Cosmological Measurements from Voids in eBOSS

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eBOSS

NSERC CRSNG

Galaxy Surveys

- 3D map of tracer (ex. LRGs)
  - Typically use to measure 2-point statistics
- Get information for distance (D_M, D_H) and growth rate of structure ($f\sigma_8$)
- We can get more out of these surveys that just 2 point statistics
  - Ex. Restrict ourselves to regions where linear theory works better, can pull information out from smaller scales.
    - Voids are perfect for this

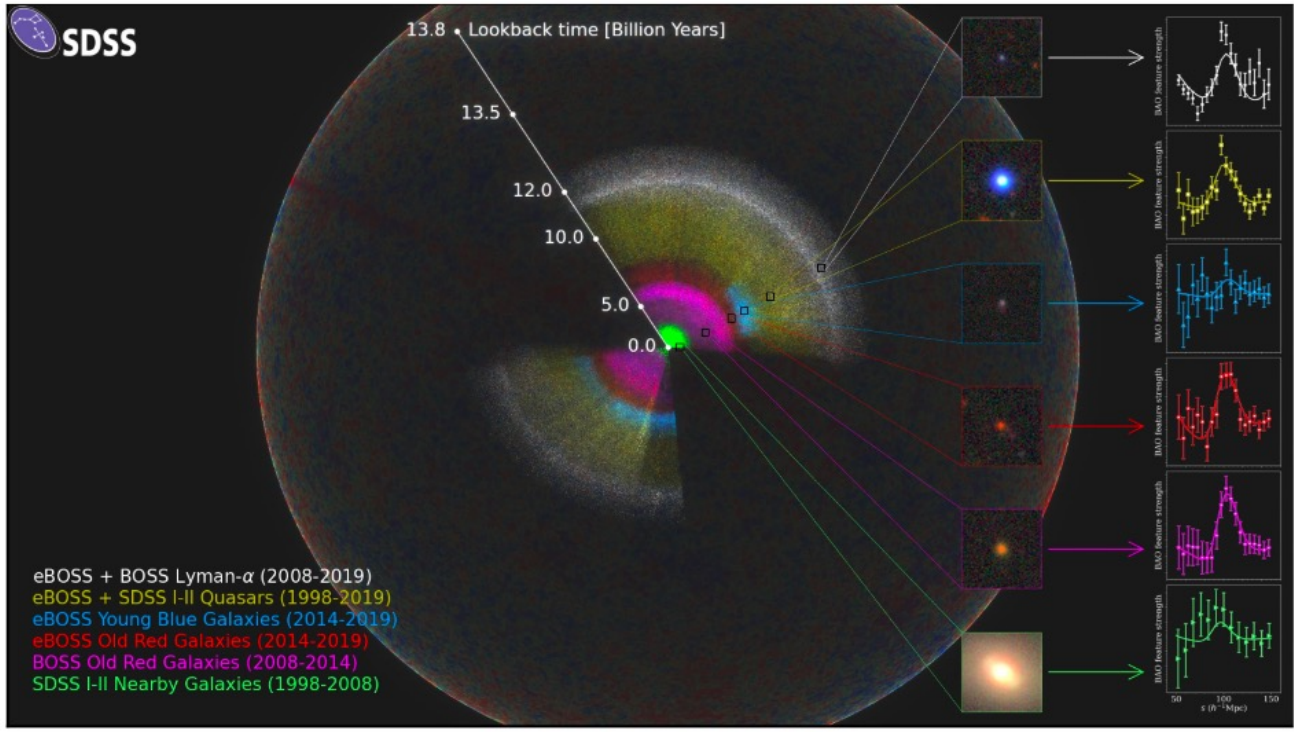
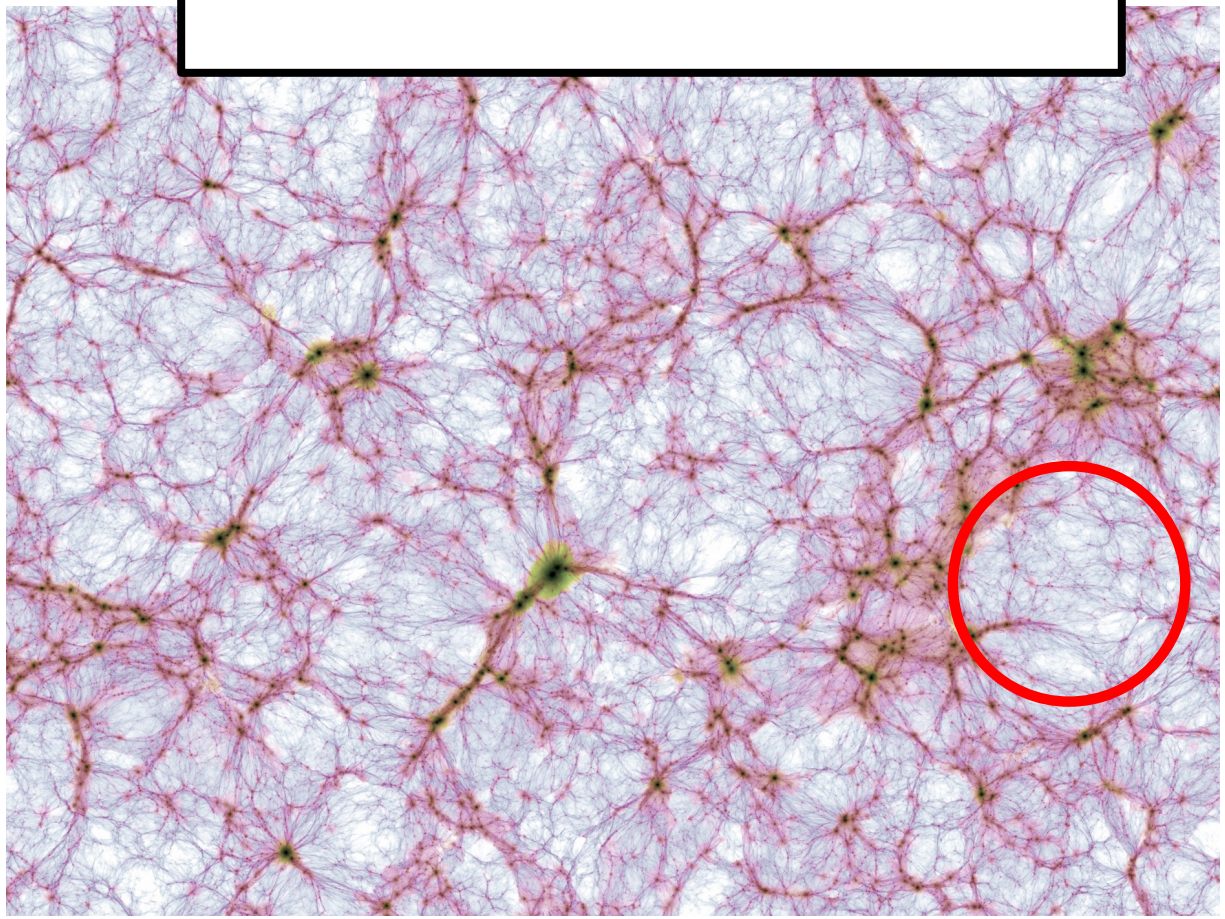


Image: eBOSS collaboration

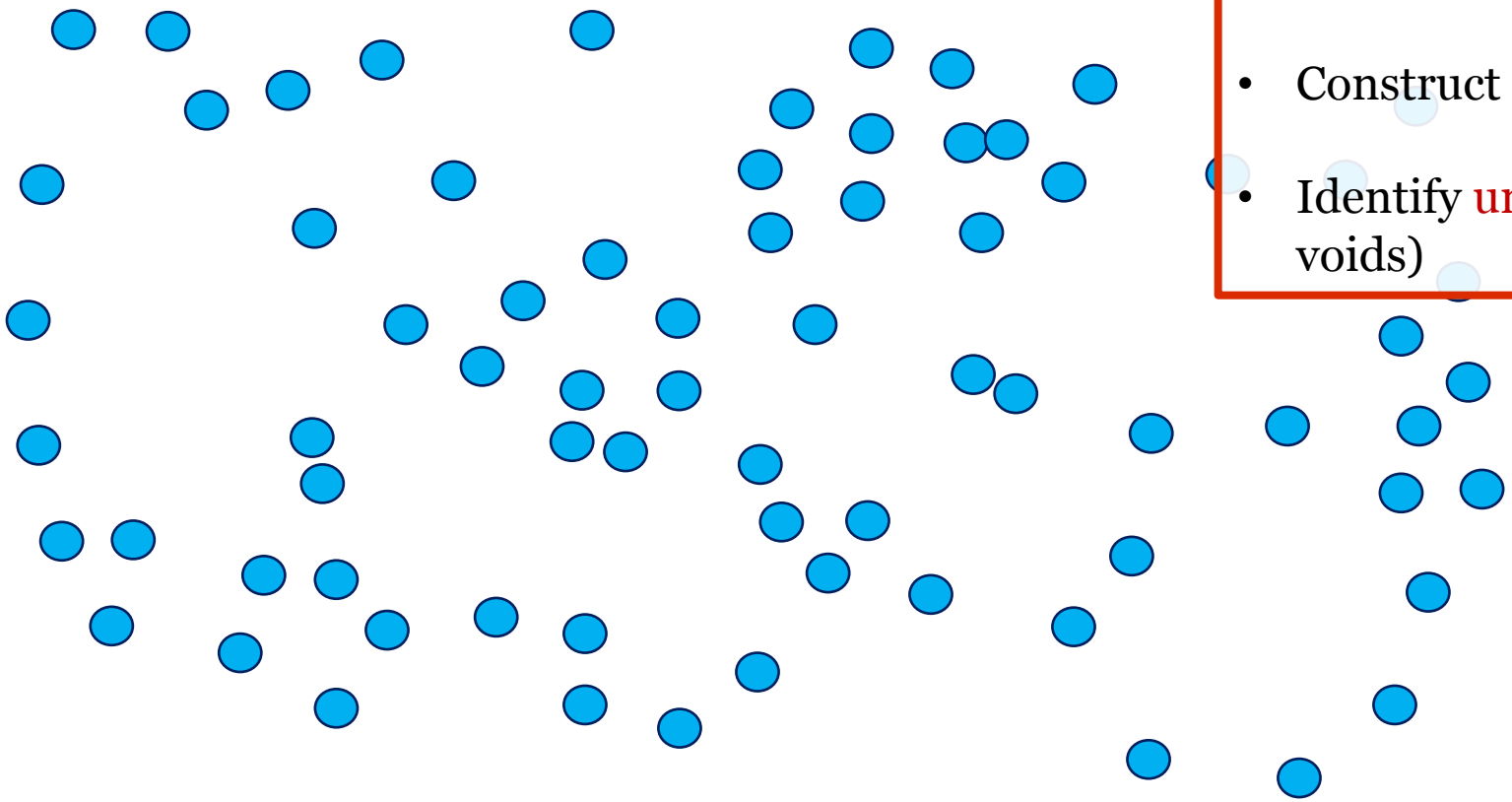
Background

- Natural Consequence of structure growth
- Voids are non-linear objects
- Motions of galaxies still track primordial form
- Galaxy motion can be well modelled through linear theory

What is a void?

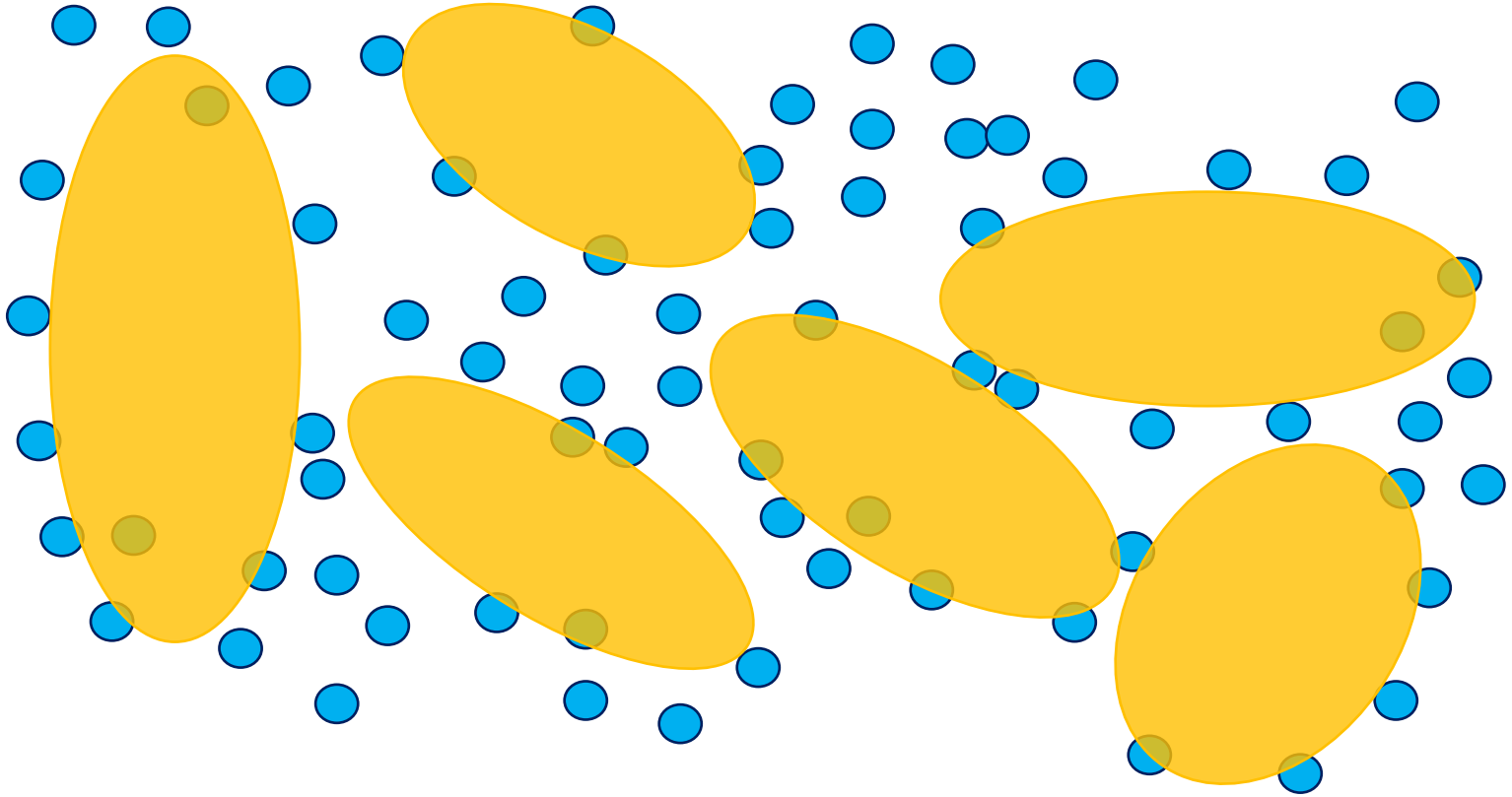


Basic Idea of Void Analysis



- Start with a tracer
  - Ex. LRGs
- Construct a density field
- Identify underdensities (i.e. voids)

Basic Idea of Void Analysis



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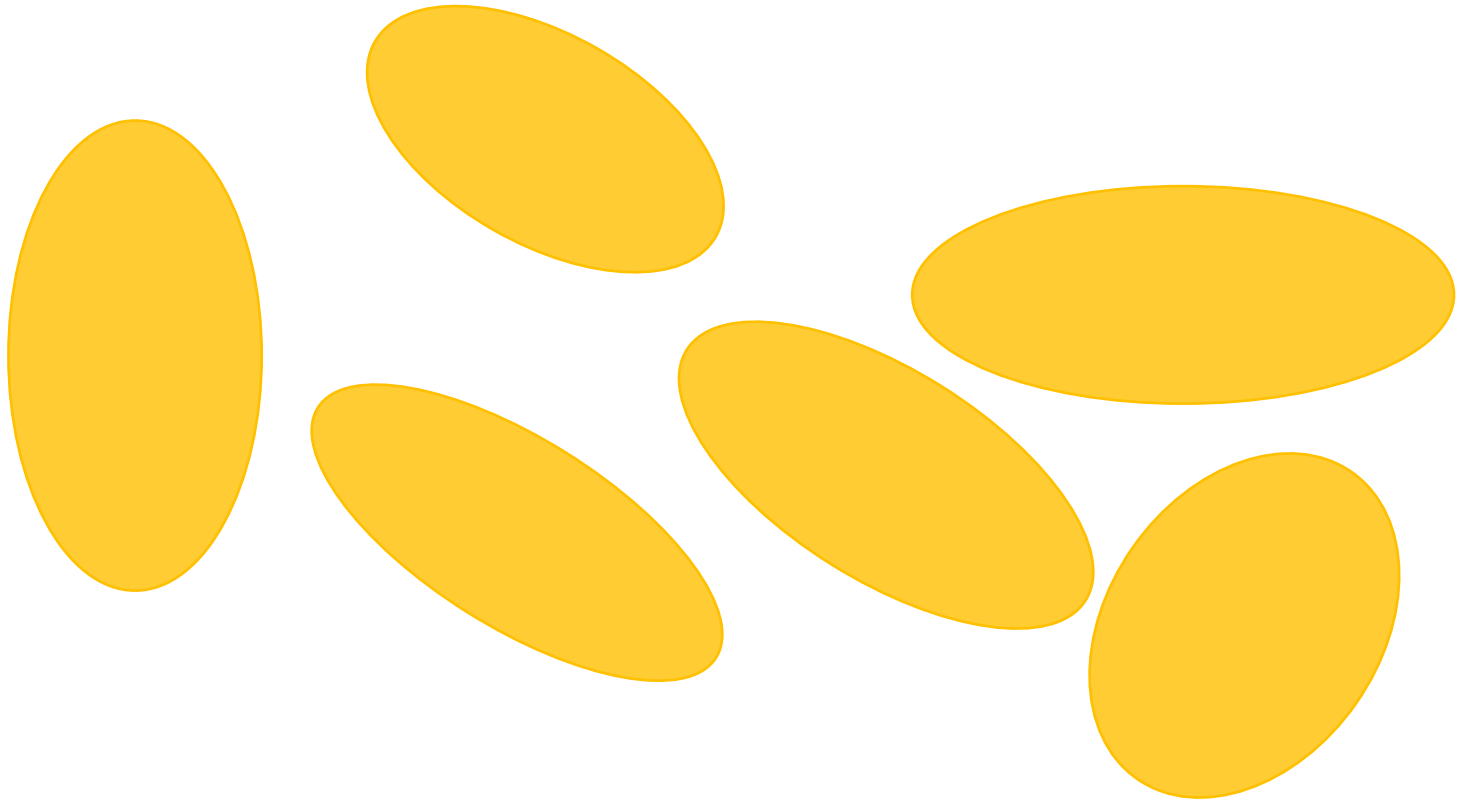
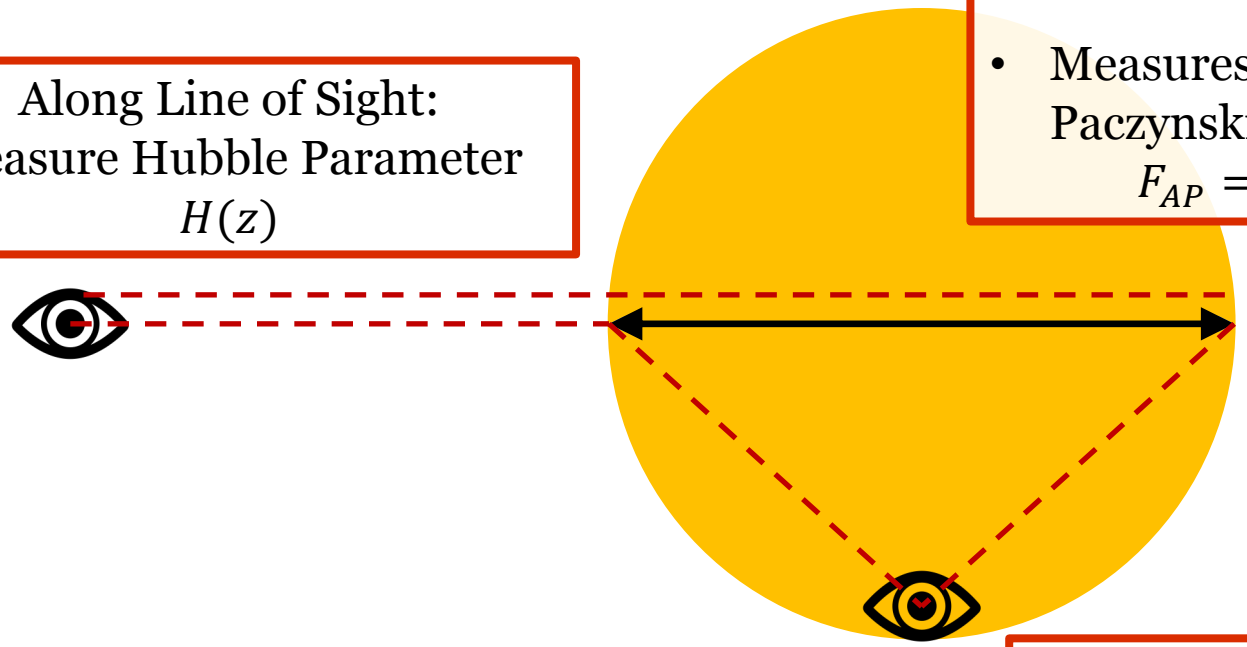


Basic Idea of Void Analysis

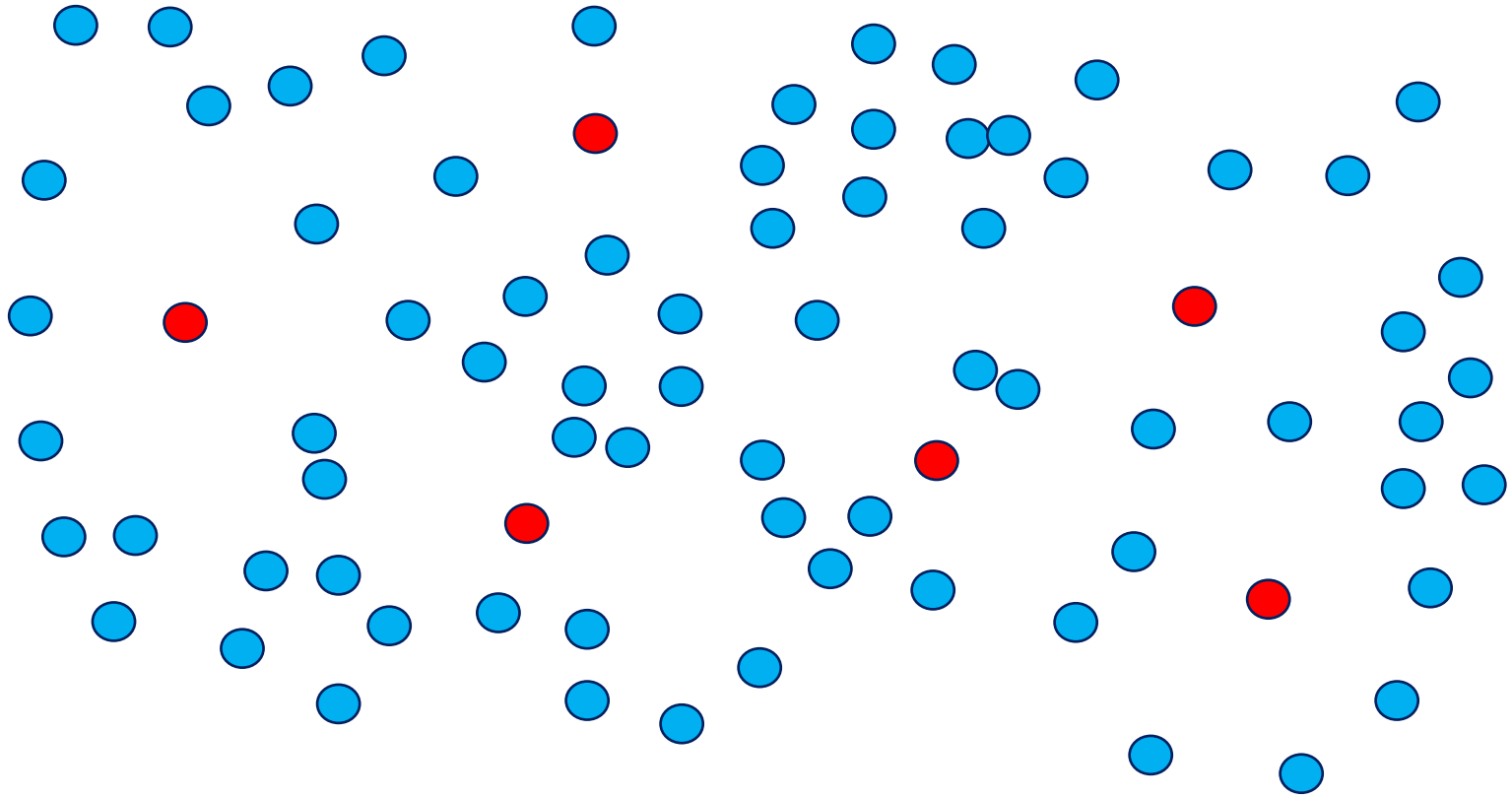
- Averaged void profile
- Spherical when measured using the correct cosmology
- Measures the Alcock-Paczynski parameter:
  $F_{AP} = D_A(z)H(z)/c$

Along Line of Sight:
Measure Hubble Parameter
$H(z)$

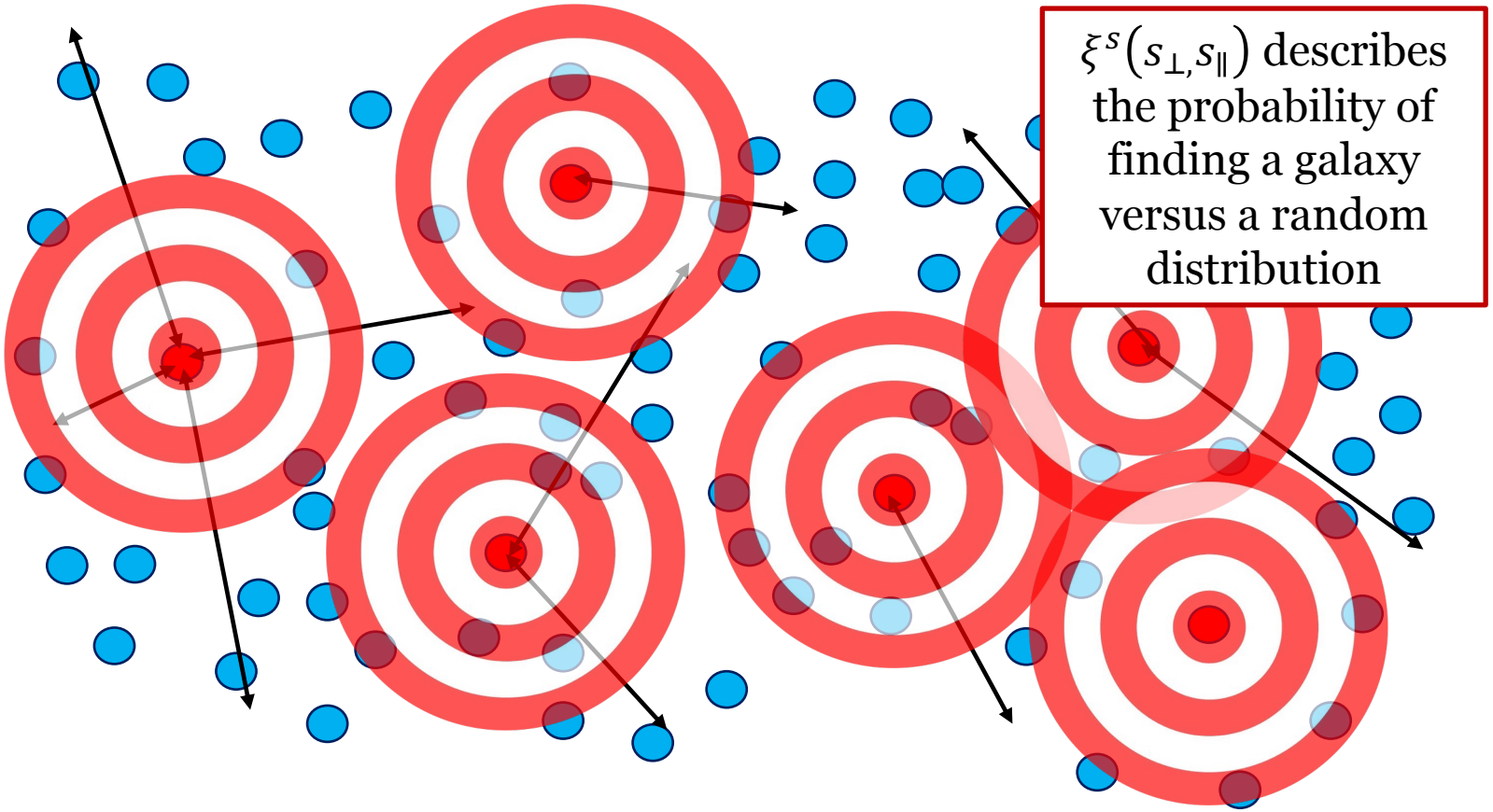


On Sky:
Measure Angular Diameter Distance $D_A(z)$

Void-Galaxy Correlation



Void-Galaxy Correlation



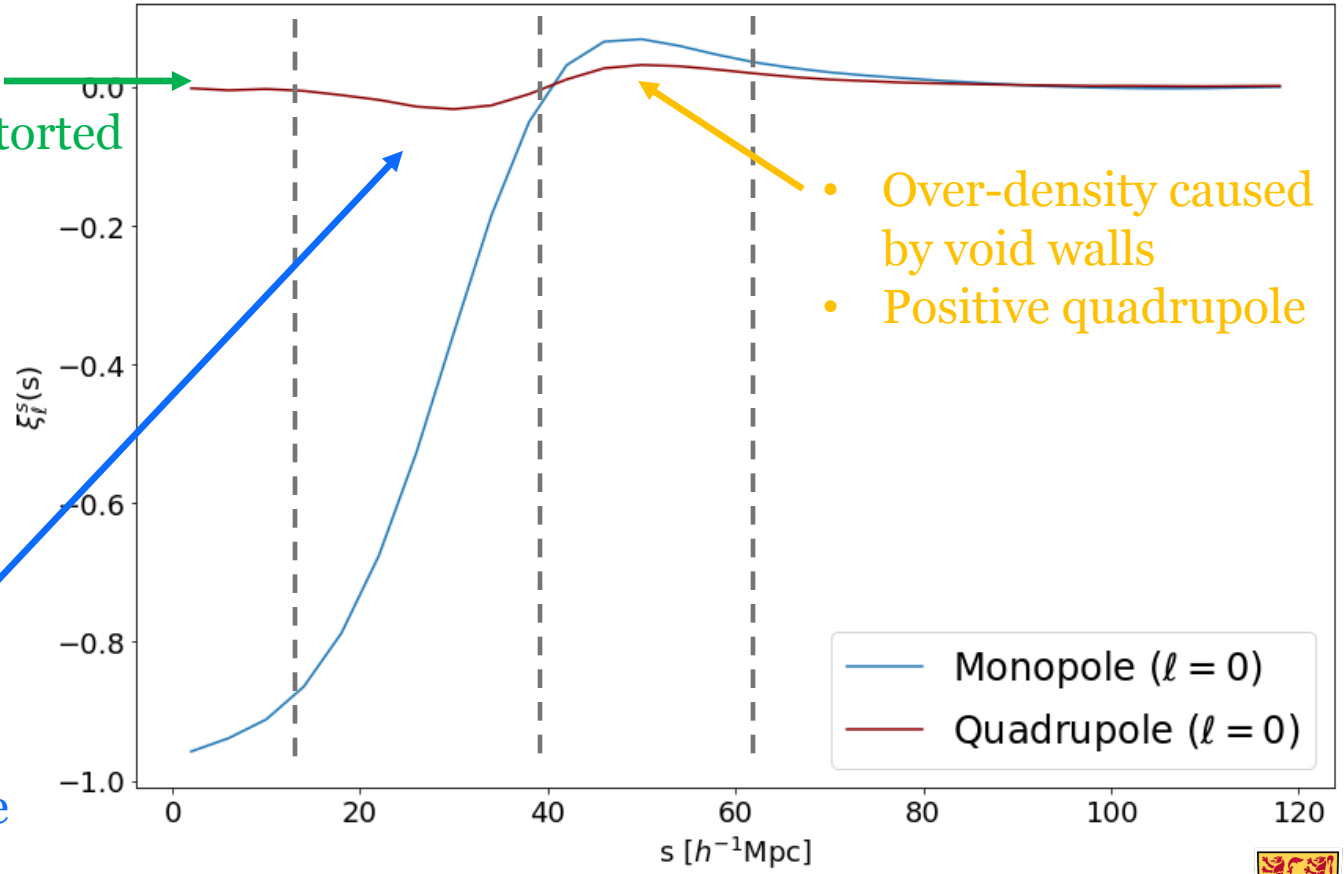
$\xi^s(s_\perp, s_\parallel)$ describes the probability of finding a galaxy versus a random distribution

Void-Galaxy Correlation & multipole decompositoin

The anisotropic correlation function $\xi^s(\boldsymbol{s})$ can be compressed into Legendre multipoles:

$$\xi_l^s(\boldsymbol{s}) = (2l+1)\xi^s(s,\mu)\mathrm{L_l}(\mu)d\mu$$

- Few to no galaxies
- Quadrupole is undistorted

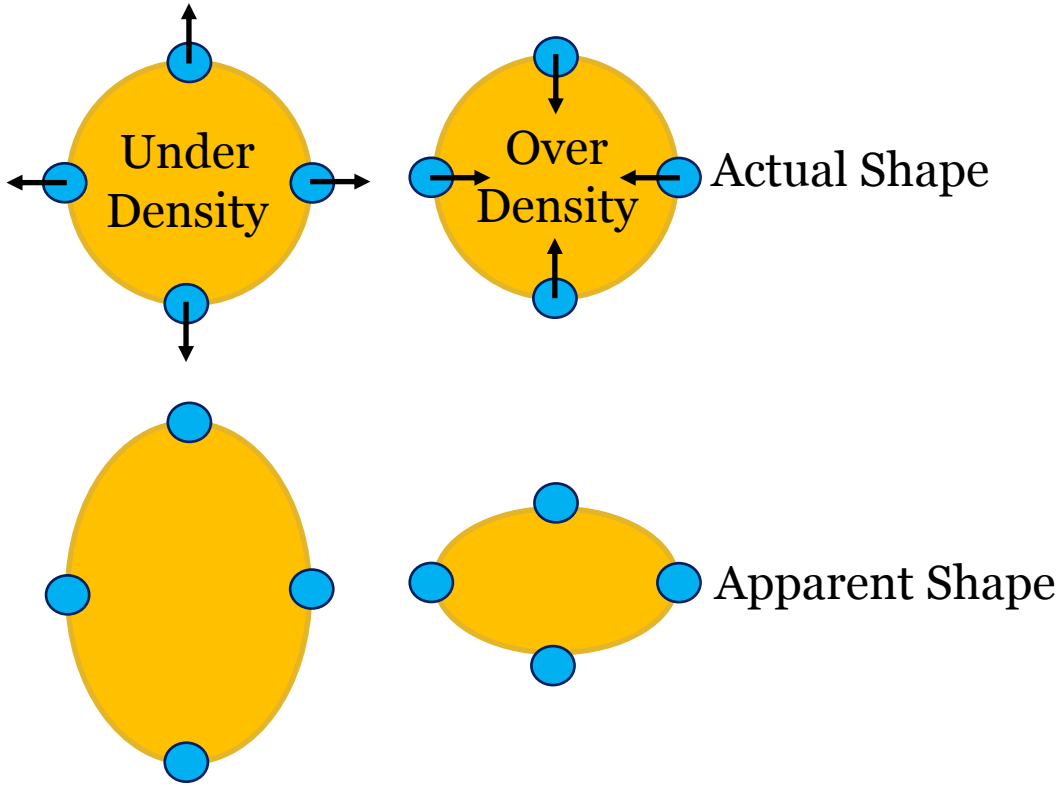


- Over-density caused by void walls
- Positive quadrupole

- Under-density stretched along line of sight
- Negative quadrupole

Redshift Space Distortions (RSDs)

- Additional distortion term that acts along the line of sight
- Velocities along the line of sight produce additional distortions converting from redshift to distance
- Structures will appear elongated or compressed along line of sight



Alcock-Paczynski Effect

- A fiducial cosmology is assumed in order to convert redshift to distance that will produce additional distortions

- We adopt two dimensionless ratios to describe the distortions parallel and perpendicular to the line of sight

$$\alpha_{\perp} = \frac{D_A(z)}{D_A^{fid}(z)}, \qquad \alpha_{\parallel} = \frac{H^{fid}(z)}{H(z)}$$

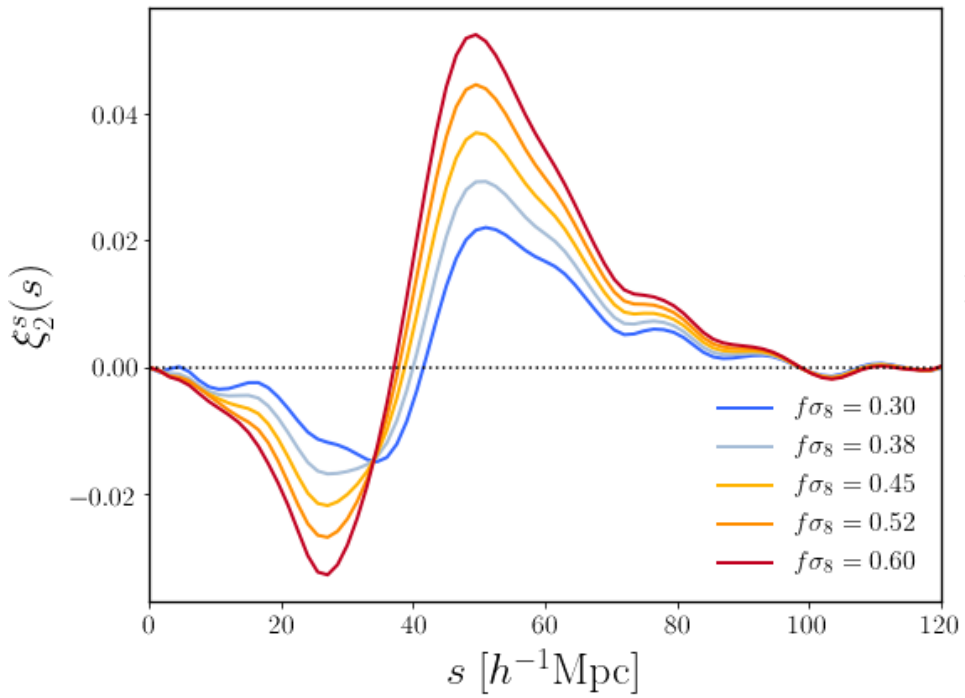
- Which we can use to rewrite the correlation function

$$\xi^s\left(s_{\perp}, s_{\parallel}\right) = \xi^{s,fid}\left(\alpha_{\perp} s_{\perp}^{fid}, \alpha_{\parallel} s_{\parallel}^{fid}\right)$$

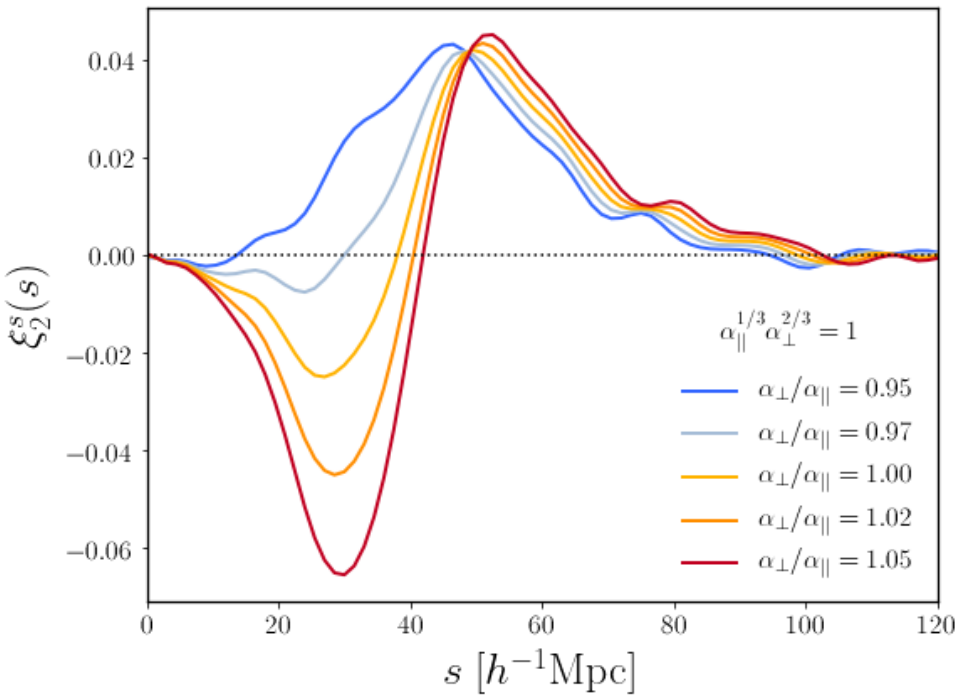
Joint Effect

Both RSDs and the Alcock-Paczynski Effect will affect the quadrupole, but in two distinct ways:

Varying the Growth Rate

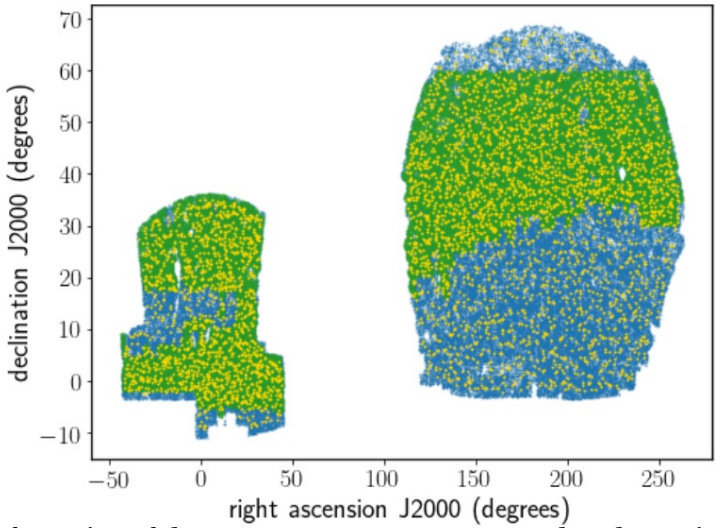


Varying $\alpha_\perp/\alpha_\parallel$

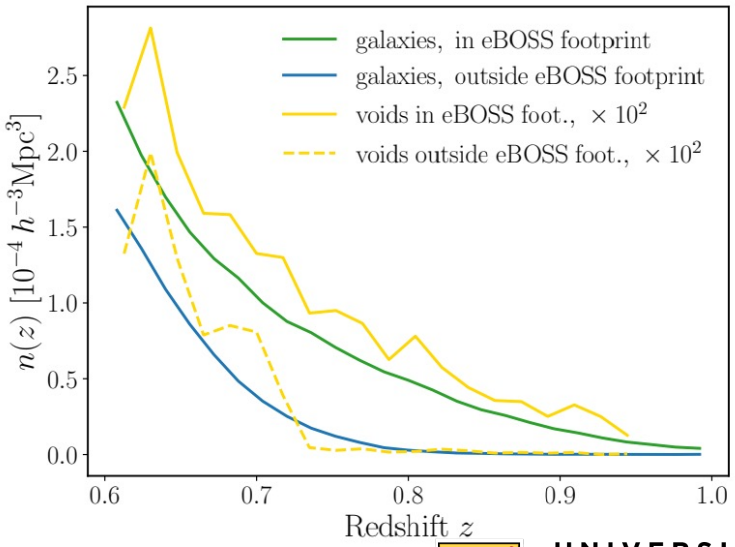


eBOSS – The Survey

- Extension of the BOSS survey that mapped galaxies in the redshift range $0.6 \leq z \leq 1$ (Tail end of BOSS galaxies extended to $z \approx 0.8$)
- 4700 voids identified in the redshift range $0.6 \leq z \leq 1$
- Void finding performed using the Revolver code
  - Reconstruction is ran over a grid of beta values to estimate real space galaxy positions, from which voids are found

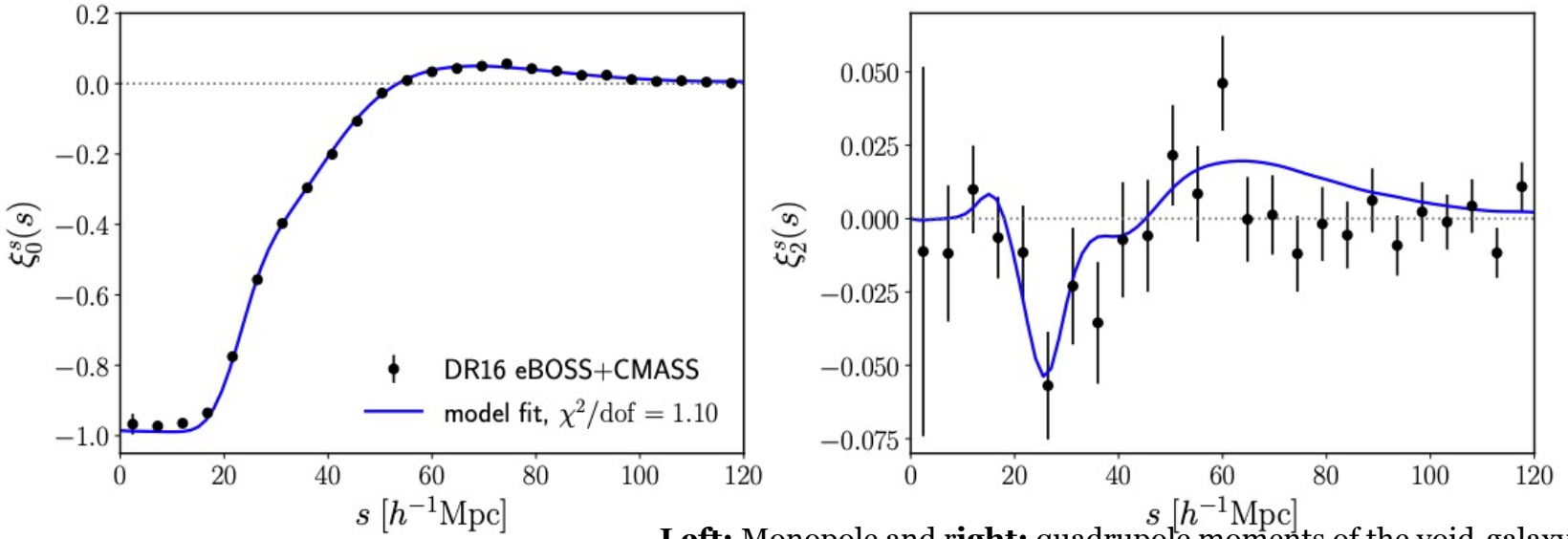


The footprint of the eBOSS+CMASS LRG sample. Blue points show the distribution of CMASS galaxies, overlapping green points show the eBOSS LRGs, and the yellow points show the locations of void centres.

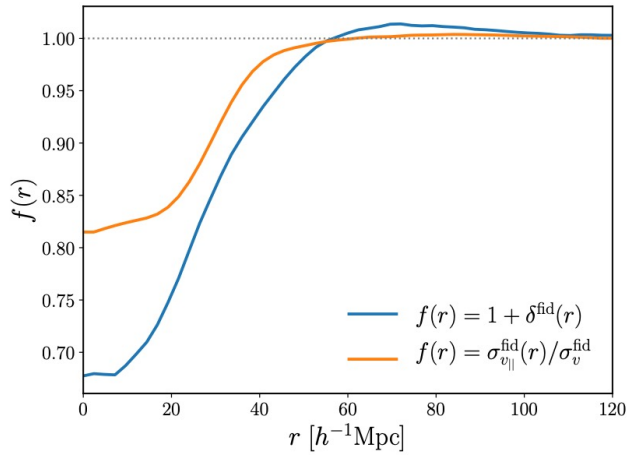


All Images from Nadathur et al. 2020

eBOSS - Results



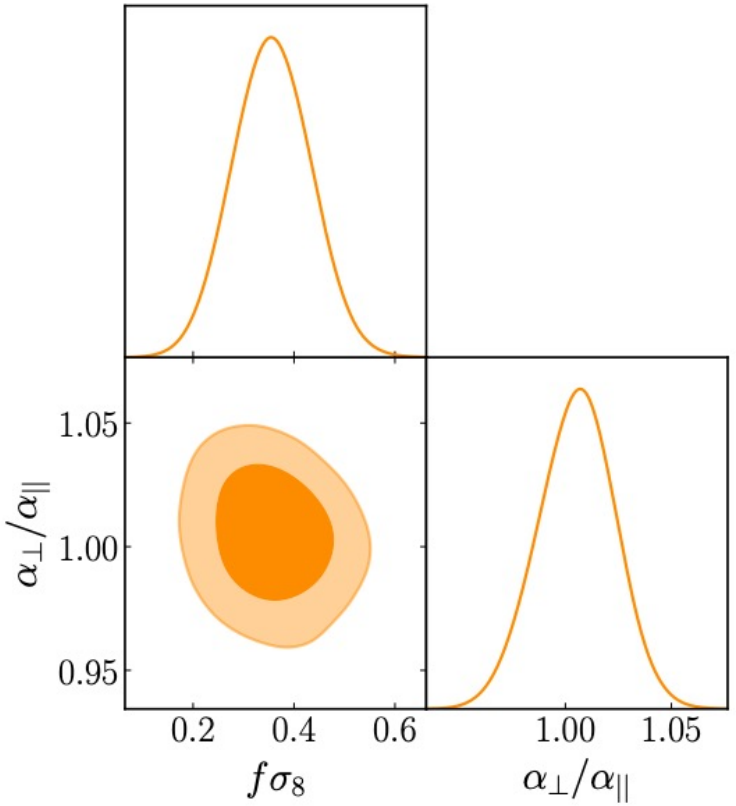
Left: Monopole and **right:** quadrupole moments of the void-galaxy correlation from the eBOSS+CMASS LRG sample along with the best fit theory describing these data, corresponding to parameter values $f\sigma_8 = 0.355$ and $\alpha_\perp/\alpha_\parallel = 1.011$ (max likelihood point). Error bars on the data points are the 1σ uncertainties derived from the diagonal entries of the covariance matrix calculated from the 1000 EZmocks



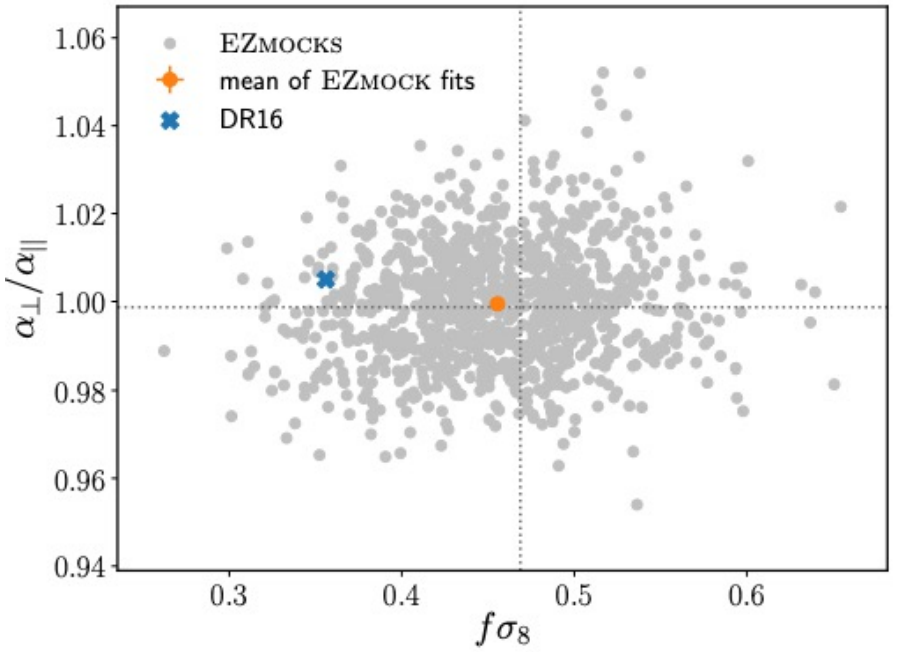
The void-matter density profile, $\delta(r)$, and galaxy velocity dispersion profile $\sigma_v(r)$ measured from eBOSS like mock galaxy catalogues in the BigMD simulation at $z = 0.70$. These functions are used to calibrate the model of the void-galaxy correlation.

All Images from Nadathur et al. 2020

eBOSS – Results - SYSTEMATICS



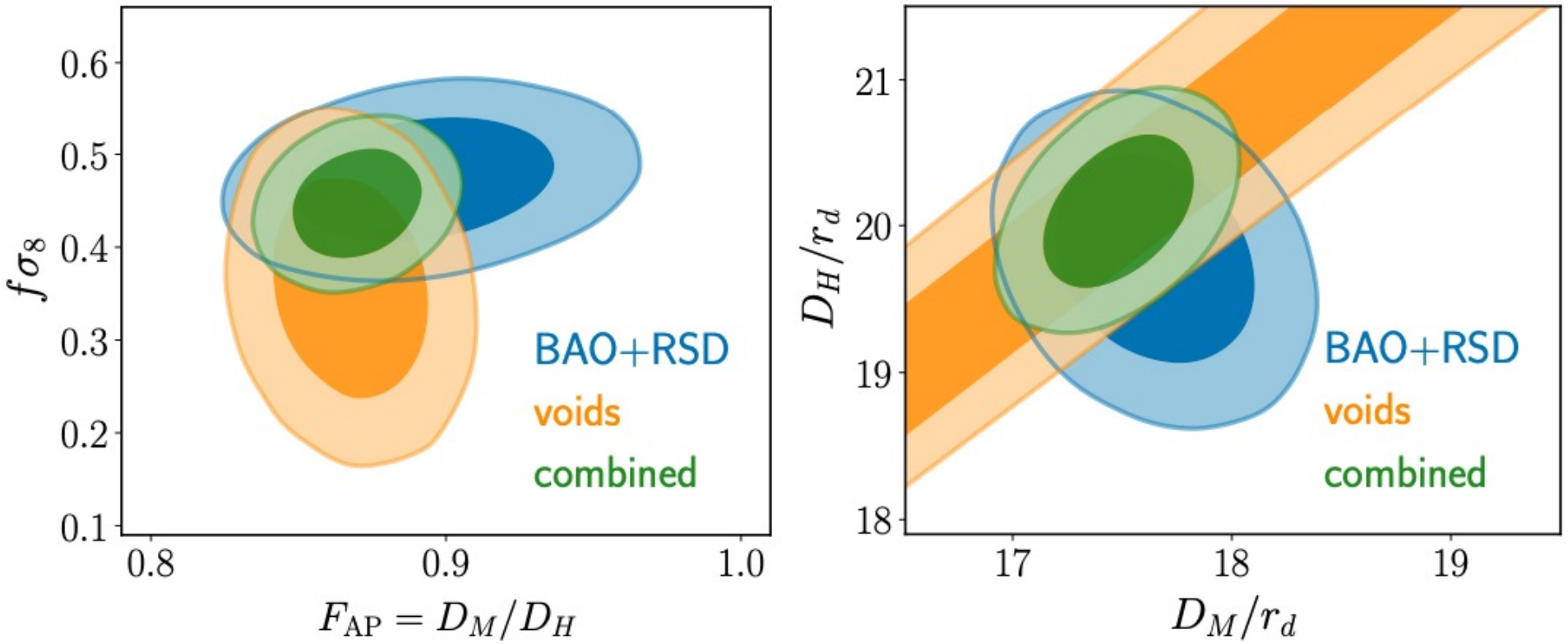
Marginalised posterior constraints on parameters $f\sigma_8$ and $\alpha_\perp/\alpha_\parallel$ from the fit to the eBOSS+CMASS data. The shaded contours show the 68% and 95% confidence limit regions



Results of the void-galaxy model applied to EZmocks ($\Omega_m = 0.310$). Grey points show the mean values in each of the 1000 EZ mock realisations. The orange circle shows the mean of these values. The dashed lines indicate the true expected values ($f\sigma_8 = 0.4687$ and $\alpha_\perp/\alpha_\parallel$=0.9987). Blue cross shows the result of the measurement on the actual eBOSS+CMASS sample

All Images from Nadathur et al. 2020

eBOSS #3 – Consensus Results



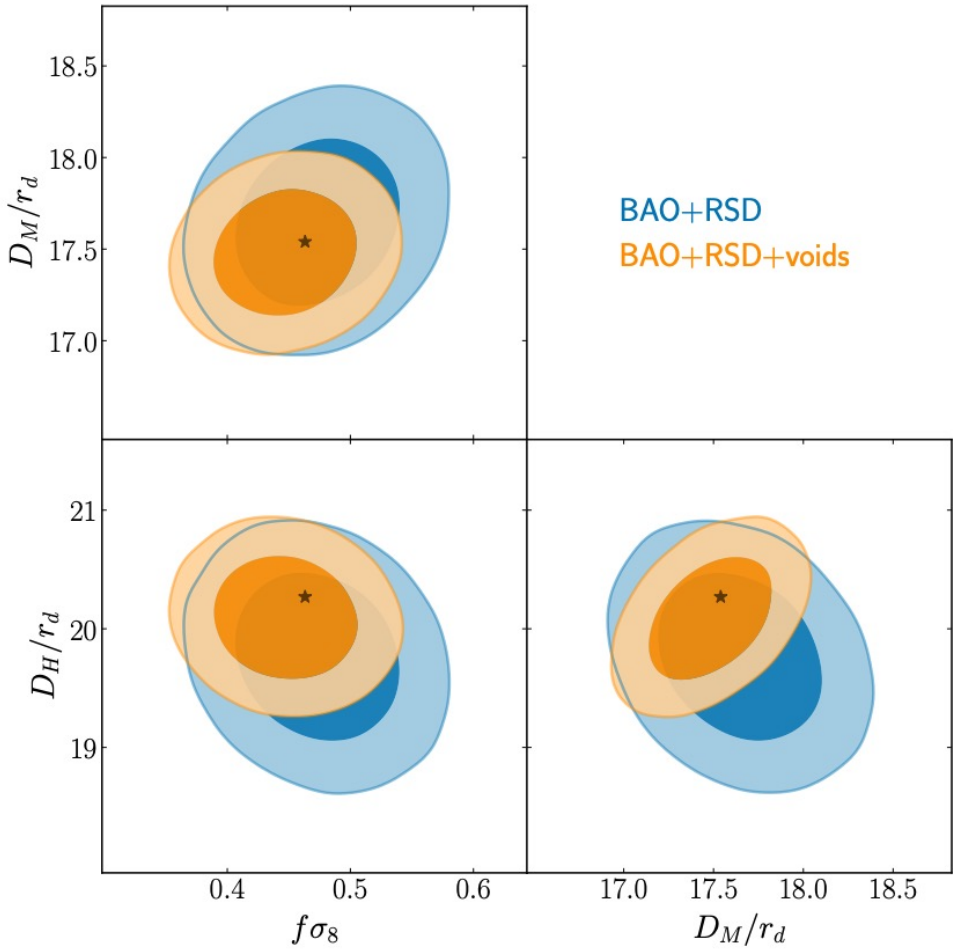
1σ and 2σ posterior constraints on cosmological parameters from eBOSS+CMASS LRG sample ($z_{eff} = 0.70$) obtained from galaxy clustering (consensus of BAO+RSD; blue), void-galaxy correlation (orange) and their combination (green). The left panel shows the growth rate $f\sigma_8$ versus the ratio of transverse comoving distance D_M to Hubble distance D_H . The right panel shows constraints on D_M/r_d and D_H/r_d, where rd is the sound horizon scale.

eBOSS #4 – Consensus Constraints

- Results can be combined with BAO+RSD measurements finding:
  - $D_m/r_d = 17.48 \pm 0.23$
  - $D_H/r_d = 20.10 \pm 0.34$
  - $f\sigma_8 = 0.447 \pm 0.0039$

- Improvement in errors of 13%, 23%, and 28% for $f\sigma_8$, D_m/r_d, D_H/r_d respectively

- Consistent with ΛCDM



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Conclusions

- There is a lot more information available in galaxy surveys
- Our void measurements are a robust new method to extract more information