COSMOLOGICAL MEASUREMENTS FROM ANGULAR POWER SPECTRA ANALYSIS OF BOSS DR12 TOMOGRAPHY

https://arxiv.org/abs/1809.07204

RESUME

- SDSS - BOSS DR12
- Angular power espctra estimators and mesurments
- Modeling Of theory and covariance matrices
- Systematics tests
- Cosmological Analysis

SDSS-BOSS DR12

Sloan digital sky survey - barion oscillation spectroscopic survey.

1.5 million galaxies in a total of 2.5 million objects.

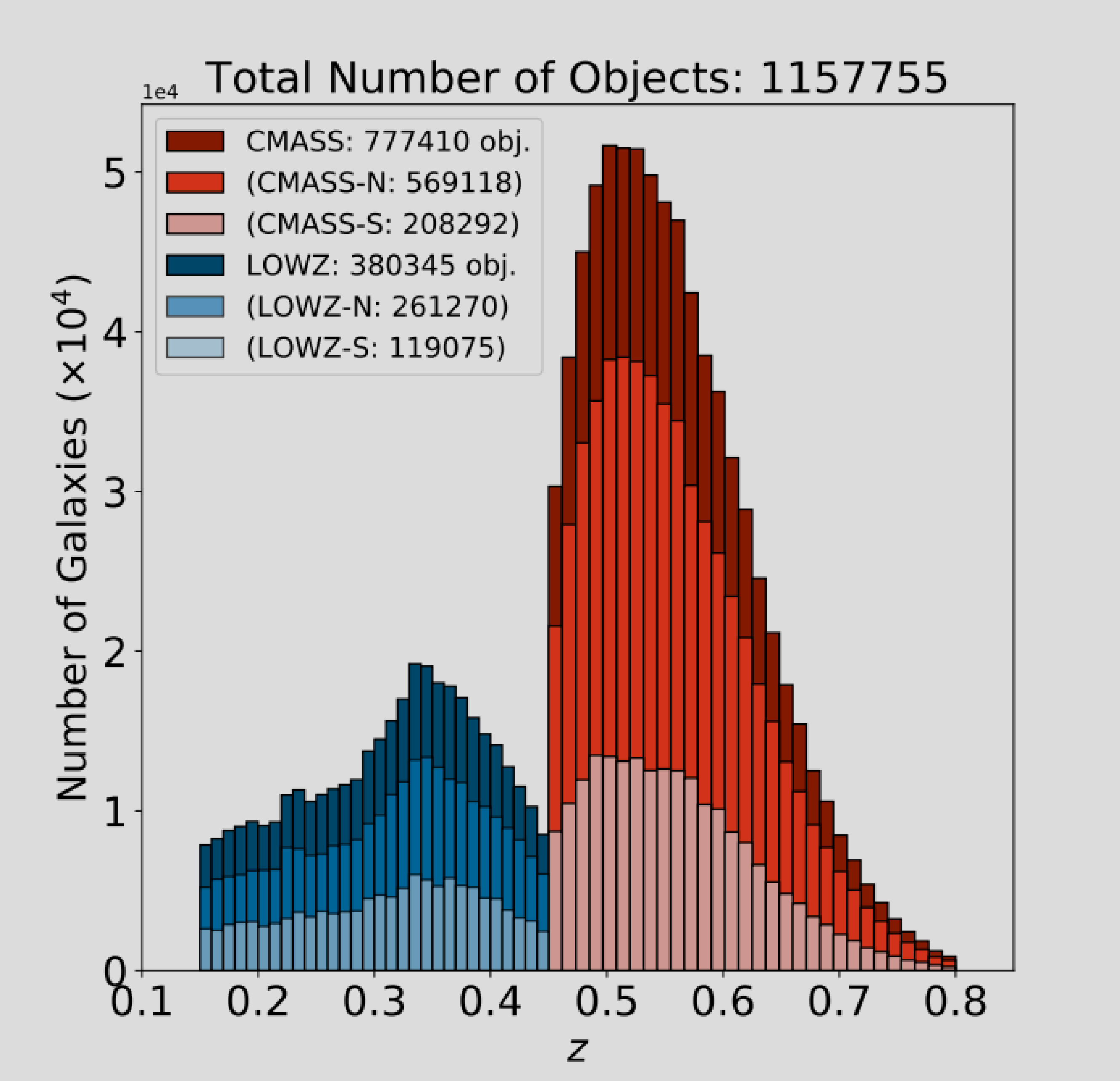
Full descripion (Alam et al (2015))

colour-magnitude and colour-colour cuts

Lowz and CMASS samples

Galaxy catalogues

0.15 < z < 0.45 for LOWZ and 0.45 < z < 0.80 for CMASS



LOWZ Selection criteria

$$|c_\perp| < 0.2 \quad (1)$$
$$r_{cmod} < 13.5 + c_{||}/0.3 \quad (2)$$
$$r_{psf} - r_{cmod} > 0.3 \quad (3)$$
$$16 < r_{cmod} < 19.6 \quad (4)$$

CMASS Selection criteria

$$i_{mod} < \min(19.86 + 1.6(d_\perp - 0.8), 19.9) \quad (5)$$
$$d_\perp > 0.55 \quad (6)$$
$$17.5 < i_{cmod} < 19.9 \quad (7)$$
$$i_{fib2} < 21.5 \quad (8)$$
$$r_{mod} - i_{mod} < 2 \quad (9)$$
$$r_{dev,i} < 20.0 \text{ pix} \quad (10)$$
$$i_{psf} - i_{mod} > 0.2(21 - i_{mod}) \quad (11)$$
$$z_{psf} - z_{mod} > 0.46(19.8 - z_{mod}) \quad (12)$$

Masks and map making

Aceptance and Veto Masks -->

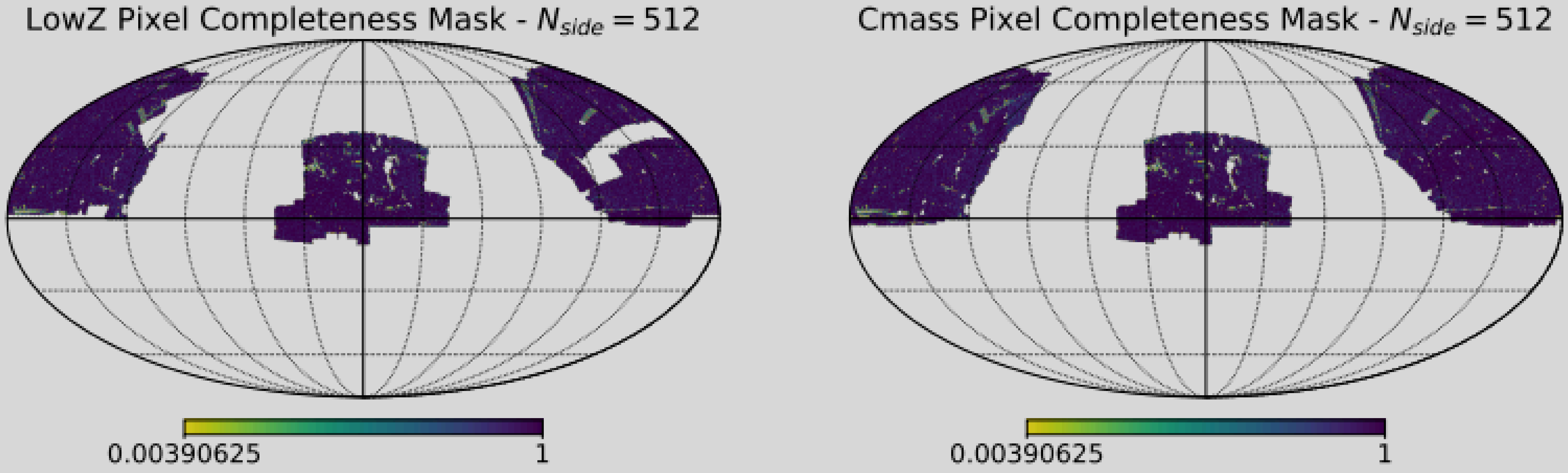
Nside 16384 --> Nside = 512

Binary mask

$$C_{BOSS} = \frac{N_{obs} + N_{cp}}{N_{obs} + N_{cp} + N_{\text{missed}}}, \qquad (14)$$

where:

- N_{obs} is the number of spectroscopically observed objects including galaxies, stars, and unclassified objects;
- N_{cp} is the number of close-pair objects;
- N_{missed} is the number of targeted objects with no spectra.



(a) (b)

Maping and mask making

For the galaxy overdensity maps:

Bin both data catalogues
(6 for LOWZ and 7 for CMASS)

Weighted number counts map
(weighted by the total galaxy weight)

$$w_{\rm tot} = w_{\rm systot}(w_{\rm cp} + w_{\rm noz} - 1)\ . \tag{13}$$

$$\delta^g_{i,p} = \begin{cases} \left(\frac{1}{C_{pix,p}} \frac{n^g_{i,p}}{\bar{n}_i}\right) - 1 & \text{if } C_{pix,p} > 0.8 \\ 0 & \text{otherwise,} \end{cases} \tag{15}$$

Sample Bin	z_{min}	z_{max}	Num galaxies	Shot noise (gal/strd)$^{-1}$
LOWZ–0	0.15	0.20	43,265	6.143×10^{-5}
LOWZ–1	0.20	0.25	51,271	5.156×10^{-5}
LOWZ–2	0.25	0.30	59,713	4.416×10^{-5}
LOWZ–3	0.30	0.35	85,394	3.064×10^{-5}
LOWZ–4	0.35	0.40	83,537	3.136×10^{-5}
LOWZ–5	0.40	0.45	57,165	4.605×10^{-5}
CMASS–6	0.45	0.50	177,383	1.577×10^{-5}
CMASS–7	0.50	0.55	217,636	1.275×10^{-5}
CMASS–8	0.55	0.60	179,571	1.545×10^{-5}
CMASS–9	0.60	0.65	114,398	2.435×10^{-5}
CMASS–10	0.65	0.70	57,537	4.850×10^{-5}
CMASS–11	0.70	0.75	23,631	1.182×10^{-4}
CMASS–12	0.75	0.80	7,253	3.839×10^{-4}

ANGULAR POWER SPECTRA ESTIMATORS AND MESEAUREMENTS

Relation between Noise, Data and Angular Power Spectra

$$S_\ell = D_\ell - N_\ell . \tag{16}$$

Noise Distribution

$$N_\ell \approx \frac{\Delta\Omega_{tot}}{n^g_{tot}} = \frac{1}{\bar{n}}, \tag{17}$$

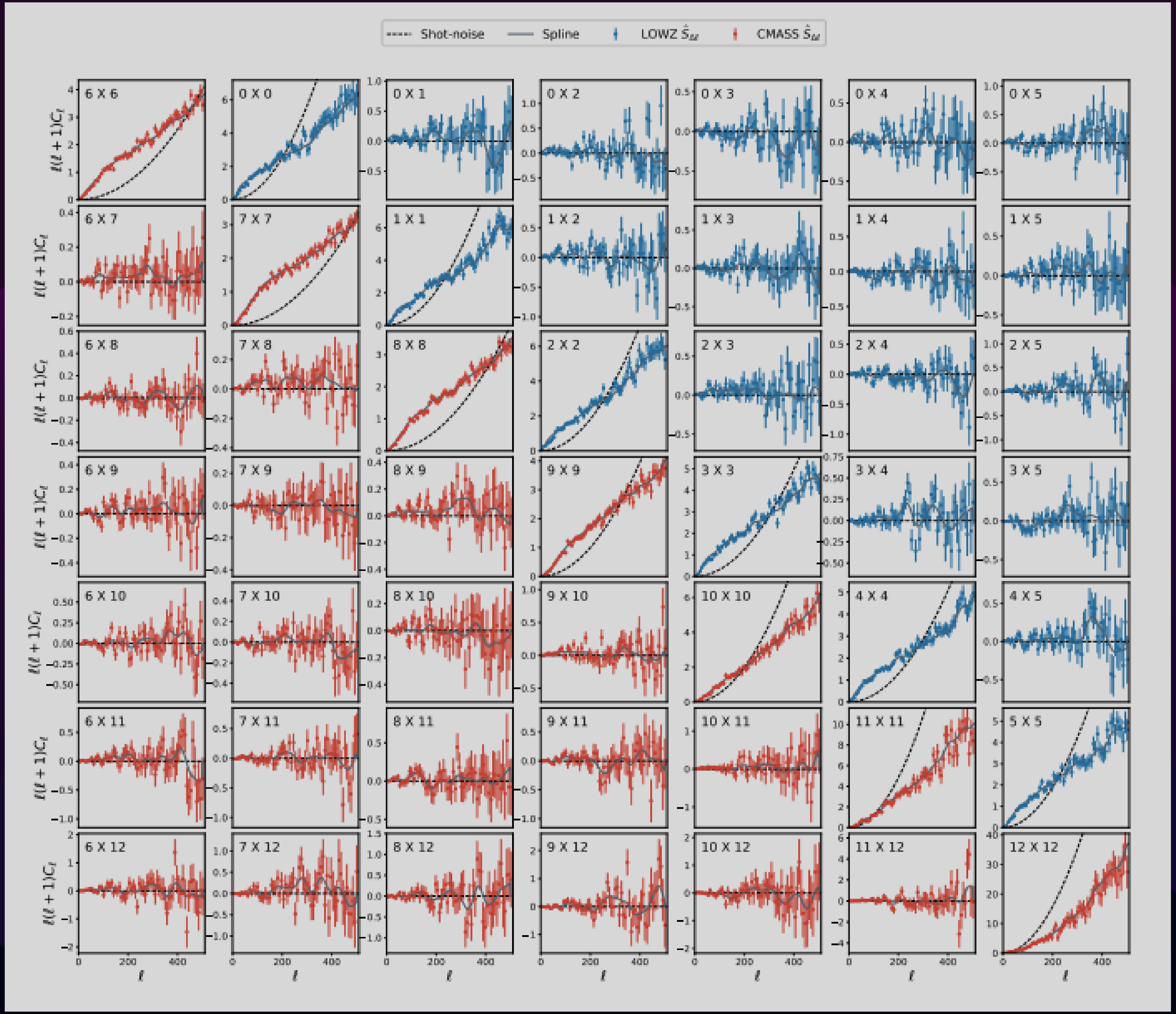
Pseudo Power Spectrum Estimator (PCL)

$$\hat{S}^{ij}_\ell = \frac{1}{w^2_\ell}\left[\left(\frac{1}{(2\ell+1)}\sum_{m=-\ell}^{\ell} D^{ij}_{\ell m}\right) - N_\ell \delta_{ij}\right], \tag{18}$$

Binning the l values

$$\hat{S}^{ij}_{\Delta\ell} = \frac{\sum_{\ell\in\Delta\ell}(2\ell+1)\hat{S}^{ij}_\ell}{\sum_{\ell\in\Delta\ell}(2\ell+1)} . \tag{19}$$

ANGULAR POWER SPECTRA ESTIMATORS AND MESEAUREMENTS



MODELING OF THEORY AND COVARIANCE MATRICES

Theoretical Angular Power Spectra:

$$C_\ell^{ij} \equiv \left\langle a_{\ell m}^{i} a_{\ell m}^{j*} \right\rangle \quad (27)$$

$$= \frac{2}{\pi} \int W_{g,\ell}^{i}(k) W_{g,\ell}^{j}(k) k^2 P(k,0) dk. \quad (28)$$

$$W_{g,\ell}(k) = \int b(z) n(z) D(z) j_\ell(k\chi(z)) dz. \quad (26)$$

$$a_{\ell m} = \int Y_{\ell m}(\hat{\mathbf{n}}) \delta_g(\hat{\mathbf{n}}) d\Omega \quad (23)$$

$$= \int Y_{\ell m}(\hat{\mathbf{n}}) \int \delta_g(\chi(z)\hat{\mathbf{n}}, z) n(z) dz d\Omega \quad (24)$$

$$= \frac{4\pi}{(2\pi)^3} \int b(z) n(z) D(z) \int \delta(\mathbf{k}, 0) i^\ell j_\ell(k\chi(z)) Y_{\ell,m}(\hat{\mathbf{k}}) d^3k dz \quad (25)$$

$$\delta_g(\hat{\mathbf{n}}) = \int_0^\infty \delta_g(\chi(z)\hat{\mathbf{n}}, z) n(z) dz \quad (22)$$

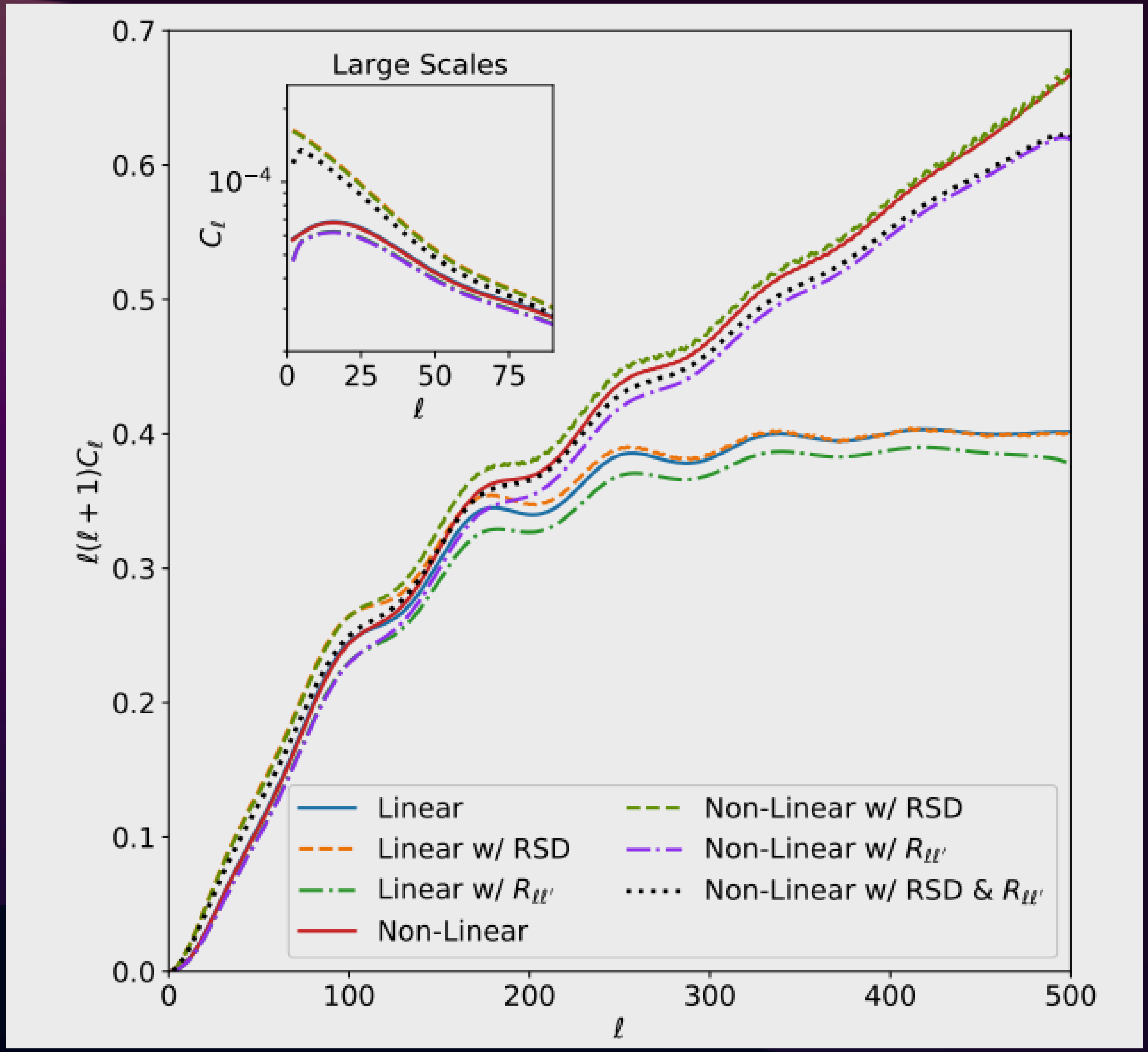
MODELING OF THEORY AND COVARIANCE MATRICES

Modelling Spectroscopic erros (convolution)

Redshift Space Distortions (Window Function)

Non-linear Cl extesion (Halofit)

Partial Sky (mix matrix convolution)



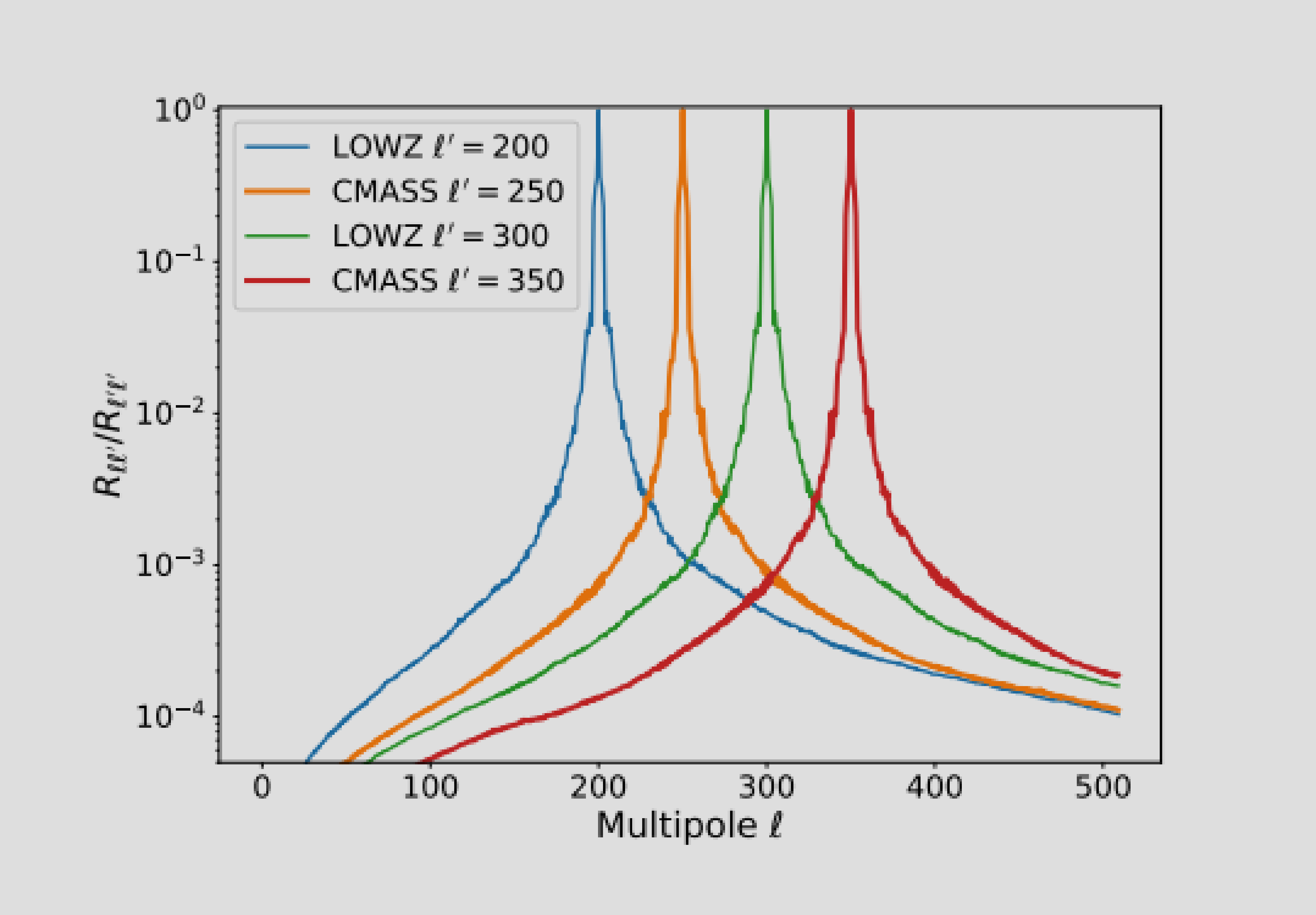
Mixing matrix

Mixing Matrix equation:

$$R_{\ell\ell'} = \frac{2\ell'+1}{4\pi}\sum_{\ell''}(2\ell''+1)W_{\ell''}\begin{pmatrix}\ell & \ell' & \ell'' \\ 0 & 0 & 0\end{pmatrix}^2 . \qquad (40)$$

Binning the theoretical Sl (After the convolution with the MixMatrix)

$$S^{ij}_{\Delta\ell} = \frac{1}{\sum_{\ell'}^{\ell'+\Delta\ell}(2\ell+1)}\sum_{\ell'}^{\ell'+\Delta\ell}(2\ell+1)S^{ij}_{\ell} . \qquad (41)$$



Covariance matrices (Log-Normal mocks)

Steps to obtain the covariance:

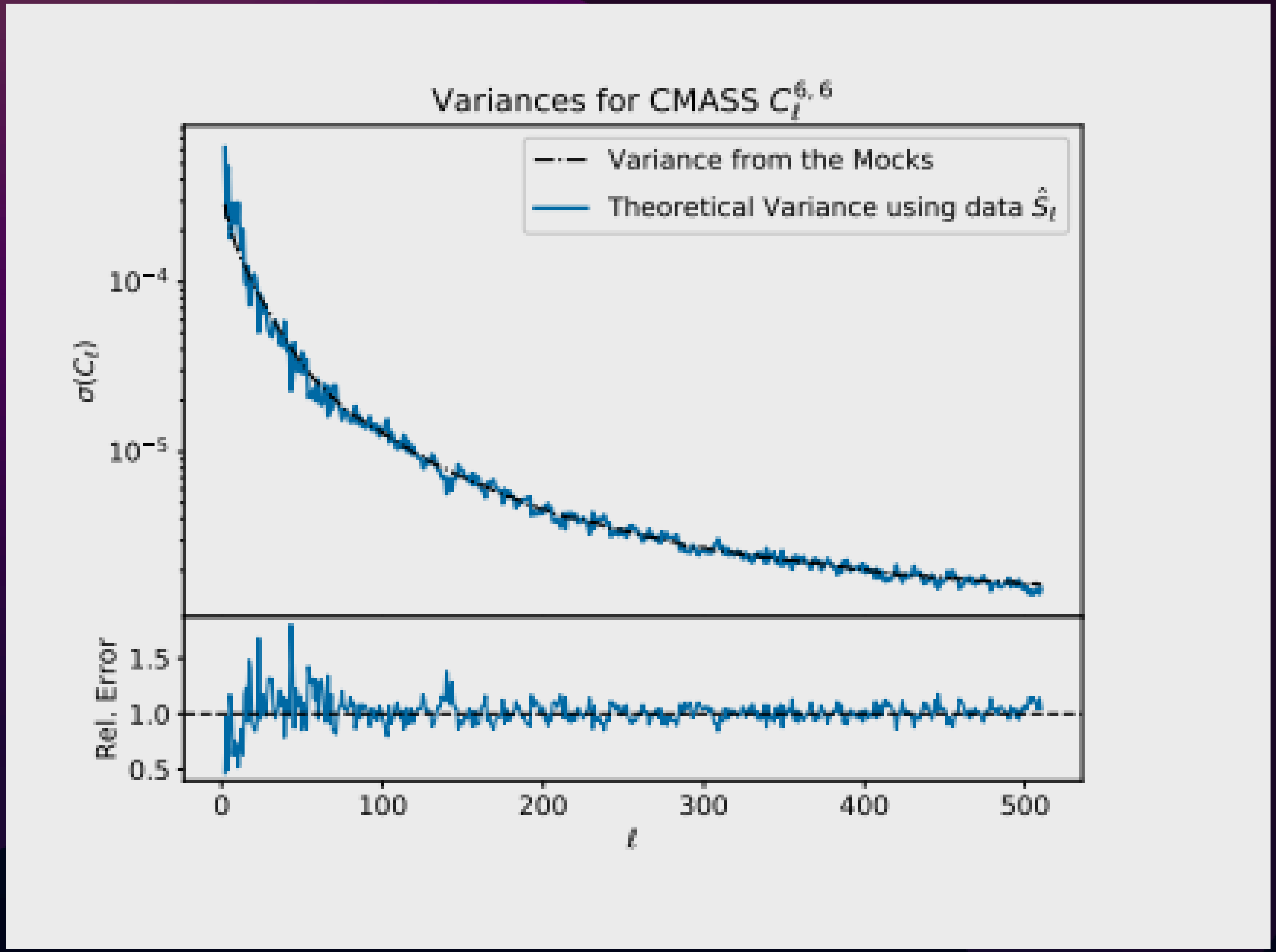
1. Produce a spline, $\tilde{S}(\ell)$, using the $\hat{S}_{\Delta\ell}$ measurements (Figure 3) and a Gaussian filter to smooth the measurements.
2. Deconvolve the mixing matrix $R_{\ell\ell'}$ from the splines to obtain

$$\tilde{C}^{ij}(\ell) = \sum_{\ell'} R^{-1}_{\ell\ell'} \tilde{S}^{ij}(\ell). \tag{51}$$

3. Linearly extrapolate the splines to $\ell_{max} = 8192$ (necessary to allow `FLASK` to create high resolution `HEALPix` maps).
4. For each tomographic redshift bin, produce `FLASK` partial sky galaxy number count mocks with $N_{side} = \ell_{max} = 2048$.[8]
5. Degrade the mocks to $N_{side} = 512$ to match the N_{side} used when analysing the data.
6. Produce up-weighted galaxy overdensity maps using the pixel completeness factor (as described in Section 2.2.2).
7. Run the partial sky PCL estimator; include here the pixel window function correction w_ℓ^2 (as described in Equations (18) and (19)) that arises from the degrading of the maps at step **5**.
8. Measure the covariance of the ensemble of angular power spectra obtained from the simulated data:

$$C^{ij}_{\Delta\ell\Delta\ell'} \equiv \frac{1}{N_S - 1} \sum_{s=1}^{N_S} \left(S^{ij,s}_{\Delta\ell} - \langle S^{ij}_{\Delta\ell} \rangle \right) \left(S^{ij,s}_{\Delta\ell'} - \langle S^{ij}_{\Delta\ell'} \rangle \right)^T. \tag{52}$$

Examples for CMASS:



SYSTEMATICS TESTS

Identification

Significant systematic effects:

Cross-power spectra deviates from zero.

Bigger than the data and cross-power spectra variance.

Procedure

Create a systematics Masks;

Reconstruct observational and pixelated information

Additional observational properties

Create systematic map

Cross-power spectra Data - Systematic Maps

COSMOLOGICAL ANALYSIS

ΛCDM model

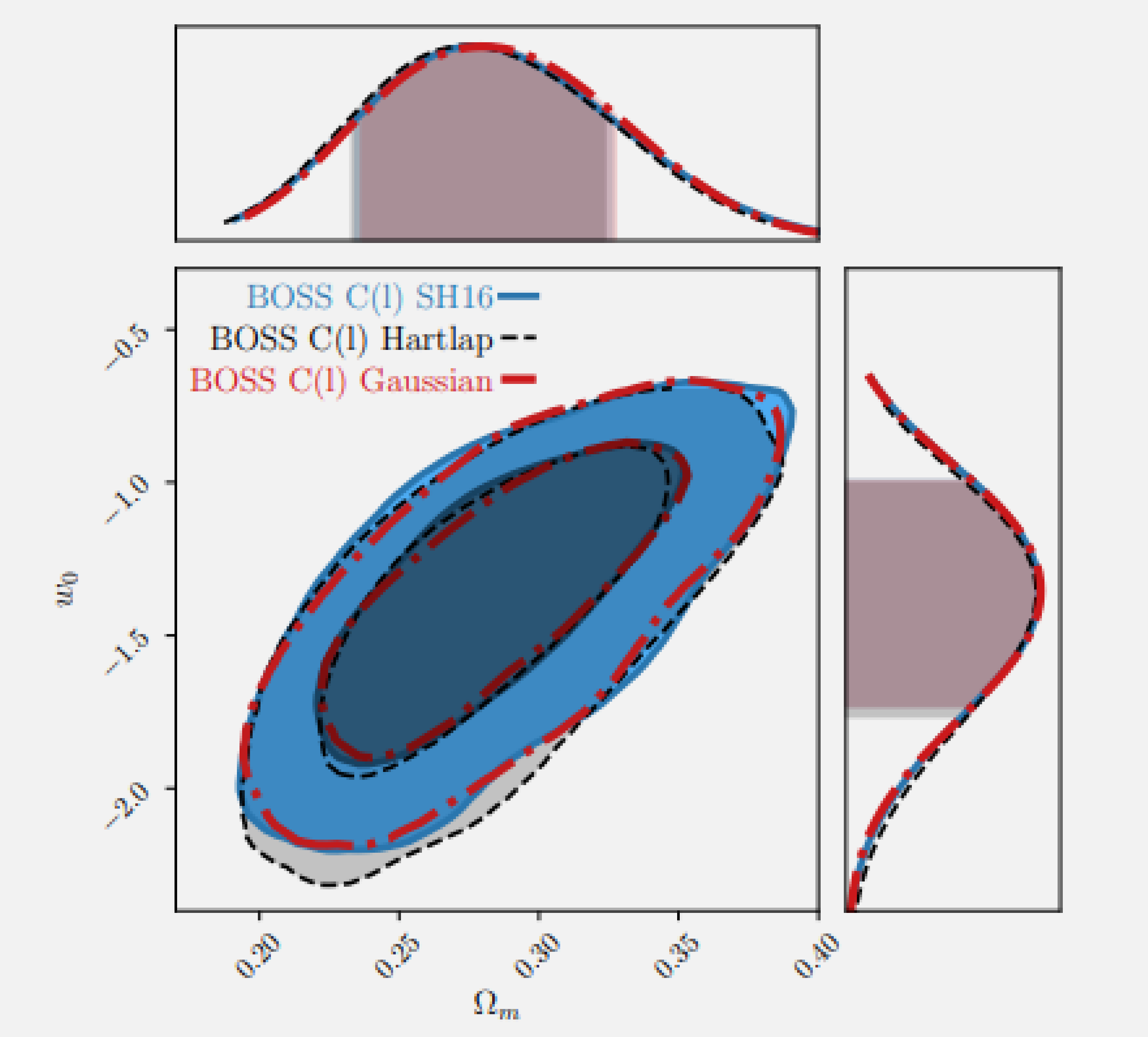
ΛCDM with sum of ν mass species

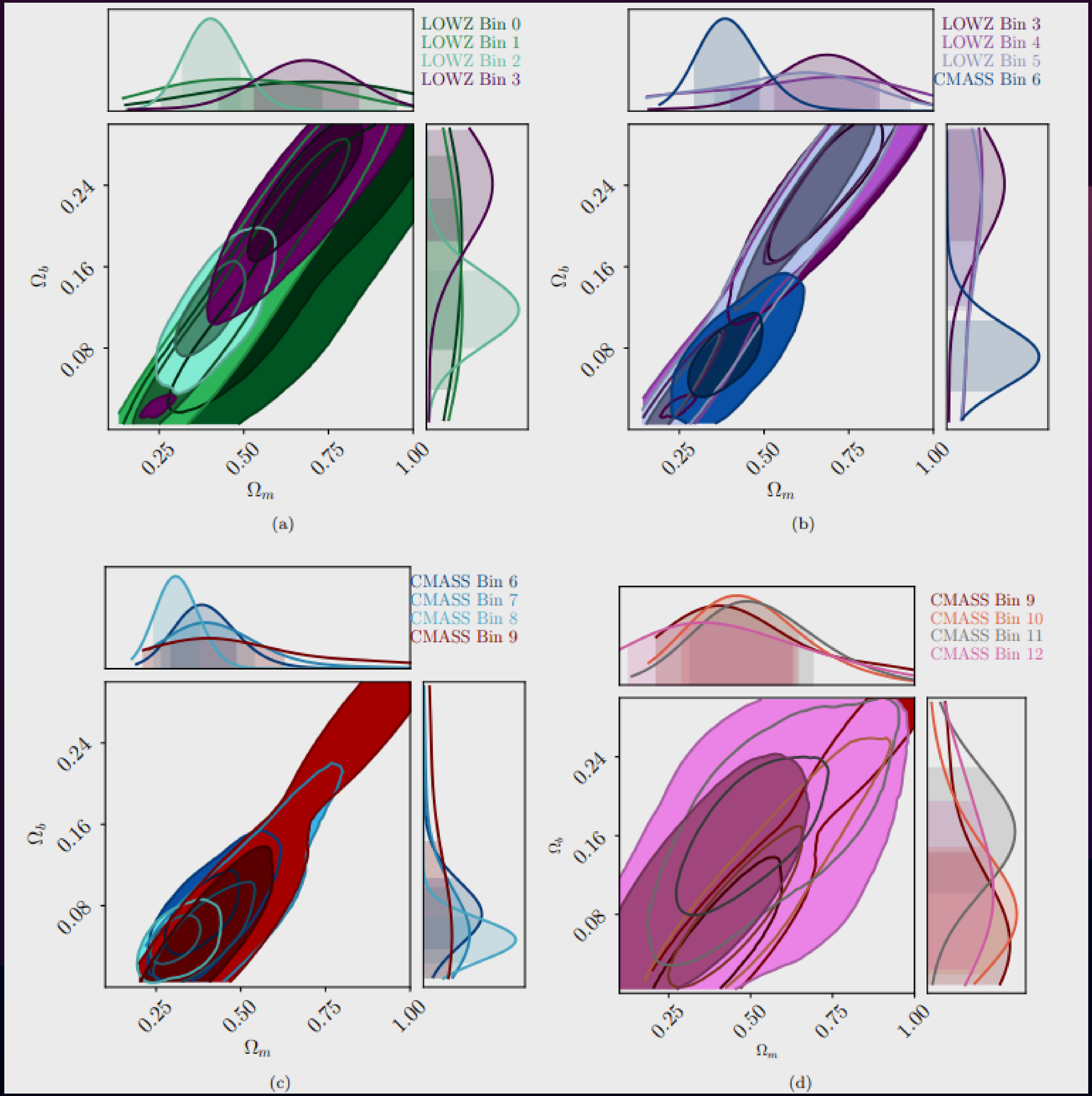
wCDM model

Sample Bin	z_{min}	z_{max}	$\ell_{max}^{5\%}$	$\ell_{max}^{10\%}$
LOWZ–0	0.15	0.20	53	69
LOWZ–1	0.20	0.25	77	93
LOWZ–2	0.25	0.30	93	109
LOWZ–3	0.30	0.35	109	133
LOWZ–4	0.35	0.40	125	157
LOWZ–5	0.40	0.45	141	173
CMASS–6	0.45	0.50	157	221
CMASS–7	0.50	0.55	165	237
CMASS–8	0.55	0.60	189	261
CMASS–9	0.60	0.65	197	277
CMASS–10	0.65	0.70	213	317
CMASS–11	0.70	0.75	245	333
CMASS–12	0.75	0.80	261	381

Priors and Likelihoods

Parameter	Prior Range
Ω_b	1×10^{-3}, 0.3
Ω_{cdm}	0.0, 0.8
$\ln 10^{10}A_s$	2.0, 4.0
n_s	0.87, 1.07
h	0.55, 0.91
w_0	-3, -0.3
$\sum m_\nu$	0.0, 1.0 eV
τ_{reio}^{Planck}	0.0, 0.8
$b(z)$	1.1, 3.3
$\sigma_s(z)$	$1\times10^{-6}, 9\times10^{-3}$
N_9, N_{10}	0.0, 1×10^{-4}
N_{11}	0.0, 8×10^{-5}
N_{12}	0.0, 4×10^{-4}
y_{cal}^{Planck}	0.99, 1.01
M_B^{JLA}	-20.0, -18.5.





Consistency checks

Parameter-dependant theoretical covariance matrix

Controlled cosmology pipeline test

Distribuition of residuals

Single z bin consistence

External data

Model	Parameter	BOSS	BOSS + JLA	BOSS + JLA + Planck	Planck
ΛCDM	Ω_m	$0.315^{+0.034}_{-0.033}$	$0.317^{+0.022}_{-0.021}$	0.327 ± 0.008	0.315 ± 0.011
	Ω_b	$0.0404^{+0.010}_{-0.009}$	$0.0381^{+0.007}_{-0.008}$	0.0502 ± 0.0006	0.0492 ± 0.0009
	S_8	$0.715^{+0.072}_{-0.064}$	$0.745^{+0.059}_{-0.052}$	$0.862^{+0.015}_{-0.016}$	$0.850^{+0.023}_{-0.021}$
	h	$0.716^{+0.088}_{-0.069}$	0.699 ± 0.039	0.663 ± 0.005	0.672 ± 0.008
	n_s	$0.929^{+0.064}_{-0.045}$	$0.955^{+0.052}_{-0.048}$	0.960 ± 0.004	0.964 ± 0.006
wCDM	Ω_m	$0.277^{+0.050}_{-0.042}$	$0.308^{+0.021}_{-0.018}$	0.330 ± 0.012	$0.213^{+0.062}_{-0.039}$
	Ω_b	$0.0318^{+0.0117}_{-0.0098}$	0.0429 ± 0.007	0.0505 ± 0.002	$0.0334^{+0.009}_{-0.006}$
	S_8	$0.726^{+0.072}_{-0.061}$	$0.743^{+0.079}_{-0.068}$	0.863 ± 0.016	$0.811^{+0.037}_{-0.034}$
	h	$0.767^{+0.069}_{-0.091}$	$0.745^{+0.049}_{-0.052}$	0.661 ± 0.012	$0.816^{+0.073}_{-0.101}$
	n_s	$0.939^{+0.057}_{-0.049}$	$0.957^{+0.049}_{-0.050}$	0.960 ± 0.004	0.964 ± 0.006
	w_0	$-1.36^{+0.36}_{-0.38}$	$-1.030^{+0.073}_{-0.076}$	$-0.993^{+0.046}_{-0.043}$	$-1.45^{+0.32}_{-0.23}$
ΛCDM + $\sum m_\nu$ [$\ell_{max}^{5\%}$ cut]	Ω_m	$0.326^{+0.038}_{-0.035}$	$0.304^{+0.022}_{-0.021}$	0.328 ± 0.009	$0.326^{+0.028}_{-0.021}$
	Ω_b	$0.040^{+0.009}_{-0.010}$	0.0432 ± 0.008	$0.05017^{+0.0009}_{-0.0008}$	$0.0506^{+0.0039}_{-0.0026}$
	S_8	$0.723^{+0.069}_{-0.063}$	$0.700^{+0.065}_{-0.056}$	0.862 ± 0.017	$0.836^{+0.031}_{-0.035}$
	h	$0.730^{+0.075}_{-0.078}$	$0.814^{+0.054}_{-0.064}$	$0.663^{+0.006}_{-0.007}$	$0.662^{+0.018}_{-0.026}$
	n_s	$0.933^{+0.066}_{-0.046}$	$0.941^{+0.055}_{-0.049}$	0.960 ± 0.042	$0.962^{+0.006}_{-0.007}$
	$\sum m_\nu$ (95% CI)[eV]	< 0.75	< 0.71	< 0.14	< 0.76
ΛCDM + $\sum m_\nu$ [$\ell_{max}^{10\%}$ cut]	Ω_m	$0.345^{+0.033}_{-0.030}$	$0.324^{+0.034}_{-0.029}$	$0.333^{+0.014}_{-0.012}$	$0.326^{+0.050}_{-0.029}$
	Ω_b	0.045 ± 0.009	0.040 ± 0.013	$0.0510^{+0.0016}_{-0.0014}$	$0.0506^{+0.0069}_{-0.0033}$
	S_8	$0.751^{+0.062}_{-0.057}$	$0.768^{+0.097}_{-0.092}$	$0.864^{+0.030}_{-0.029}$	$0.839^{+0.058}_{-0.067}$
	h	$0.689^{+0.076}_{-0.066}$	$0.661^{+0.067}_{-0.063}$	$0.658^{+0.010}_{-0.011}$	$0.662^{+0.024}_{-0.044}$
	n_s	$0.930^{+0.062}_{-0.044}$	$1.011^{+0.056}_{-0.086}$	0.958 ± 0.006	0.962 ± 0.013
	$\sum m_\nu$ (95% CI)[eV]	< 0.72	< 0.66	< 0.16	< 0.76

ΛFlat CDM Constraints

Fixed Parameters

$\Omega_k = 0$

$w_0 = -1$

Sum of $m_\nu = 0.06$ eV

Sampled Parameters

Ω_{cdm}

Ω_b

A_s

n_s

h

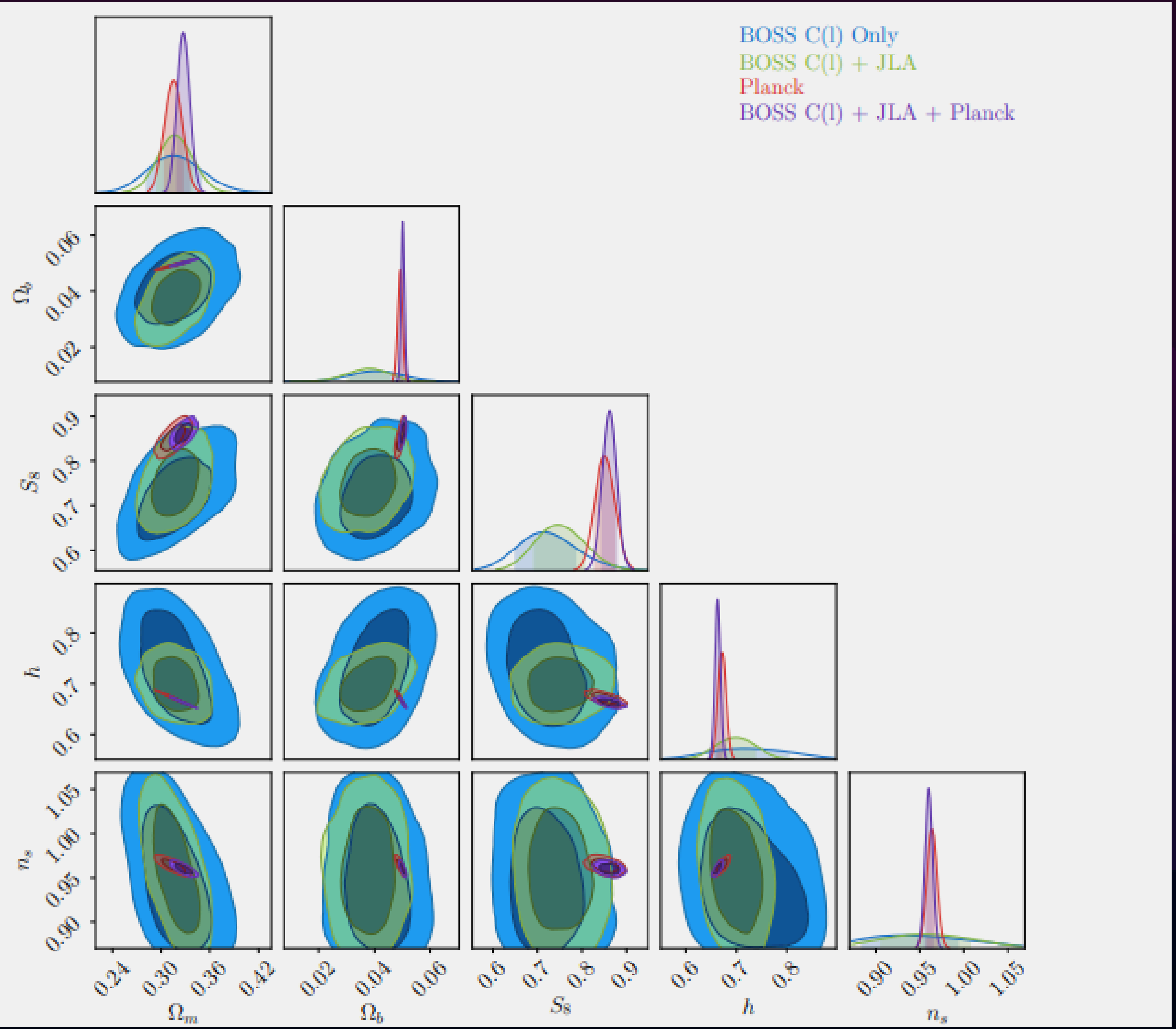
$$R^{\Lambda CDM}_{\mathrm{BOSS+JLA}} \simeq 18 \tag{70}$$

$$R^{\Lambda CDM}_{\mathrm{BOSS+PLANCK}} \simeq 74 \tag{71}$$

$$R^{\Lambda CDM}_{\mathrm{PLANCK+JLA}} \simeq 11 \tag{72}$$

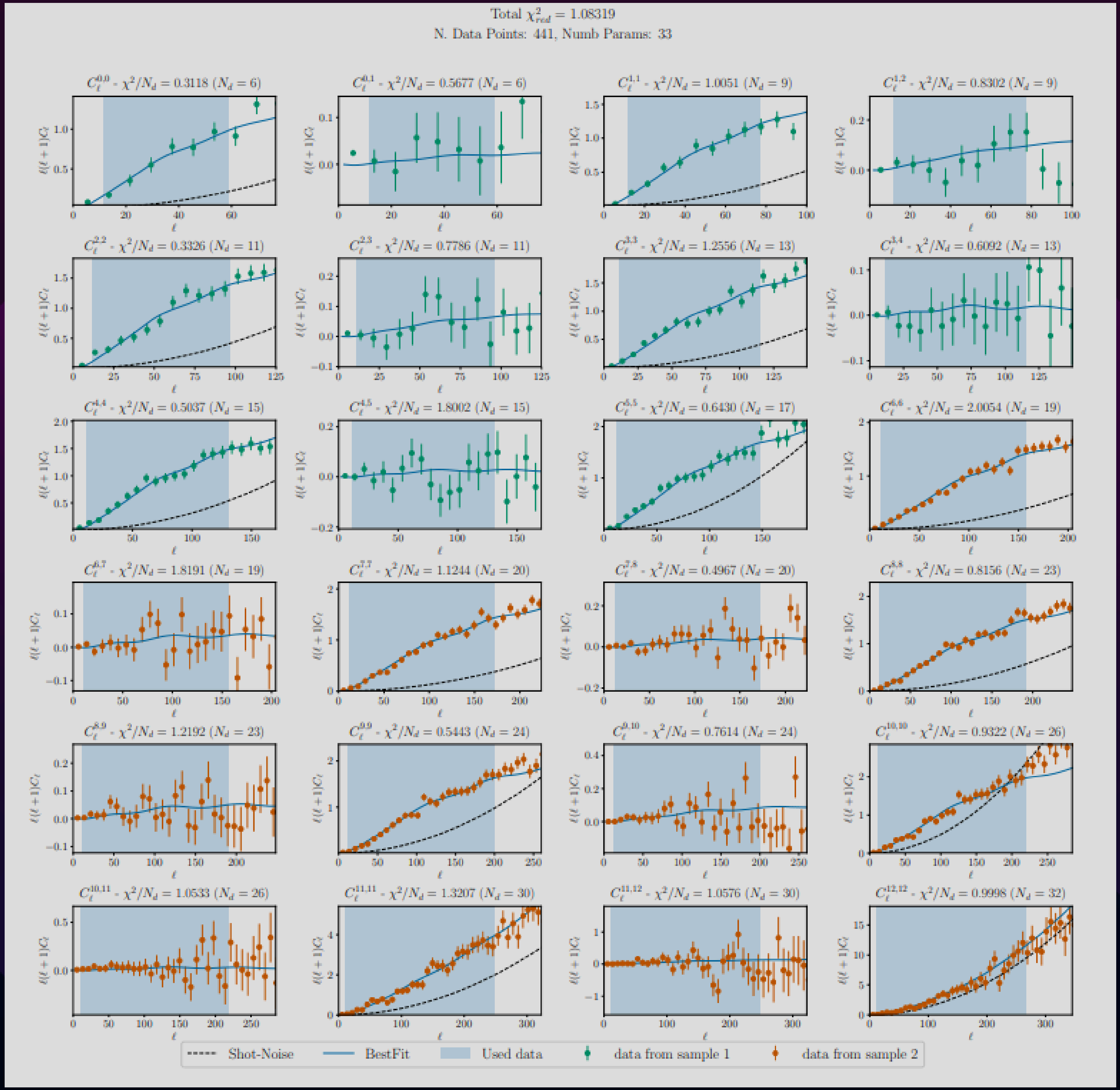
$$R^{\Lambda CDM}_{\mathrm{BOSS+PLANCK+JLA}} \simeq 4 \times 10^4 \,; \tag{73}$$

ΛFlat CDM Constraints



ΛFlat CDM Constraints

$\chi^2 = 1.08$



wCDM model

ΛCDM with sum of v mass species

CONCLUSIONS

1. Competitive results for all three models
2. Data prefers massive neutrinos
3. Very high Bayes factor values
4. Small tension for S_8
5. Comparisons between neutrino mass
6. Equation-of-state of dark energy constraints

Bibliography and references

- https://arxiv.org/abs/1809.07204
- https://www.sdss4.org/dr12/

THANK YOU

I hope you learned something new!