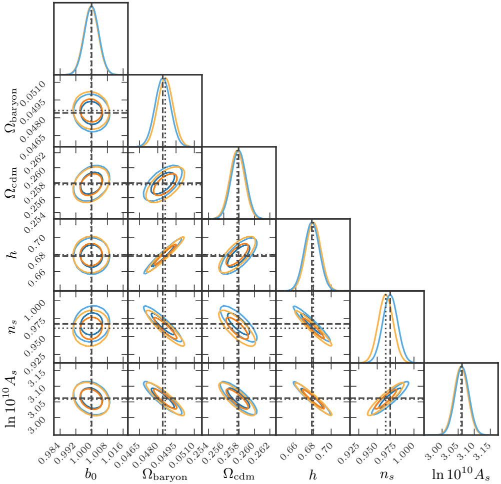

Figure: Contour plot of ΛCDM parameters used for the Fisher matrix analysis for SKA II

Cosmological parameters - constraints and bias (cont.)

Table: SKA II, 8 bin configuration, no lensing in parameter constraints

parameter	b_0	Ω_b	Ω_cdm	h	n_s	$\ln 10^{10} A_s$
$\sigma(\theta_i)/\theta_i$ (%)	0.36	1.31	0.37	1.25	1.04	0.69
$\Delta(\theta_i)/\sigma(\theta_i)$	-0.072	0.32	-0.19	0.19	-0.6	-0.14

- constraints on the sub-percent level for some parameters
- bias for standard ΛCDM parameters smaller than 1σ for all parameters
- DESI - constraints between 0.8% and 3.5%, bias negligible

Measuring the growth function

- we now assume that the ΛCDM parameters are fixed, and want to know what's the accuracy with which we can constrain the parameters $\tilde{b}(z) \equiv \sigma_8 D_1(z) b(z)$ and $\tilde{f}(z) \equiv \sigma_8 D_1(z) f(z)$ in each redshift bin
- Reasoning - the $L = 0, 2, 4$ multipoles of the correlation function, neglecting wide-angle effects, are proportional to:

$$\xi_L \sim D_1^2 \, \alpha \, \beta \, P(k)$$

where $\alpha, \beta \in \{b, f\}$, so we can rewrite ξ_L completely in terms of $\tilde{f}$ and $\tilde{b}$, with fiducial values taken to be those of ΛCDM

Results for $\tilde{f}$

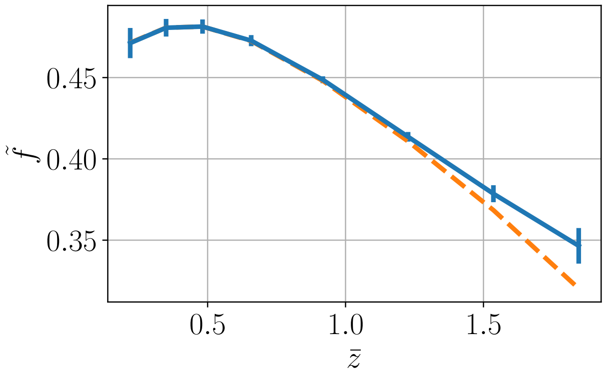

Figure: Value and constraints for $\tilde{f}$ (blue), as well as the values offset by the bias (orange) for SKA II, 8 bin configuration

Results for $\tilde{b}$

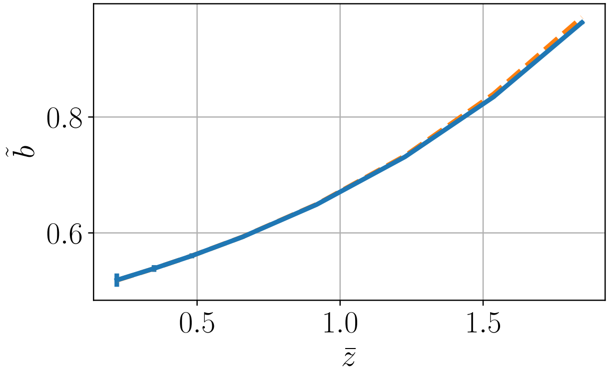

Figure: Value and constraints for $\tilde{b}$ (blue), as well as the values offset by the bias (orange) for SKA II, 8 bin configuration. Note that for $z > 0.5$ the errors are smaller than the line thickness.

Tables

Table: SKA II, 8 bin configuration: the values of the parameters $\tilde{b}_i$ and $\tilde{f}_i$, their constraints, and shifts when neglecting the lensing contribution to the correlation function.

$\bar{z}_i$	$\tilde{b}_i$	$\frac{\sigma}{\theta}(\tilde{b}_i)(\%)$	$\frac{\Delta}{\sigma}(\tilde{b}_i)$
0.22	0.52	2.22	-0.02
0.35	0.54	1.08	-0.01
0.48	0.56	0.77	0.01
0.66	0.59	0.50	0.07
0.92	0.65	0.22	0.36
1.23	0.73	0.21	1.17
1.54	0.83	0.25	2.45
1.85	0.96	0.29	3.27

$\bar{z}_i$	$\tilde{f}_i$	$\frac{\sigma}{\theta}(\tilde{f}_i)(\%)$	$\frac{\Delta}{\sigma}(\tilde{f}_i)$
0.22	0.47	1.97	0.02
0.35	0.48	1.13	0.01
0.48	0.48	0.91	-0.01
0.66	0.47	0.72	-0.06
0.92	0.45	0.48	-0.30
1.23	0.41	0.71	-0.95
1.54	0.38	1.38	-1.94
1.85	0.35	3.16	-2.40

- bias significant for SKA II, negligible for DESI

Conclusions and remarks

- Questions answered:
  - Will relativistic effects be detectable in the 2PCF for single tracers of future spectroscopic surveys? Probably not
  - Does lensing have an impact on constraints on standard cosmological parameters? Not much
  - Does neglecting lensing induce a bias in the values of standard cosmological parameters? Yes, but less than 1σ
  - Does neglecting lensing induce a bias when measuring $\tilde{f}$ and $\tilde{b}$? Yes, up to 3σ
- Future work:
  1. combining spectroscopic and and photometric surveys $\to$ impact on bias and constraints (talk by Francesca tomorrow!)
  2. nonlinear effects neglected in analysis $\to$ does it increase or decrease the signal?
  3. analysis for Euclid (when we get the specs)

Fin