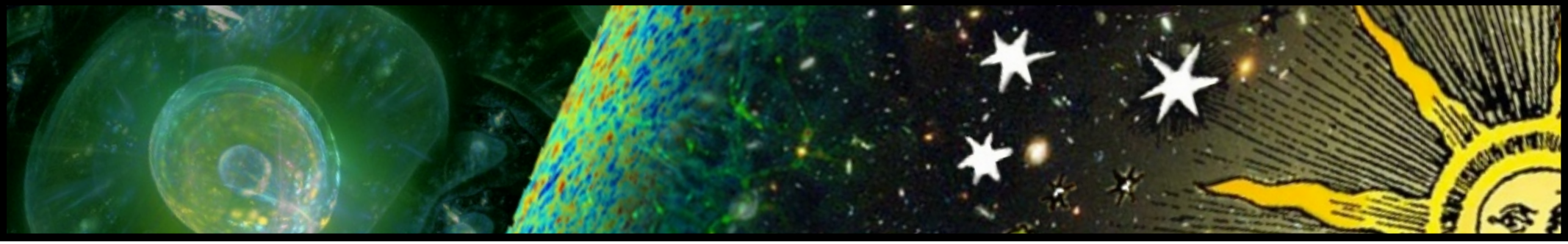

Constraints on primordial NG from 800,000 photometric quasars

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Science & Technology Facilities Council

European Research Council

IDEAS

Constraints on primordial NG from 800,000 photometric quasars

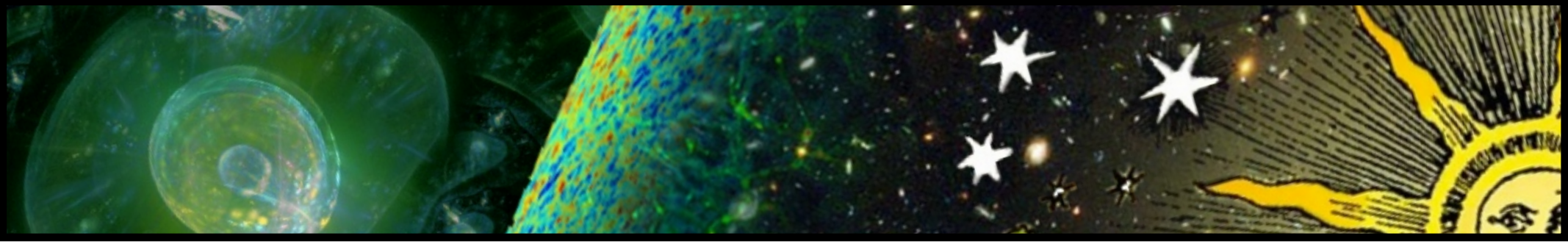
Boris Leistedt (UCL)

Nina Roth (UCL)

with

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

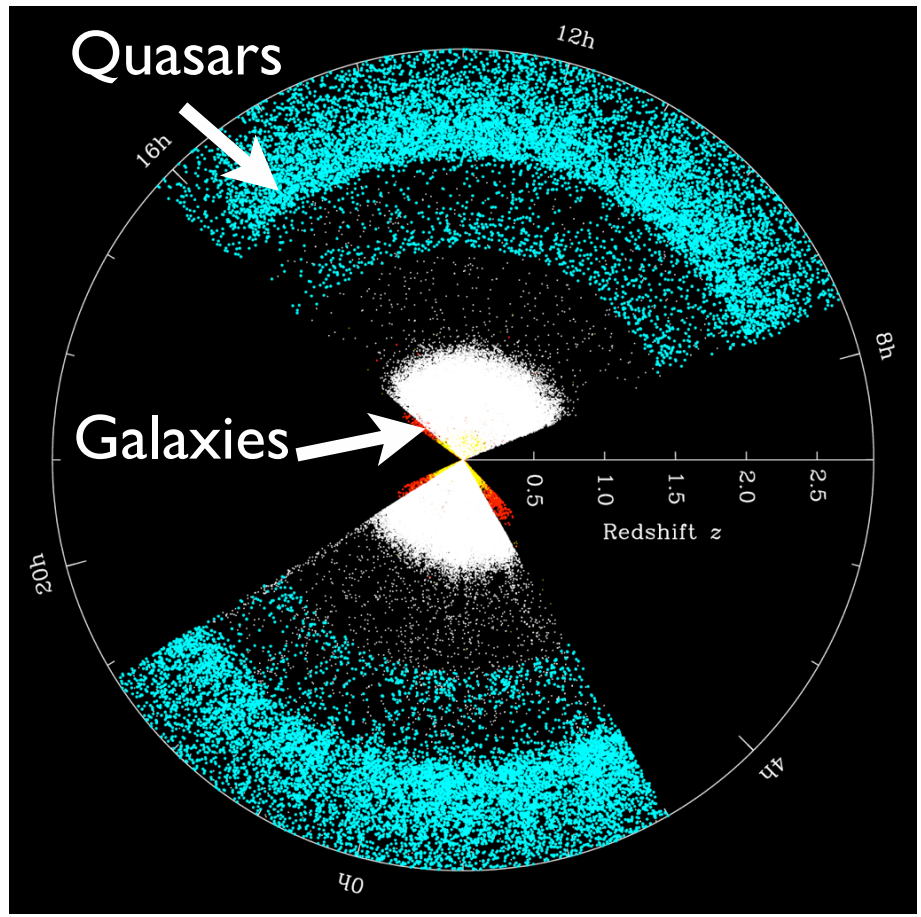
arXiv:1306.0005 (MNRAS), 1404.6530 (MNRAS), 1405.4315



Overview

- Primordial NG from quasar surveys
- Data analysis considerations
- Theory considerations
- Results and outlook

Cosmology with quasar surveys



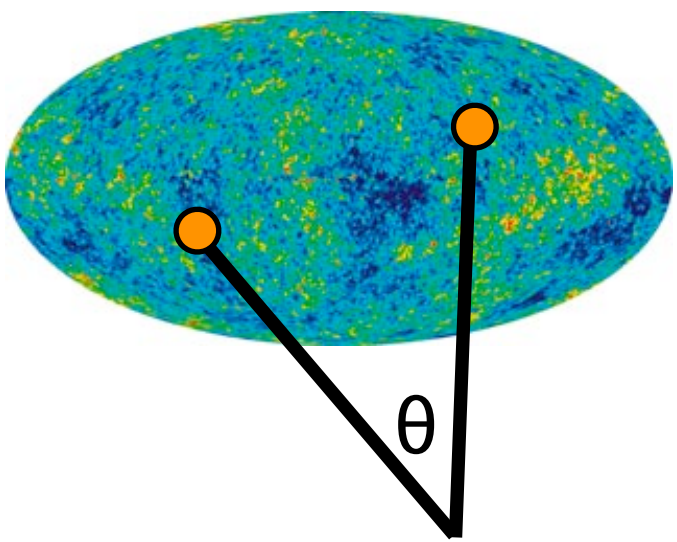
SDSS3; Credit: M.Blanton

- **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, ...

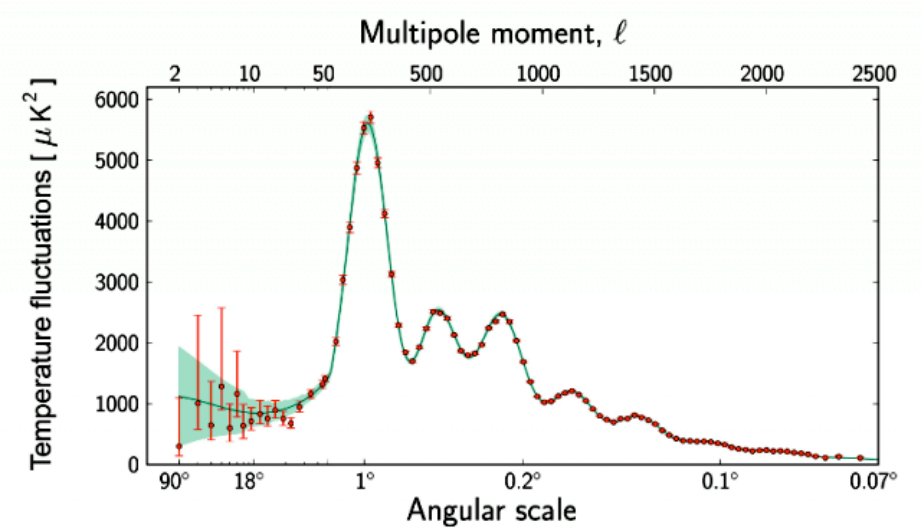
Non-Gaussianity: maximising physical information

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



map
50 million pixels

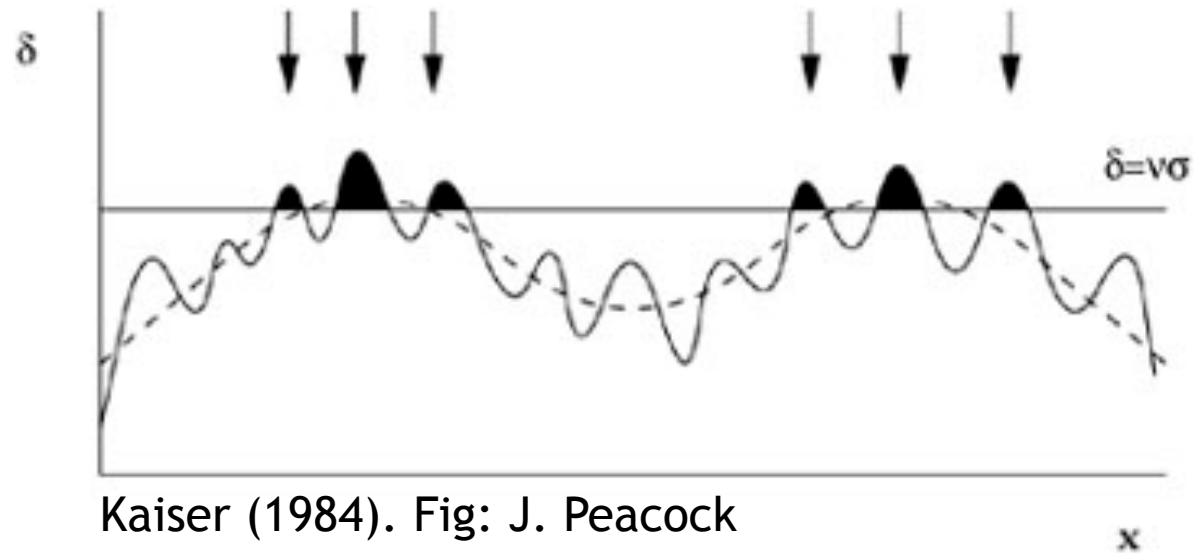
radical data compression



angular power spectrum
2500 multipoles

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

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.

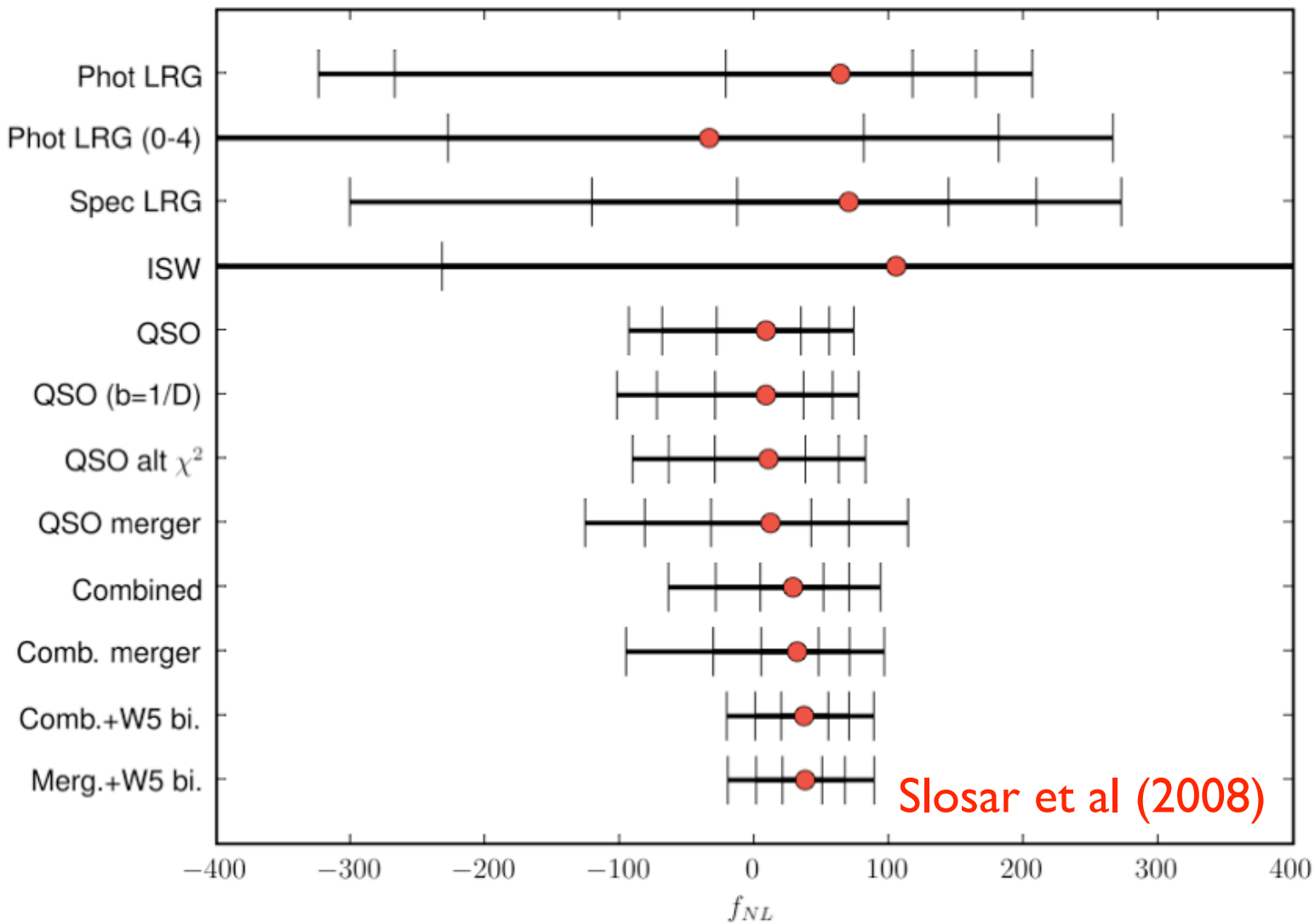
- Enhanced abundance of massive objects in overdense regions leads to enhanced clustering.

- 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

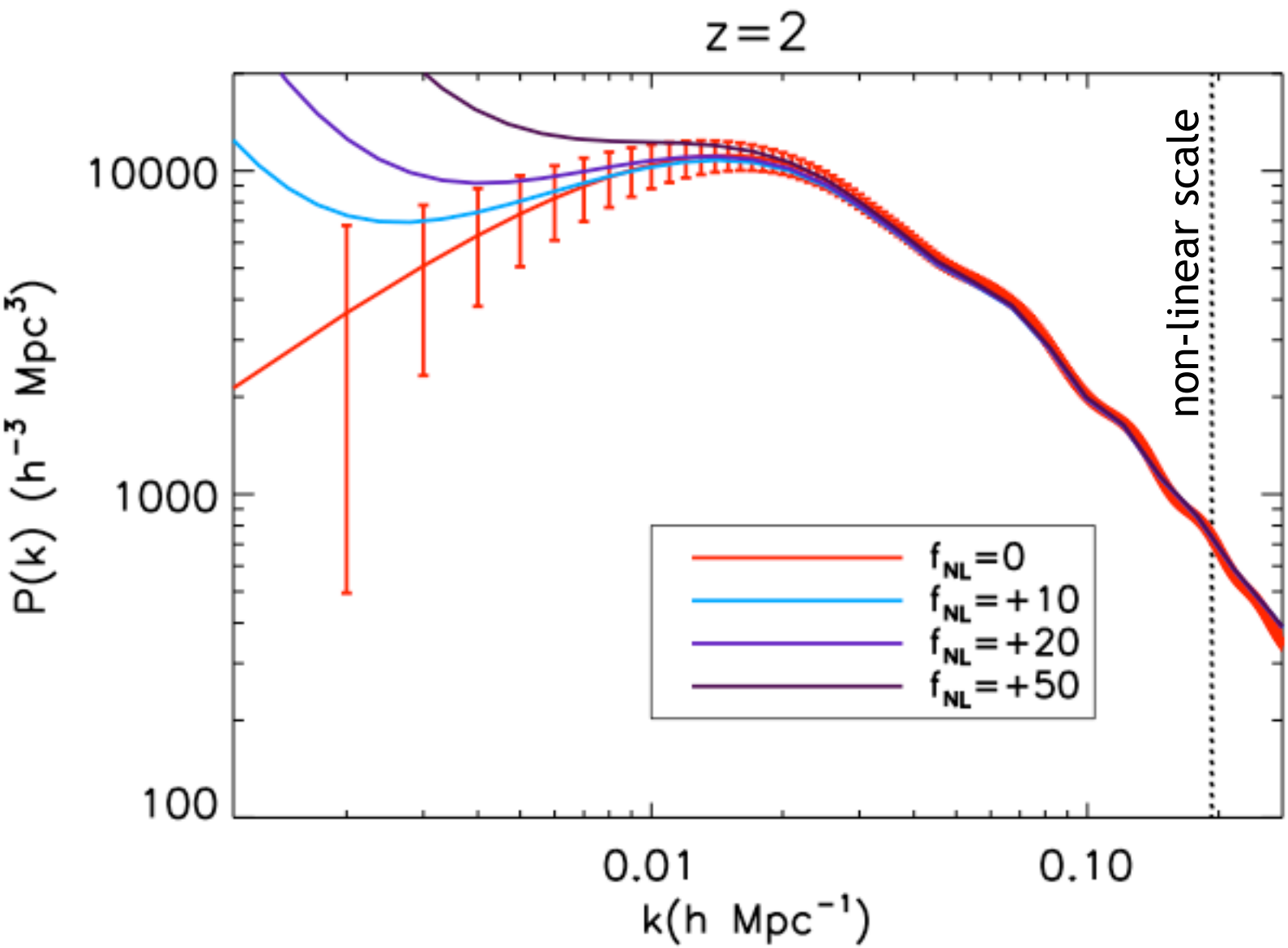
"Local" PNG $\Phi(\mathbf{x}) = \phi(\mathbf{x}) + f_{\rm NL}^{\rm loc}\phi^2(\mathbf{x})$ imprints halo bias $\Delta b \propto k^{-2}$



Slosar et al (2008)

scale-dependent halo bias (Dalal et al 2008)

Effect on the halo power spectrum



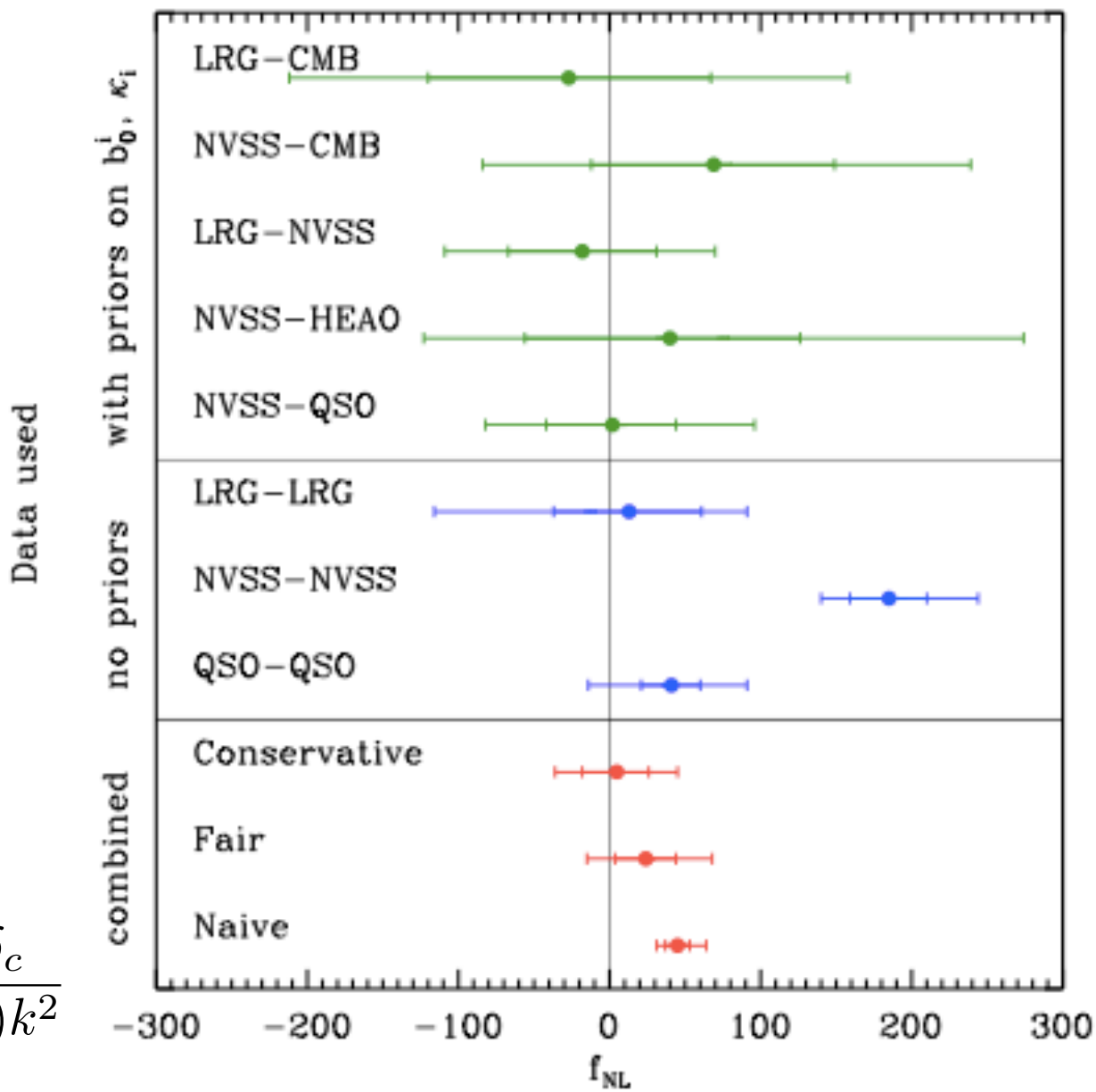
Power spectra at z=2 for a spectroscopic survey

Figure: HSLS white paper, HVP CMB/LSS Coordinator

The potential of quasar surveys for PNG

- **Quasars**: highly-biased LSS tracers, spanning large cosmological volumes

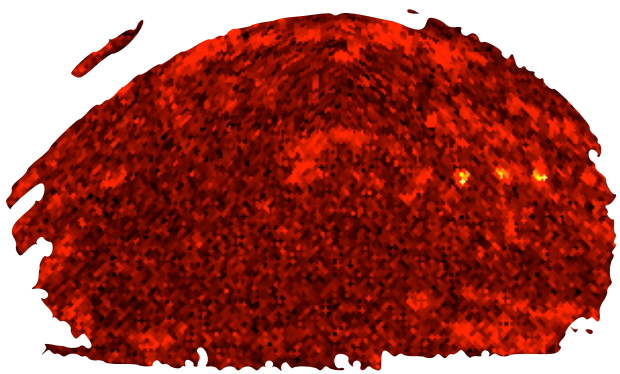
Giannantonio et al (2013)



$$\Delta b(k,z) = f_{\rm NL}(b_g - 1)\frac{3\Omega_{\rm m}h_0^2\delta_c}{D(z)T(k)k^2}$$

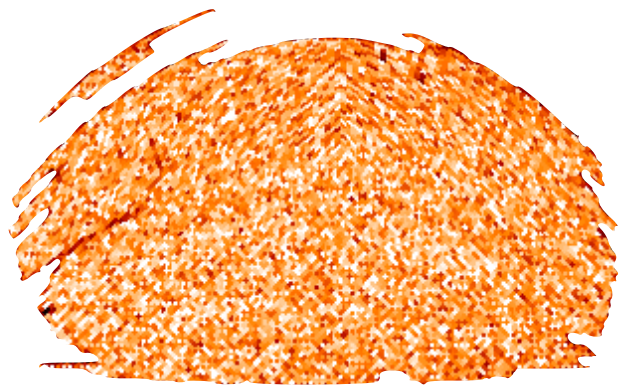
Photometric quasars

Spectroscopic catalogues are small, incomplete



~ 3 QSOs / deg^2

z_s < 2.2 Spec QSOs from SDSS-DR7

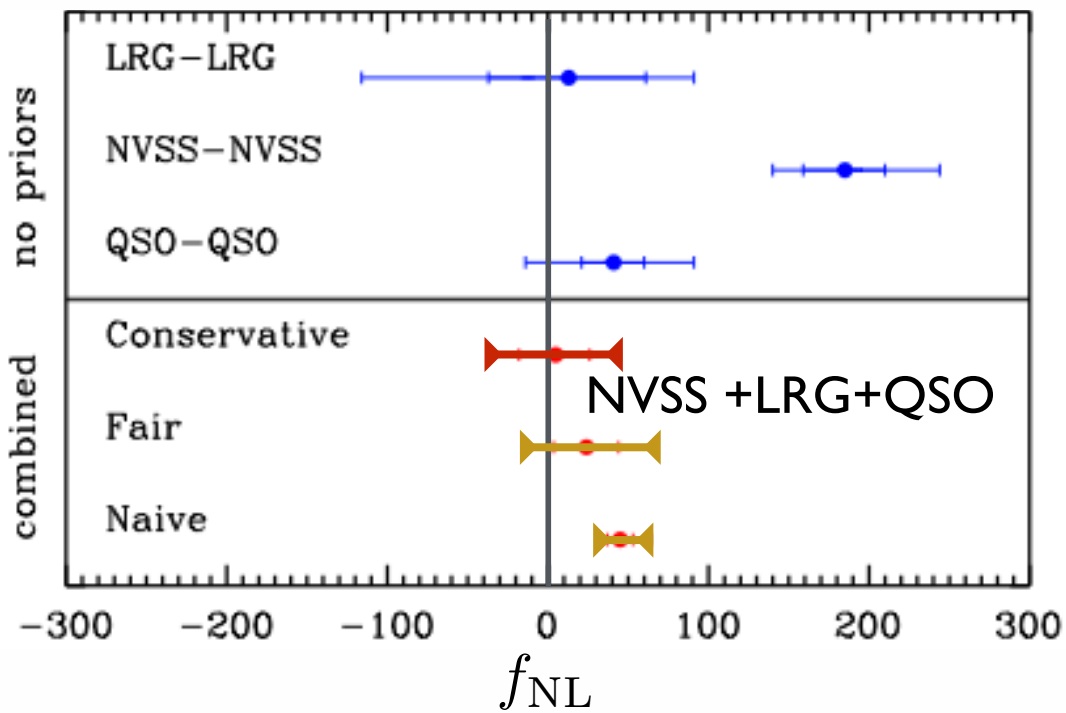


~ 15 QSOs / deg^2

z_p < 2.2 UVX Photo QSOs from RQCat (SDSS-DR6)

Systematics in quasar surveys

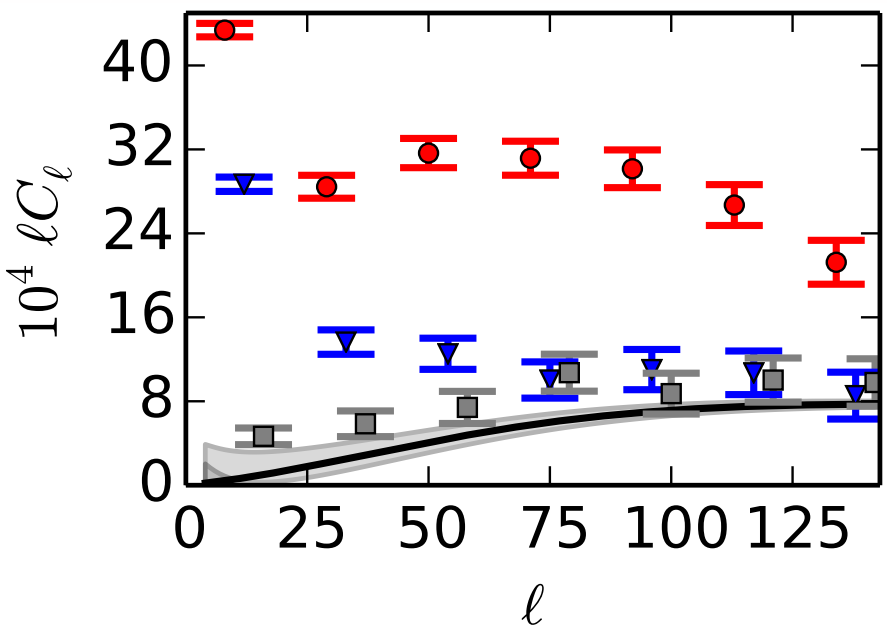
Giannantonio *et al* (2013)



- Quasars give best PNG constraints
- BUT plagued by systematics…

Slosar *et* al (2008), Xia *et al* (2010), Pullen & Hirata (2012), Leistedt *et al* (2013), Giannantonio *et al* (2013), Ho *et al* (2013), Agarwal *et al* (2014) …

Systematics in quasar surveys



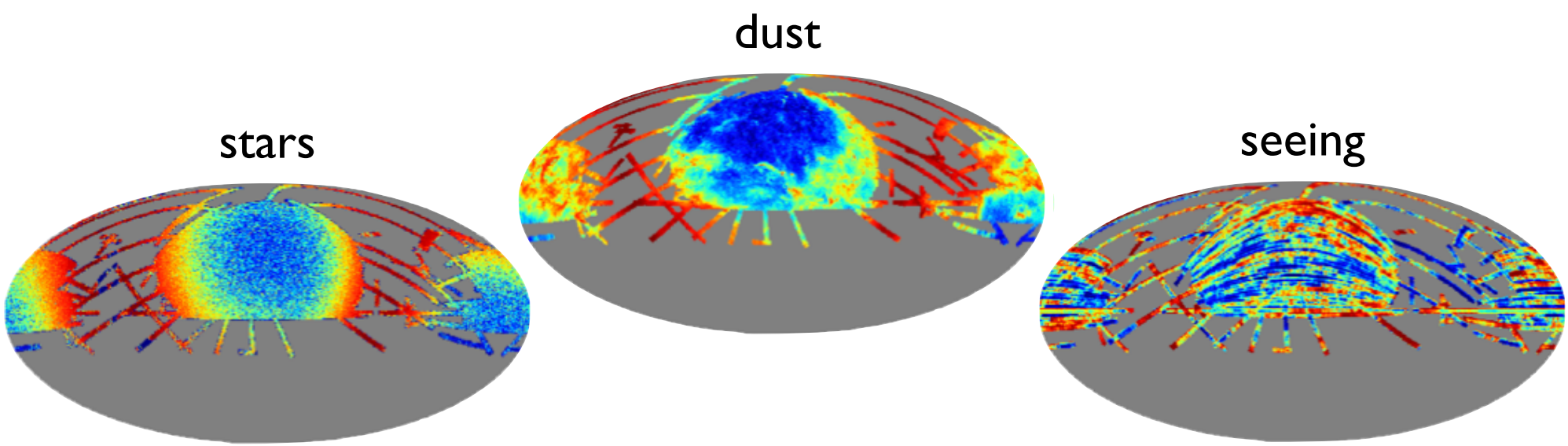
- **SDSS photometric quasars:** excess clustering power on large scales due to systematics.

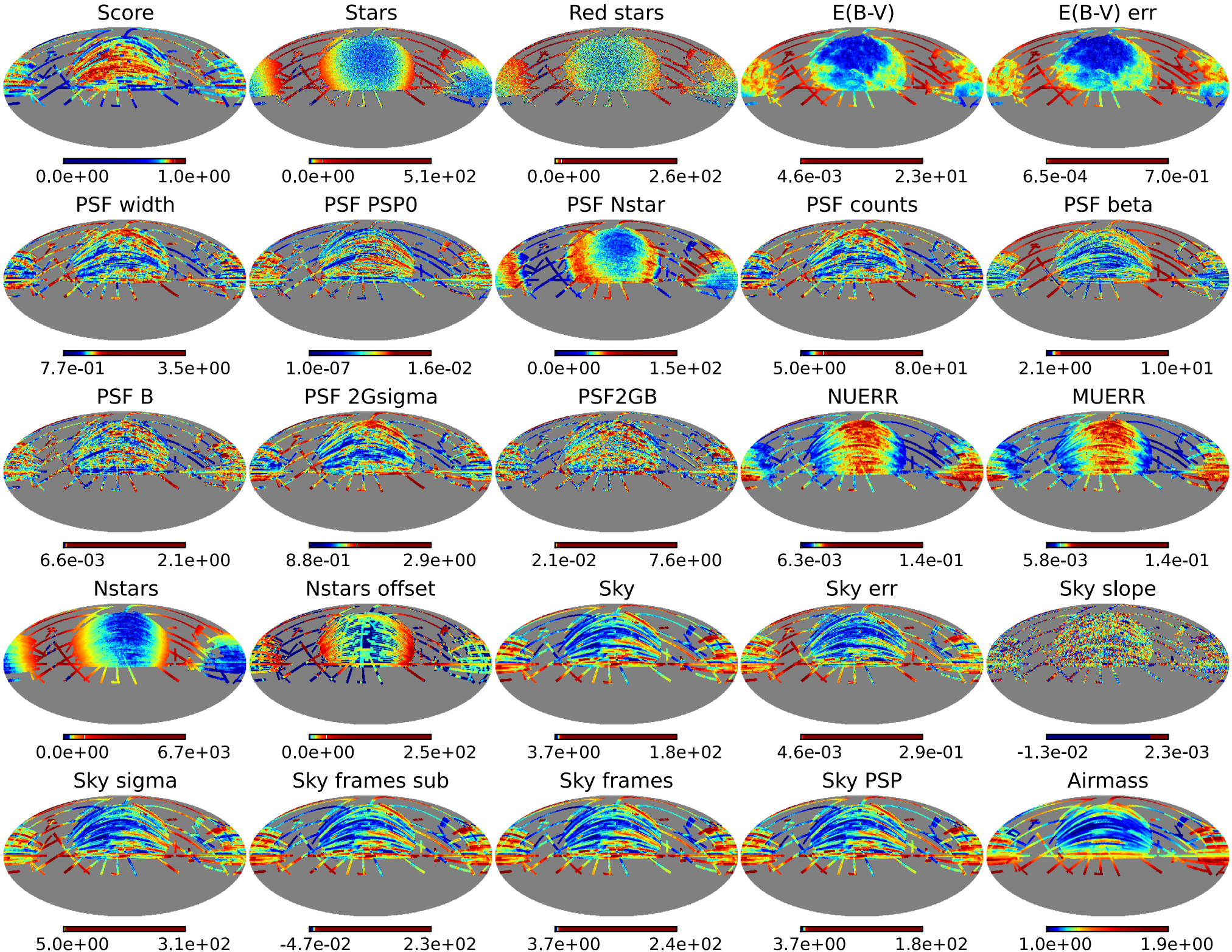
- Concerns about its use for clustering studies. Pullen and Hirata 2012; Giannantonio et al. 2013

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



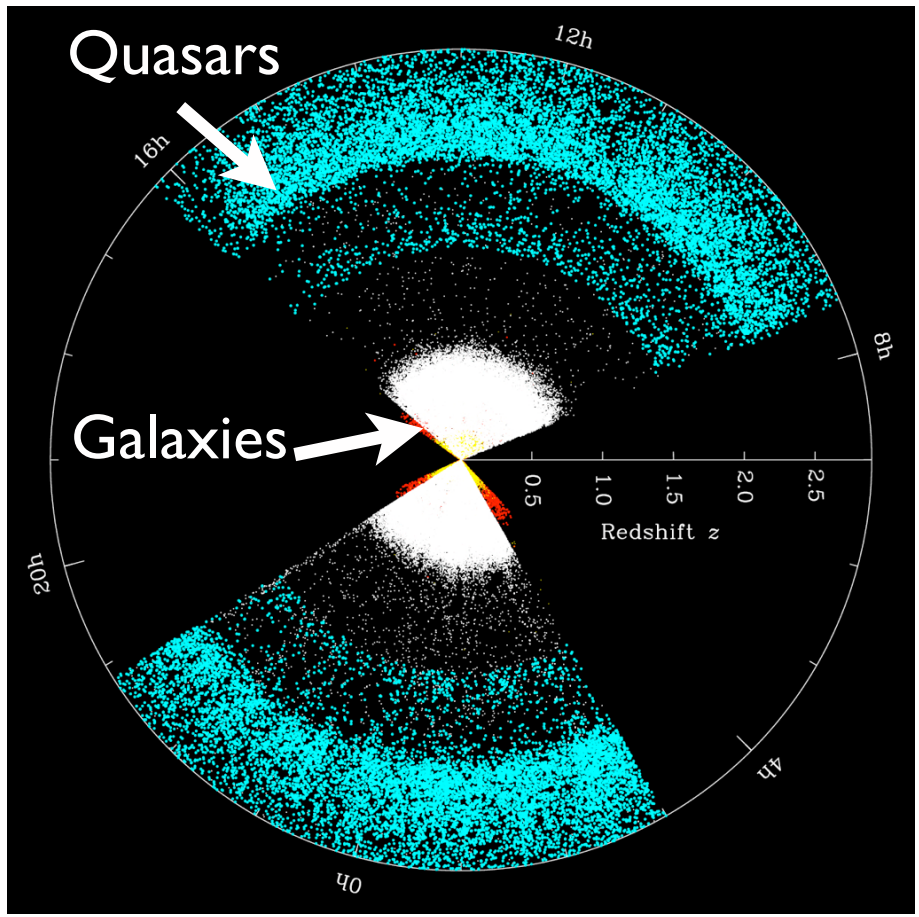


Wednesday, 27 August 14

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

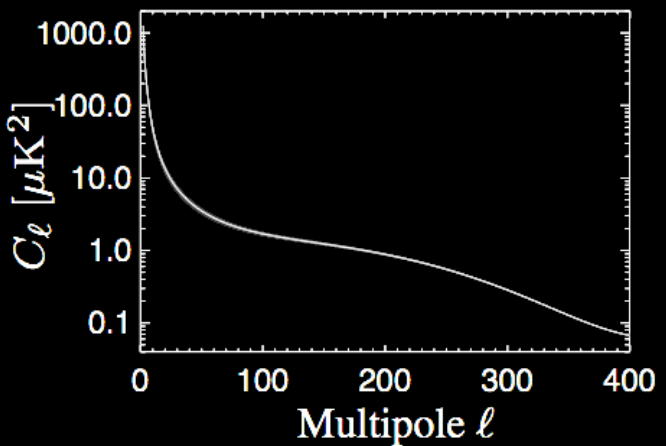
Noise, systematics, ...

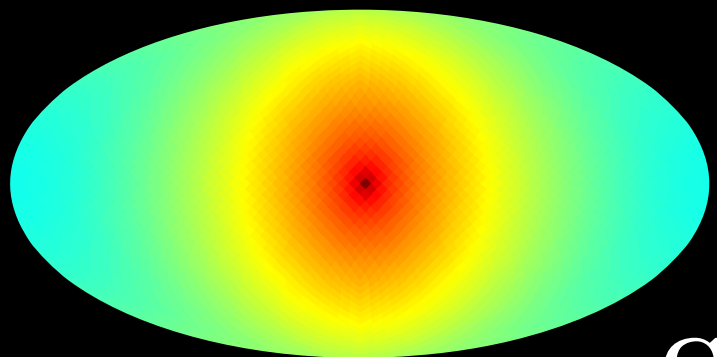
- Pseudo-spectrum estimator (PCL) = QML with diagonal pixel-pixel covariance, i.e. a flat power spectrum

(= uncorrelated pixels)

PCL or QML? CMB vs LSS correlations

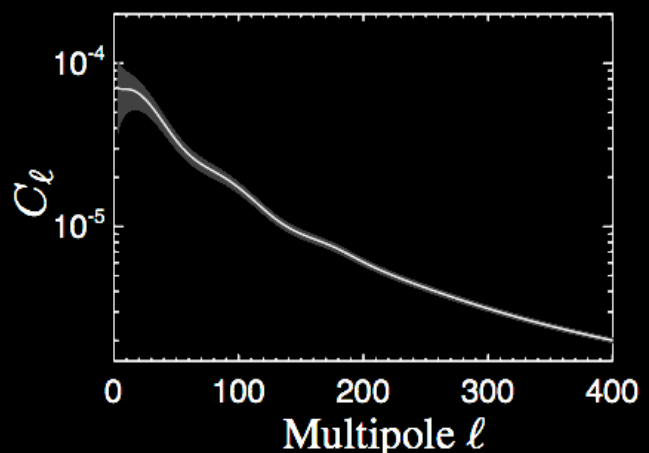
CMB

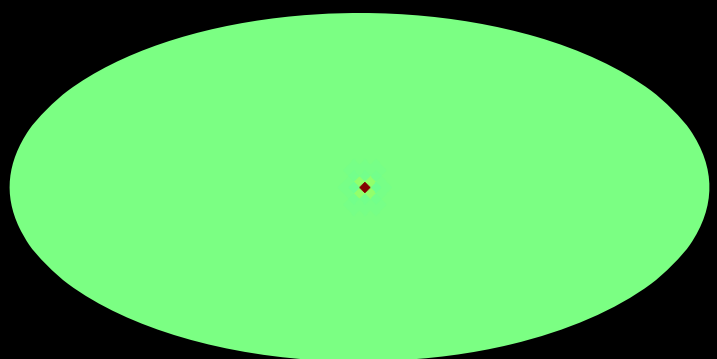




$\mathbf{C}(\theta_{ij})$
with i fixed

LSS



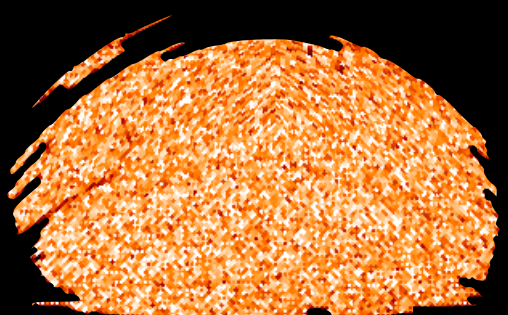


The LSS spectrum is quasi flat => PCL is nearly optimal
in the absence of systematics...

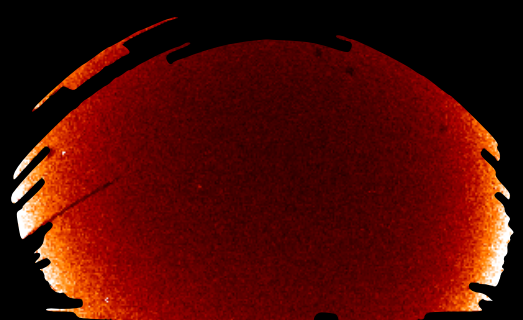
Systematics and mode projection

- PCL suboptimal with complex masks and systematics
- QML with mode projection: marginalises over linear contamination models, using systematics templates $\vec{c}_k$

$$\mathbf{C} = \sum_\ell \mathcal{C}_\ell \mathbf{P}_\ell + \mathbf{N} + \sum_{k \in \mathrm{sys}} \xi_k \vec{c}_k \vec{c}_k^{\,t} \quad \text{with} \quad \xi_k \to \infty$$

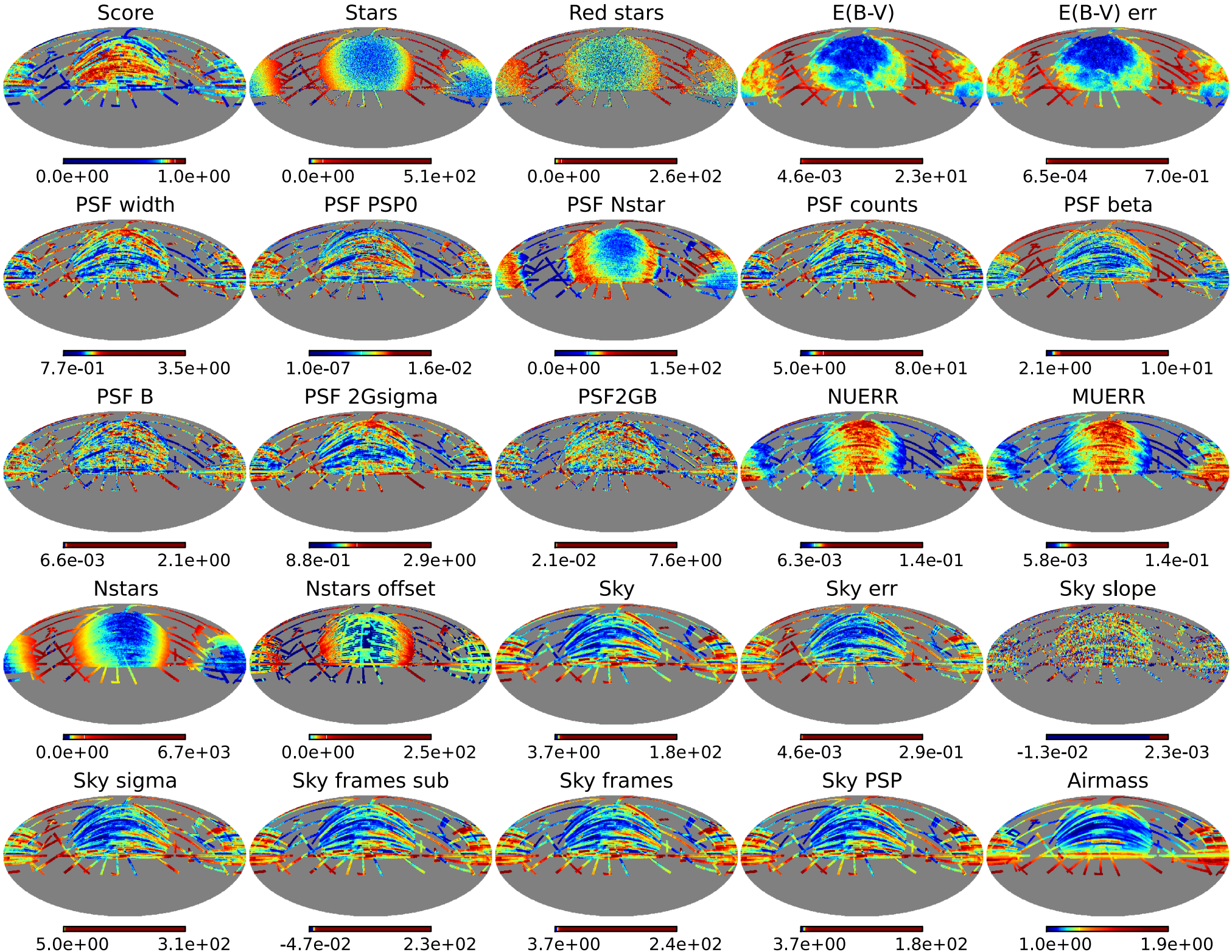


RQCat



stars

dust extinction



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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

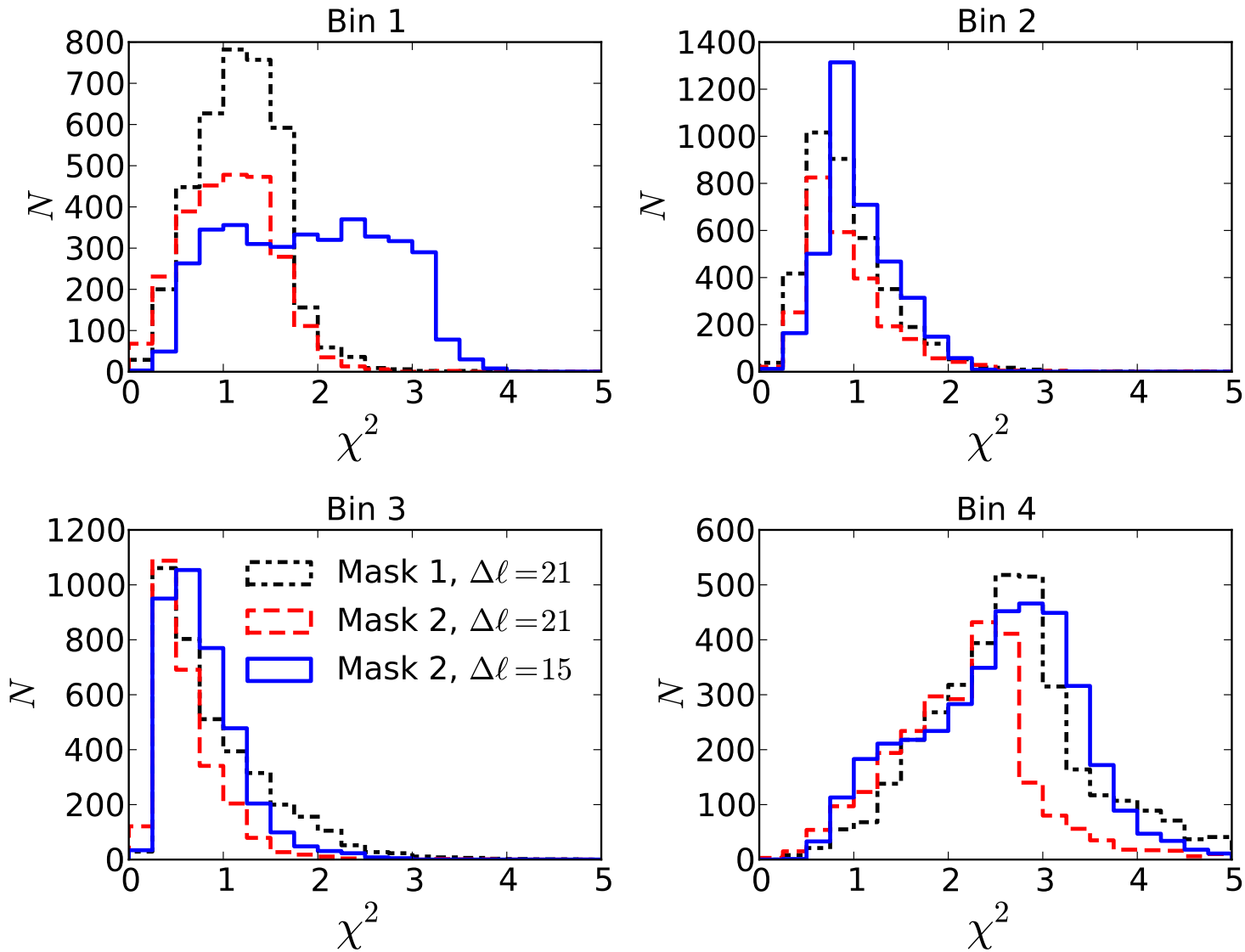
  3,700 null tests; project out modes with red chi2>1

Sacrificing some signal in favour of robustness

⇒ **Blind mitigation of systematics**

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

Null tests

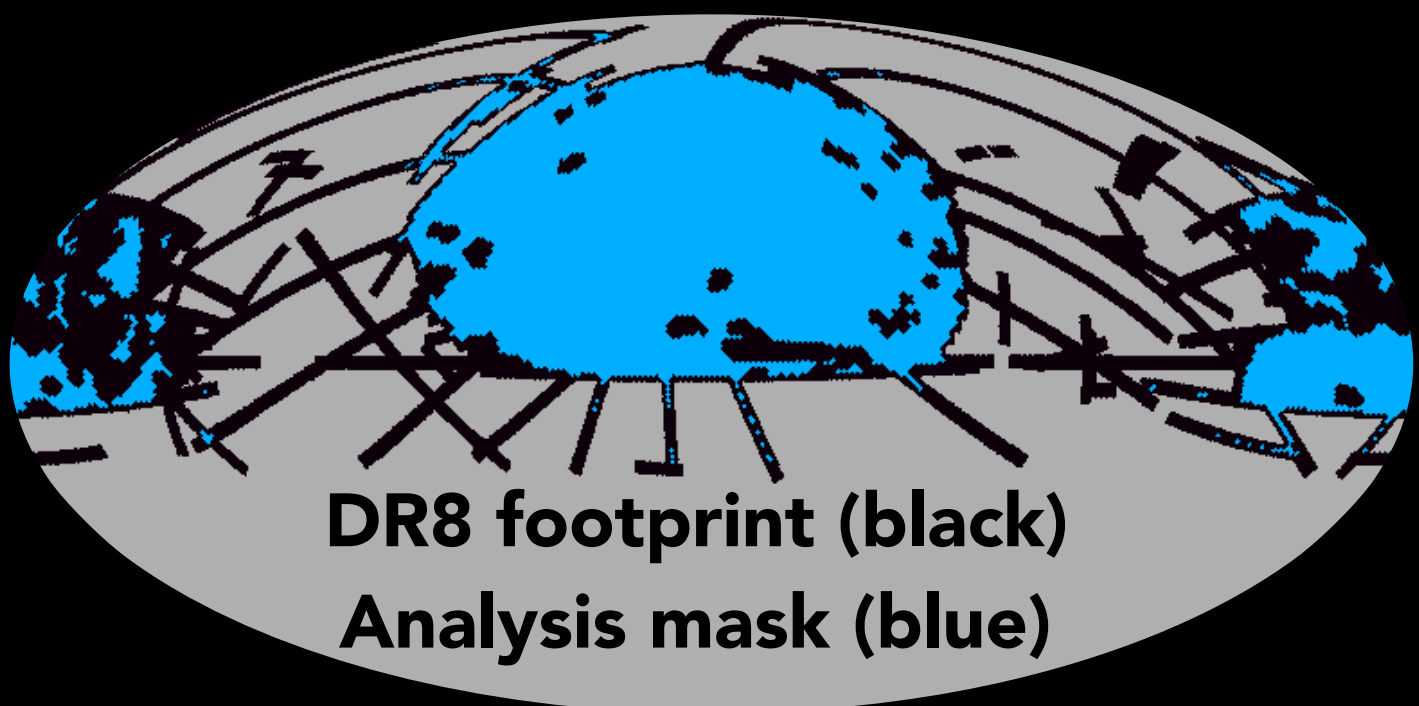


- Red. chisq. from cross-power spectra with 4 redshift samples

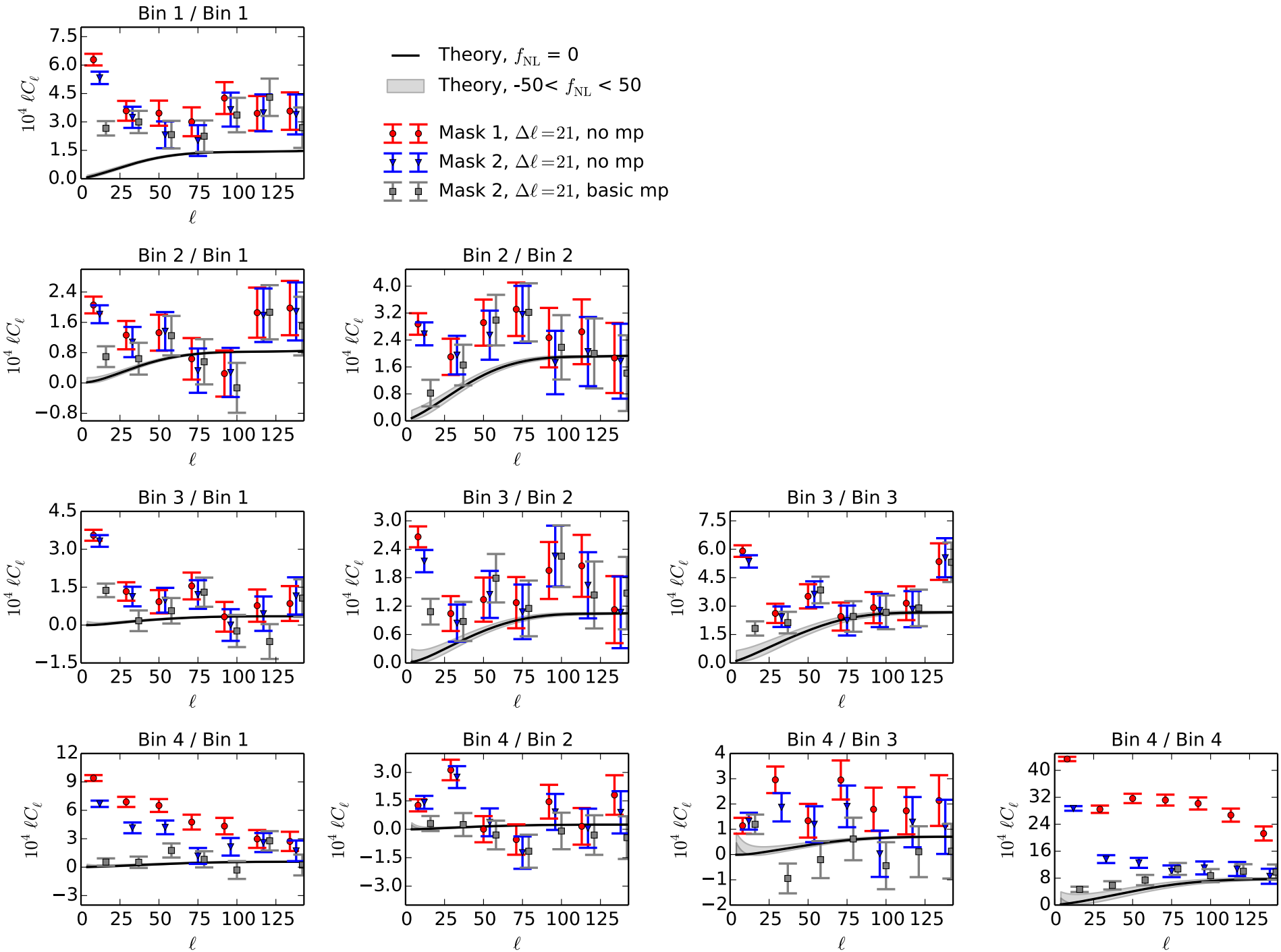
  3,700 null tests; project out modes with red chi2>1

Angular power spectrum estimation

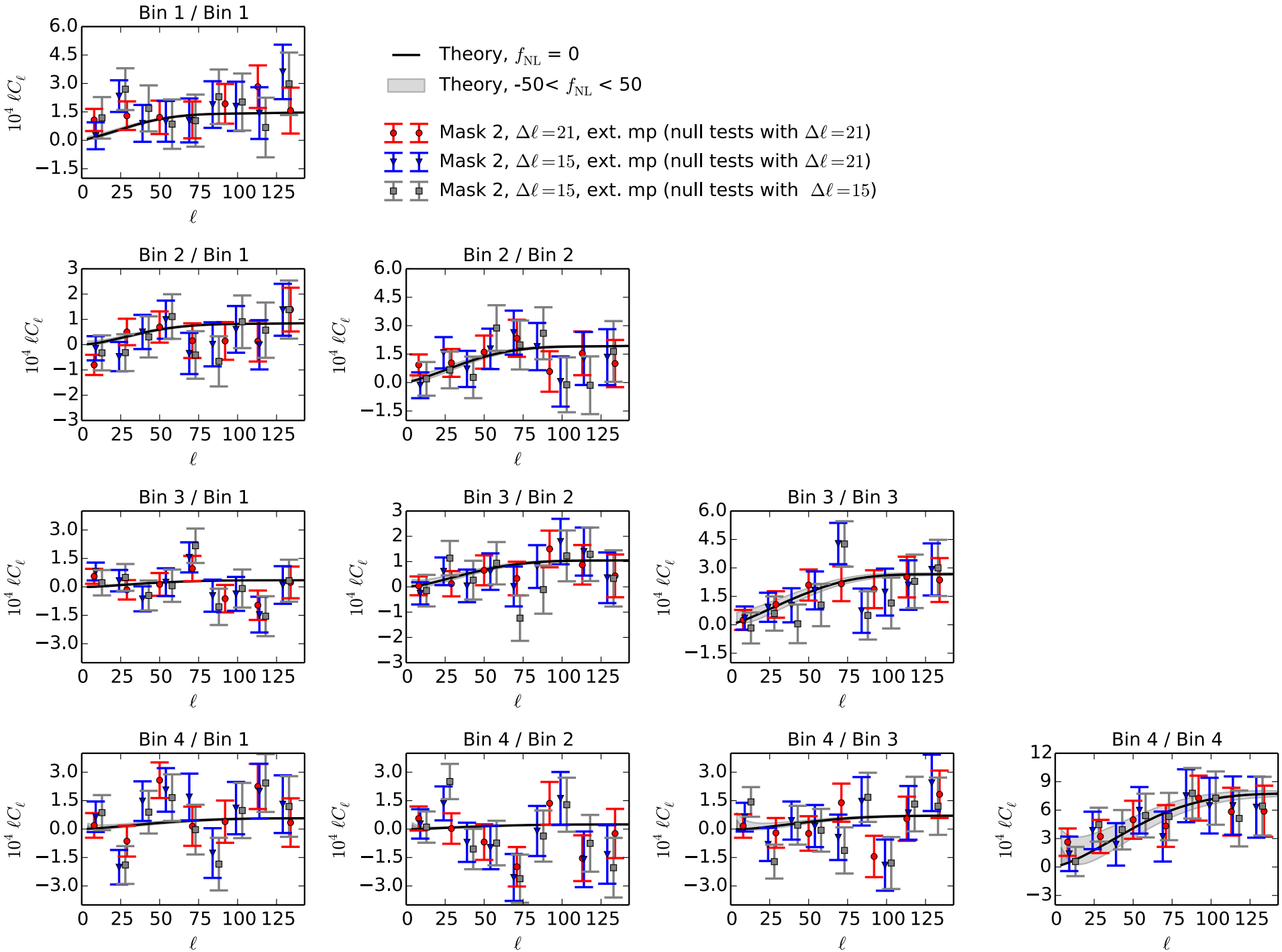
- Sky masks: cuts on extinction, seeing & quality flags
- Maximum Likelihood estimator to simultaneously compute 10 auto + cross angular power spectra



DR8 footprint (black)
Analysis mask (blue)

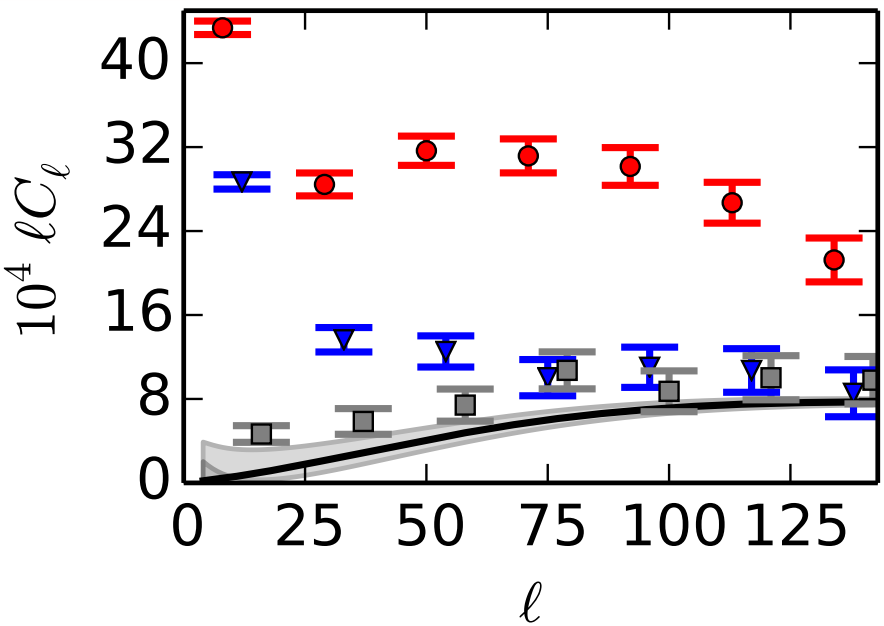


Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)

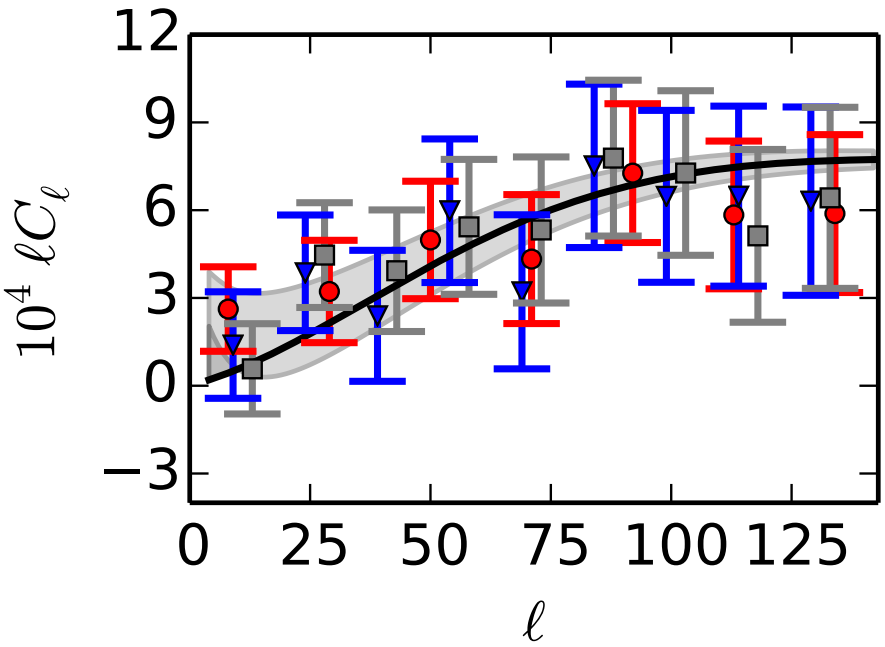


Leistedt & Peiris+ (MNRAS 2013, 1404.6530), Leistedt, Peiris & Roth (1405.4315)

Blind mitigation of systematics



Raw spectra



Clean spectra

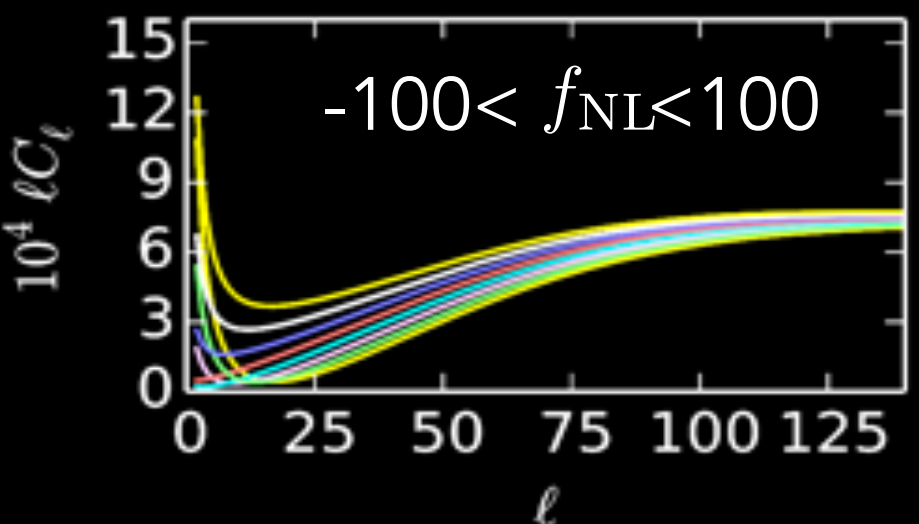
- Example: one of 10 spectra (auto + cross in four z-bins) in likelihood
- Grey bands: -50 < f_{NL} < 50; colours: basic masking + m.p.

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



PNG: enhances large scale quasar bias

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

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

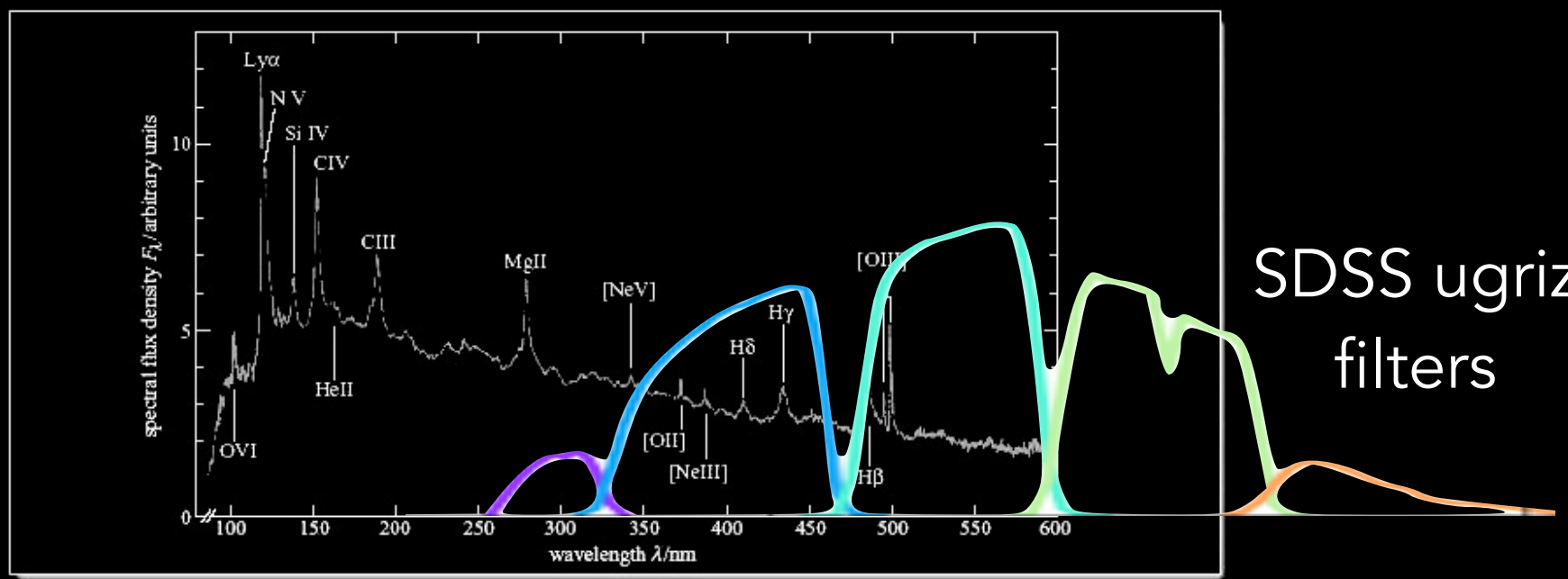
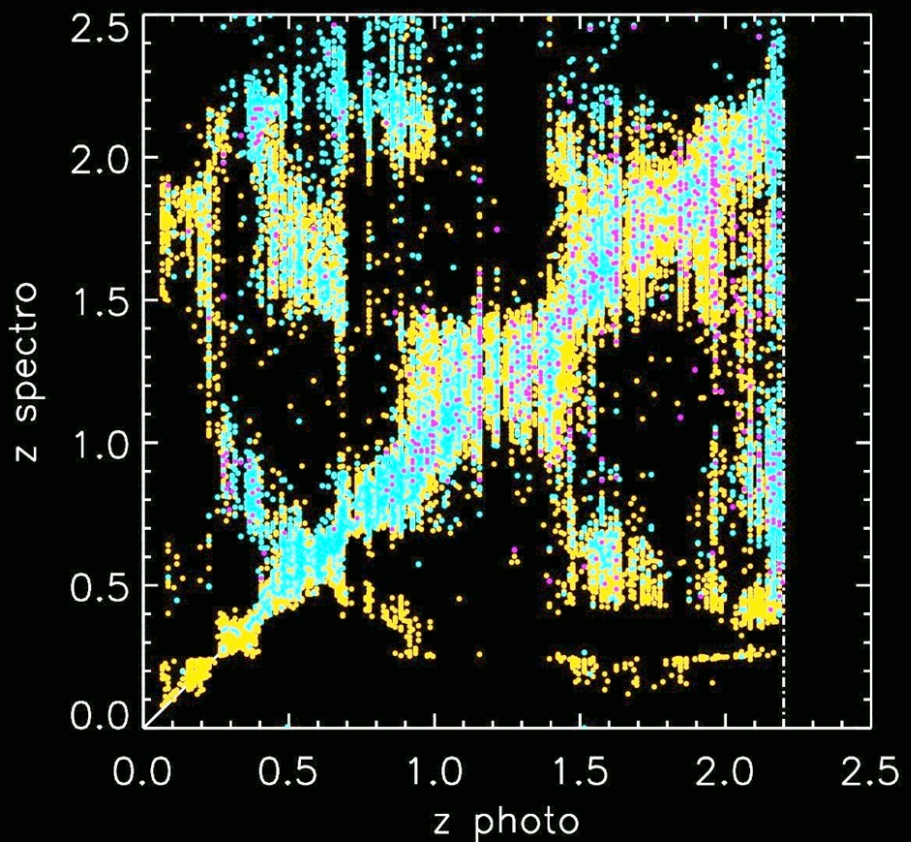


Figure 16: The mean optical spectrum of a sample of more than 700 quasars. The individual spectra were all corrected to remove the effect of red-shift before the spectra were averaged. Note the broad emission lines

An Introduction to Active Galactic Nuclei, Cambridge University Press

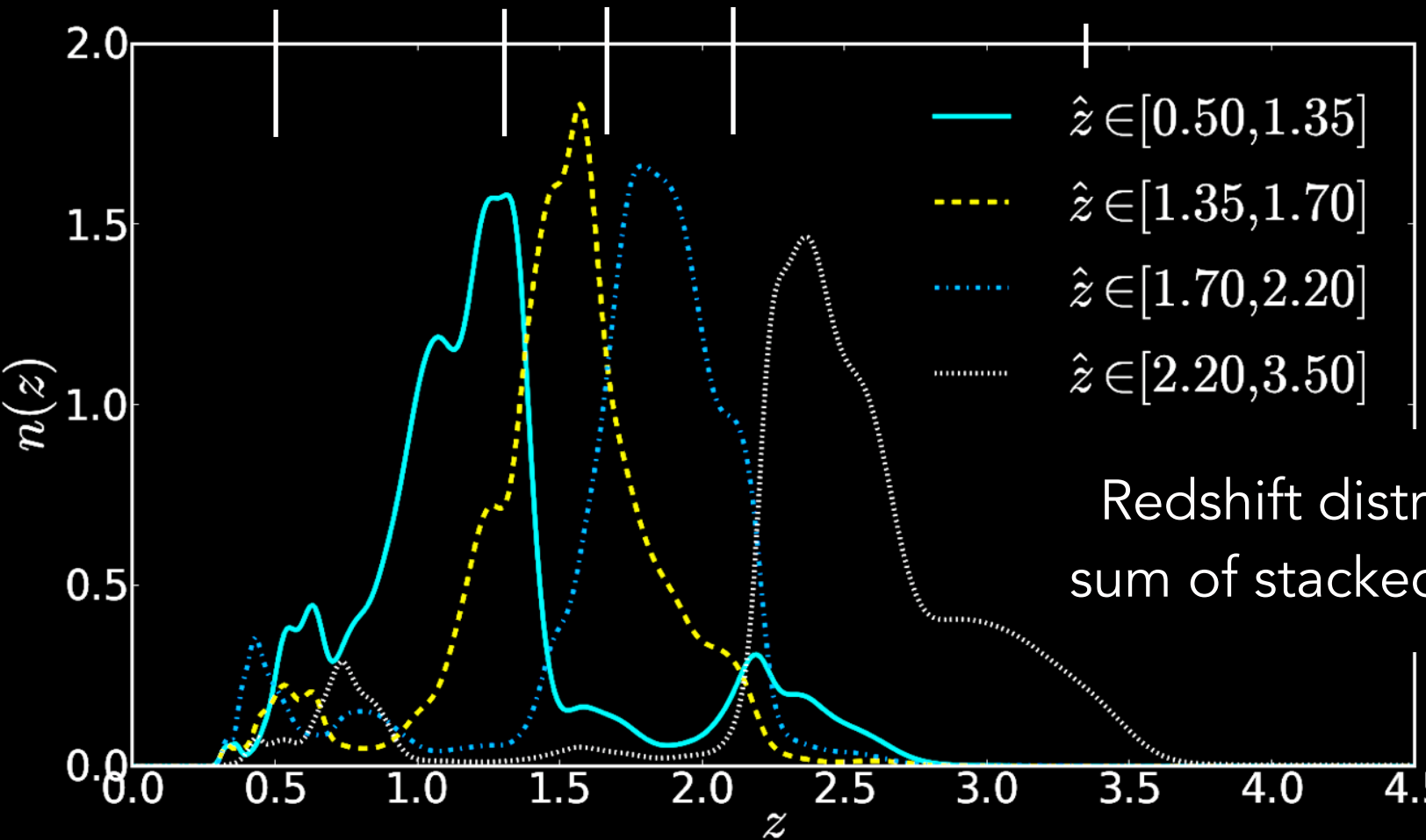
Photometric redshift estimates



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

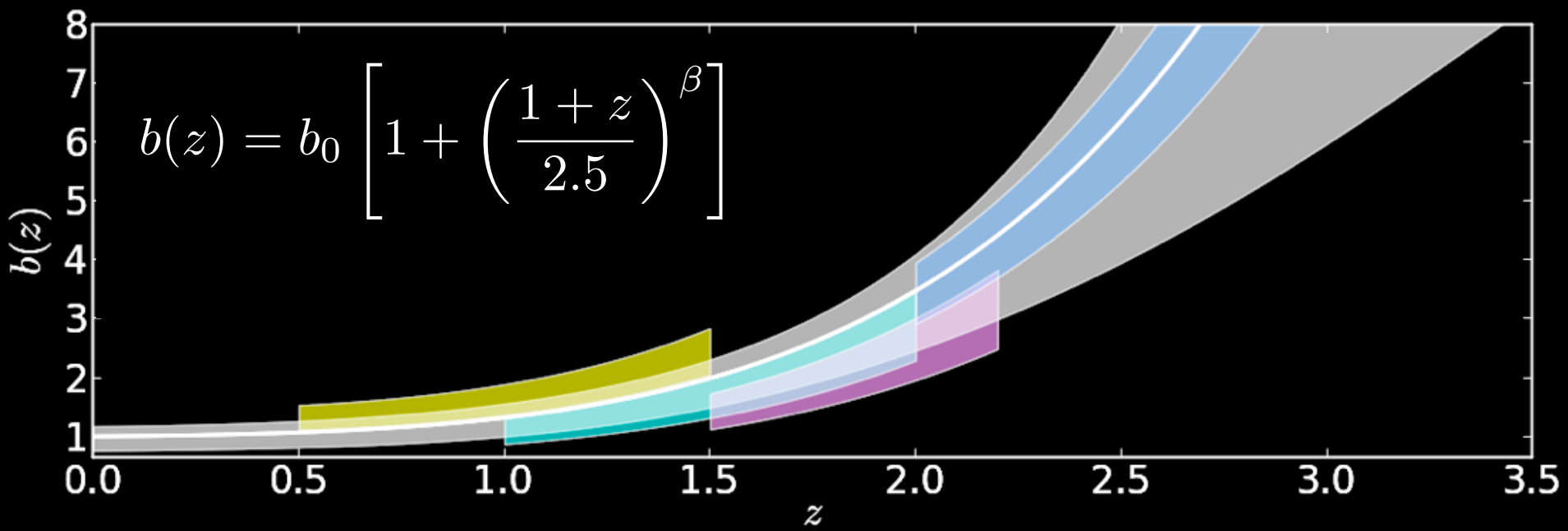
Analysis of XDQSOz quasars

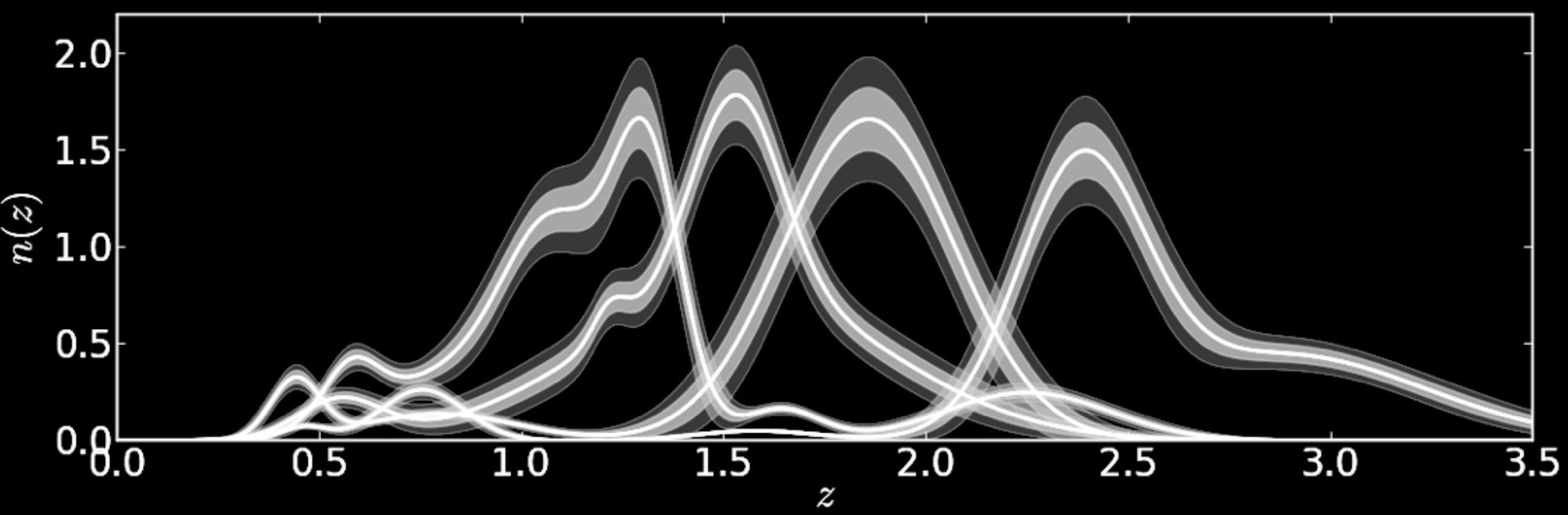


Redshift distributions = sum of stacked posteriors

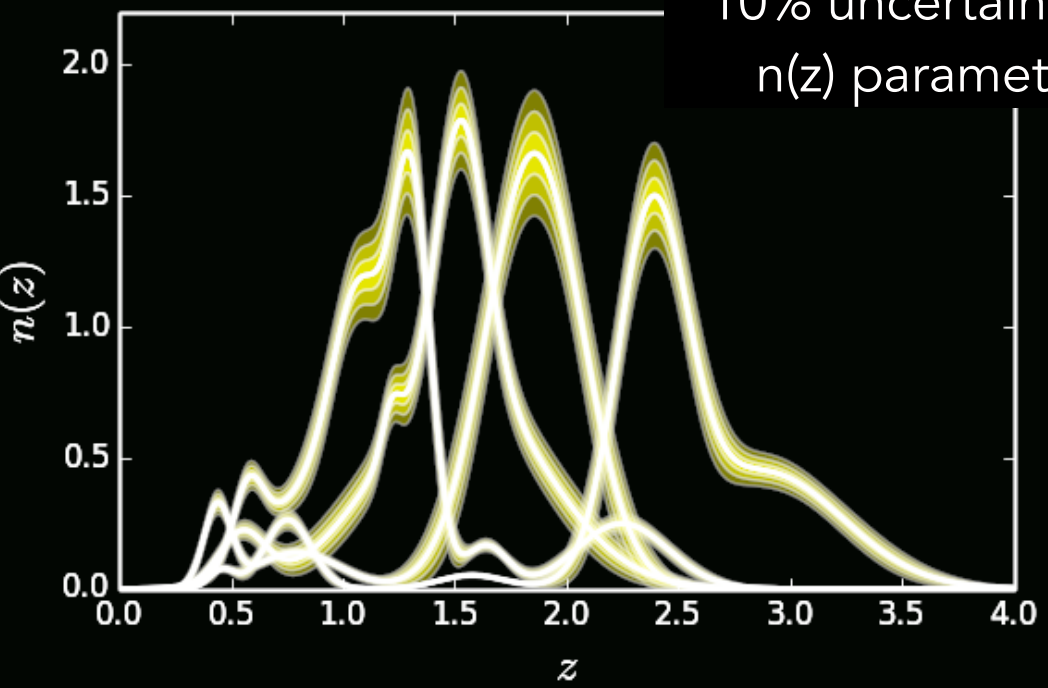
arXiv: 1404:6530

Constraints on the quasar bias

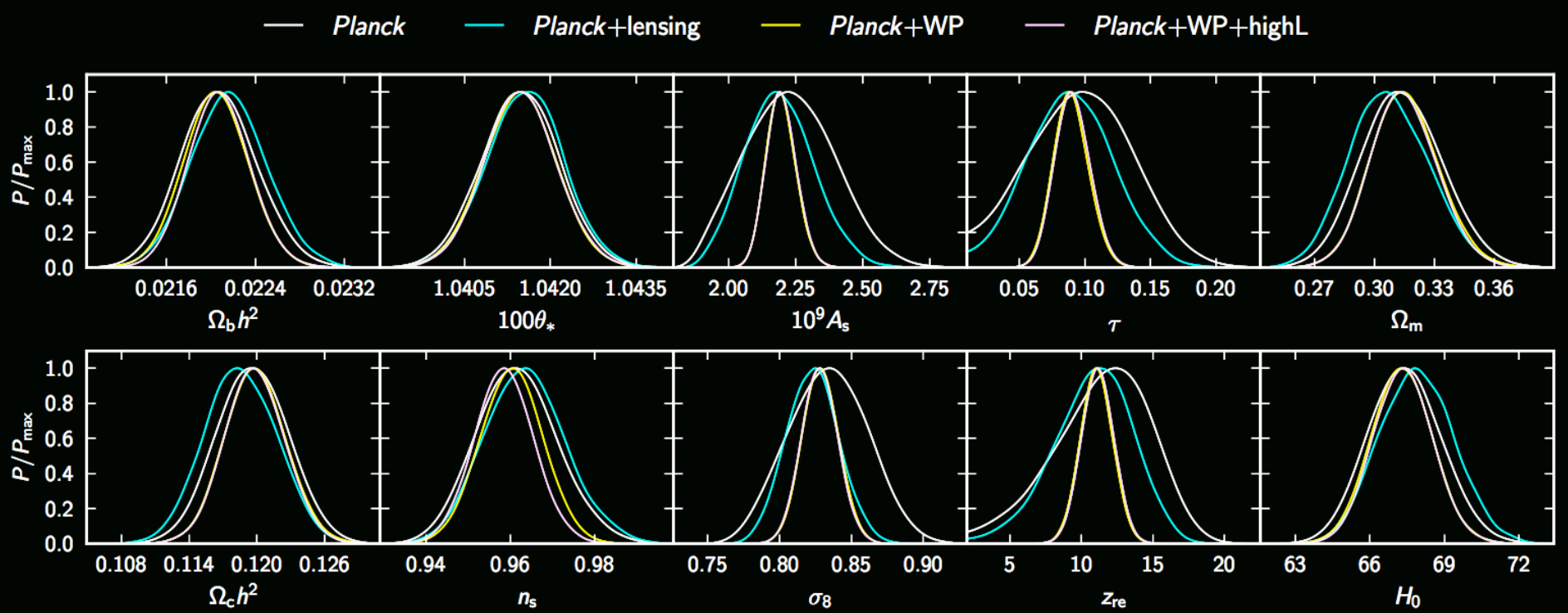




10% uncertainty on
n(z) parameters

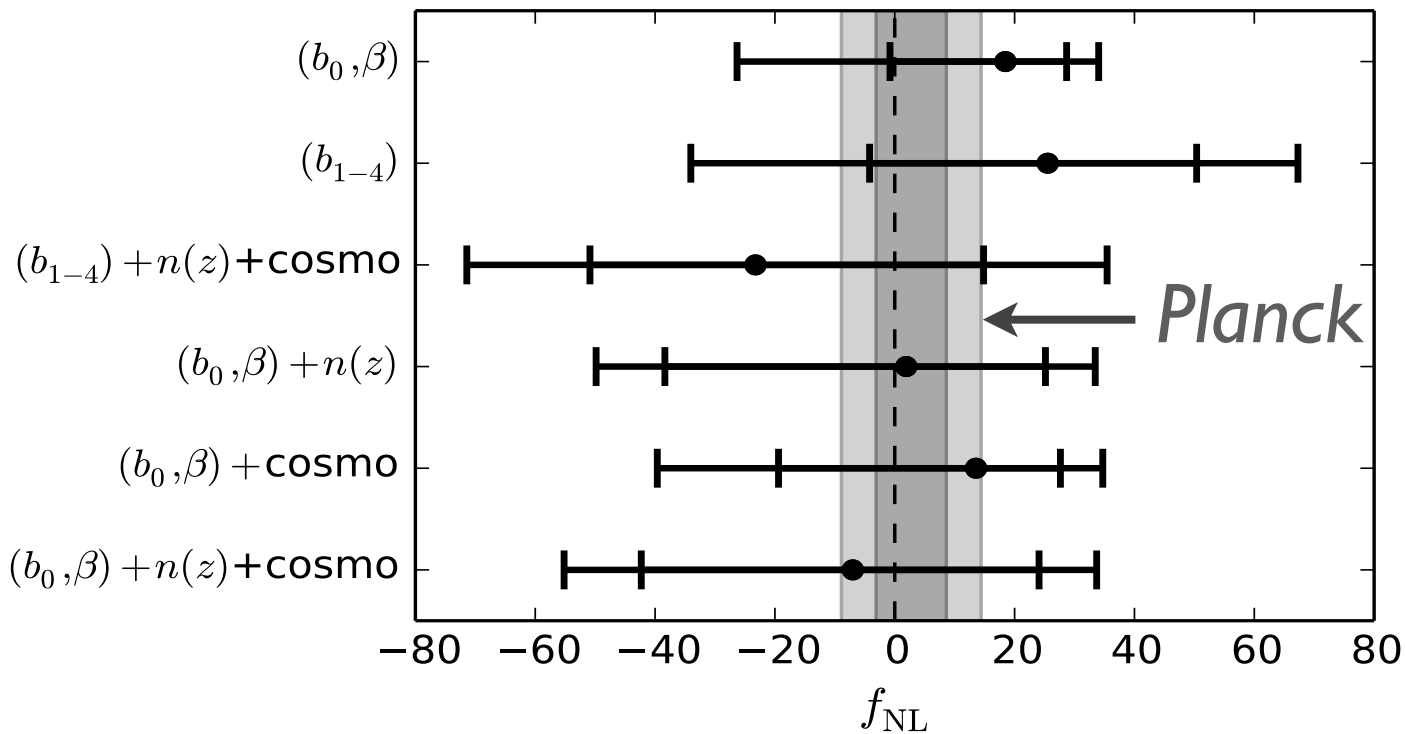


Varying n(z)
+ cosmology
+ bias model



Planck collaboration 2013

Constraints on f_{NL}



$-16 < f_{\rm NL} < 47\ (2\sigma)$

Fixed cosmology & n(z)

$-49 < f_{\rm NL} < 31\ (2\sigma)$

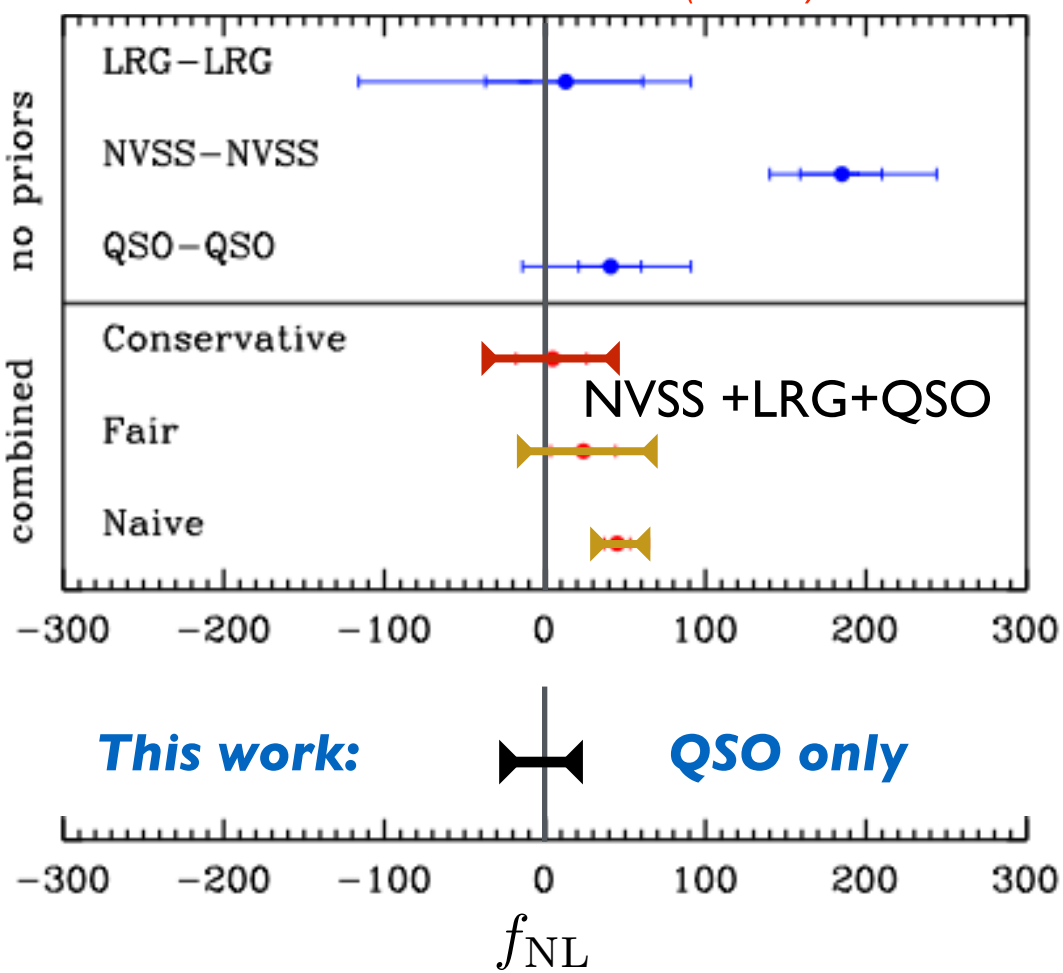
Varying all parameters

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

Leistedt, Peiris & Roth (1405.4315)

Constraints on f_{NL}

Giannantonio *et al* (2013)



$-16 < f_{\rm NL} < 47\ (2\sigma)$

Fixed cosmology & n(z)

$-49 < f_{\rm NL} < 31\ (2\sigma)$

Varying all parameters

Leistedt, Peiris & Roth (1405.4315)

Higher order terms

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

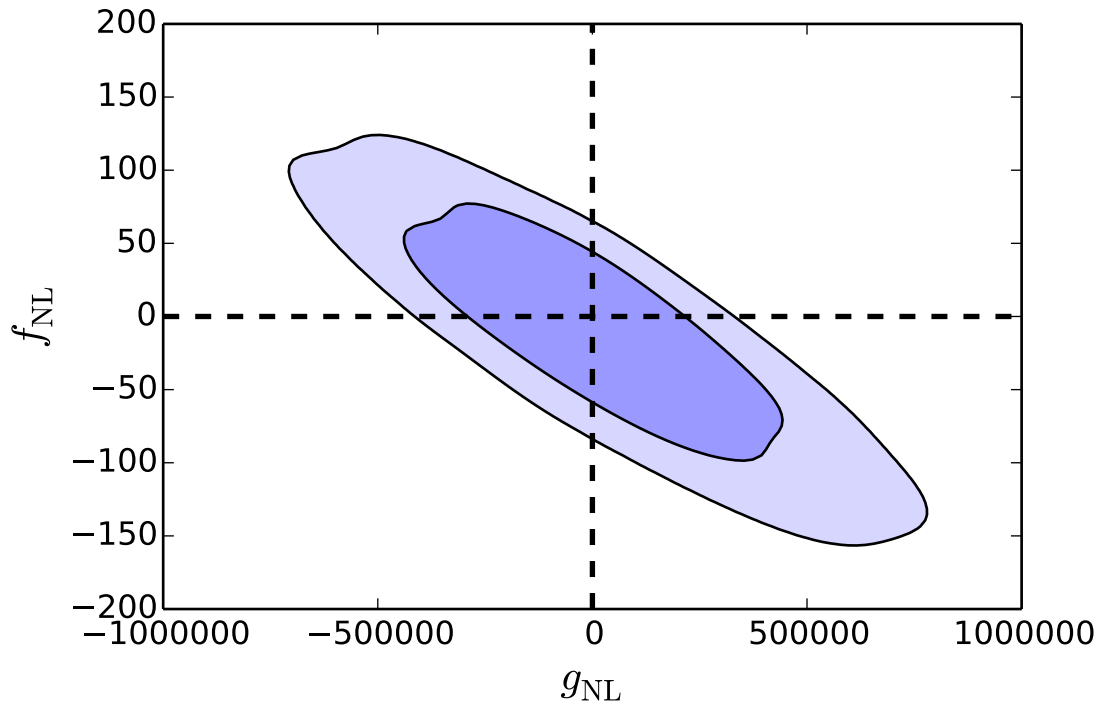
$|g_{NL}| < 10^6$ (CMB, LSS)

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

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

Smith, Ferraro & LoVerde (2012)

Constraints on g_{NL}



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

individually

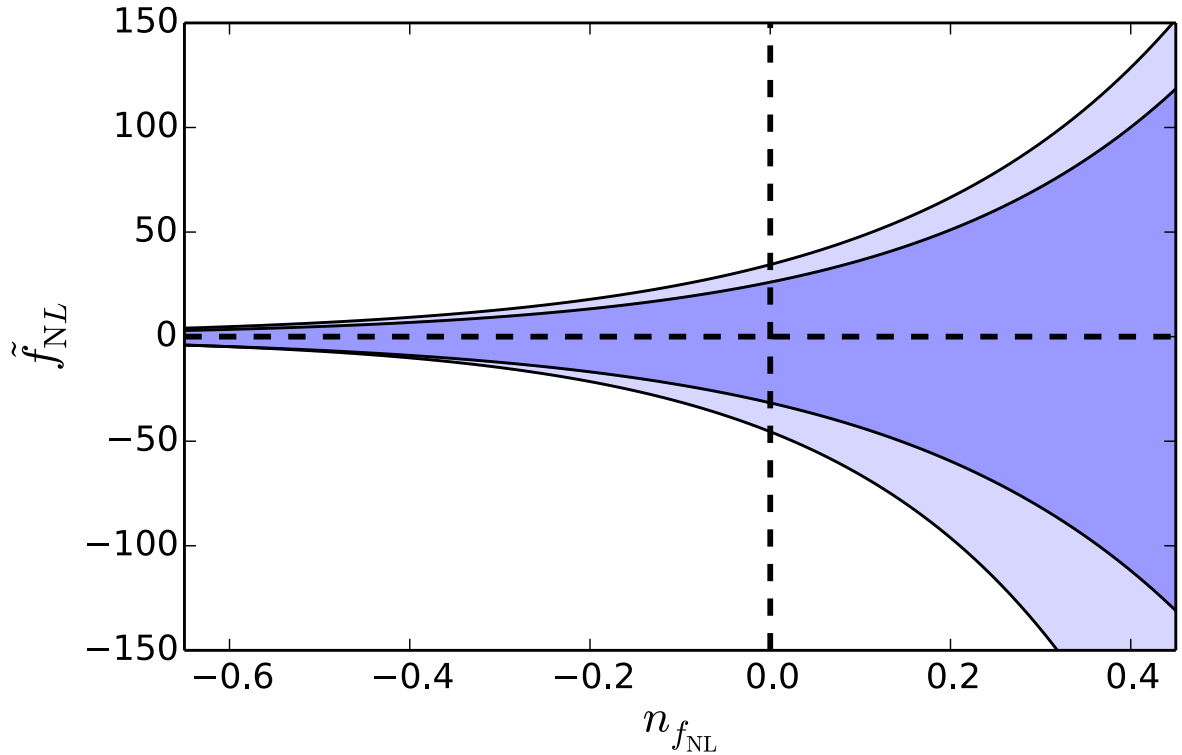
$$-4.0 < g_{\rm NL}/10^5 < 4.9 \ (2\sigma)$$

joint with f_{NL}

- Best available constraint on g_{NL}

Leistedt, Peiris & Roth (1405.4315)

Extended model with running



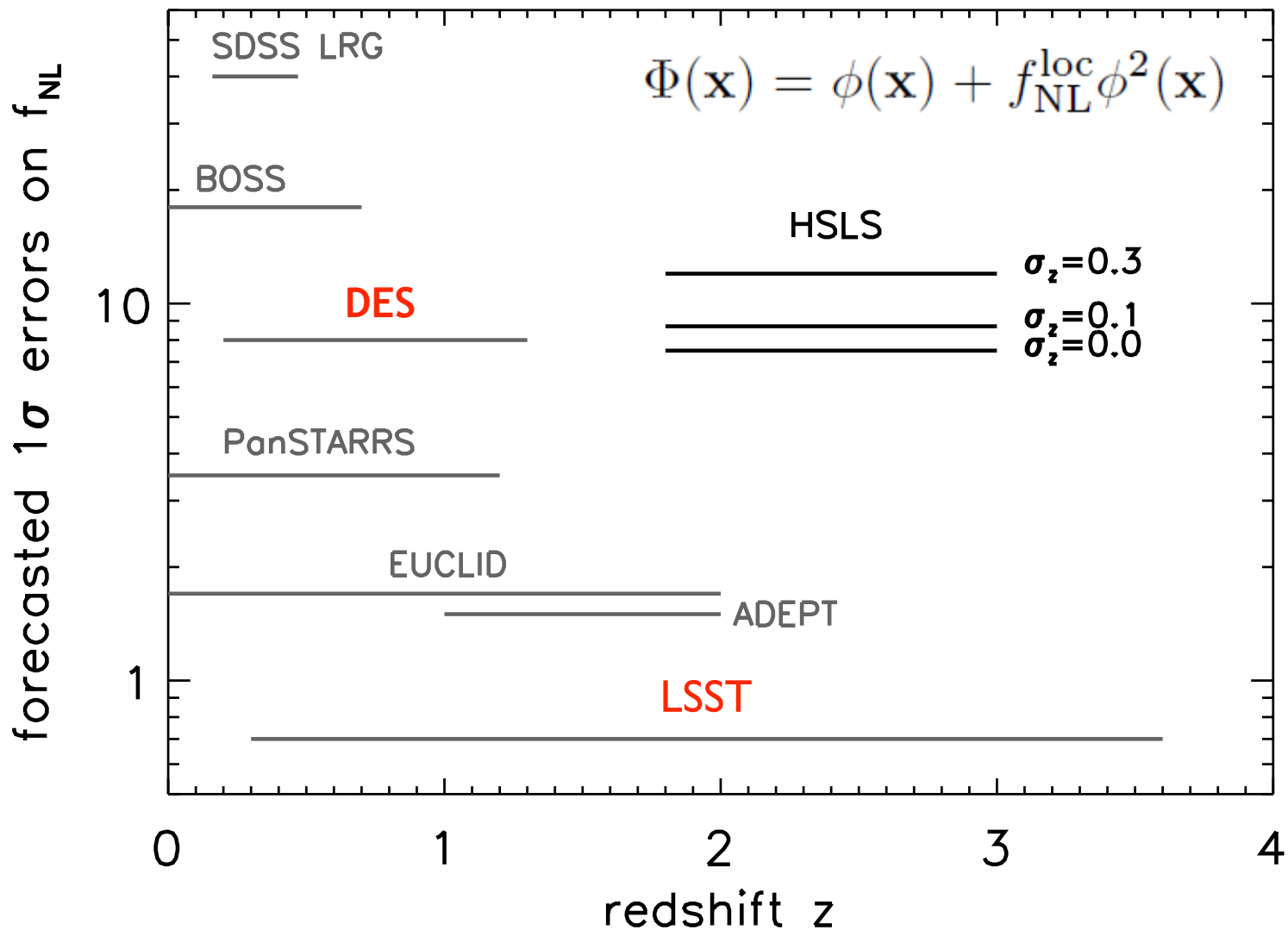
$$b(k) \propto k^{-2+n_{f_{\rm NL}}}$$

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



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

Figure: HSLS white paper, HVP CMB/LSS Coordinator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