Analysis of the response of void BAO to systematic effects in the SDSS observations using mock datasets

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Outline I

Introduction I

- The use of voids + matter ones $\Rightarrow$ $\sim 10\%$ improvement of error & 20% survey size increase.
- Voids could be less sensitive to systematic effects than matter.

Voids I

Definition is controversial, we use a **geometrical** one.
Delaunay Triangulation $\longrightarrow$ Voids are circumspheres in the simplices with tracers as vertices.

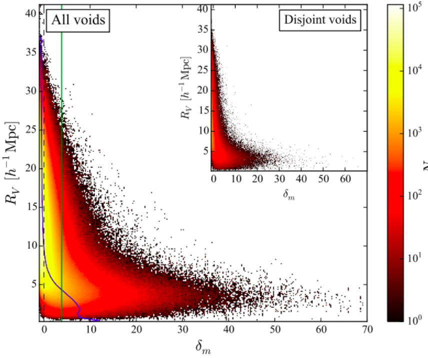
Small voids

- Radius cut: $R_c < 8\,h^{-1}\mathrm{Mpc}$
- Located in regions with high δ_{dm}
- Correlated with galaxy sample
- Are actually Dark Matter

Big voids

- Radius cut: $R_c > 15.5\,h^{-1}\mathrm{Mpc}$
- Located in regions with low δ_{dm}
- Anticorrelated with galaxy sample
- Are actually empty

Voids II



Number of voids, N_V, as a function of Dark Matter density, δ_{dm}, and void radius, R_V. Taken from (Zhao et al., 2016)

How do we know?

- Large voids are constrained to regions with low matter density.
- Small void population spans a wide range of densities.

Data I

We use 1000 **EZ mocks** Zhao and Chuang (2020).

- Displacement field from Zel'dovich
- PDF extraction from n-body simulation
- Halo position assignment

Table: Fiducial cosmology parameters used to produce the EZmocks used in this work.

Parameter	Value
Ω_m	0.307115
Ω_b	0.048206
h	0.6777
σ_8	0.8225
n_s	0.9611

Systematics: Fiber collisions I

- Objects too close in the sky ($r_{cp} < 62''$) can't be seen at the same time due o width of the fiber.
- One is measured by the plate. The other one(s) could still be measured by other plate.
- Define $\mathrm{TSR} = \frac{\text{measured targets}}{\text{total number of targets}}$, per sector.
- Compensate this effect with $w_{cp} \approx \mathrm{TSR}^{-1}$
  Actually $w_{cp} = \frac{\text{total number of targets}}{\text{measured targets}}$ but defined per **collision group**.

Systematics: Redshift Failures I

- Errors in the spectroscopic pipeline $\Rightarrow \; \mathrm{SSR} < 1$.
- Two sources of error: Observational conditions & Position of fiber
- This is corrected by the weight

$$w_{noz} \equiv (\mathrm{SSR}_{\mathrm{obs}}\mathrm{SSR}_{\mathrm{pos}})^{-1}.$$

Systematics: Angular Photometric I

- Represented as HEALPIX maps containing different photometric parameters, p_i.
- Parameters are combined as

$$y^k = \epsilon + \sum_i c_i p_i^k$$

where the model weights, c_i are optimized (per chunk) such that $n_{\mathrm{dat},k} \approx n_{\mathrm{ran},k} y^k$, where k indicates the pixels.

- The photometric weights designed to partially correct for these effects are defined as

$$w_{\mathrm{systot}} = \left(y^k\right)^{-1}.$$

Systematics: Normalization I

- Completeness weights are defined as:

$$w_{\mathrm{comp}} = w_{\mathrm{systot}} w_{cp} w_{noz}.$$

- Some normalization is done (on w_{systot} before w_{comp} and on w_{noz} after).
- Invalid objects are set $w_{cp}, w_{noz} = 0$.
- Only elements with $\mathrm{SSR} \geq 0$, $z \in (0.6, 1.1)$ and completeness $> 50\%$ are selected.
- The dependence on $n(z)$ is corrected by

$$w_{\mathrm{FKP}} \equiv \frac{1}{1 + n(z) P_0}; \quad P_0 = 4000\, h^{-3}\mathrm{Mpc}^3.$$

Systematics: Application I

- We compute $w_{\mathrm{comp}}^{\mathrm{ALLSYST}} = w_{\mathrm{systot}} w_{cp} w_{noz} w_{\mathrm{FKP}}$ and the effective number of tracers in each chunk

$$n_{eff} = \sum_{i=1}^{N_{chunk}} w_{\mathrm{comp},i}^{\mathrm{ALLSYST}},$$

where N_{chunk} is the number of tracers in the chunk considered.

- We then compute

$$w_{\mathrm{comp}}^{\mathrm{PARTIAL}} = w_{\mathrm{FKP}} \prod_{s \in \mathcal{S}'} w_s,$$

Systematics: Application II

where $\mathcal{S}' \subseteq \mathcal{S}$ is the subset of systematic effects to be considered and $\mathcal{S} = \{\mathrm{systot},\ noz,\ cp\}$. In this case we compute the new effective number of tracers

$$n'_{eff} = \sum_{i=1}^{N_{chunk}} w^{\mathrm{PARTIAL}}_{\mathrm{comp},i}.$$

- Objects in the catalog with $w^{\mathrm{PARTIAL}}_{\mathrm{comp}} = 0$ or $\mathtt{veto} = 0$ (such as objects outside the survey area or masked by bright stars) are removed.
- We then normalize the completeness weights in each chunk by the corresponding n_{eff}/n'_{eff} to keep the original effective number of tracers.

Catalog generation I

- Export catalogs with

$$\mathrm{RA},\ \mathrm{DEC},\ z,\ w_{cp}w_{\mathrm{FKP}},\ w_{cp},\ w_{\mathrm{FKP}},\ n(z)$$

- Use DIVE to extract void catalogs with

$$\mathrm{RA},\ \mathrm{DEC},\ z,\ R$$

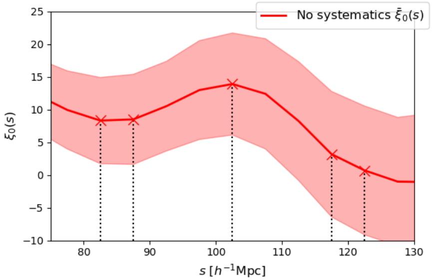
- Mask void catalogs
- Create void randoms
  - Combine 100 void mocks
  - Divide into z bins
  - divide each bin in R bins

- Split "vertically" into $\mathrm{RA},\ \mathrm{DEC} \mid z,\ R$.
- Shuffle one of the two halves.
- Recombine halves and all bins.
- Randomly choose 2 700 000 with $R > R_c (= 15.5\,h^{-1}\mathrm{Mpc})$

Radius cut I

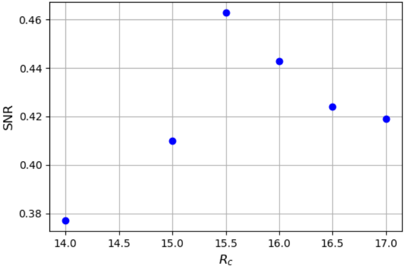
Analyze signal-to-noise ratio $(\mathrm{SNR} \equiv \frac{\langle S \rangle}{\sigma_S})$ for 100 void mocks with different R_c. Use definition of signal, S, as in Liang, Zhao, Chuang, Kitaura, and Tao (2016).

$$S = \xi_0(s^{\mathrm{BAO}}) - \frac{\xi_0(s_1^{\mathrm{dl}}) + \xi_0(s_2^{\mathrm{dl}}) + \xi_0(s_1^{\mathrm{dr}}) + \xi_0(s_2^{\mathrm{dr}})}{4} \quad (1)$$



$s_1^{\mathrm{dl}} = 82.5$, $s_2^{\mathrm{dl}} = 87.5$, $s_1^{\mathrm{BAO}} = 102.5$, $s_1^{\mathrm{dr}} = 117.5$ and $s_2^{\mathrm{dr}} = 122.5\,h^{-1}\mathrm{Mpc}$ respectively from left to right.

Radius cut II



SNR vs low radius cut R_c. Upper cut is always set to $50\,h^{-1}$Mpc. Maximum SNR is obtained for $R_c = 15.5\,h^{-1}$Mpc.

The BAO model I

We use the model in Zhao et al. (2018):

$$\xi_t(s) = \int \frac{k^2 \mathrm{d}k}{2\pi^2} \frac{\sin ks}{ks} P_t(k) \exp\left(-k^2 a^2\right), \quad a = 1\, h^{-1}\mathrm{Mpc} \tag{2}$$

$$P_t(k) = \left\{ [P_{\mathrm{lin}}(k) - P_{\mathrm{nw}}(k)] \exp\left(\frac{-\Sigma_{\mathrm{nl}}^2 k^2}{2} \right) + P_{\mathrm{nw}}(k) \right\} \frac{P_{\mathrm{t,nw}}(k)}{P_{\mathrm{lin,nw}}(k)}, \tag{3}$$

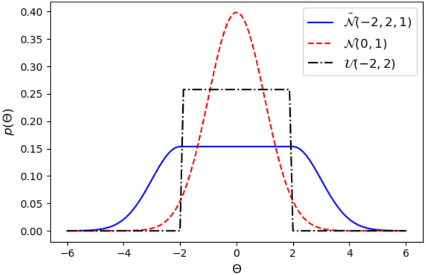
$$\xi_{\mathrm{model}}(s) \equiv B^2 \xi_t(\alpha s) + A(s), \quad A(s) = \frac{a_1}{s^2} + \frac{a_2}{s} + a_3 \tag{4}$$

	Galaxies	Voids
$\frac{P_{\mathrm{t,nw}}(k)}{P_{\mathrm{lin,nw}}(k)}$	1	$1 + ck^2$

Parameter fitting I

Bayesian inference:

$$p(\Theta|X) = \frac{p(X|\Theta)p(\Theta)}{p(X)} = \frac{\mathcal{L}(\Theta)p(\Theta)}{\mathcal{Z}}, \quad (5)$$



Examples of the different kinds of priors used in the fitting.

Parameter fitting II

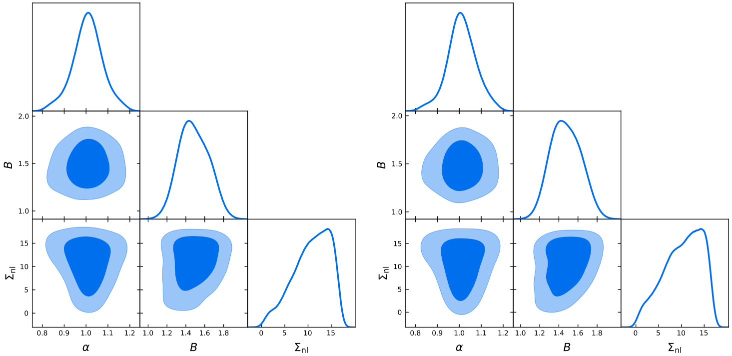
Voids

$$p(\Sigma_{\mathrm{nl}}) = \mathcal{U}(0, 20) \tag{6}$$
$$p(B) = \mathcal{N}(2, 0.15) \tag{7}$$
$$p(\alpha) = \mathcal{U}(0.8, 0.12) \tag{8}$$
$$p(c) = \bar{\mathcal{N}}(-500, 1000, 100) \tag{9}$$

Galaxies

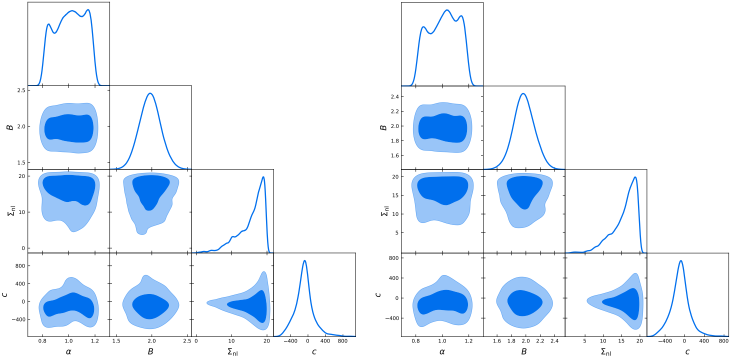
$$p(\Sigma_{\mathrm{nl}}) = \mathcal{U}(5, 17) \tag{10}$$
$$p(B) = \bar{\mathcal{N}}(1.4, 1.6, 0.12) \tag{11}$$
$$p(\alpha) = \mathcal{U}(0.8, 0.12) \tag{12}$$

Results: Mean 2PCF I



Posterior distributions for the model parameters in the galaxy BAO fit. Left panel shows the case in which no systematical effects were applied. Right panel shows the results for mocks with all systematics applied.

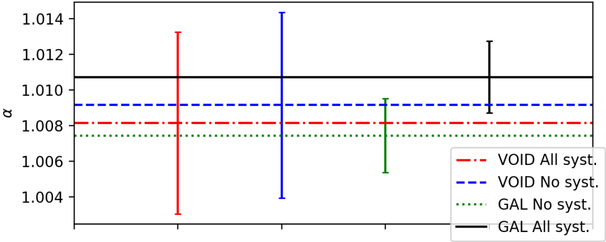
Results: Mean 2PCF II



Posterior distributions for the model parameters in the void BAO fit. Left panel shows the case in which no systematical effects were applied. Right panel shows the results for mocks with all systematics applied.

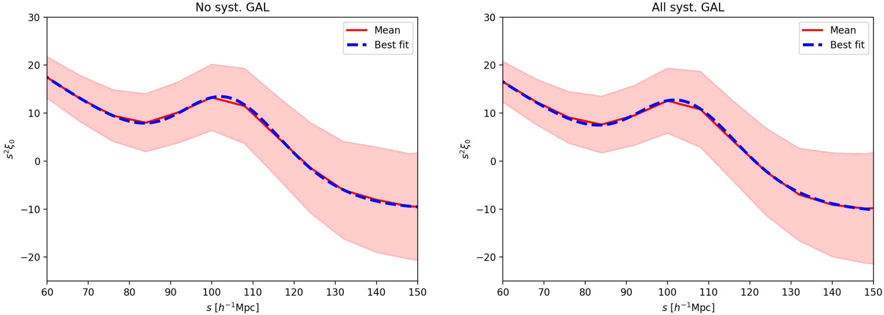
Results: Mean 2PCF III

	Galaxies	Voids
$\alpha_{\mathrm{all}} - \alpha_{\mathrm{none}}$	$(3.34 \pm 2.89) \times 10^{-3}$	$(-9.9 \pm 72.9) \times 10^{-4}$



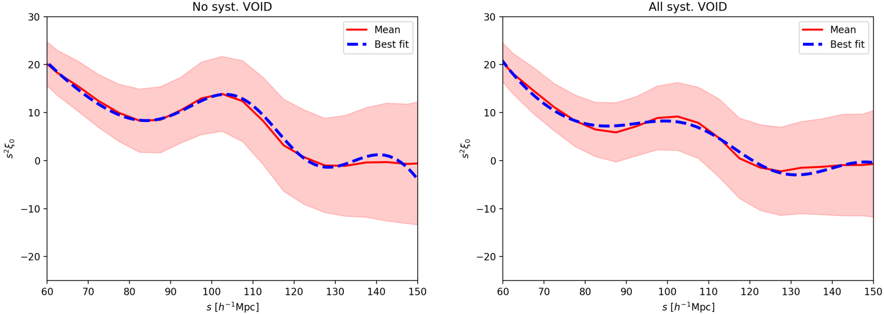
Fit results for the dilation parameter α when using the mean of the mocks.

Results: Mean 2PCF IV



Best fit curves for galaxy tracers with (right) and without (left) systematics. Shaded region shows the 1σ band obtained from the mock sample.

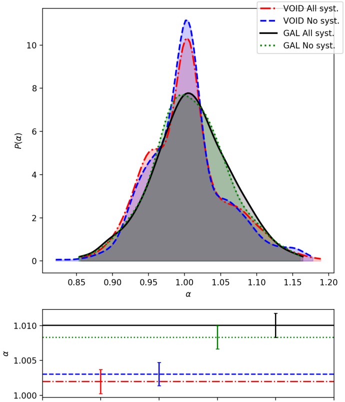
Results: Mean 2PCF V



Best fit curves for void tracers with (right) and without (left) systematics. The model fits the mean curve well within the 1σ band (shaded region). We observe, however, that the model does not follow the mean curve as close as for the galaxy case, specially at larger scales.

Results: Individual 2PCF I

	Galaxies	Voids
$\alpha_{\text{all}} - \alpha_{\text{none}}$	$(1.89 \pm 2.39) \times 10^{-3}$	$(-1.07 \pm 2.39) \times 10^{-3}$



Fit results for the α parameter from fitting each of the mocks individually. Top panel shows the distributions obtained. Bottom panel shows the mean values and the (scaled) standard deviation as error.

References I

Liang, Y., Zhao, C., Chuang, C.-H., Kitaura, F.-S., & Tao, C. (2016). Measuring baryon acoustic oscillations from the clustering of voids. *Monthly Notices of the Royal Astronomical Society*, *459*(4), 4020–4028. doi:10.1093/mnras/stw884

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Zhao, C., Tao, C., Liang, Y., Kitaura, F.-S., & Chuang, C.-H. (2016). DIVE in the cosmic web: voids with Delaunay triangulation from discrete matter tracer distributions. *Monthly Notices of the Royal Astronomical Society*, *459*(3), 2670–2680. doi:10.1093/mnras/stw660