LoTSS DR2 cross correlating with eBOSS

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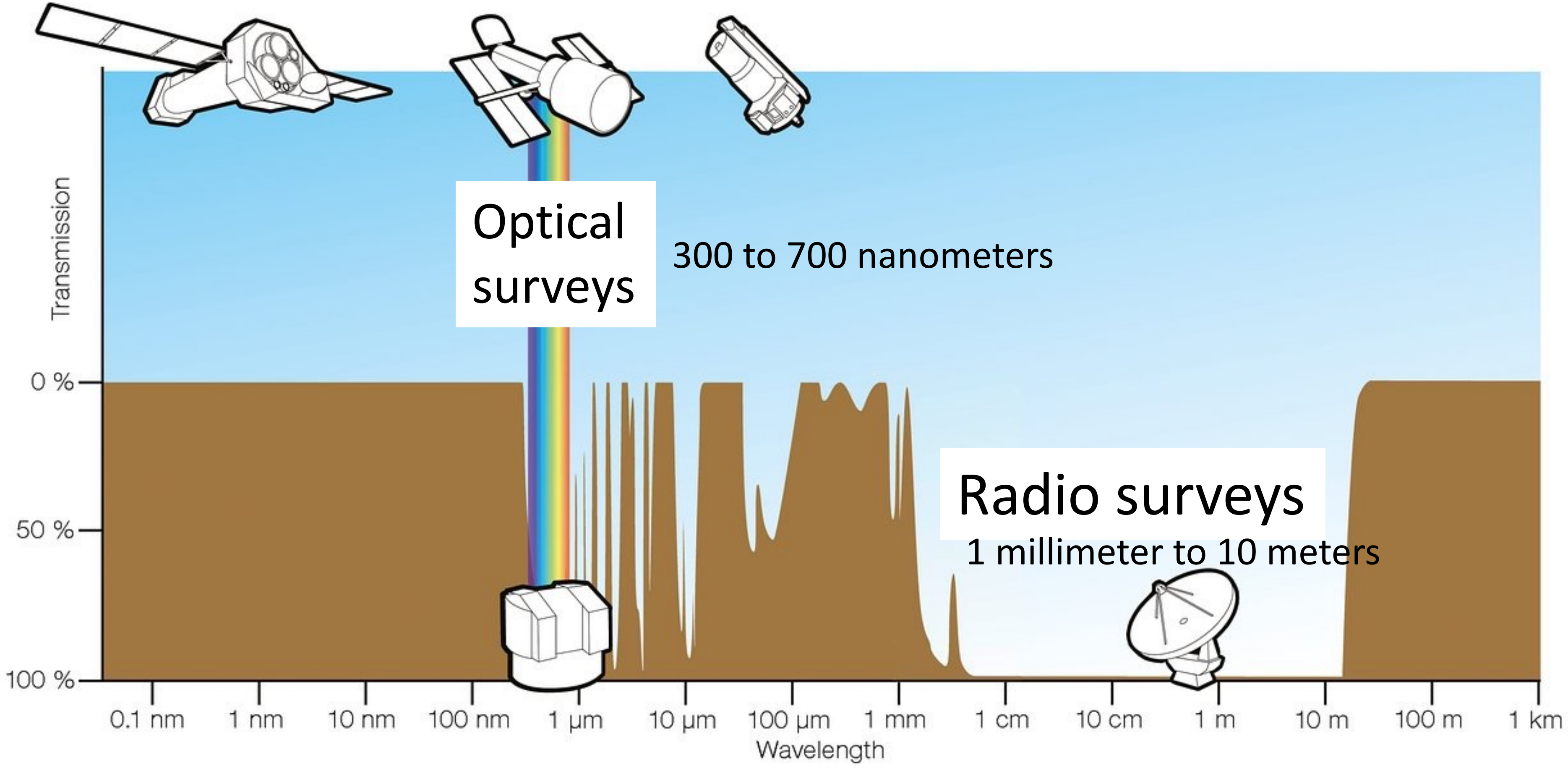
[LOFAR cosmology collaboration]

LOFAR family meeting 2024

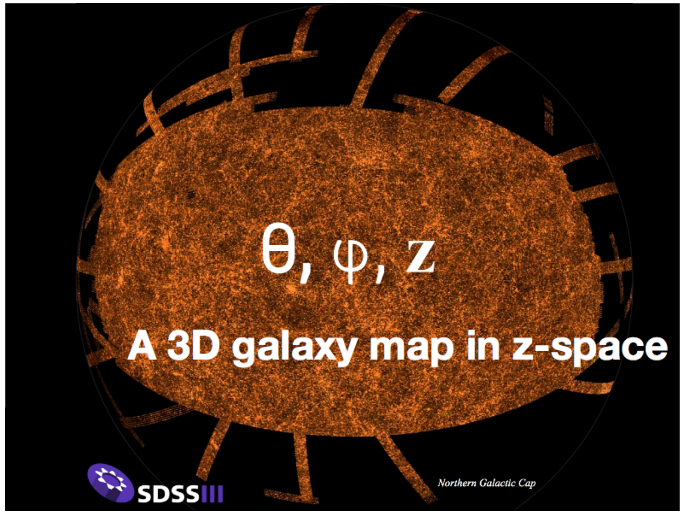
Cosmology: Observations



Transparency of the atmosphere. Credit : ESA/Hubble (F. Granato)

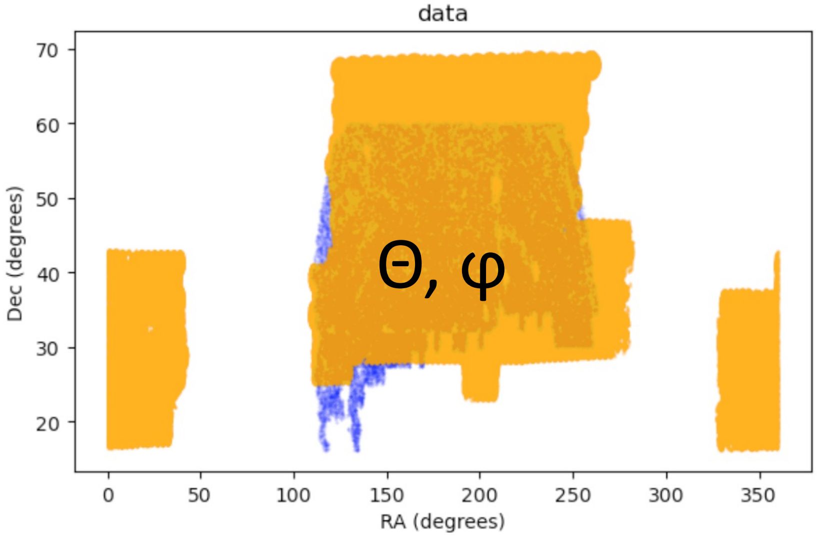
Cosmology: Observations

Optical survey:



Credit: sdss.org

Radio continuum surveys:

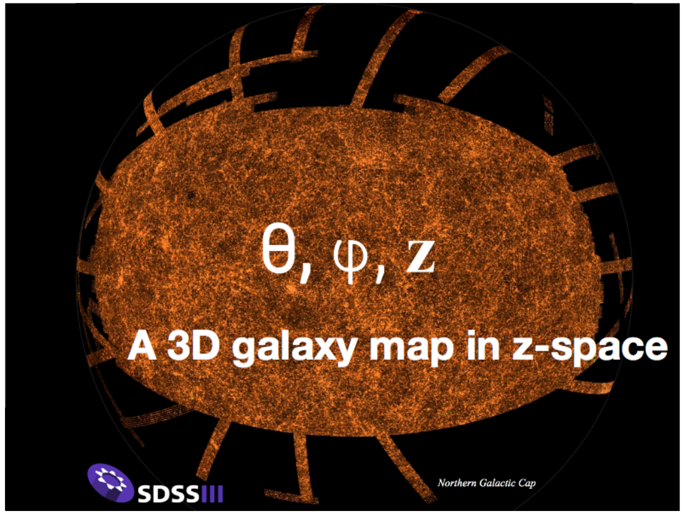


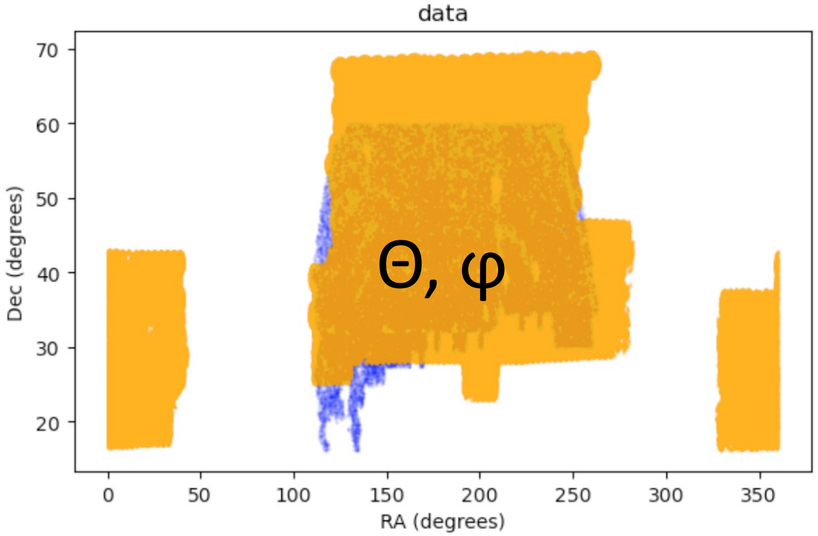
Cosmology: Observations

Optical survey:

cross-correlate

Radio continuum surveys:





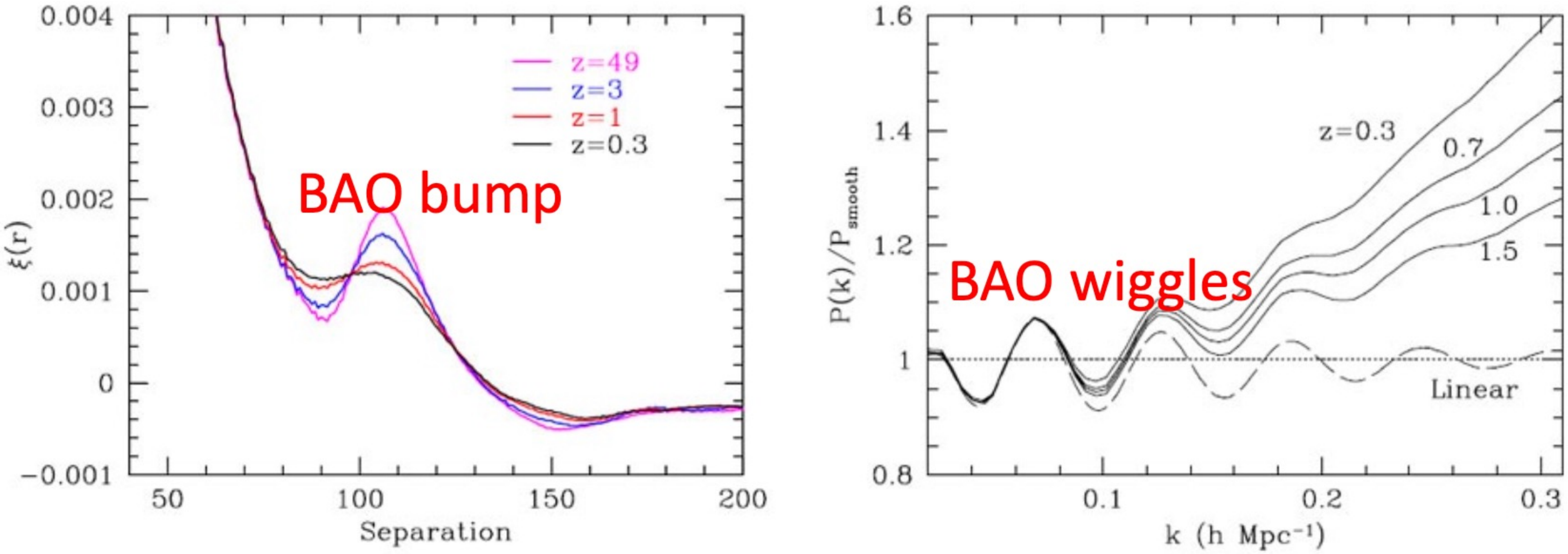
Credit: sdss.org

BAO

In cosmology, baryon acoustic oscillations (BAO) are fluctuations in the density of the visible baryonic matter (normal matter) of the universe, caused by acoustic density waves in the primordial plasma of the early universe

BAO

In cosmology, baryon



Seo and Eisenstein (2005): CF to PS by Fourier transformation

Cosmology: Theory

Modified Gravity **Dark Energy**

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Cosmology: Theory

Modified Gravity **Dark Energy**

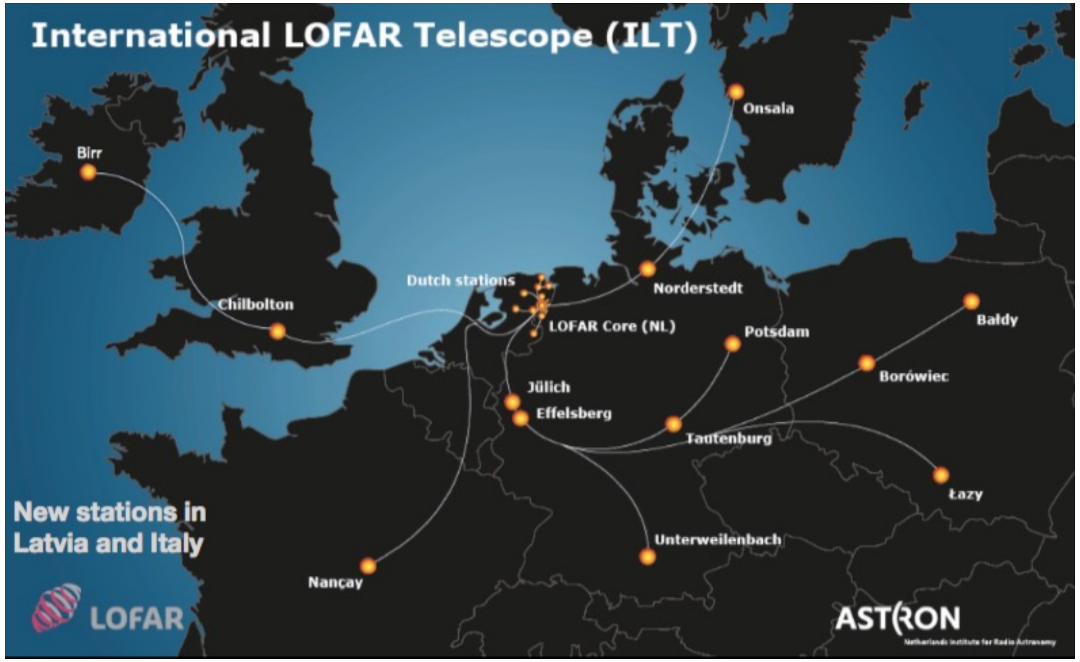
$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

RSD measurements BAO

(perturbation) (background)

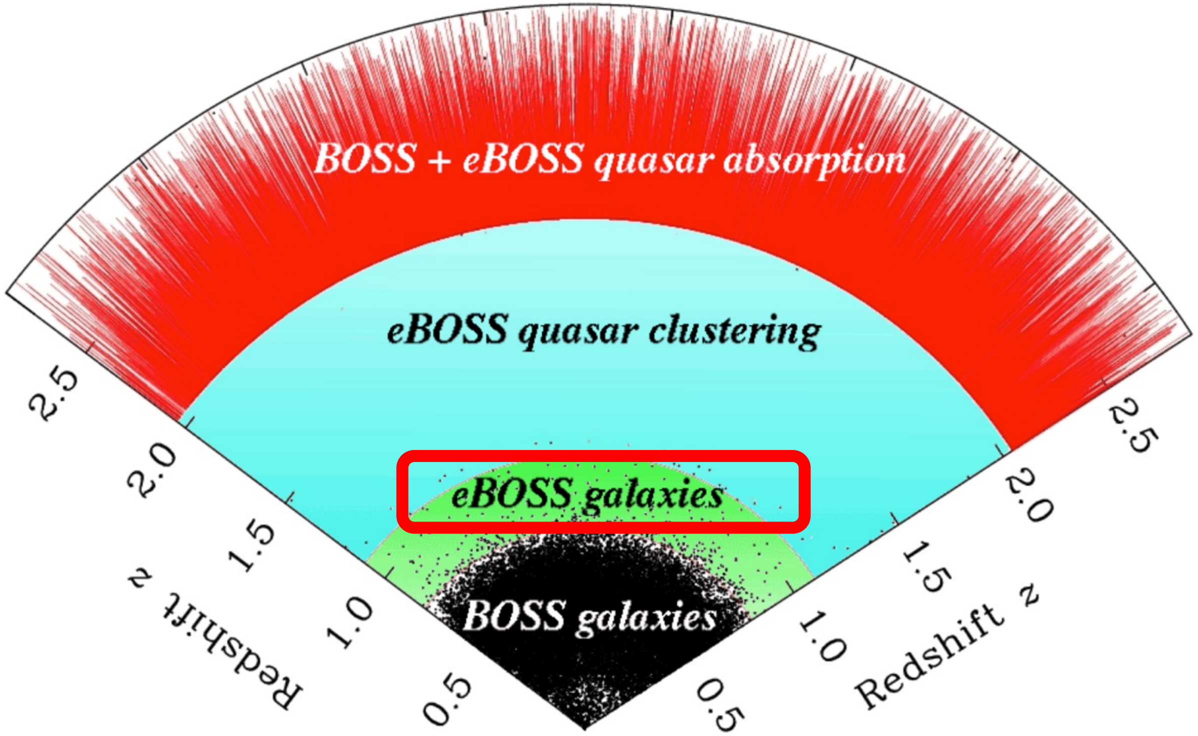
LoTSS(LOFAR Two-metre Sky Survey)

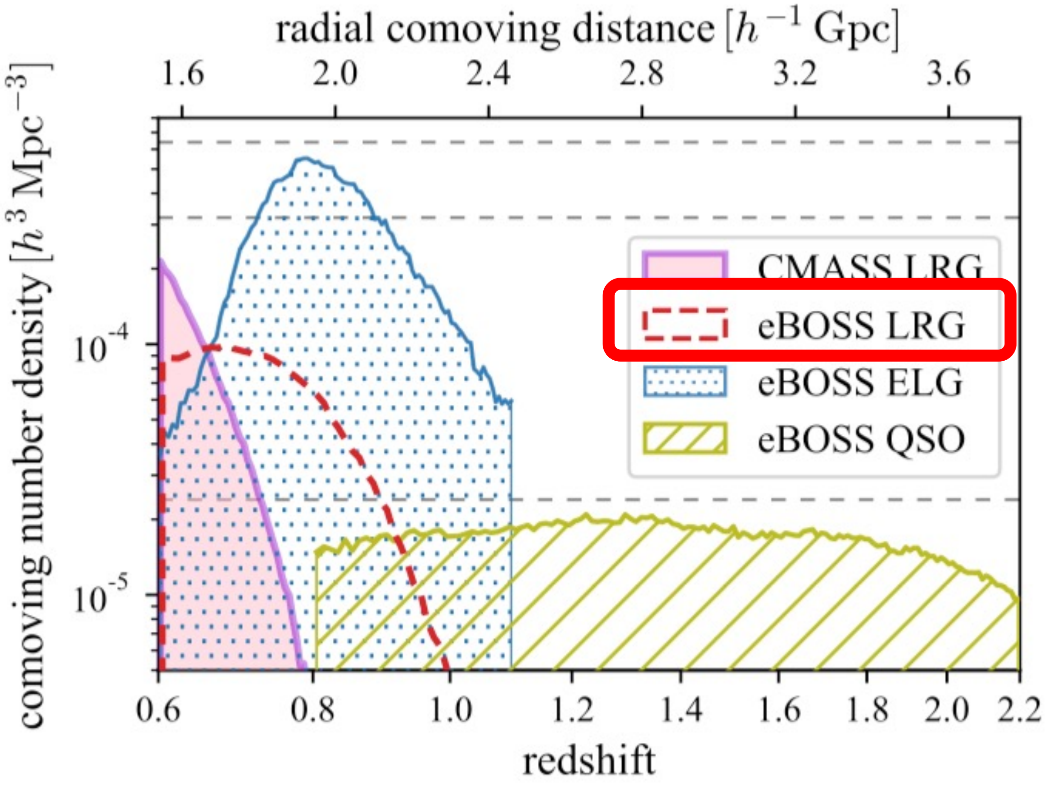
- Continuum map
- LoTSS will be the deepest radio continuum survey at low radio frequencies for the next decades
- will cover the complete Nothern sky, its high angular allows to identify multi-wavelength counterparts for which photometric redshifts are obtained
- WEAVE-LOFAR will obtain a million of spectroscopic redshifts for LoTSS selected radio sources



Credit: www.astron.nl

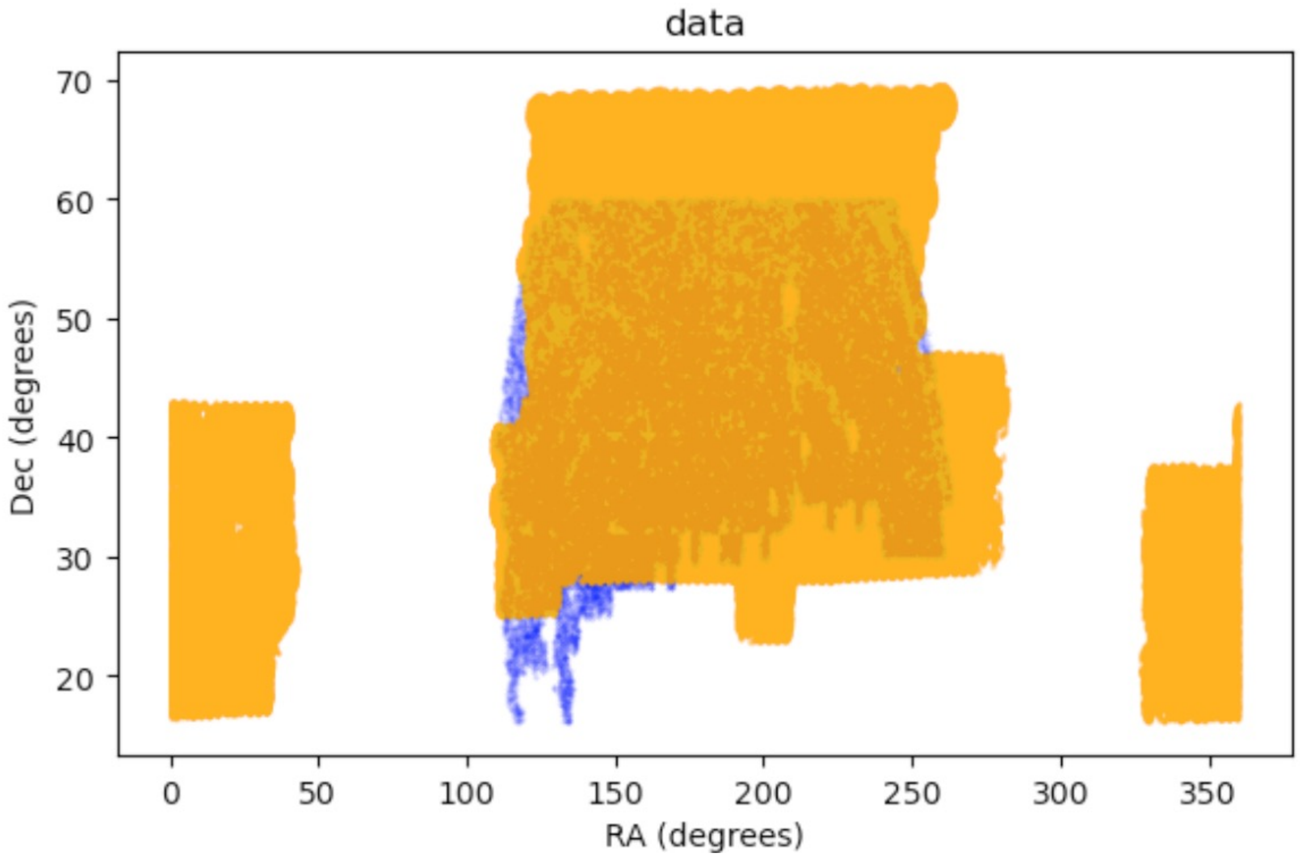
eBOSS





credit: sdss.org

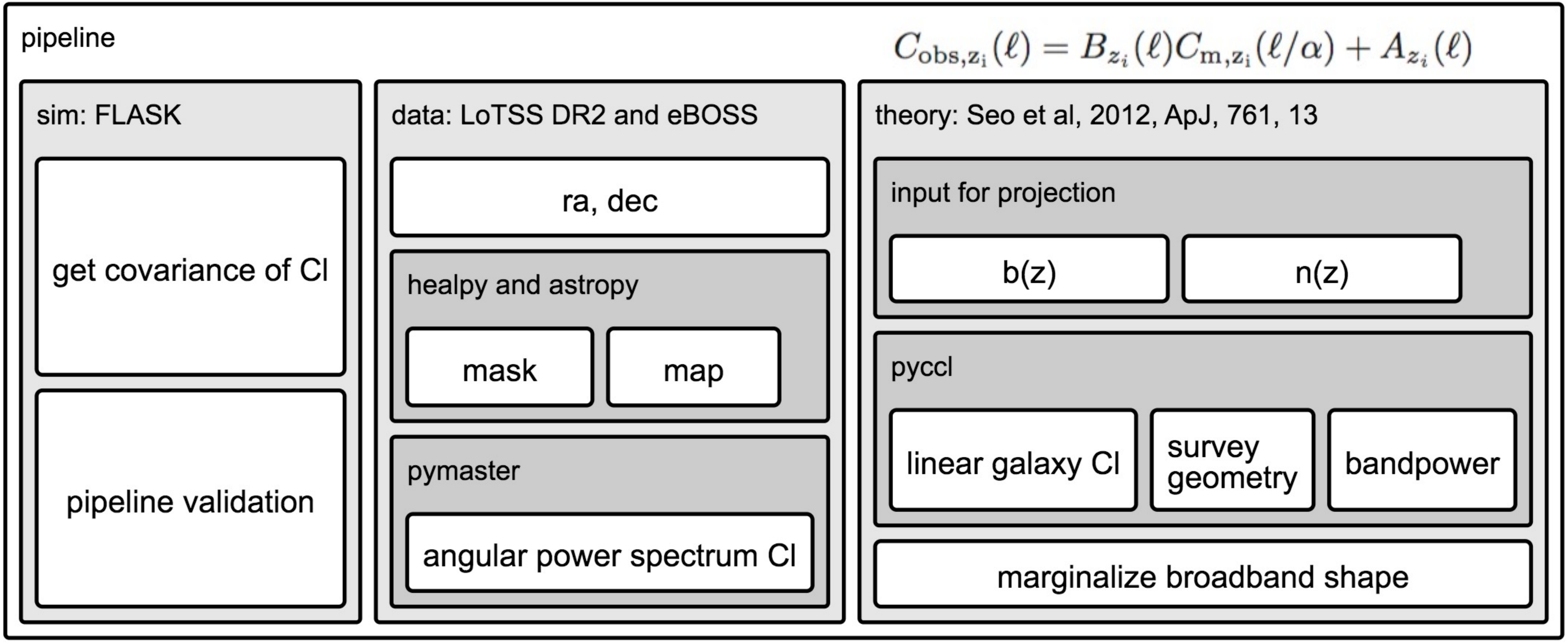
- LoTSS DR2 cross correlates with eBOSS (Zheng et al, to be submitted to A&A)



1.5 mjy flux cut for LoTSS
delta_z = 0.06 for eBOSS

	N_{tot}	N_{cut}
eBOSS	107500	16559(15.4%)
LoTSS	4395448	2111178(48.0%)

- pipeline



pipeline
$C_{\mathrm{obs,z_i}}(\ell) = B_{z_i}(\ell)C_{\mathrm{m,z_i}}(\ell/\alpha) + A_{z_i}(\ell)$
sim: FLASK
get covariance of Cl
pipeline validation
data: LoTSS DR2 and eBOSS
ra, dec
healpy and astropy
mask
map
pymaster
angular power spectrum Cl
theory: Seo et al, 2012, ApJ, 761, 13
input for projection
b(z)
n(z)
pyccl
linear galaxy Cl
survey geometry
bandpower
marginalize broadband shape

- To be more specific, the angular power spectrum measurement template reads,

$$C_g(\ell) = \frac{B(\ell)}{\alpha^2} C^{BAO}(\frac{\ell}{\alpha}) + A(\ell)$$

- the A(l) and B(l) terms are polynomial terms to marginalize the broadband shape of the power spectrum, can be tested by the mock catalogue;
- whilst the theoretical angular power spectrum of suvery A and B is,

$$C_{l,g}^{AB} = \frac{2}{\pi} \int dk k^2 P_m(k) W_{AB}^2(k)$$

- Here we need to project bias b(z) and redshift distribution p(r) or n(z) of both surveys

$$W_{AB}(k) = \left| \int D(z) b_A(z) p_A(r) j_l(kr) dr \right| \left| \int D(z) b_B(z) p_B(r) j_l(kr) dr \right|$$

How to choose b(z) and n(z)?

eBOSS

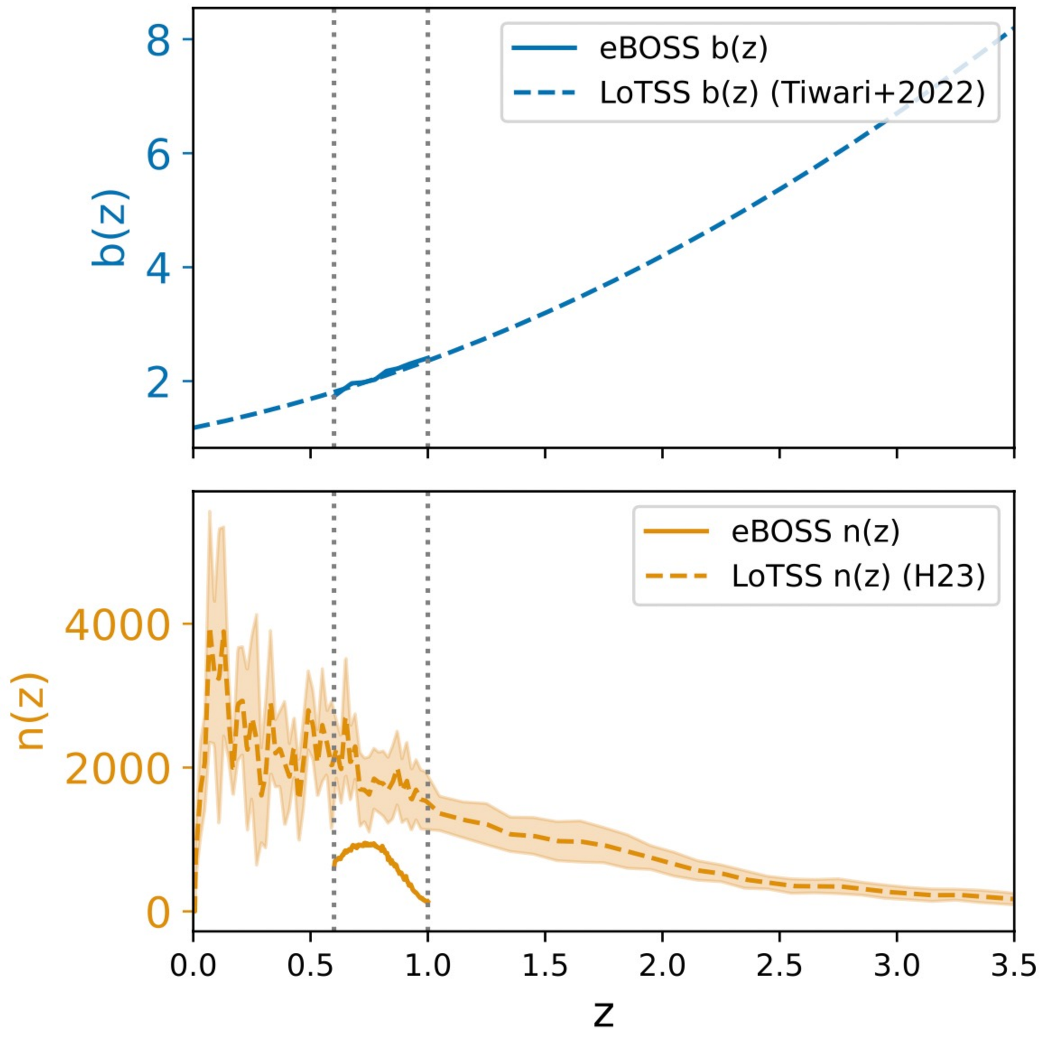
b(z): EZmock (Zhao et al. 2021)

N(z): directly from catalogue

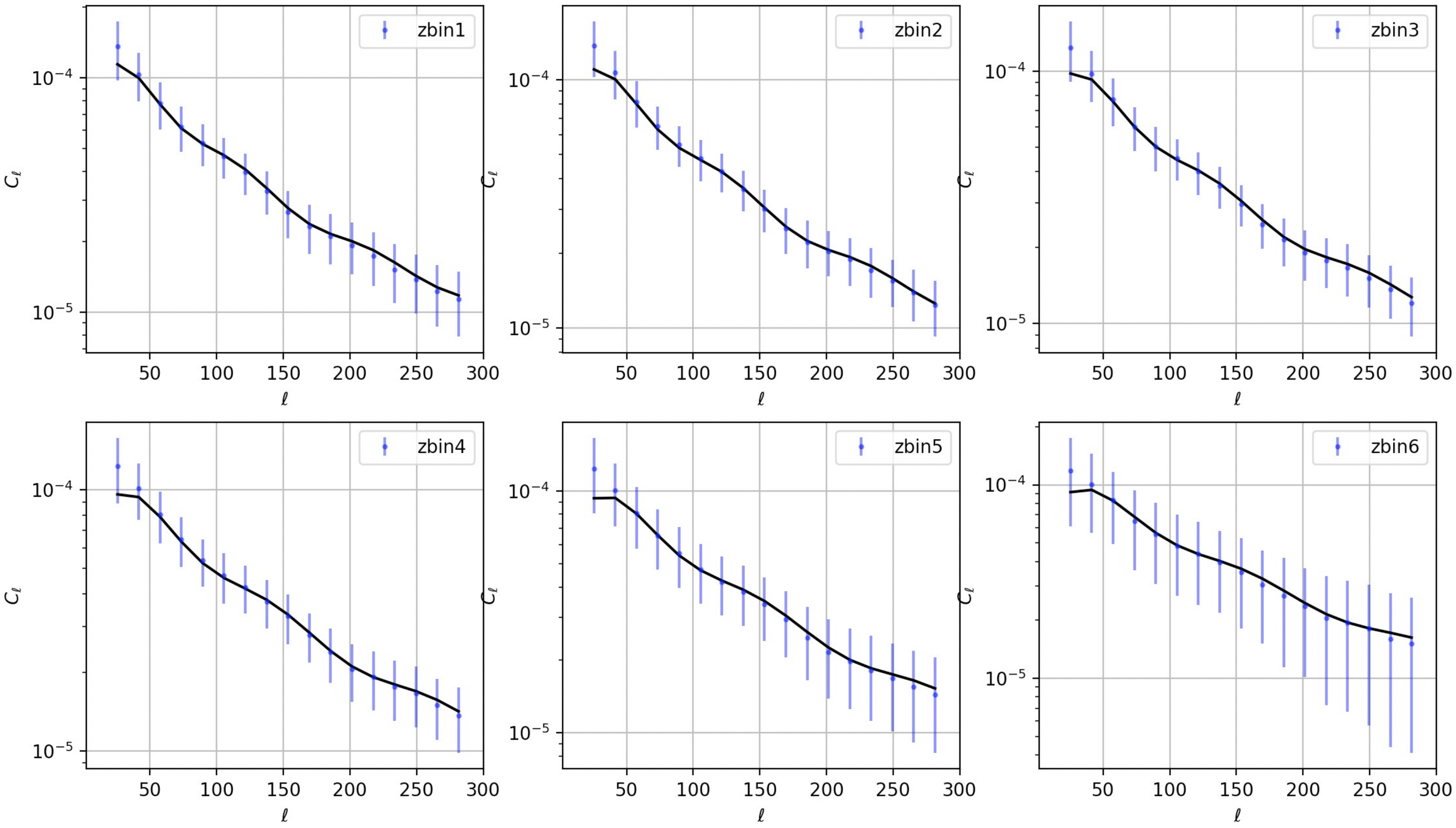
LoTSS

B(z): DR1 best fit (Tiwari et al. 2022)

N(z): Deep-Fields (Hale et al. 2024)

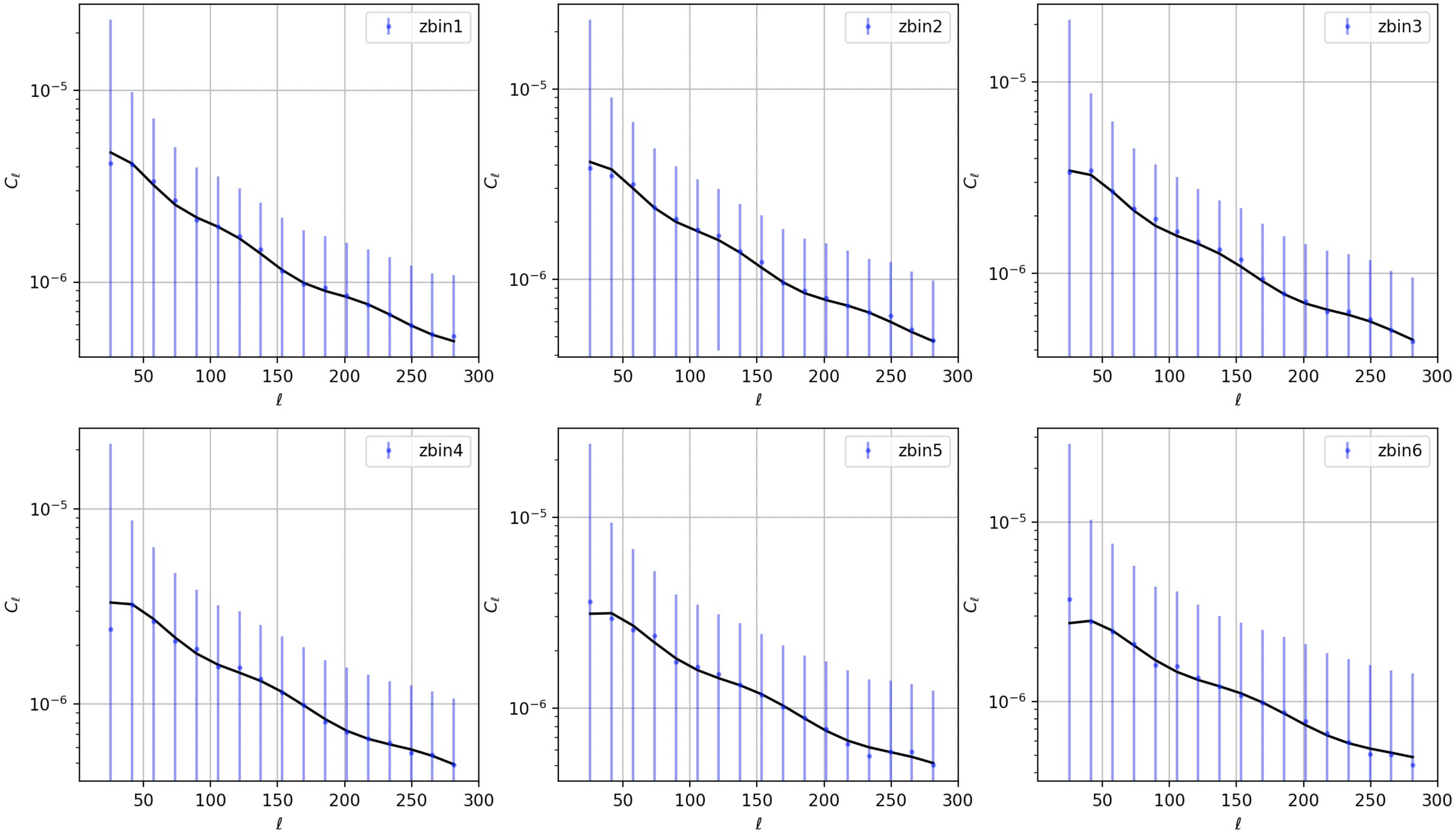


Mock test: using FLASK (Xavier et al. 2016))
eBOSS x eBOSS z=0.6-1, △z=0.06

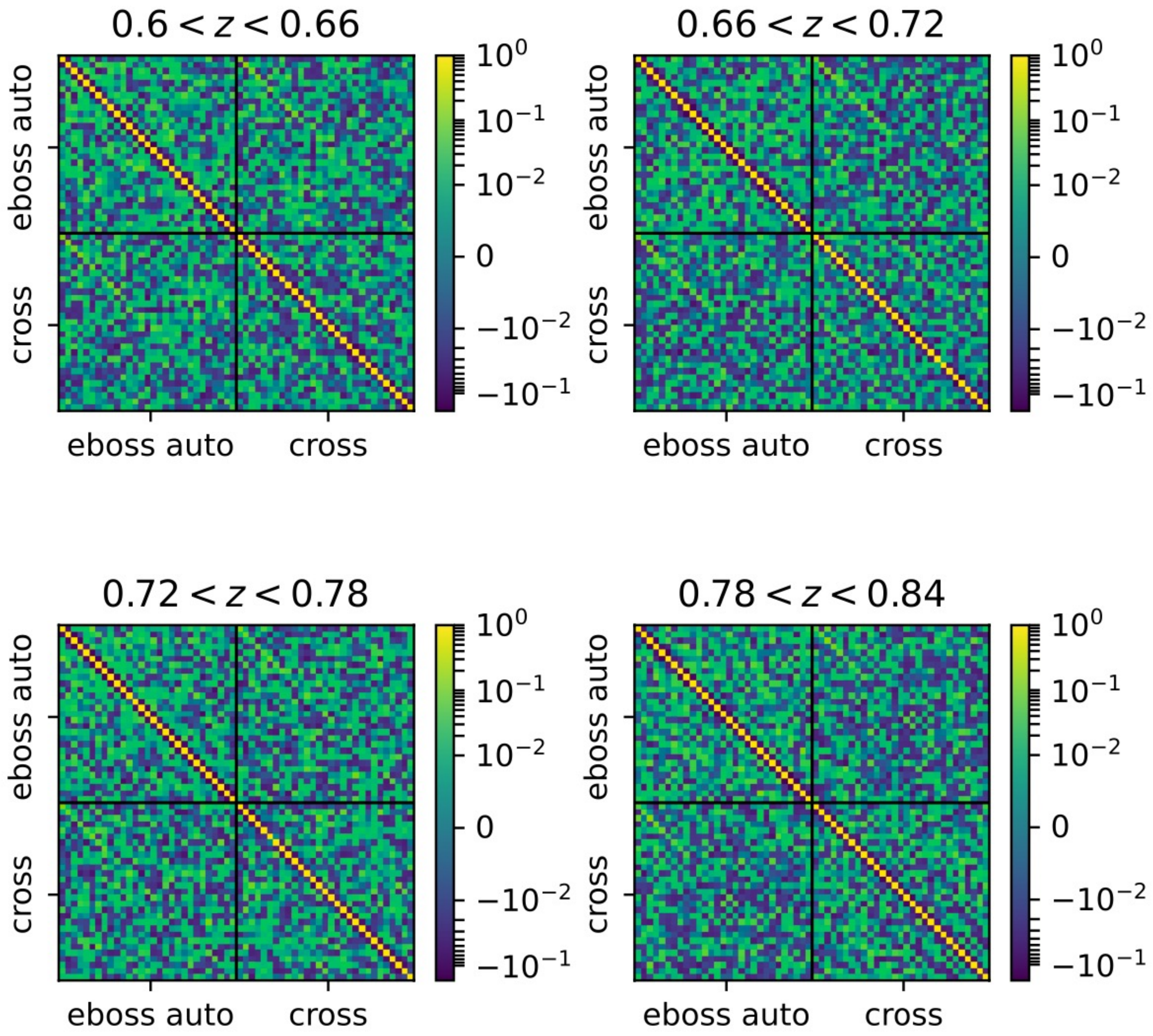


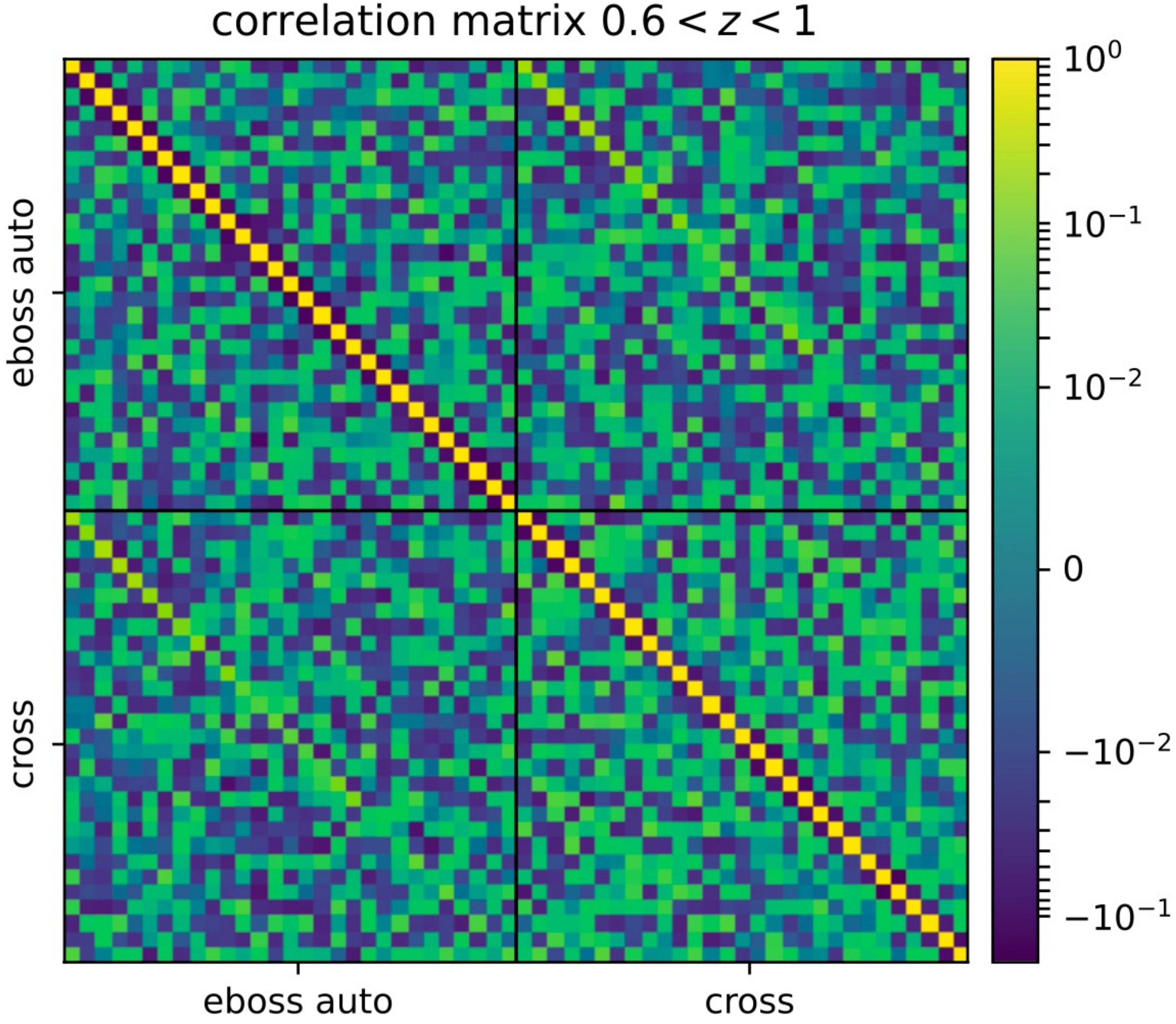
*the redshift binning always means the eBOSS redshift binning; auto means eBOSS auto correlation

Mock test: cross (LoTSS x eBOSS)

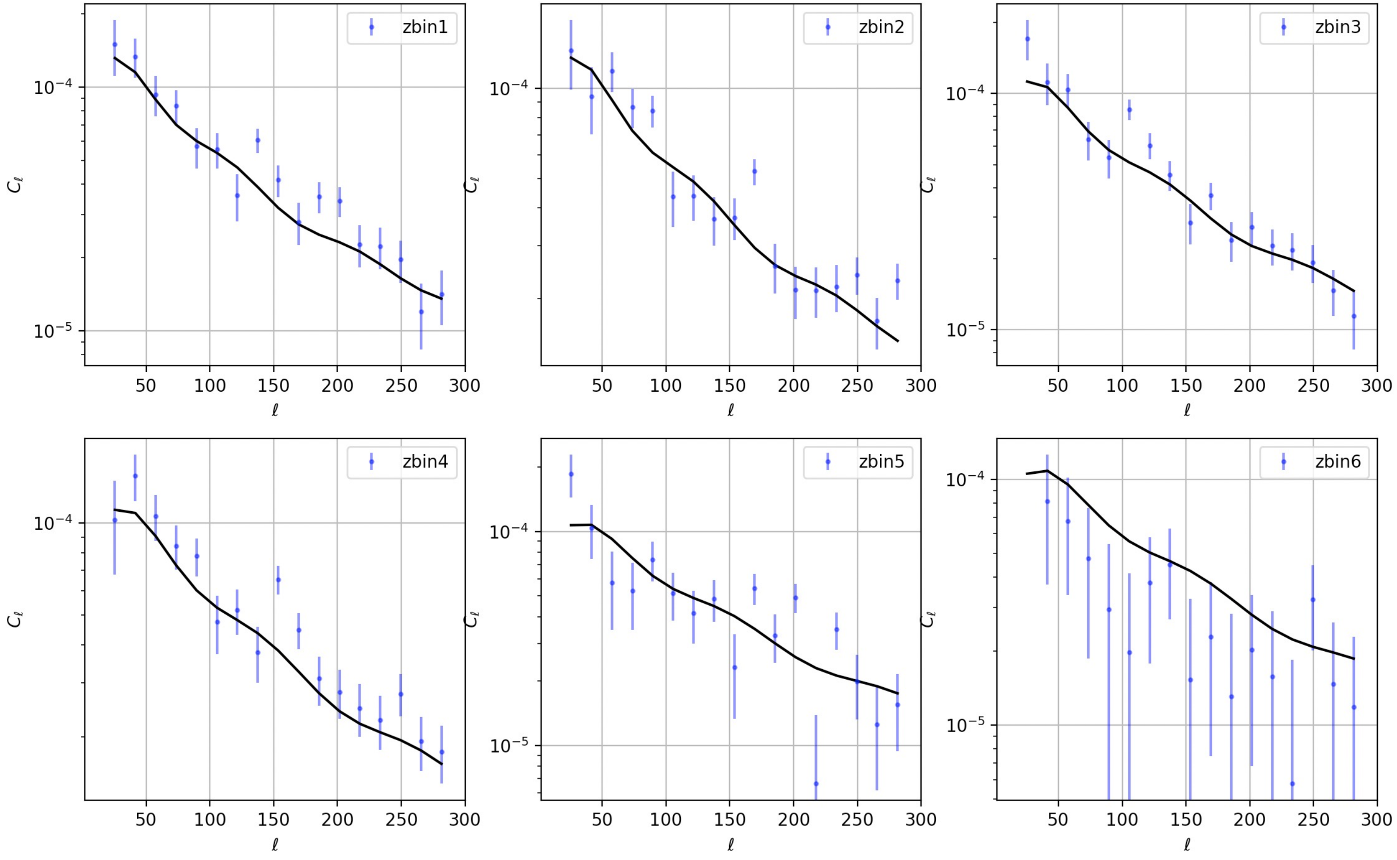


• correlation matrix

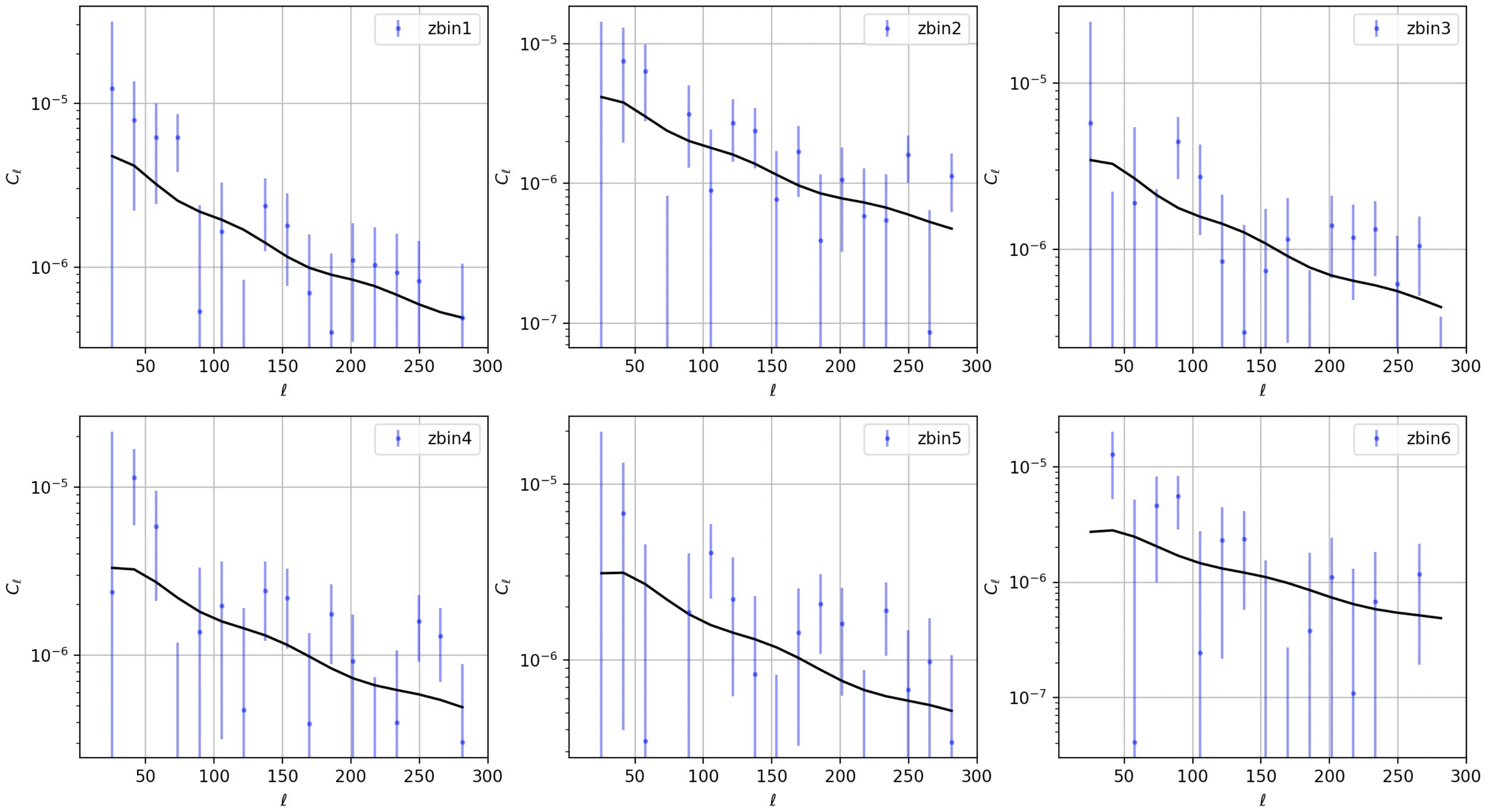



correlation matrix $0.6 < z < 1$
eboss auto
cross
eboss auto
cross
10^0
10^{-1}
10^{-2}
0
-10^{-2}
-10^{-1}

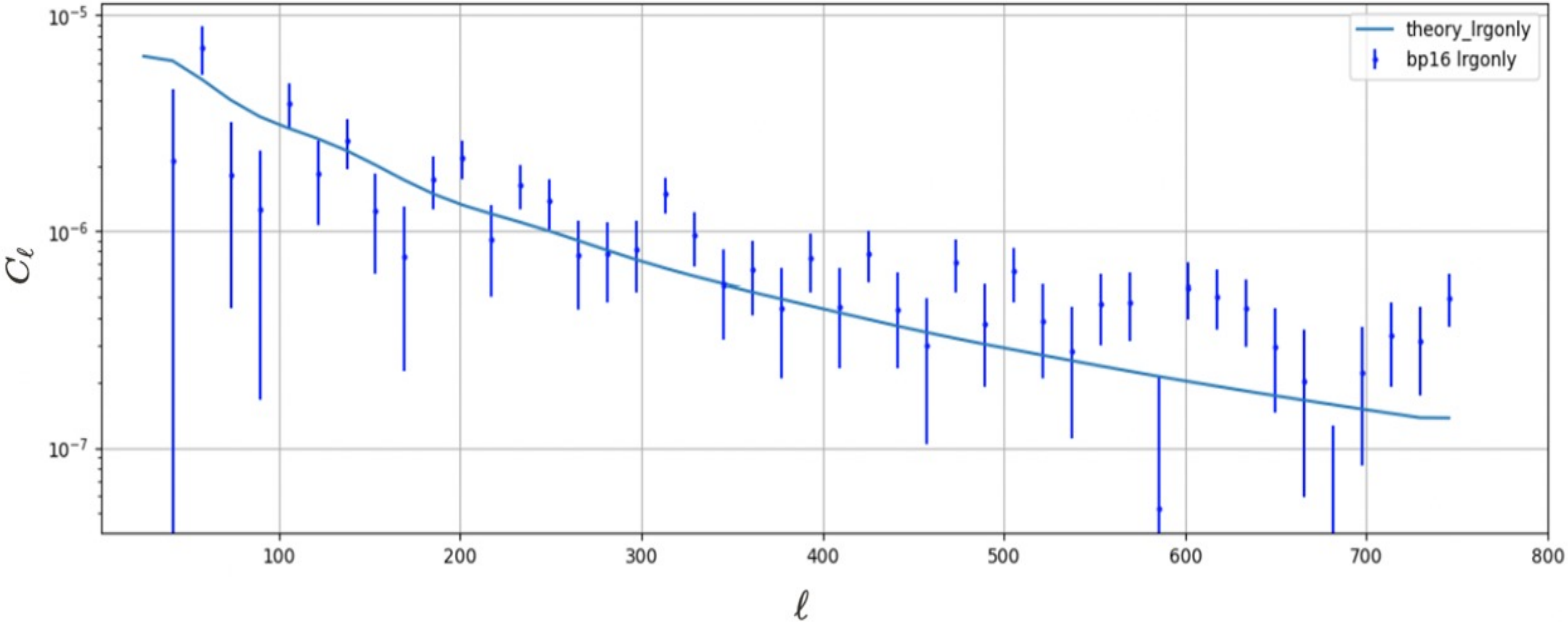
measurements: eBOSS x eBOSS



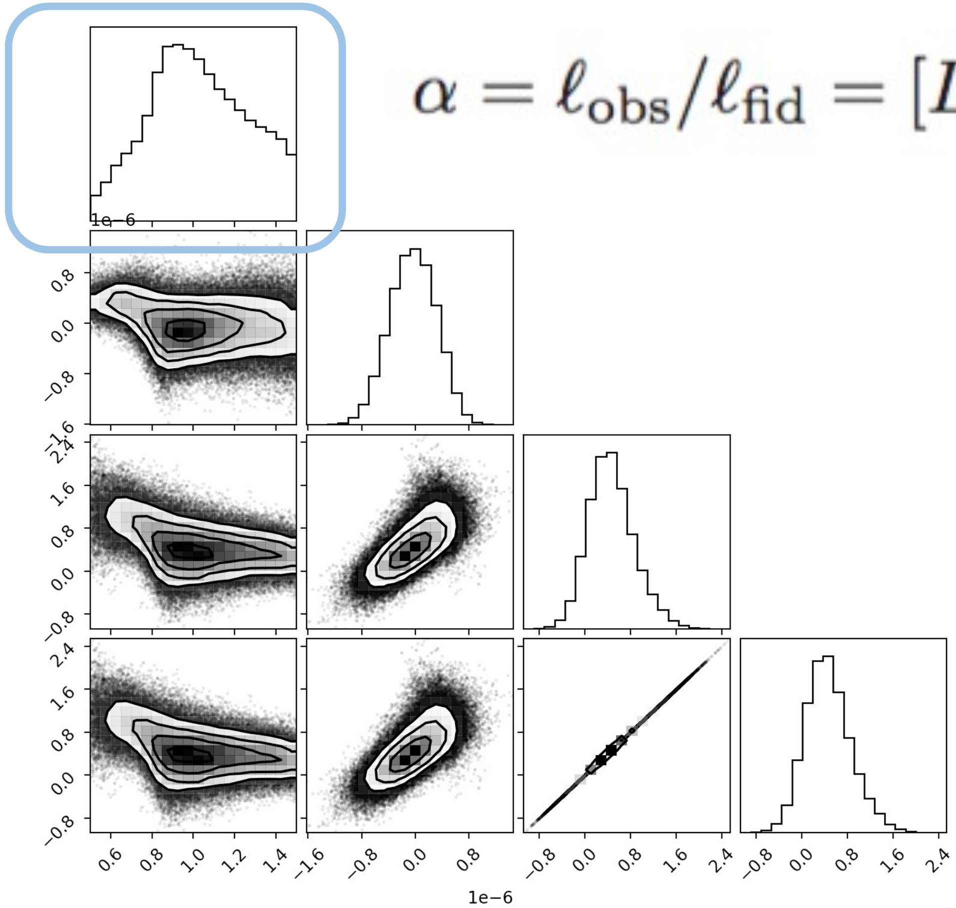
measurements: LoTSS x eBOSS



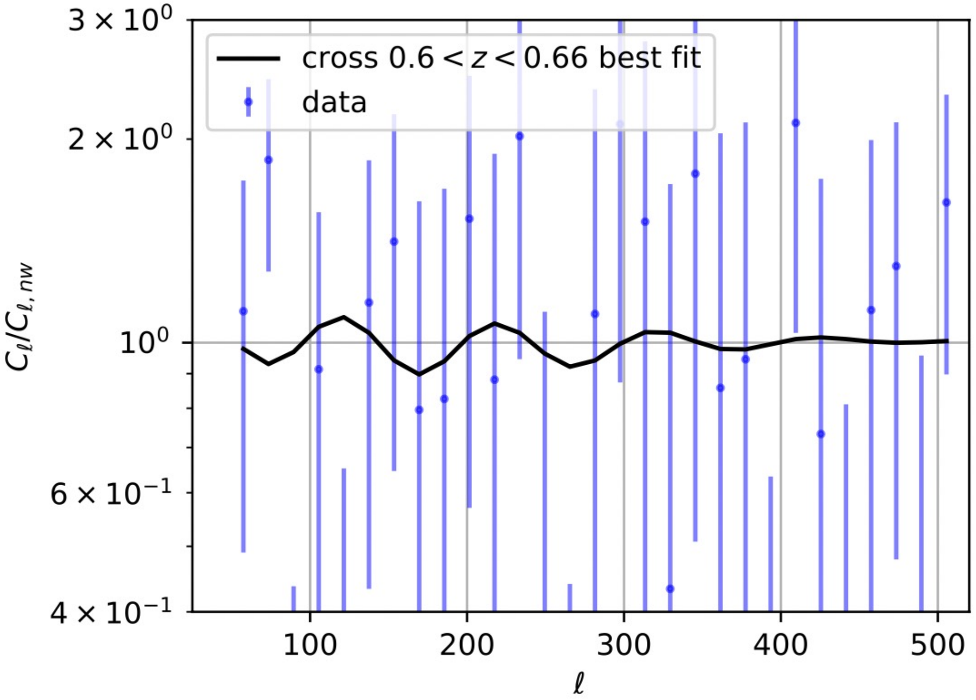
Measurements vs theory: LoTSS x eBOSS (all redshift bins)



contrain the angular diameter distance



$$\alpha = \ell_{\rm obs}/\ell_{\rm fid} = [D_A(z)/r_s]_{\rm obs}/[D_A(z)/r_s]_{\rm fid}$$



contrain the angular diameter distance

$$\alpha = \ell_{\rm obs}/\ell_{\rm fid} = [D_A(z)/r_s]_{\rm obs}/[D_A(z)/r_s]_{\rm fid}$$

	$z_{\rm eff}$	α	$D_{\rm A}(z_{\rm eff})/r_d$	χ^2_{min}/dof
cross $0.6 < z < 0.66$	0.63	1.01 ± 0.11	9.997 ± 1.089	21.20/25
cross + auto $0.6 < z < 0.66$	0.63	$0.988^{+0.080}_{-0.16}$	$9.779^{+0.792}_{-1.584}$	30.66/50
cross 4 zbins combined	0.72	$0.968^{+0.060}_{-0.095}$	$10.122^{+0.627}_{-0.993}$	99.72/103

contrain the bias of LoTSS radio sources

We measure:

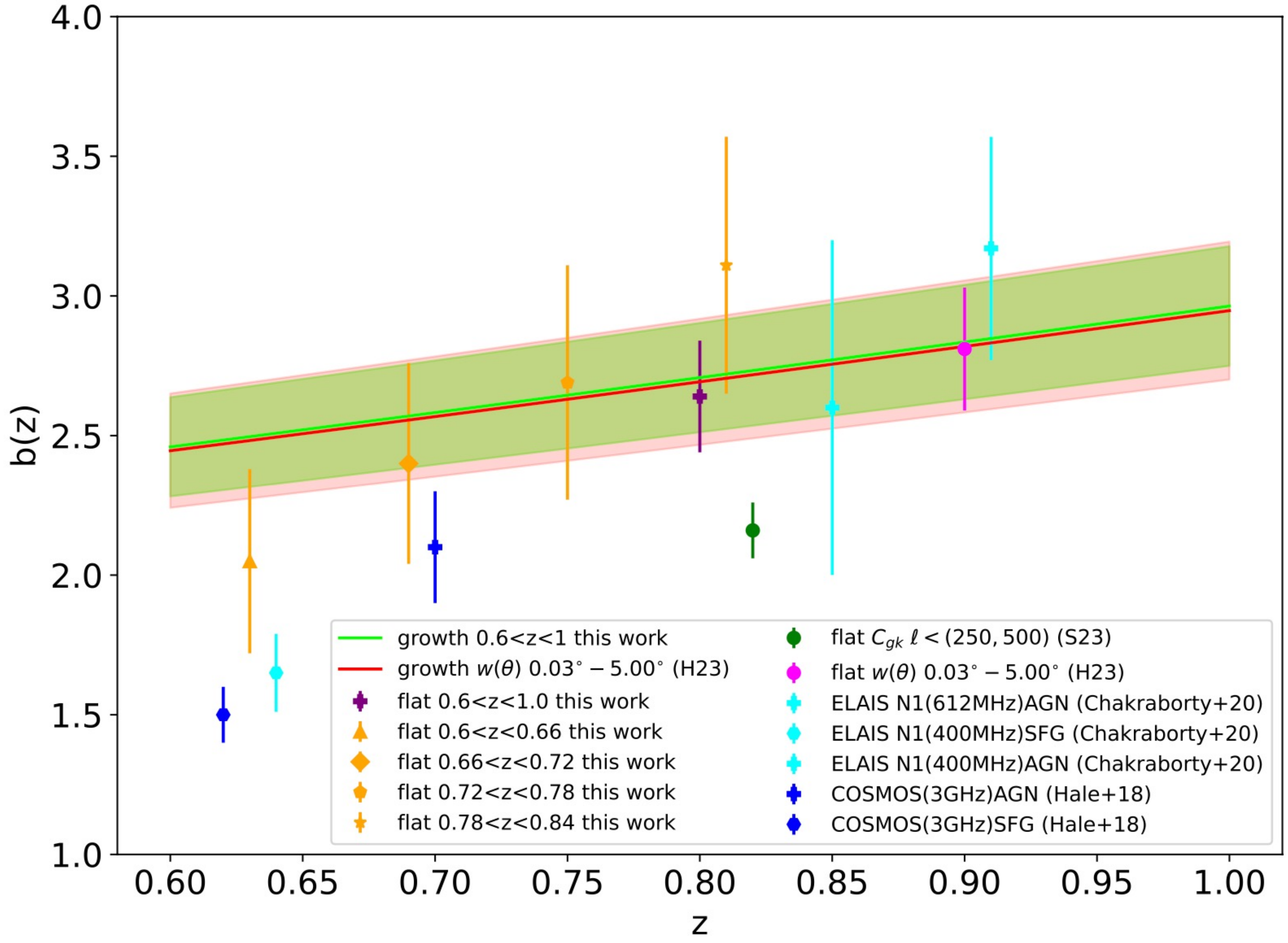
- a flat bias

b = 2.64 ± 0.20

- an evolving bias

b_D = 1.80 ± 0.13/D(z).

- Additionally, we calculate biases for four individual redshift bins.



Summary

- We cross-correlate the LOw-Frequency ARray (LOFAR) Two-metre Sky Survey (LoTSS) second data release (DR2) catalogue with the extended Baryon Oscillation Spectroscopic Survey (eBOSS) luminous red galaxies(LRGs) sample to extract the Baryon Acoustic Oscillation (BAO) signal and constrain the bias of radio sources in LoTSS DR2.
- In the LoTSS catalogue, employing a flux limit of 1.5mJy and a signal-to-noise ratio (SNR) of 7.5, and considering a redshift interval of $\Delta z = 0.06$ in the eBOSS LRG catalogue, we measure both the cross angular power spectrum $C_{l,x}$ and the eBOSS auto- power spectrum $C_{l,e}$. These measurements are performed across various eBOSS redshift slices. By marginalising over the broadband information of the Cl's, we detect a mild BAO signal, and determine the bias of radio sources.
- We derive the isotropic BAO dilation parameter 1.01 ± 0.11 at $0.6 < z < 0.66$($z_{eff} = 0.631$). By combining four redshift bins
- $0.6 < z < 0.66$($z_{eff} = 0.631$), $0.66 < z < 0.72$($z_{eff} = 0.689$), $0.72 < z < 0.78$($z_{eff} = 0.750$), and $0.78 < z < 0.84$($z_{eff} = 0.809$), we determine a more constrained value, $\alpha = 0.968 \pm 0.060$. For the entire redshift range $z_{eff} = 0.715$, we measure a flat bias $b = 2.64 + 0.20 -0.095$ and an evolving bias $b_D = 1.80 \pm 0.13$. Additionally, we calculate biases for individual redshift bins.

	α	68% CI	f_α
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO}$	1.0125	(0.976,1.2)	10.00%
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO} + a_{1,x}$	1.0041	(0.8,1.2)	7.06%
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO} + a_{1,x}/\ell$	1.0119	(0.964,1.2)	6.96%
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO} + a_{1,x} + a_{2,x}/\ell$	1.0065	(0.8,1.2)	5.70%
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO} + a_{1,x} + a_{2,x}/\ell + a_{3,x}/\ell^2$	1.0204	(0.8,1.2)	7.20%
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO} + a_{1,x} + a_{2,x}/\ell + a_{3,x}\ell$	1.0041	(0.9,1.12)	5.79%
$C_{\ell,x} = \frac{b_x}{\alpha^2} C_{\ell,BAO} + a_{1,x} + a_{2,x}/\ell^2 + a_{3,x}\ell$	1.0089	(0.8,1.2)	6.90%
$C_{\ell,e} = \frac{b_e}{\alpha^2} C_\ell + a_{1,e}$	1.0134	(0.982,1.2)	6.01%
$C_{\ell,e} = \frac{b_e}{\alpha^2} C_\ell + a_{1,e}/\ell$	1.0305	(0.967,1.2)	6.21%
$C_{\ell,e} = \frac{b_e}{\alpha^2} C_\ell + a_{1,e} + a_{2,e}/\ell$	1.0062	(0.96, 1.19)	5.11%
$C_{\ell,e} = \frac{b_e}{\alpha^2} C_\ell + a_{1,e} + a_{2,e}/\ell + a_{3,e}/\ell^2$	1.0019	(0.993,1.2)	6.25%
$C_{\ell,e} = \frac{b_e}{\alpha^2} C_\ell + a_{1,e} + a_{2,e}/\ell + a_{3,e}\ell$	1.0085	(0.92,1.13)	5.16%
$C_{\ell,e} = \frac{b_e}{\alpha^2} C_\ell + a_{1,e} + a_{2,e}/\ell^2 + a_{3,e}\ell$	1.0146	(0.952,1.2)	6.19%