Science with large imaging surveys

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Science from LSS surveys:
A case study of SDSS quasars

Boris Leistedt (UCL)
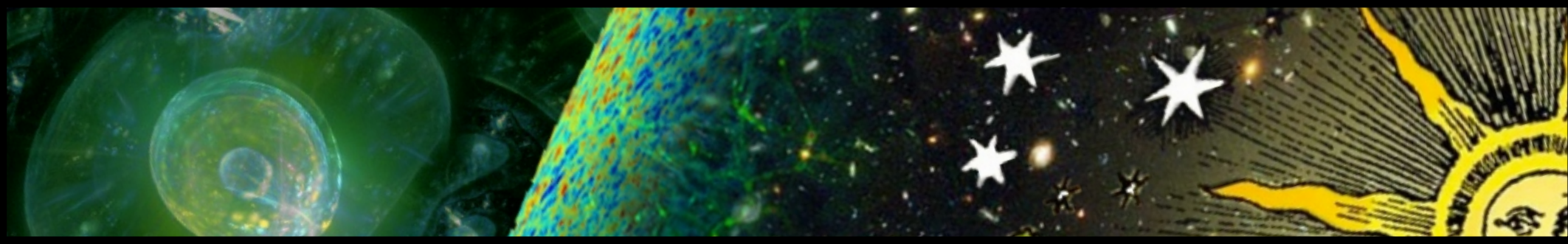

Nina Roth (UCL)

with

Daniel Mortlock (Imperial)
Aurelien Benoit-Levy (UCL)
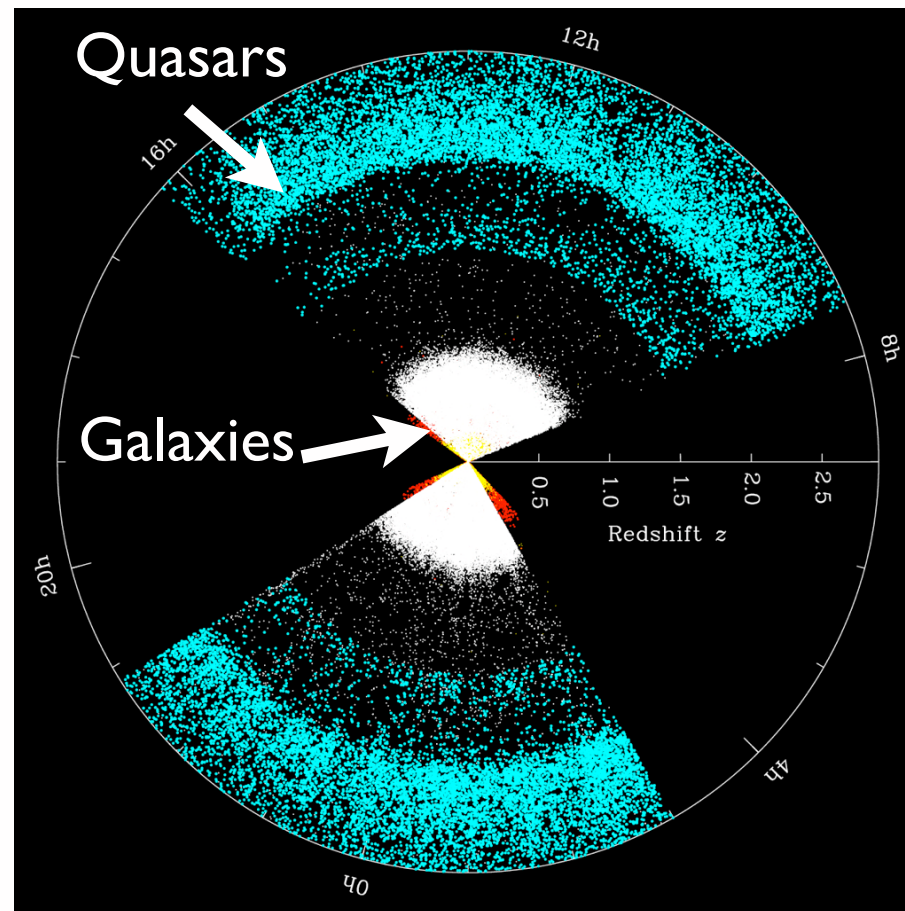*Andrew Pontzen (UCL)*

arXiv:1306.0005 (MNRAS), 1404.6530, 1405.4315

Overview

- Case study: primordial NG from quasar surveys

- Data analysis considerations

- Theory considerations

- Results and outlook

Cosmology with quasar surveys

SDSS3; Credit: M.Blanton

- **Quasars**: bright, highly biased tracers; span large cosmological volumes

- Probe super horizon / large scale modes: ISW, PNG,...

  Giannantonio et al. 2006, 2008; Slosar et al. 2008; Xia et al. 2010, 2011, ...
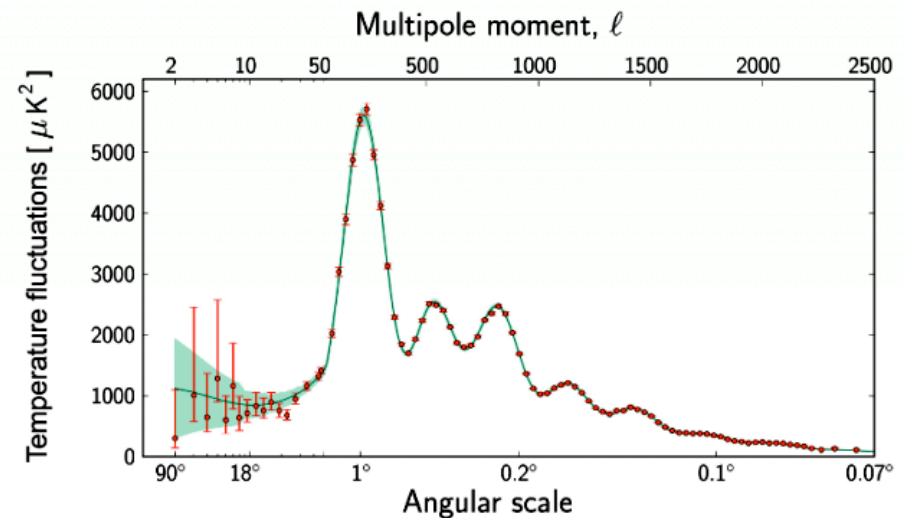
Non-Gaussianity: maximising physical information

Pre-Planck: constraints on inflation come mainly from **2-pt correlations**. *Only captures all information if data are completely Gaussian.*
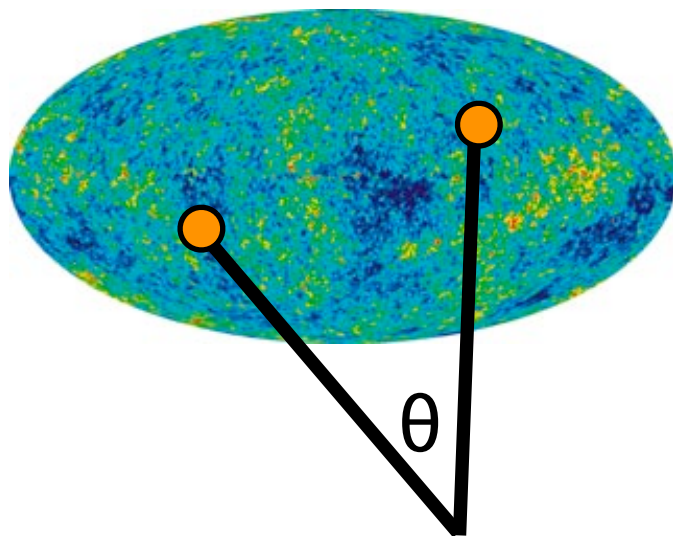
radical data compression

map
50 million pixels

angular power spectrum
2500 multipoles

Post-Planck: signals giving **physical** understanding are **non-Gaussian**. *Higher-order correlations can encode much information.*

Primordial non-Gaussianity (PNG)

- Gaussian fluctuations: described by a simple sum of Fourier modes with random phases.

- Gaussian fluctuations fully described 2-pt correlation.

- NG is measured using higher order correlations (e.g. 3-pt function).

- A detection of $f_{NL} \gg 1$ will immediately rule out the "textbook" picture of inflation.

$$\Phi(\mathbf{x}) = \phi(\mathbf{x}) + f_{\mathrm{NL}}^{\mathrm{loc}}\phi^2(\mathbf{x})$$

primordial potential   Gaussian field

Effect of PNG on large scale structure


Kaiser (1984). Fig: J. Peacock
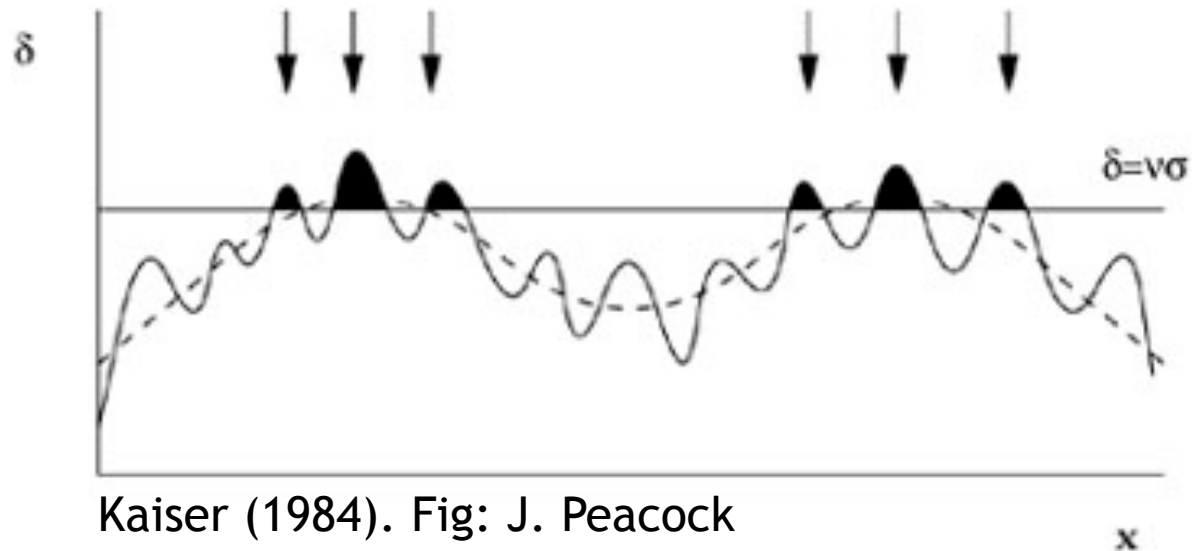
- **High-peak bias**: rare high-density fluctuation in large scale overdensity collapses sooner.

- Enhanced abundance of massive objects in overdense regions leads to enhanced clustering.

- Effect modified in NG case to lead to a scale dependent bias at large scales.

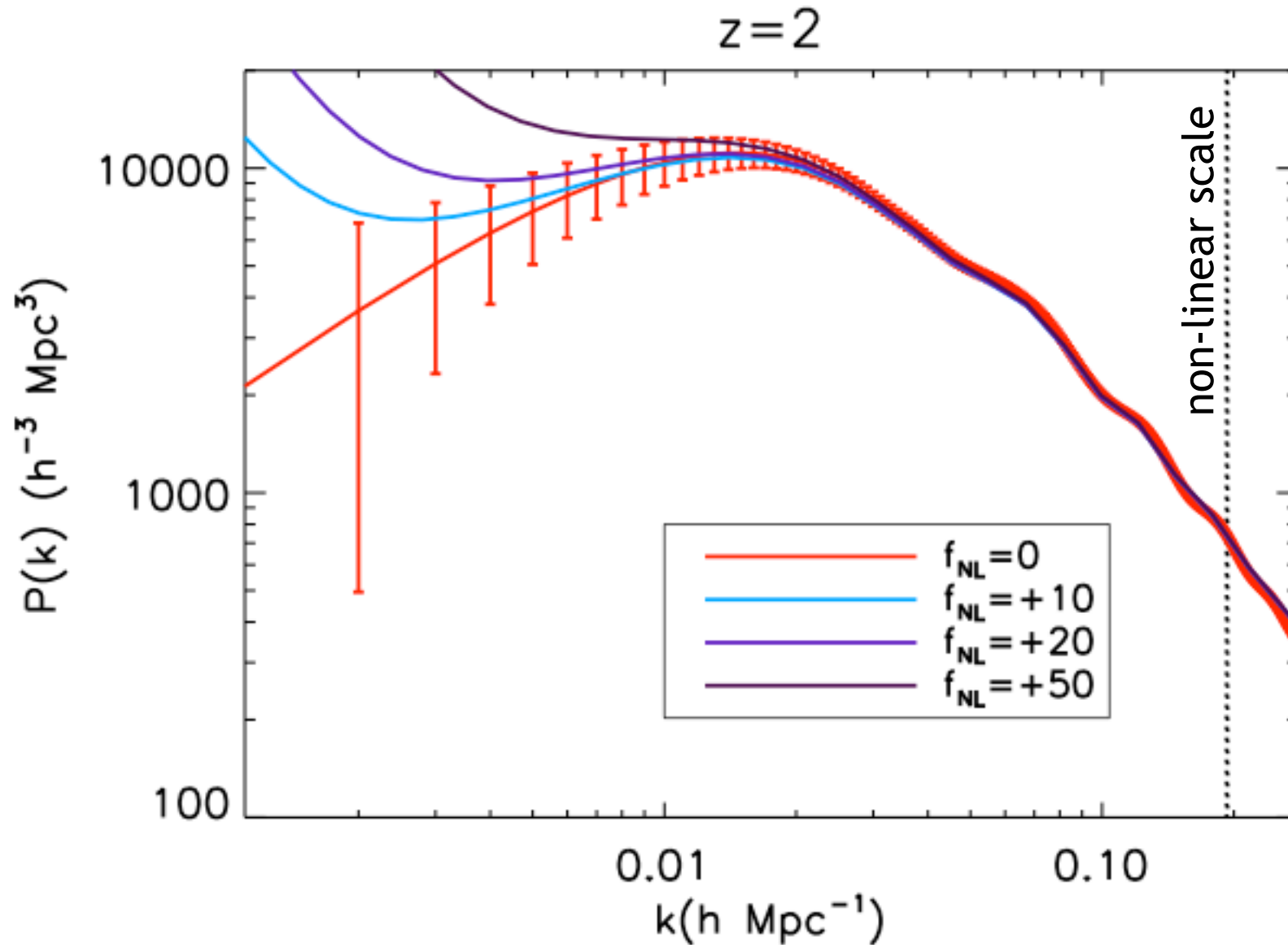e.g. Dalal, Dore et al (2007), Matarrese & Verde (2008), Slosar et al (2008)

PNG from large scale LSS angular power spectrum

"Local" PNG $\quad \Phi(\mathbf{x}) = \phi(\mathbf{x}) + f_{\mathrm{NL}}^{\mathrm{loc}}\phi^2(\mathbf{x}) \quad$ imprints halo bias $\Delta b \propto k^{-2}$

Slosar et al (2008)
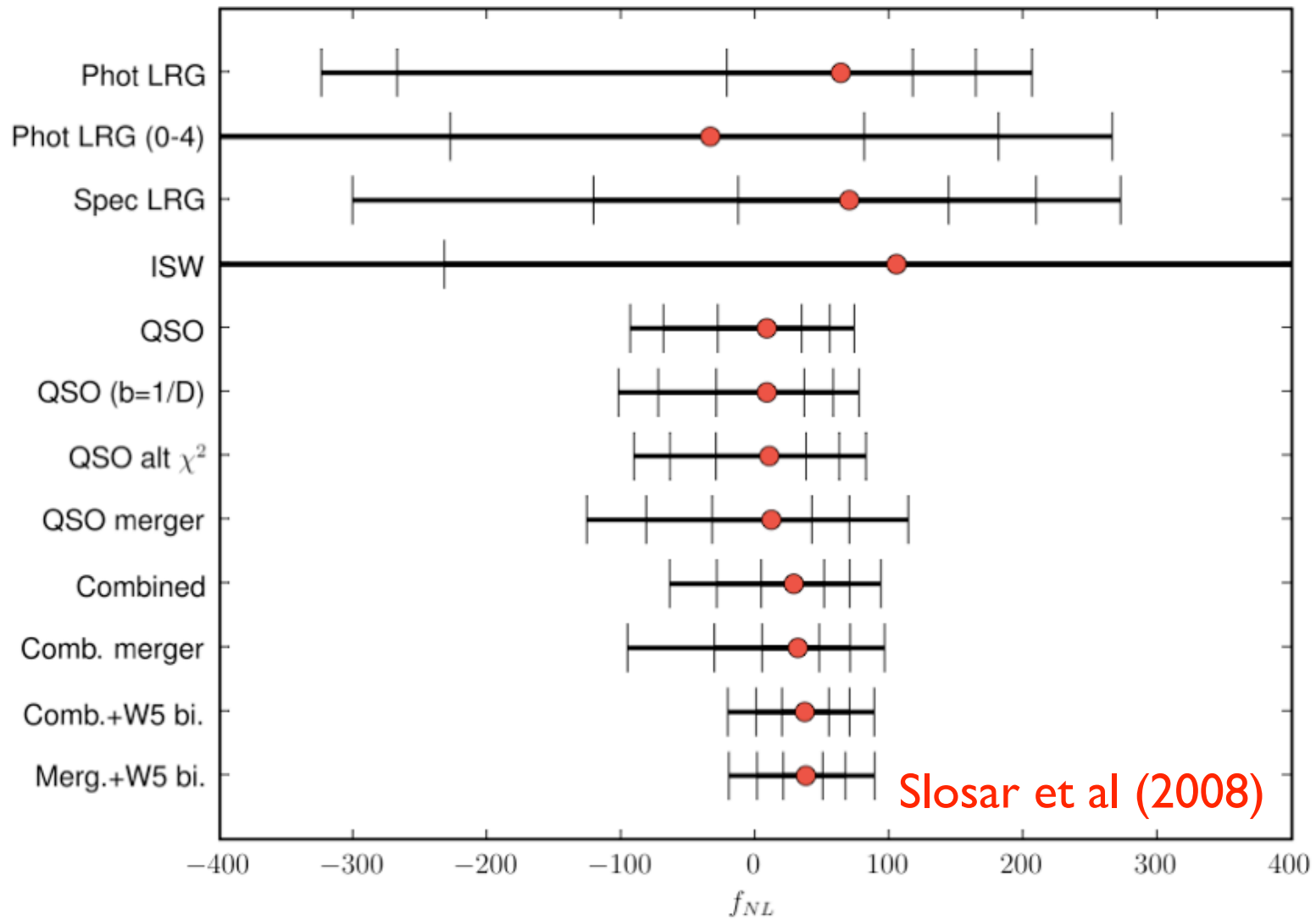
scale-dependent halo bias (Dalal et al 2008)

Effect on the halo power spectrum

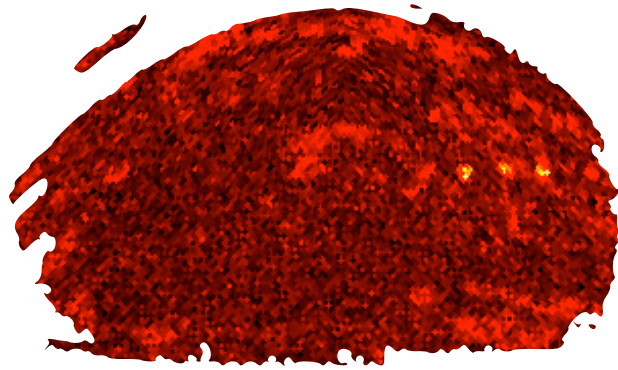Power spectra at z=2 for a spectroscopic survey

The potential of quasar surveys for PNG

•**Quasars**: highly-biased LSS tracers, spanning large cosmological volumes
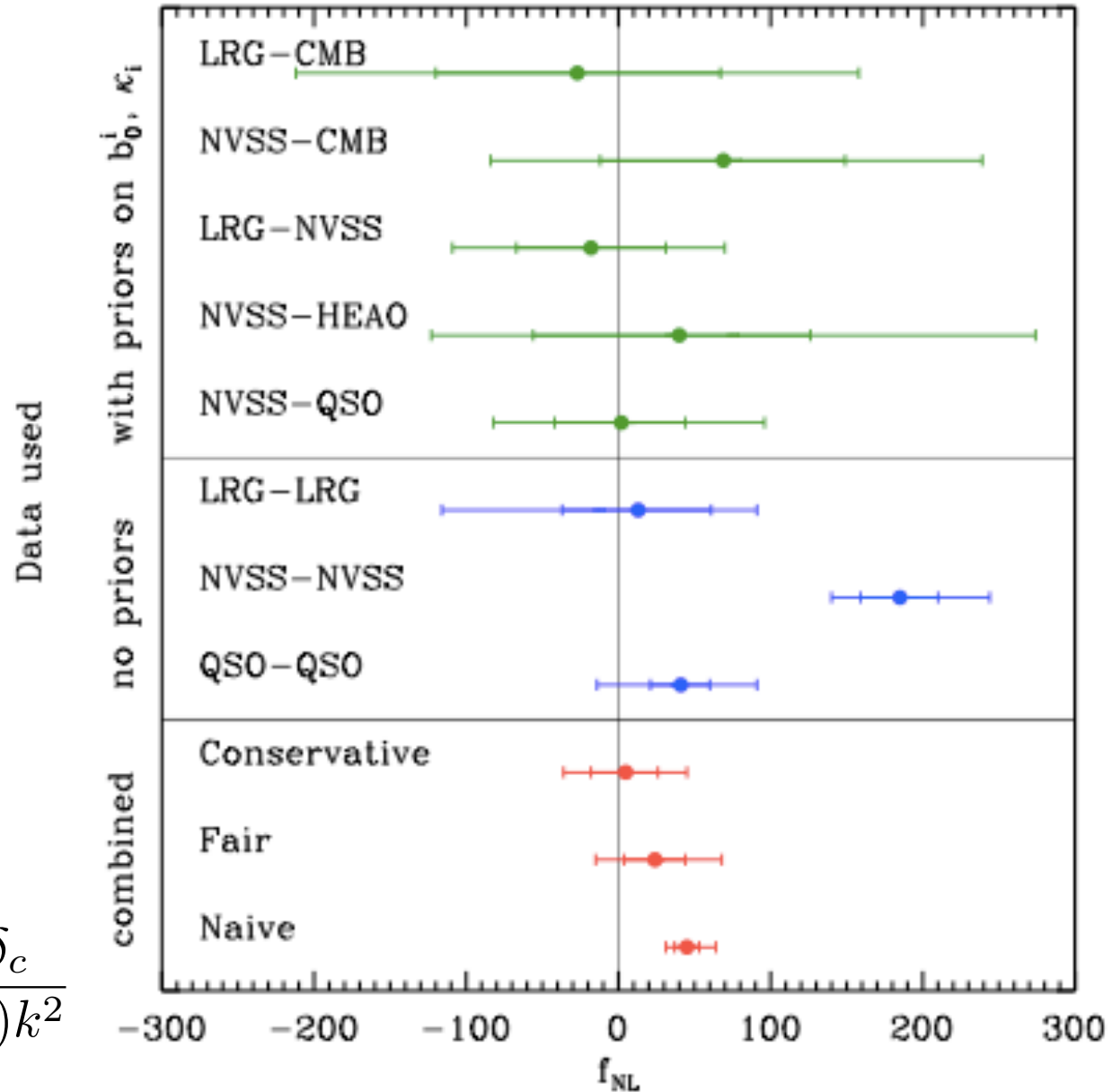
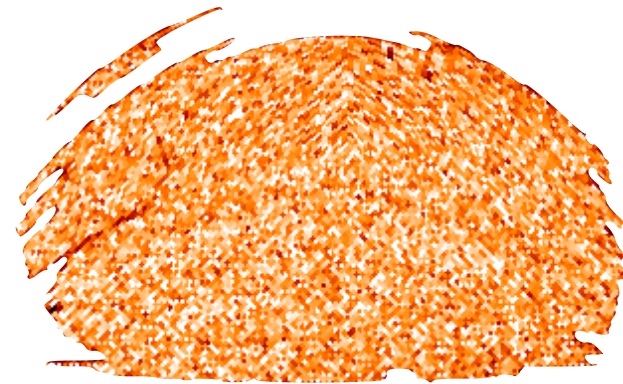$$\Delta b(k, z) = f_{\mathrm{NL}}(b_g - 1)\frac{3\Omega_{\mathrm{m}}h_0^2\delta_c}{D(z)T(k)k^2}$$

Photometric quasars

Spectroscopic catalogues are small, incomplete

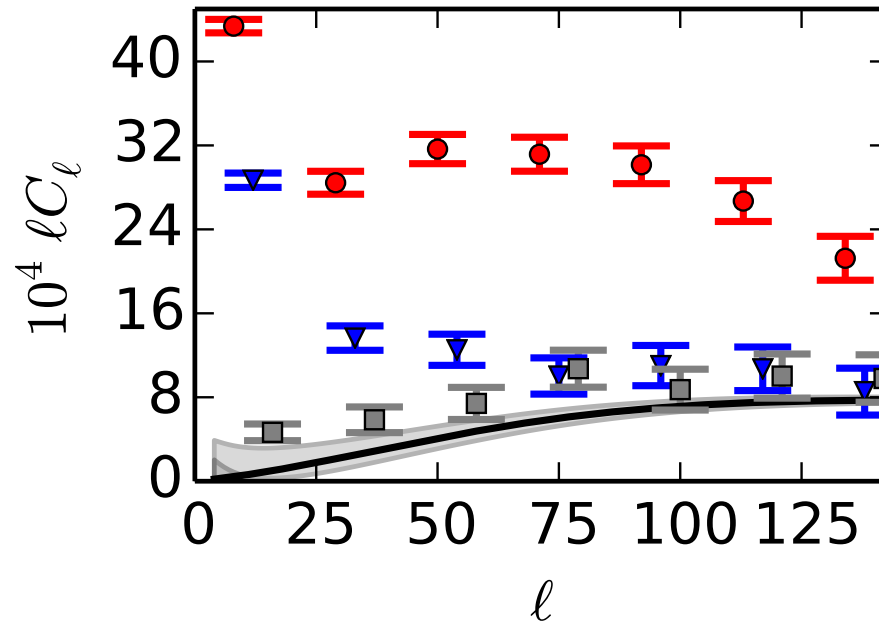~ 3 QSOs / deg^2

$z_s < 2.2$ *Spec QSOs*
from SDSS-DR7

~ 15 QSOs / deg^2

$z_p < 2.2$ *UVX Photo QSOs*
from RQCat (SDSS-DR6)
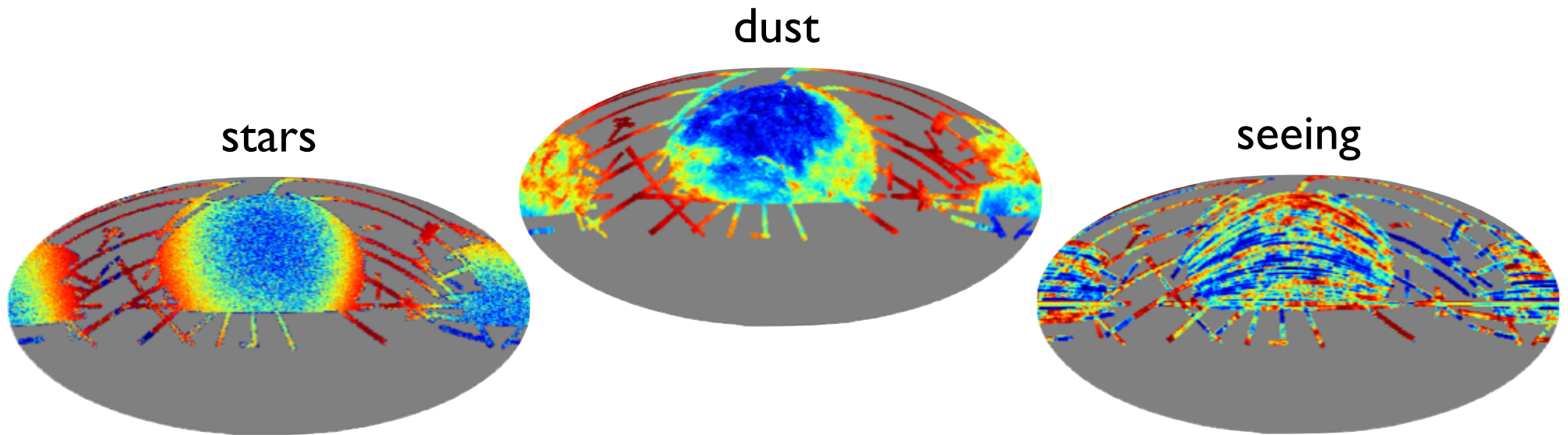
Systematics in quasar surveys

- **SDSS photometric quasars:** excess clustering power on large scales due to systematics.

- Concerns about its use for clustering studies. Pullen and Hirata 2012; Giannantonio et al. 2013

Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)

Systematics in quasar surveys

- Anything that affects point sources or colours
  seeing, sky brightness, stellar contamination, dust obscuration, calibration etc..

- Create spatially varying depth & stellar contamination

stars

dust

seeing

Score · Stars · Red stars · E(B-V) · E(B-V) err · PSF width · PSF PSP0 · PSF Nstar · PSF counts · PSF beta · PSF B · PSF 2Gsigma · PSF2GB · NUERR · MUERR · Nstars · Nstars offset · Sky · Sky err · Sky slope · Sky sigma · Sky frames sub · Sky frames · Sky PSP · Airmass
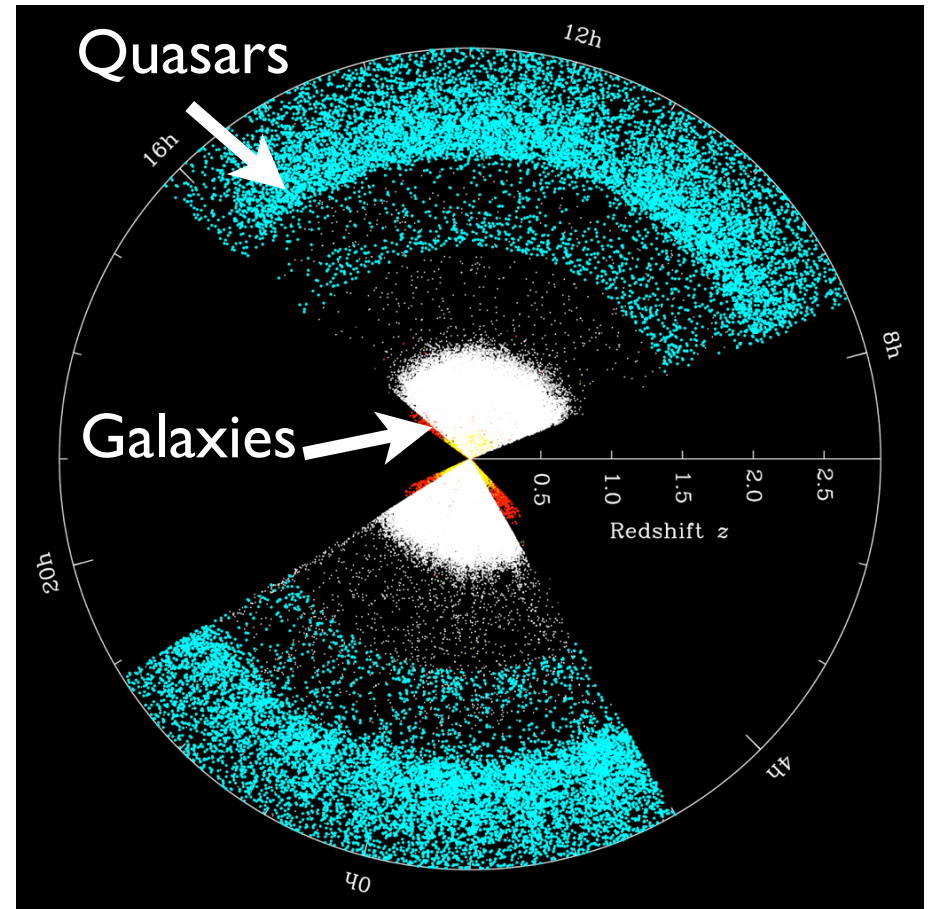
Monday, 14 July 14
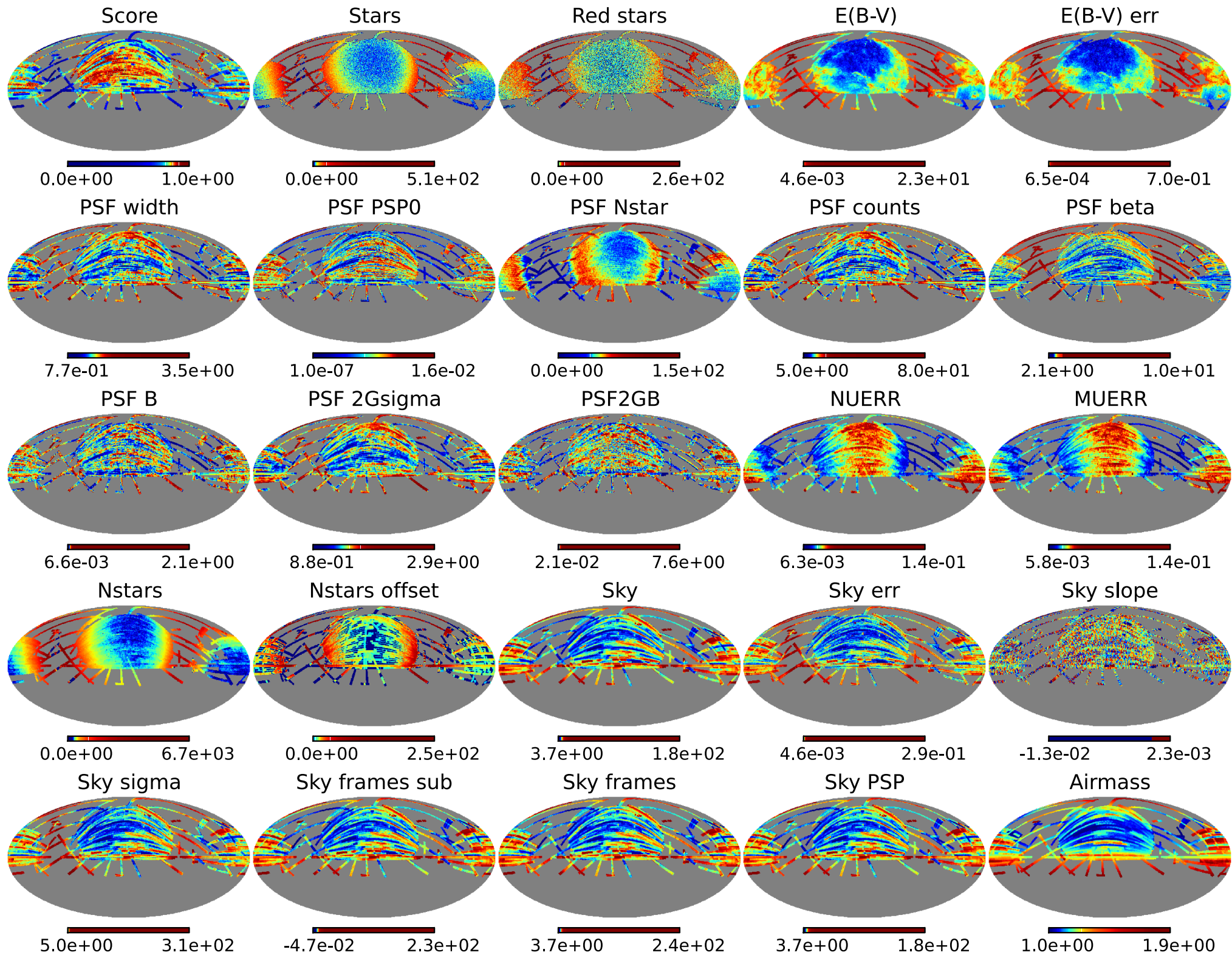
PNG from blind mitigation of systematics

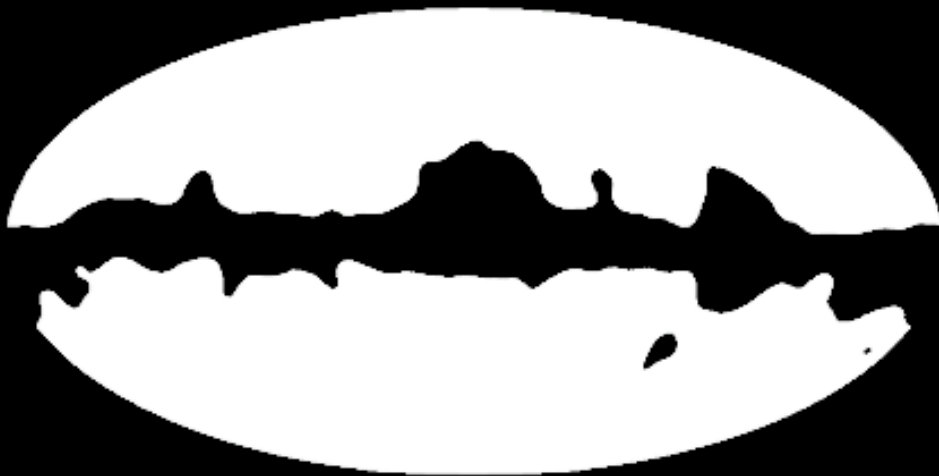**RQCat:** UVX sources from Richards et al (2008) catalogue.

XDQSOz: 1.6 million QSO candidates from SDSS DR8 spanning z ~ 0.5-3.5 (800,000 QSOs after basic masking).

Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)

Estimating angular power spectra

▸ Power spectra must be estimated from cut-sky data

▸ Critical on large-scales due to the cut-induced variance
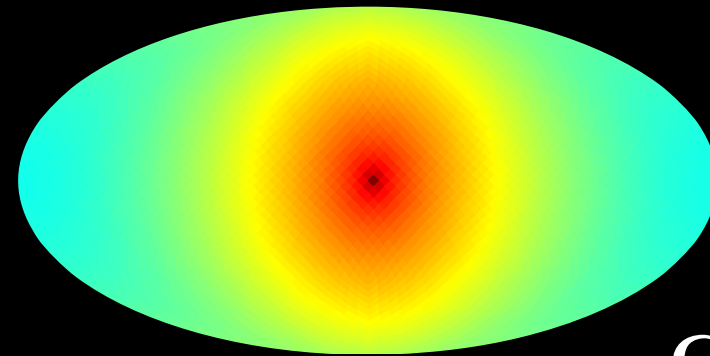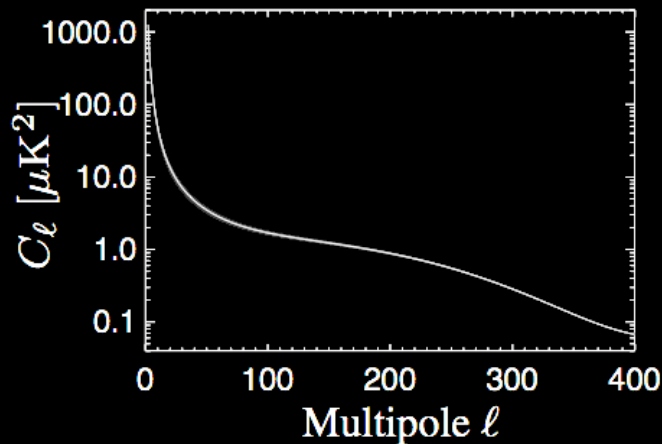

CMB mask
$f_{\rm sky} > 0.7$

LSS mask
$f_{\rm sky} < 0.2$

The QML and PCL estimators

- Quadratic Maximum Likelihood (QML): optimal, requires a model of the pixel-pixel covariance matrix:

$$\mathbf{C}(\theta_{ij}) = \langle x_i x_j \rangle = \sum_\ell \left(\frac{2\ell + 1}{4\pi} \right) \mathcal{C}_\ell \, P_\ell(\cos \theta_{ij}) + \mathbf{N}_{ij}$$

↑ Covariance matrix   ↑ Theory spectrum   ↑ Noise, systematics, ...

- Pseudo-spectrum estimator (PCL) = QML with diagonal pixel-pixel covariance, i.e. a flat power spectrum
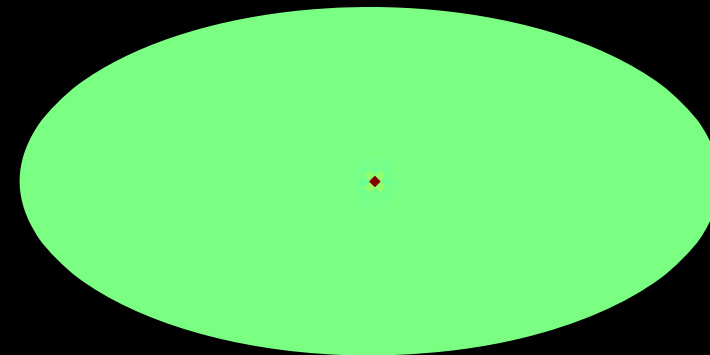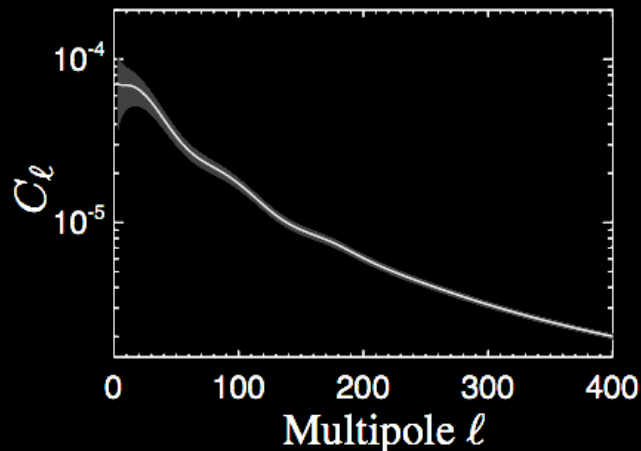
  (= uncorrelated pixels)

PCL or QML? CMB vs LSS correlations
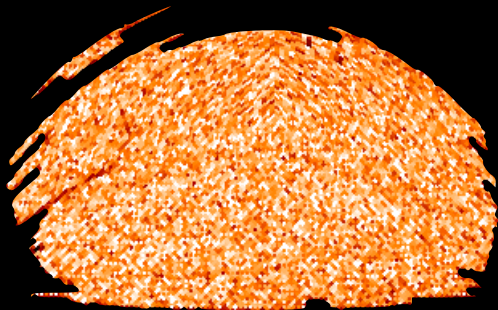

CMB

LSS

$\mathbf{C}(\theta_{ij})$
with i fixed

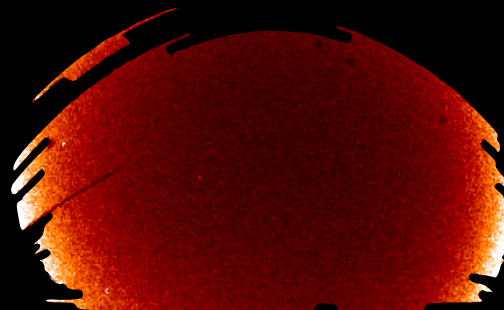The LSS spectrum is quasi flat => PCL is nearly optimal
in the absence of systematics...

Systematics and mode projection

▸ PCL suboptimal with complex masks and systematics

▸ QML with mode projection: marginalises over linear contamination models, using systematics templates $\vec{c}_k$
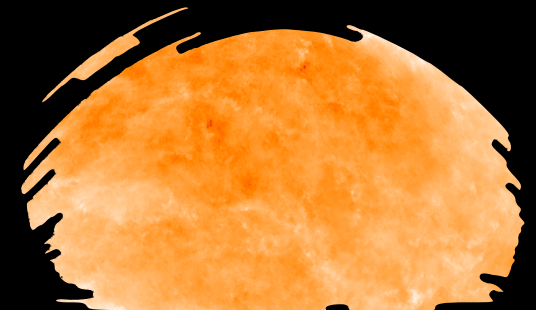
$$\mathbf{C} \;=\; \sum_\ell \mathcal{C}_\ell \mathbf{P}_\ell + \mathbf{N} + \sum_{k \in \mathrm{sys}} \xi_k \vec{c}_k \vec{c}_k^t \quad \text{with} \quad \xi_k \to \infty$$

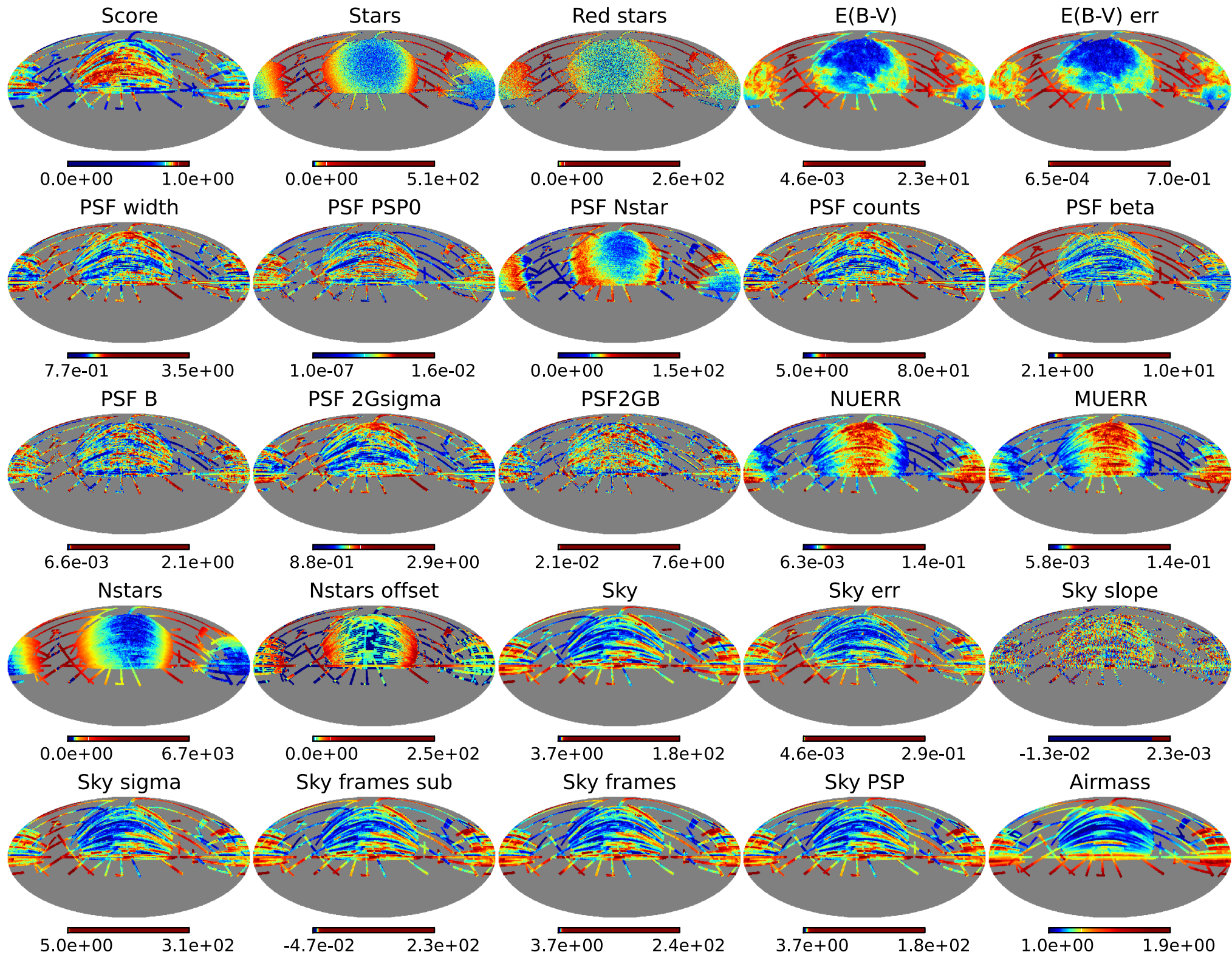RQCat   stars   dust extinction

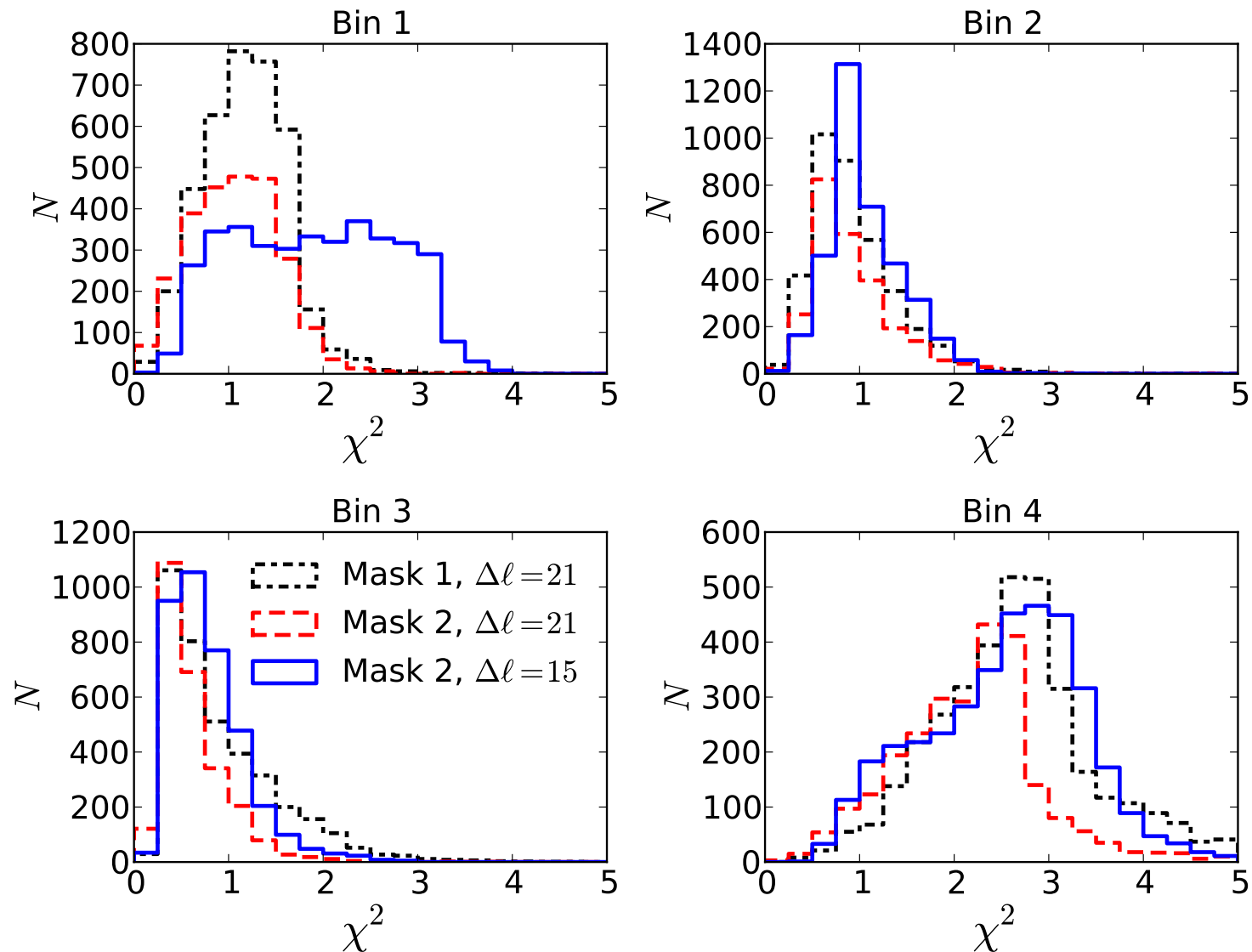# *Extended mode projection*

- Create set of input systematics
  220 templates + pairs ⇒ >20,000 templates

- Decorrelate systematics
  20,000 templates ⇒ 3,700 uncorrelated modes

- Ignore modes 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**

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

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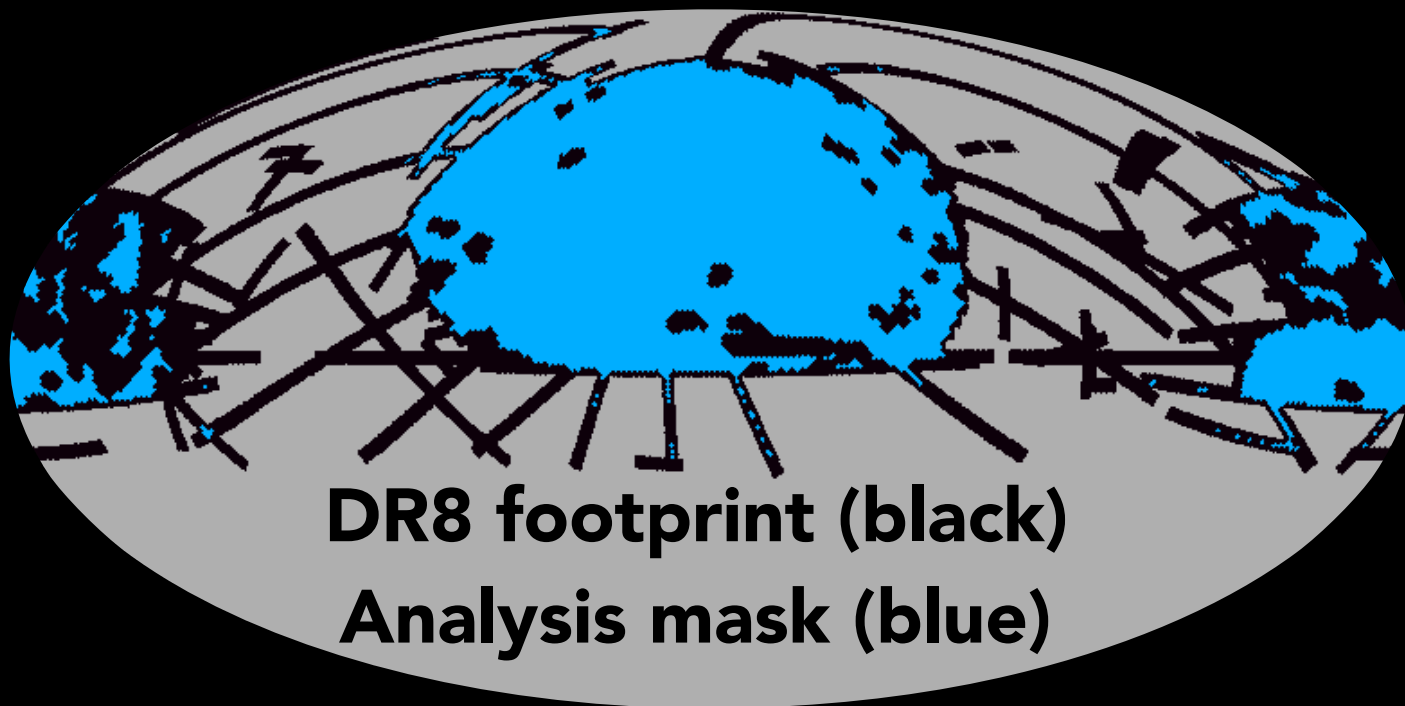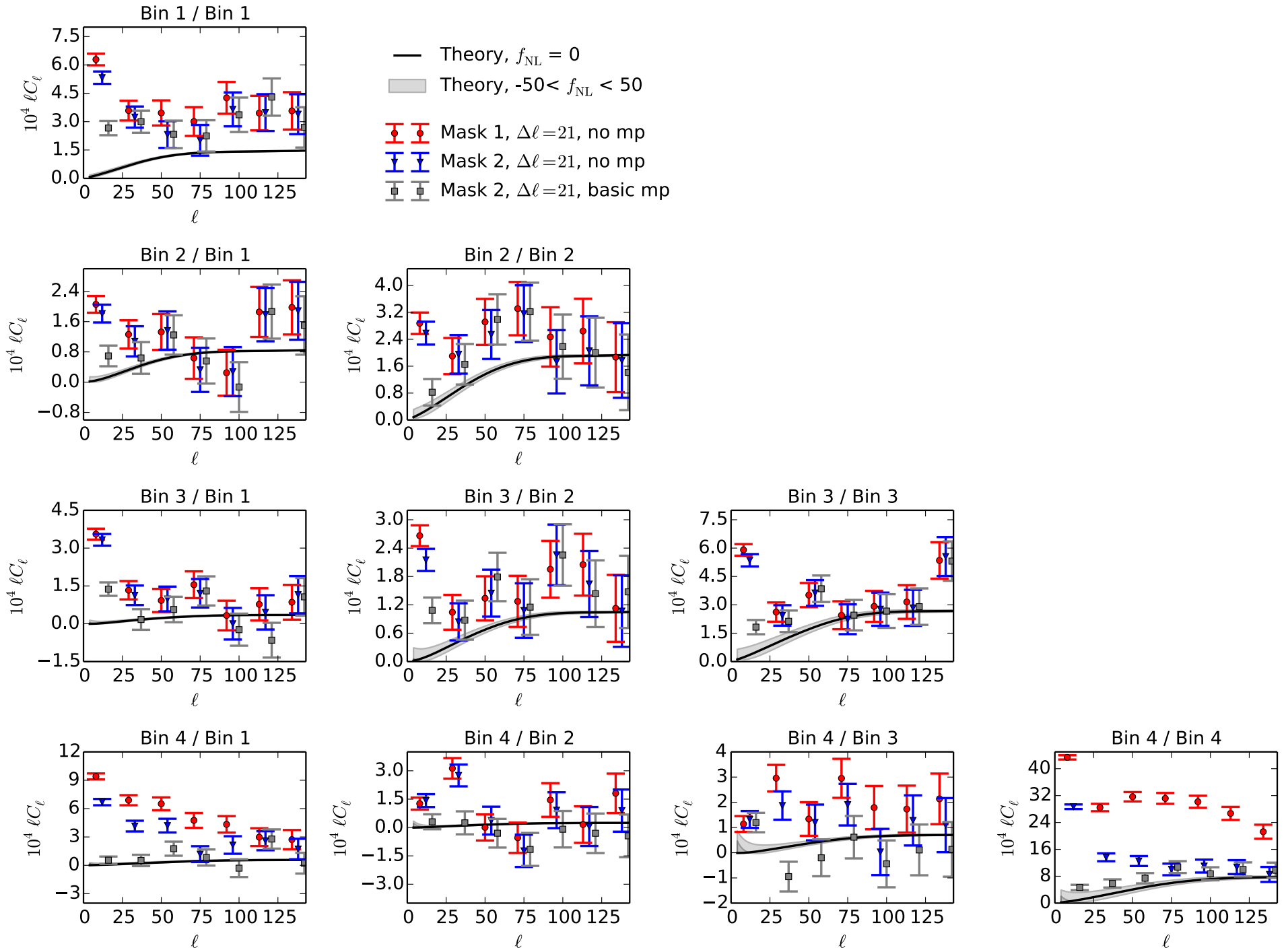# Null tests

- Red. chisq. from cross-power spectra with 4 redshift samples

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

Angular power spectrum estimation

▸ Sky masks: cuts on extinction, seeing & quality flags

▸ Maximum Likelihood estimator to simultaneously compute 10 auto + cross angular power spectra

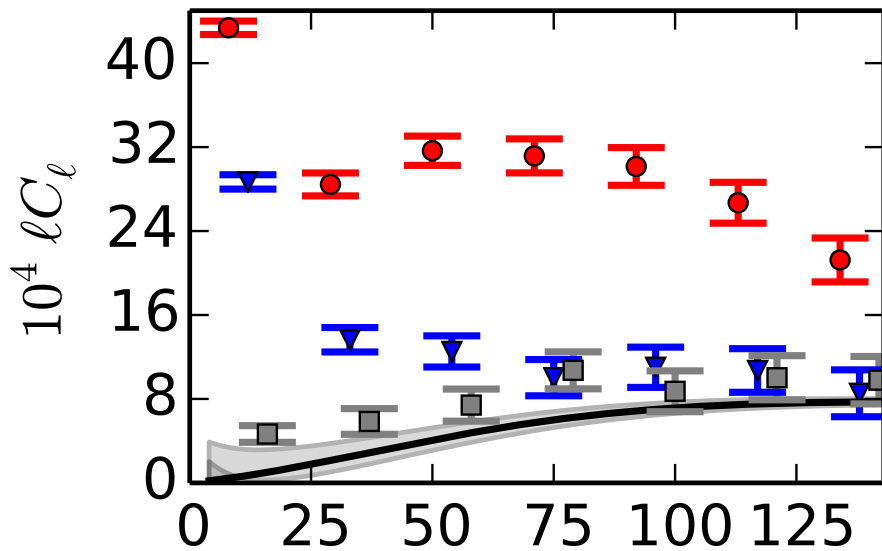**DR8 footprint (black)**
Analysis mask (blue)

Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)
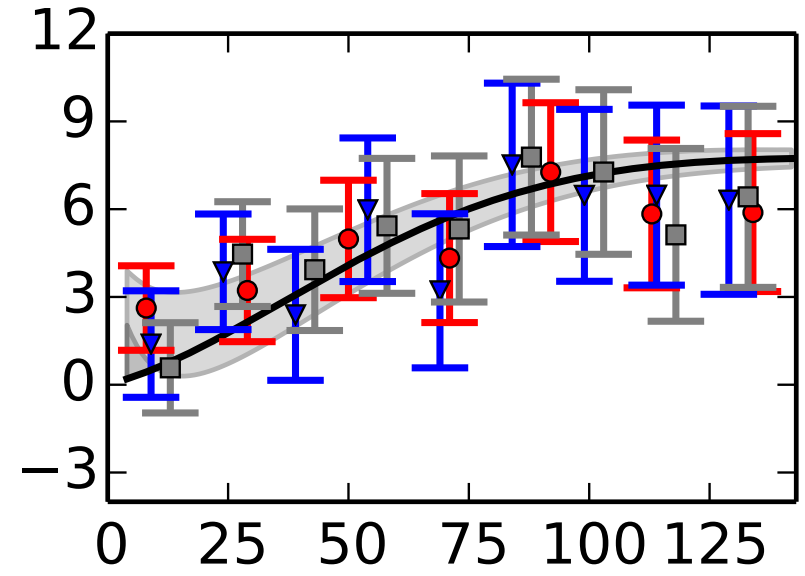
Monday, 14 July 14

Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)

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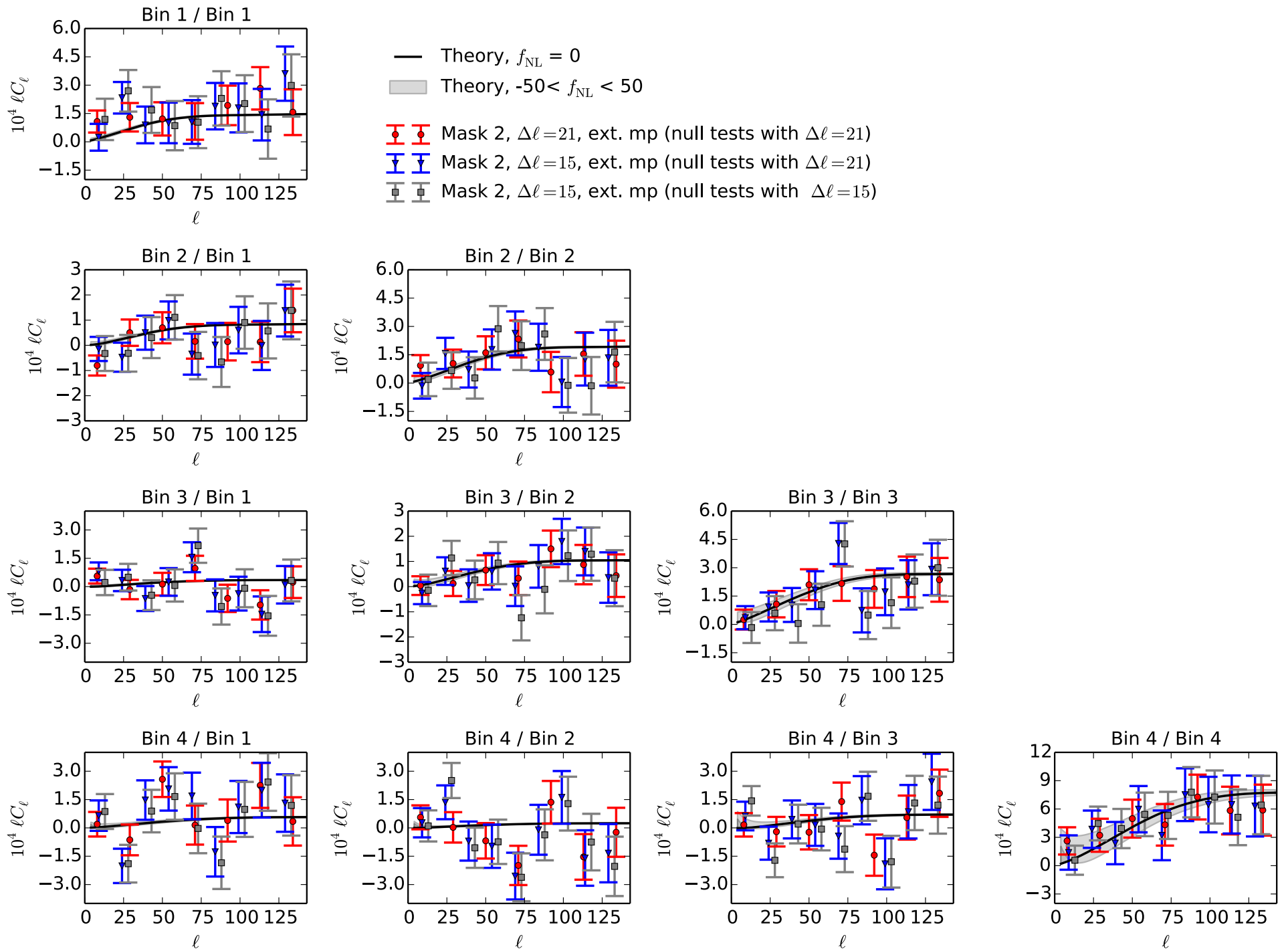
Blind mitigation of systematics

Raw spectra

Clean spectra

- Example: one of 10 spectra (auto + cross in four z-bins) in likelihood

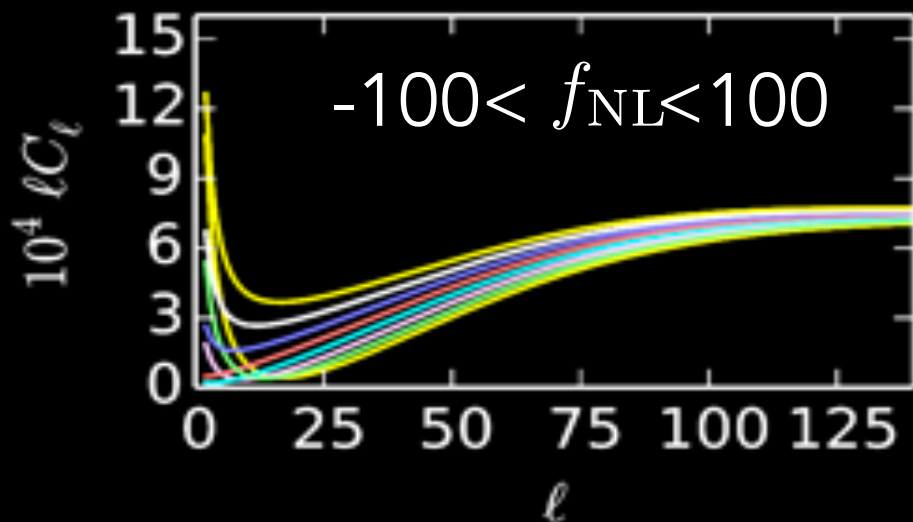- Grey bands: $-50 < f_{NL} < 50$; colours: basic masking + m.p.

Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)

Theory

Ingredients for computing theory power spectra:

▸ Cosmological parameters (LCDM + $f_{\rm NL}$)

▸ Redshift distribution, shot noise, nb count slope

▸ Quasar bias model: $b(z) = b_0 \left[1 + \left(\dfrac{1+z}{\alpha} \right)^{\beta} \right]$

-100< $f_{\rm NL}$<100

PNG: enhances large scale quasar bias

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

Computing theory spectra

Line of sight integral:
$$C_\ell = \frac{2}{\pi} \int dk\, k^2 P(k) [W_\ell(k)]^2$$

with kernel
$$W_\ell(k) = \int dz\, [b_g n(z) + 2(2.5s - 1)f(z)]\, D(z) j_\ell(kr),$$

Linear bias and redshift distribution

Magnification effects

$$s = \frac{d\log N(m)}{dm}$$

Spectroscopic vs photometric samples

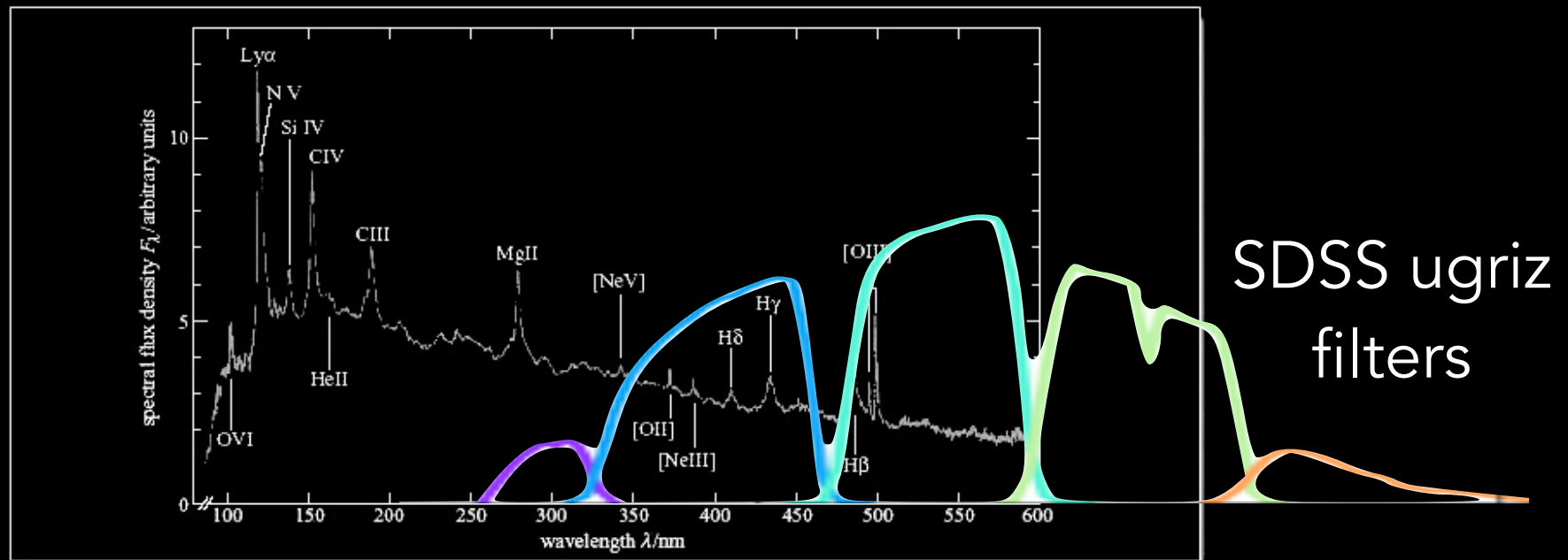▸ Photometric catalogues: redshift estimation

SDSS ugriz filters

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

Photometric redshift estimates

Cross-matching RQCat with
SDSS-DR7, BOSS, and 2SLAQ
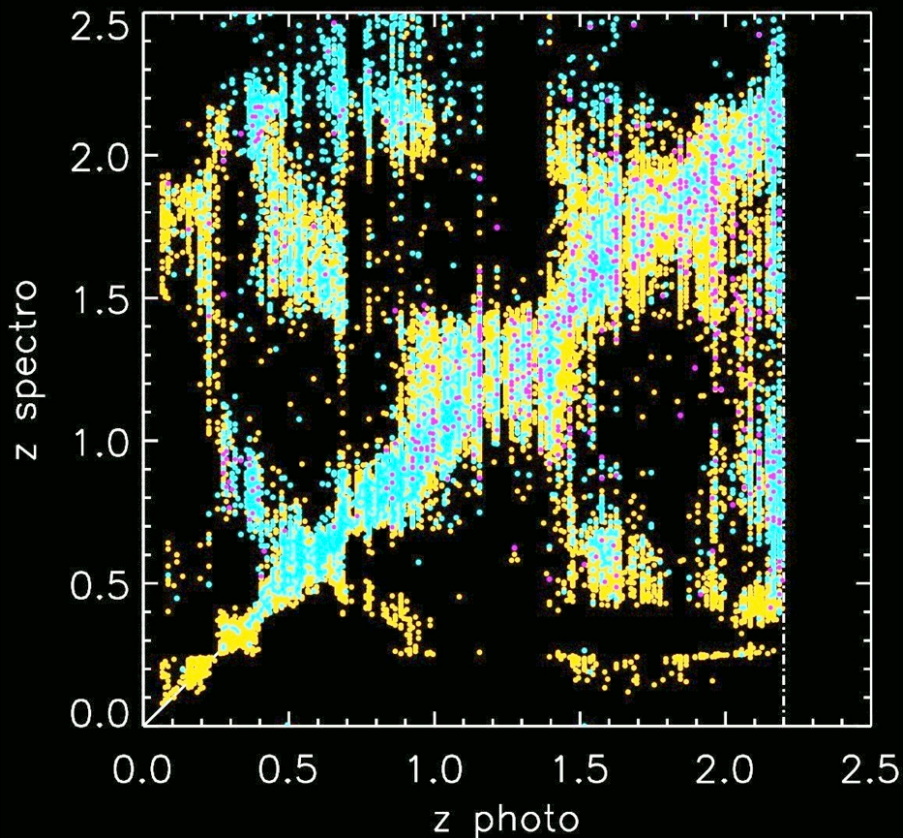
- ▸ Quasar photo-z have large fraction of outliers

- ▸ Redshift distributions poorly known
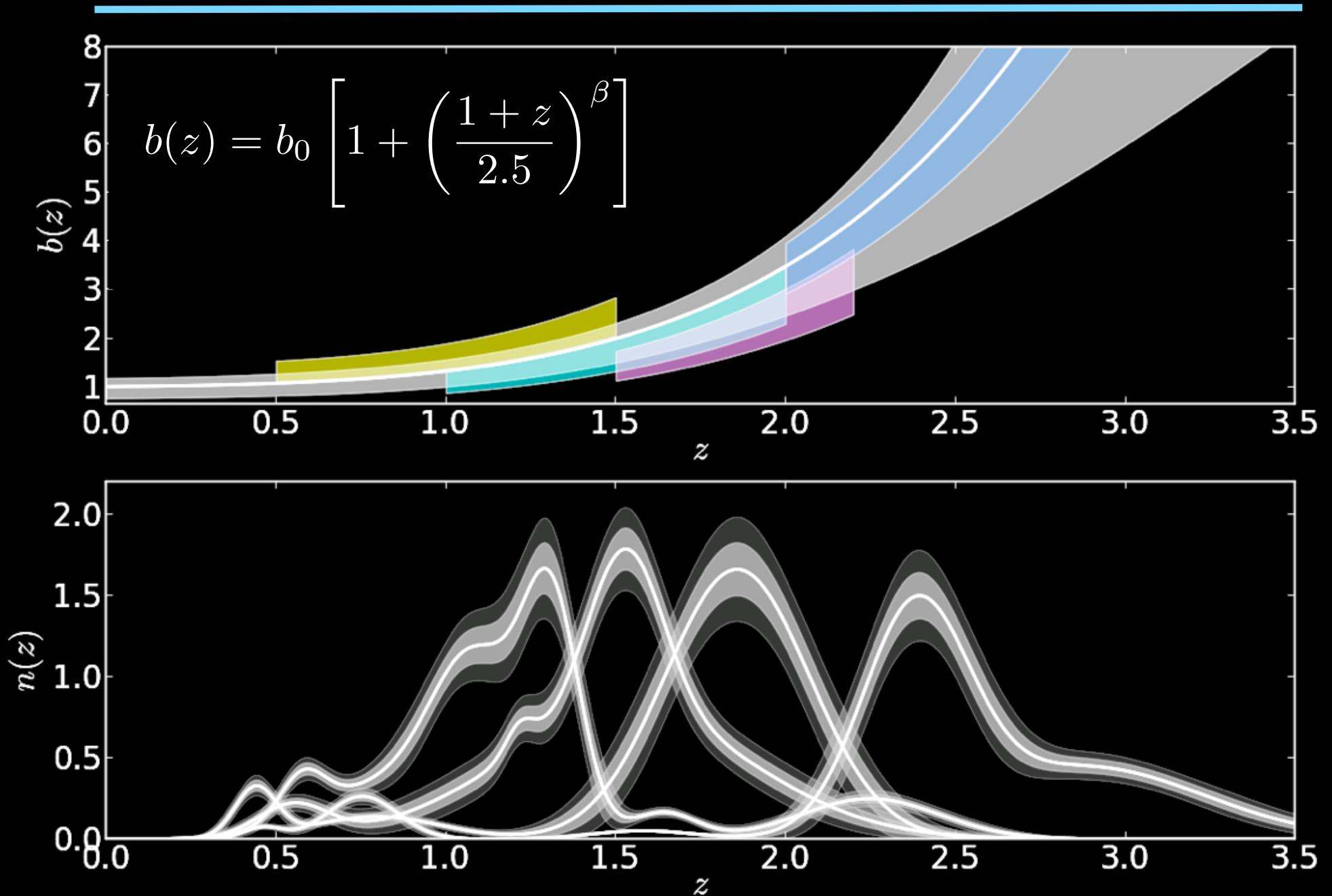
- ▸ Impacts robustness of theory power spectra

Analysis of XDQSOz quasars

Redshift distributions =
sum of stacked posteriors
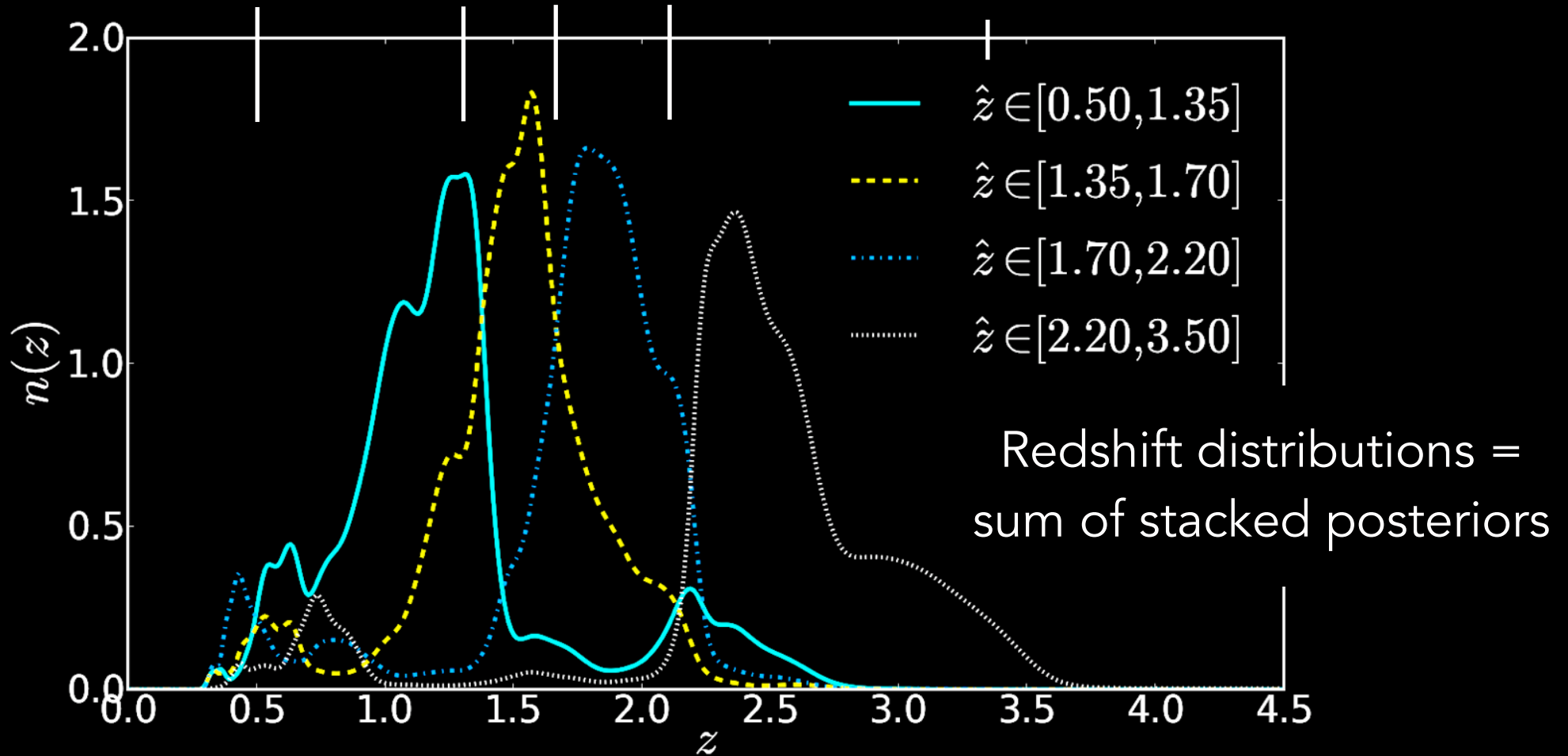
arXiv: 1404:6530

Constraints on the quasar bias

$$b(z) = b_0 \left[1 + \left(\frac{1+z}{2.5} \right)^{\beta} \right]$$

10% uncertainty on n(z) parameters
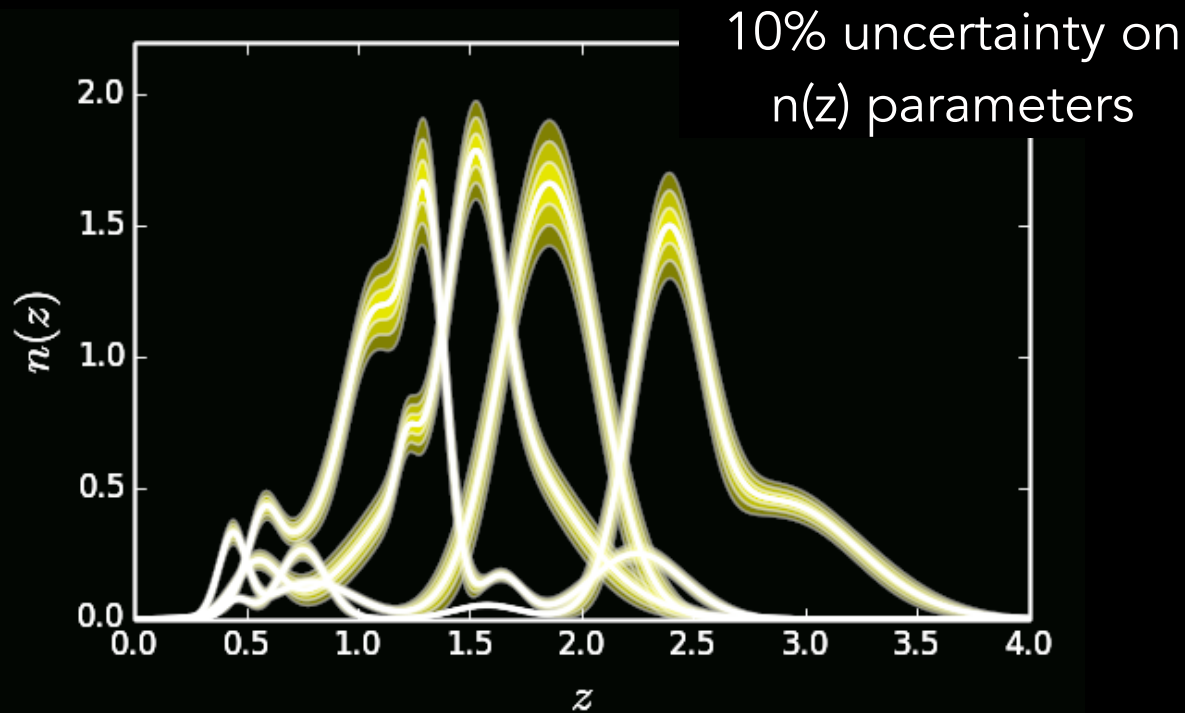
Varying n(z) + cosmology + bias model
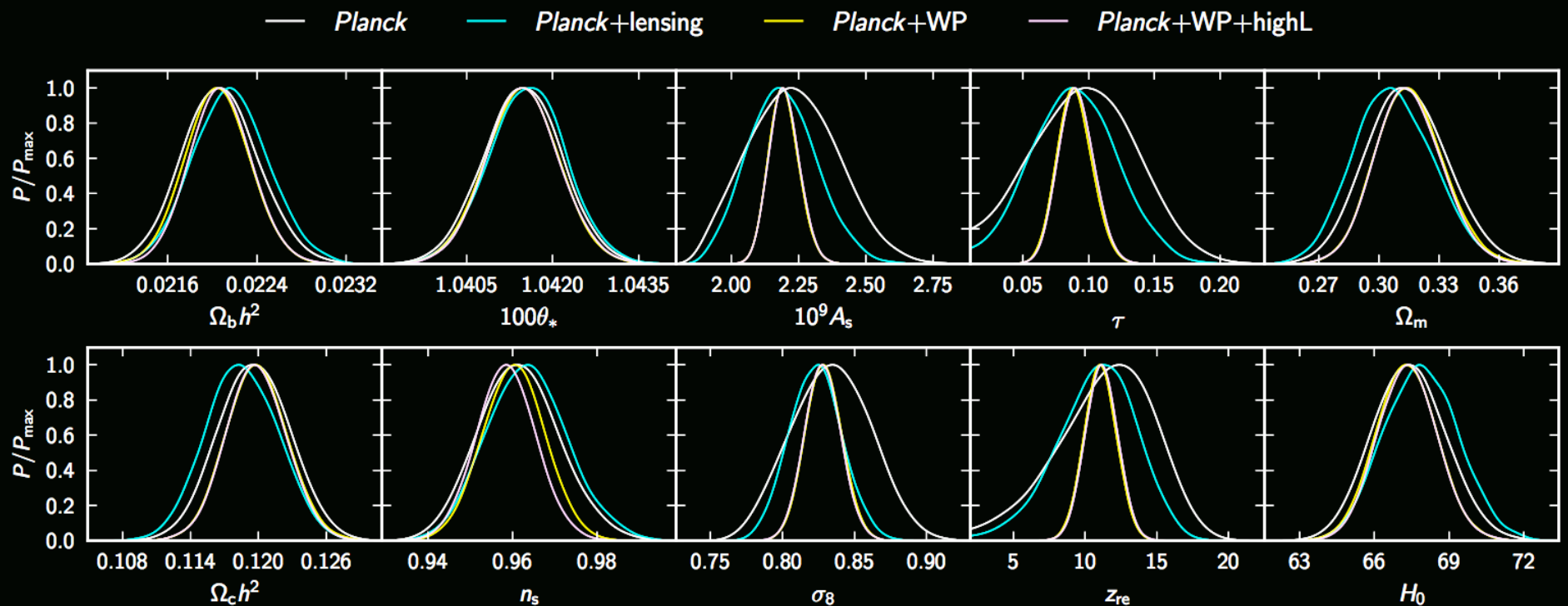
Planck collaboration 2013

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Constraints on f_{NL}
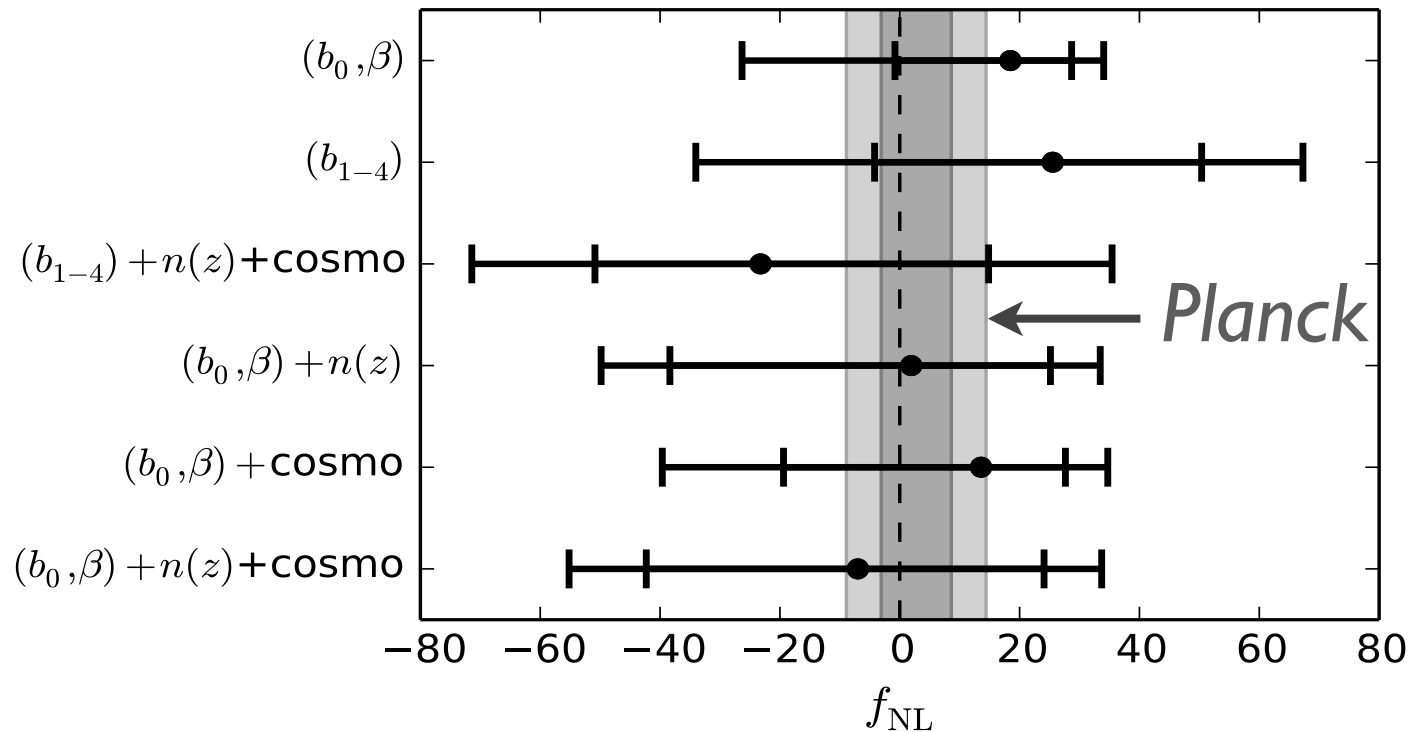
$-16 < f_{\rm NL} < 47 \; (2\sigma)$ $\qquad\qquad\qquad -49 < f_{\rm NL} < 31 \; (2\sigma)$

Fixed cosmology & n(z) $\qquad\qquad\qquad$ *Varying all parameters*

- Comparable to WMAP9 from single LSS tracer(!)
- Robust to modelling & priors

Leistedt, Peiris & Roth (1405.4315)

Higher order terms

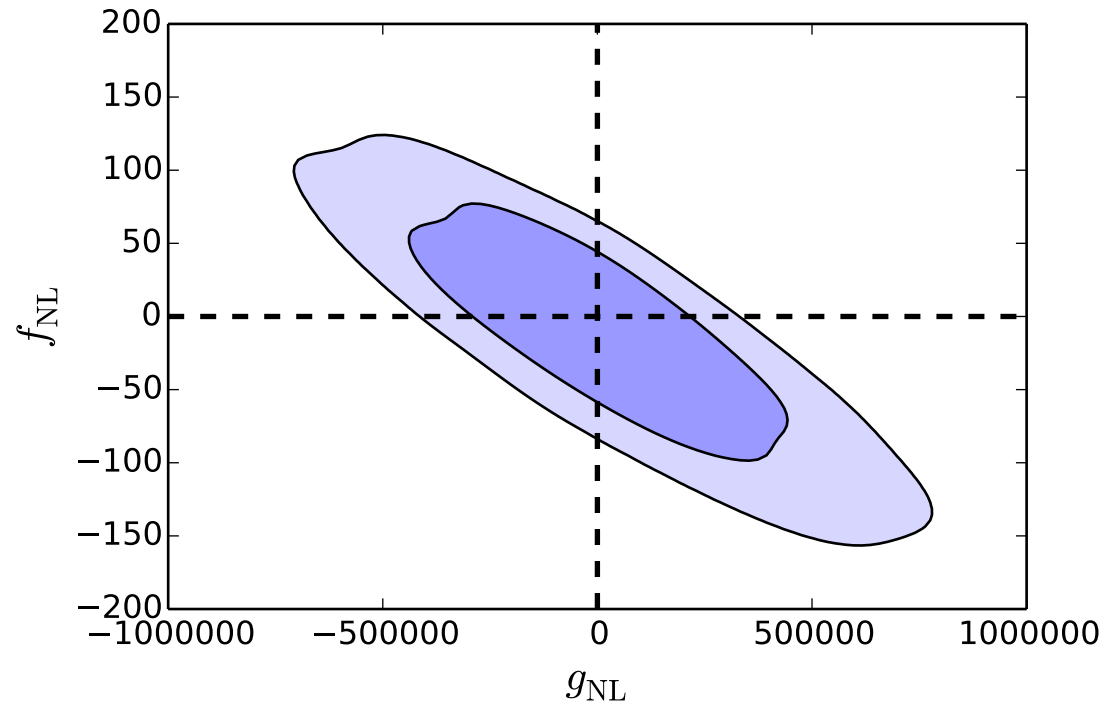$$\Phi = \phi + f_{\mathrm{NL}}[\phi^2 - \langle\phi^2\rangle] + g_{\mathrm{NL}}[\phi^3 - 3\phi\langle\phi^2\rangle]$$

$|g_{\mathrm{NL}}| < 10^6$ (CMB, LSS)

Degeneracy between f_{NL} and g_{NL} (Roth & Porciani 2012)

$$\Delta b \sim \frac{f_{\mathrm{NL}}\,\beta_f(M,z) + g_{\mathrm{NL}}\,\beta_g(M,z)}{k^2\,D(z)} \to k^{-2}$$

Smith, Ferraro & LoVerde (2012)

Constraints on g$_{NL}$

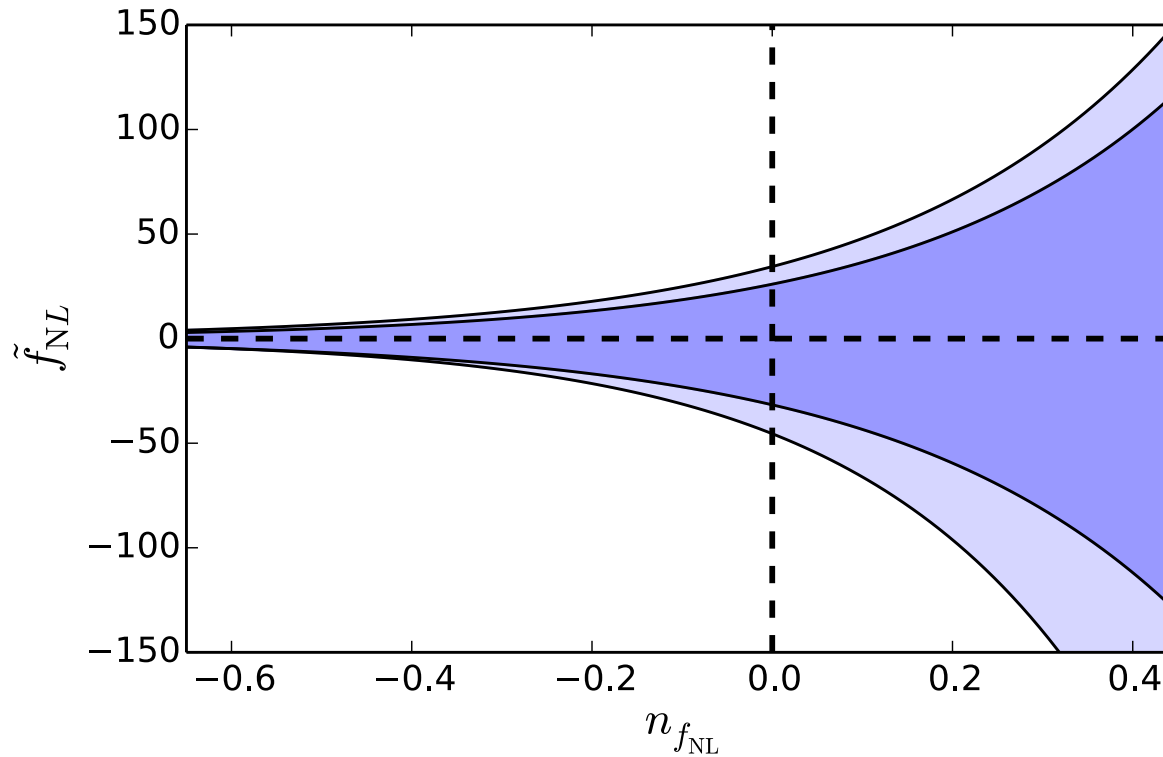$$-2.7 < g_{\mathrm{NL}}/10^5 < 1.9 \ (2\sigma)$$

individually

$$-4.0 < g_{\mathrm{NL}}/10^5 < 4.9 \ (2\sigma)$$

joint with f$_{NL}$

- Best available constraint on g$_{NL}$

Leistedt, Peiris & Roth (1405.4315)
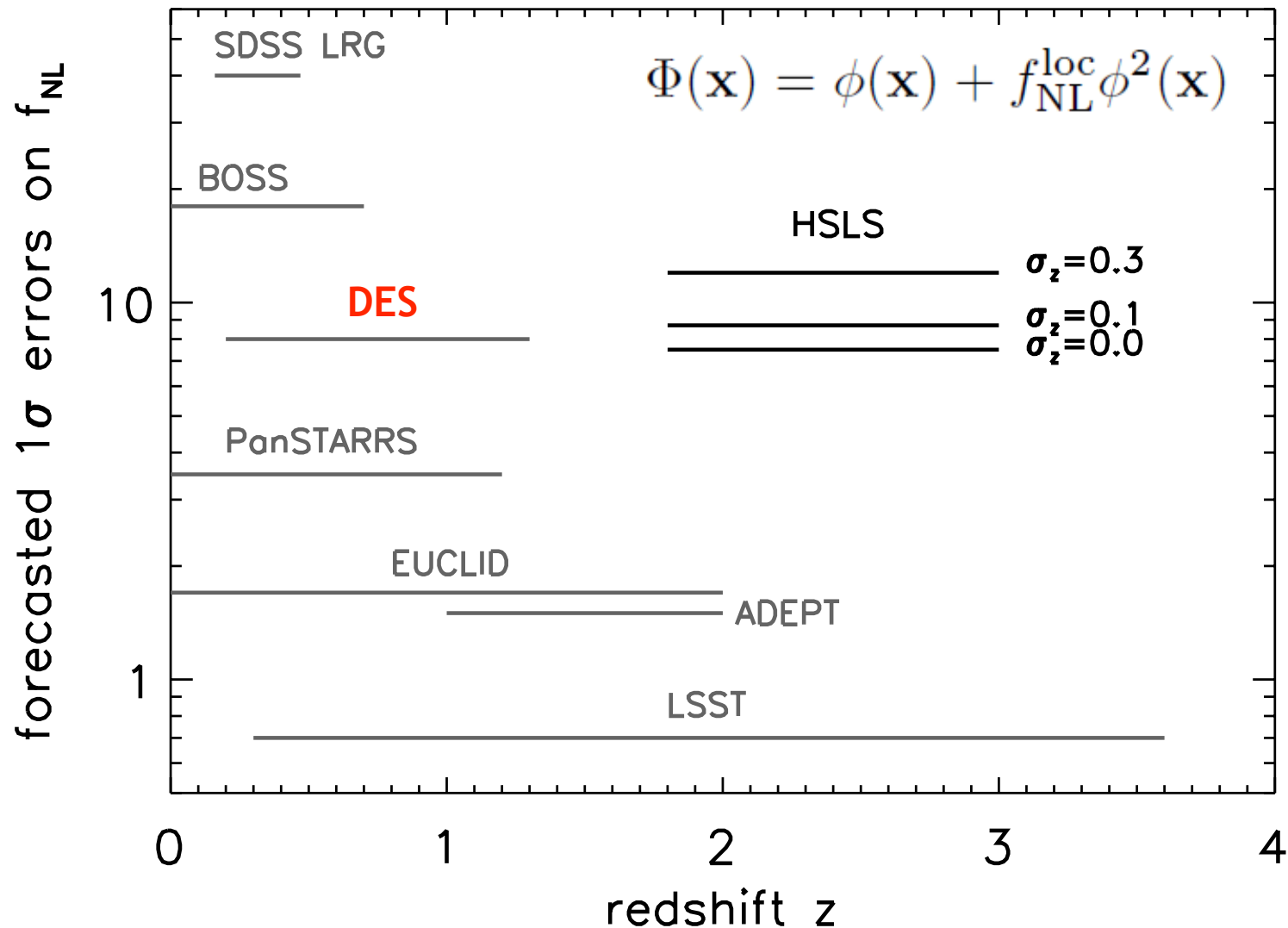
Extended model with running

$$b(k) \propto k^{-2+n_{f_{\rm NL}}}$$

Constrains single field inflation with a modified initial state, or models with several light fields.

Leistedt, Peiris & Roth (1405.4315)

Agullo and Shandera (2012), Dias, Ribero and Seery (2013)

LSS forecast for "local" shape

$$\Phi(\mathbf{x}) = \phi(\mathbf{x}) + f_{\mathrm{NL}}^{\mathrm{loc}}\phi^2(\mathbf{x})$$

Constraints on f_{NL} assuming Planck priors on the cosmological parameters

Figure: HSLS white paper, HVP CMB/LSS Coordinator

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