Cross-correlation of Planck CMB lensing with DESI galaxy groups

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Introduction

- CMB lensing: secondary anisotropy of CMB
  - deflect the paths of photons
  - integral of all deflections sourced by the large-scale-structure
- Advantages of cross-correlation
  - immune to certain systematics in auto-correlation
  - LSS provide essential information: redshift information
- Progress in our study
  - galaxy groups: better photo-z, estimation of halo mass
  - directly compare the measured group bias with theory
  - improved S/N by a factor $\gtrsim 5$
  - wide sky coverage $\sim 16900\ \mathrm{deg}^2\ (40\%)$

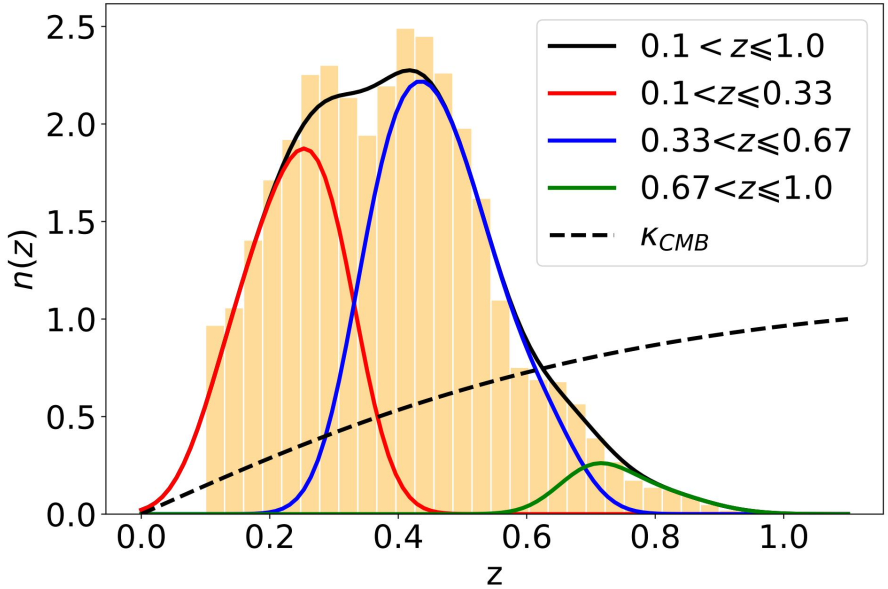
Theoretical background

- galaxy group overdensity × CMB lensing convergence

$$C_\ell^{\kappa g} = \int d\chi W^\kappa(\chi) W^g(\chi) \frac{1}{\chi^2} P_{mg}\left(k = \frac{\ell + 1/2}{\chi}; z\right)$$

$$W^\kappa(z) = \frac{3}{2c}\Omega_{m0}\frac{H_0^2}{H(z)}(1+z)\frac{\chi(\chi_* - \chi)}{\chi_*} = \frac{c}{H(z)} W^\kappa(\chi)$$

$$W^g(z) = n(z) = \frac{c}{H(z)} W^g(\chi)$$



- assume bg is scale-independent

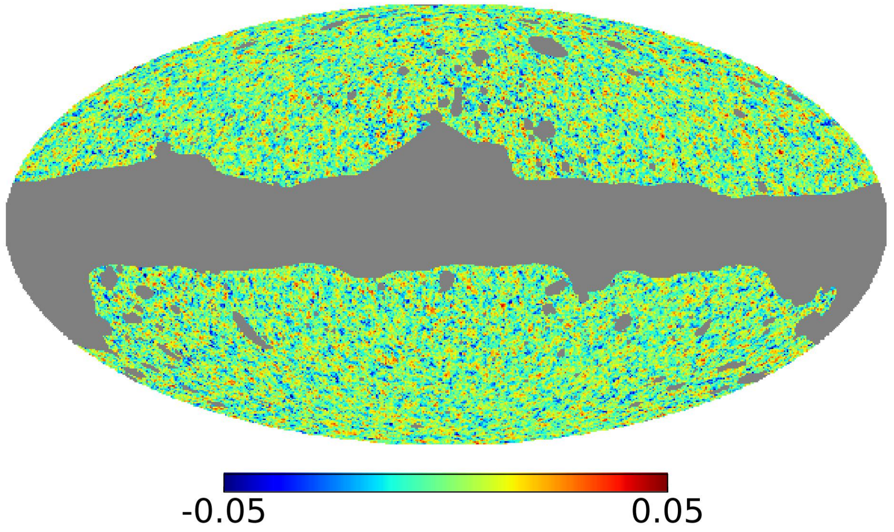
$$b_g \equiv P_{mg}/P_{mm}$$

Cross-correlation measurement

$$C_\ell^{\kappa g} = \frac{1}{2\ell+1} \sum_{m=-\ell}^{\ell} \delta_{\ell m} \kappa^*_{\ell m}$$

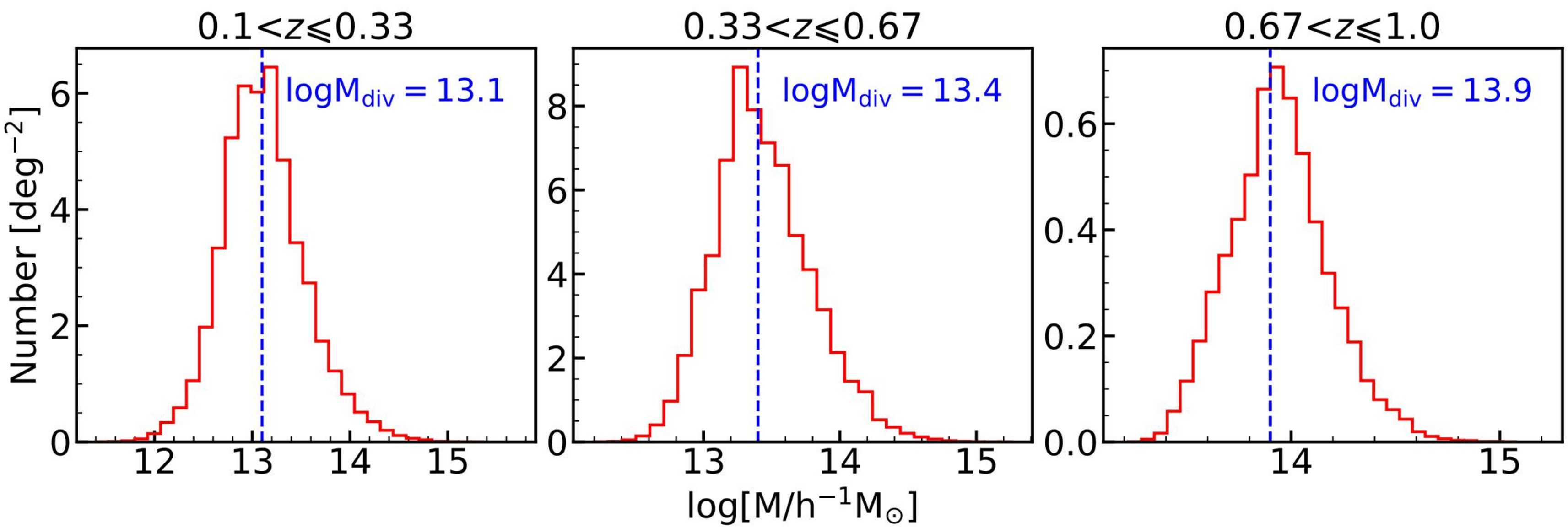
$$\hat{\delta}_\alpha = \frac{N_\alpha / f_\alpha}{\langle N_\alpha / f_\alpha \rangle} - 1$$

$$f_\alpha = \frac{\sum_{i=1}^{16} w_i}{\sum_i} \geqslant f^{\mathrm{threshold}} = 0.5$$



$$\mathbf{Cov}_{\ell\ell'} = \frac{1}{N-1} \sum_{n=1}^{N=240} [(C_n^{\kappa g}(\ell) - \overline{C}^{\kappa g}(\ell)) \times (C_n^{\kappa g}(\ell') - \overline{C}^{\kappa g}(\ell'))]$$

DESI 2 million galaxy groups with Ng ≥ 5

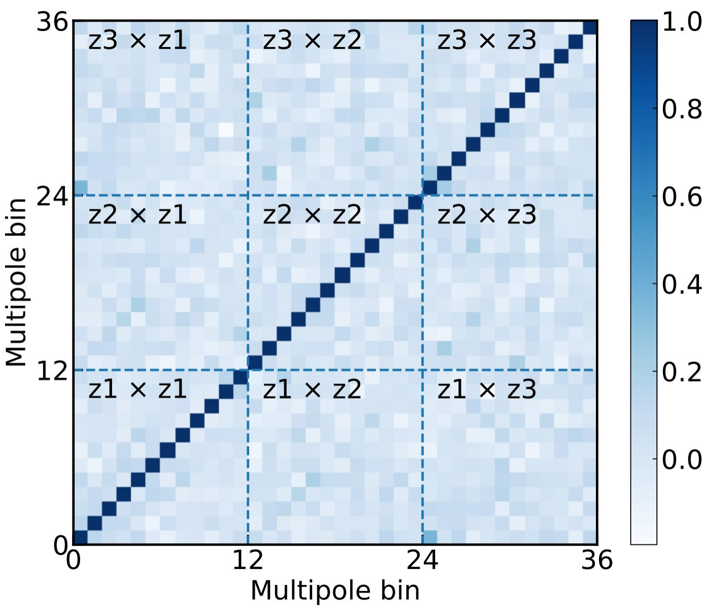


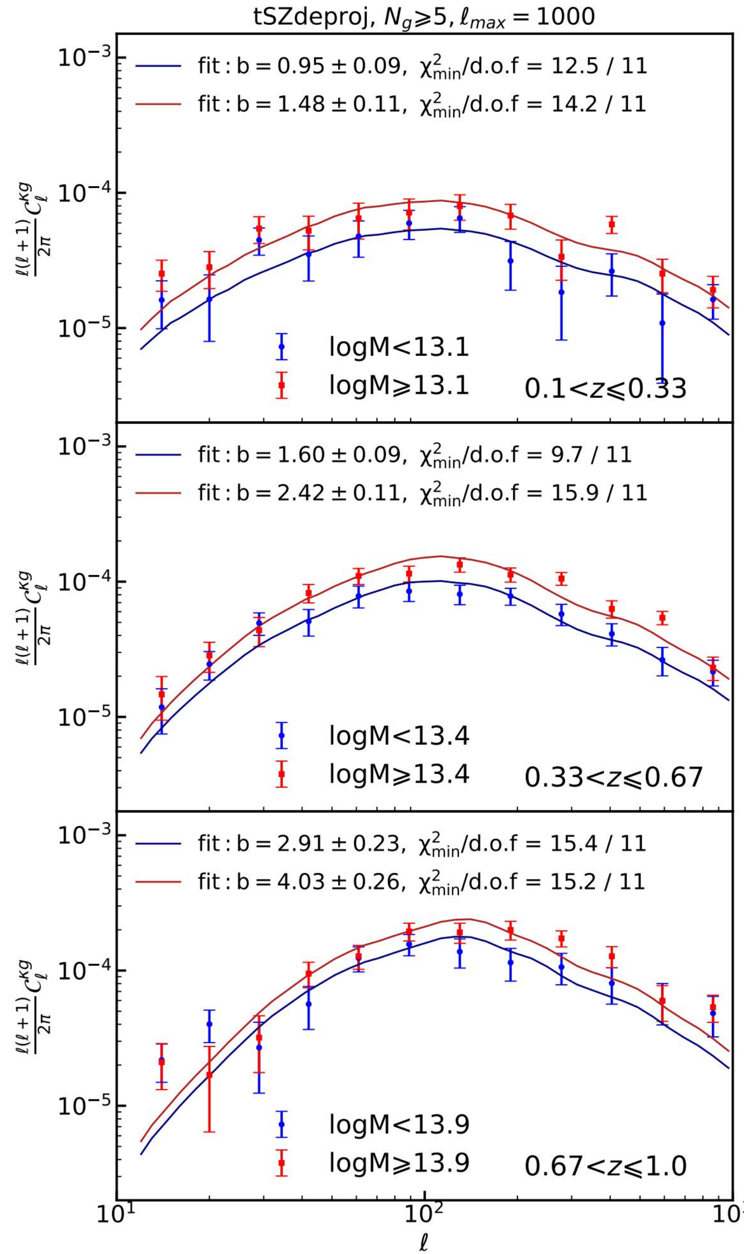
z	of groups	with $N_g \geqslant 5$	$\log M_{\rm div}$
$0.1 < z \leqslant 0.33$	20151147	800606	13.1
$0.33 < z \leqslant 0.67$	49901082	1134482	13.4
$0.67 < z \leqslant 1.0$	20829772	101676	13.9

Yang+ (2020)

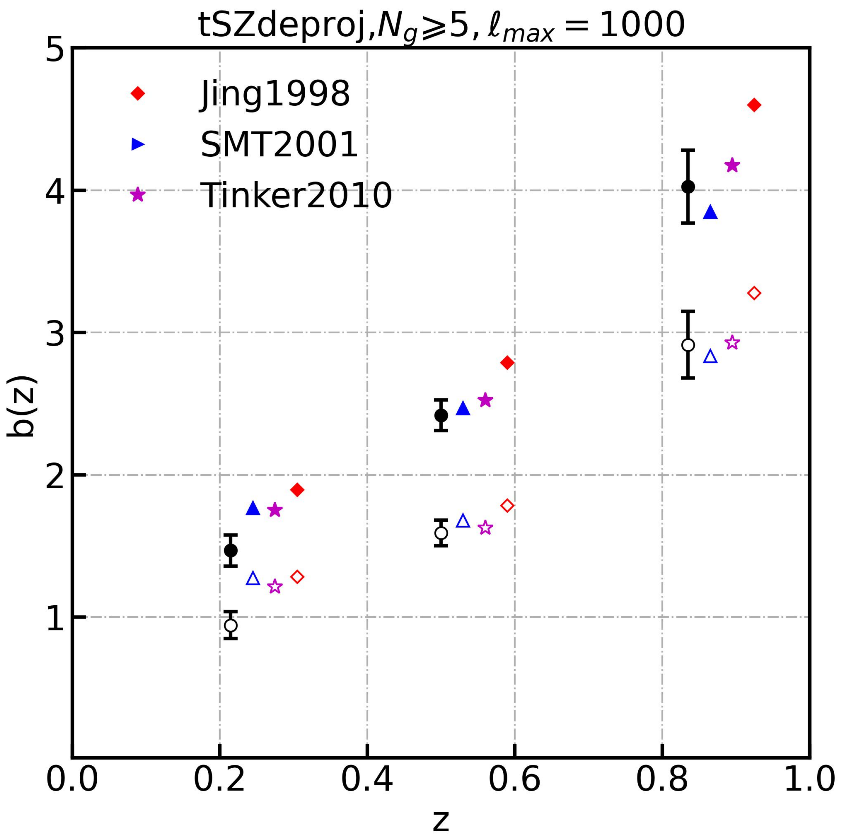
Results: cross-power spectra

- 6 redshift-mass bins: **10–20σ**
- S/N=38.7 for detection and 39.8 for null
- fitting with a single bias parameter returns reasonable $\chi^2_{\min}$/d.o.f. ~ 1 .
- strong support that the measured signal originates from CMB lensing-matter correlation

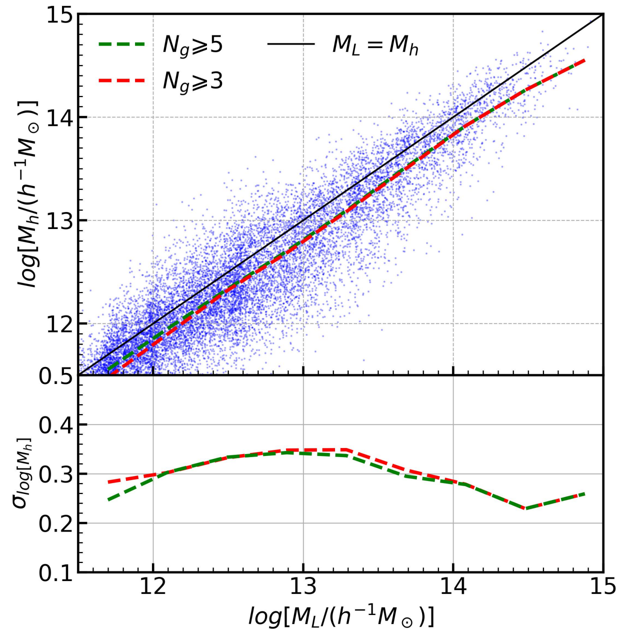




Result: fitting bias vs. three halo bias models



black circles: fitting bias
solid colored symbols: high mass samples
empty colored symbols: low mass samples



Yang+ (2020)

$$b^{\text{th}} = \frac{\sum_i^N b(M_i, z_i) W^\kappa(z_i)\chi(z_i)}{\sum_i^N W^\kappa(z_i)\chi(z_i)}$$

consider: halo mass scatter,
log-normal uncertainty

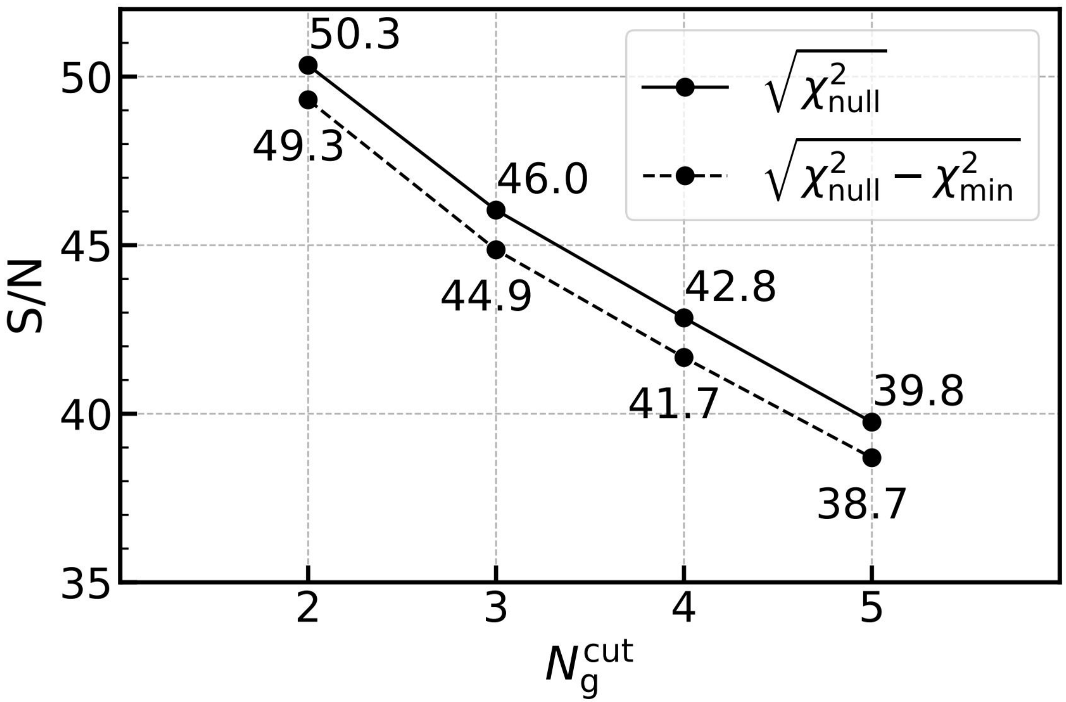
Signal–to–noise ratio

$$\chi^2_{\rm null} = \sum_{\ell\ell'} C_\ell^{\kappa g,{\rm o}} \mathbf{C}^{-1}_{\ell\ell'} C_{\ell'}^{\kappa g,{\rm o}}$$

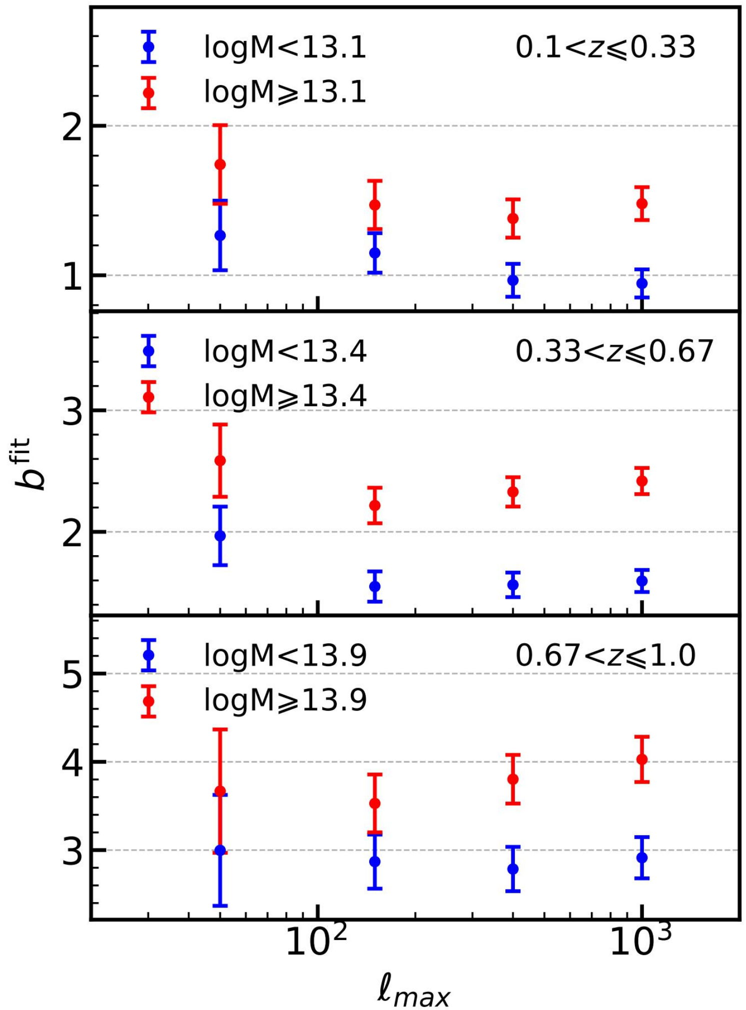
$$\chi^2_{\rm min} = \sum_{\ell\ell'} (C_\ell^{\kappa g,{\rm o}} - b^{\rm bestfit} C_\ell^{\kappa g,{\rm th}}) \mathbf{C}^{-1}_{\ell\ell'} (C_{\ell'}^{\kappa g,{\rm o}} - b^{\rm bestfit} C_{\ell'}^{\kappa g,{\rm th}})$$

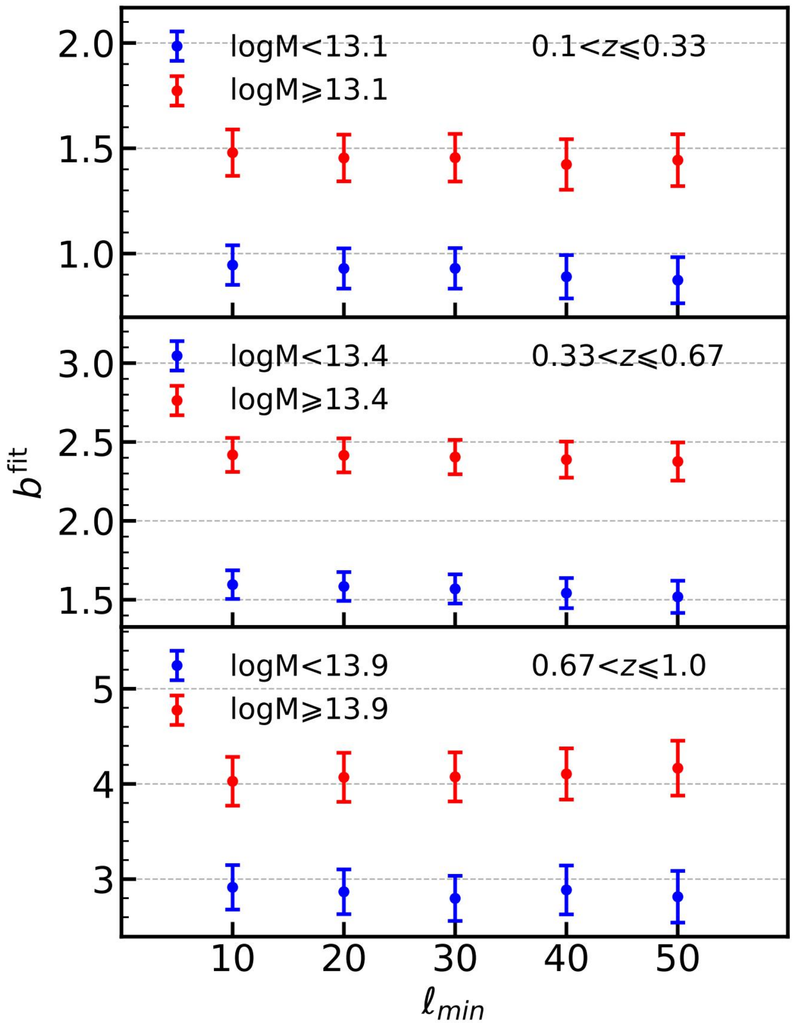
$$\mathrm{S/N} \equiv \sqrt{\chi^2_{\rm null} - \chi^2_{\rm min}}$$

$$\left(\frac{S}{N}\right)_{\rm total} = \sqrt{\sum_\beta \left(\frac{S}{N}\right)^2_\beta}\,.$$

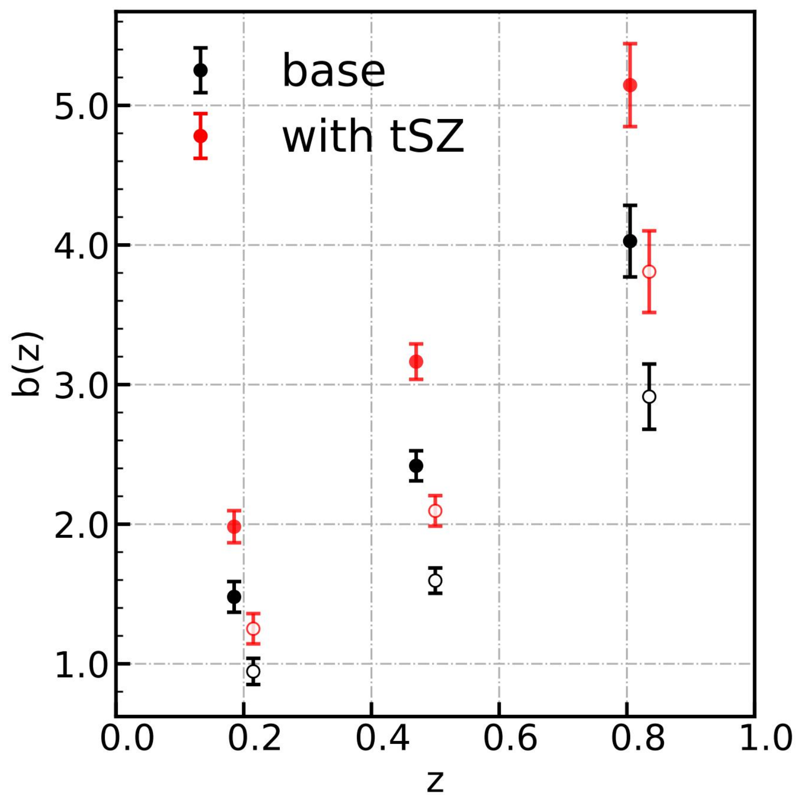


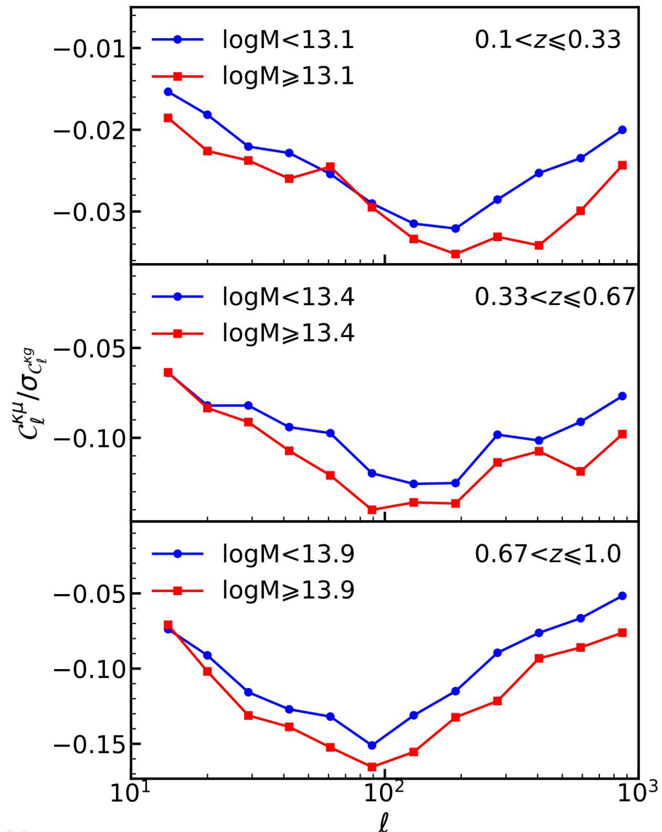
Internal tests: multipole cut





The impact of tSZ is significant



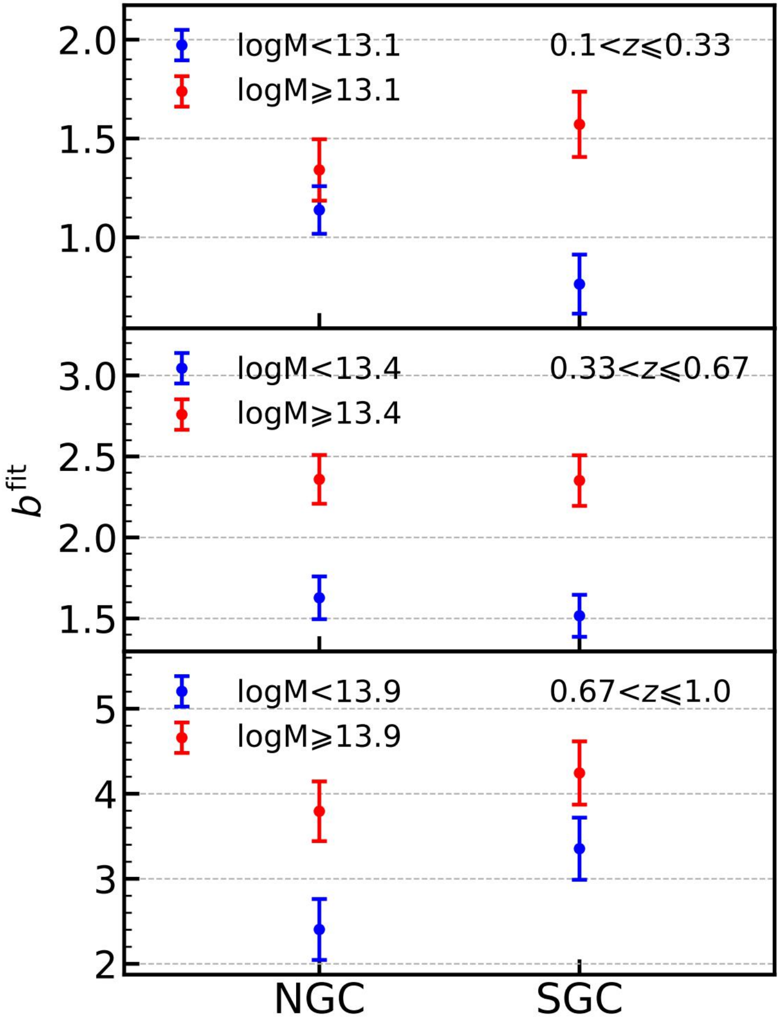


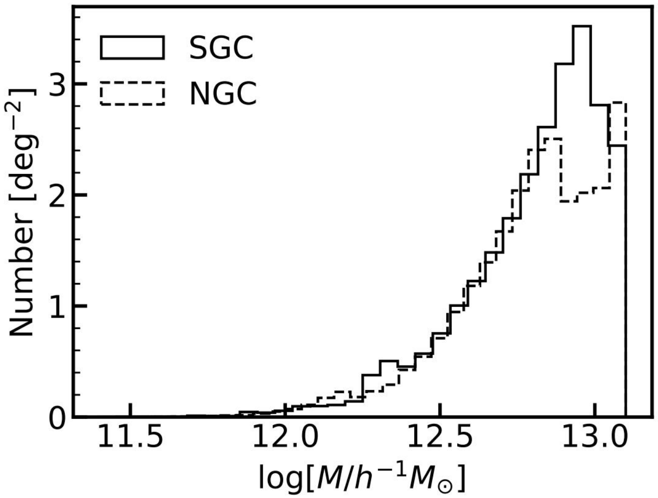
with tSZ: 30% higher

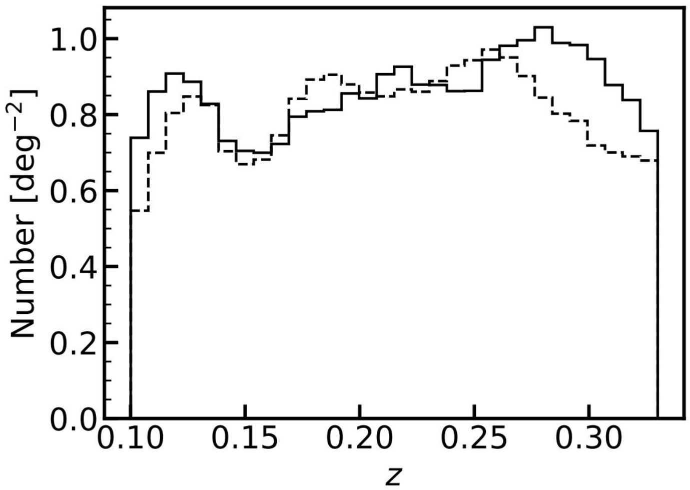
$$C_\ell^{\kappa\mu}/\sigma_{C_\ell^{\kappa g}} < 20\%$$

$$\sigma_{C_\ell^{\kappa g}}/C_\ell^{\kappa g} \sim 30\% \implies C_\ell^{\kappa\mu}/C_\ell^{\kappa g} < 6\%$$

NGC vs. SGC


logM<13.1
logM⩾13.1
0.1<z⩽0.33
logM<13.4
logM⩾13.4
0.33<z⩽0.67
logM<13.9
logM⩾13.9
0.67<z⩽1.0
b^fit
NGC
SGC


SGC
NGC
Number [deg^-2]
log[M/h^-1 M_⊙]


Number [deg^-2]
z

Summary

- **DESI groups – *Planck* CMB lensing cross-correlation**
  - sky coverage: **16890** deg^2, f_{sky}=40%
  - cross power spectrum detection: **39.8σ(38.7σ)**
- **Fitting bias vs. three halo bias models (Jing98, SMT01, Tinker10)**
  - consider halo mass scatter, log-normal uncertainty
- **Internal tests**
  - magnification bias: has small impact on our measurement
  - CMB lensing map with tSZ: **30%** increase on the bias
  - S/N vs. richness cut: increasing richness cuts reduce the signal-to-noise in exchange for good halo properties
  - consistency tests: L range cut, NGC/SGC, pixel coverage fraction

Thanks！