BAO measurement from joint analysis of galaxies and cosmic voids

(Cheng Zhao, Chuang, et al. 2018)

&

Robust estimation of covariance matrix of galaxy clustering

(Falk Baumgarten & Chuang 2018)

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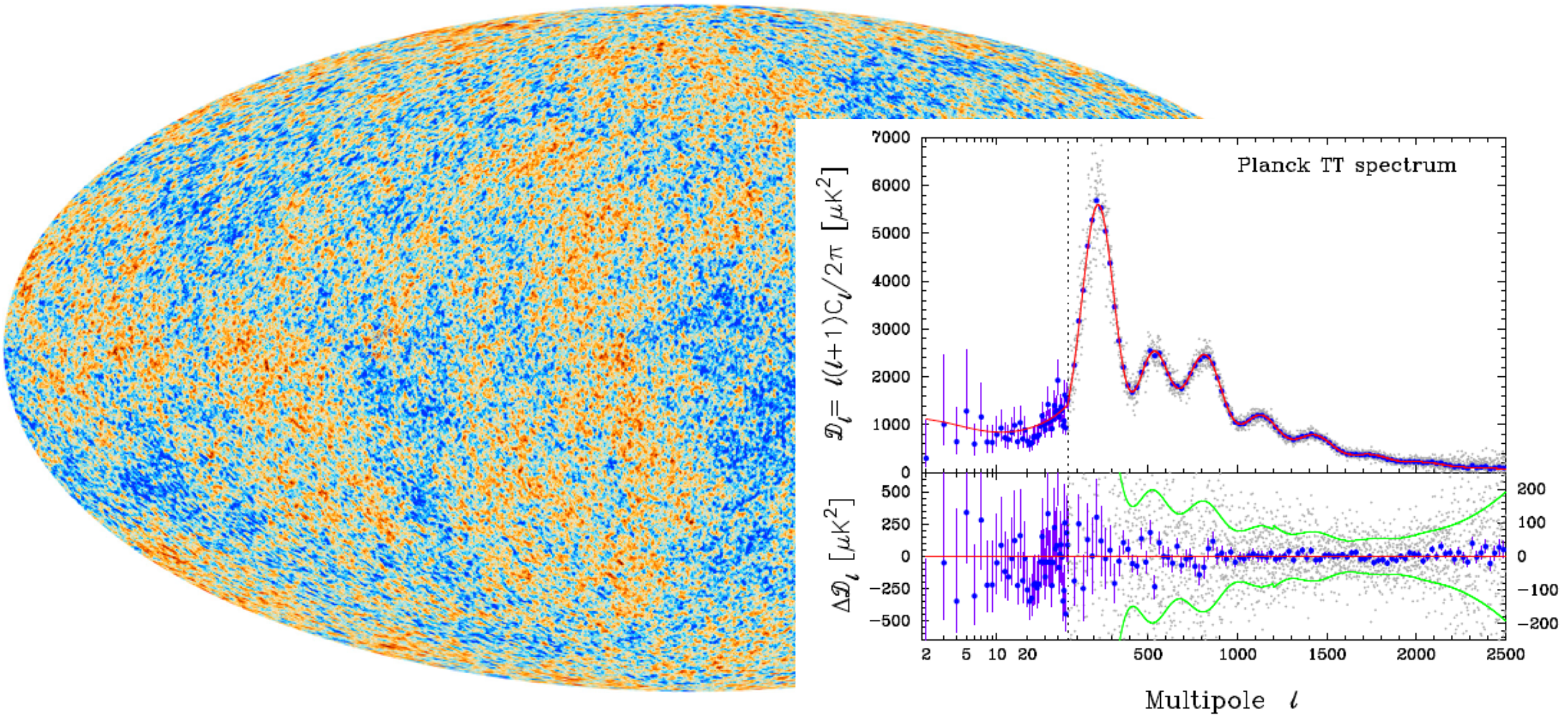
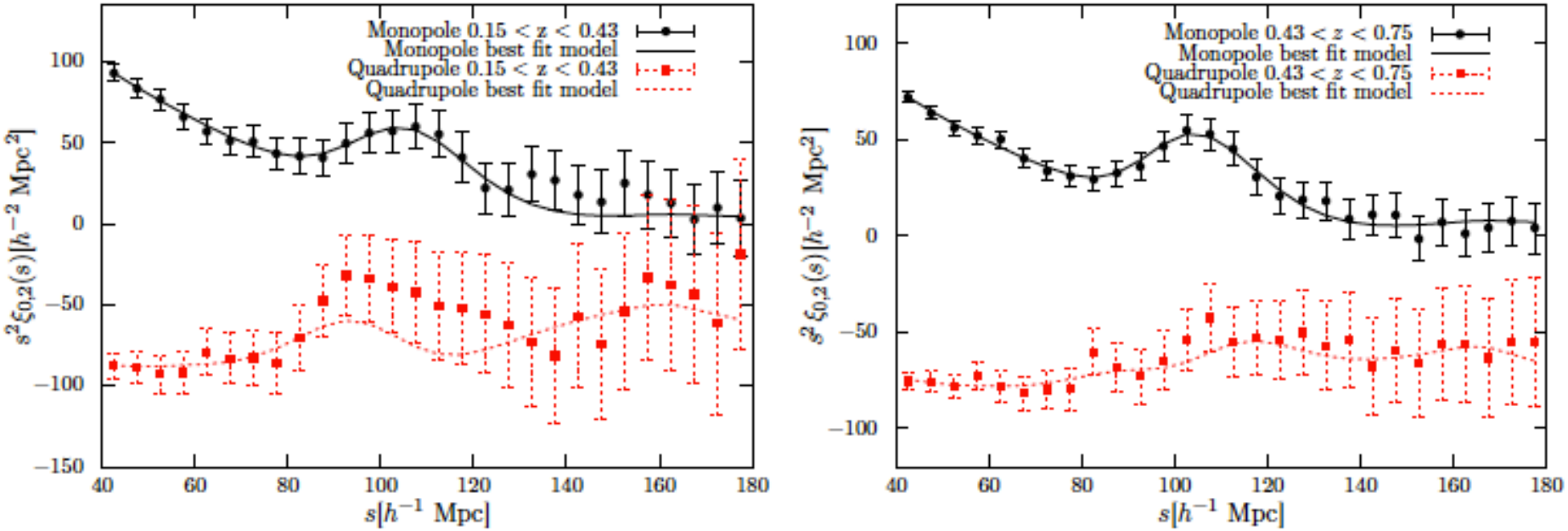
What is the optimal way to measure baryon acoustic oscillations (BAO)?

Baryon Acoustic Oscillations in the Density distribution measured from CMB

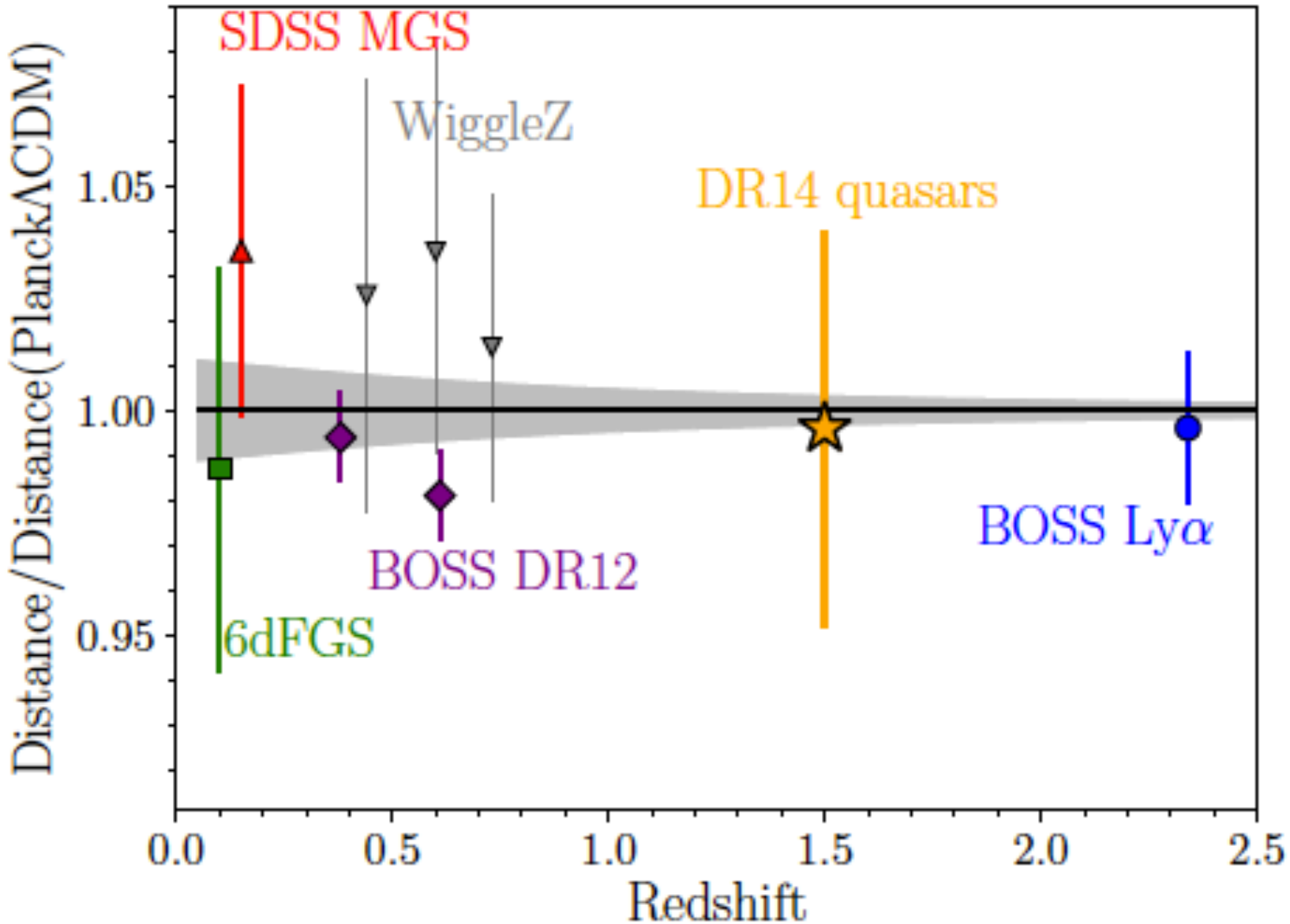


BAO in the Density distribution measured from galaxy sample

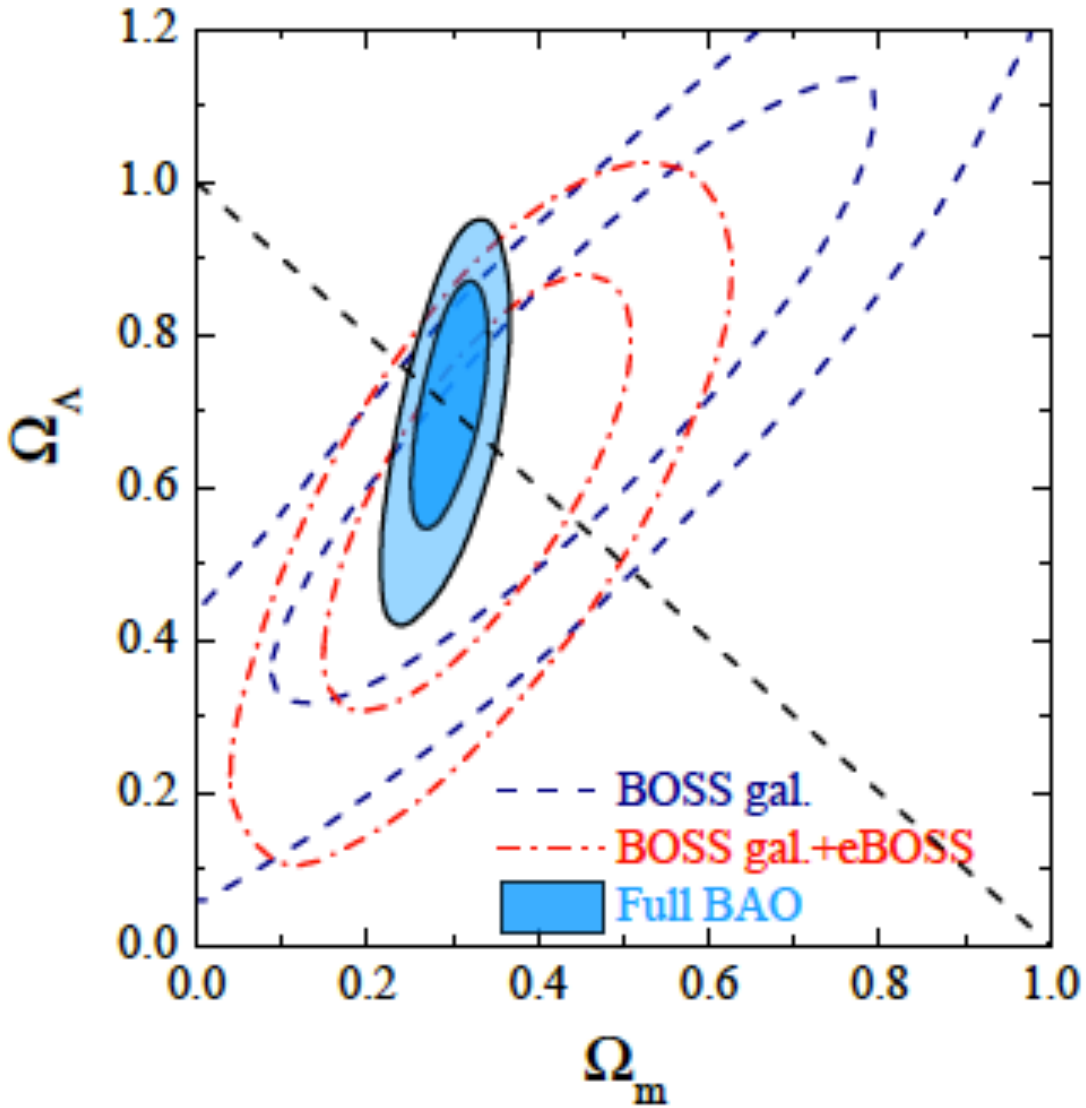
Chuang et al. 2016

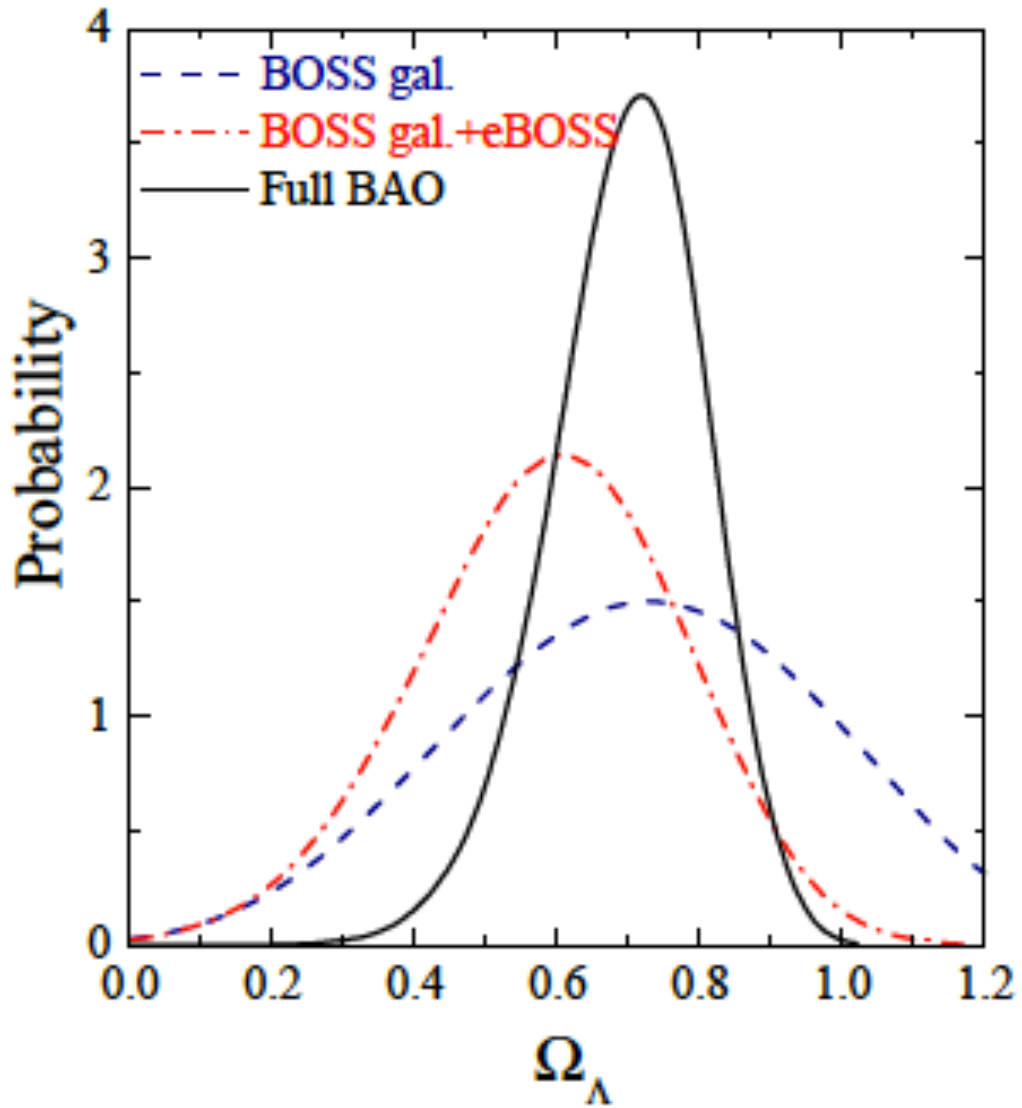


We can measure the evolution of dark energy by measuring the evolution of the density distribution.



eBOSS collaboration: Ata et al. 2017

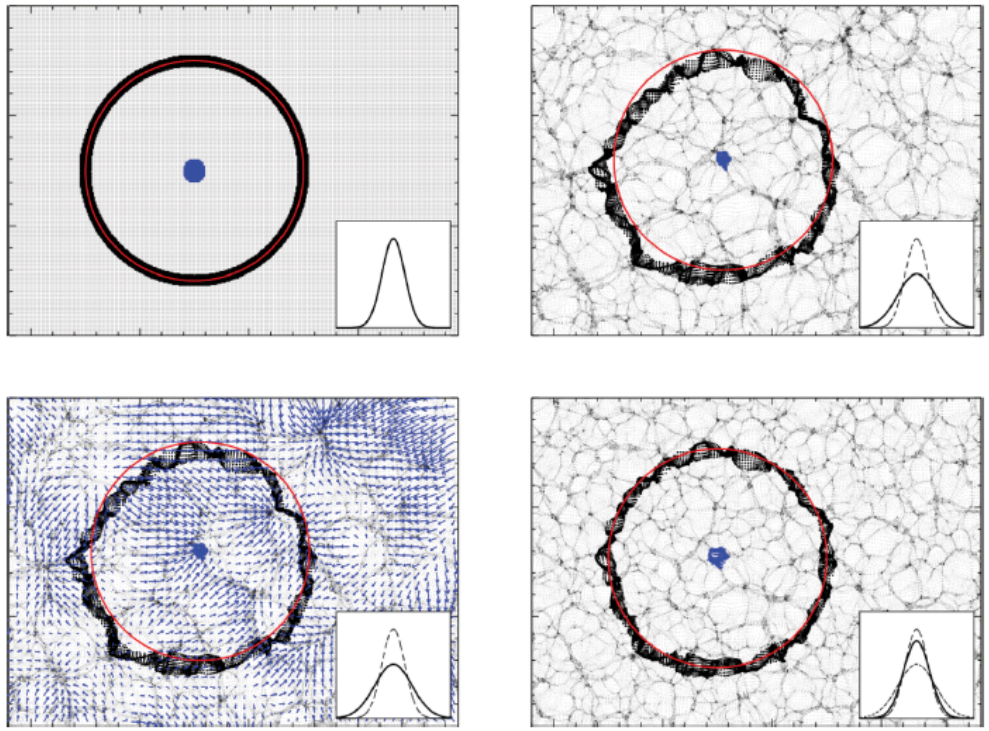




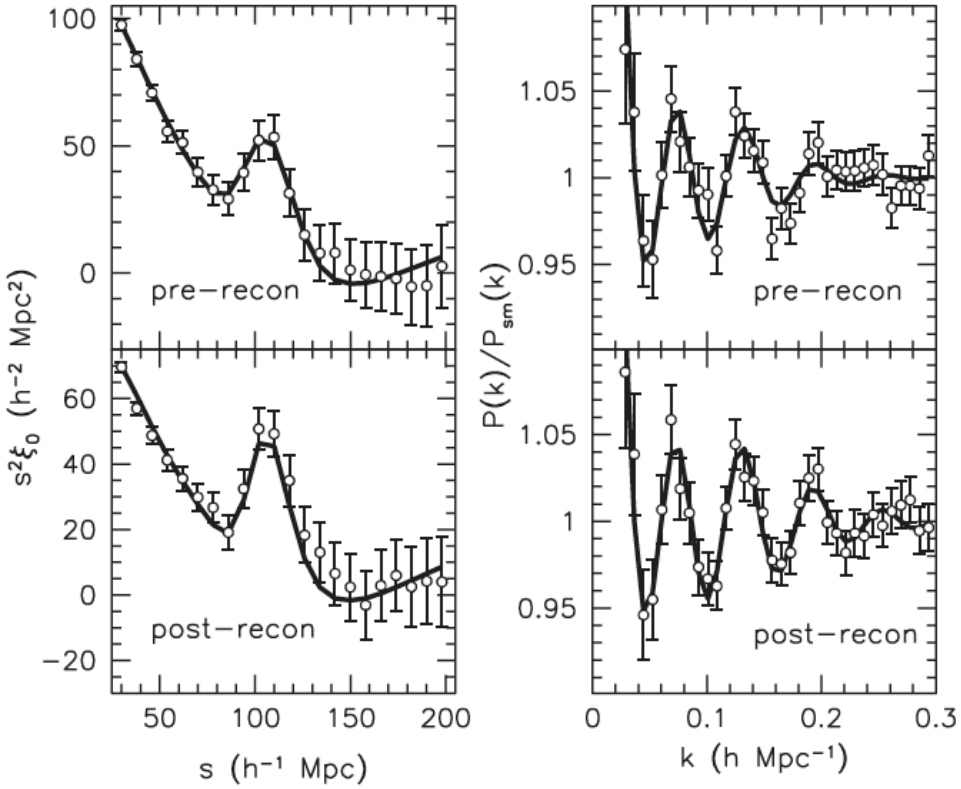
eBOSS collaboration: Ata et al. 2017

Can we improve the BAO measurements?

BAO reconstruction methodology (Eisenstein et al. 2007)



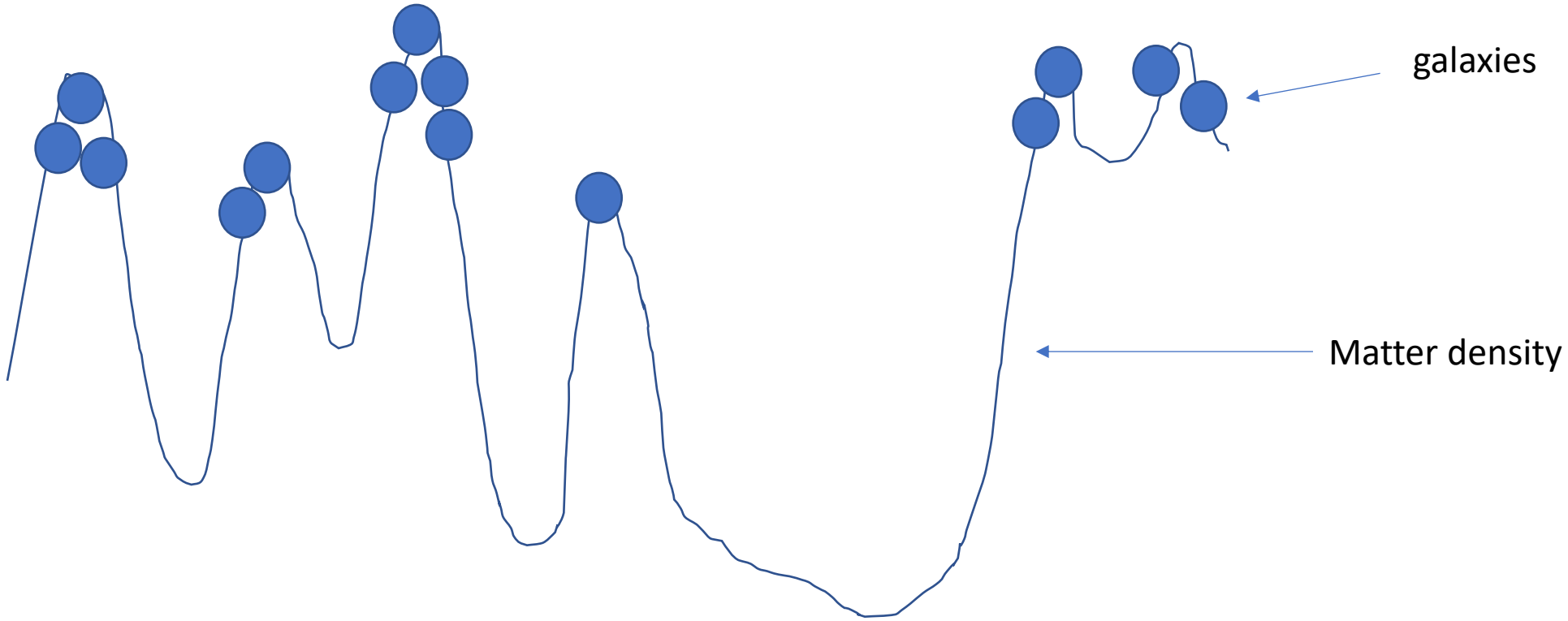
Padmanabhan et al. 2012



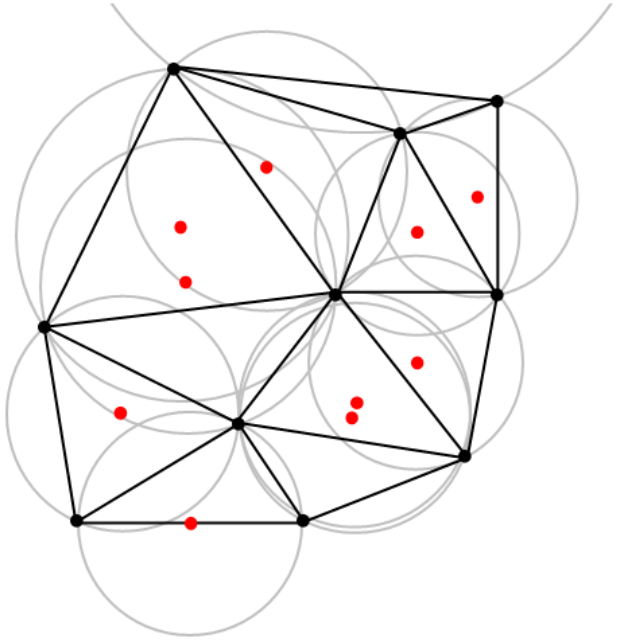
BOSS DR11 BAO measurement

Can we do even better?

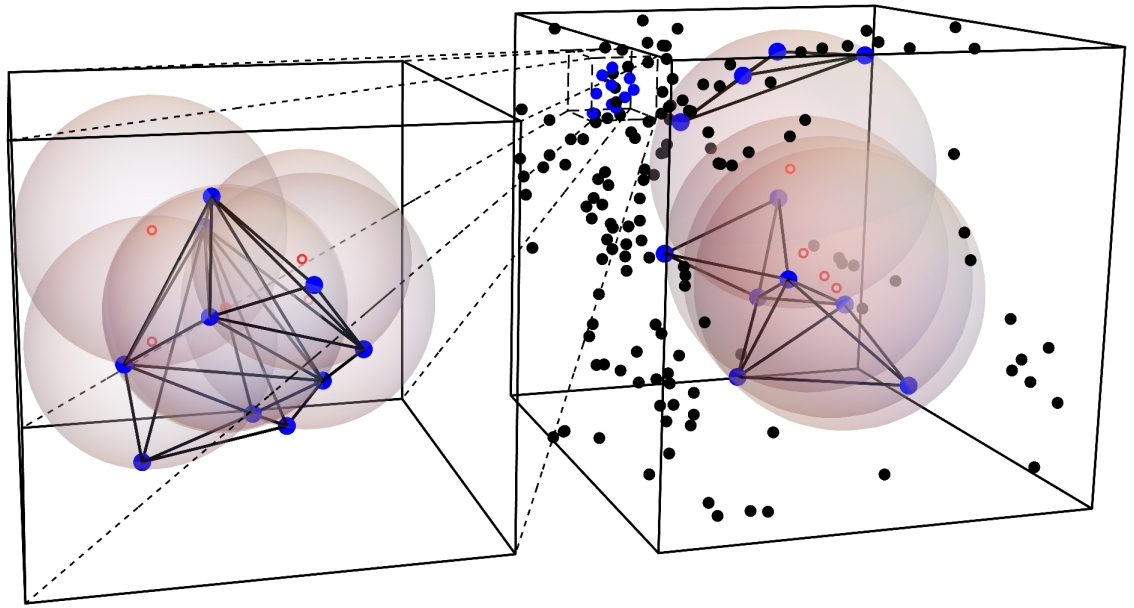
- Galaxies are tracing density peaks of the matter density field.
- Can we gain some information from under-dense region?



Delaunay Tr**I**angulation **V**oid Find**E**r



Delaunay Triangulation (DT)
Wikipedia

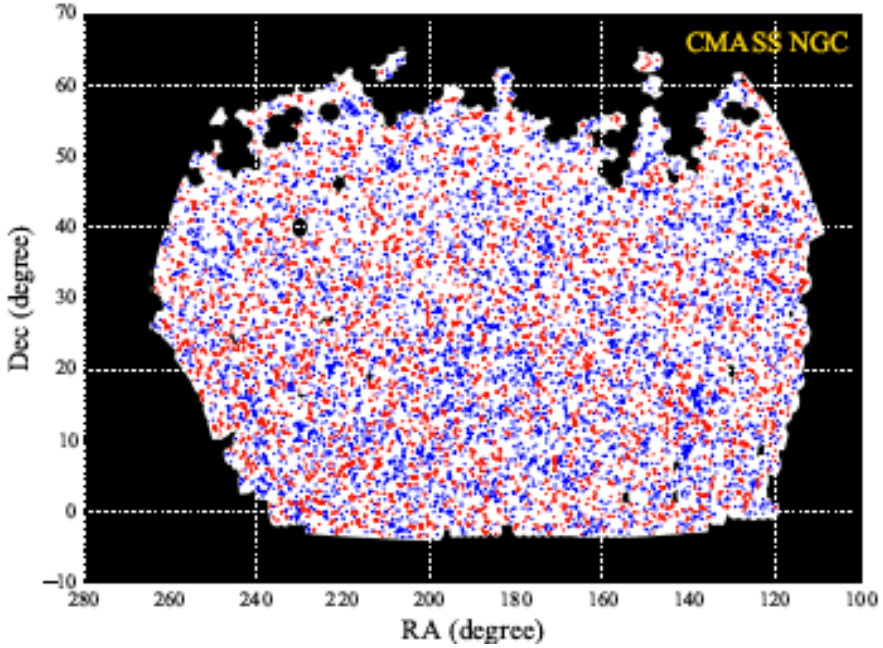


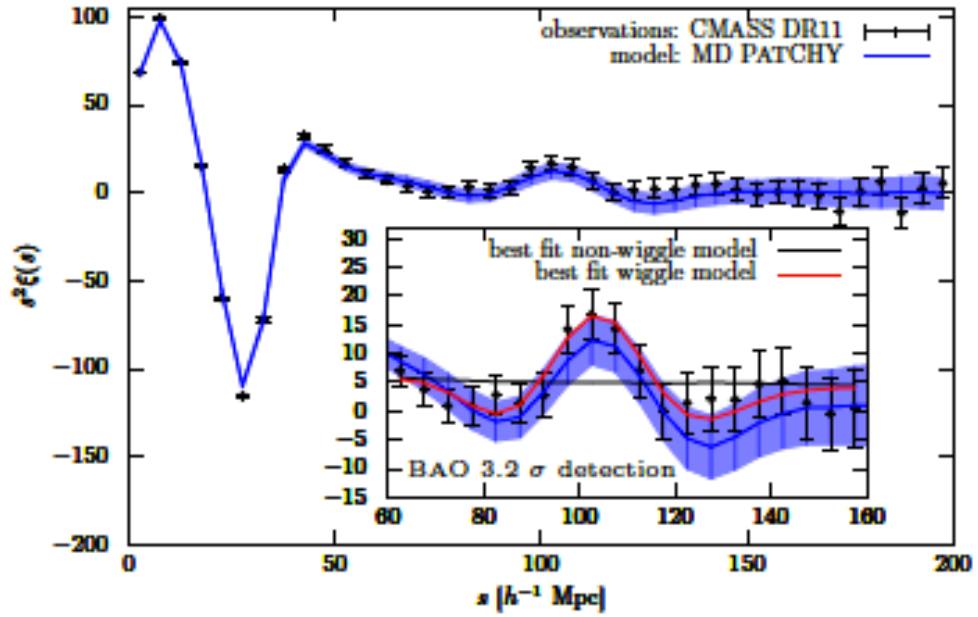
Zhao et al. 2016

Dots: haloes
Open circles: centre of voids

~10 minutes for 5.5 million haloes with a single CPU core

Measure BAO from void clustering





Kitaura, Chuang et al. 2016 (Phys. Rev. Lett. 116, 171301 (2016))

Zhao, Chuang, et al. 2018

BAO measurement from galaxies & voids

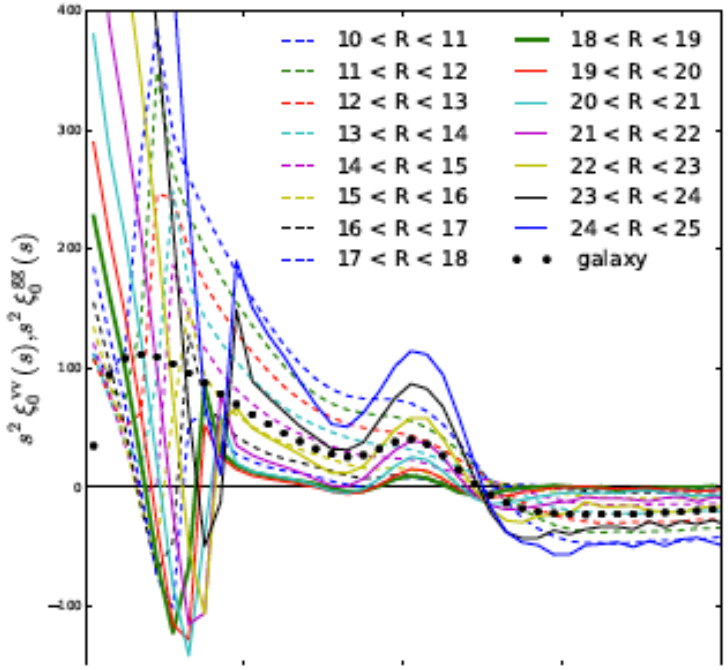
1000 post-recon MultiDark Patchy BOSS DR12 mocks

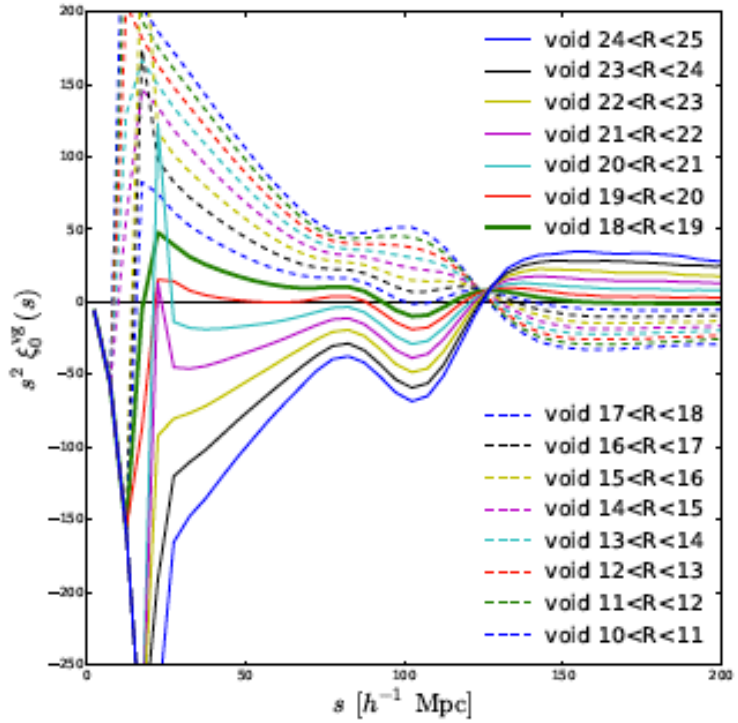
α	0.2 < z < 0.5	0.5 < z < 0.75
galaxy	0.9981 ± 0.0132	0.9996 ± 0.0123
void	0.9962 ± 0.0202	1.0177 ± 0.0575
combine (w = –0.07)	0.9981 ± 0.0114	0.9998 ± 0.0110
Improvement on σ_α	13.7%	11.1%
galaxy (Vargas-Magana et al.)	0.9986 ± 0.0136	1.0007 ± 0.0121

The gain is like increasing >20% volume of the survey

Can we improve growth rate measurement by including voids as well?

- Very challenging to get unbiased measurement!
- Voids are defined based on the galaxy sample. The selection has suffered the redshift distortion effect in the galaxy sample.

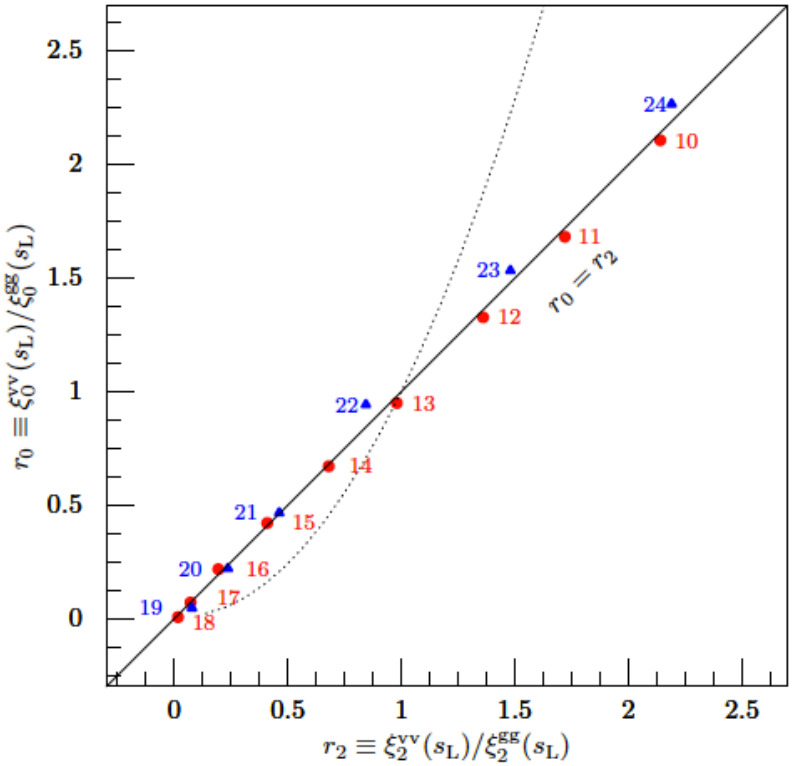




We show: (Chuang et al. 2017)
The void clustering has the same linear redshift distortion factor as the galaxy clustering!

$$\hat{\delta}^s_{\rm v}(\boldsymbol{k}) = (1+\beta_{\rm v}\mu^2)\, b^s_{\rm v}\, \hat{\delta}(\boldsymbol{k})$$

$$\beta_{\rm v} = \beta_{\rm g} = f/b_{\rm g}$$



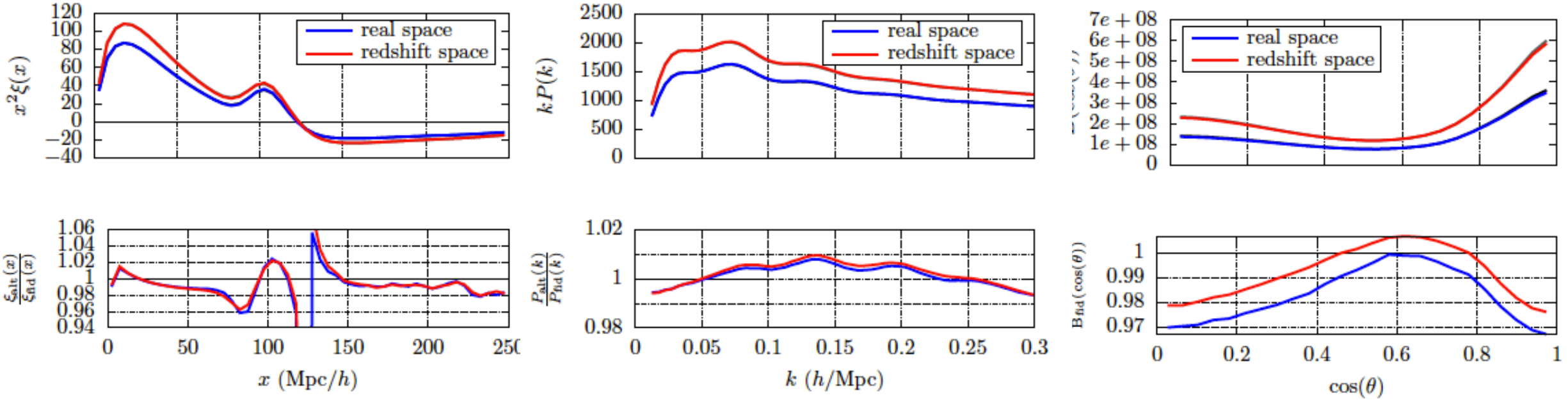
Robustness of the covariance matrix of galaxy clustering (Baumgarten & Chuang 2018)

- We test how the covariance matrix depends on the fiducial cosmology used by generating the mock catalogues.
- We test how the covariance matrix depends on different biased samples.
- To have perfect control of the other factors, we use EZmocks (Chuang, Kitaura, et al. 2015) of which the 2-point and 3-point can be tuned to fit a reference data. Each set has 3000 EZmock boxes.

Mocks with different fiducial cosmologies

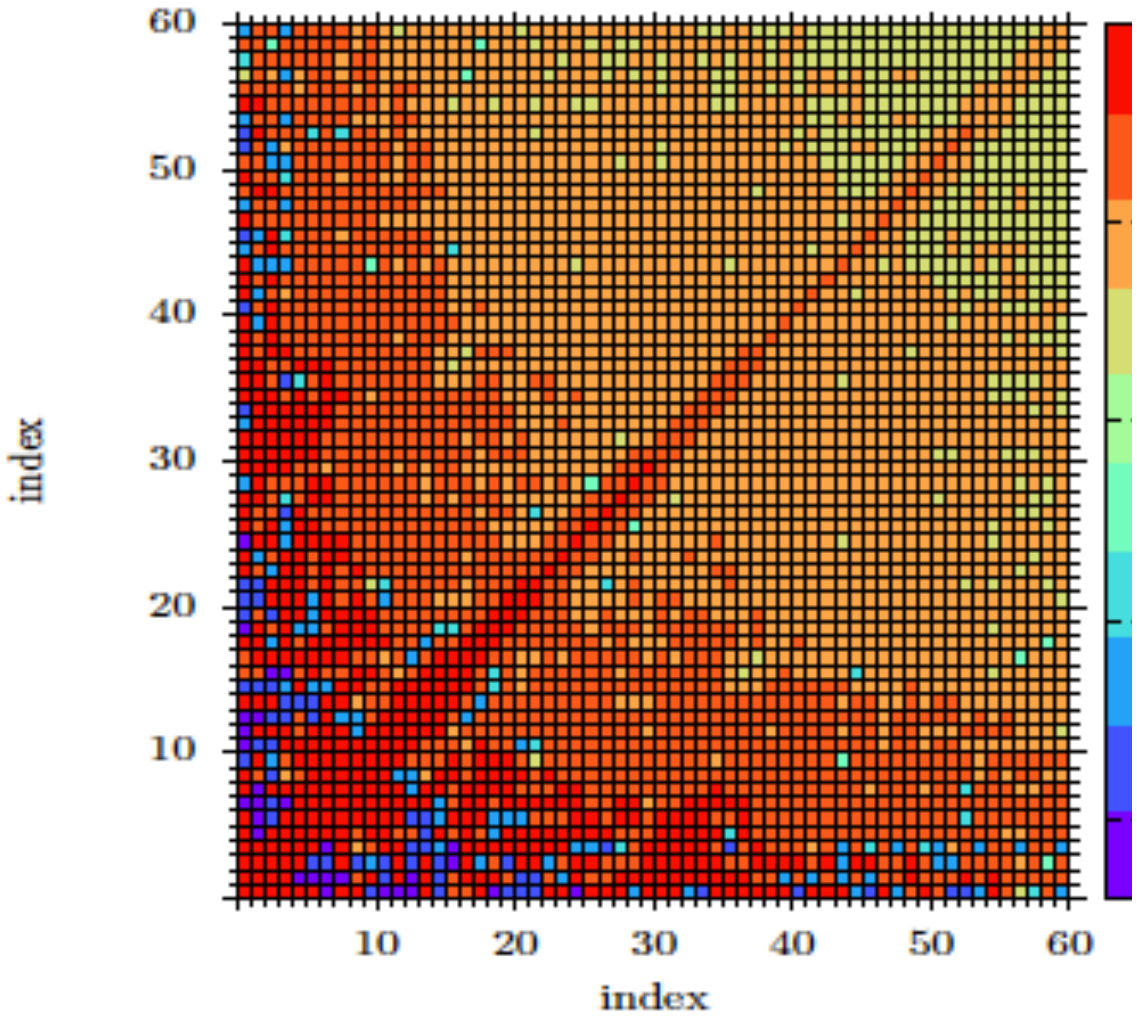
- We vary σ_8 since it has largest uncertainty based on CMB measurements.

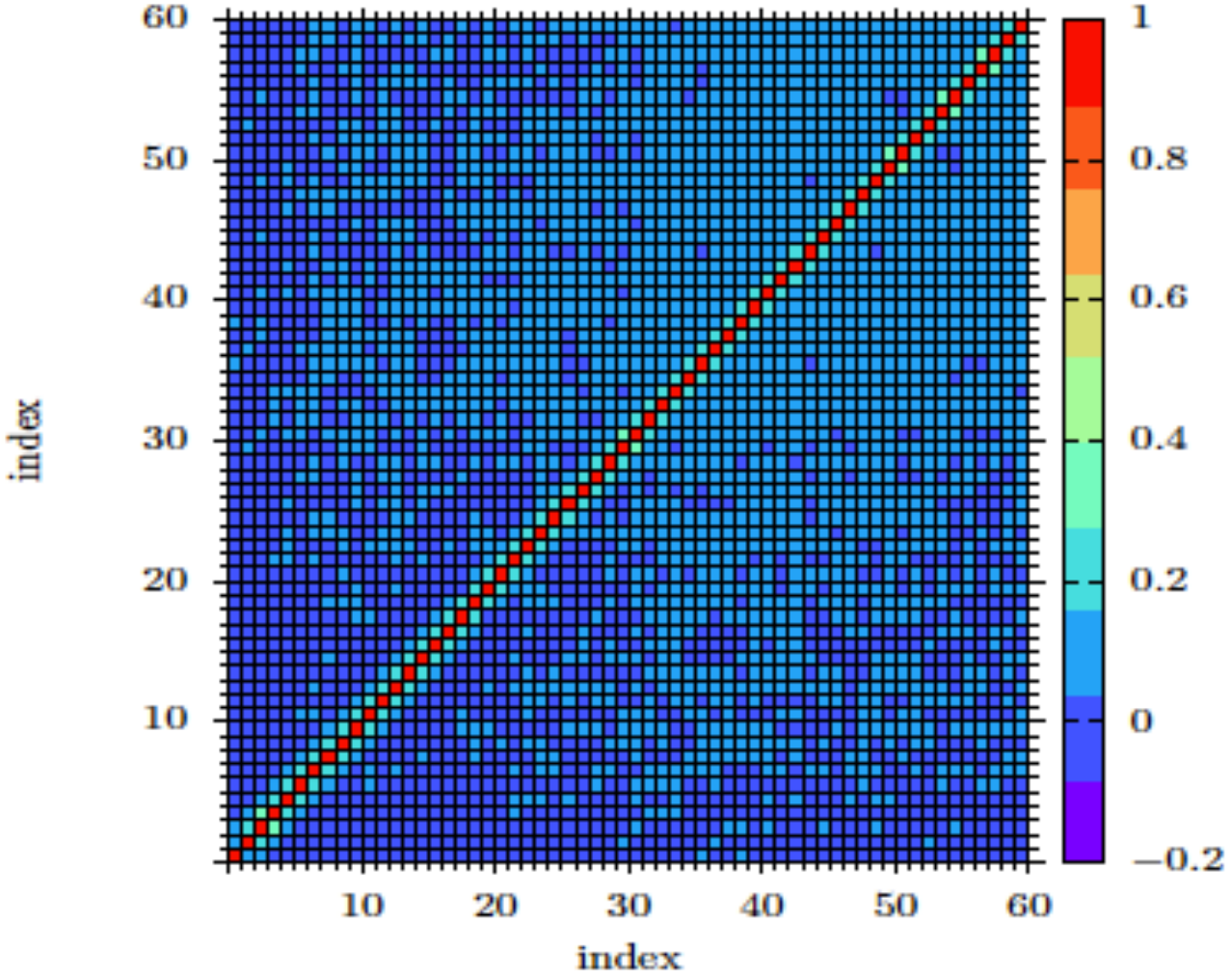
Baumgarten & Chuang 2018

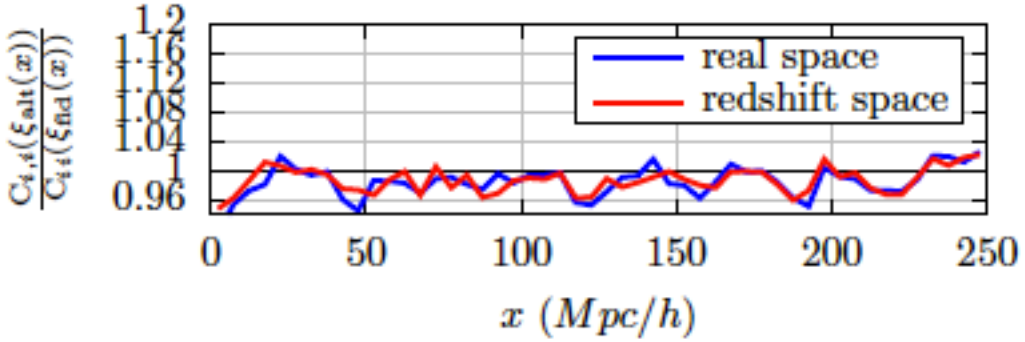


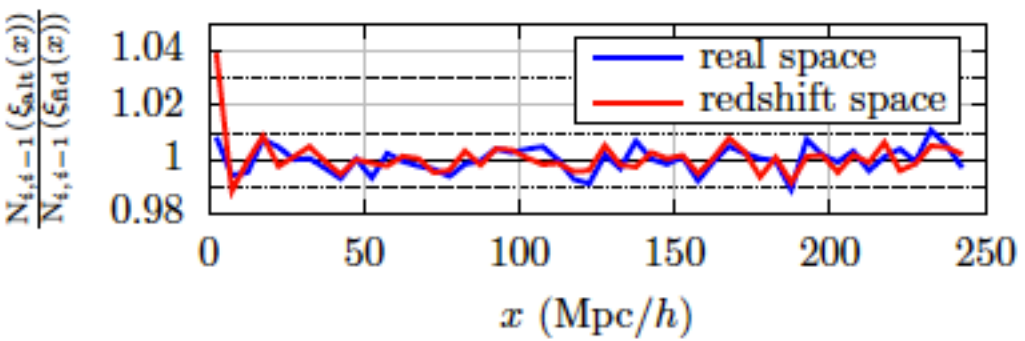
Covariance matrix & Normalized covariance matrix

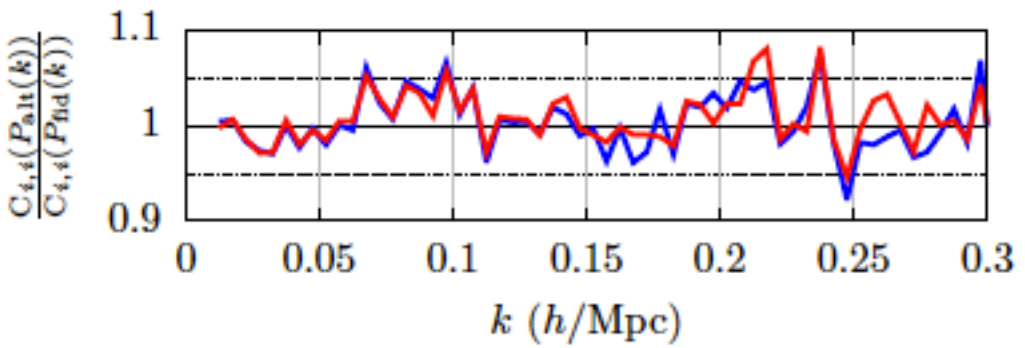
Baumgarten & Chuang 2018

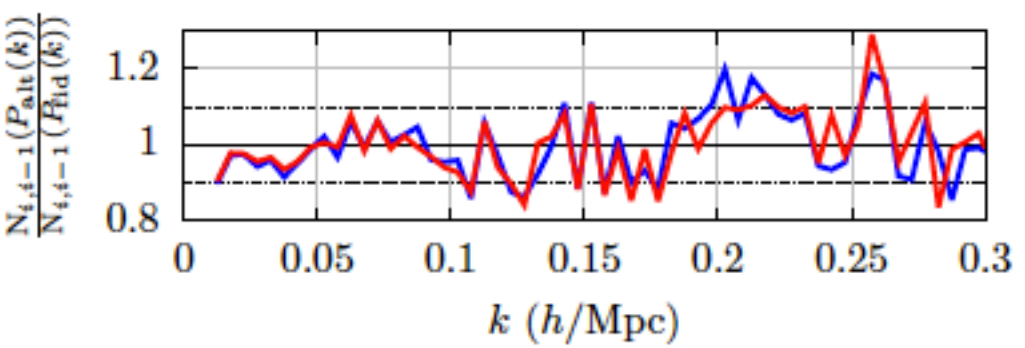


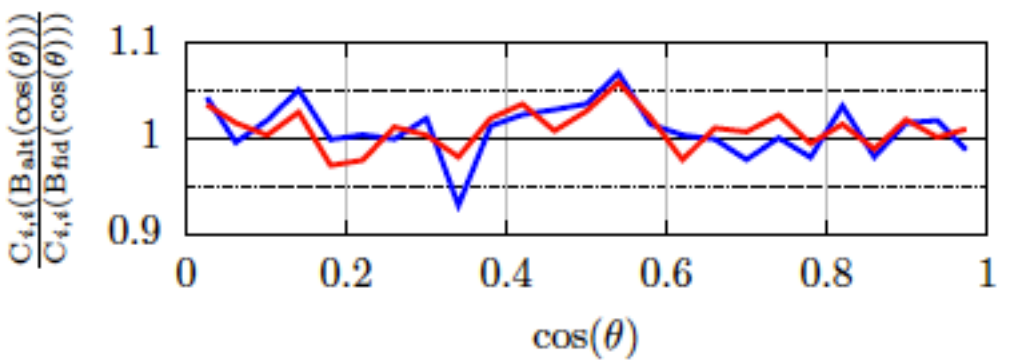


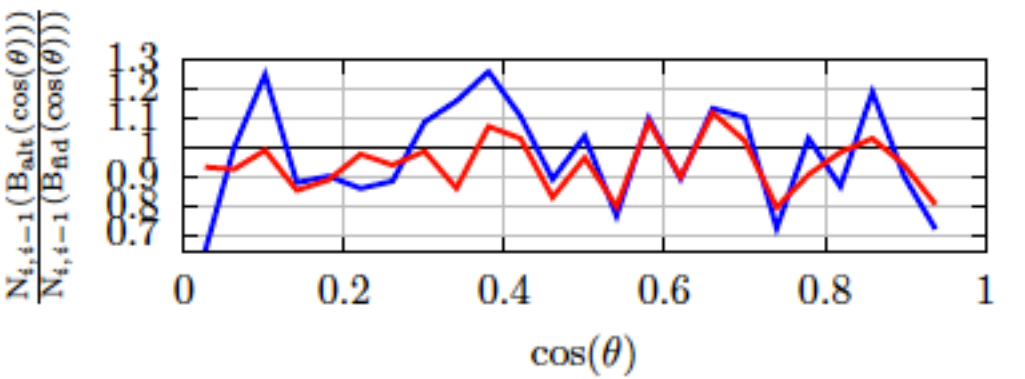








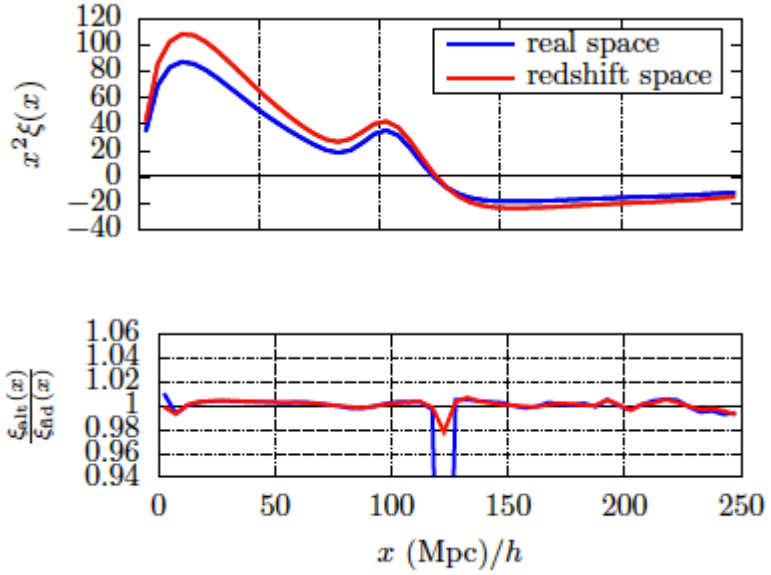


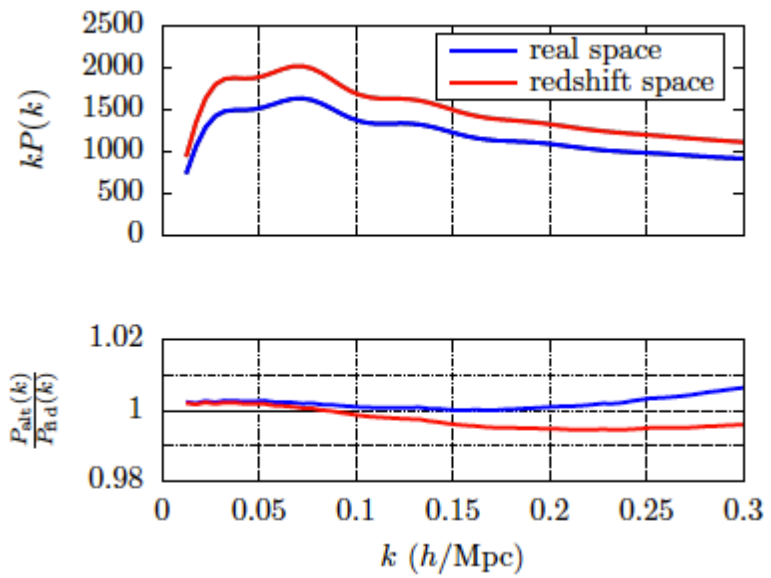


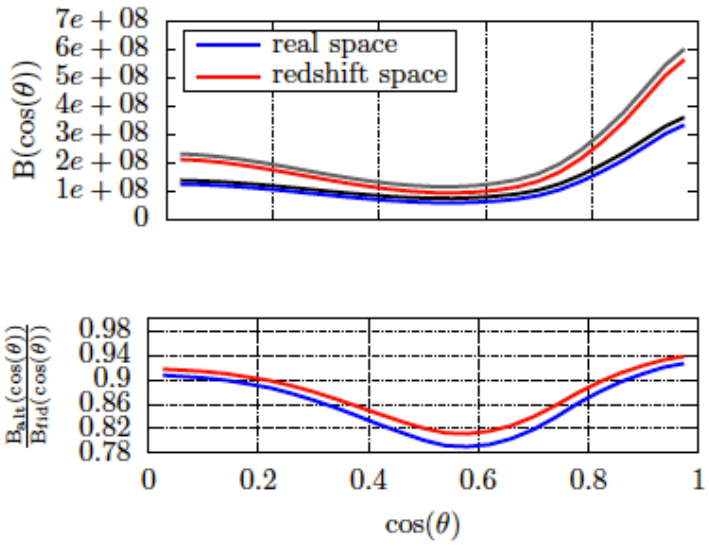
Baumgarten & Chuang 2018

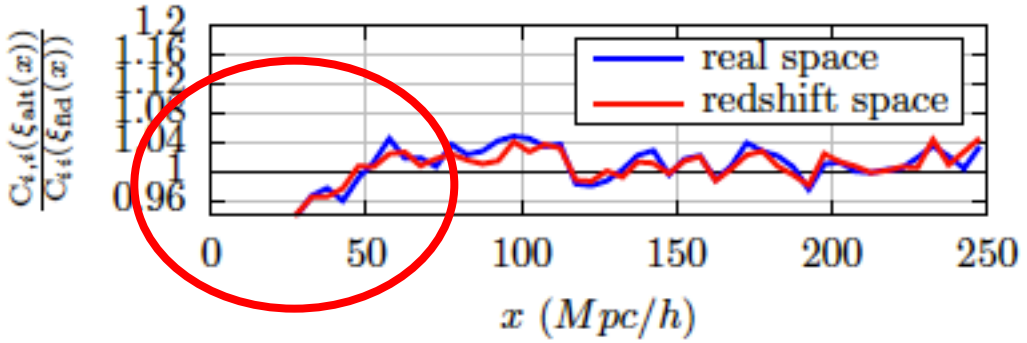
Mocks of different biased sample

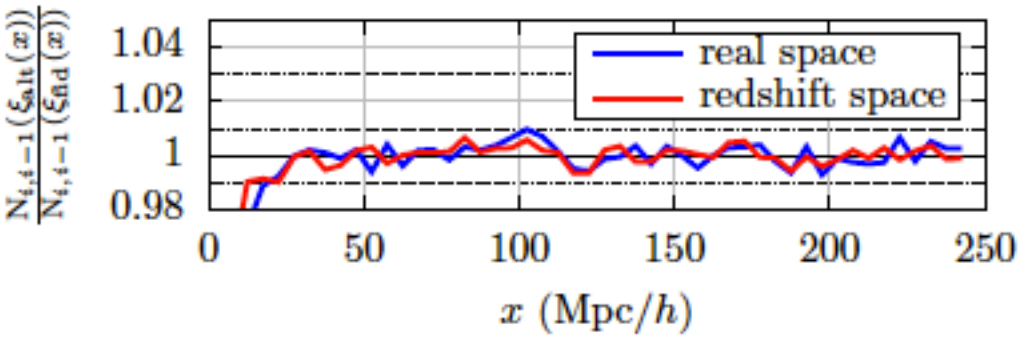
- We expect that the covariance matrix of 2-point clustering measurement is sensitive to the 2-point clustering.
- What we are interested is the impact of 3-point statistics.

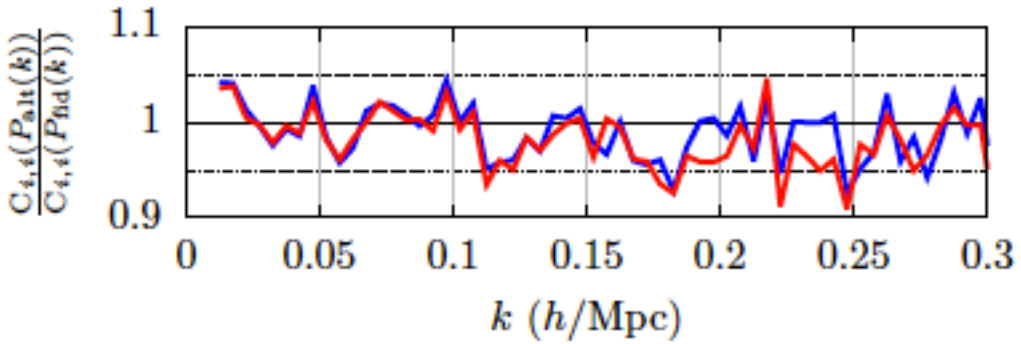


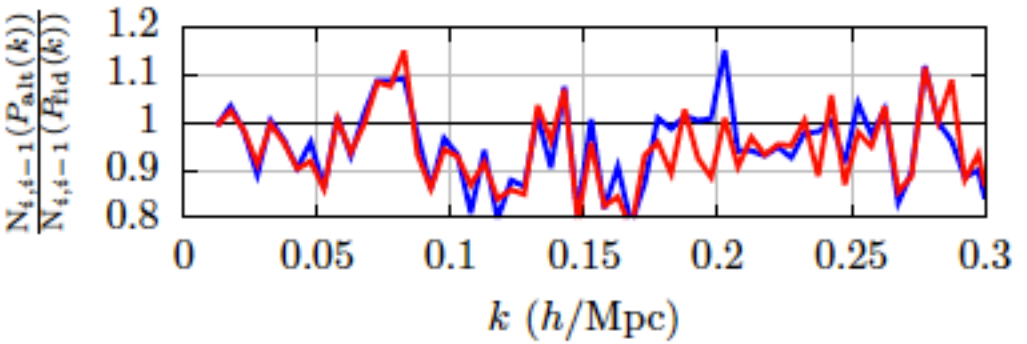


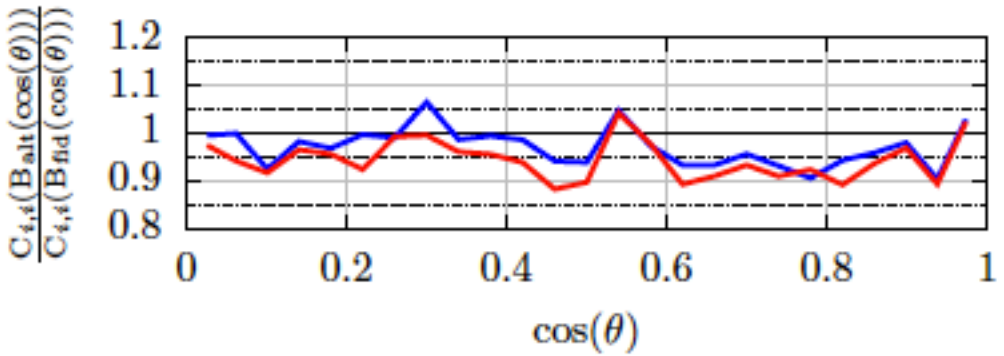


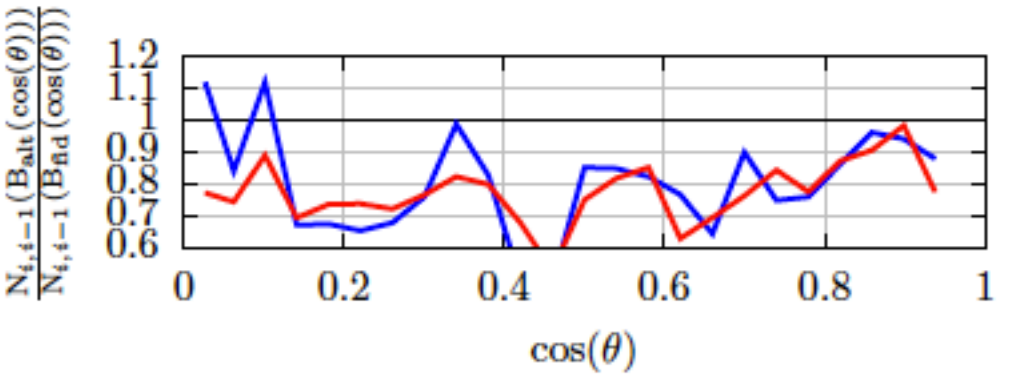

real space
redshift space
$x\ (Mpc/h)$


real space
redshift space
x (Mpc/h)


k (h/Mpc)


k (h/Mpc)


$\cos(\theta)$


$\cos(\theta)$

Summary

- We develop a methodology to optimize the measurement of Baryon Acoustic Oscillation (BAO) from a given galaxy sample.
- In simulations, the joint sample improves by more than 10% the constraint for the post-reconstruction BAO peak position compared to the result from galaxies alone, which is equivalent to an enlargement of the survey volume by 20 %
- The covariance matrix constructed based on mock catalogues is insensitive to the fiducial cosmology used.
- The covariance matrix of small-scale 2-point clustering is sensitive to 3-point statistics.

backup slides

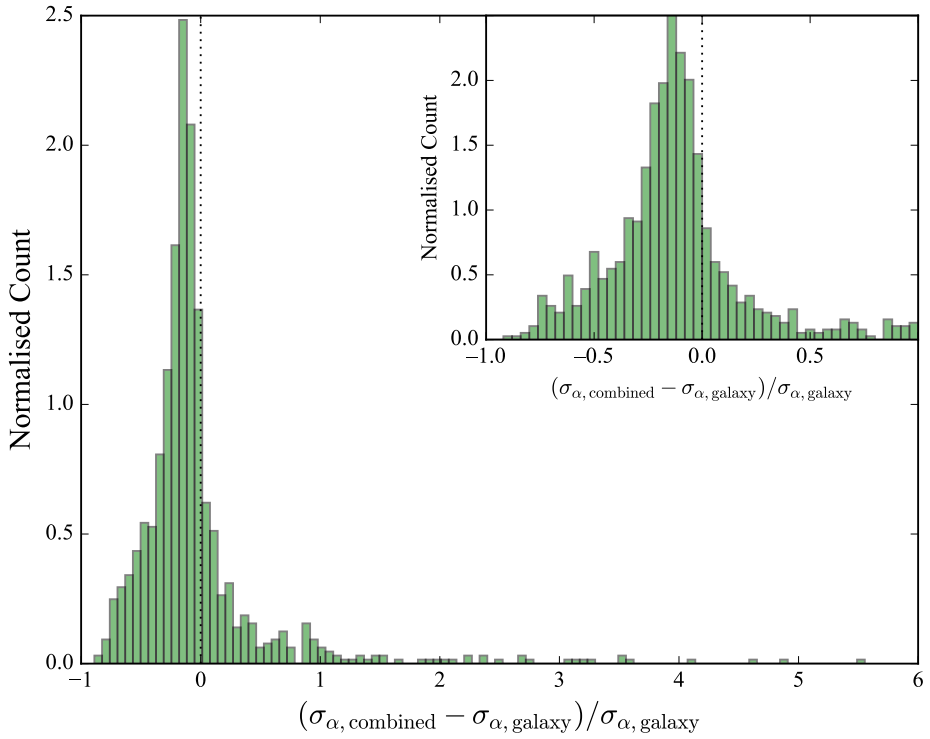
BAO fitting: BOSS DR12 data

Zhao, Chuang, et al. 2018

α	0.2 < z < 0.5	0.5 < z < 0.75
galaxy	0.9966 ± 0.0092	0.9801 ± 0.0094
combine (w = –0.07)	0.9933 ± 0.0081	0.9814 ± 0.0102
Improvement on σ_α	11.6%	–8.7%
galaxy (Vargas-Magana et al.)	0.9995 ± 0.0098	0.9820 ± 0.0091

Fitting results for individual mocks

Zhao, Chuang, et al. 2018

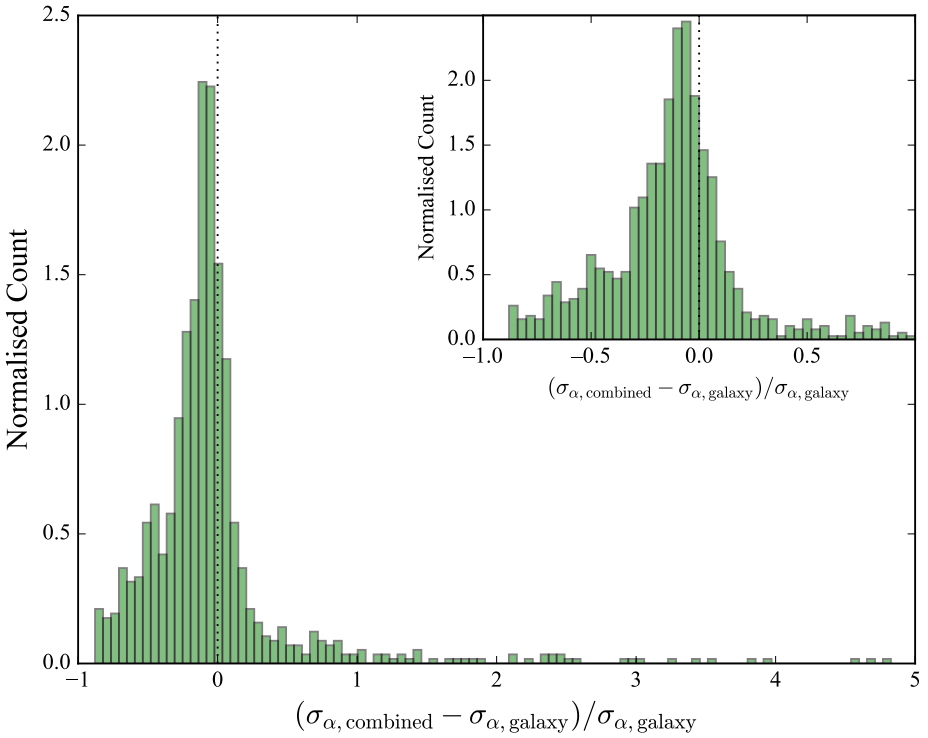


0.2 < z < 0.5

Improvement: 759 of 1000

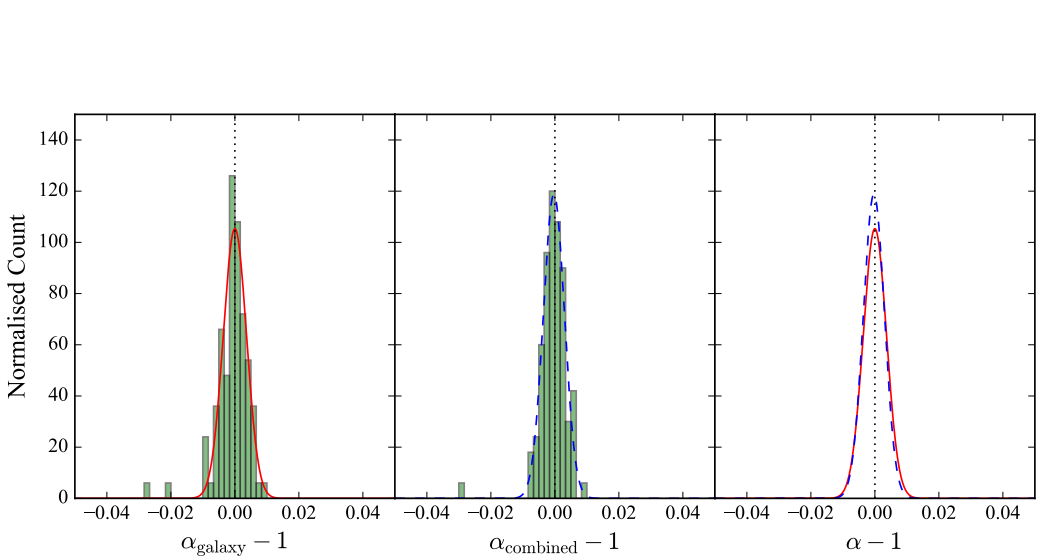
Improvement: 715 of 1000

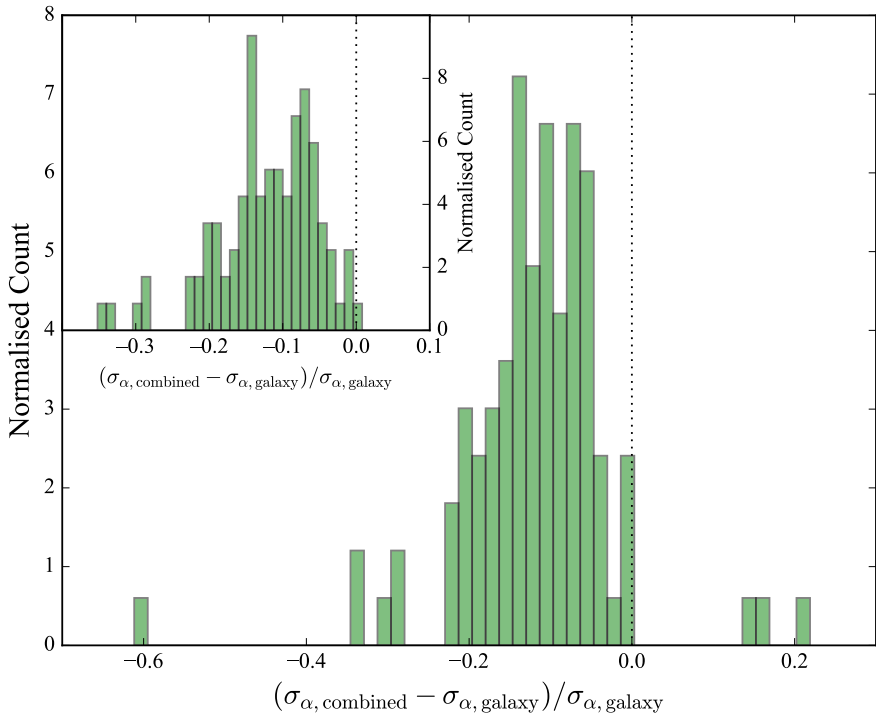
0.5 < z < 0.75



Fitting results for groups of mocks

Group every 10 mocks (0.5 < z < 0.75):
Effectively larger volume for 100 mocks





Improvement: 98 of 100

Zhao, Chuang, et al. 2018