Cross-correlation with CMB lensing convergence, redshift distribution and bias of LoTSS-DR1 sources

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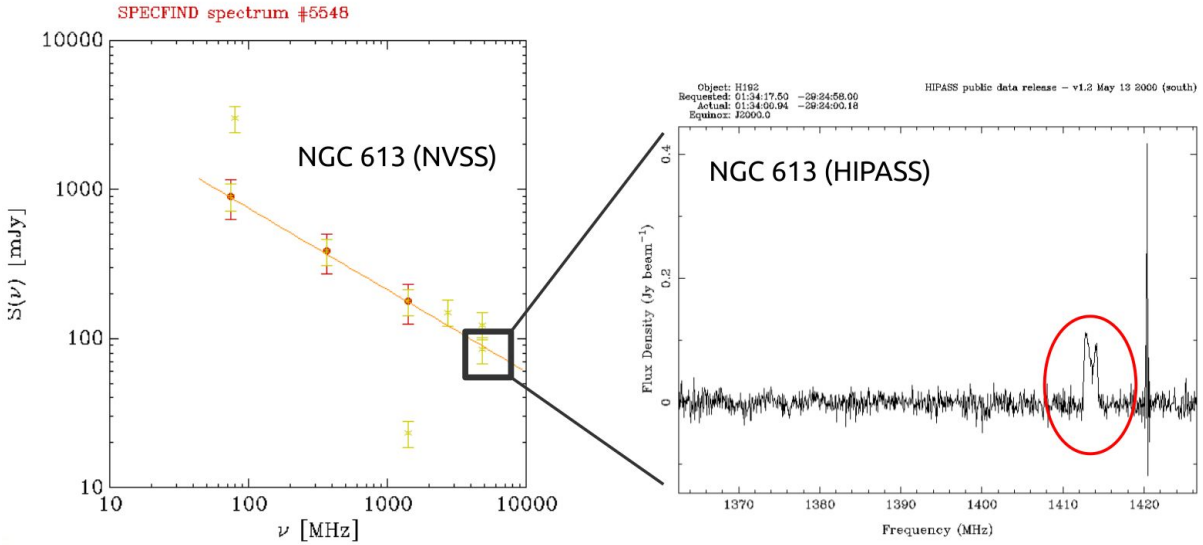
Continuum surveys and CMB lensing

Radio spectra:

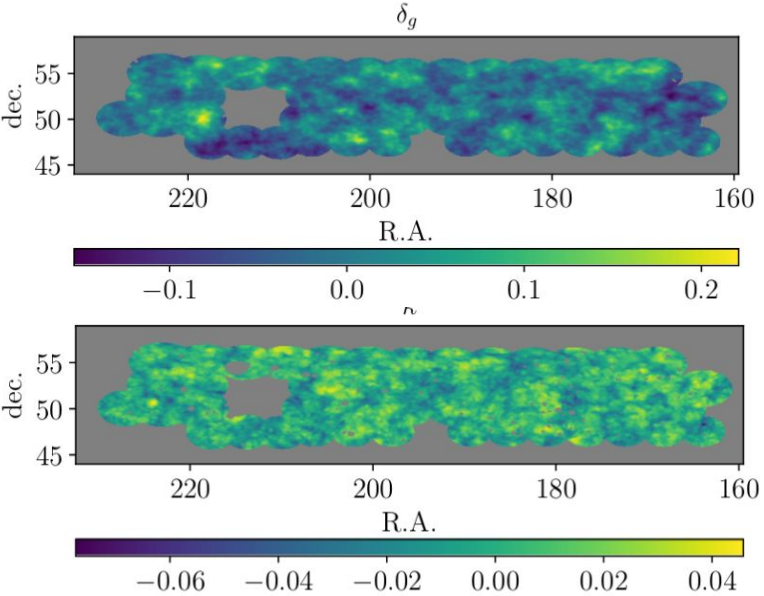
- Power-law unless you're willing to resolve HI.
- HI surveys: spec-z but shallow.
- Intensity mapping (integrate over area): spec-z but foregrounds.
- Continuum surveys (integrate over freq.): super deep, but no z!

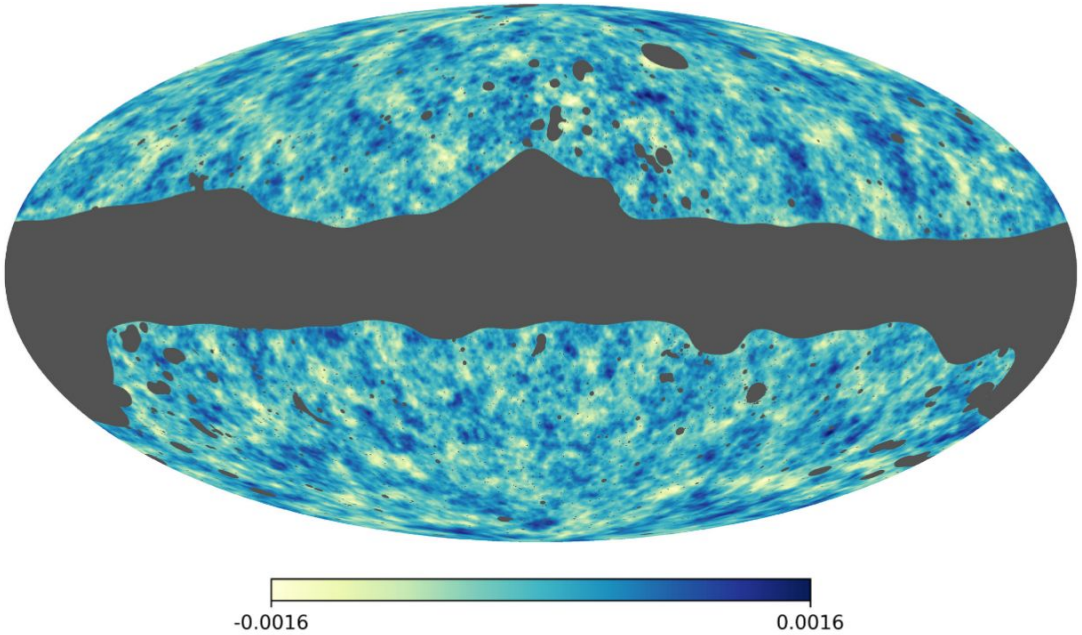


Continuum surveys:

- Great to trace structure over huge volumes (*Siewert et al. 2019*, *Hale et al. 2017*, *Nusser et al. 2015*, *Lindsay et al. 2014*)
- Can be good for measuring f_{NL} (*Ferramacho et al. 2014*, *DA et al. 2015*)
- Good radial overlap with CMB lensing (*Allison et al. 2015*)

CMB lensing from Planck



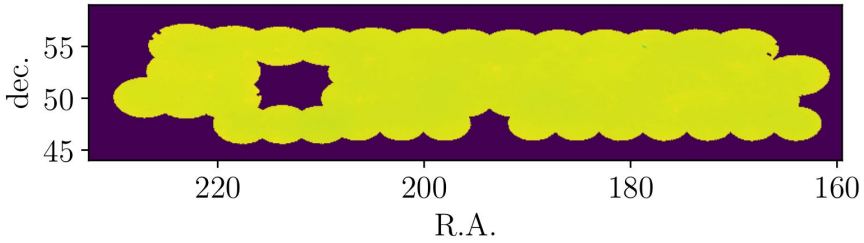


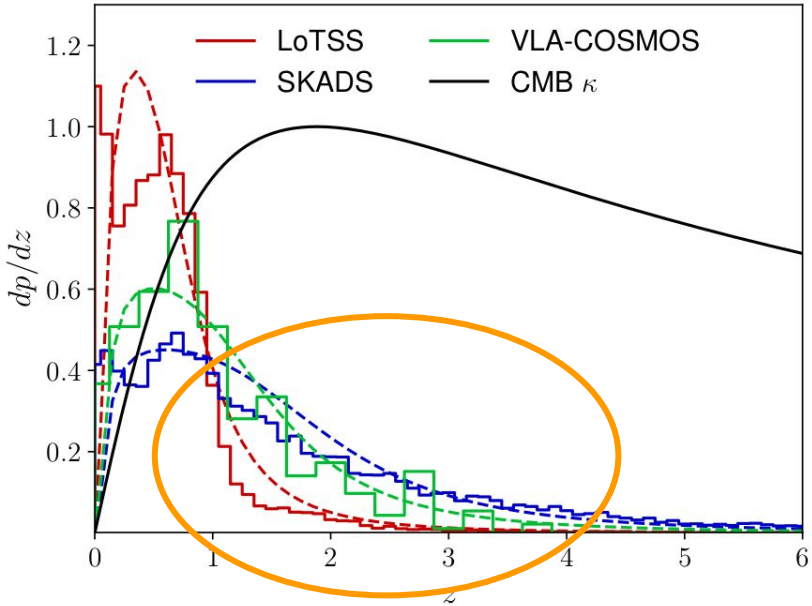
Presented in Planck 2018 (VIII).

- Minimum-variance estimator (Carron & Lewis 2017).
- Different flavours of map and mask publicly available.

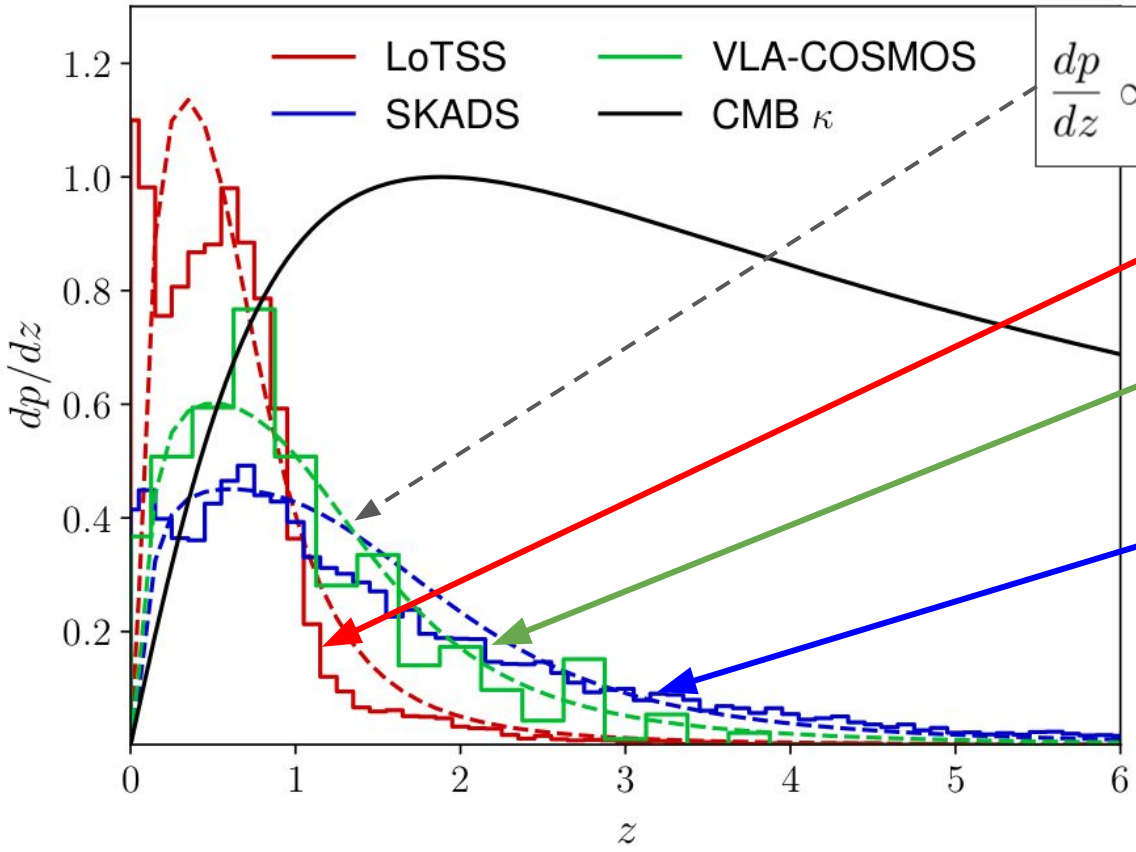
The LOFAR Two-metre Sky Survey

- Cont. Survey at ~150 MHz.
- DR1: ~424 deg2, ~320k objects @ I > 2mJy (as in Siewert et al.)
- Photo-zs from PanSTARRs matches (++)
- Large uncertainties over high-redshift tail.
- Think of a faint LSST sample with bad photo-zs and lots of outliers.
- Good overlap with CMB-κ kernel.





Redshift distributions



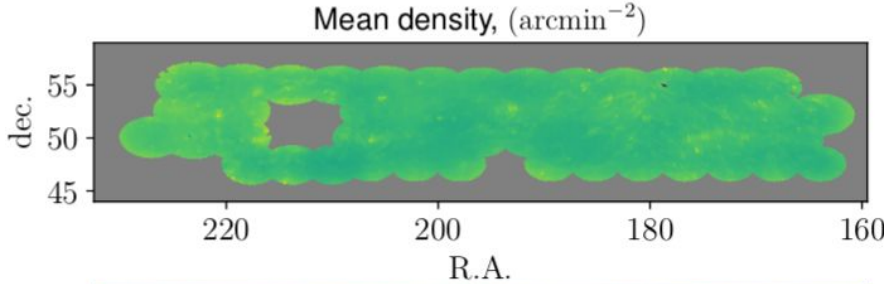
Direct measurement from PanSTARRs photo-zs.

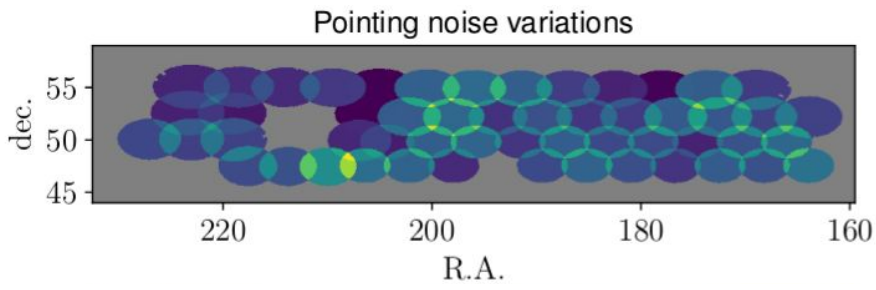
Spec-z data from COSMOS field (different sample, ~500 galaxies).

Prediction from SKA simulation (S-cubed).

Analysis choices and tools: data analysis

- We use harmonic-space power spectra (C_ℓ). Advantages:
  a) Simpler covariance matrix and scale cuts
  b) Potentially faster than correlation functions.
- **NaMaster:** public pseudo-C_ℓ code (DA et al. 2018). Most complete public power spectrum estimator in the market. https://github.com/LSSTDESC/NaMaster.
- Mean density (aka “randoms” in real space) calculated analytically from noise rms fluctuations. Equivalent to the method used in Siewert et al. This should probably be improved.
- Systematics deprojected at the map level: pointing noise variations and mean density map. A more complete census would be great for DR2.
- Analytical covariance matrix accounting for mode-coupling (also in NaMaster - Garcia-Garcia et al. 2019).





Analysis choices and tools: theory

- CMB convergence and galaxy clustering trace the projected matter density fluctuations:

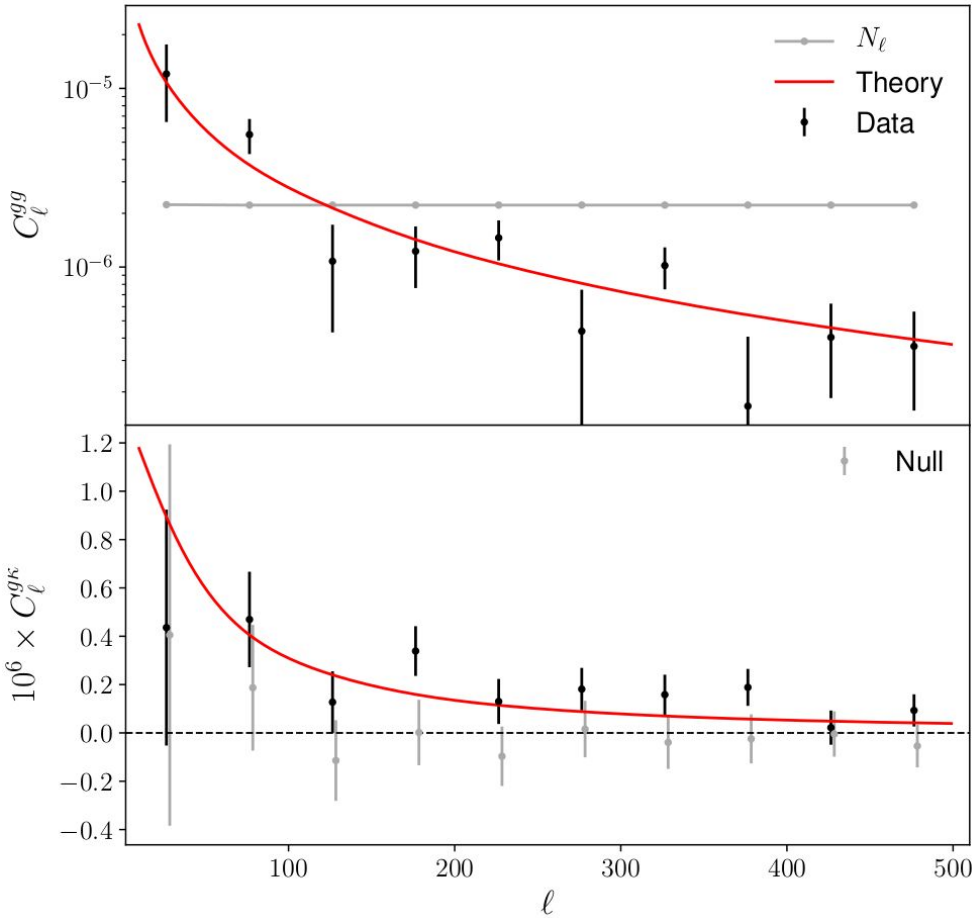
$$\delta_g(\hat{\mathbf{n}}) = \int dz \frac{dp}{dz} \Delta_g(\chi(z)\hat{\mathbf{n}}, z) \qquad \kappa(\hat{\mathbf{n}}) = \int_0^{\chi_{\rm LSS}} d\chi \frac{3H_0^2\Omega_m}{2a} \chi \frac{\chi_{\rm LSS} - \chi}{\chi_{\rm LSS}} \Delta_m(\chi\hat{\mathbf{n}}, z(\chi))$$

- The angular power spectrum is related to the 3D matter power spectrum via a line-of-sight (Limber) integral.

$$C_\ell^{uv} = \int \frac{d\chi}{\chi^2} W_u(\chi) W_v(\chi) P_{UV}\left(k = \frac{\ell + 1/2}{\chi}, z(\chi)\right)$$

- We use the **Core Cosmology Library** (Chisari, DA et al. 2019).
  - Developed within LSST DESC: https://github.com/LSSTDESC/CCL.
  - Public and open source.
  - Able to compute C_ℓs between many different tracers (as well as many other observables).
  - Supports most observables targetted by DR2 papers (clustering, ISW, CMB lensing, HOD modelling etc.).

CMB-κ cross-correlation

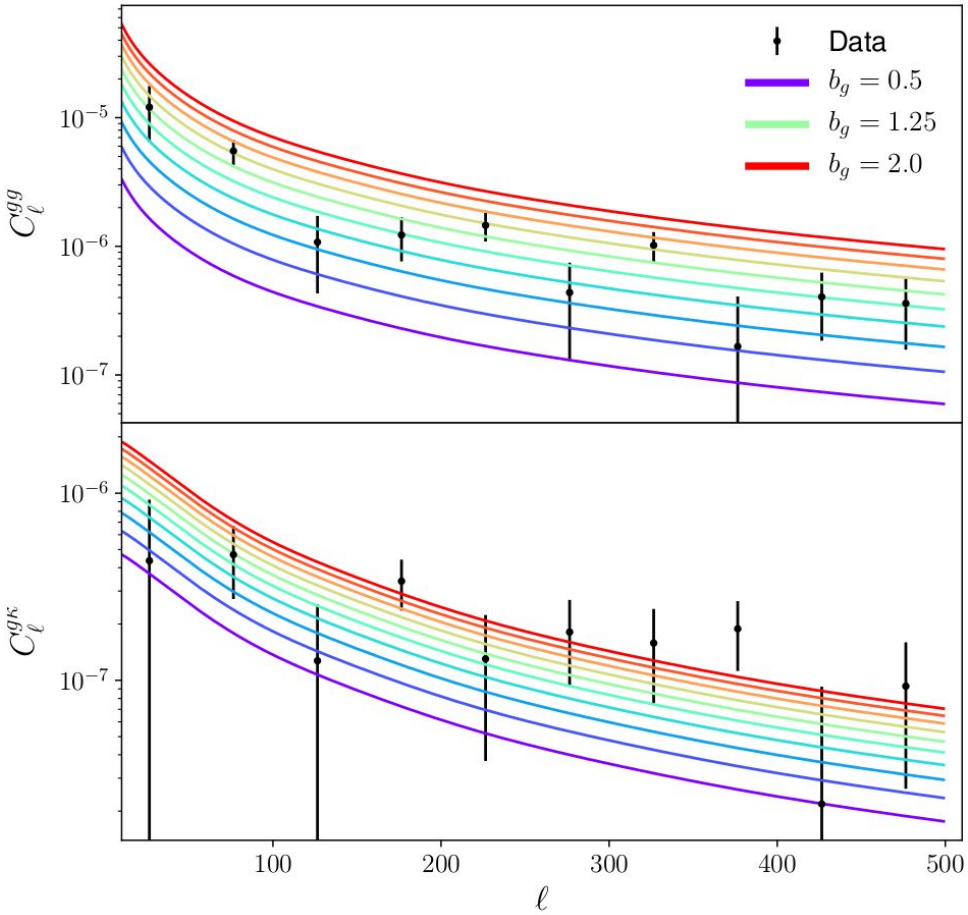


~ 5σ detection of x-correlation.

Main factors affecting g-g and g-κ amplitudes:

- Galaxy bias
- N(z) width/tail.
- σ_8

CMB-κ cross-correlation



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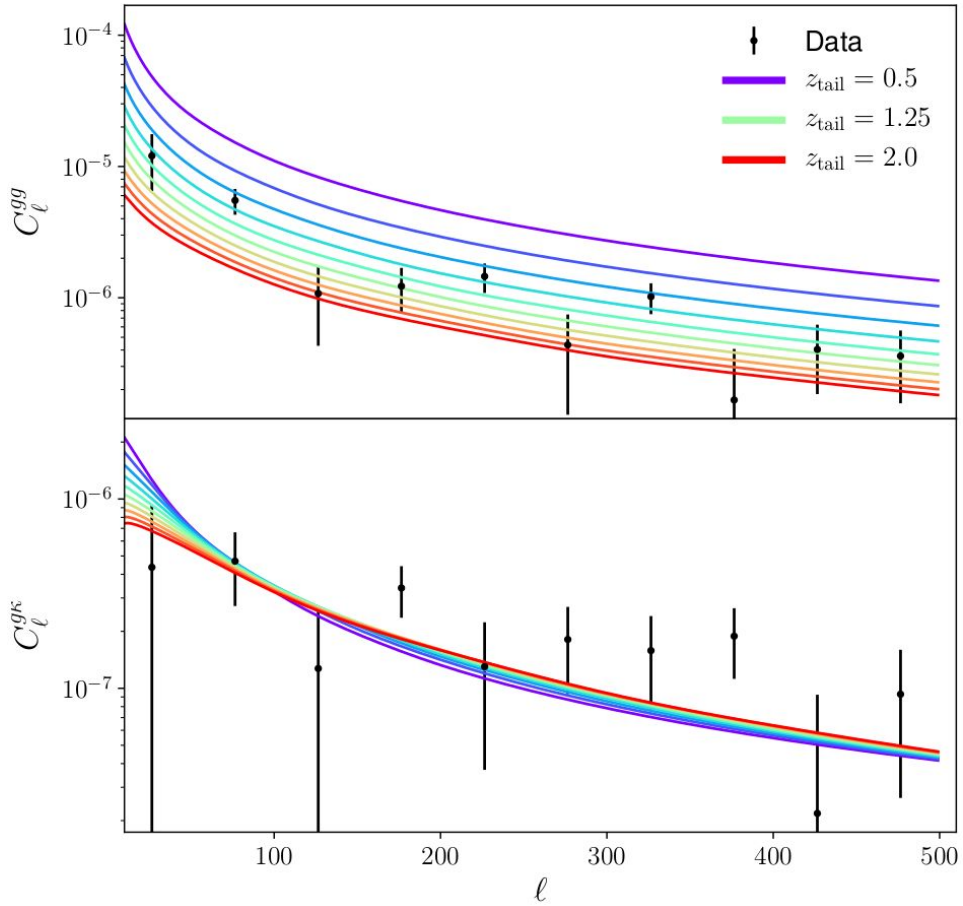


~ 5σ detection of x-correlation.

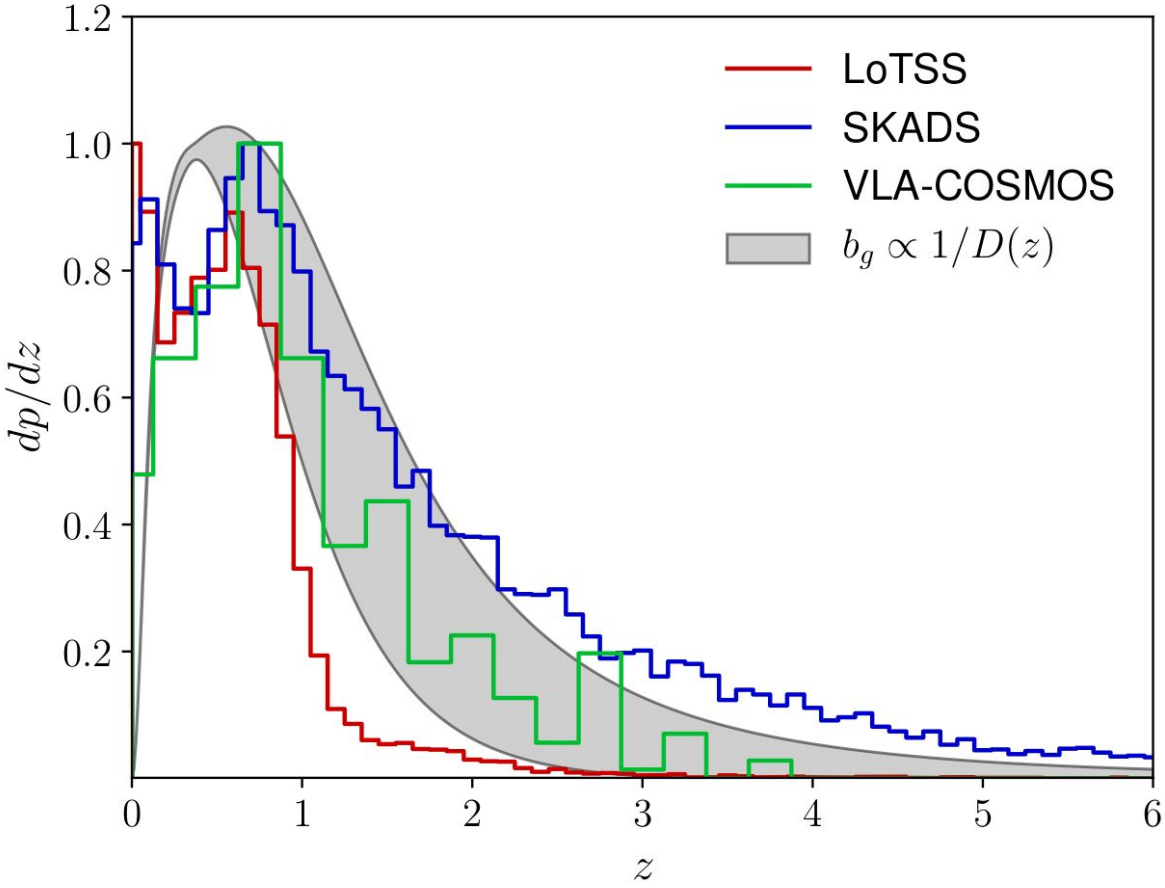
Main factors affecting g-g and g-κ amplitudes:

- Galaxy bias
- **N(z) width/tail.**
- σ_8

You can constrain z_{tail}!

Also, CMB-κ x-corr quite insensitive to width-like systematics.

N(z) tail constraints



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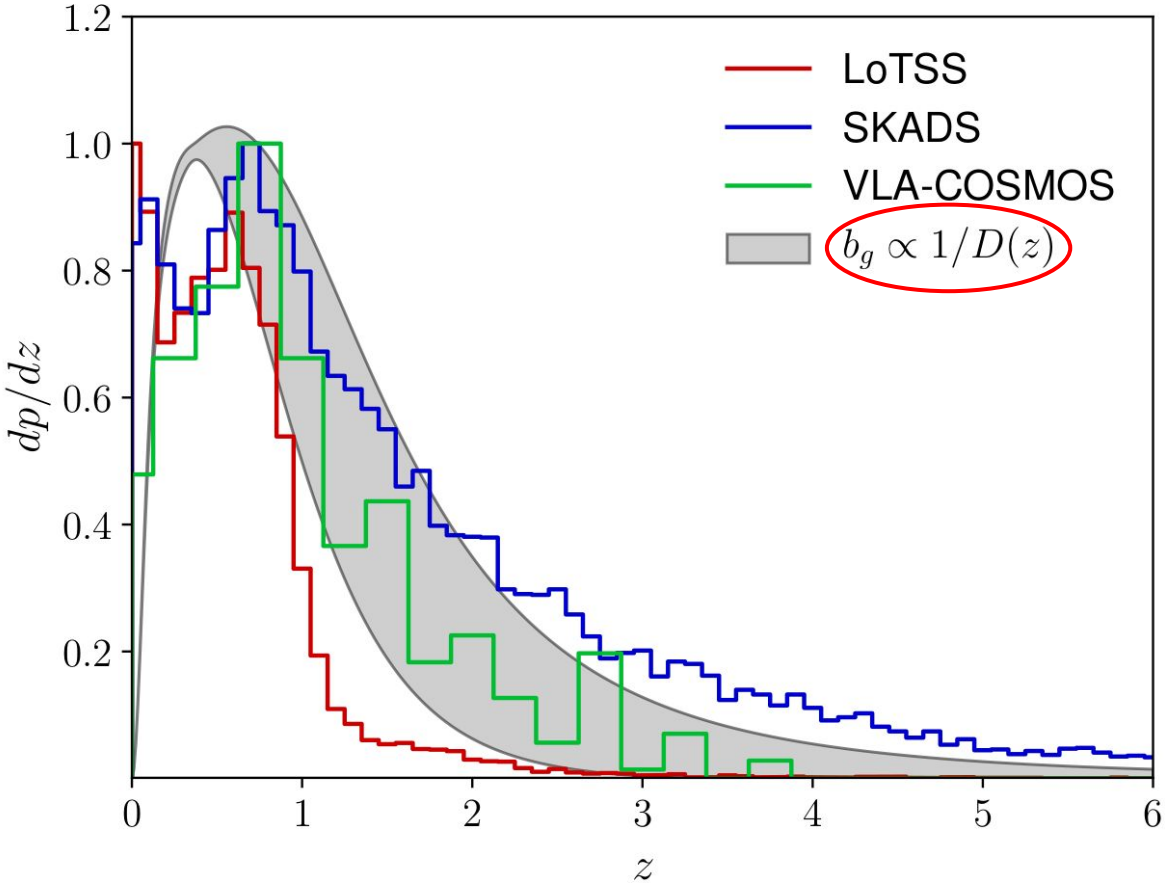
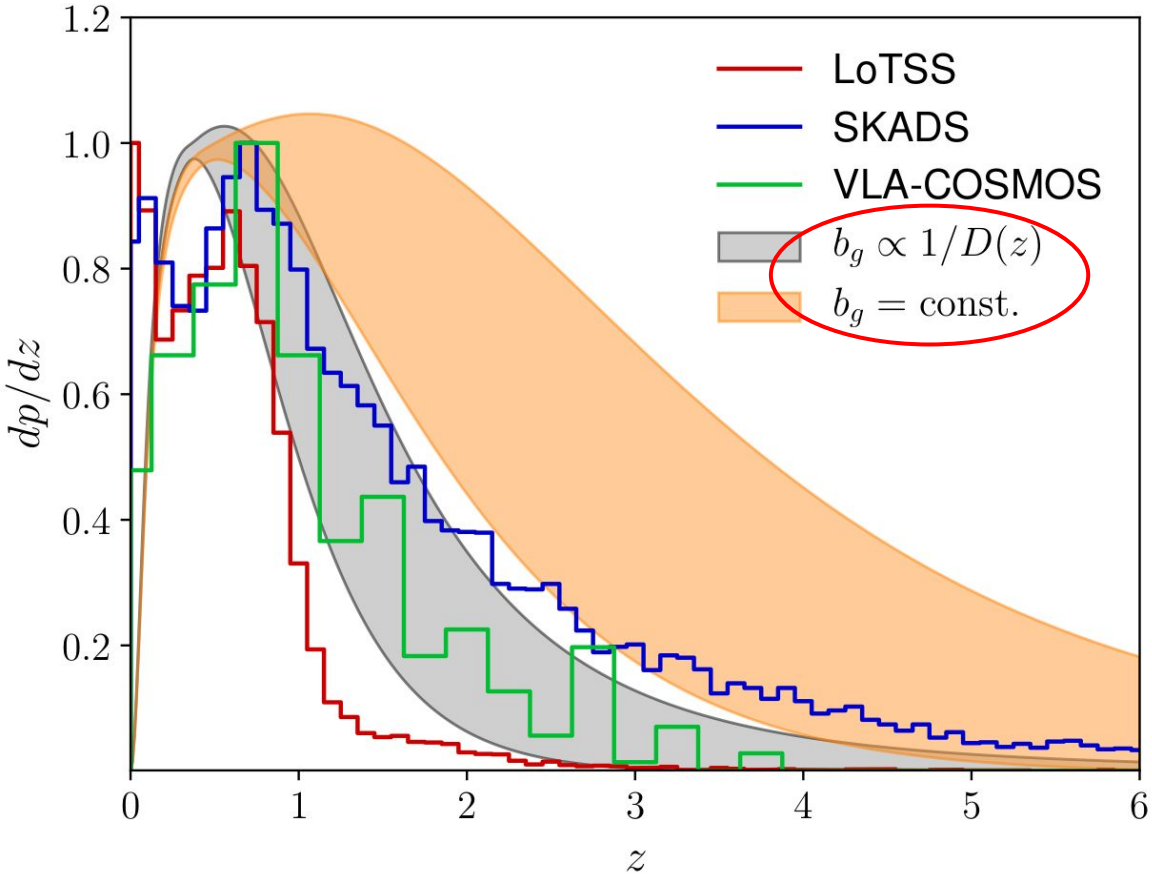


N(z) tail constraints

Constraints depend on bias evolution.

Short tails predicted by photo-zs **disfavoured** in all cases.

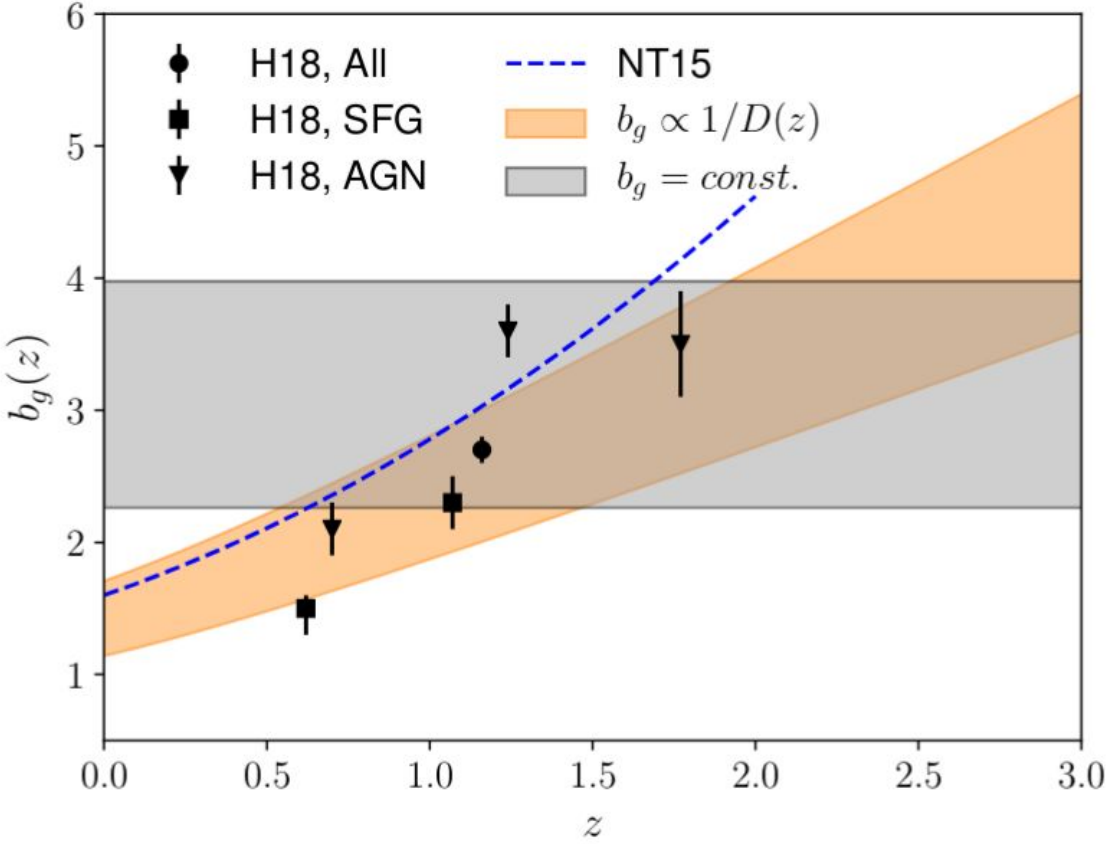


Bias constraints

Constraint on b depends on assumed N(z).

Assuming VLA-COSMOS:
b(z) = (1.8±0.1)/D(z)

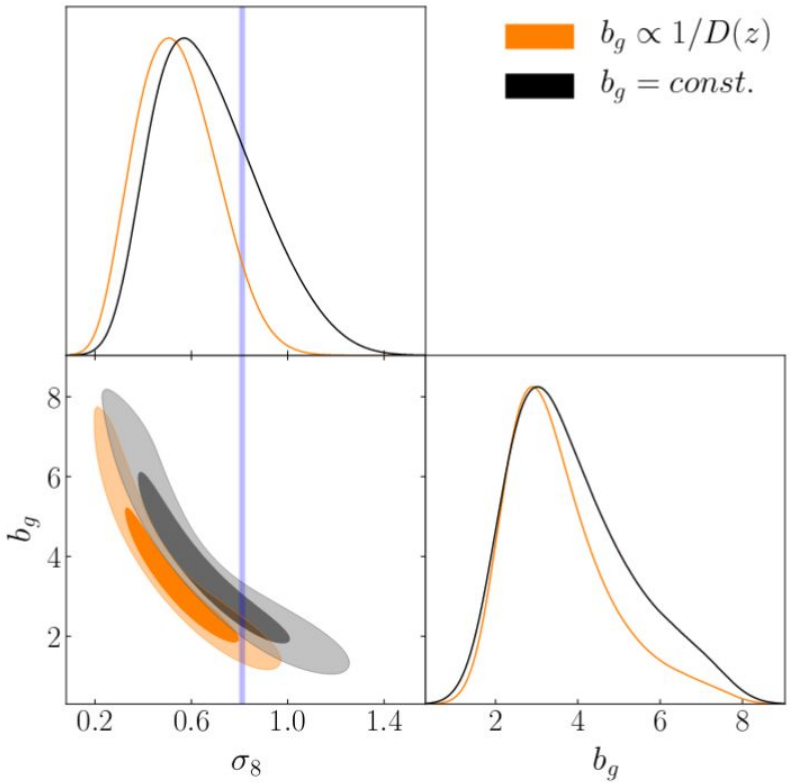
With CMB lensing we can explore the degeneracy with N(z).



Cosmology constraints

We can’t constrain 3 parameters (b, z_{tail}, σ_8) with 2 power spectra (g-g, g-κ).

Assuming the SKADS N(z):



Summary


Nick Koukoufilippas

This analysis:

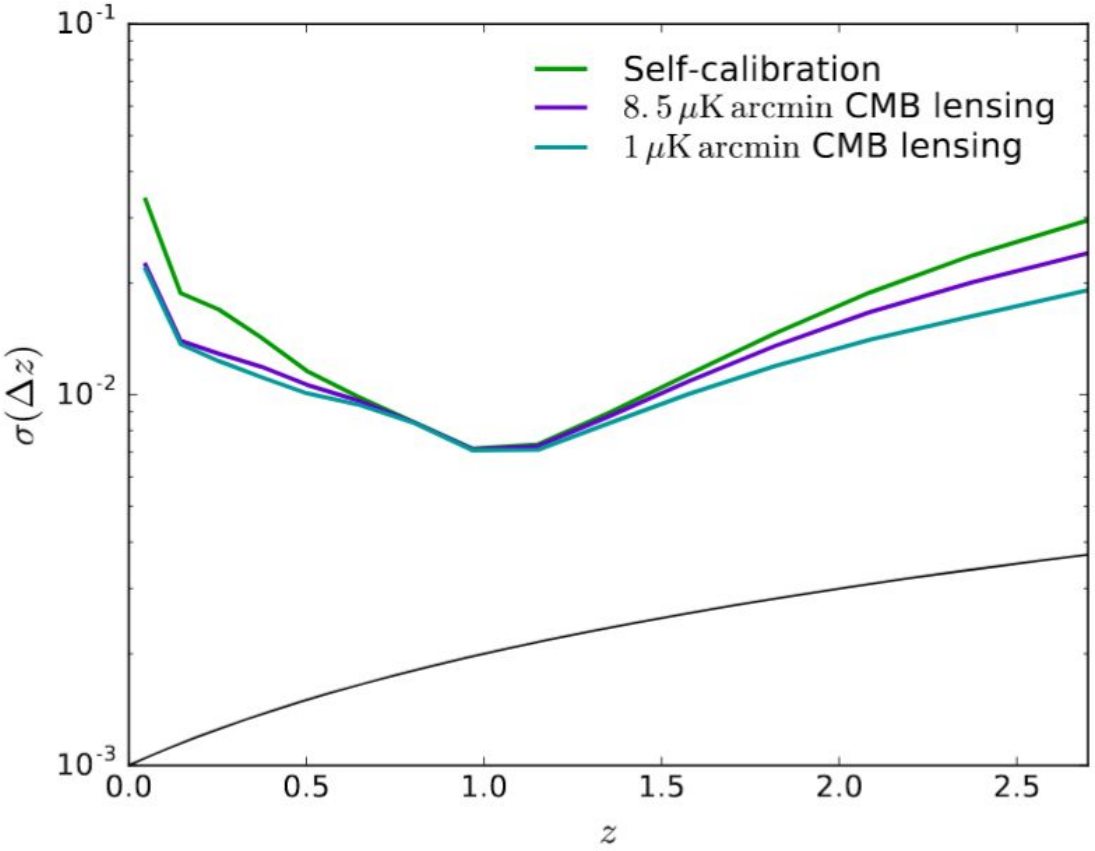
- 5s detection of cross-correlation with CMB lensing. Only 400 deg2!
- CMB x-correlation is almost insensitive to N(z) tail/width.
  -> We can use it to constrain it!
- Harder tails than that implied by PanSTARRs are preferred.
  Compatible with VLA-COSMOS or SKADS.
- We can measure 2 out of (ztail, bg, s8): need priors on N(z) to break the degeneracy!
- We can make a poor man's measurement of s8.

Thoughts on DR2:

- Let's not reinvent the wheel on standard calculations (power spectra, covariances, theory calculations).
- Need improvements on flux distribution, noise statistics, completeness estimation.
- Need a better census of systematics that can affect source detection.
- We should explore other CMB lensing datasets (e.g. ACT) and try going to smaller scales.

Thanks!

Shifts



DA et al. arXiv:1704.01941