Stringent constraints on primordial non-Gaussianity from photometric quasars

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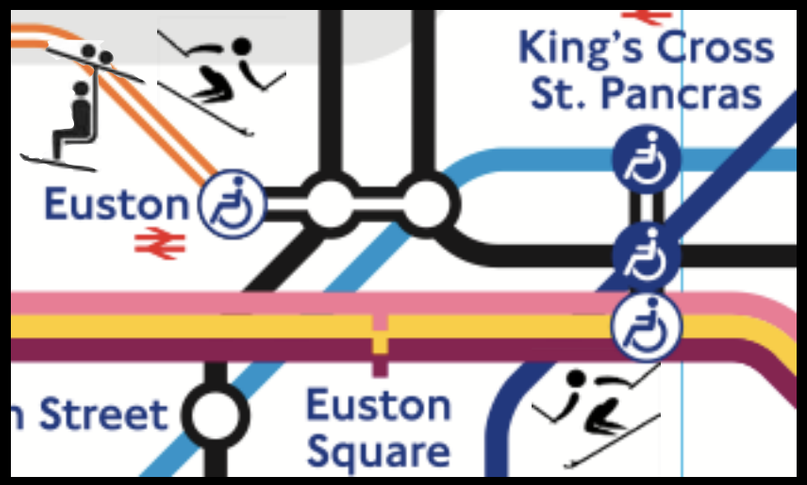
arXiv: 1306:0005 and 1404.xxxx

In collaboration with Hiranya Peiris, Nina Roth

Motivation for this work

- Want not just precision, but accurate cosmology e.g., Primordial Non-Gaussianity (PNG)
- Galaxy surveys: many observational systematics
- This work: blind mitigation of systematics in quasar clustering + robust PNG constraints



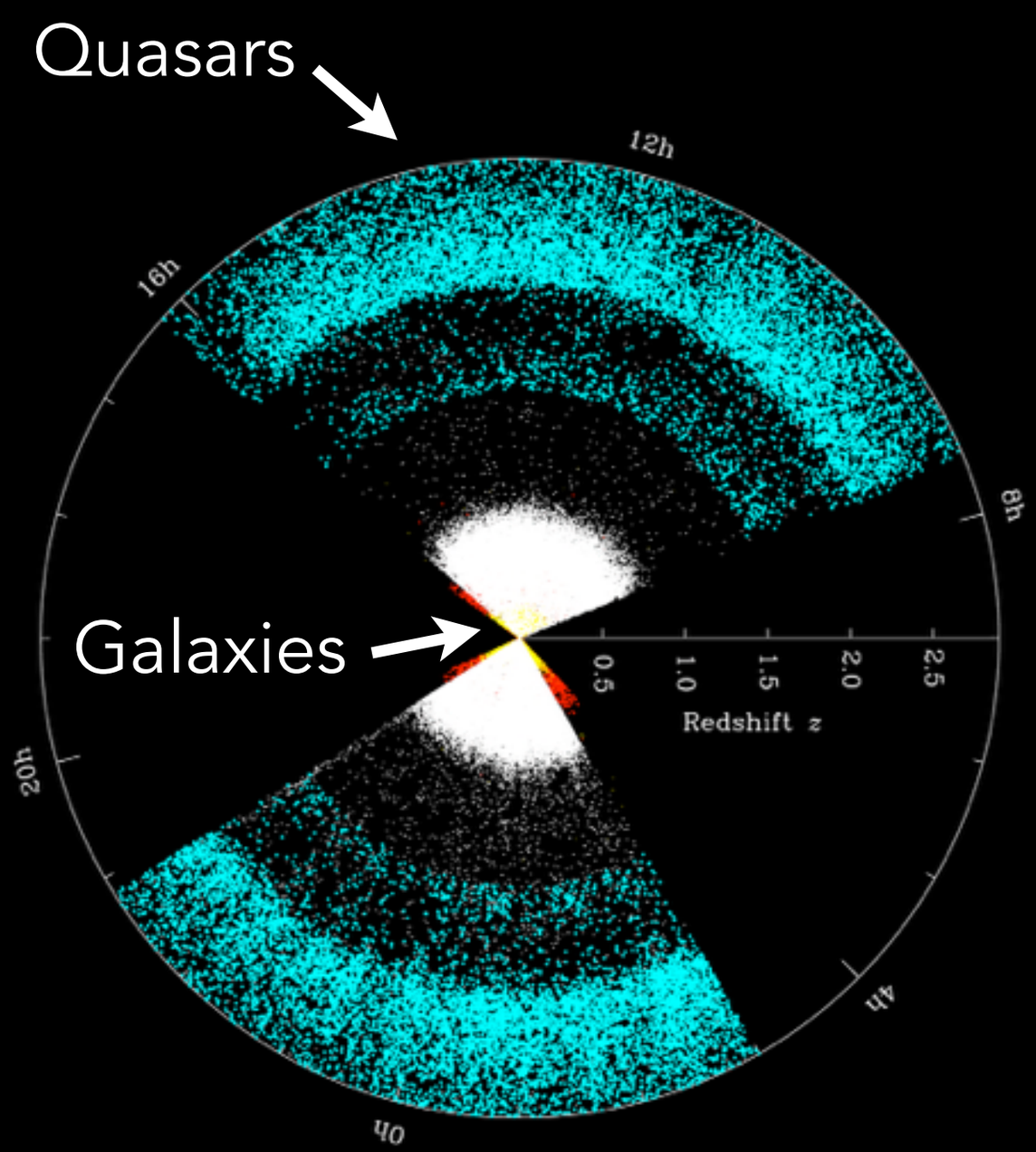
Roadmap

1. Photometric quasars from SDSS

2. Clean power spectrum measurements using extended mode projection

3. Constraints on PNG and quasar bias

Cosmology with quasar surveys



SDSS3 ; Credit: M.Blanton

- Quasars are bright, highly biased tracers that span large cosmological volumes
- Probe super horizon / large scales modes, e.g., PNG

Slosar et al 2008, Mana et al 2013, Giannantonio et al 2013, Ho et al 2013, etc...

Spectroscopic vs photometric samples

- Photometric catalogues: large, deep
  but: redshift estimation & star-quasar classification

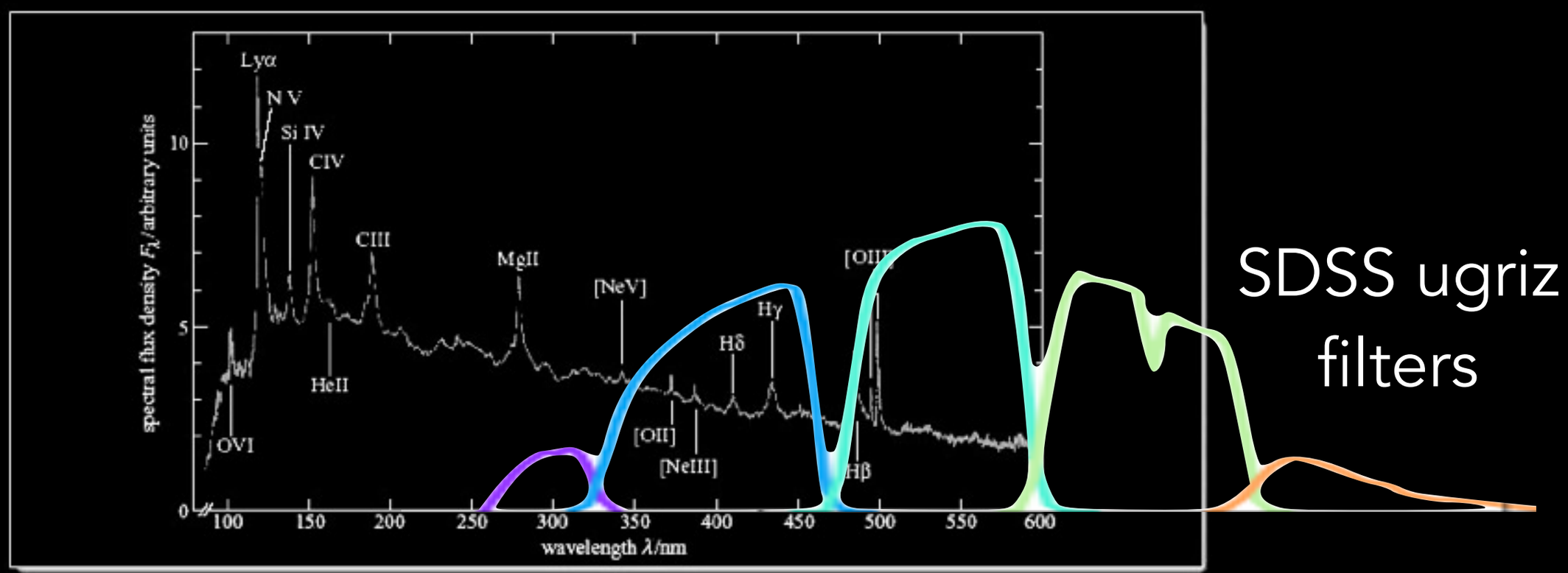
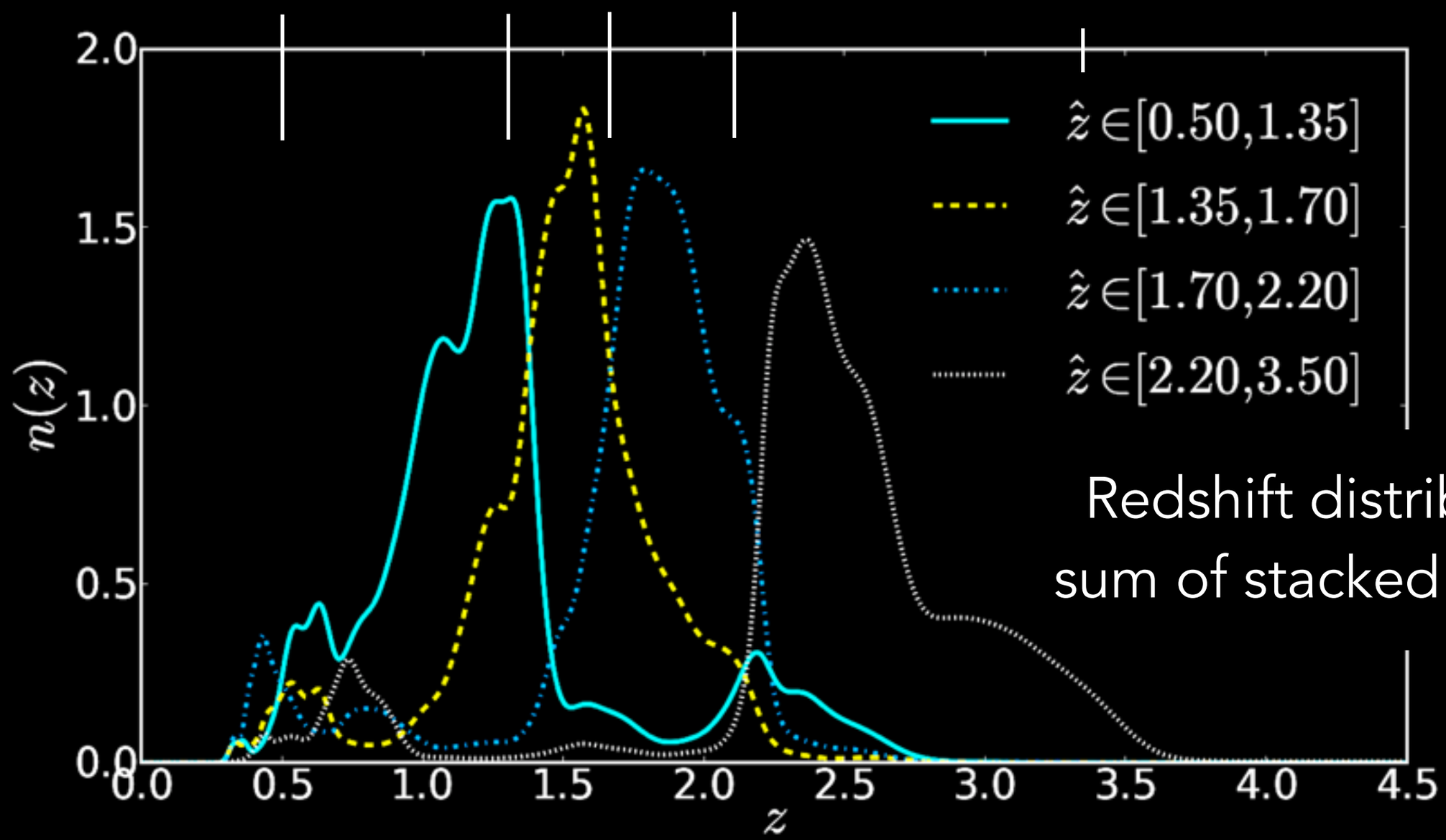


Figure 16: The mean optical spectrum of a sample of more than 700 quasars. The individual spectra were all corrected to remove the effect of red-shift before the spectra were averaged. Note the broad emission lines

An Introduction to Active Galactic Nuclei, Cambridge University Press

The XDQSOz catalogue and our samples

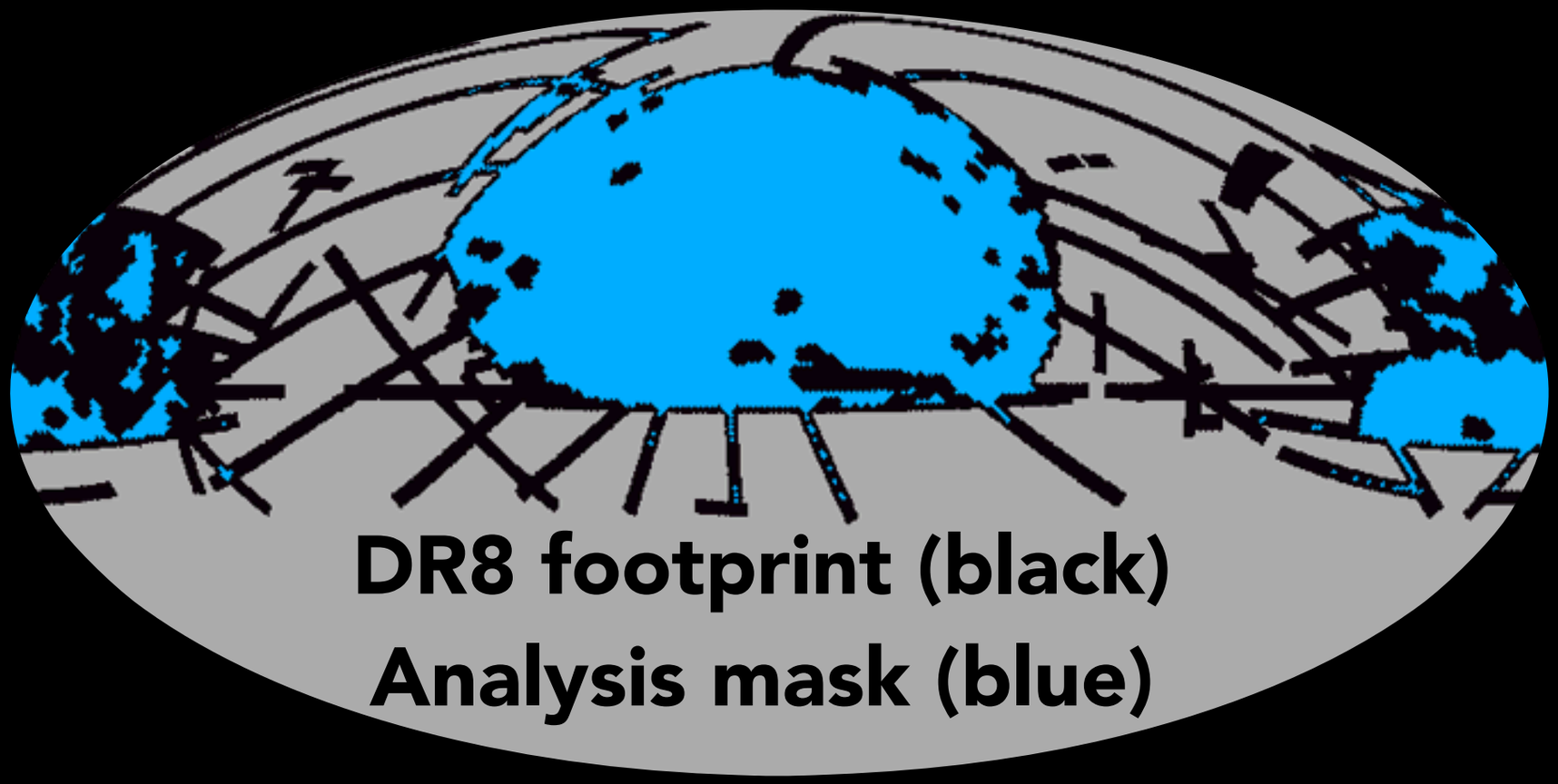
- XDQSOz: 1.6 million QSO candidates from SDSS DR8

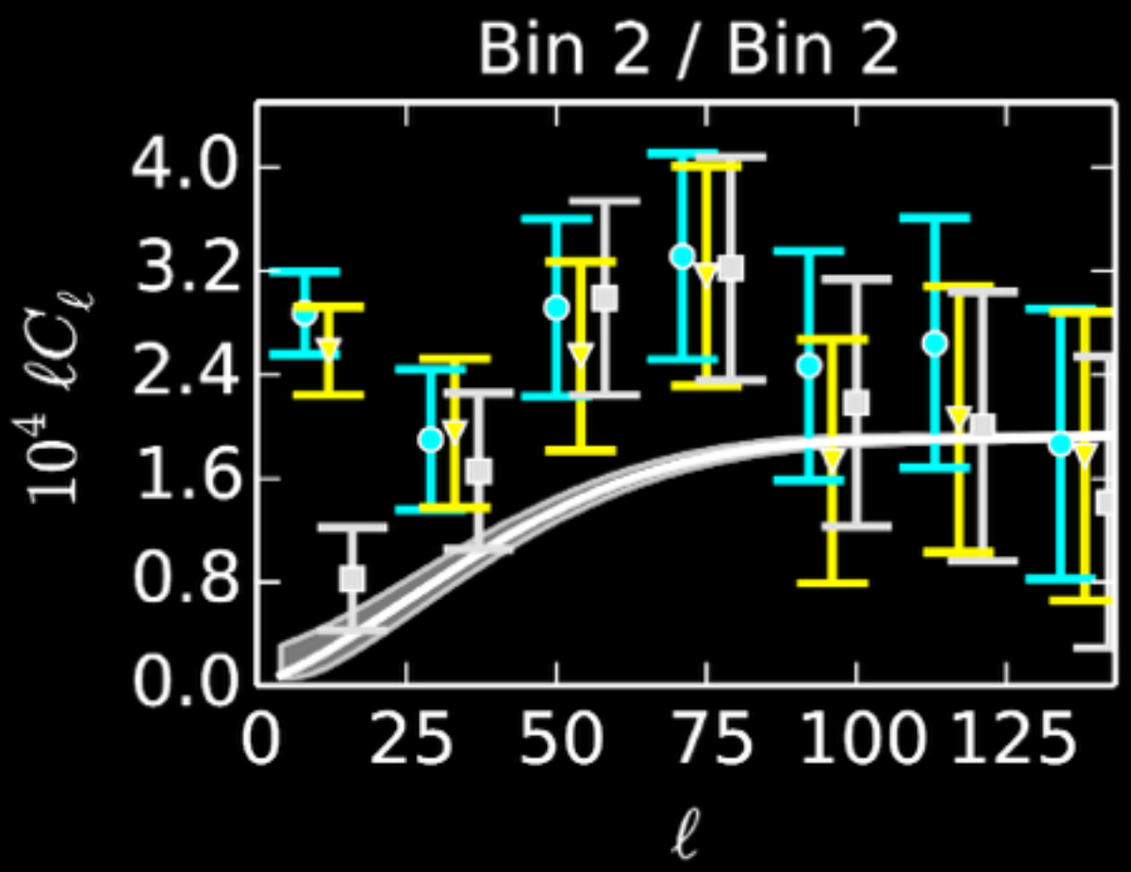


Redshift distributions = sum of stacked posteriors

Angular power spectrum estimation

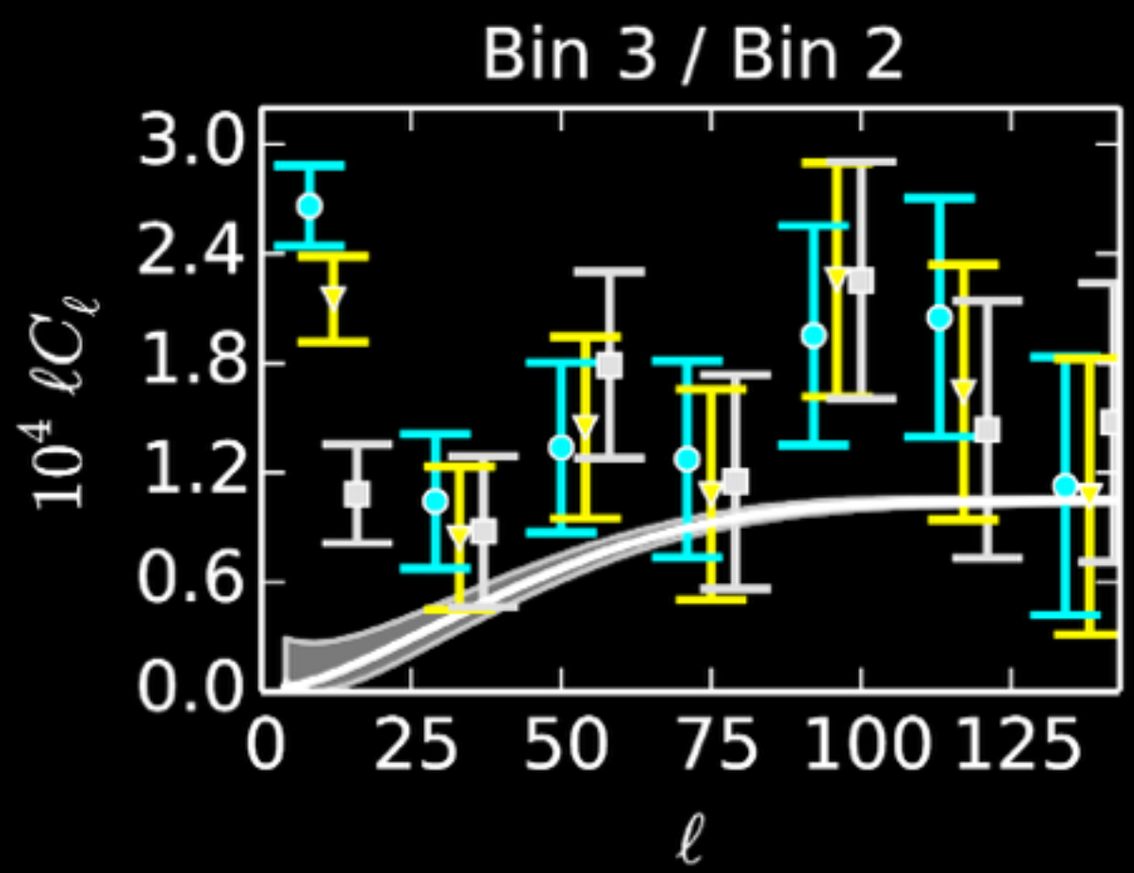
- Sky masks: cuts on extinction, seeing & quality flags
- Maximum Likelihood estimator to simultaneously compute 10 auto + cross angular power spectra

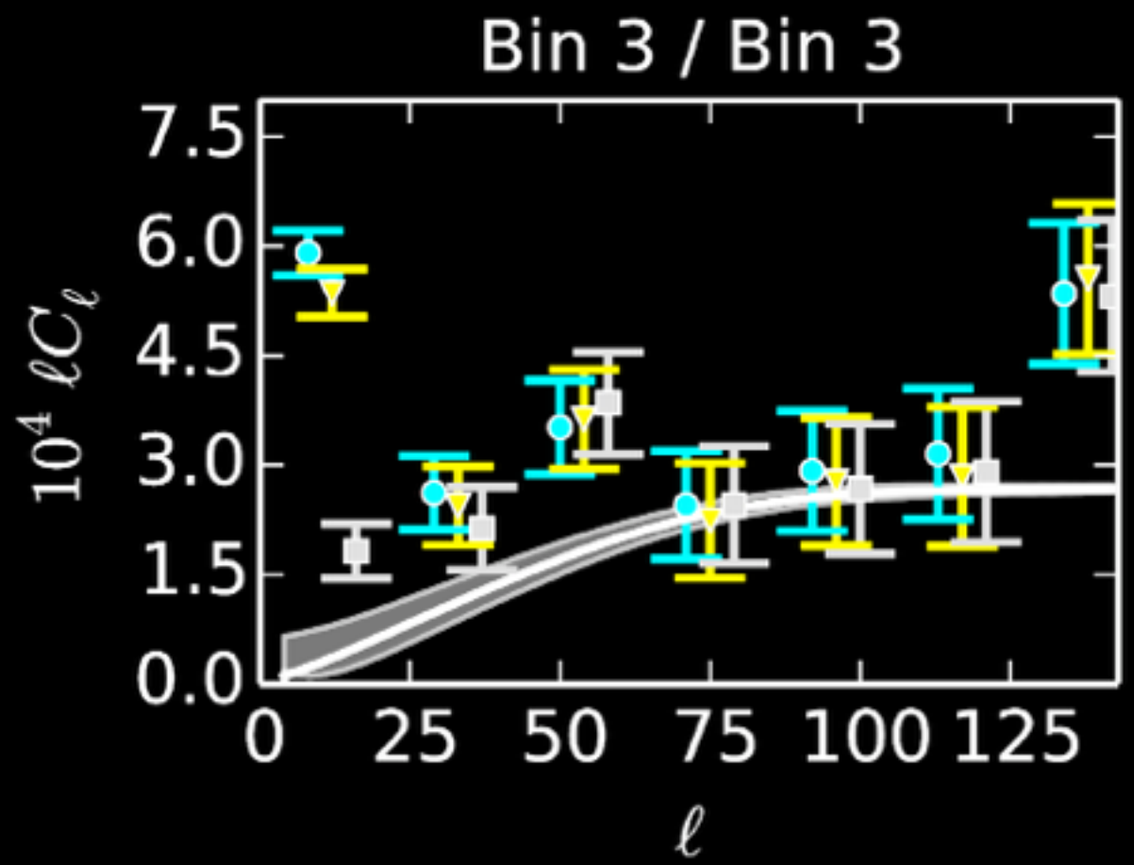




Raw power spectra

- Evidence for strong systematics in all samples
- Mimic PNG signal



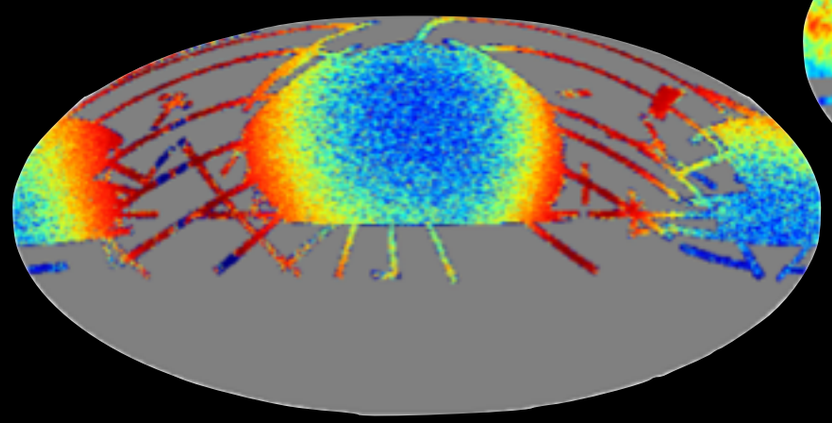


Systematics in quasar surveys

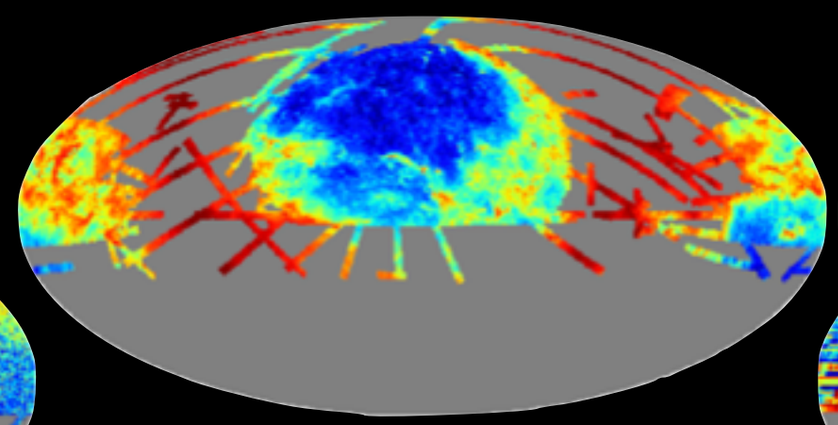
- Anything that affects point sources or colours:
  e.g., dust extinction, seeing, airmass, zero points, etc

- Create spatially varying depth & stellar contamination

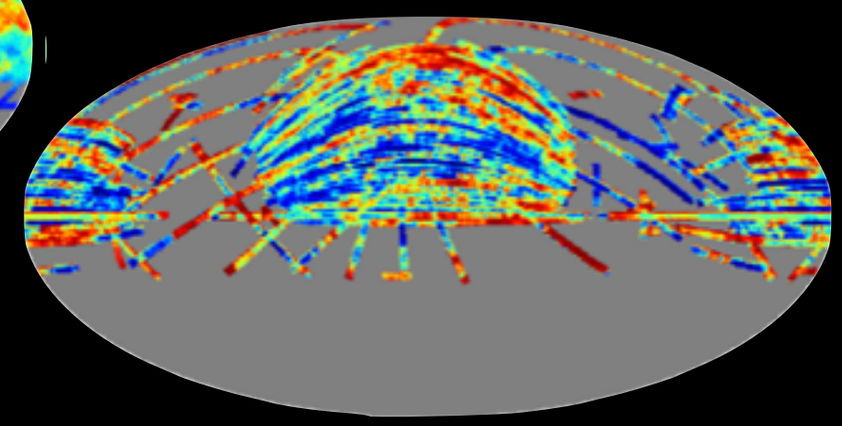
stars

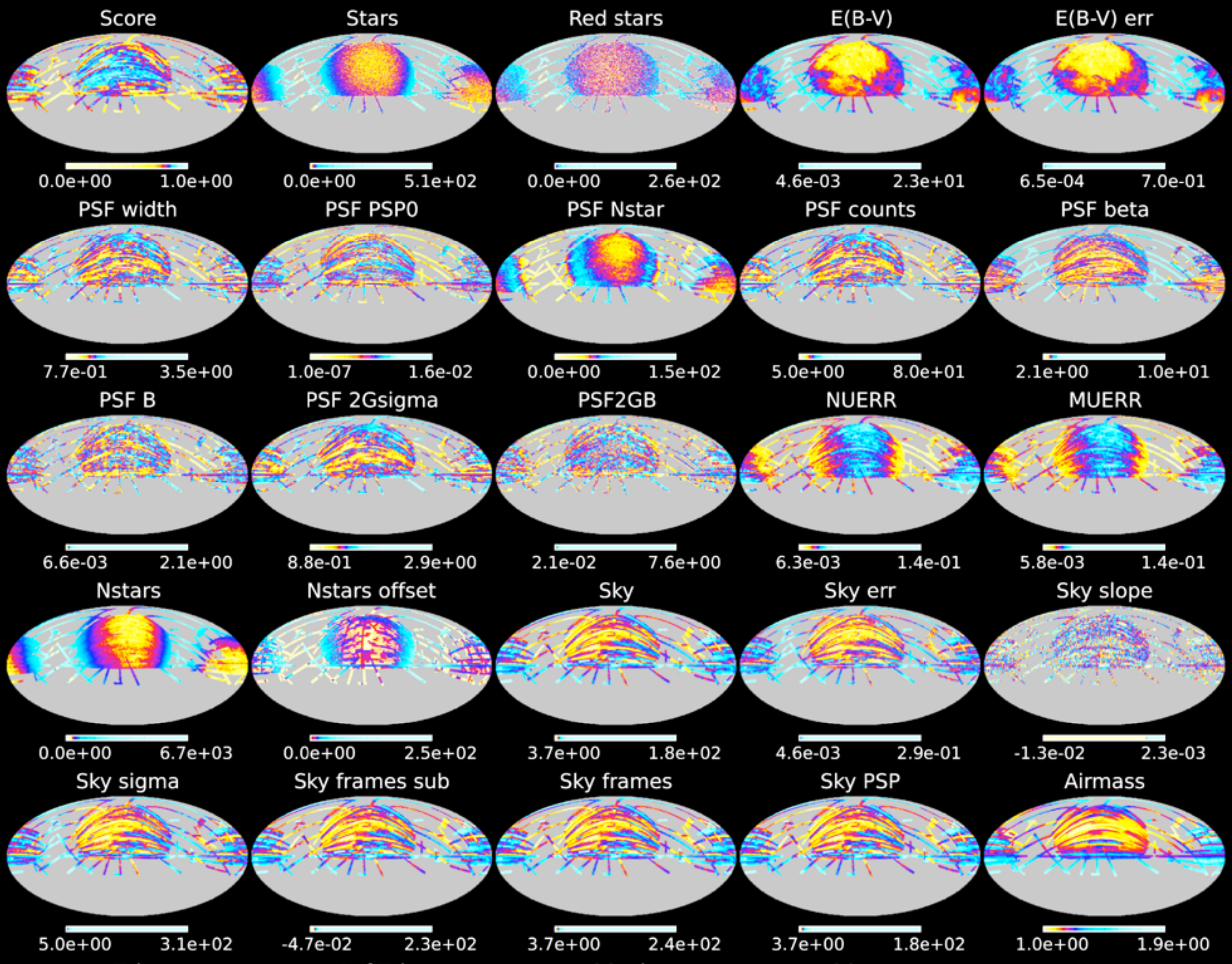


dust



seeing




Score
0.0e+00 1.0e+00
Stars
0.0e+00 5.1e+02
Red stars
0.0e+00 2.6e+02
E(B-V)
4.6e-03 2.3e+01
E(B-V) err
6.5e-04 7.0e-01
PSF width
7.7e-01 3.5e+00
PSF PSP0
1.0e-07 1.6e-02
PSF Nstar
0.0e+00 1.5e+02
PSF counts
5.0e+00 8.0e+01
PSF beta
2.1e+00 1.0e+01
PSF B
6.6e-03 2.1e+00
PSF 2Gsigma
8.8e-01 2.9e+00
PSF2GB
2.1e-02 7.6e+00
NUERR
6.3e-03 1.4e-01
MUERR
5.8e-03 1.4e-01
Nstars
0.0e+00 6.7e+03
Nstars offset
0.0e+00 2.5e+02
Sky
3.7e+00 1.8e+02
Sky err
4.6e-03 2.9e-01
Sky slope
-1.3e-02 2.3e-03
Sky sigma
5.0e+00 3.1e+02
Sky frames sub
-4.7e-02 2.3e+02
Sky frames
3.7e+00 2.4e+02
Sky PSP
3.7e+00 1.8e+02
Airmass
1.0e+00 1.9e+00

Extended mode projection

1. Create set of input systematics

220 templates + pairs ⇒ >20,000 templates

2. Decorrelate systematics

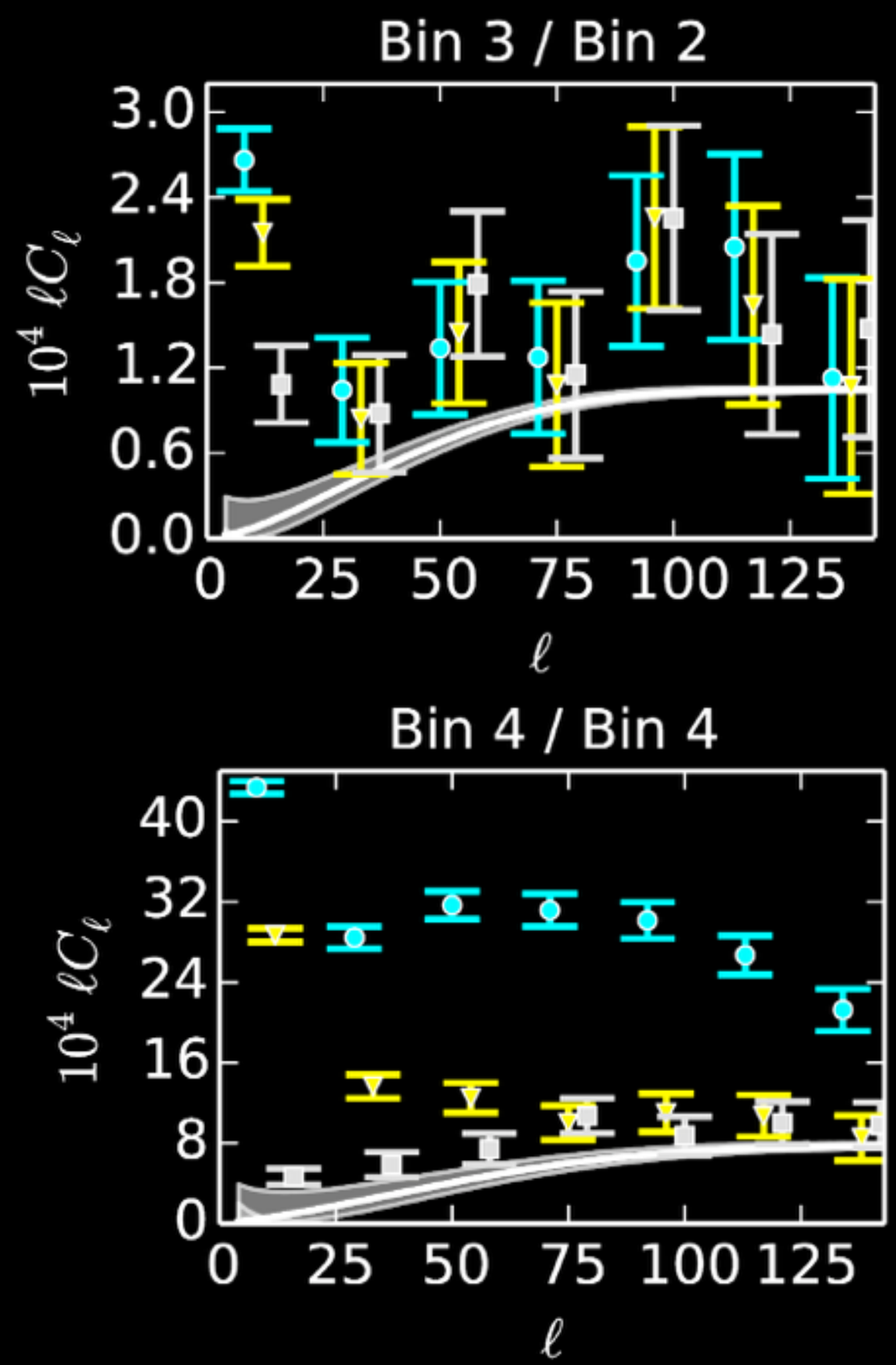
20,000 templates ⇒ 3,700 uncorrelated modes

3. Ignore the most correlated with data

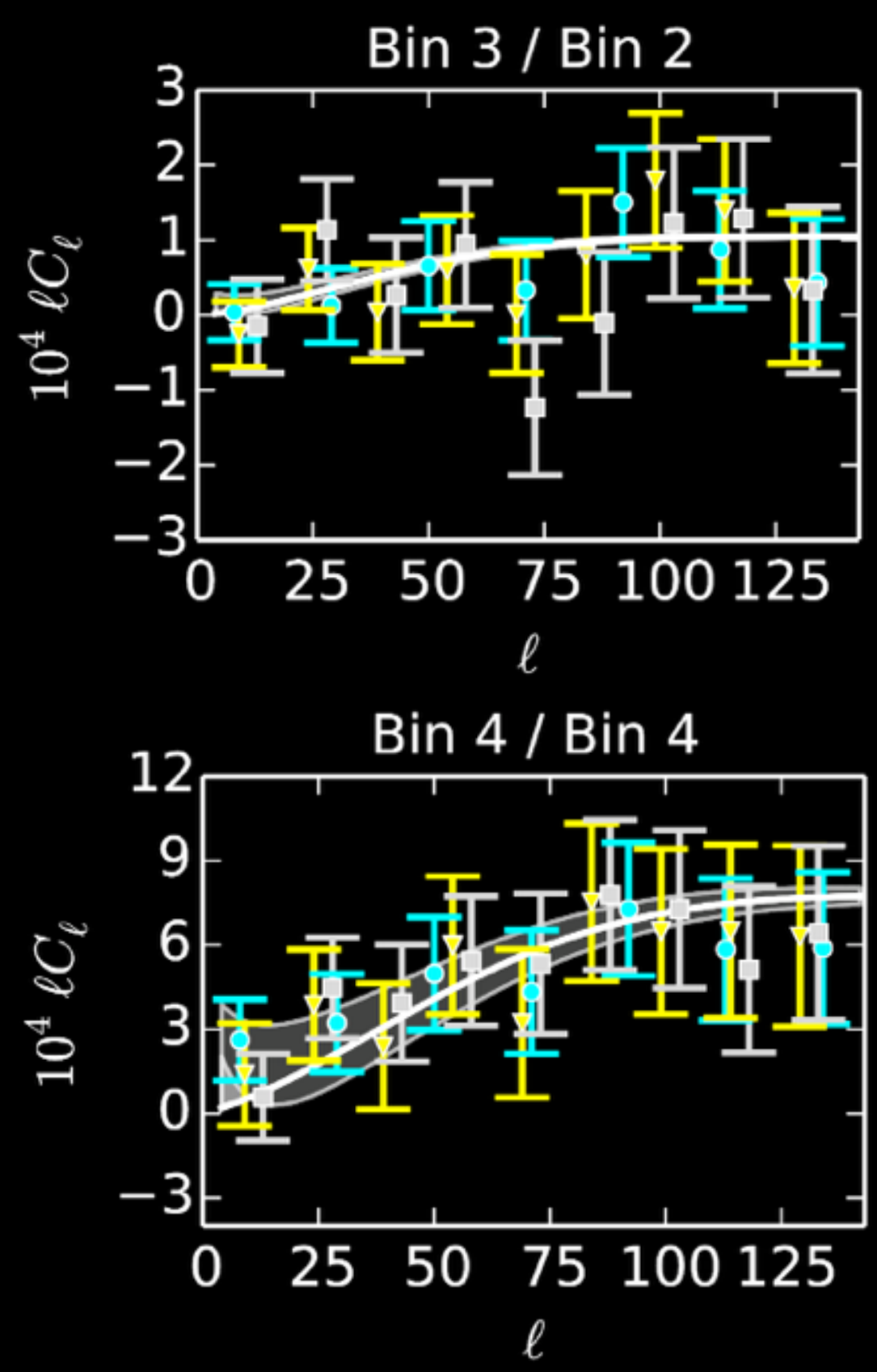
3,700 null tests; project out modes with red chi2>1

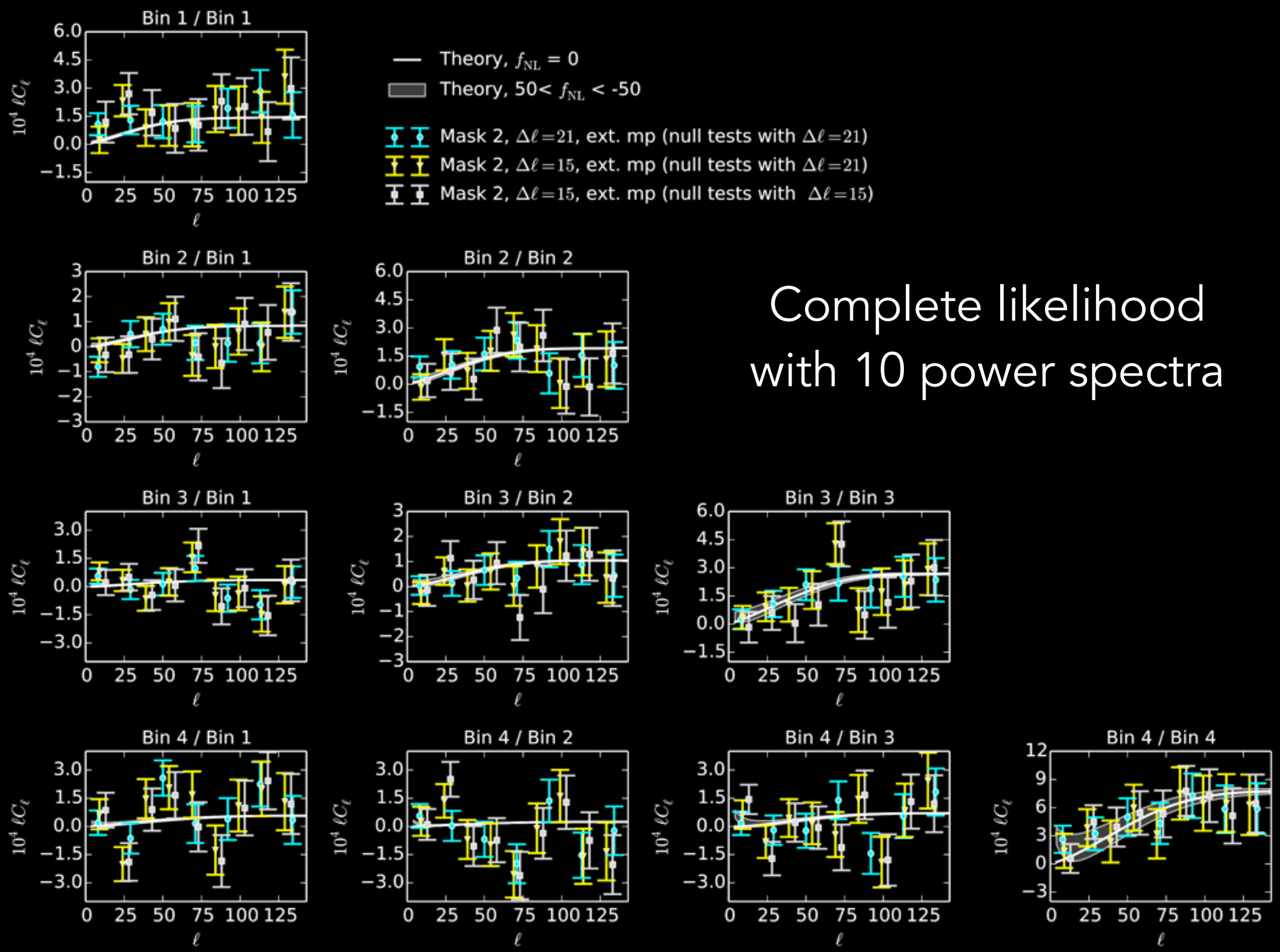
Sacrificing some signal in favour of robustness
⇒ **Blind mitigation of systematics**

Raw spectra



Clean spectra



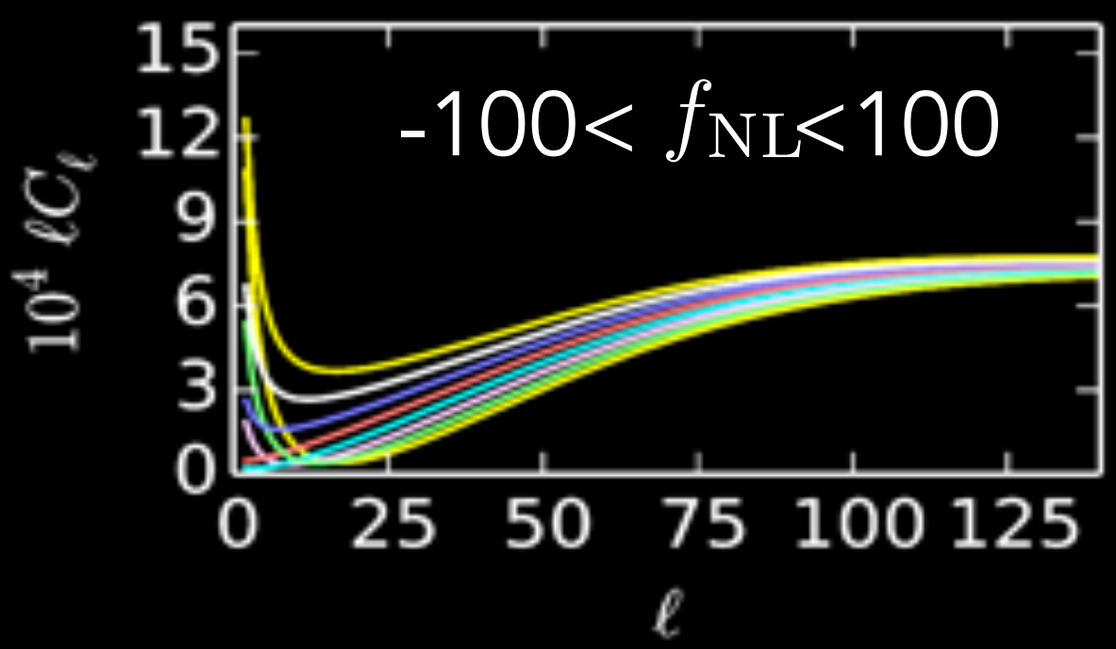


Complete likelihood with 10 power spectra

Theory

Ingredients for computing theory power spectra:

- Cosmological parameters (LCDM + $f_{\rm NL}$)
- Redshift distribution, shot noise, nb count slope
- Quasar bias model: $b(z) = b_0 \left[1 + \left(\frac{1+z}{\alpha} \right)^{\beta} \right]$



PNG: enhances large scale quasar bias

Used **emcee** (Foreman-Mackey et at 2013) + **CAMB_sources** (Challinor & Lewis 2011)

PNG constraints from XDQSOz

Fixed cosmology & n(z)

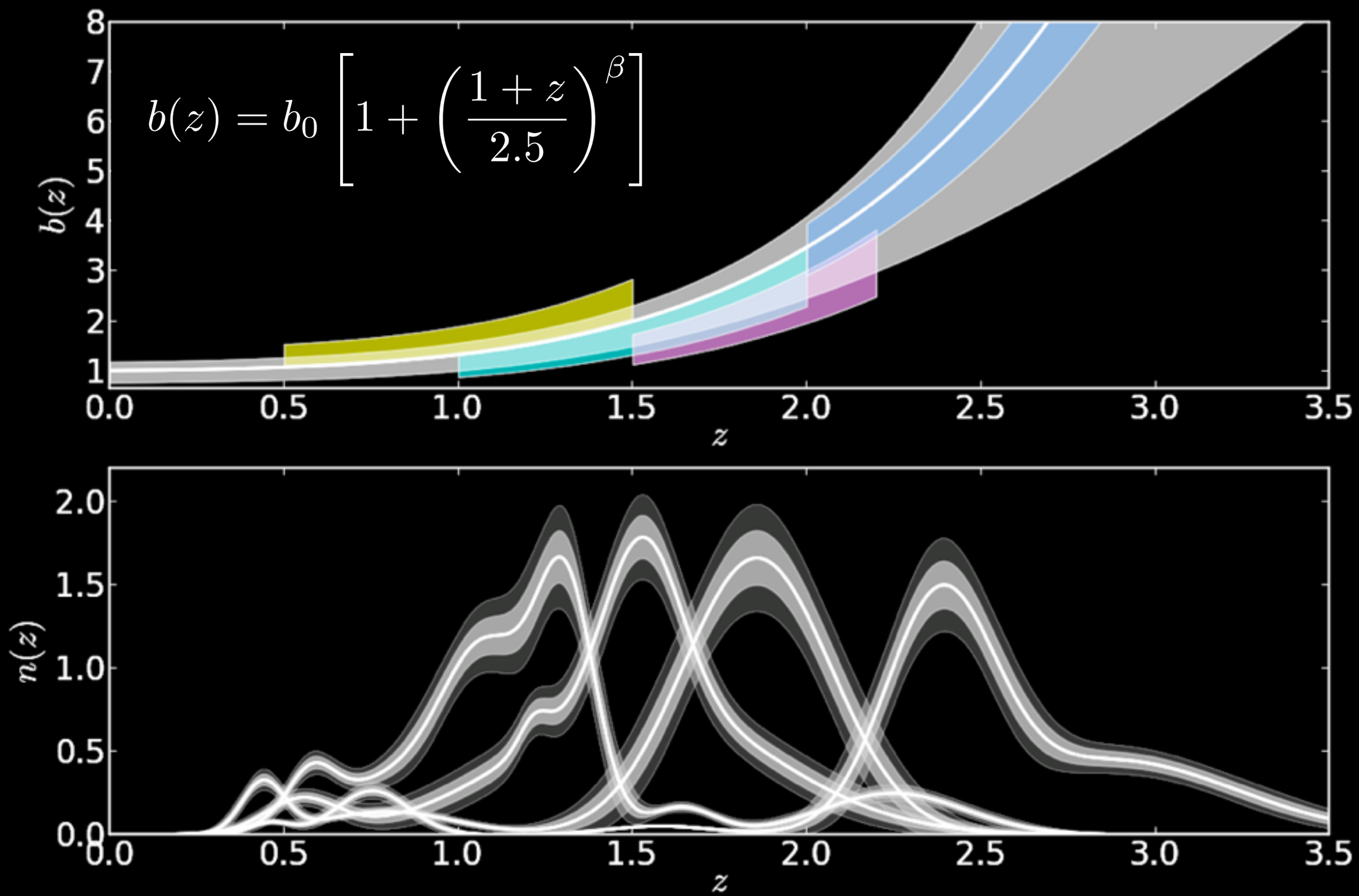
$$f_{\rm NL} = 22 \pm 15 \quad (1\sigma)$$
$$-16 < f_{\rm NL} < 47 \quad (2\sigma)$$

Varying all parameters

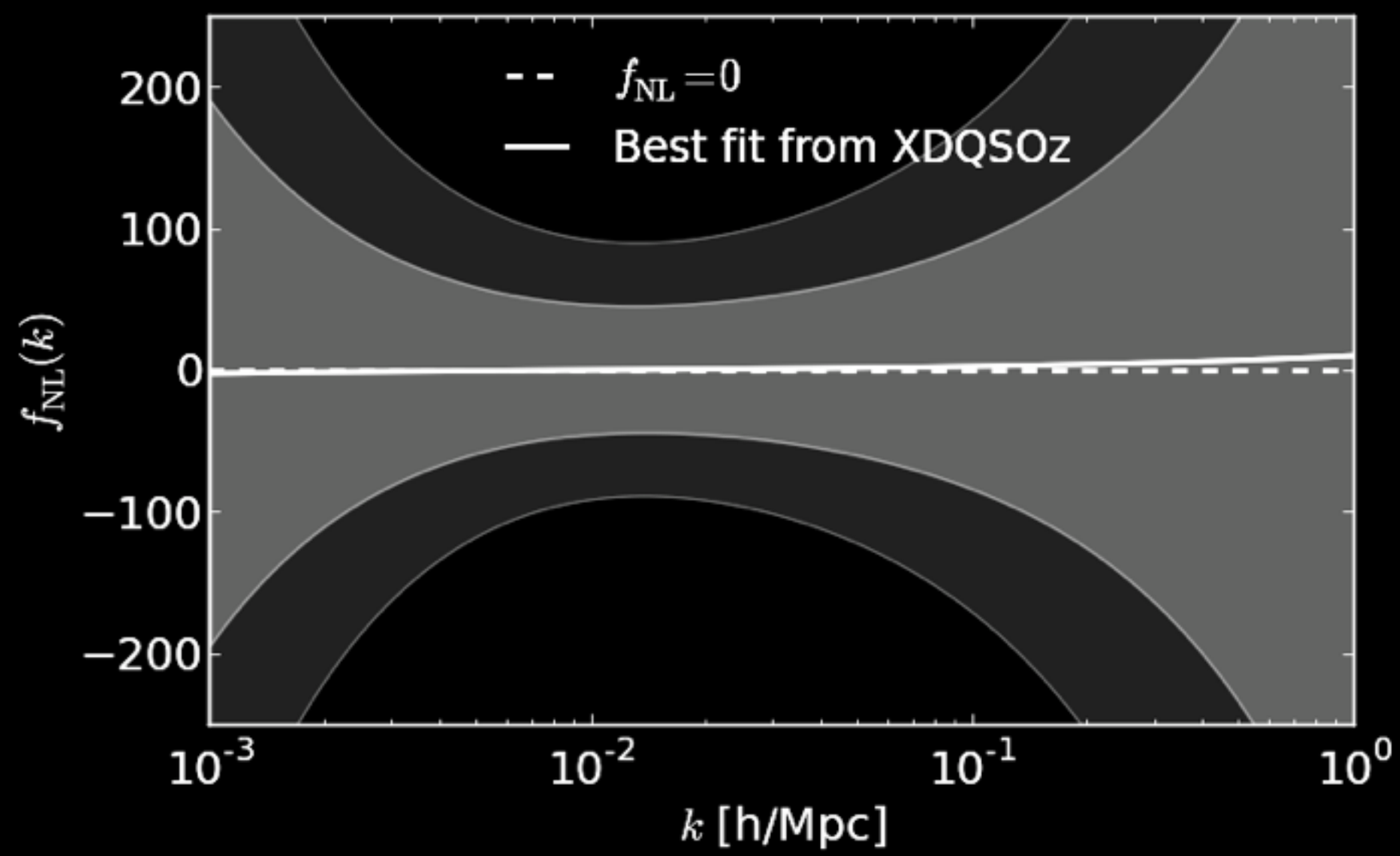
$$f_{\rm NL} = -9 \pm 33 \quad (1\sigma)$$
$$-56 < f_{\rm NL} < 34 \quad (2\sigma)$$

- Competitive with WMAP constraints
- Compatible with Planck $f_{\rm NL} = 2.7 \pm 5.8$
- Competitive with previous QSO+LRG studies

Constraints on the quasar bias



Scale dependent PNG



$$f_{\rm NL}\left(\frac{k}{k_{\rm piv}}\right)^{n_f}$$

$$k_{\rm piv} = 0.06$$

- Competitive with WMAP
- To be confronted to / combined with Planck

Conclusions

- $-56 < f_{\rm NL} < 34 \quad (2\sigma)$ using quasars only
- Extended mode projection: "blind" mitigation of thousands of systematics
- Future: Dark Energy Survey

1306.0005

1404.xxxx

Extra slides

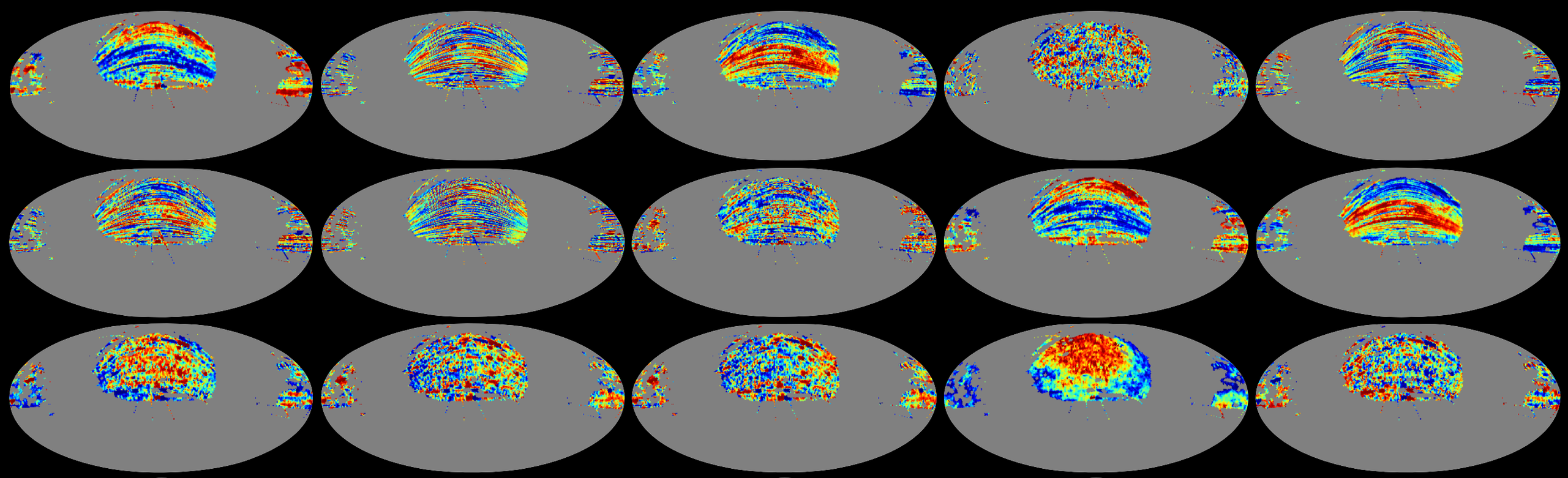
Extended mode projection

1. Create set of input systematics

300 templates + pairs ⇒ >20,000 templates

2. Decorrelate them and remove noisy modes

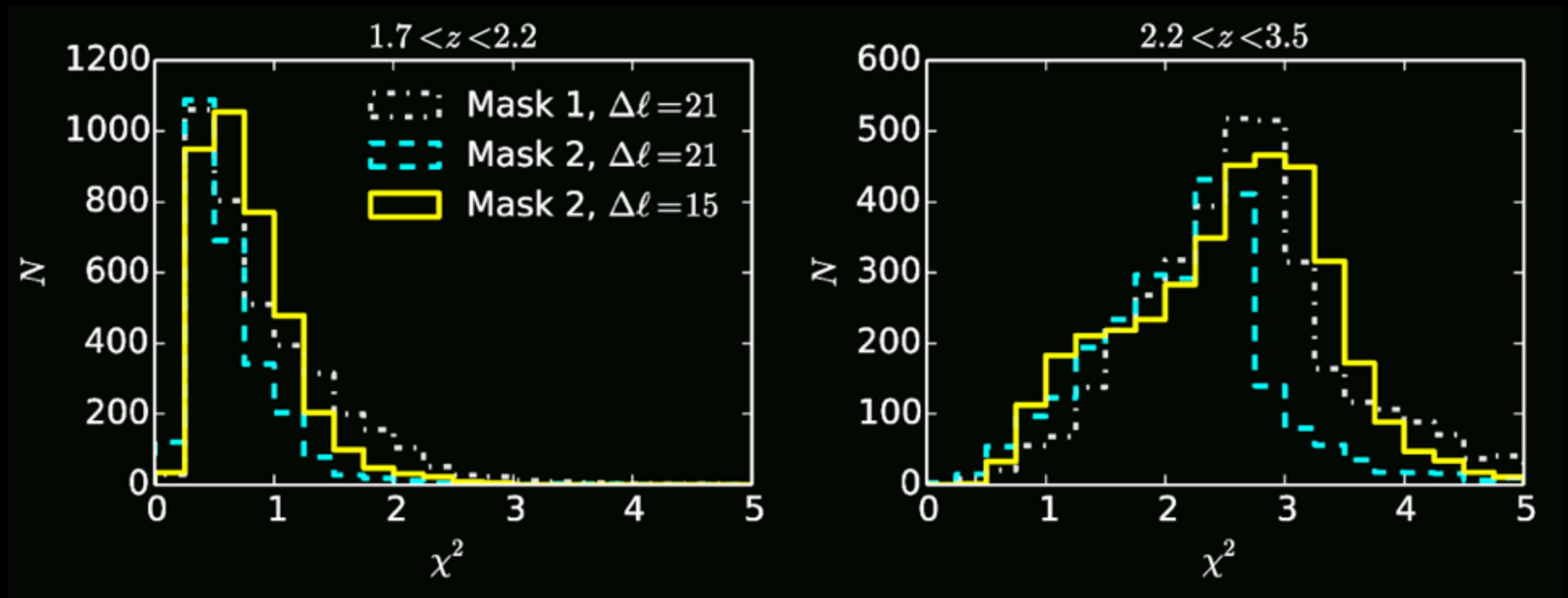
20,000 templates ⇒ 3,700 uncorrelated modes



Extended mode projection

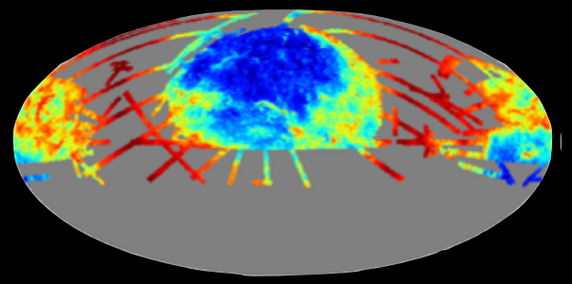
3. Project out the modes the most correlated with data

Cross correlate modes with QSO samples. Use cross-spectra as null tests. Mode projection based on χ^2



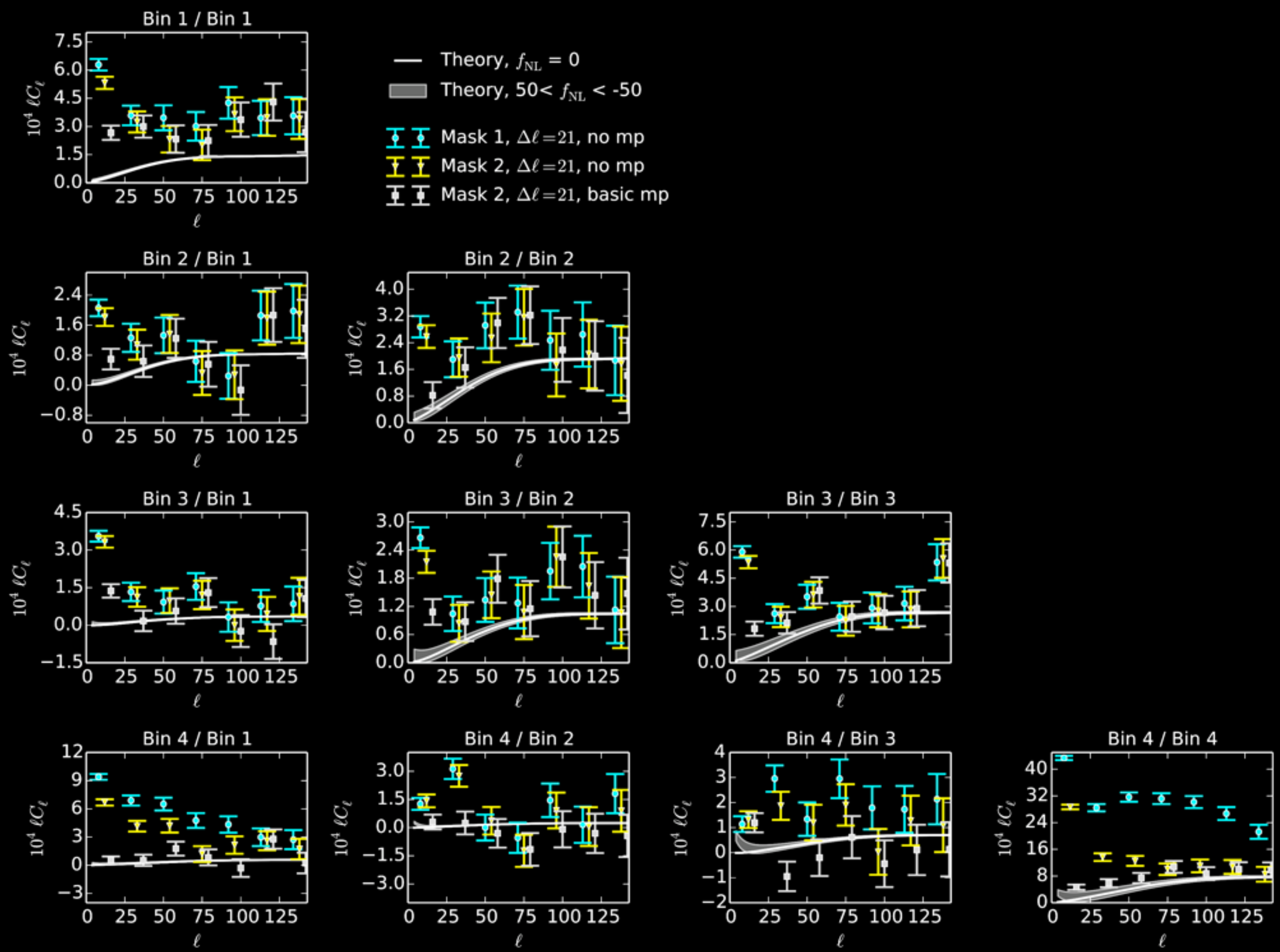
Mode projection

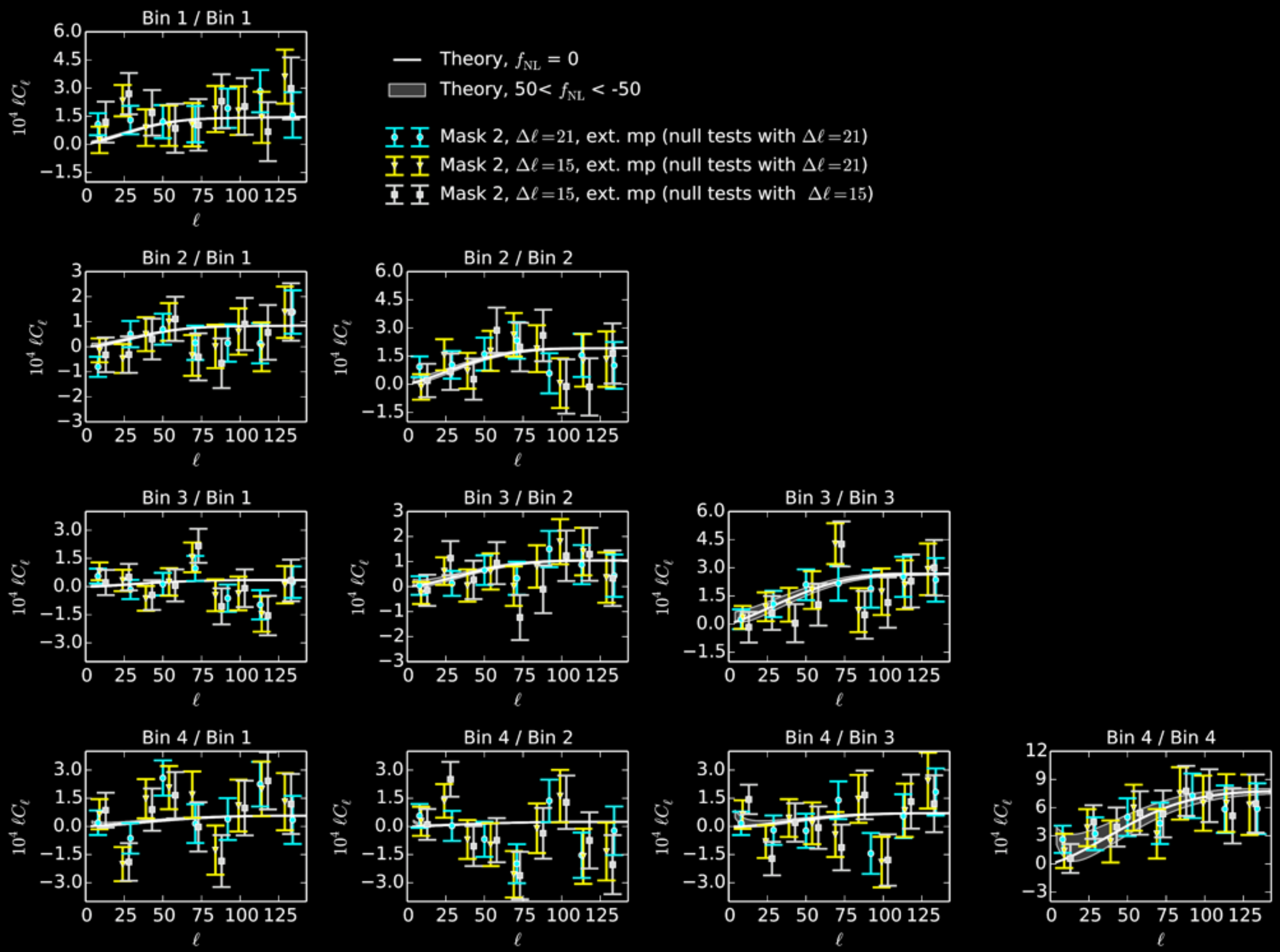
- Assuming a linear model:

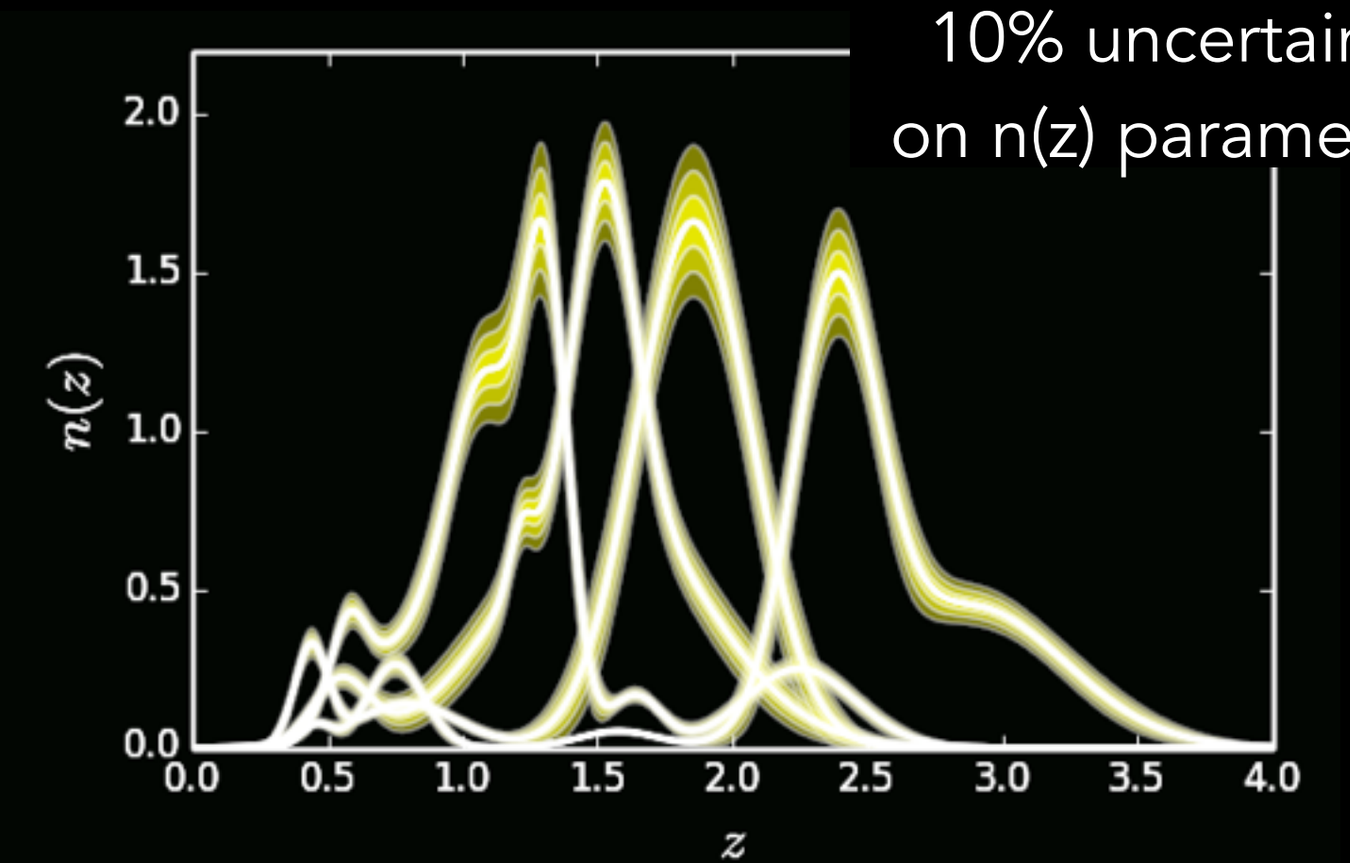


$$\vec{y}_{\rm obs} = \vec{x}_{\rm true} + \alpha\ \vec{c}_{\rm sys1} + \beta\ \vec{c}_{\rm sys2} + \ldots$$

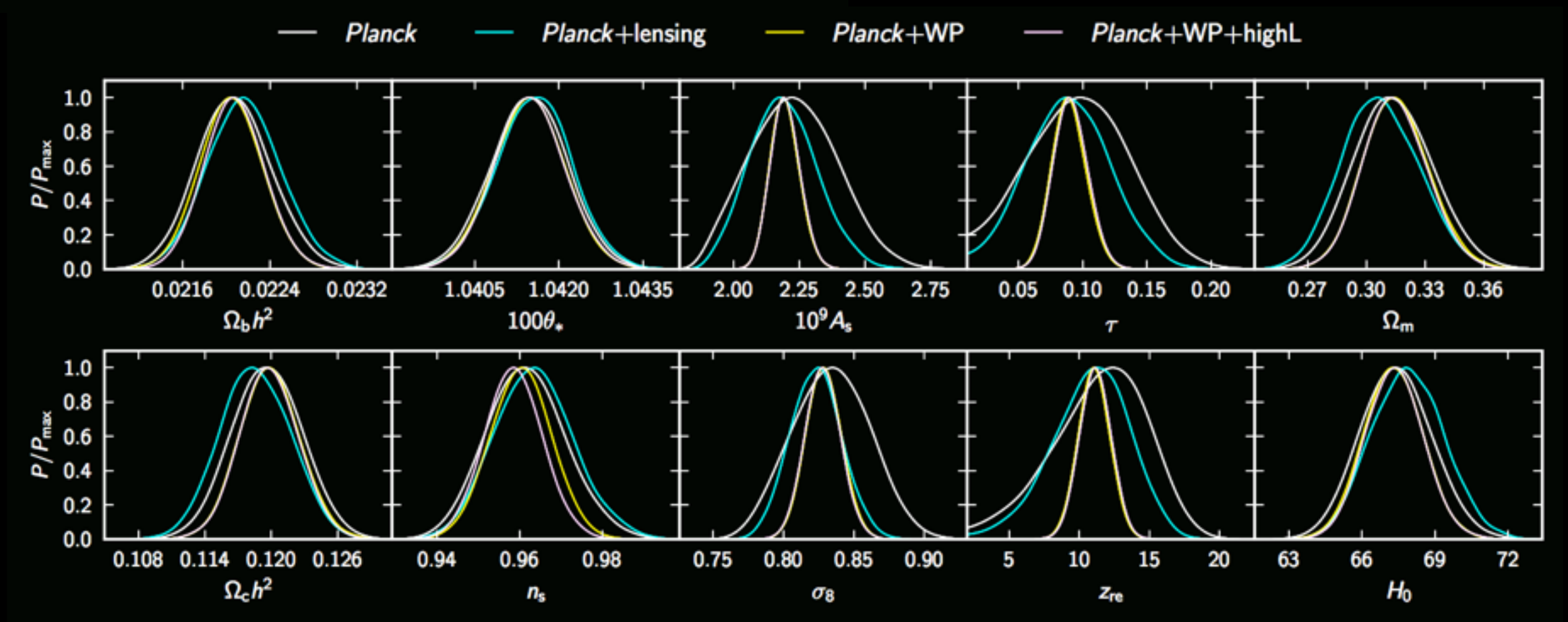
- Solution 1: fix parameters and correct data / spectra
- Solution 2: mode projection, i.e. marginalisation over all possible parameter values (performed within QML)
- Main issue: not suitable for non-linear models, and many correlated systematics (LSS != CMB)


Bin 1 / Bin 1
Theory, $f_{\rm NL}$ = 0
Theory, 50< $f_{\rm NL}$ < -50
Mask 1, $\Delta\ell=21$, no mp
Mask 2, $\Delta\ell=21$, no mp
Mask 2, $\Delta\ell=21$, basic mp
Bin 2 / Bin 1
Bin 2 / Bin 2
Bin 3 / Bin 1
Bin 3 / Bin 2
Bin 3 / Bin 3
Bin 4 / Bin 1
Bin 4 / Bin 2
Bin 4 / Bin 3
Bin 4 / Bin 4
$10^4\,\ell C_\ell$
ℓ


Bin 1 / Bin 1
Bin 2 / Bin 1
Bin 2 / Bin 2
Bin 3 / Bin 1
Bin 3 / Bin 2
Bin 3 / Bin 3
Bin 4 / Bin 1
Bin 4 / Bin 2
Bin 4 / Bin 3
Bin 4 / Bin 4
$10^4\,\ell C_\ell$
ℓ
Theory, $f_{\rm NL}$ = 0
Theory, 50< $f_{\rm NL}$ < -50
Mask 2, $\Delta\ell=21$, ext. mp (null tests with $\Delta\ell=21$)
Mask 2, $\Delta\ell=15$, ext. mp (null tests with $\Delta\ell=21$)
Mask 2, $\Delta\ell=15$, ext. mp (null tests with $\Delta\ell=15$)



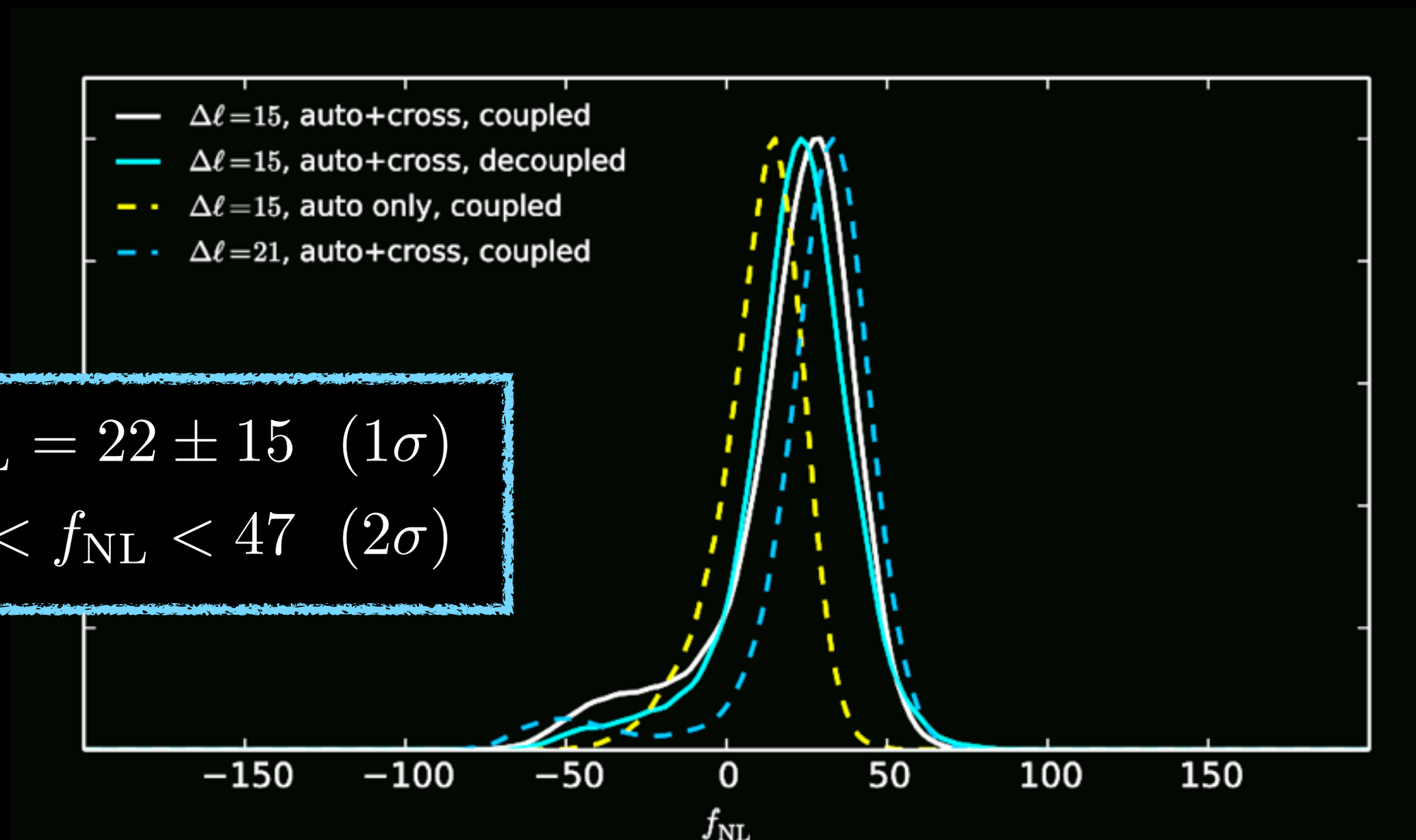
Varying n(z)
+ cosmology
+ bias model



Planck collaboration 2013

PNG constraints from XDQSOz

- Varying only PNG, shot noise, bias amplitude(s).



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Running of primordial non-Gaussianity

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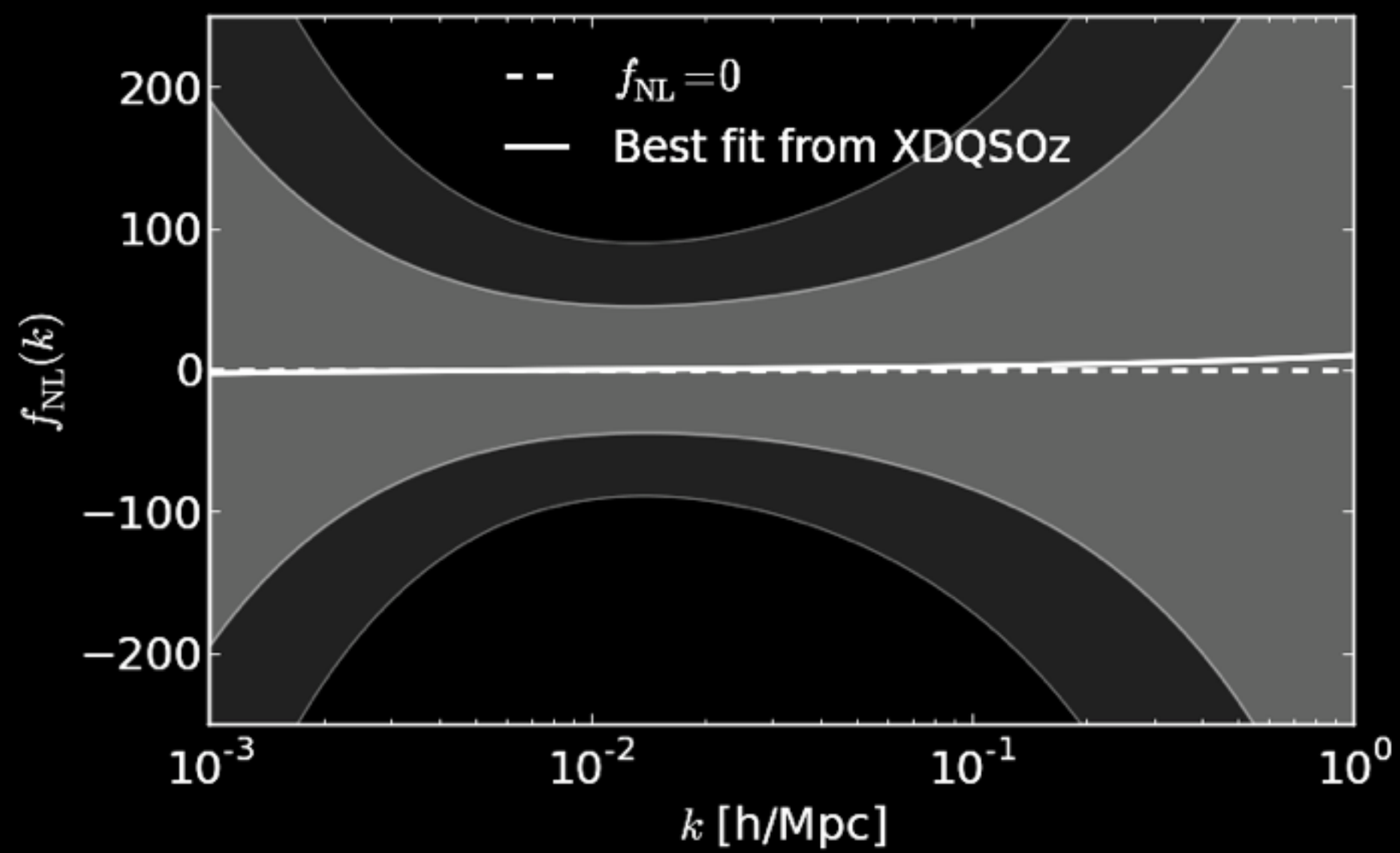

$$f_{\rm NL} = 4 \pm 59 \quad (1\sigma)$$
$$-120 < f_{\rm NL} < 117 \quad (2\sigma)$$

$$n_f = 0.24 \pm 0.4 \quad (1\sigma)$$
$$-0.41 < n_f < 0.86 \quad (2\sigma)$$