Cross-correlating the EMU Pilot Survey 1 with CMB lensing: Constraints on cosmology and galaxy bias with harmonic-space power spectra

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EMU Pilot Survey 1

- Using ASKAP at 944MHz, covering a contiguous patch of ~270 sq.deg, at a depth of 25-30 μJy/beam rms and with spatial resolution of 11-18 arcsec
- By the end of EMU, 70 million galaxies will be detected in the whole southern sky covered up to +30 deg. in declination. The total sky coverage will be ~30,000 sq.deg, ideal for ultra large-scale cosmology (relativistic effects and primordial Non-Gaussianity)

EMU Pilot Survey I

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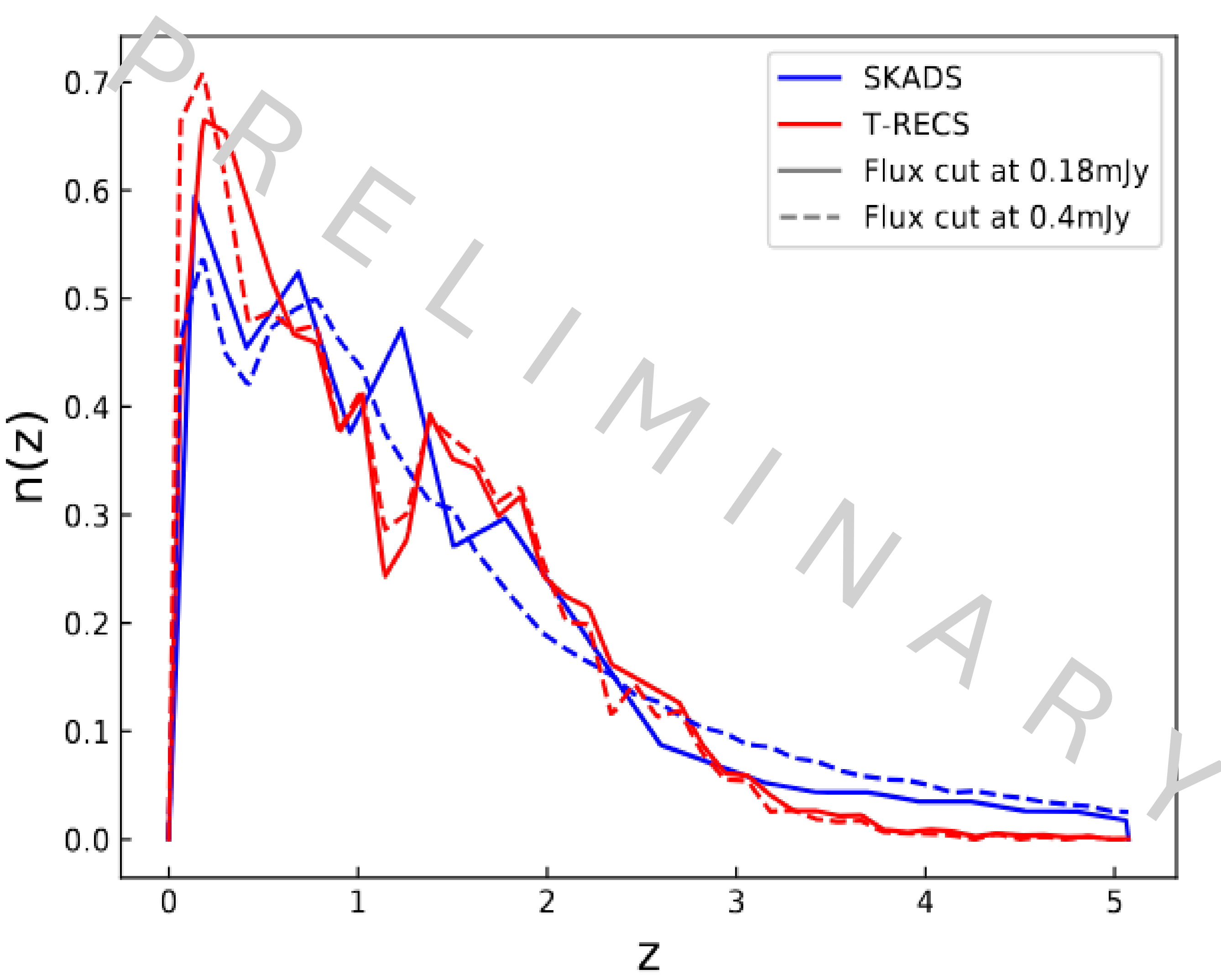
- Featureless, smooth power-law spectrum, w/o sharp features; redshift information unfeasible leading to large uncertainties on the redshift distribution of galaxy sample and its properties like the galaxy bias and halo mass

- Radio galaxy populations: AGN and SFG



Limber approximated harmonic-space power spectra

$$S_{\ell,\mathrm{th}}^{XY} = \int \frac{\mathrm{d}\chi}{\chi^2} W^X(\ell,\chi)\, W^Y(\ell,\chi)\, P_{mm}\left(k = \frac{\ell + 1/2}{\chi}, \chi\right)$$

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Galaxy number counts:

$$\delta_g(\hat{n}) = \int b(\chi) n(\chi) \delta_m(z(\chi), \chi\hat{n})$$

$$W^{\delta_g}(\ell,\chi) \equiv W^{\delta_g}(\chi) = n(\chi) b(\chi)$$

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- Lifts degeneracy between the galaxy bias and the amplitude of the matter fluctuations

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Convergence:

$$\kappa(\hat{n}) = \int_0^{\chi^\star} d\chi \frac{3\Omega_{\mathrm{m},0}H_0^2}{2c^2}[1+z(\chi)]\chi\frac{\chi^\star-\chi}{\chi^\star}\delta_m(z(\chi),\chi\hat{n})$$

$$W^\kappa(\ell,\chi) = L(\ell)\frac{3\Omega_m H_0^2}{2c^2}[1+z(\chi)]\chi\frac{\chi^\star-\chi}{\chi^\star}$$

$$L(\ell) = \frac{\ell(\ell+1)}{(\ell+1/2)^2}$$

Detection algorithms

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- Apply two flux cuts:

-0.18mJy: 166,801 and 188,034 objects

-0.4mJy: 83,222 and 89,320 objects

- Overdensity

$$\delta_g(\hat{n}) = \frac{N_g(\hat{n})}{\bar{N}_g w_g(\hat{n})} - 1$$

$$\bar{N}_g = \langle N_g(\hat{n}) \rangle_n / \langle w_g(\hat{n}) \rangle_n$$

Set to 0 pixels with

$$w_g(\hat{n}) < 0.5.$$

Maps

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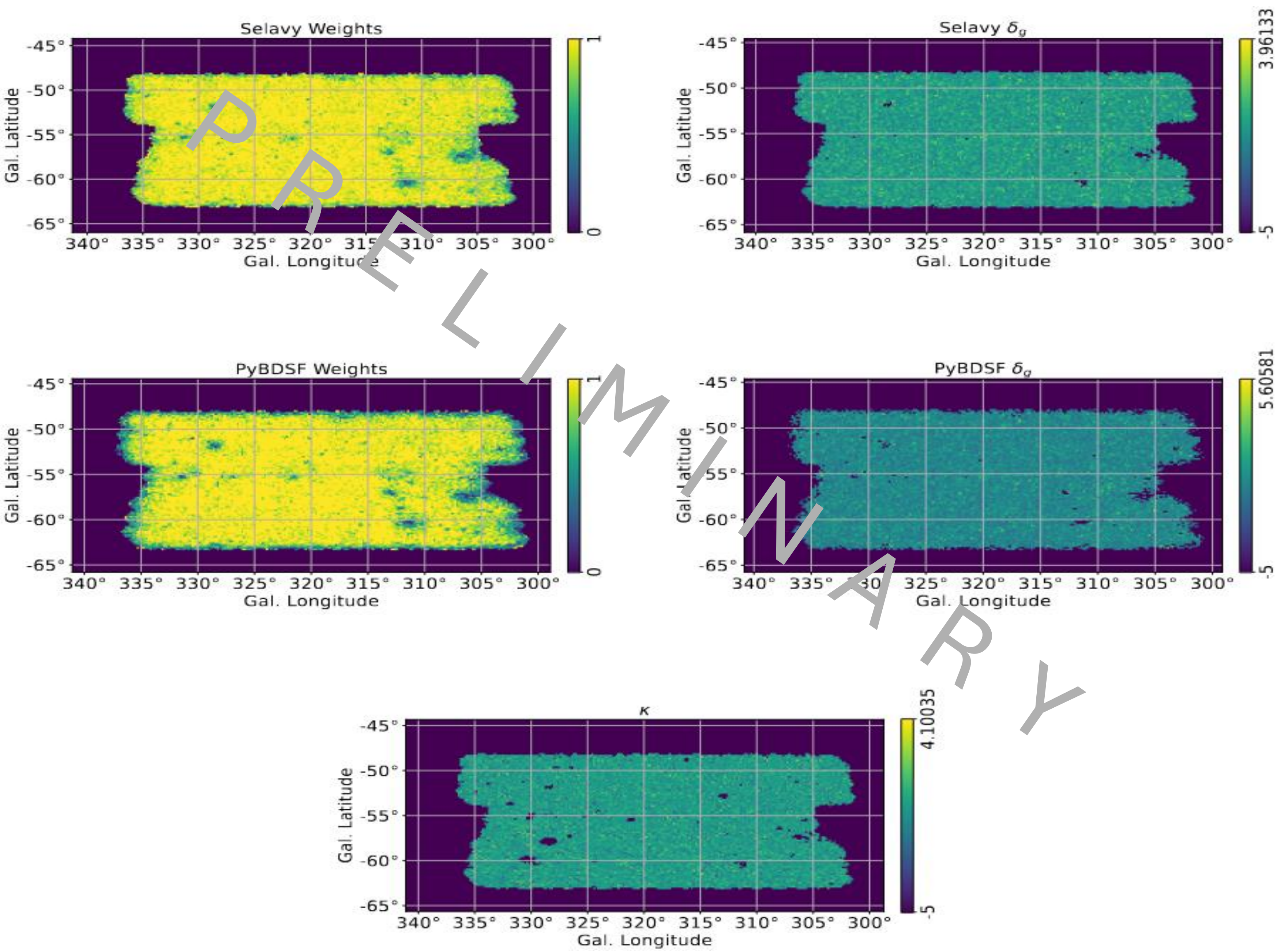
- Planck PR4 convergence data

- Calculate pseudo-Cls accounting for the effect of the masks



Gaussian covariance and log-likelihood

$$\mathrm{Cov} = \begin{bmatrix} \mathrm{Cov}^{gg,gg} & \mathrm{Cov}^{gg,g\kappa} \\ (\mathrm{Cov}^{gg,g\kappa})^T & \mathrm{Cov}^{g\kappa,g\kappa} \end{bmatrix}$$

$$\mathrm{Cov}^{gX,gY}_{\ell\ell'} = \frac{\delta_{\ell\ell'}}{(2\ell+1)\Delta\ell f_{\rm sky}^{gX,gY}}[(\tilde{C}^{gg}_\ell + N^{gg}_\ell)(\tilde{C}^{XY}_{\ell'} + N^{XY}_{\ell'}) + (\tilde{C}^{gX}_\ell + N^{gX}_\ell)(\tilde{C}^{gY}_{\ell'} + N^{gY}_{\ell'})],$$

$$f_{\rm sky}^{gX,gY} = \sqrt{f_{\rm sky}^{gX} \cdot f_{\rm sky}^{gY}} \qquad f_{\rm sky}^{gg} \approx f_{\rm sky}^{g\kappa}.$$

$$\chi^2(\boldsymbol{q}) = \sum_{\ell,\ell'} [\boldsymbol{d}_\ell - \boldsymbol{t}_\ell(\boldsymbol{q})]^T \mathrm{Cov}^{-1}_{\ell\ell'} [\boldsymbol{d}_\ell - \boldsymbol{t}_\ell(\boldsymbol{q})]$$

$$\boldsymbol{d}_\ell = \{\tilde{C}^{gg}_\ell, \tilde{C}^{g\kappa}_\ell\} \text{ and } \boldsymbol{t}_\ell = \{\tilde{S}^{gg}_\ell, \tilde{S}^{g\kappa}_\ell\}$$

Methodology

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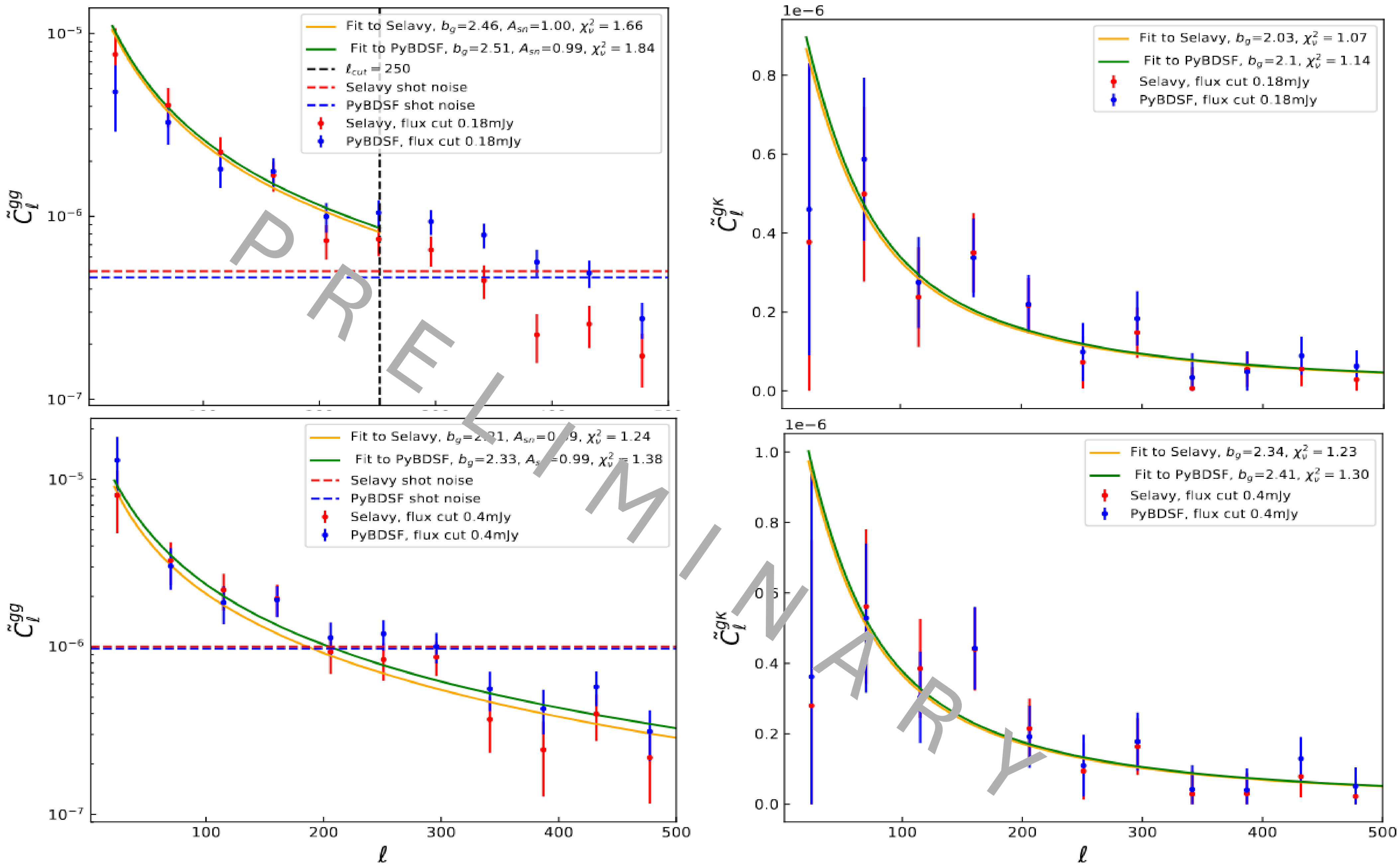
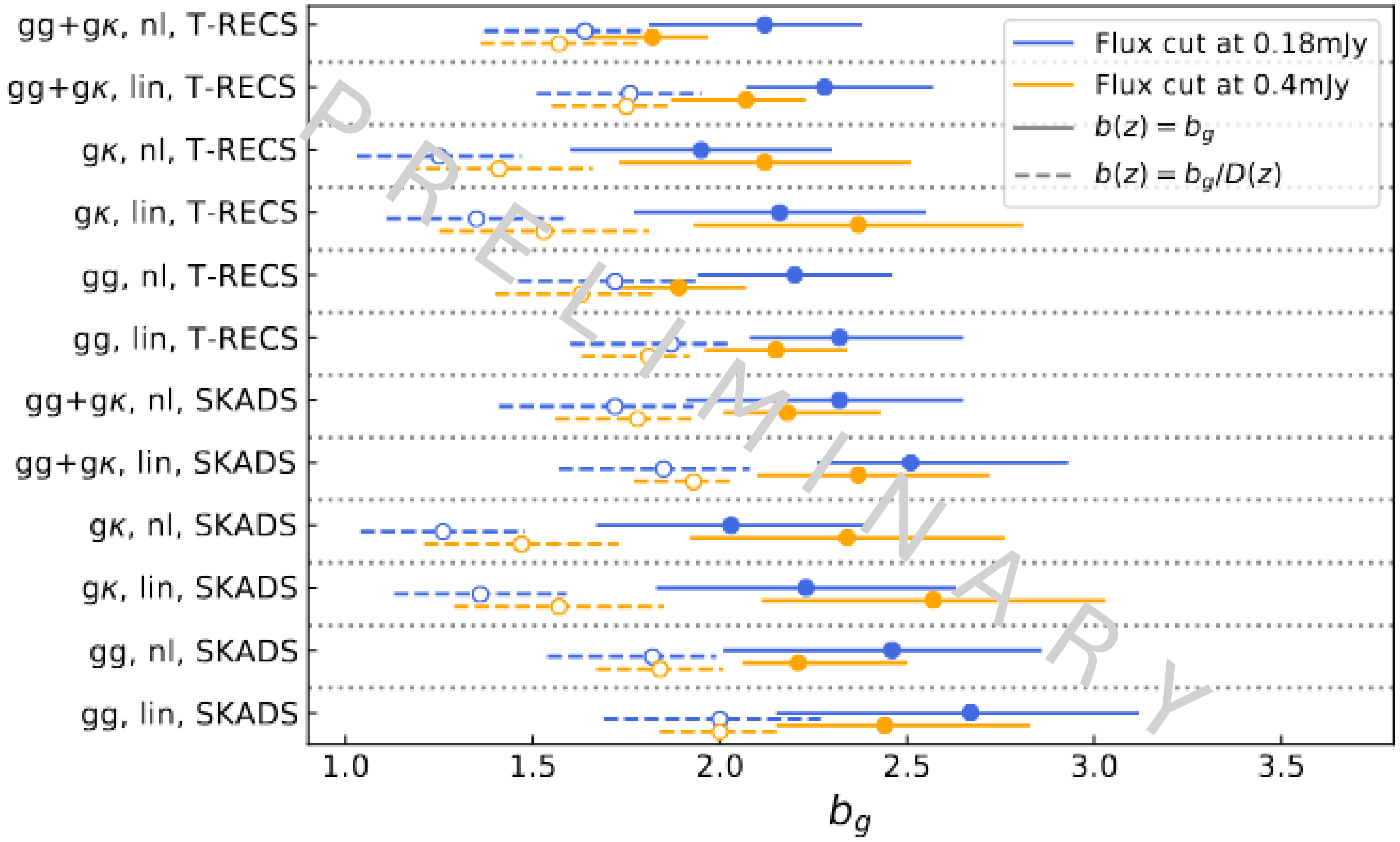
- Consider scales from l=2 to 500 (corresponding to kmax=0.15 Mpc^-1 at z~1, after which linear galaxy models no longer hold)

- Add an extra nuisance amplitude parameter to account for deviations from shot noise (contributions from multi-components, halo exclusion, non-local and stohastic effects in galaxy formation)

Cross-correlation significance ~5.4σ



Galaxy bias constraints (fixed cosmology)



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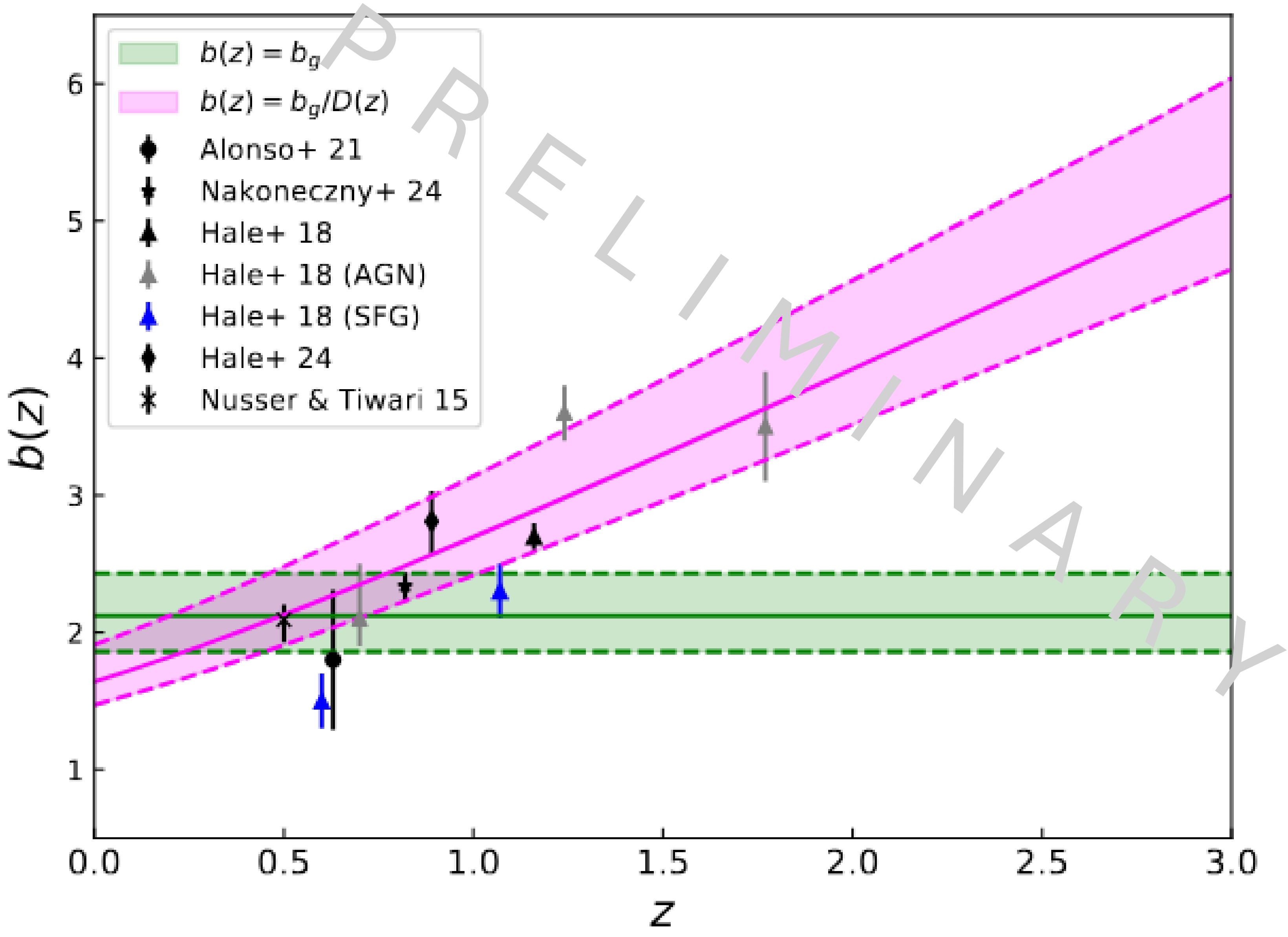
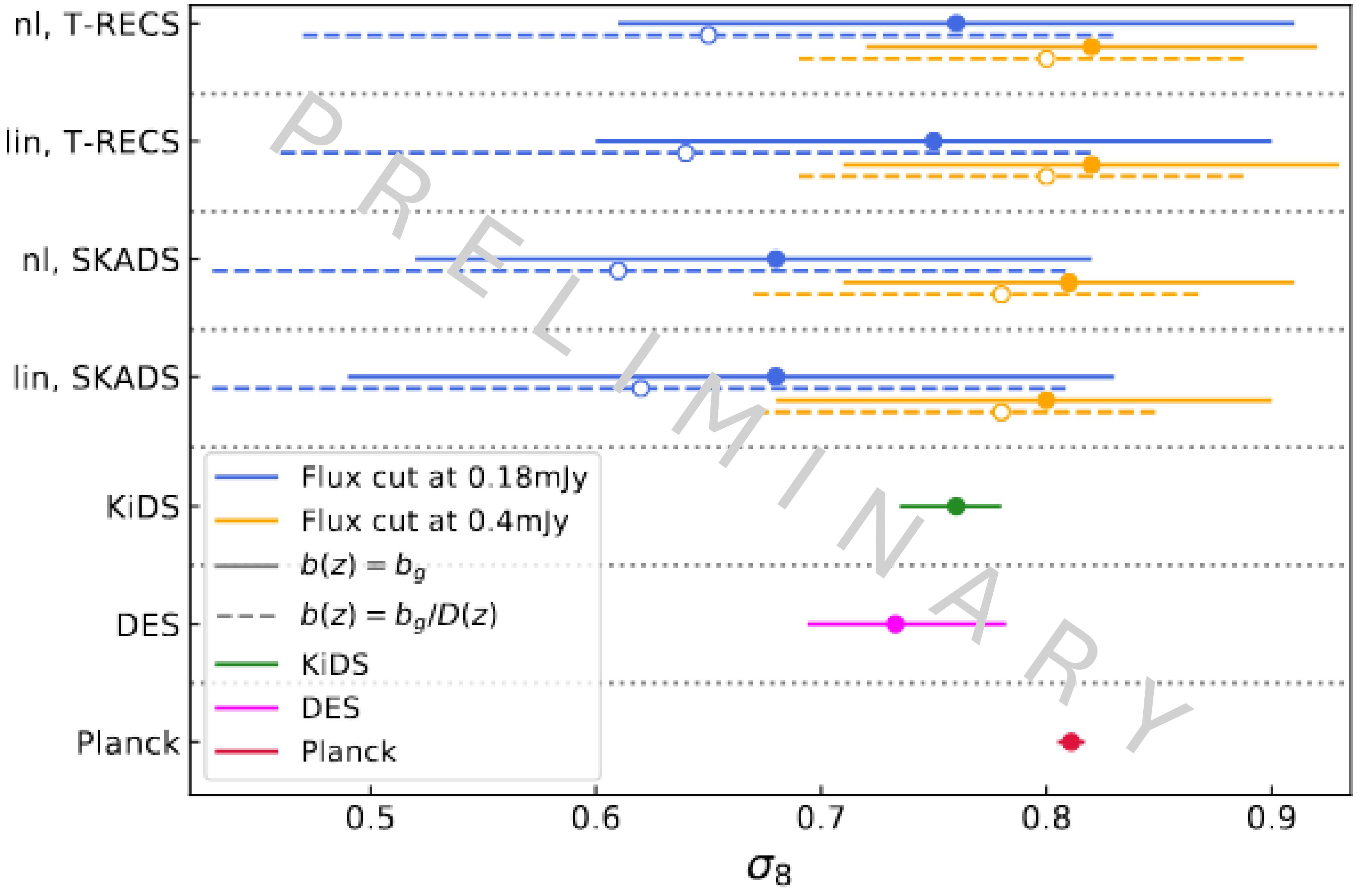
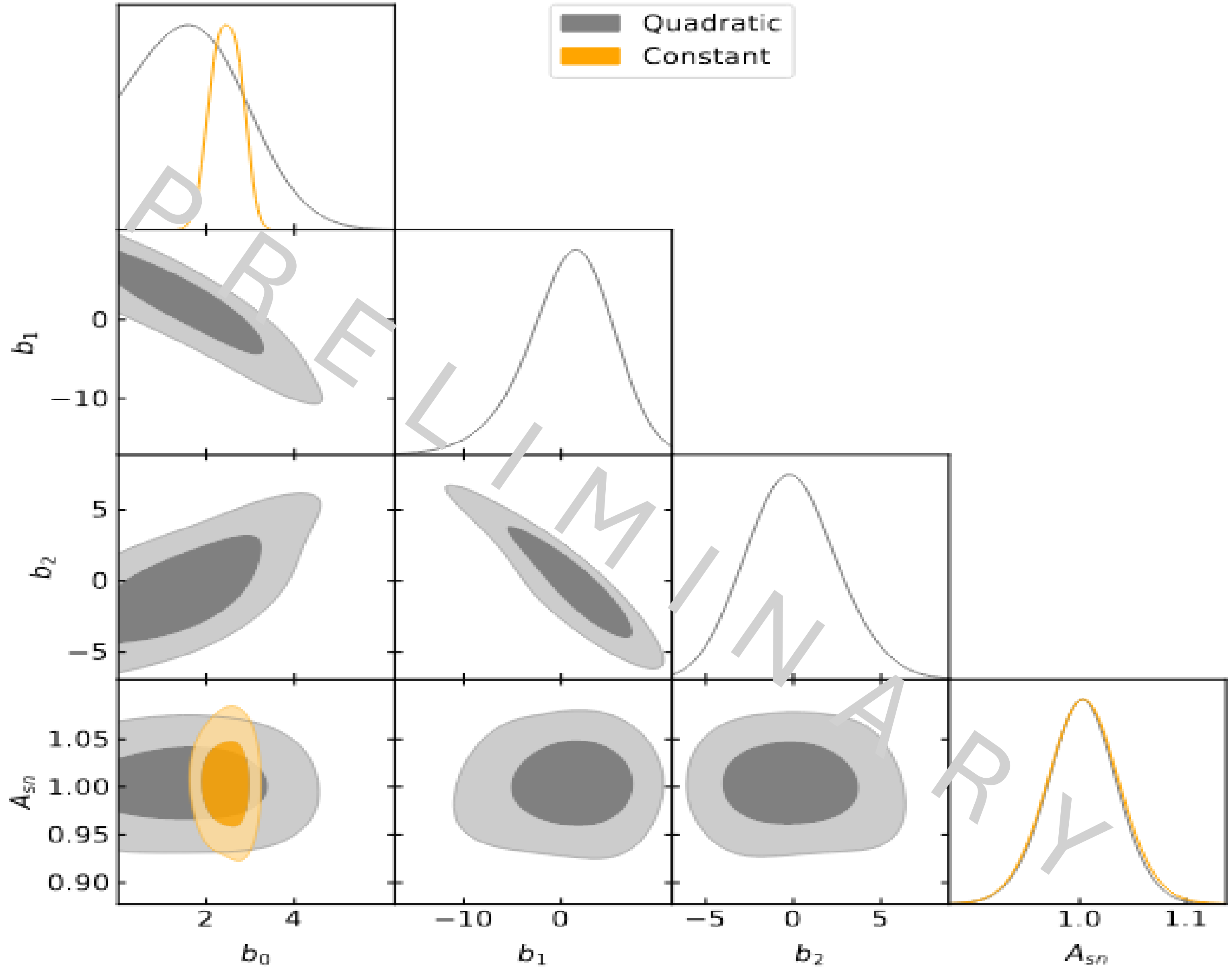


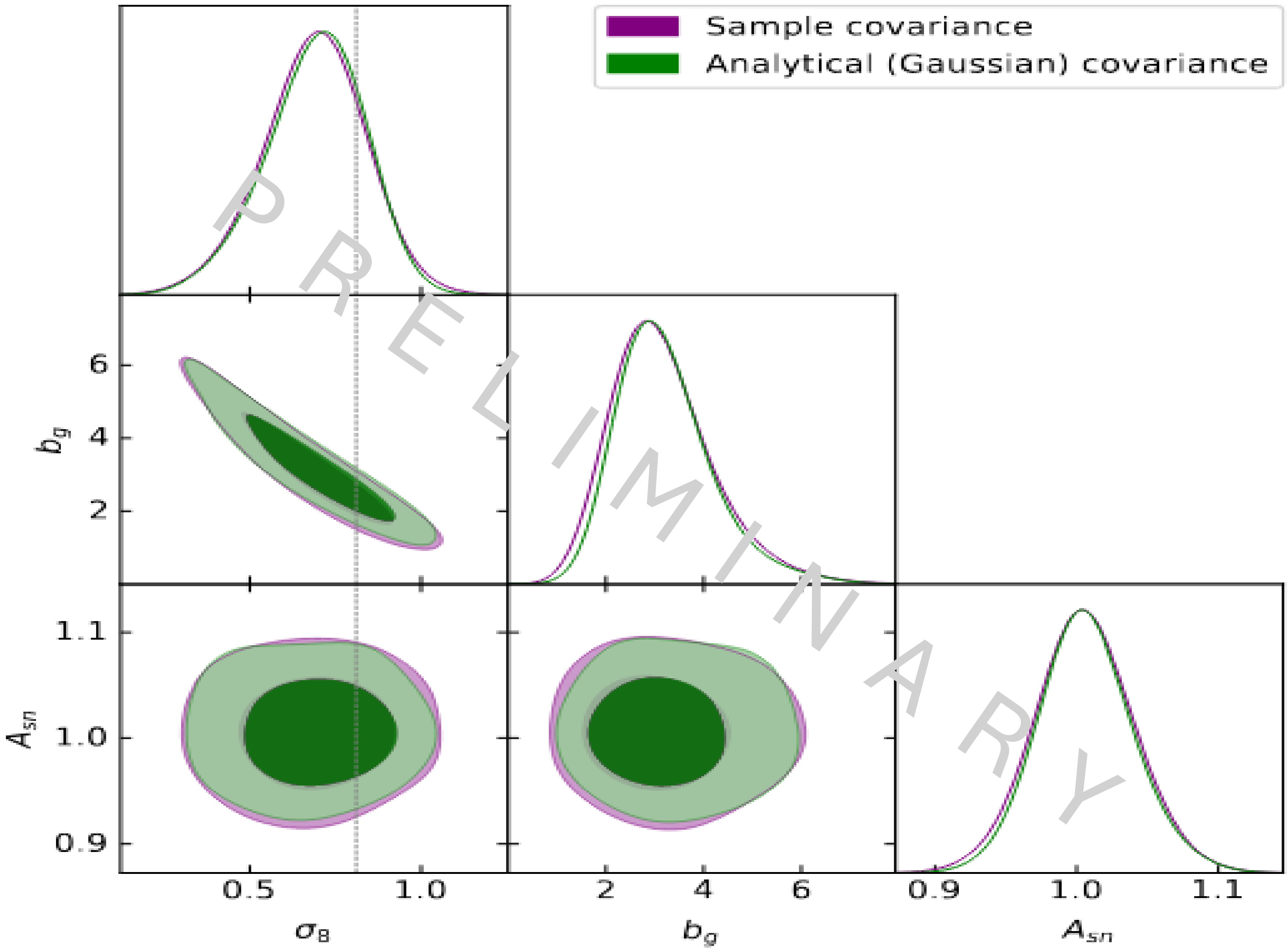
Cosmology constraints



Quadratic galaxy bias: $b(z) = b_0 + b_1 z + b_2 z^2$



Comparison with numerical covariance



Conclusions

- Analysed the EMU PS1 data using the harmonic-space power spectra
- Considered two catalogues for the measurements, Selavy and PyBDSF, and saw differences after $l \sim 250$ depending on the flux cut
- Detected cross-correlation with CMB lensing with SNR$\sim$5.4
- Constrained the galaxy bias and $\sigma 8$ using different flux cuts, a linear and HALOFIT power spectrum and assuming the SKADS and T-RECS redshift distributions for a constant bias and a constant amplitude model

Thank you!

Back-up slides

Numerical covariance using GLASS

$$\mathrm{Cov}_{\ell\ell'}^{WX,YZ} = \frac{1}{N_m - 1} \sum_{m=1}^{N_m} \left(\tilde{C}_\ell^{WX,m} - \left\langle \tilde{C}_\ell^{WX} \right\rangle \right) \left(\tilde{C}_\ell^{YZ,m} - \left\langle \tilde{C}_\ell^{YZ} \right\rangle \right)$$

$$\left\langle \tilde{C}_\ell^{WX} \right\rangle = \frac{1}{N_m} \sum_{m=1}^{N_m} \tilde{C}_\ell^{WX,m}$$

$$\mathrm{Cov}^{-1} \rightarrow \frac{N_m - N_d - 2}{N_m - 2} \mathrm{Cov}^{-1}$$

2D corner plots