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

Daniel Felipe Forero-Sánchez

Laboratory of Astrophysics (LASTRO)

École Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Suisse

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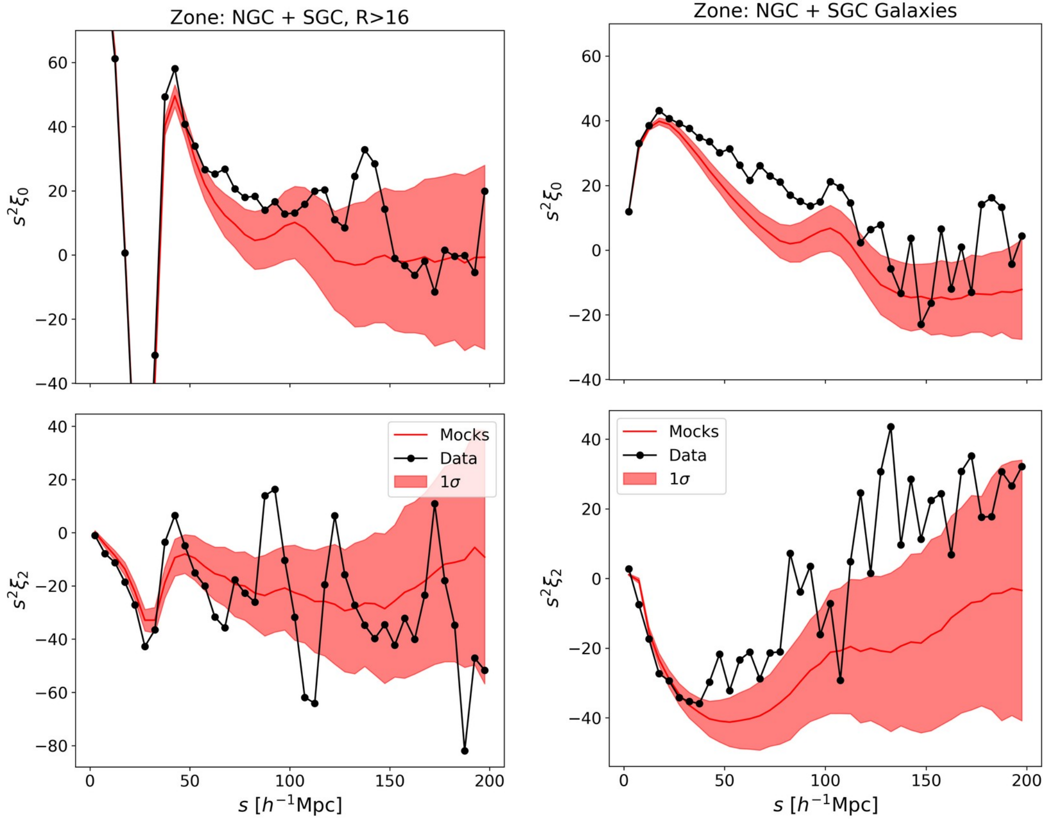
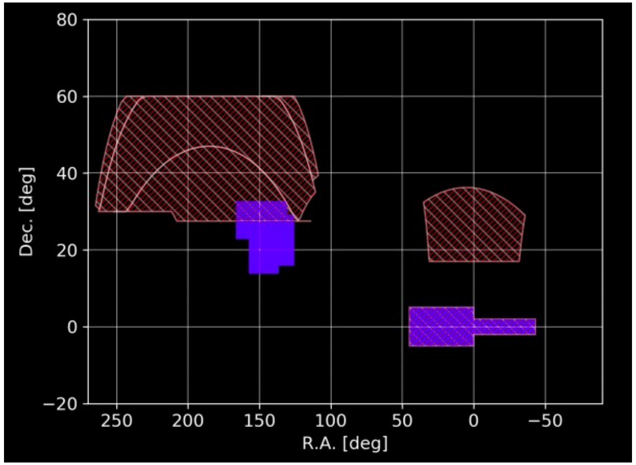
Introduction

- Void + Matter
  - 10% improvement in error
  - 20% Survey size increase
- Voids less sensitive to systematical effects.
- **Negativity of quadrupole** is expected for galaxies at large scales.
- Systematics affect the measurement of BAO peak.
- **How different is this effect on voids?**

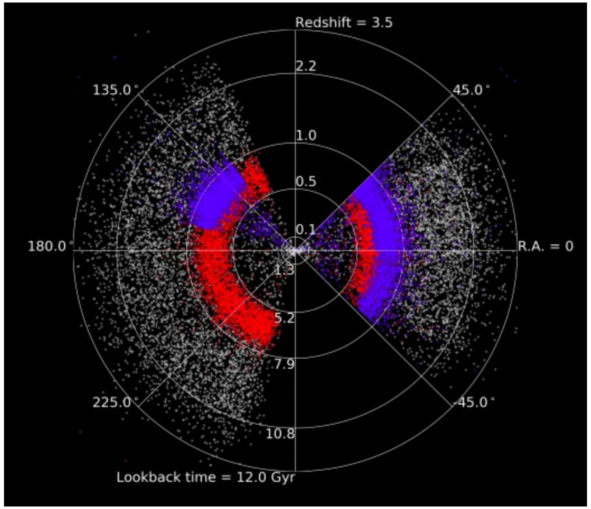


The eBOSS Survey

- **Extended Baryon Oscillation Spectroscopic Survey**
- Measure 3D (RA, DEC, z) position of matter tracers:
  - LRG: $z \in (0.6, 1)$
  - ELG: $z \in (0.6, 1.1)$
  - QSO: $z \in (0.8, 2.2)$
- Data taking from 2014 to 2019
- Currently: Final data analysis

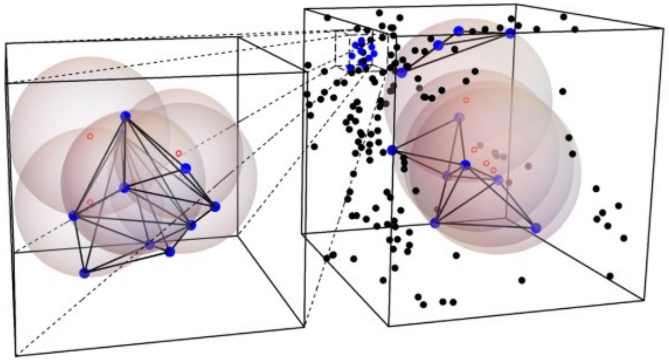


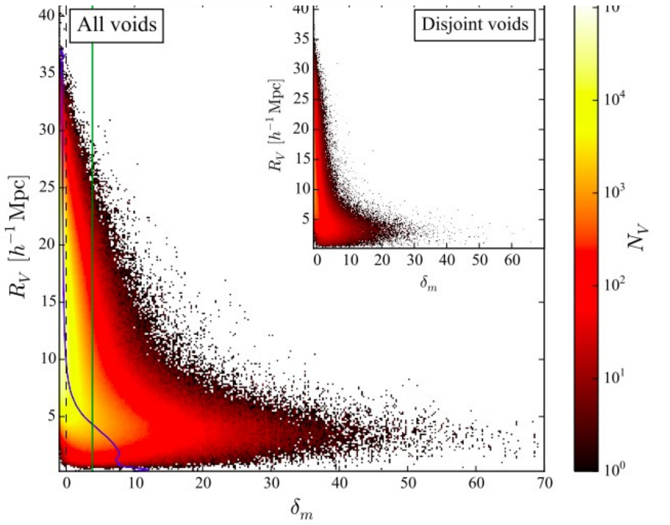
Credits: A. Raichoor



Voids

- Geometrical definition: Delaunay Triangulation: Spherical voids.
- Two populations:
  - **Small “voids”:**
    - Not actually voids
    - Small radii $R_c < 8\ h^{-1}\ \mathrm{Mpc}$
    - Correlated with matter tracers.
  - **Big voids:**
    - Underdensities
    - Large radii $R_c > 15.5\ h^{-1}\ \mathrm{Mpc}$
    - Anticorrelated with matter tracers



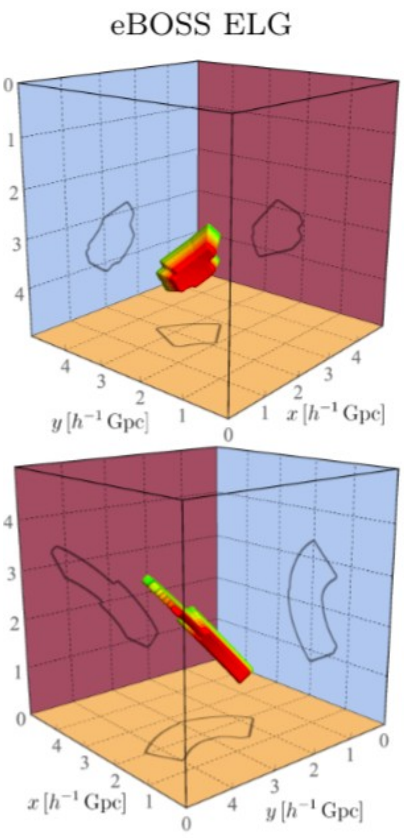


Zhao et. al. 2016

Data

- **1000 EZ mocks** emulating ELG observations.**:**
  - Displacement field from Zel'dovich Approximation
  - PDF extraction from n-body simulation.
  - Halo position assignment
- Planck fiducial cosmology:

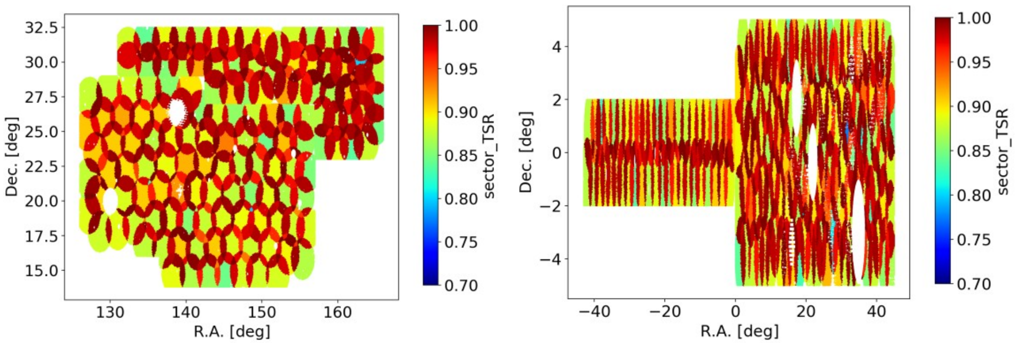
Parameter	Value
Ω_m	0.307115
Ω_b	0.048206
h	0.6777
σ_8	0.8225
n_s	0.9611



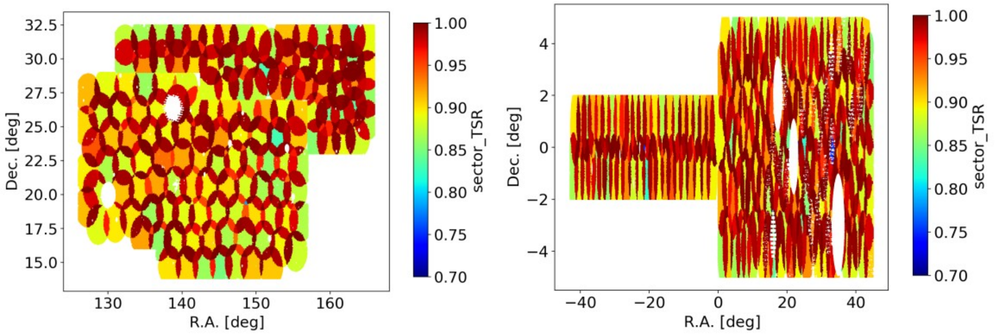
Zhao et. al. 2020

Systematics: Fiber Collisions

- Two (or more) objects too close in the sky (62'') can't be resolved by a single fiber.
- Choose which one to measure. The remaining ones can be seen by other plate.
- **Tiling Success Rate** (by sector) $\mathrm{TSR} = \dfrac{\text{measured targets}}{\text{total number of targets}}$
- **Upweight missing objects** (by collision group) $w_{cp} = \dfrac{\text{total number of targets}}{\text{measured targets}}$



eBOSS



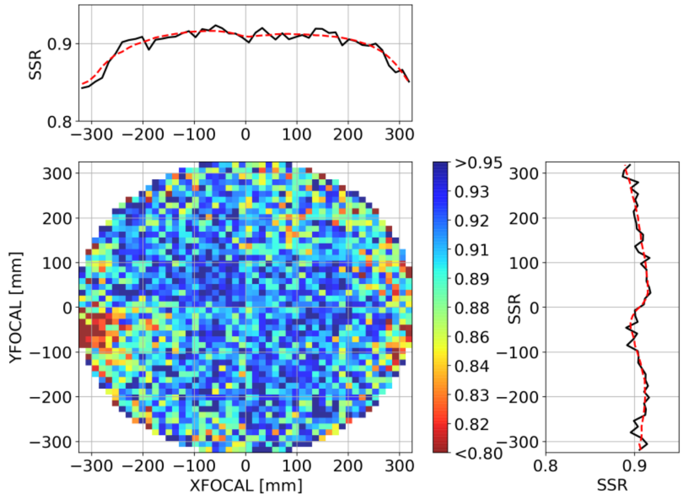
De Mattia et. al., 2020

EZ mocks

Systematics: Redshift Failures

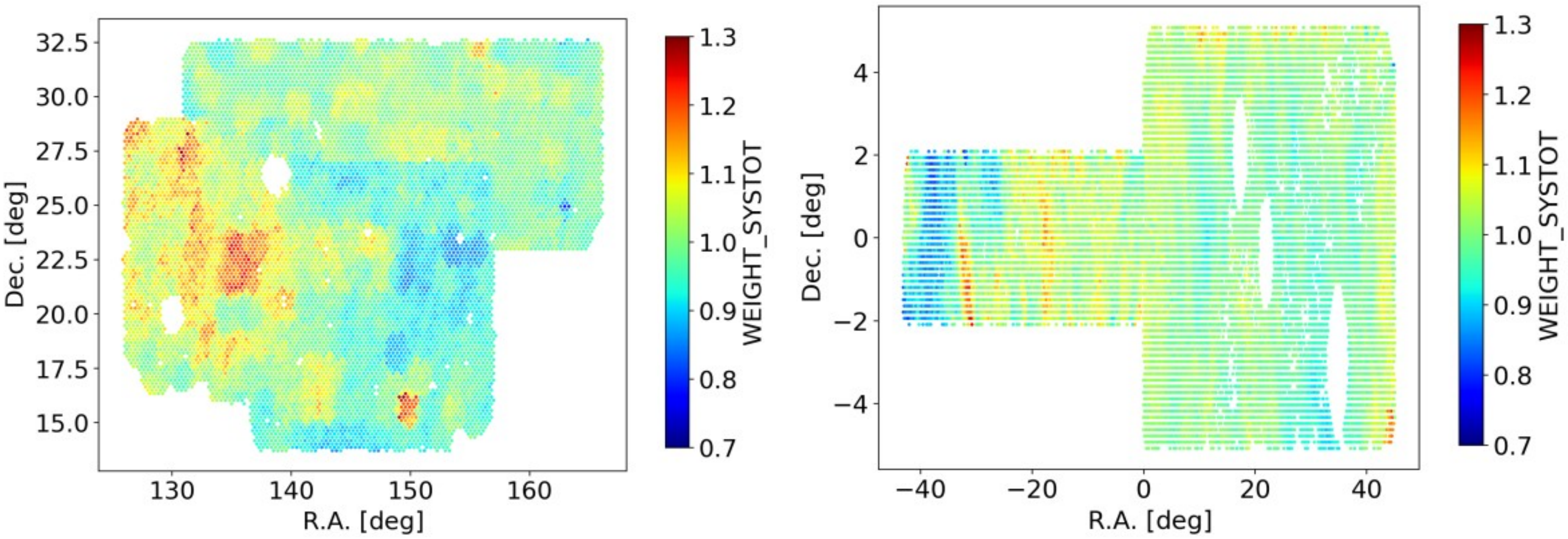
- Errors in spectroscopic pipeline: **Spectroscopic Success Rate (SSR)**
  $\mathrm{SSR} < 1$
- Errors due to observational conditions (SNR) and fiber position.
- Upweight objects teking into account both effects.

$$w_{noz} \equiv (\mathrm{SSR_{obs}SSR_{pos}})^{-1}$$



De Mattia et. al.. 2020

Systematics: Angular Photometric



De Mattia et. al.. 2020

- Model inhomogeneities in the sky with some function of observational parameters

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

- Partially correct for a "homogeneous sky"

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

Systematics: Normalization and cuts

- Define

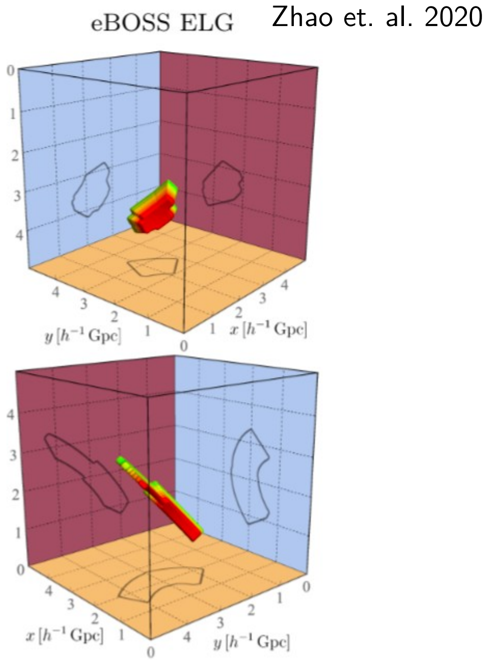
$$w_{\text{comp}} = w_{\text{systot}} w_{cp} w_{noz}$$

- Normalize photometrics before and redshift failures after computing completeness.
- Remove invalid objects by setting weight to 0
- Choose elements with SSR > 0.5
- Choose elements with $z \in (0.6, 1.1)$
- Take into account the redshift density $n(z)$

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

Catalog generation

- 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 catalogs to the survey geometry
- Create randoms:
  - Combine 100 mocks
  - Divide in redshift bins
  - Divide each in radius bins
  - Split columns as $\mathrm{RA},\ \mathrm{DEC} \mid z,\ R$
  - Shuffle one half
  - Recombine
  - Randomly choose 2 700 000 elements with $R > R_c (= 15.5\ h^{-1}\ \mathrm{Mpc})$

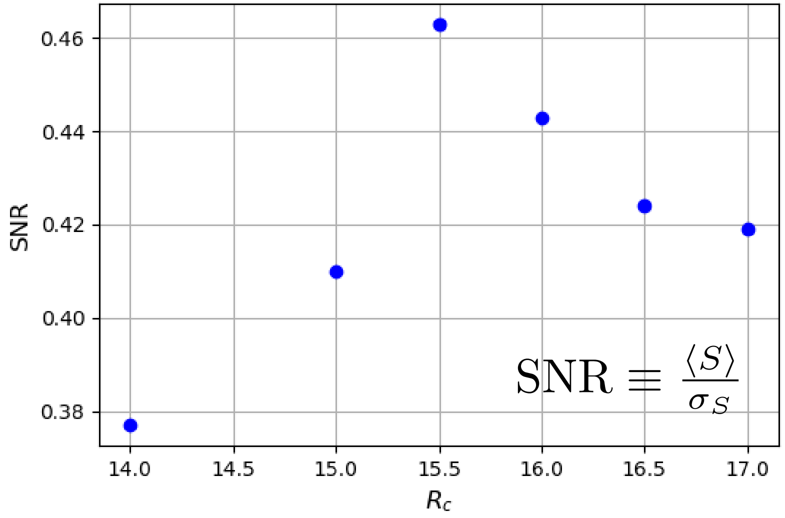


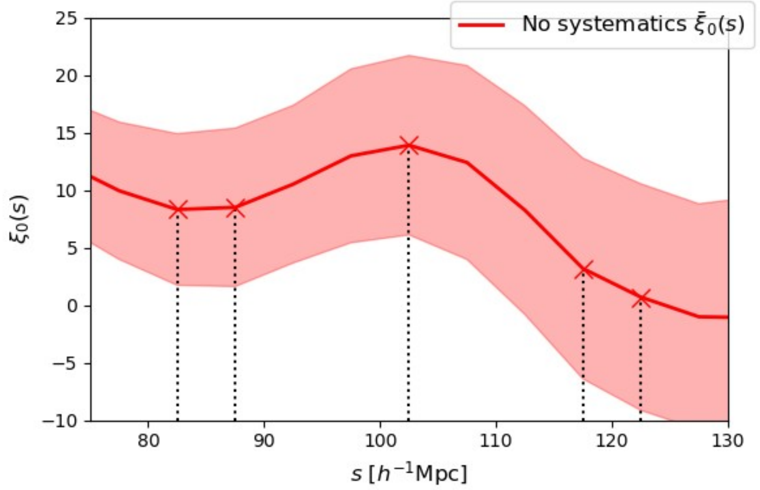
Radius cut

- Define signal as in Liang et. al. (2016)

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

- Analyze the signal-to-noise ratio SNR using 100 EZ mocks without systematics.





$$s_1^{\mathrm{dl}} = 82.5,\ s_2^{\mathrm{dl}} = 87.5,\ s_1^{\mathrm{BAO}} = 102.5,$$
$$s_1^{\mathrm{dr}} = 117.5,\ s_2^{\mathrm{dr}} = 122.5\ h^{-1}\ \mathrm{Mpc}$$

Optimum cut $R_c = 15.5\ h^{-1}\ \mathrm{Mpc}$

The BAO Model

- We use the model in Zhao et. al. (2019)
- We need a template (halo) correlation function:

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

- With

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

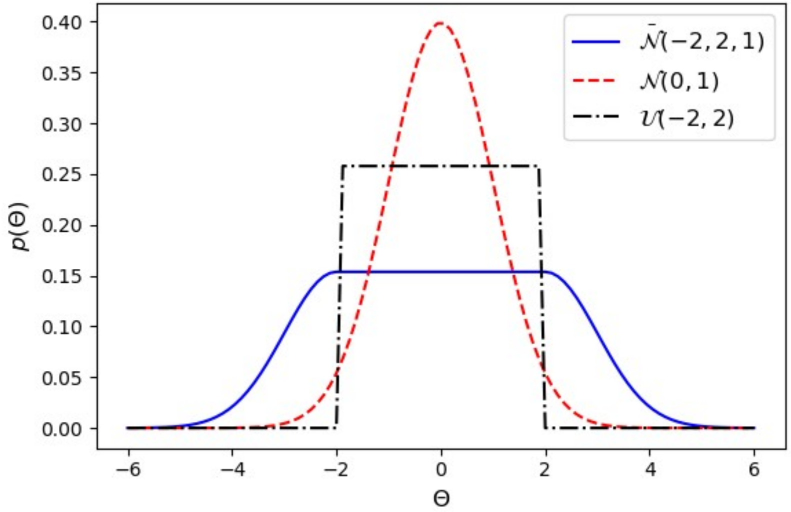
$$\frac{P_{\mathrm{t,nw}}(k)}{P_{\mathrm{lin,nw}}(k)} \xrightarrow{\text{Galaxies}} 1$$

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

- Finally our tracer model is given by

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

Parameter Fitting



Voids

$p(\Sigma_{\rm nl}) = \mathcal{U}(0, 20)$

$p(B) = \mathcal{N}(2, 0.15)$

$p(\alpha) = \mathcal{U}(0.8, 1.2)$

$p(c) = \bar{\mathcal{N}}(-500, 1000, 100)$

- Bayesian inference:

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

- Priors:

Galaxies

$p(\Sigma_{\rm nl}) = \mathcal{U}(5, 17)$

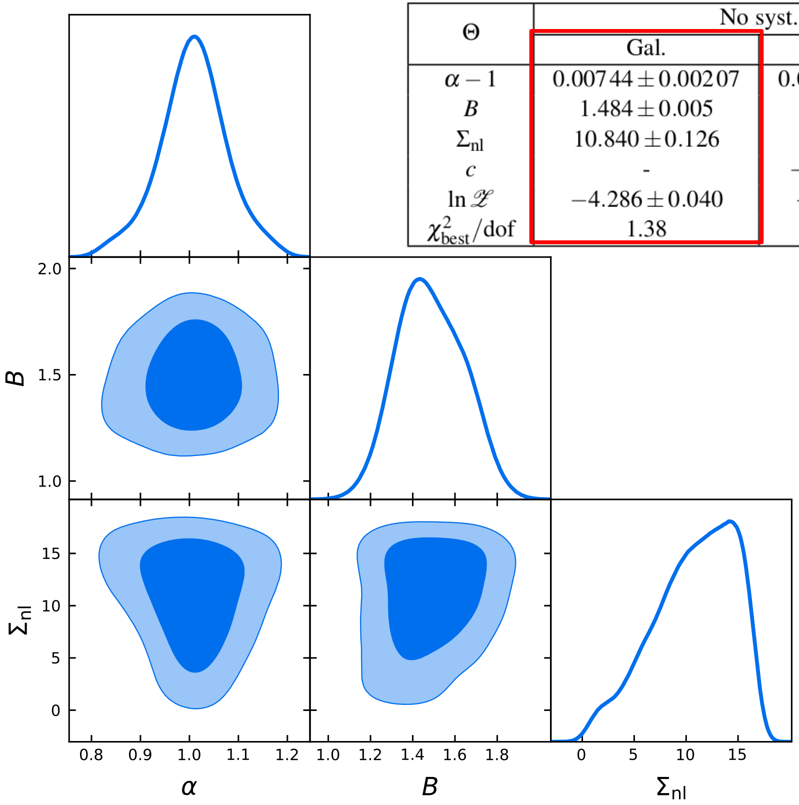
$p(B) = \bar{\mathcal{N}}(1.4, 1.6, 0.12)$

$p(\alpha) = \mathcal{U}(0.8, 1.2)$

Results: Galaxy Mean 2PCF

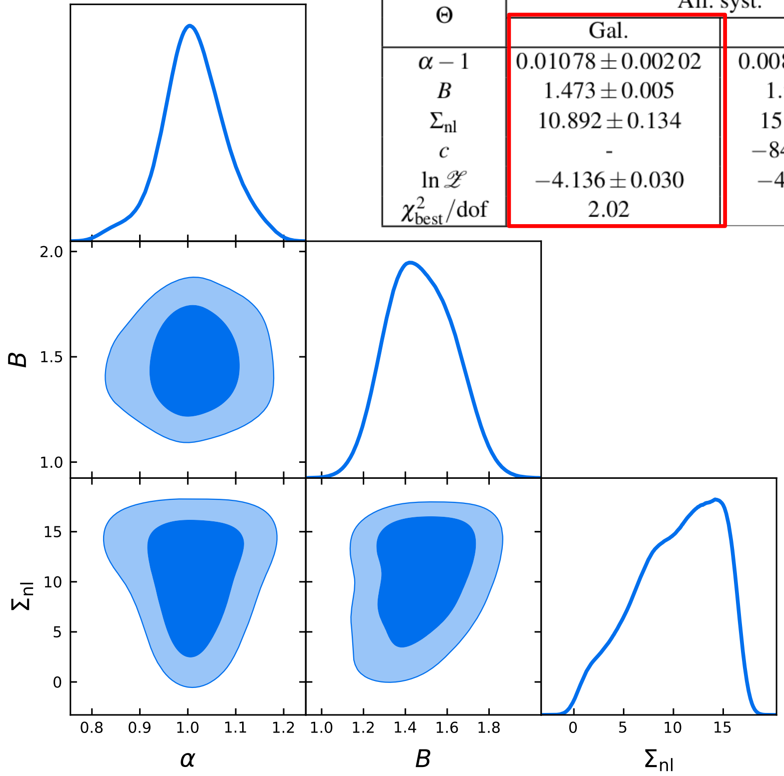
No systematics

Θ	No syst.	
	Gal.	Void
$\alpha - 1$	0.00744 ± 0.00207	0.00915 ± 0.00522
B	1.484 ± 0.005	1.975 ± 0.005
$\Sigma_{\rm nl}$	10.840 ± 0.126	15.537 ± 0.121
c	-	-81.744 ± 6.819
$\ln \mathscr{L}$	-4.286 ± 0.040	-4.225 ± 0.040
$\chi^2_{\rm best}/{\rm dof}$	1.38	11.29



All systematics

Θ	All. syst.	
	Gal.	Void
$\alpha - 1$	0.01078 ± 0.00202	0.00816 ± 0.00509
B	1.473 ± 0.005	1.974 ± 0.005
$\Sigma_{\rm nl}$	10.892 ± 0.134	15.822 ± 0.108
c	-	-84.956 ± 6.106
$\ln \mathscr{L}$	-4.136 ± 0.030	-4.109 ± 0.050
$\chi^2_{\rm best}/{\rm dof}$	2.02	13.25



Results: Void Mean 2PCF

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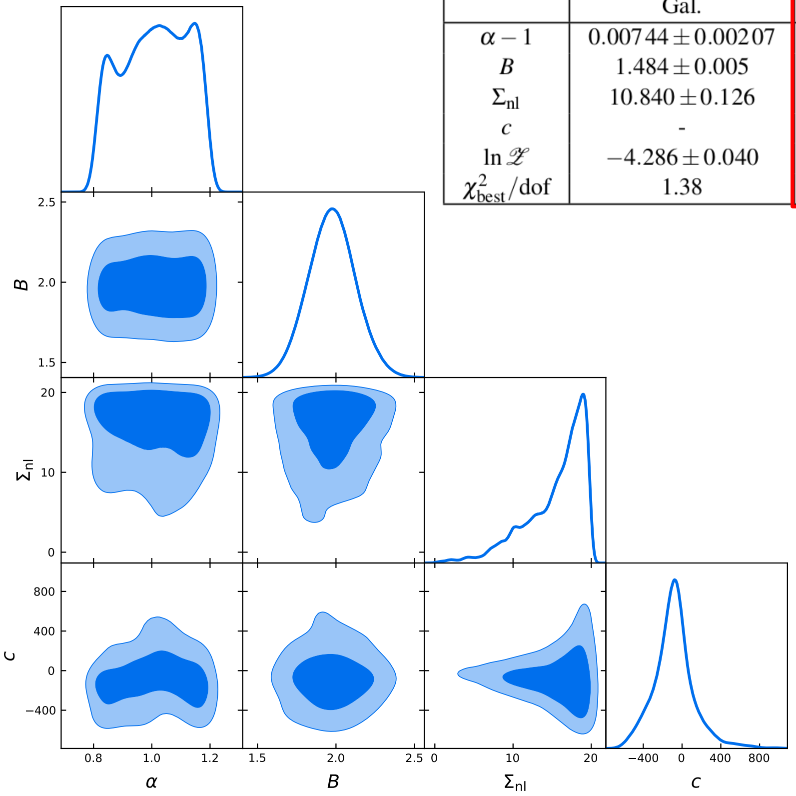

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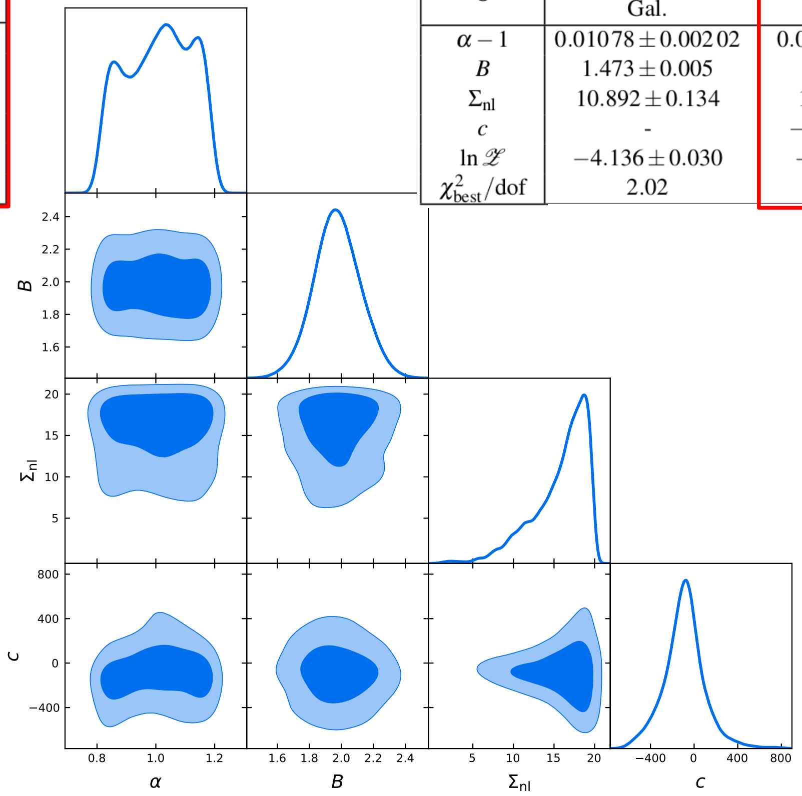
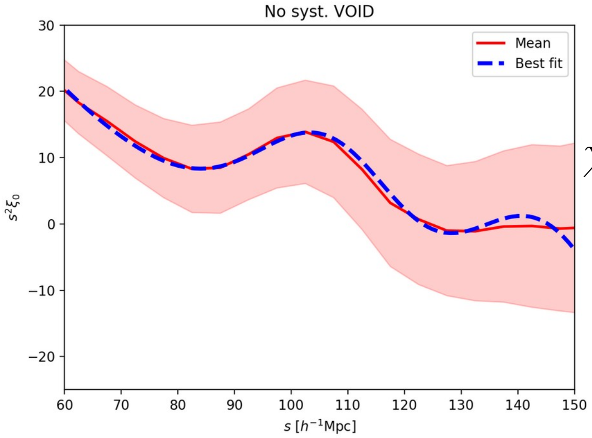
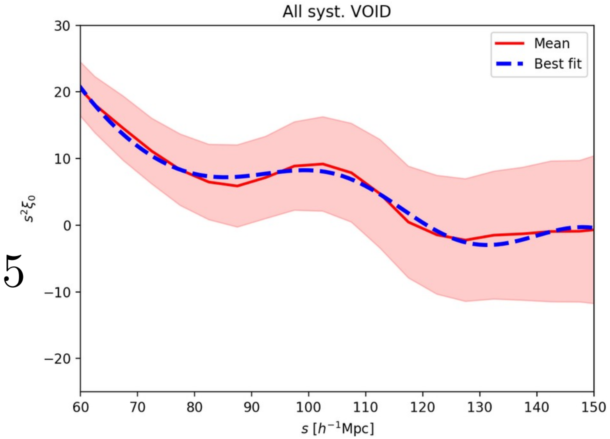


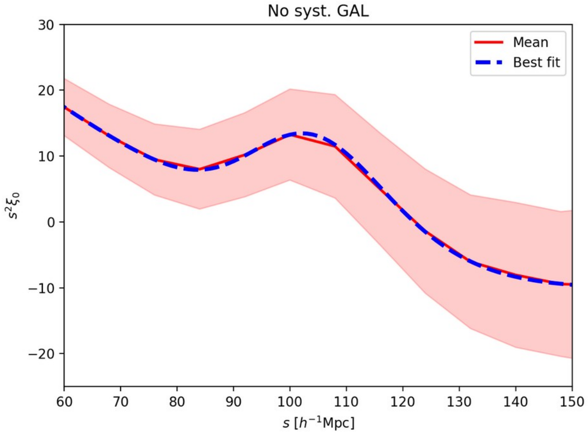
Results: Mean 2PCF Best-fits



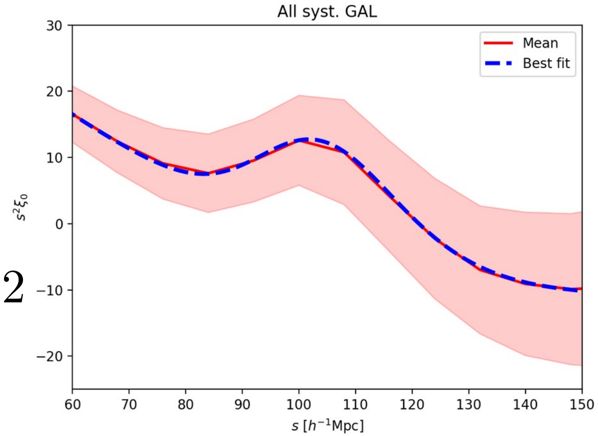
$$\chi^2_{\text{best}}/\text{dof}= 11.29$$



$$\chi^2_{\text{best}}/\text{dof}= 13.25$$

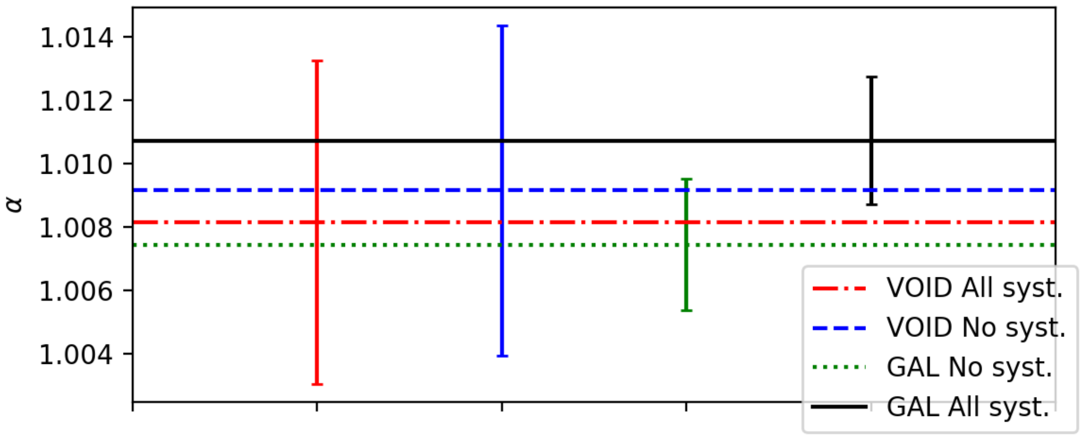


$$\chi^2_{\text{best}}/\text{dof}= 1.38$$



$$\chi^2_{\text{best}}/\text{dof} = 2.02$$

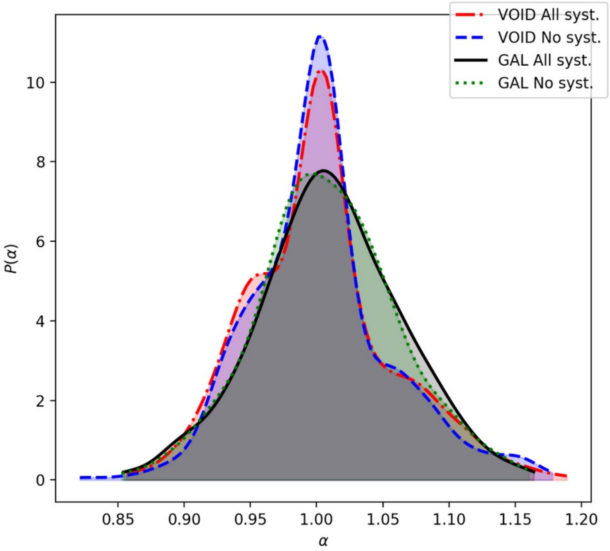
Results: Mean 2PCF Comparison

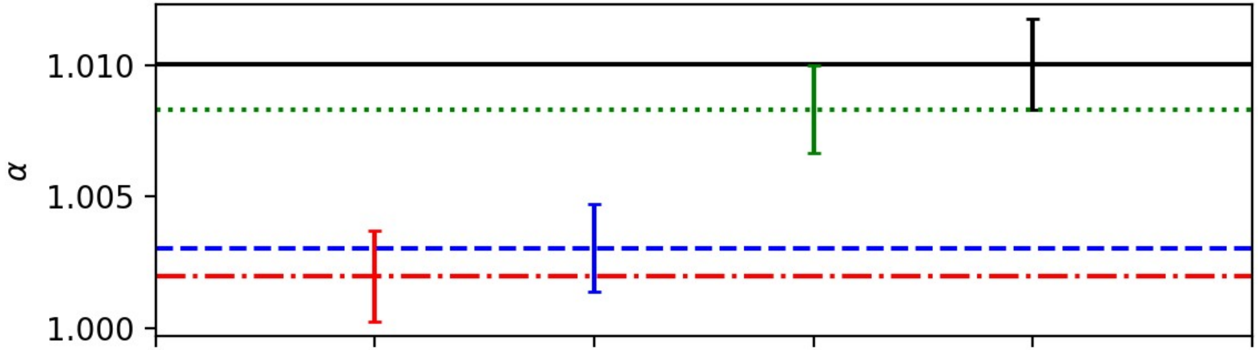


		Galaxies	Voids
Mean	$\alpha_{\mathrm{all}} - \alpha_{\mathrm{none}}$	$(3.34 \pm 2.89) \times 10^{-3}$	$(-9.9 \pm 72.9) \times 10^{-4}$

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

Results: Individual 2PCF Comparison





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

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

Conclusion

- **Mean 2PCF:** Smaller shift using voids
- **Void posteriors:** Very wide – Multimodal-like
- **Improve fitting method** (increase evidence)**:**
  - Improve/tweak priors: Difficult, time consuming.
  - Template non-wiggle void power spectra (See. Variu et.al. 2020) **Already shows better results.** Relies on decreasing complexity by removing parameter **c.**
- **Individual 2PCF:** Smaller widths in distribution shows robustness in the analysis
- **Individual 2PCF:** Smaller shift using voids
- **ELG BAO is noisy:** SNR < 1 so BAO signal not significant.
- **Use tracer with higher SNR:** Repeat analysis with LRG (SNR$\sim$10, Liang et. al. 2016) and QSO