Redshift Calibration with CMB+LSS Cross-Correlations

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Redshift Estimation

Accurate galaxy redshifts are needed for future optical surveys like LSST
- For LSST, mean \( z \) of galaxy bins must be known to \( \sim 0.002 \) (Zhan, Knox 2006, Newman et al. 2013)

**Standard photo-z methods**
- Templates
  - Match observed galaxy colors to library of redshifted template spectra
  - Problem: templates don’t necessarily match real galaxies
- Machine learning
  - Obtain spectroscopic \( z \) for set of “training” galaxies, then use machine learning techniques to predict \( z \) for photometric galaxies
  - Problem: it is difficult to obtain training set at high-\( z \)

**Fundamental problem:** degeneracies in color-redshift space

- **“Correlation methods”**
  - Correlate photometric galaxy sample with spectroscopic galaxy sample (Newman 2008, McQuinn & White 2010)
  - Correlate galaxy sample with CMB lensing maps
Photometric Redshift Calibration with CMBxLSS 2pt functions

Three observables from optical imaging survey + CMB

- $\gamma$: galaxy shears
- $g$: galaxy positions
- $\kappa$: CMB lensing

Two Point Functions:

- **CMB x LSS**: $g \times \kappa, \gamma \times \kappa$
- **LSS-only**: $\gamma \times \gamma, g \times g, g \times \gamma$
- **CMB-only**: $\kappa \times \kappa$

CMB x LSS 2pt functions depend on galaxy redshifts distributions

- $g \times \kappa$ depends on redshifts of lens galaxies
- $\gamma \times \kappa$ depends on redshifts of source galaxies

Broad CMB lensing weight means $g \times \kappa$ and $\gamma \times \kappa$ aren’t very sensitive to small shifts in $N(z)$

However: including CMBxLSS 2pt functions breaks degeneracies between $N(z)$ and e.g. galaxy bias $\rightarrow$ improved constraints on $N(z)$
An Example from DES + SPT

Data:
• DES Science Verification (roughly 150 sq. deg.)
• SPT-SZ

N(z) bias parameterization:
• Use standard photo-z methods to estimate \( N(z) \)
• Use cross-correlation to constrain bias parameter \( \Delta z = \text{shift in } N(z) \)
• Only considering \( \Delta z \) for lenses here

Baxter et al. 2016
Projection: source galaxy redshifts

Calibrating photo-z of source galaxies is exciting because it is hard to obtain spectroscopic training sets for high-z objects.

- Roughly S4 noise level for CMB lensing
- LSST-like source density
- Assumes relatively low density lens galaxies with very accurate photo-z
- Single lens and source bin
- Planck priors on cosmological parameters
CMB lensing can also be used to constrain redshifts of “lens” galaxy sample

- Assume high density lens galaxies
- Marginalize over source galaxy photo-z bias with \( \sigma = 0.01 \) prior
- Lens galaxy \( N(z) \) bias not degenerate with \( m \)
  - Consistent with findings of Schaan et al. 2016
Summary

• Future optical surveys need very accurate redshifts

• CMB 2pt functions provide additional information in joint analyses that can be used to constrain $N(z)$