LoTSS DR2 cross correlating with eBOSS

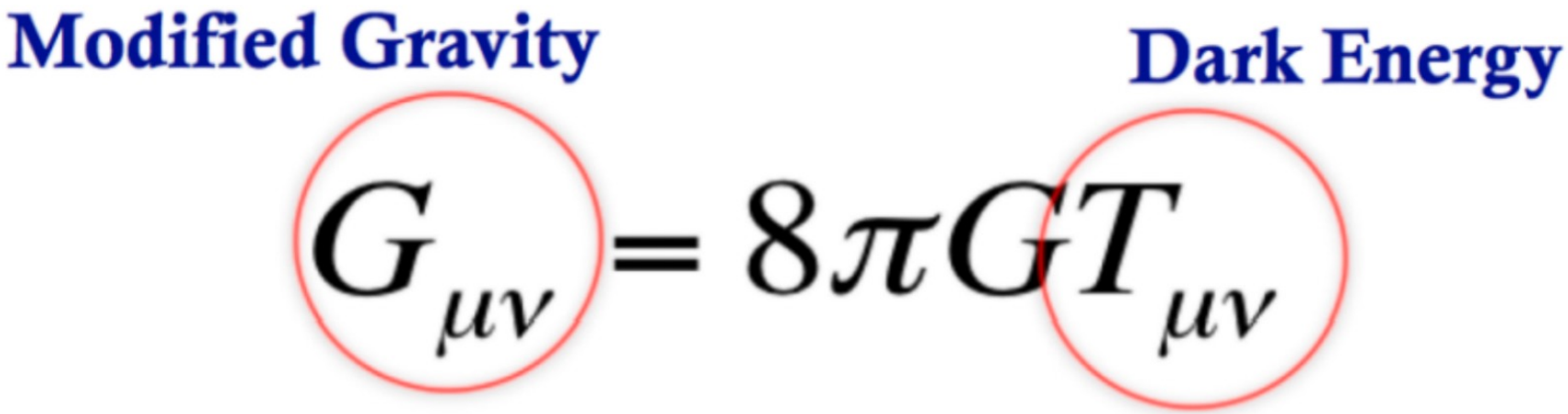
Jinglan Zheng
Postdoc at Universität Bielefeld
jzheng@physik.uni-bielefeld.de

LOFAR family meeting 2023

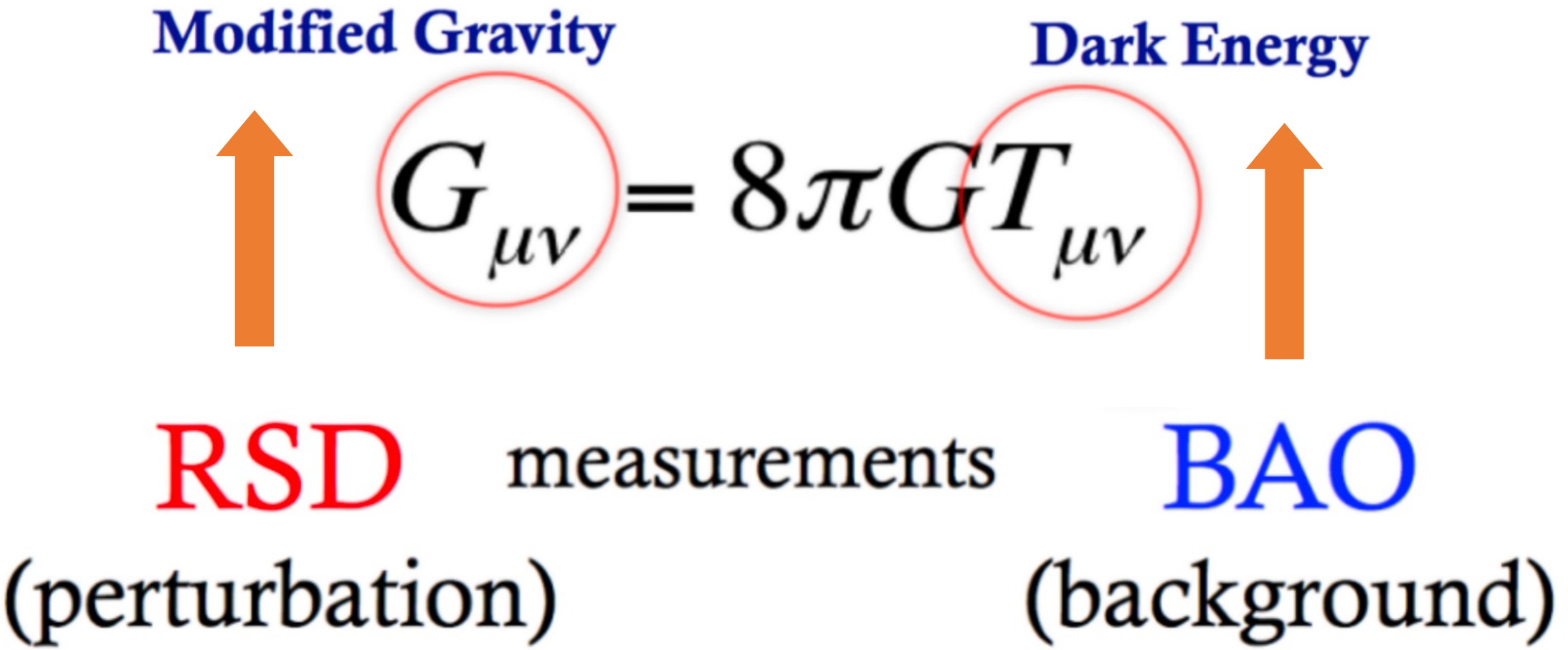
Outline

- The background of BAO
- why and how to calculate angular power spectrum
- the results of BAO and bias constraints

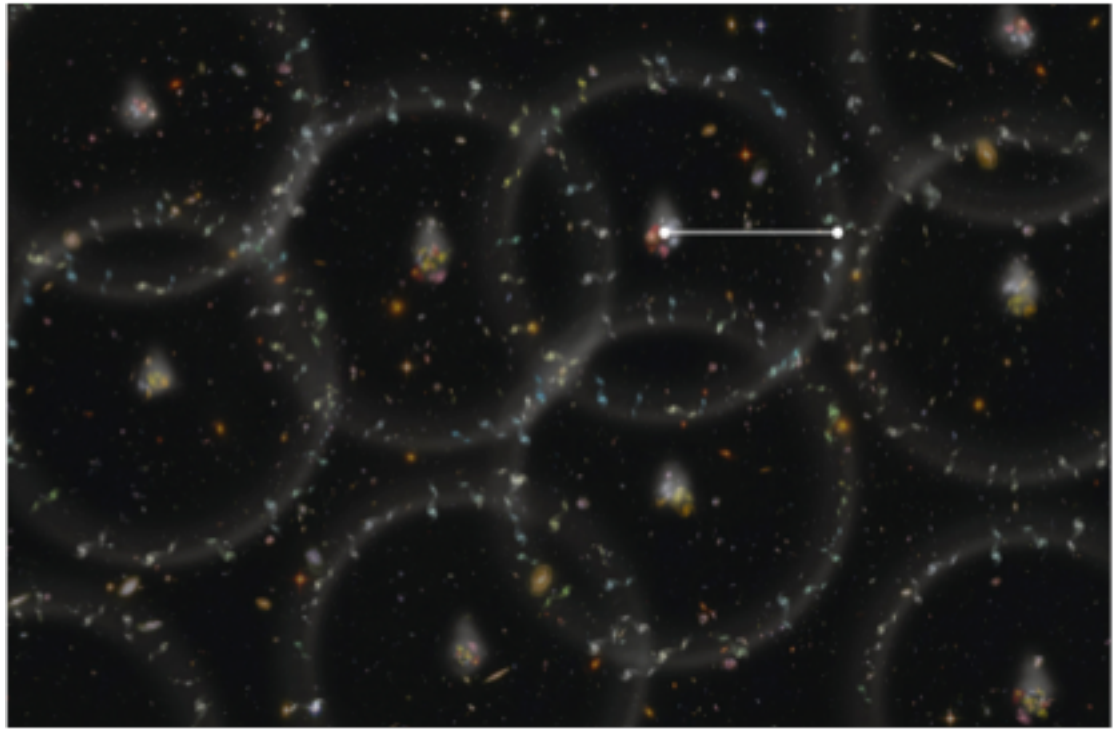
Cosmology: Theory



Cosmology: Theory

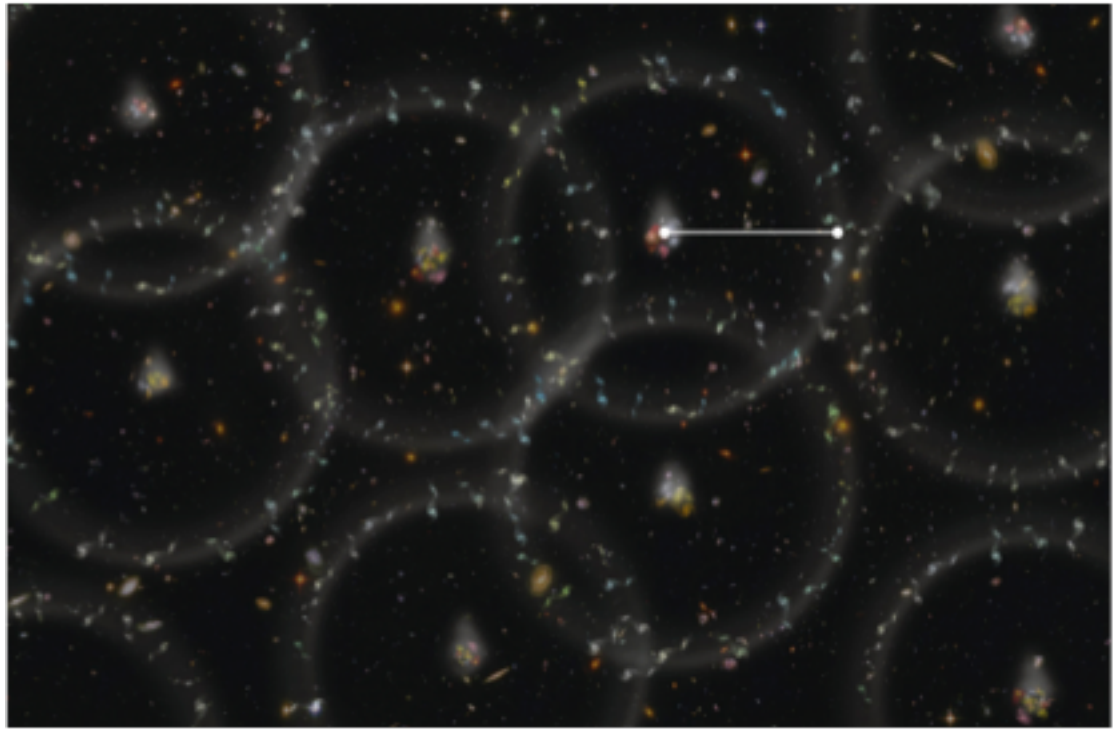


Baryon Acoustic Oscillation(BAO)

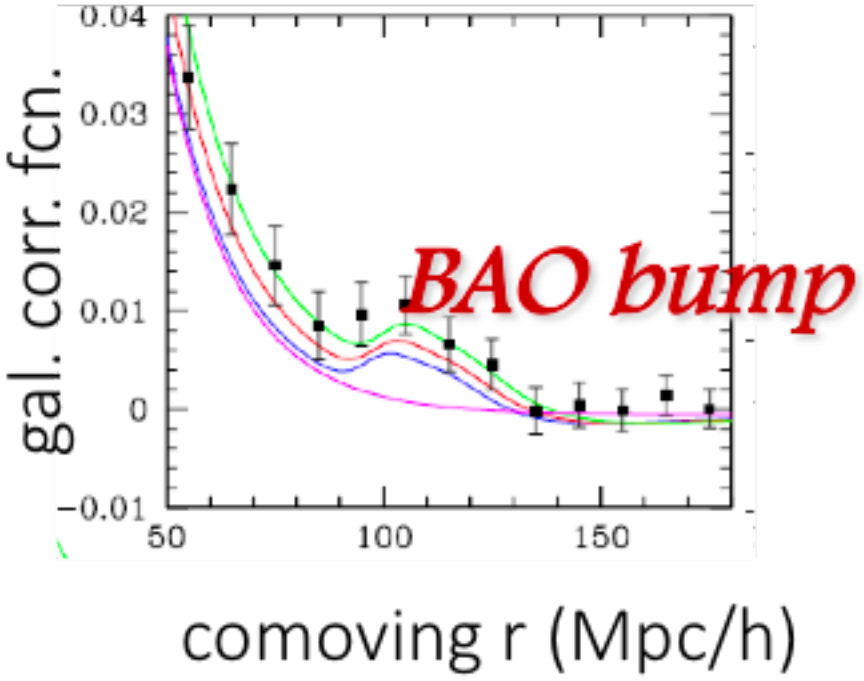


- Oscillations in photon-baryon fluid: pressure vs gravitational instability
- sound wave propagates until decoupling of matter and radiation
- maximum wavelength is horizon scale at decoupling
- “the standard ruler” of the universe

Baryon Acoustic Oscillation(BAO)

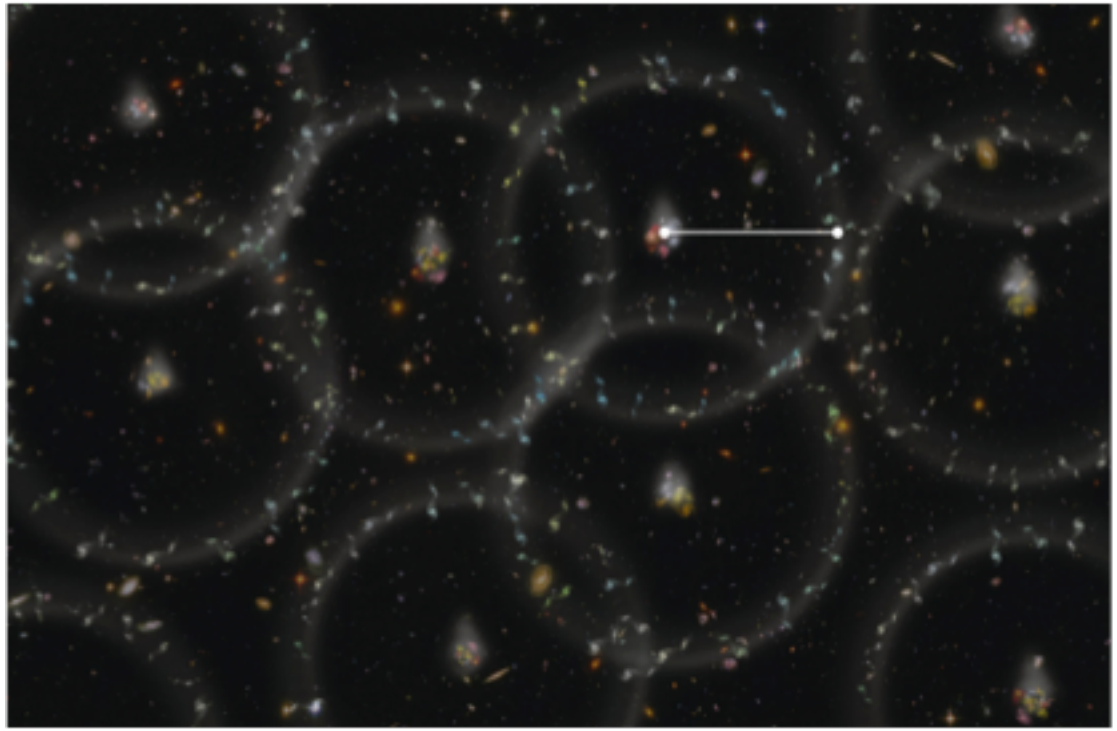


correlation function

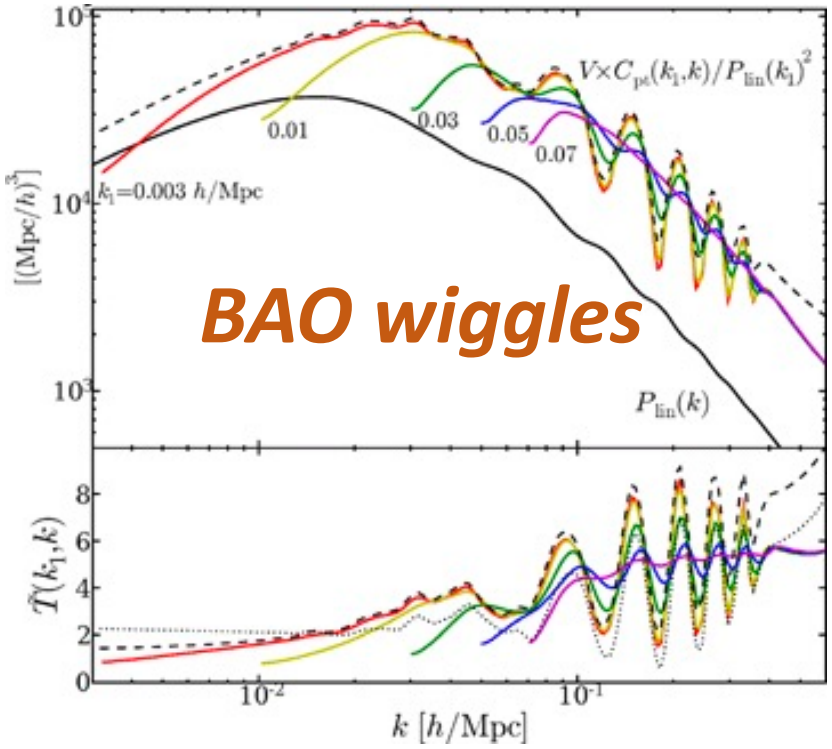


http://apod.nasa.gov/apod/ap140120.html

Baryon Acoustic Oscillation(BAO)



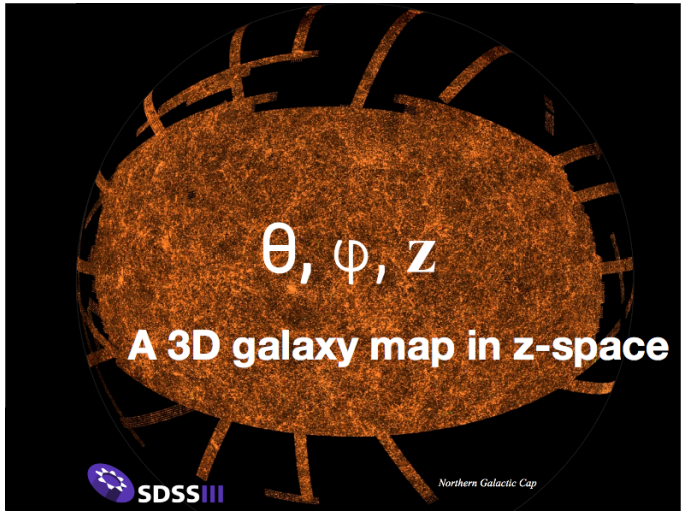
power spectrum



Neyrinck et al 2008

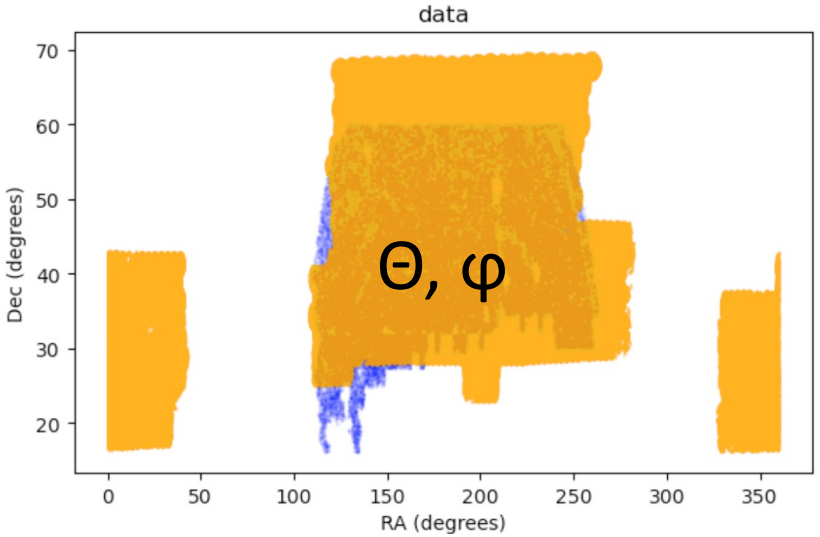
introduction

Optical survey:



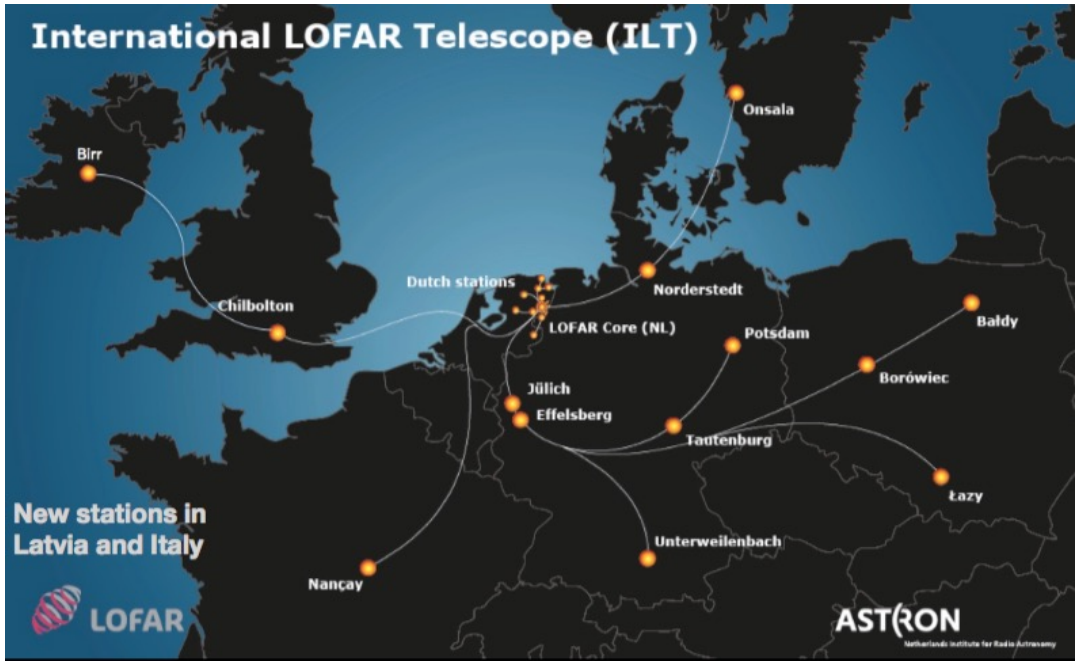
Credit: sdss.org

Radio continuum surveys:



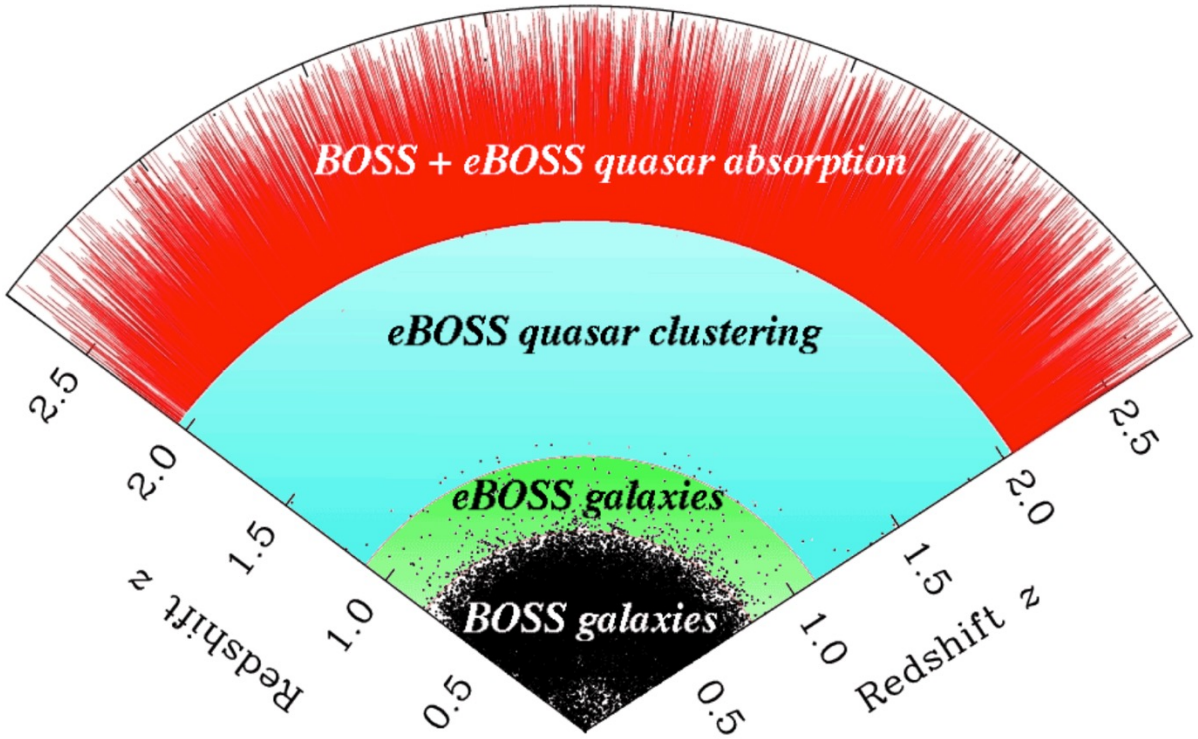
LoTSS(LOFAR Two-metre Sky Survey)

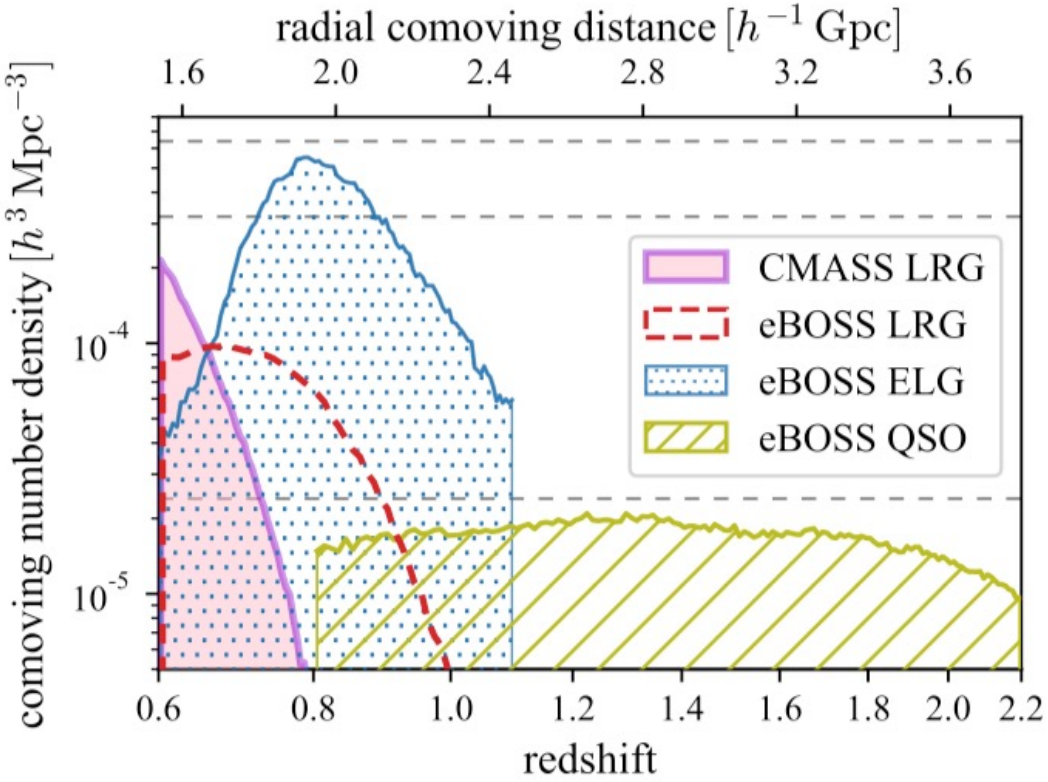
- Continuum map
- LoTSS will be the deepest radio continuum survey at low radio frequencies for the next decades
- will cover the complete Nothern sky, its high angular allows to identify multi-wavelength counterparts for which photometric redshifts are obtained
- WEAVE-LOFAR will obtain a million of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



Credit: www.astron.nl

eBOSS: luminous red galaxies

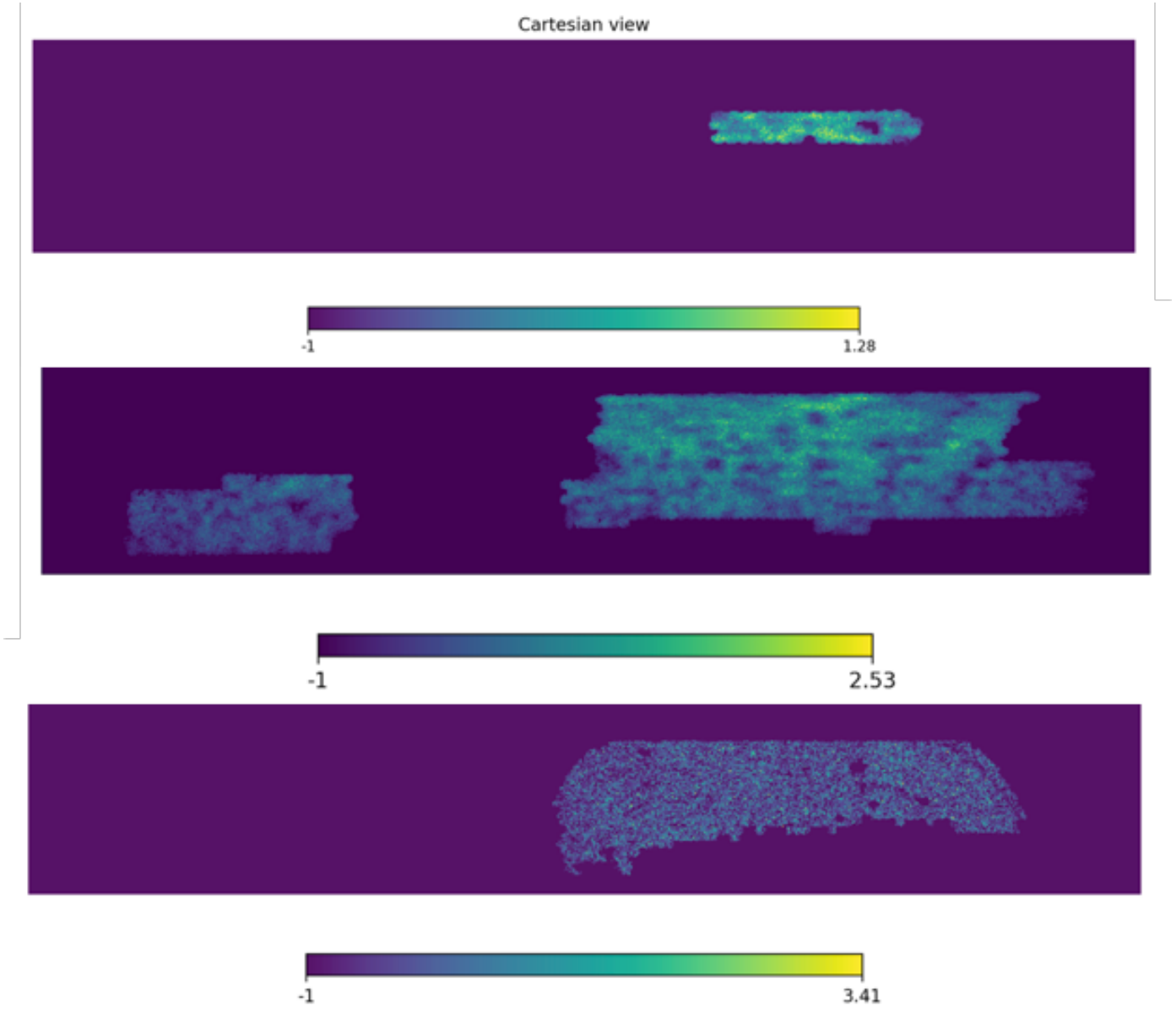




LoTSS DR1

LoTSS DR2

eBOSS LRG



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

the trimming of the catalogue:

- 1.5 mjy flux cut and 7.5 SNR for LoTSS
- binning using redshift, $\triangle z = 0.06$ for eBOSS

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

the first redshift bin 0.6<z<0.66

Formulas of angular power spectrum

theory

$$\Delta(\hat{\boldsymbol{r}}) = \int_0^\infty \delta_g(\boldsymbol{r}, z(r)) p(r) dr$$
$$= \int_0^\infty \delta_m(\boldsymbol{r}, z=0) D(z) b(z) p(r) dr$$

marginalize bias to get BAO

$$C_{\mathrm{obs},z_i}(\ell) = B_{z_i}(\ell) C_{\mathrm{m},z_i}(\ell/\alpha) + A_{z_i}(\ell)$$

$$B \to B/\alpha^2$$

measurement

$$C_l^{\mathrm{obs}} = \frac{\langle |a'_{lm}|^2 \rangle}{J_{lm}} - \frac{1}{\bar{\mathcal{N}}}$$

Formulas of angular power spectrum

theory

$$\Delta(\hat{\boldsymbol{r}}) = \int_0^\infty \delta_g(\boldsymbol{r}, z(r)) p(r) dr$$
$$= \int_0^\infty \delta_m(\boldsymbol{r}, z=0) D(z) b(z) p(r) dr$$

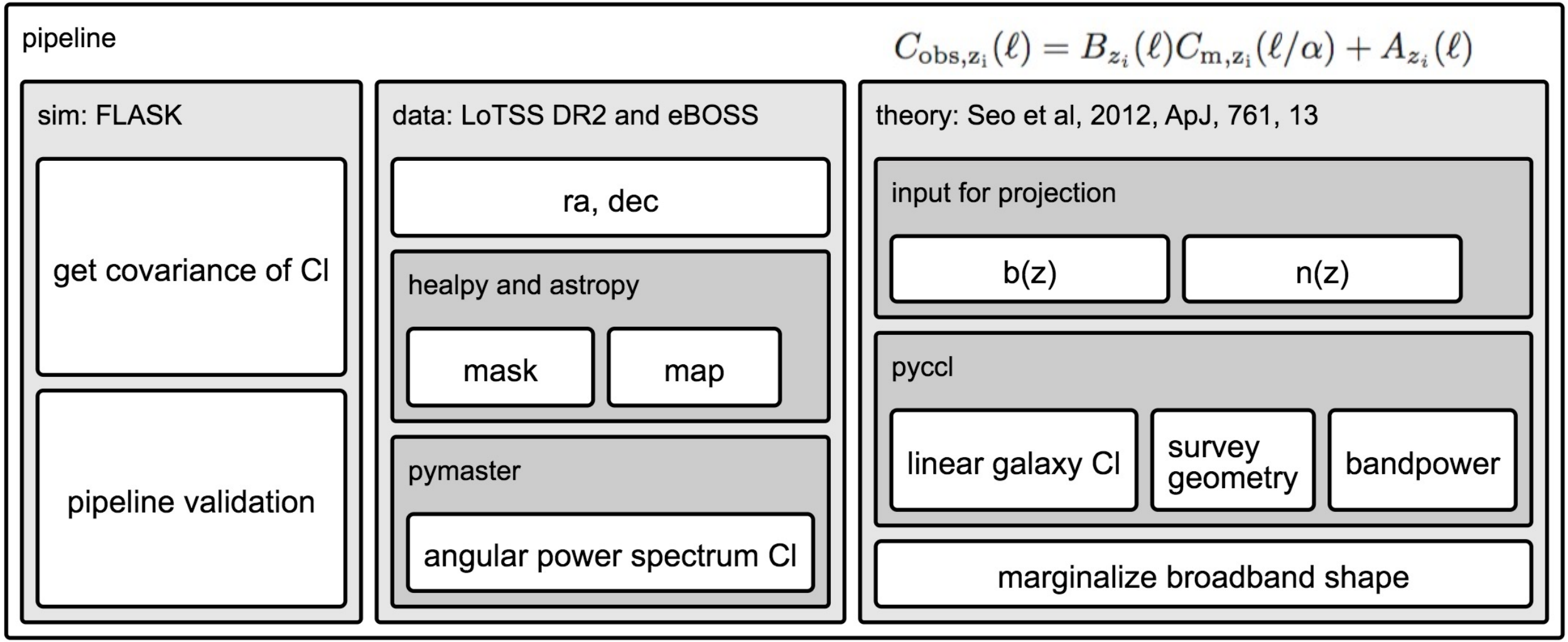
$$C_\ell = < |a_{\ell m}|^2 >$$
$$= \frac{2}{\pi} \int dk k^2 P(k) \left| \int_0^\infty dr D(z) b(z) p(r) j_\ell(kr) \right|^2$$
$$= \frac{2}{\pi} \int dk k^2 P(k) W^2(k) \,,$$

fix BAO to get bias

measurement

$$C_l^{\rm obs} = \frac{\langle |a'_{lm}|^2 \rangle}{J_{lm}} - \frac{1}{\bar{\mathcal{N}}}$$

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

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

- eBOSS

b(z): 1.7/D(z) or from EZmock

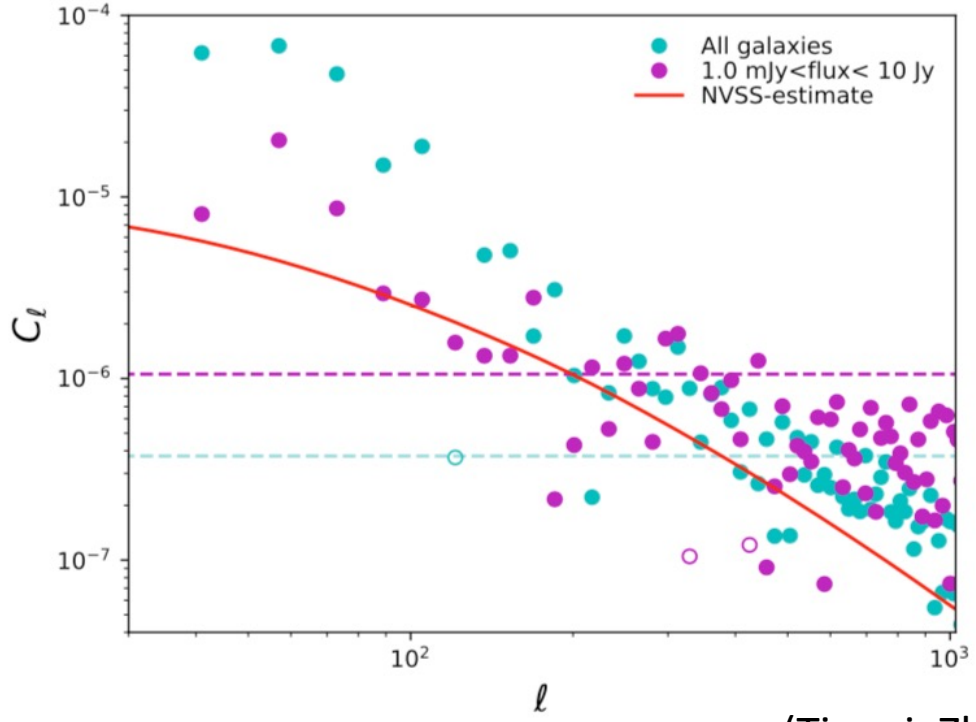
n(z): directly from catalogue

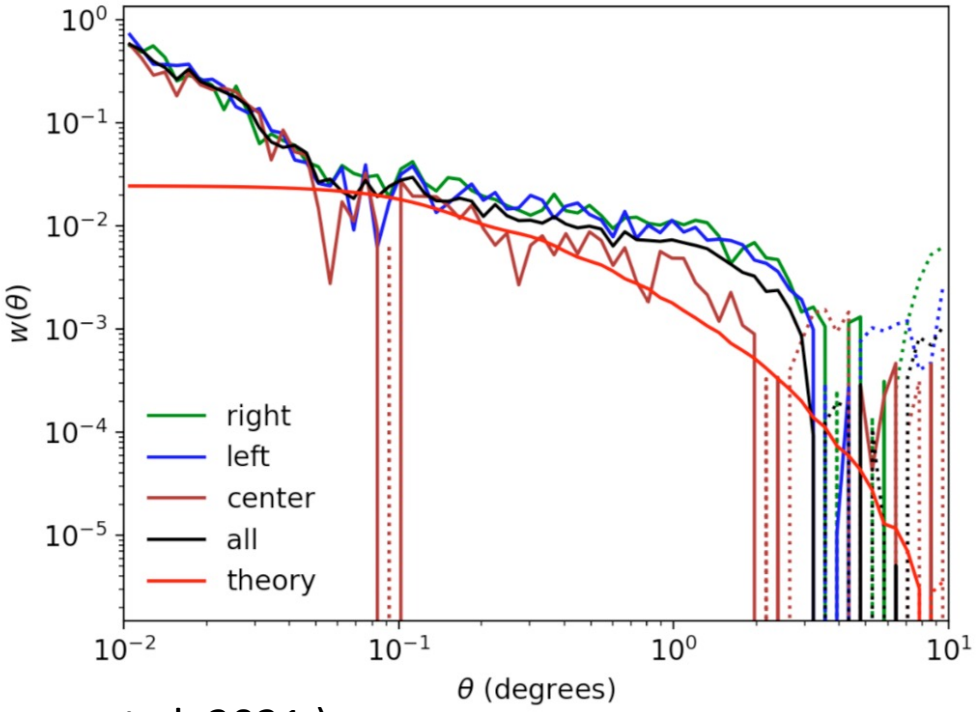
- LoTSS

b(z): DR1 best fit

n(z): T-RECS or Deep-Fields

b(z) of LoTSS: LoTSS DR1



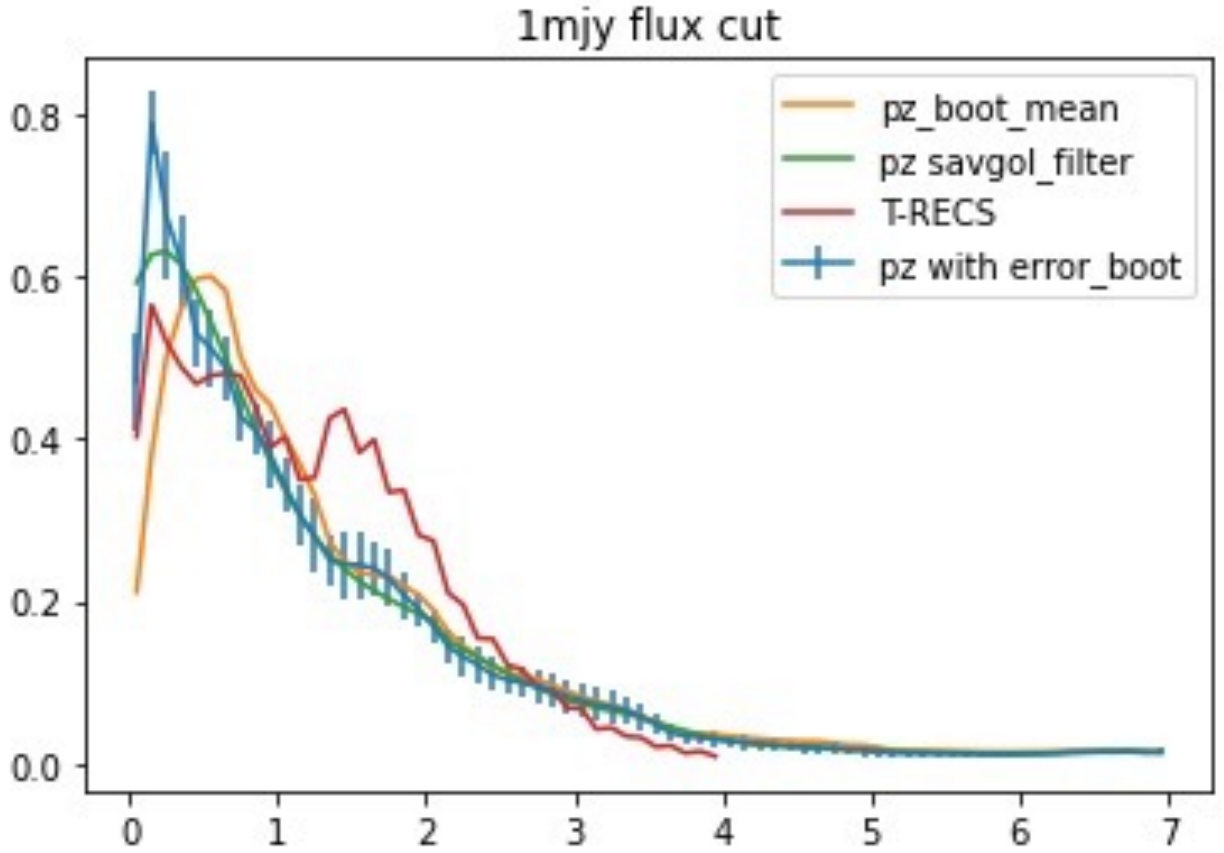


(Tiwari, Zhao, Zheng et al. 2021)

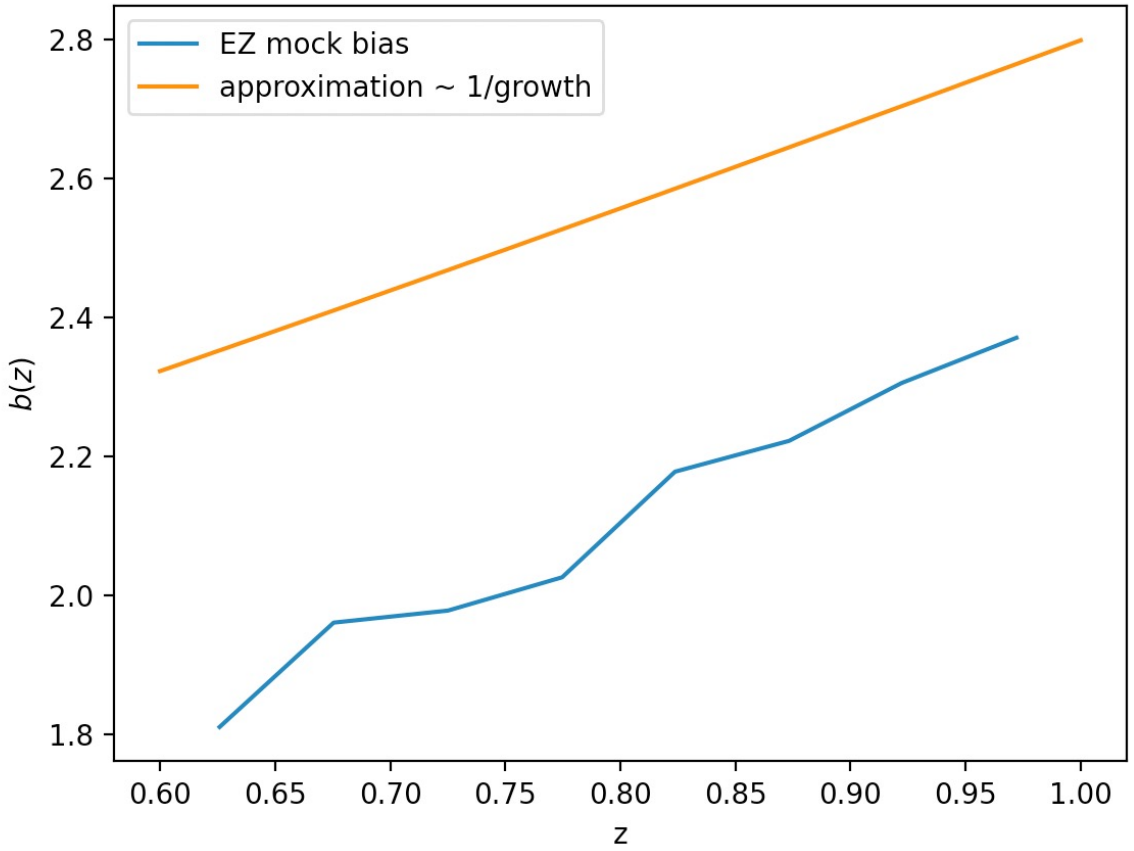
Get best fit bias

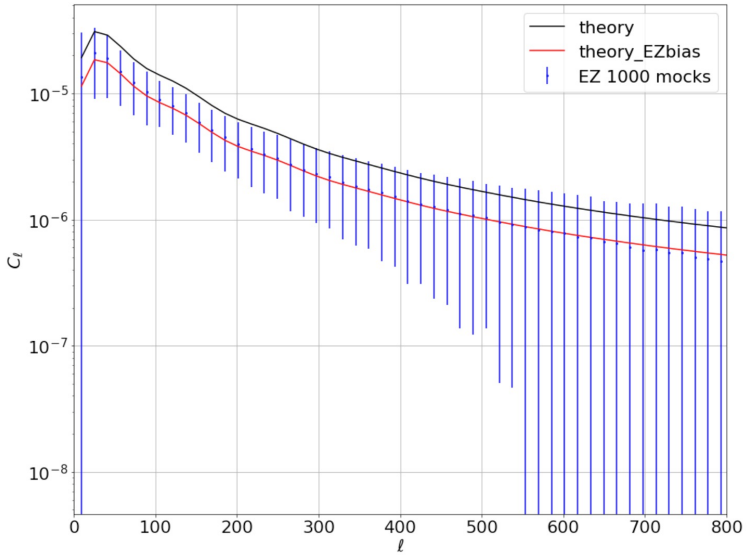
$$b(z) = 0.36z^2 + 1.23z + 2.21$$

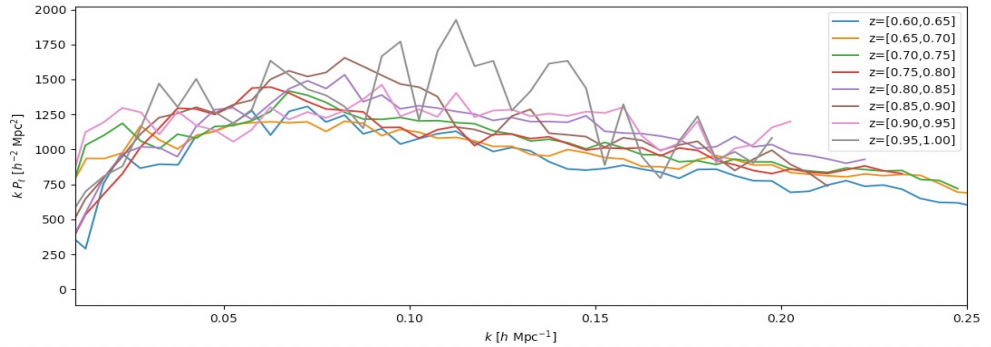
n(z) of LoTSS: from deep Fields DR1 or from simulation(T-RECS, Bonaldi et al.)



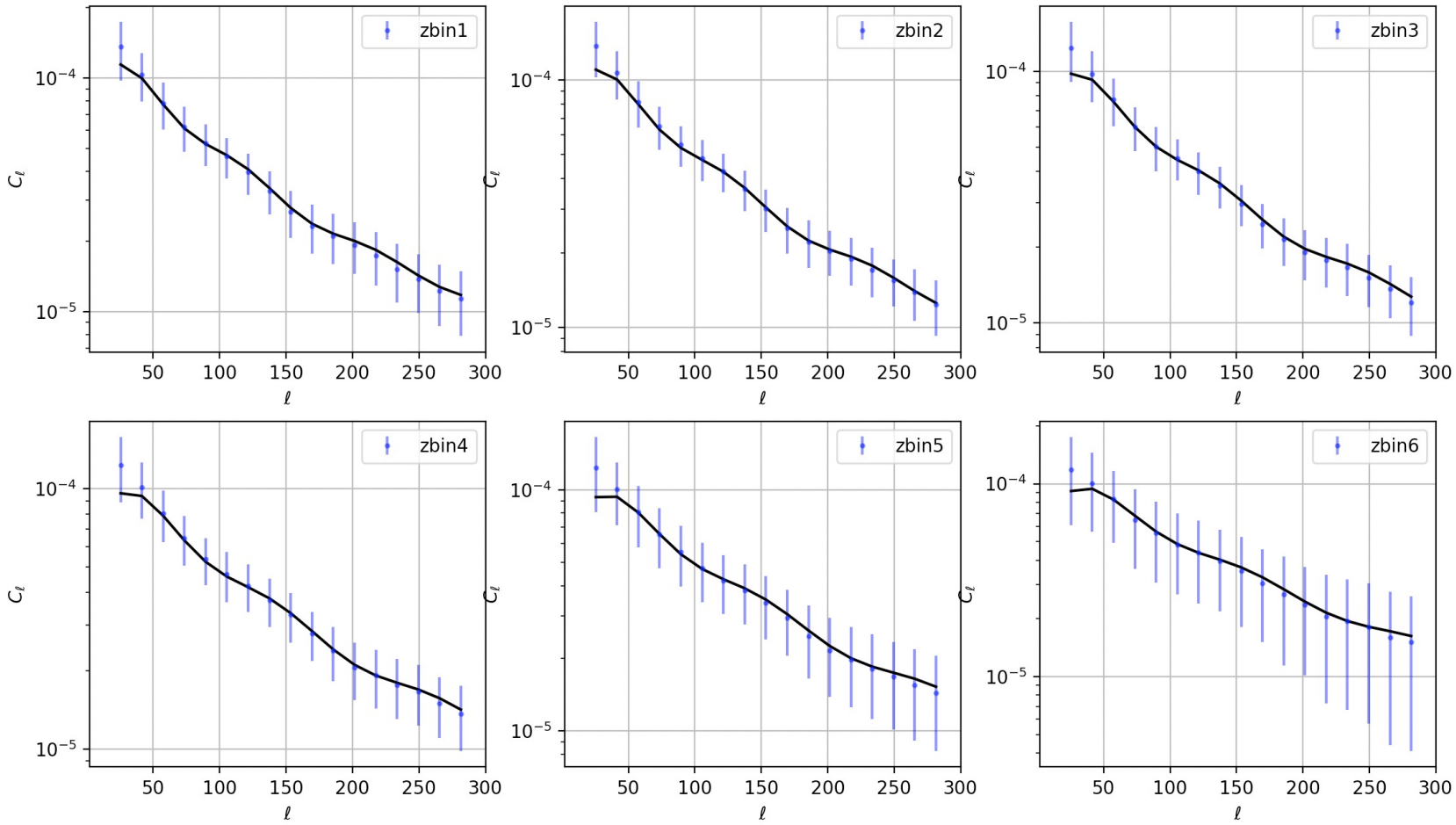
b(z) of eBOSS: from EZmock



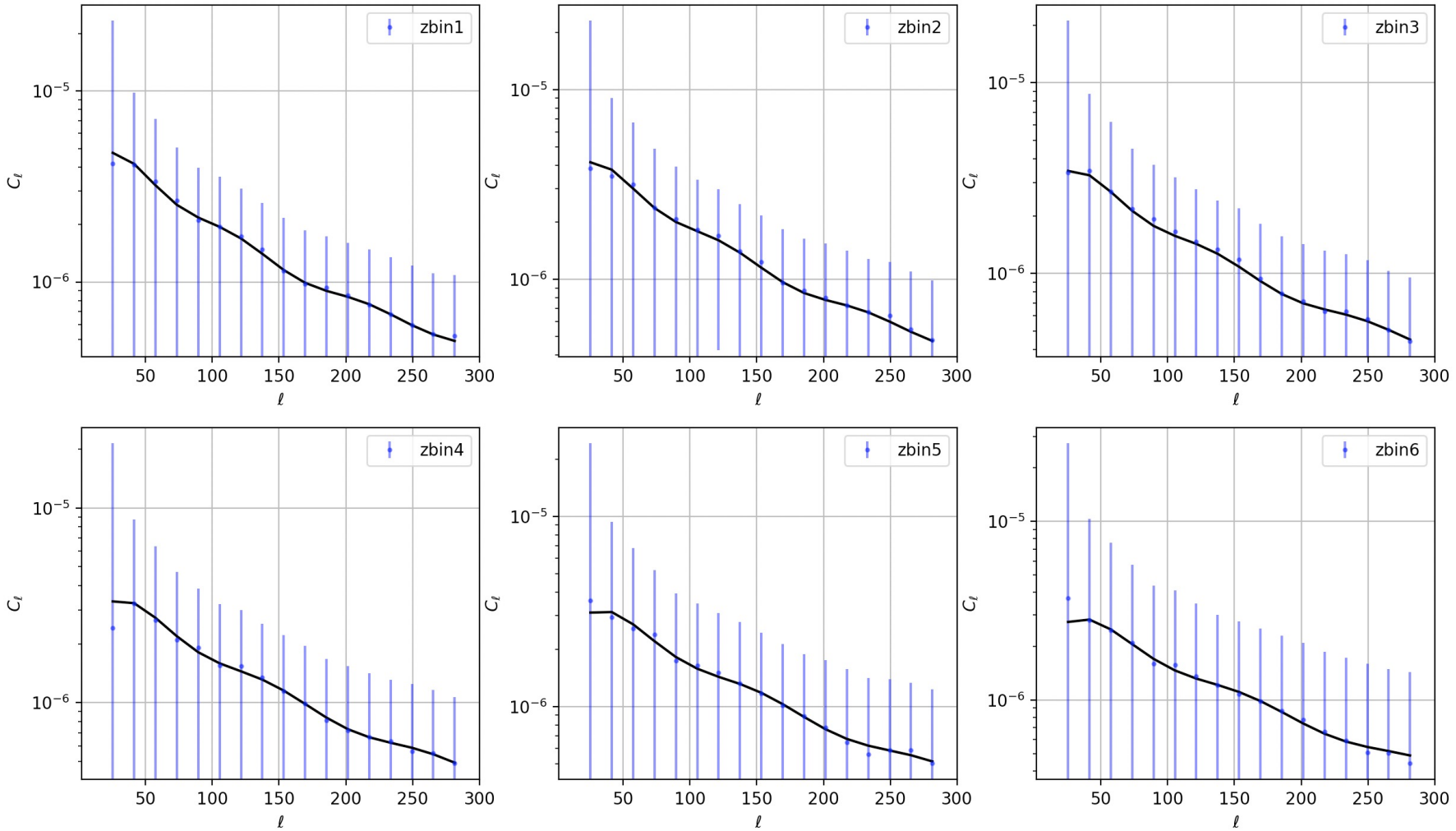




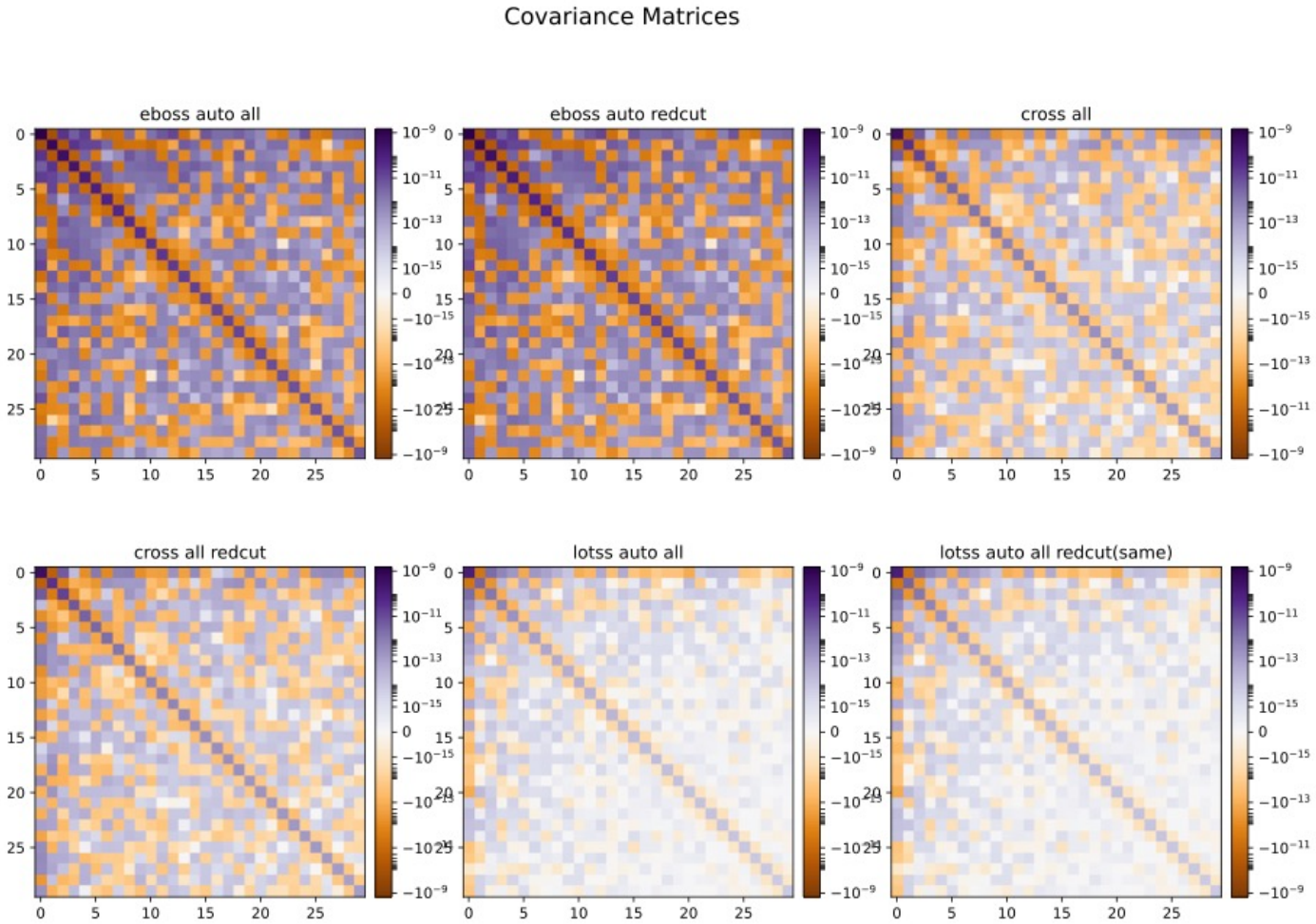
2, Mock test: eboss auto z=0.6-1, △z=0.06



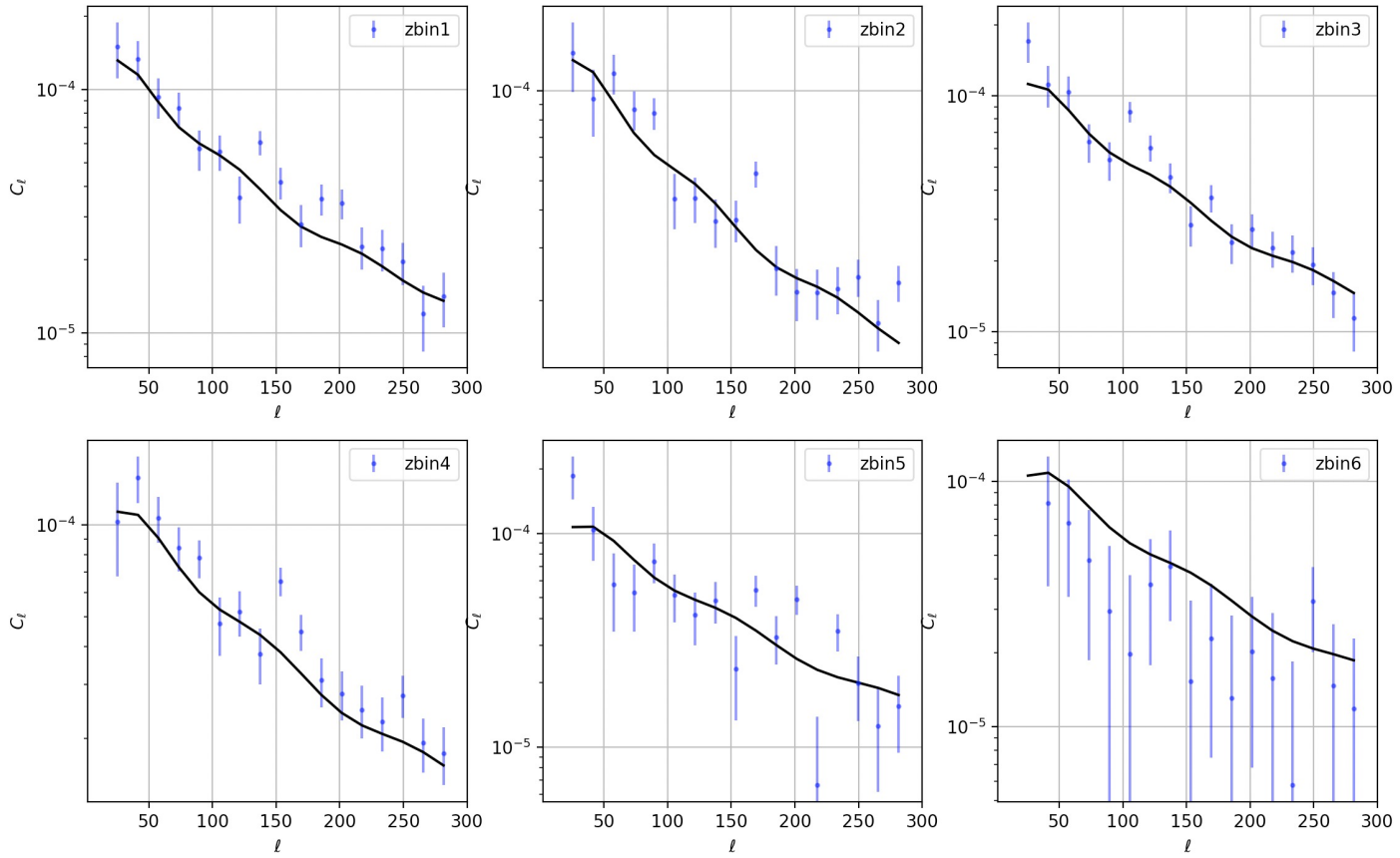
Mock test: cross (lotss x eboss)



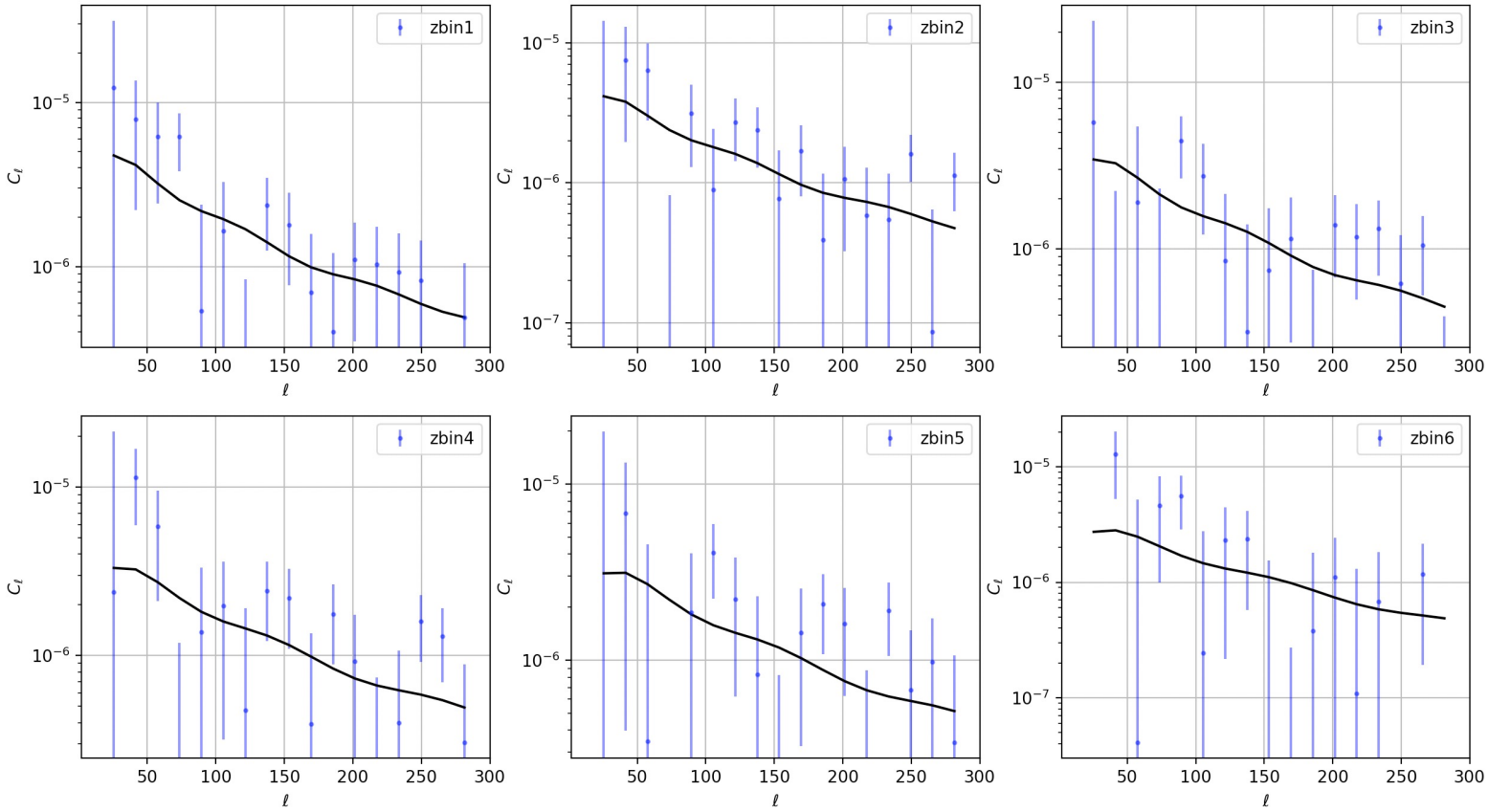
covariance mattrix



3, measurements: eboss auto

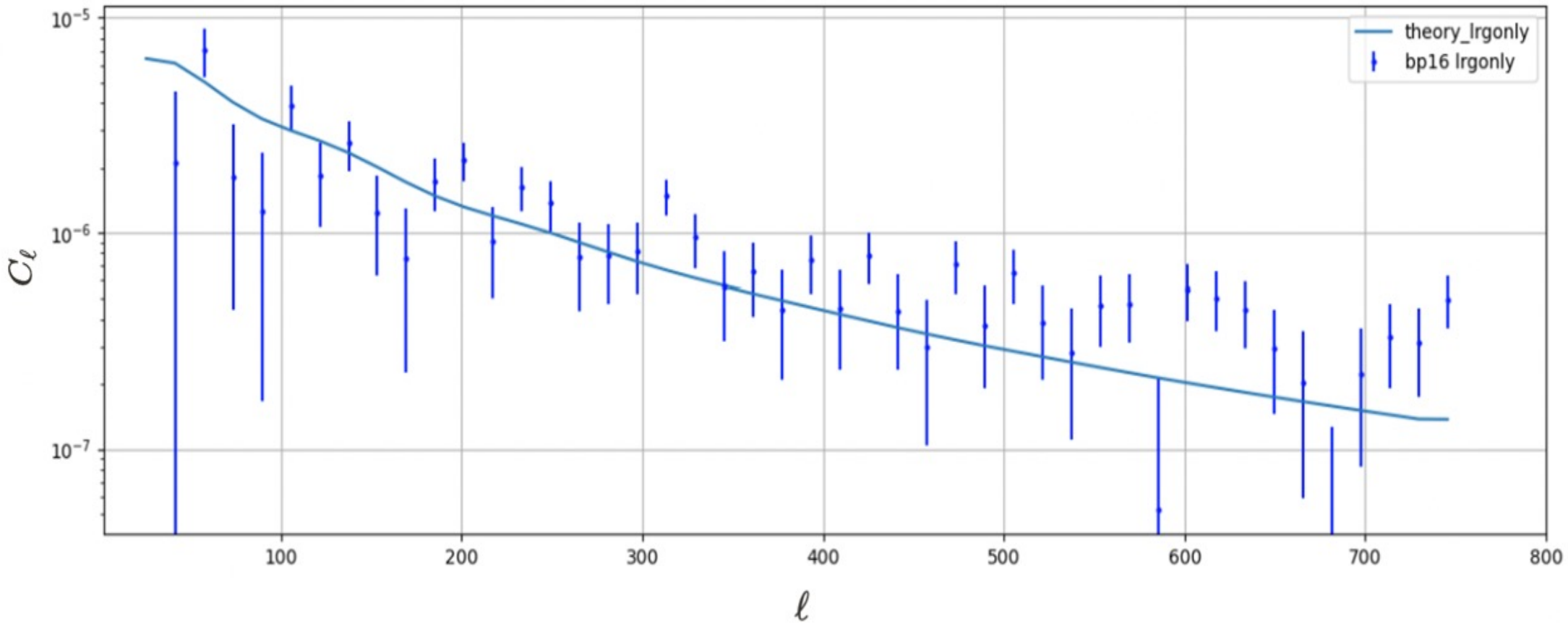


measurements: cross angular power spectrum in different redshift binnings



8.9sigma detection of one single redshift bin

Measurements vs theory: all redshift bins



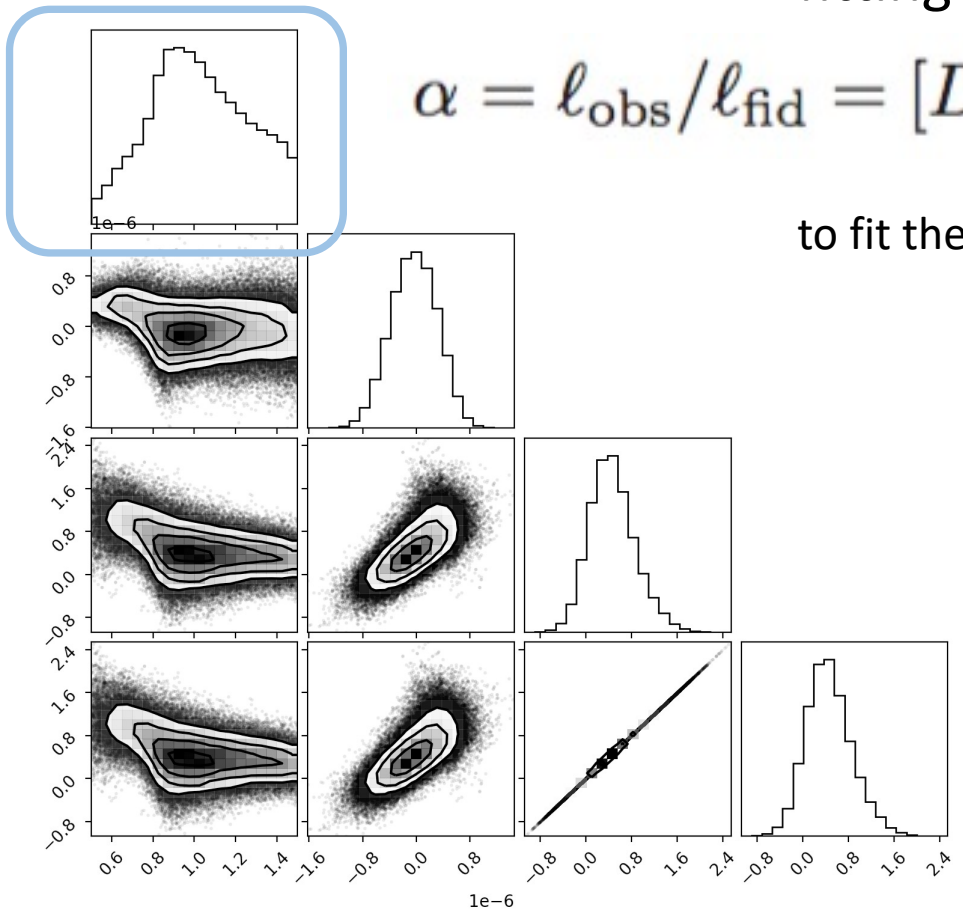
15.7sigma detection of cross correlation

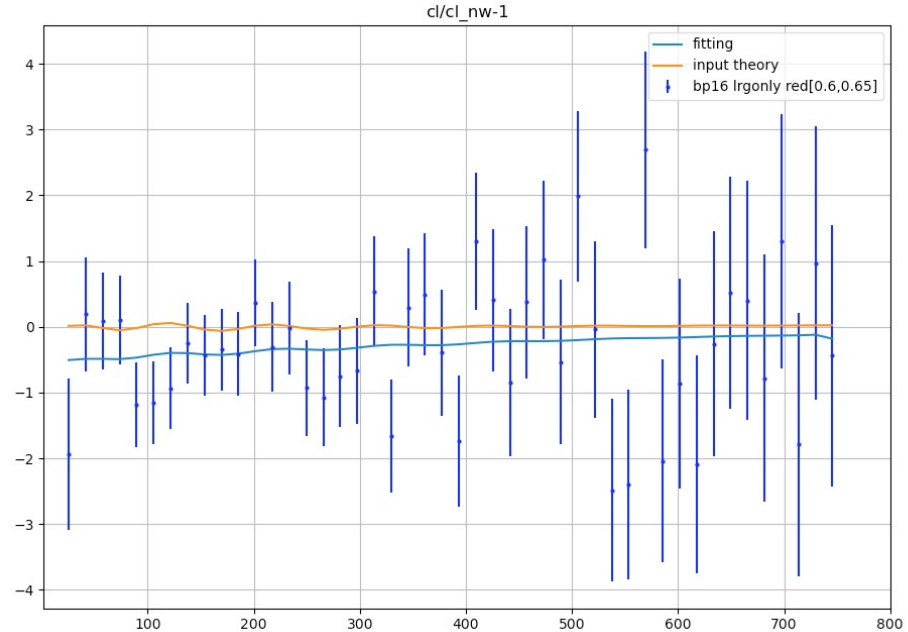
4, BAO fitting using one redshift bin

fitting alpha = 1.05±0.3

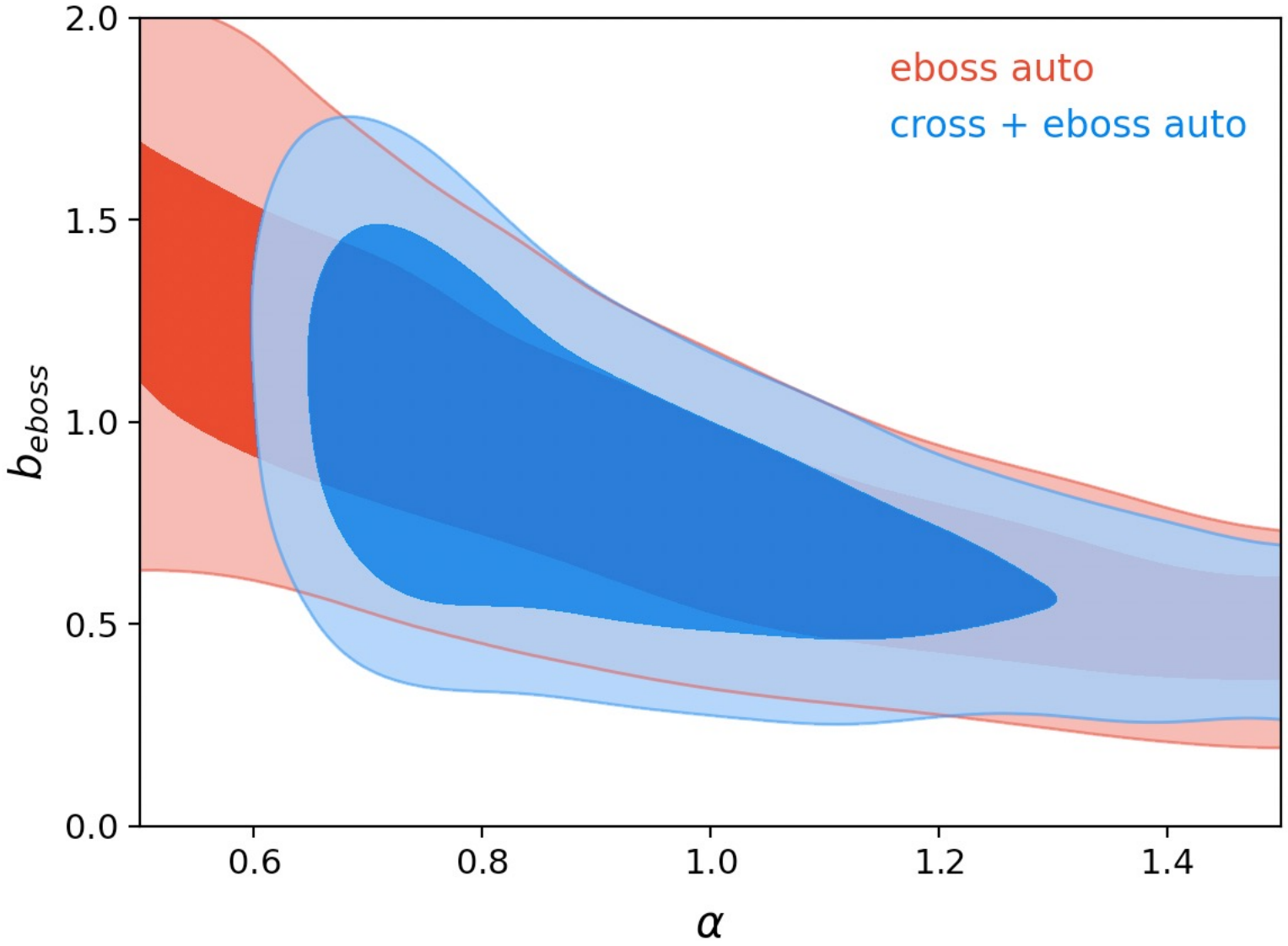
$$\alpha = \ell_{\rm obs}/\ell_{\rm fid} = [D_A(z)/r_s]_{\rm obs}/[D_A(z)/r_s]_{\rm fid}$$

to fit the shifting of the “wiggles” in the power spectrum

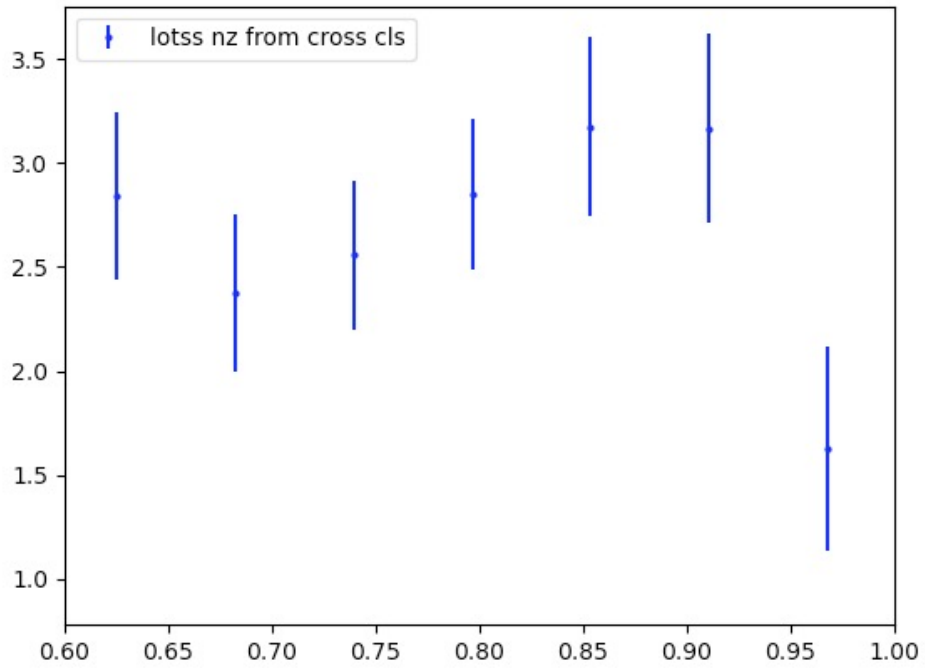




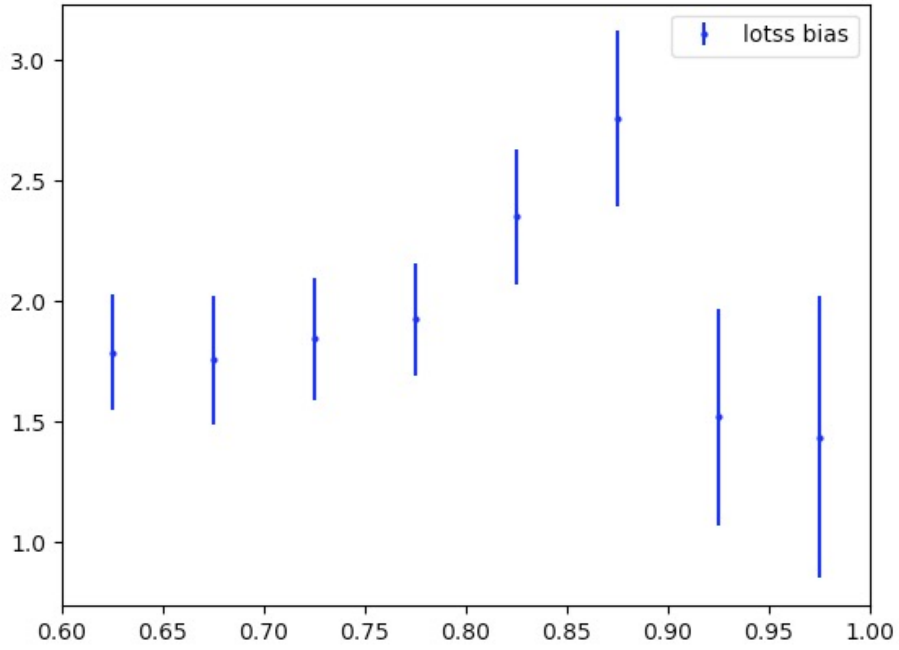
The improvements compared with eBOSS alone



5, redshift estimation(left) and bias(right) estimation for LoTSS

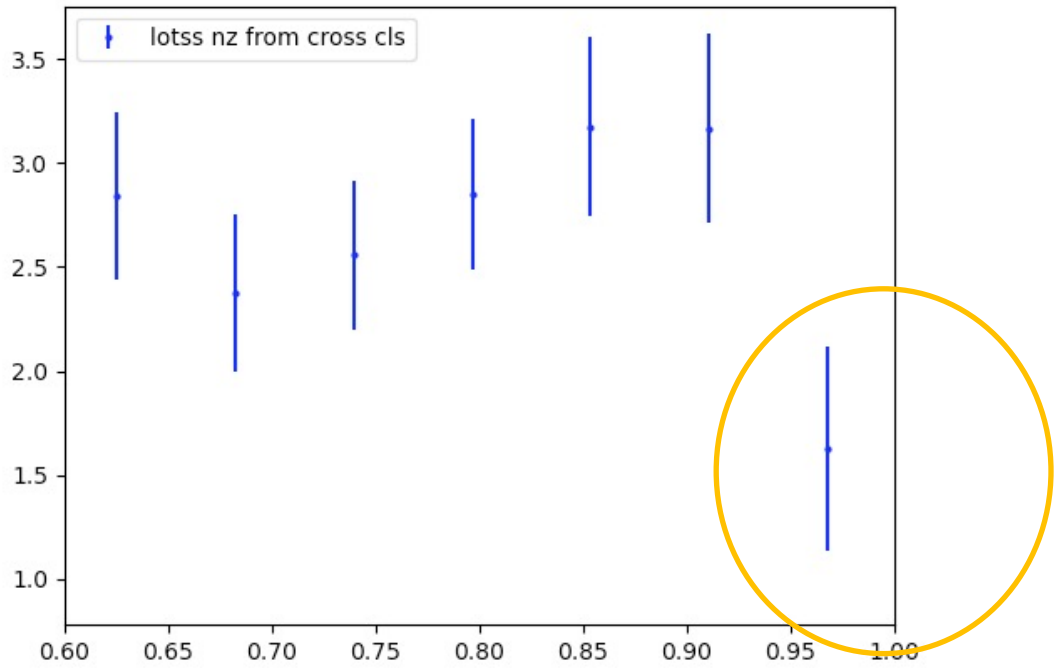


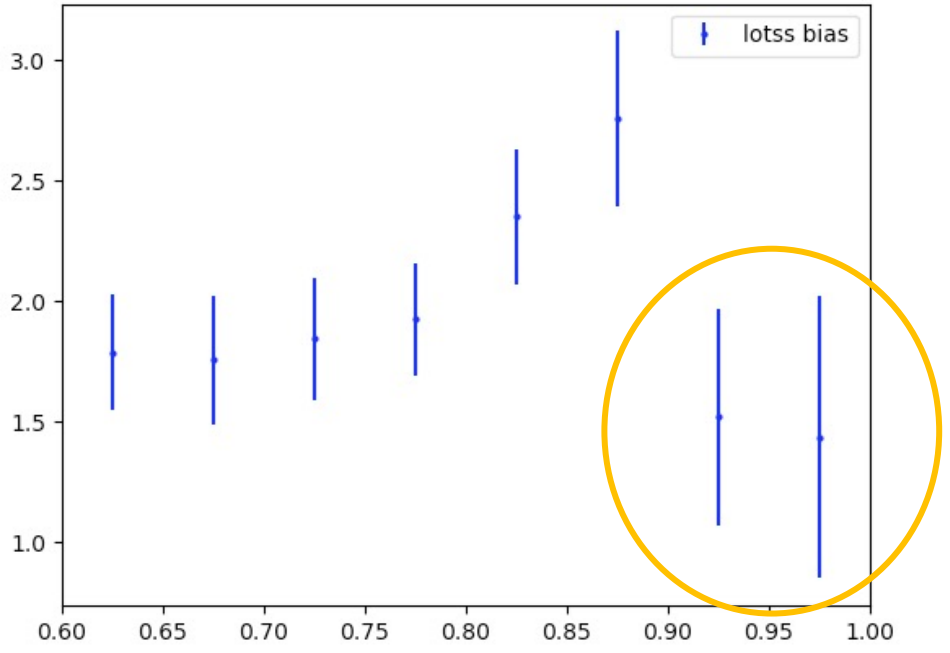
redshift



redshift

- Output: redshift estimation and bias estimation for LoTSS





Due to low galaxy number density at higher redshift

Conclusion and summary

- We use LoTSS DR2 and eBOSS LRGs, calculate auto and cross angular power spectrum, and obtain Baryon Acoustics Oscillaition constraints
- We obtain for the first time a slight BAO signal using cross-correlation alone and an achieve an improvement combining the auto correlation, proving that there is BAO signal in the LoTSS radio catalogue
- We are also able to constrain LoTSS DR2 bias and redshift distribution with cross-correlation

Future:

- WEAVE-LOFAR get spectra-z we will have 3D power spectrum of continuum radio sources!

Thank you!