NOTES ON THE POWER SPECTRUM AND BISPECTRUM OF DR12 BOSS GALAXIES

HÉCTOR GIL-MARÍN

1. Introduction

The power spectrum and bispectrum are the Fourier transform of the 2- and 3-point correlation function in Fourier Space, respectively. In these notes I describe the public measurements on the BOSS DR12 dataset.

The power spectrum, P, is formally defined as,

$$\langle \delta(\mathbf{k})\delta(\mathbf{k}')\rangle \equiv (2\pi)^3 P(\mathbf{k})\delta^{\rm Dirac}(\mathbf{k}+\mathbf{k}') \tag{1}$$

where $\delta(\mathbf{k})$ is the Fourier Transform of the galaxy over-density field in configuration space,

$$\delta(\mathbf{k}) = \frac{1}{2\pi^3}\int d\mathbf{k}\,\delta(\mathbf{x})e^{i\mathbf{k}\cdot\mathbf{x}}, \tag{2}$$

$$\delta(\mathbf{x}) \equiv \frac{\rho(\mathbf{x})}{\bar\rho} - 1, \tag{3}$$

Here $\rho(\mathbf{x})$ is the number density of objects at position $\mathbf{x}$, and $\bar\rho$ is the mean number density of objects of the sample.

In the same way, the bispectrum, B, is defined as,

$$\langle \delta(\mathbf{k}_1)\delta(\mathbf{k}_2)\delta(\mathbf{k}_3)\rangle \equiv (2\pi)^3 B(\mathbf{k}_1,\mathbf{k}_2)\delta^{\rm Dirac}(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3) \tag{4}$$

Note that these are formal definitions of the power spectrum and bispectrum. In practice these quantities are affected by observational features as, redshift space distortions, Alcock-Pacynski effects, sky-geometry, selection function of objects, changing line-of-sight, variation of density of objects with the position of the sky, etc. These notes do not aim to be complete on describing all these phenomena, nor describing how to account or correct for them. Please read the original papers where the catalogues, measurements and analysis are described in order to understand how to interpret the measurements presented here. Below I leave with a non-exhaustive list of reference which useful information.

- BOSS Catalogues: [1]
- Mask selection effects: [2]
- Covariances and Mocks: [3]
- Power Spectrum analysis: [4]
- Power Spectrum post-reconstruction analysis: [5]

Date: February 13, 2020.

Contact: hectorgil@icc.ub.edu or hector.gil.marin@gmail.com.

- Power Spectrum estimator: [6]
- Bispectrum analysis and estimator: [7]
- BOSS main results: [8]

2. DATASET

We provide the power spectrum and bispectrum measurements of the Baryon Oscillation Spectroscopic Survey (BOSS) Data Release 12, galaxy sample, split by selection algorithm into LOWZ and CMASS galaxies. The LOWZ sample contains 361,762 galaxies between redshifts $0.15 < z < 0.43$ with an effective redshift of $z_{\rm LOWZ} = 0.32$; and the CMASS sample contains 777,202 galaxies between redshifts $0.43 < z < 0.70$ with an effective redshift of $z_{\rm CMASS} = 0.57$. Combining the power spectrum, measured relative to the line-of-sight, with the spherically averaged bispectrum, one can put constrains on the product of the growth of structure parameter f, and the amplitude of dark matter density fluctuations, σ_8, along with the geometric Alcock-Paczynski parameters, the product of the Hubble constant and the comoving sound horizon at the baryon drag epoch, $H(z)r_s(z_d)$, and the angular distance parameter divided by the sound horizon,$D_A(z)/r_s(z_d)$.

Additionally we also make available the reconstructed power spectrum measurements. In the reconstructed catalogues the position of the galaxies and randoms is shifted to undo the non-linear gravitational bulk flow motions. In order to produce these catalogues a fiducial value of the logarithmic growth factor f, and the linear bias b_1 is assumed to infer the underlaying dark matter field. Additionally a smoothing filer corresponding to a smoothing length of $15\,{\rm Mpc}/h$ was applied. For a further information we refer the reader to [5].

3. Public files

3.1. Data.

We provide the measurements of the power spectrum monopole, quadrupole, hexadecapole and bispectrum monopole, of both LOWZ and CMASS redshift samples. For each of these samples, the measurements of the northern and southern galactic cap are provided. Since these are disconnected patches of the sky, one can safely treat the likelihoods as independent, $\mathcal{L} = \mathcal{L}_{\rm NGC} \times \mathcal{L}_{\rm SGC}$. In all the cases we assume a ΛCDM model for redshift-distance relation with $\Omega_m = 0.31$.

The power spectrum is provided for two different k-spacing options: linear and logarithmic. The user can choose either one or the other for their own analysis depending on their own convenience (but not both at the same time, of course!). For the linear binning, the spacing corresponds to $\Delta k = 0.01\,h/{\rm Mpc}$, whereas for the k-spacing it corresponds to $\Delta \log[k/(h/{\rm Mpc})] = 0.01$ The power spectrum multipoles are contained in the following files,

```
PS_data/linear/Power_Spectrum_lowz_ngc_v5.txt
PS_data/linear/Power_Spectrum_lowz_sgc_v5.txt

PS_data/linear/Power_Spectrum_cmass_ngc_v5.txt
PS_data/linear/Power_Spectrum_cmass_sgc_v5.txt
```

```
PS_data/log/Power_Spectrum_lowz_ngc_v5.txt
PS_data/log/Power_Spectrum_lowz_sgc_v5.txt

PS_data/log/Power_Spectrum_cmass_ngc_v5.txt
PS_data/log/Power_Spectrum_cmass_sgc_v5.txt
```

in the following format,

```
#k-centerbin  k-eff  P0  P2  P4  N_modes  P0_shotnoise
```

where $k-$centerbin is the value of k in the center of the k-bin; k-eff is the mean k-value in each bin, $P0$, $P2$ and $P4$ stand for the monopole, quadrupole and hexadecapole, respectively in units of $(\mathrm{Mpc}/h)^3$. The power spectrum monopole has the Poisson shot noise component already subtracted, and its value is given by the P0_shotnoise column. N_modes provide the number of k-vectors contained in each k-bin.

We provide the reconstructed power spectrum multipoles in the same format,

```
PS_data_postrecon/lin/Power_Spectrum_BOSSDR12_LOWZ_NGC_recon_v5.txt
PS_data_postrecon/lin/Power_Spectrum_BOSSDR12_LOWZ_SGC_recon_v5.txt

PS_data_postrecon/lin/Power_Spectrum_BOSSDR12_CMASS_NGC_recon_v5.txt
PS_data_postrecon/lin/Power_Spectrum_BOSSDR12_CMASS_SGC_recon_v5.txt
```

The bispectrum monopole is contained in the following files,

```
BS_data/Bis_lowz_ngc_Dk6.txt
BS_data/Bis_lowz_sgc_Dk6.txt

BS_data/Bis_cmass_ngc_Dk6.txt
BS_data/Bis_cmass_sgc_Dk6.txt
```

in the following format,

```
#k1 k2 k3 B Bnoise Ntri_eff Ntri_theo
```

where $k1$, $k2$ and $k3$ are the values of the 3 k-vectors in h/Mpc units, corresponding to the bispectrum monopole, B in $(\mathrm{Mpc}/h)^6$. Such measurement has the shot noise subtracted already, which is also given by Bnoise. Note that unlike the power spectrum, the bispectrum shot noise is scale- and shape-dependent. The two last columns, $Ntri$ are the number of fundamental triangles inferred from a direct count on the number of modes used for each bin, Ntri_eff, and by the approximative formula,

$$\text{Ntri\_theo} = 8\pi^2 k_1 k_2 k_3 \Delta_k^3 \tag{5}$$

For CMASS, the galaxies were embedded in a box of size $L_{\mathrm{CMASS}} = 4000\,\mathrm{Mpc}/h$ ($L_{\mathrm{CMASS}} = 3500\,\mathrm{Mpc}/h$ for bispectrum and post-reconstructed measurements), whereas for LOWZ, $L_{\mathrm{LOWZ}} = 3000\,\mathrm{Mpc}/h$ ($L_{\mathrm{LOWZ}} = 2300\,\mathrm{Mpc}/h$ for the bispectrum and post-reconstructed measurements). Therefore the fundamental frequency associated to those measurements is $k_f = 2\pi/L$. For the power spectrum Δk is chosen to be $0.01\,[\mathrm{Mpc}/h]$ in the linear binning case, and for the bispectrum $\Delta k = 6k_f$.

3.2. **Density.** We also provide the number density of objects within each redshift bin, and for each NGC and SGC regions in the following files,

```
PS_data/density/Density_galaxies_lowz_ngc.txt
PS_data/density/Density_galaxies_lowz_sgc.txt

PS_data/density/Density_galaxies_cmass_ngc.txt
PS_data/density/Density_galaxies_cmass_sgc.txt
```

In the following format,

```
# z <nobs> <wc nobs> <wc wfkp nobs>
```

where z is the mean redshift within the bin, $\langle \mathrm{nobs} \rangle$ is the raw number density of objects, $\langle \mathrm{wc\,nobs} \rangle$ is the number density of objects weighted by the collision weight, and $\langle \mathrm{wc\,wfkp\,nobs} \rangle$ is the number density of objects weighed by the collision and FKP-weight.

3.3. **Covariance & Mocks.** We do not directly provide the covariance of the data as a single file as it could be difficult to interpret when the power spectrum and bispectrum are put together in the same data-vector. Instead, we provide the power spectrum and bispectrum measurements of 2048 realizations of the MD-Patchy mocks, where mocks and data have been indistinguishably treated. Such mocks are provided within the following tar-balls and have the same format as the files for the data.

A data-vector contains the power spectrum multipoles and bispectrum monopole within certain $k-$ ranges ordered in some arbitrary order. For example,

$$D(\vec{w}) = P_0(k_1), P_0(k_2), \ldots, P_0(k_n), P_2(k_1), \ldots, P_2(k_m), B(k_{x1}, k_{y_1}, k_{z1}), \ldots B(k_{xq}, k_{y_q}, k_{zq}) \tag{6}$$

where $\vec{w}$ represents the entries of the elements of the data-vector, which can be either a given k-bin of a power spectrum multipole, or a specific triangular configuration of the bispectrum monopole; $N_{bin} = n + m + q$ is the number of elements of the data vector D_v. The estimate covariance C of such data-vector has therefore dimensions of $N_{bin} \times N_{bin}$ and is obtained in the following way,

$$\hat{C}_{ij} = \frac{1}{N_{\mathrm{real}} - 1} \sum_{r=1}^{N_{\mathrm{real}}} [D_r(w_i) - \tilde{D}(w_i)] \cdot [D_r(w_j) - \tilde{D}(w_j)] \tag{7}$$

$$\tilde{D}(w_x) = \frac{1}{N_{\mathrm{real}}} \sum_{r=1}^{N_{\mathrm{real}}} D_r(w_x) \tag{8}$$

where the summation is performed over all available realisations data-vectors, D_r of the covariance-mocks (in this case MD-Patchy, with $N_{\mathrm{real}} = 2048$). Here we represent the element (i, j) of the covariance, which can indistinctly come from two k-bins of the same power spectrum multipole; two power spectrum multipoles, two bispectrum triangles, or the cross between power spectrum and bispectrum.

Note that the resulting estimate of the covariance will equally describe the covariance of the elements of the actual DR12 CMASS data-vector, D_d, as well as of each individual realisations of the MD-PATCHY mocks.

One should compute independently the covariances of CMASS-NGC, CMASS-SGC, LOWZ-NGC and LOWZ-SGC, as their likelihoods are considered independent.

In the end we will need to invert the covariance C to compute the likelihood,

$$\mathcal{L} = [D^{\rm model}(w_i) - D_v(w_i)][C^{-1}]_{ij}[D^{\rm model}(w_j) - D_v(w_j)]^T \tag{9}$$

The process of inversion will irretrievably produce a bias in the estimate of the covariance due to the finitness of $N_{\rm real}$ with respect to $N_{\rm bin}$[1]. Such bias should be mitigated by applying the Hartlap correction term [9] to all the elements of the inverted covariance.

$$[C^{-1}]_{ij} = [\hat{C}^{-1}]_{ij}\left[1 - \frac{N_{\rm bin}+1}{N_{\rm real}-1}\right]. \tag{10}$$

As long as $N_{\rm real} \gg N_{\rm bin}$ such correction will be small, typically less than 10%.

The power spectra (linearly binned) corresponding to the 2048 realizations can be found in the following tar-balls,

```
PS_mocks/linear/Power_Spectrum_lowz_ngc_v5_Patchy.tar.gz
PS_mocks/linear/Power_Spectrum_lowz_sgc_v5_Patchy.tar.gz

PS_mocks/linear/Power_Spectrum_cmass_ngc_v5_Patchy.tar.gz
PS_mocks/linear/Power_Spectrum_cmass_sgc_v5_Patchy.tar.gz
```

and similarly for the log-binned power spectrum. The reconstructed power spectra of the mocks can be found in,

```
PS_mocks_postrecon/Power_Spectrum_Patchy_dr12lowz_NGC_recon.zip
PS_mocks_postrecon/Power_Spectrum_Patchy_dr12lowz_SGC_recon.zip

PS_mocks_postrecon/Power_Spectrum_Patchy_dr12cmass_NGC_recon.zip
PS_mocks_postrecon/Power_Spectrum_Patchy_dr12cmass_SGC_recon.zip
```

For the bispectrum the corresponding mocks tar-balls are in,

```
BS_mocks/Bispectrum_ngc_lowz_dr12.tar.gz
BS_mocks/Bispectrum_sgc_lowz_dr12.tar.gz

BS_mocks/Bispectrum_ngc_cmass_dr12.tar.gz
BS_mocks/Bispectrum_sgc_cmass_dr12.tar.gz
```

3.4. **Mask.** In order to account for the survey selection, the theoretical power spectrum, $P^{\rm theo}$ must be convolved with the mask in order to match the measured power spectrum, $\hat{P}^{\rm meas.}$, and to recover unbiased cosmological parameters. Note that the selection function is computed from the random catalogue, and therefore only depends on the geometry of

---

[1] In case of having derived the covariance theoretically such correction does not apply.

the survey and not in any clustering property. The convolved power spectrum ℓ-multipoles are therefore written as the Hankel transform of $\hat{\xi}_\ell$,

$$\hat{P}_\ell^{\rm meas.}(k) = 4\pi(-i)^\ell \int dr\, r^2 \hat{\xi}_\ell(r) j_\ell(kr) \tag{11}$$

where $j_\ell(x)$ is the spherical Bessel function of order ℓ and $\hat{\xi}_\ell(r)$ are given by

$$\hat{\xi}_0(r) = \xi_0(r)W_0^2(r) + \frac{1}{5}\xi_2(r)W_2^2(r) + \frac{1}{9}\xi_4(r)W_4^2(r) \tag{12}$$

$$\begin{aligned}\hat{\xi}_2(r) &= \xi_0(r)W_2^2(r) + \xi_2(r)\left[W_0^2(r) + \frac{2}{7}W_2^2(r) + \frac{2}{7}W_4^2(r)\right] \\ &+ \xi_4(r)\left[\frac{2}{7}W_2^2(r) + \frac{100}{693}W_4^2(r) + \frac{25}{143}W_6^2(r)\right]\end{aligned} \tag{13}$$

$$\begin{aligned}\hat{\xi}_4(r) &= \xi_0(r)W_4^2(r) + \xi_2(r)\left[\frac{18}{35}W_2^2(r) + \frac{20}{77}W_4^2(r) + \frac{45}{143}W_6^2(r)\right] \\ &+ \xi_4(r)\left[W_0^2(r) + \frac{20}{77}W_2^2(r)\frac{162}{1001}W_4^2(r) + \frac{20}{143}W_6^2(r) + \right. \\ &+ \left. \frac{490}{2431}W_8^2(r)\right]\end{aligned} \tag{14}$$

where ξ_ℓ is the inverse Hankel Transform of $P^{\rm theo}$,

$$\xi_\ell(r) = \frac{4\pi i^\ell}{(2\pi)^3}\int dk\, k^2 P_\ell^{\rm theo}(k) j_\ell(kr) \tag{15}$$

Note that the case $W_0^2(r) = 1$ and $W_{\ell>0}^2(r) = 0$ corresponds to the case of no-selection function, where $P^{\rm theo} = \hat{P}^{\rm meas.}$, as it happens within a cubic box with uniform mean density and periodic boundary conditions.

The files,

```
PS_data/mask/mask_lowz_ngc.txt
PS_data/mask/mask_lowz_sgc.txt

PS_data/mask/mask_cmass_ngc.txt
PS_data/mask/mask_cmass_sgc.txt
```

contain the $W_\ell^2(r)$ functions (note that the functions provided are already squared) for the DR12 CMASS and LOWZ, NGC and SGC geometry, in the following format,

```
#r W0^2 W2^2 W4^2 W6^2 W8^2
```

We do not provide a formal extension of this formalism to describe the window function of the bispectrum. As an approximation, if one writes the theoretical bispectrum as a function of power spectra (as it is the case for the tree-level form) one can individually apply the window formalism above to those individual power spectra. This should partially account for the window effects, which unless one needs to focus on very squeezed triangles, showed to be sufficient given the precision of this dataset.

TABLE 1. True cosmologies of the N-body Nseries mocks and the MD-PATCHY fast mocks. $\Omega_\nu = 0$ for both cosmologies

	Ω_m	Ω_b	H_0	n_s	σ_8^0	$r_{\rm drag}$
$\Omega_{\rm Patchy}$	0.307	0.048	67.8	0.96	8288	147.66
$\Omega_{\rm Nseries}$	0.286	0.0470	70.0	0.96	0.82	147.15

4. NSERIES MOCKS

The NSERIES mocks are full N-body mocks populated with a Halo Occupation Distribution (HOD) model similar to the one corresponding to the DR12 BOSS NGC CMASS LRGs. Their effective redshift's, $z_{\rm eff} = 0.55$. They were generated out of 7 independent periodic boxes of 2.6Gpc/h side, projected through 12 different orientations and cuts, per box. In total, after these projections and cuts 84 pseudo-independent realisations were produced. The mass resolution of these boxes is $1.5 \times 10^{11}\, M_\odot/h$ and with 2048^3 particles per box. The large effective volume makes them ideal to test potential BAO and RSD systematics generated by the analysis pipeline. We recommend to use the NGC MD-PATCHY mocks to describe their covariance. The reader should rescale the covariance terms by $\sim 10\%$ based on the ratio of particles, as the MD-PATCHY mocks have fewer particles than the NSERIES mocks due to veto effects on DR12 CMASS data, which was also imprinted into the MD-PATCHY mocks but not into NSERIES mocks. The true cosmology of these mocks is close to WMAP7 cosmology and can be found in table 1 along with the true cosmology of the MD-PATCHY mocks.

Note that both set of mocks (as well as the data) have been analyzed assuming $\Omega_m = 0.31$ when converting redshifts into comoving distances. As for the data, we provide the measurement (only linear binning), density and the mask files of these 84 realizations of the Nseries mocks,

```
PS_Nseries/lin/Power_Spectrum_cmass_ngc_Nseries_Om0.310.zip
PS_Nseries_postrecon/Power_Spectrum_Nseries_recon.zip
BS_Nseries/Bispectrum_cmass_ngc_Nseries_Om.310.zip
PS_Nseries/density/Density_galaxies_cmass_ngc_Nseries_Om0.310.zip
PS_Nseries/mask/mask_cmass_ngc_Nseries.txt
```

We recommend to validate the pipeline applied to the data using these full N-body mocks, instead of the approximative fast mocks, which should only be used to build the covariance.

5. RANGE OF FITTING

All the available products, data, fast-mocks and N-body mocks provides the statistic of interest in the k-range that goes from a certain k-fundamental associated to the largest scale available (which is set by the size of the survey, or the size of the box), down to a certain $k_{\rm max}$ set by the size of the grid used to perform the Fourier transforms. When applying this data to a given model one has to bear in mind few considerations,

- The smallest scale (largest k-value) used in an analysis is determined by the accuracy of the theoretical model when reproducing the small scale physics of the galaxy field. For BOSS analysis this value was set around $k_{\rm max} = 0.20\,h/{\rm Mpc}$. Note that data and the NSERIES mocks should be correct at any arbitrary small scale (large k-value scale). However, this is not true for the fast MD-PATCHY mocks, which are not full N-body mocks. We encourage the readers to test their pipelines with NSERIES mocks and not with MD-PATCHY mocks.
- The largest scale (smallest k-value) used in an analysis is determined by the ability of systematic weights to account for large scale variations of density caused by the presence of stars, seeing variations, etc. Given the findings described in the Appendix A of [4] (for the power spectrum) and Appendix A of [7] (for bispectrum) we recommend not to exceed $k_{\rm min} = 0.02\,h/{\rm Mpc}$ for the power spectrum monopole, $k_{\rm min} = 0.04\,h/{\rm Mpc}$ for the power spectrum quadrupole, and $k_{\rm min} = 0.03\,h/{\rm Mpc}$ for the bispectrum monopole. Such large scale effects are only imprinted in the data catalogues (not in the NSERIES nor MD-PATCHY mocks). This implies that the reader should not use these mocks to test the validity of their model at scales larger (k-values smaller) than these $k_{\rm min}$ values, as such tests will not be representative for the data catalogue.

6. REFERENCES AND DISCLAIMER

If you use any of these datasets please refer to [7] for the bispectrum, [4] for the pre-reconstructed power spectrum and [5] for the post-reconstructed power spectrum. Please also quote the original catalogue paper [1] and the cosmological interpretation paper [8].

If you use the MD-PATCHY mocks for generating the covariance please refer to [3].

Finally, the mask formalism was originally described by [2].

Part of these products are also available at the official BOSS SDSS website. Please check the SDSS citing policies in 'How to Cite SDSS', and in particular Official SDSS-III Acknowledgment

The author assumes no responsibility or liability for any errors or omissions in the content of these notes or data-files. The information contained in this site is provided on an "as is" basis with no guarantees of completeness, accuracy, usefulness or timeliness.

ACKNOWLEDGEMENTS

The catalogues associated to the data products described by these notes are publicly available within the SDSS-III BOSS products. The production of these catalogues has been a very long time effort lead by many scientists within the SDSS-III collaboration. Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy Office of Science. The SDSS-III web site is http://www.sdss3.org/.

References

[1] Beth Reid, Shirley Ho, Nikhil Padmanabhan, Will J. Percival, Jeremy Tinker, Rita Tojeiro, Martin White, Daniel J. Eisenstein, Claudia Maraston, Ashley J. Ross, Ariel G. Sánchez, David Schlegel, Erin Sheldon, Michael A. Strauss, Daniel Thomas, David Wake, Florian Beutler, Dmitry Bizyaev, Adam S. Bolton, Joel R. Brownstein, Chia-Hsun Chuang, Kyle Dawson, Paul Harding, Francisco-Shu Kitaura, Alexie Leauthaud, Karen Masters, Cameron K. McBride, Surhud More, Matthew D. Olmstead, Daniel Oravetz, Sebastián E. Nuza, Kaike Pan, John Parejko, Janine Pforr, Francisco Prada, Sergio Rodríguez-Torres, Salvador Salazar-Albornoz, Lado Samushia, Donald P. Schneider, Claudia G. Scóccola, Audrey Simmons, and Mariana Vargas-Magana. SDSS-III Baryon Oscillation Spectroscopic Survey Data Release 12: galaxy target selection and large-scale structure catalogues. *MNRAS*, 455(2):1553–1573, Jan 2016.

[2] M. J. Wilson, J. A. Peacock, A. N. Taylor, and S. de la Torre. Rapid modelling of the redshift-space power spectrum multipoles for a masked density field. *MNRAS*, 464(3):3121–3130, Jan 2017.

[3] Francisco-Shu Kitaura, Sergio Rodríguez-Torres, Chia-Hsun Chuang, Cheng Zhao, Francisco Prada, Héctor Gil-Marín, Hong Guo, Gustavo Yepes, Anatoly Klypin, Claudia G. Scóccola, Jeremy Tinker, Cameron McBride, Beth Reid, Ariel G. Sánchez, Salvador Salazar-Albornoz, Jan Niklas Grieb, Mariana Vargas-Magana, Antonio J. Cuesta, Mark Neyrinck, Florian Beutler, Johan Comparat, Will J. Percival, and Ashley Ross. The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: mock galaxy catalogues for the BOSS Final Data Release. *MNRAS*, 456(4):4156–4173, Mar 2016.

[4] Héctor Gil-Marín, Will J. Percival, Joel R. Brownstein, Chia-Hsun Chuang, Jan Niklas Grieb, Shirley Ho, Francisco-Shu Kitaura, Claudia Maraston, Francisco Prada, Sergio Rodríguez-Torres, Ashley J. Ross, Lado Samushia, David J. Schlegel, Daniel Thomas, Jeremy L. Tinker, and Gong-Bo Zhao. The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: RSD measurement from the LOS-dependent power spectrum of DR12 BOSS galaxies. *MNRAS*, 460(4):4188–4209, Aug 2016.

[5] Héctor Gil-Marín, Will J. Percival, Antonio J. Cuesta, Joel R. Brownstein, Chia-Hsun Chuang, Shirley Ho, Francisco-Shu Kitaura, Claudia Maraston, Francisco Prada, Sergio Rodríguez-Torres, Ashley J. Ross, David J. Schlegel, Donald P. Schneider, Daniel Thomas, Jeremy L. Tinker, Rita Tojeiro, Mariana Vargas Magaña, and Gong-Bo Zhao. The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: BAO measurement from the LOS-dependent power spectrum of DR12 BOSS galaxies. *MNRAS*, 460(4):4210–4219, Aug 2016.

[6] Davide Bianchi, Héctor Gil-Marín, Rossana Ruggeri, and Will J. Percival. Measuring line-of-sight-dependent Fourier-space clustering using FFTs. *MNRAS*, 453(1):L11–L15, Oct 2015.

[7] Héctor Gil-Marín, Will J. Percival, Licia Verde, Joel R. Brownstein, Chia-Hsun Chuang, Francisco-Shu Kitaura, Sergio A. Rodríguez-Torres, and Matthew D. Olmstead. The clustering of galaxies in the SDSS-III Baryon Oscillation Spectroscopic Survey: RSD

measurement from the power spectrum and bispectrum of the DR12 BOSS galaxies. *MNRAS*, 465(2):1757–1788, Feb 2017.

[8] Shadab Alam, Metin Ata, Stephen Bailey, Florian Beutler, Dmitry Bizyaev, Jonathan A. Blazek, Adam S. Bolton, Joel R. Brownstein, Angela Burden, Chia-Hsun Chuang, Johan Comparat, Antonio J. Cuesta, Kyle S. Dawson, Daniel J. Eisenstein, Stephanie Escoffier, Héctor Gil-Marín, Jan Niklas Grieb, Nick Hand, Shirley Ho, Karen Kinemuchi, David Kirkby, Francisco Kitaura, Elena Malanushenko, Viktor Malanushenko, Claudia Maraston, Cameron K. McBride, Robert C. Nichol, Matthew D. Olmstead, Daniel Oravetz, Nikhil Padmanabhan, Nathalie Palanque-Delabrouille, Kaike Pan, Marcos Pellejero-Ibanez, Will J. Percival, Patrick Petitjean, Francisco Prada, Adrian M. Price-Whelan, Beth A. Reid, Sergio A. Rodríguez-Torres, Natalie A. Roe, Ashley J. Ross, Nicholas P. Ross, Graziano Rossi, Jose Alberto Rubiño-Martín, Shun Saito, Salvador Salazar-Albornoz, Lado Samushia, Ariel G. Sánchez, Siddharth Satpathy, David J. Schlegel, Donald P. Schneider, Claudia G. Scóccola, Hee-Jong Seo, Erin S. Sheldon, Audrey Simmons, Anže Slosar, Michael A. Strauss, Molly E. C. Swanson, Daniel Thomas, Jeremy L. Tinker, Rita Tojeiro, Mariana Vargas Magaña, Jose Alberto Vazquez, Licia Verde, David A. Wake, Yuting Wang, David H. Weinberg, Martin White, W. Michael Wood-Vasey, Christophe Yèche, Idit Zehavi, Zhongxu Zhai, and Gong-Bo Zhao. The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological analysis of the DR12 galaxy sample. *MNRAS*, 470(3):2617–2652, Sep 2017.

[9] J. Hartlap, P. Simon, and P. Schneider. Why your model parameter confidences might be too optimistic. Unbiased estimation of the inverse covariance matrix. *A&A*, 464(1):399–404, Mar 2007.