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Cross Correlating Cosmological Probes for Stage-IV Surveys

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Background

- In the near future, Stage-IV surveys such as Rubin Observatory Legacy Survey of Space and Time (LSST) and CMB-S4 will map the universe with unprecedented precision.
- These surveys help us explore the nature of dark energy and dark matter through matter tracers such as galaxy clustering, weak gravitational lensing, and CMB lensing.
- Due to extensive footprint overlap of these surveys, there is a strong opportunity for cross-correlating probes.
  - This will allow tighter constraints on these fundamental components of the universe.

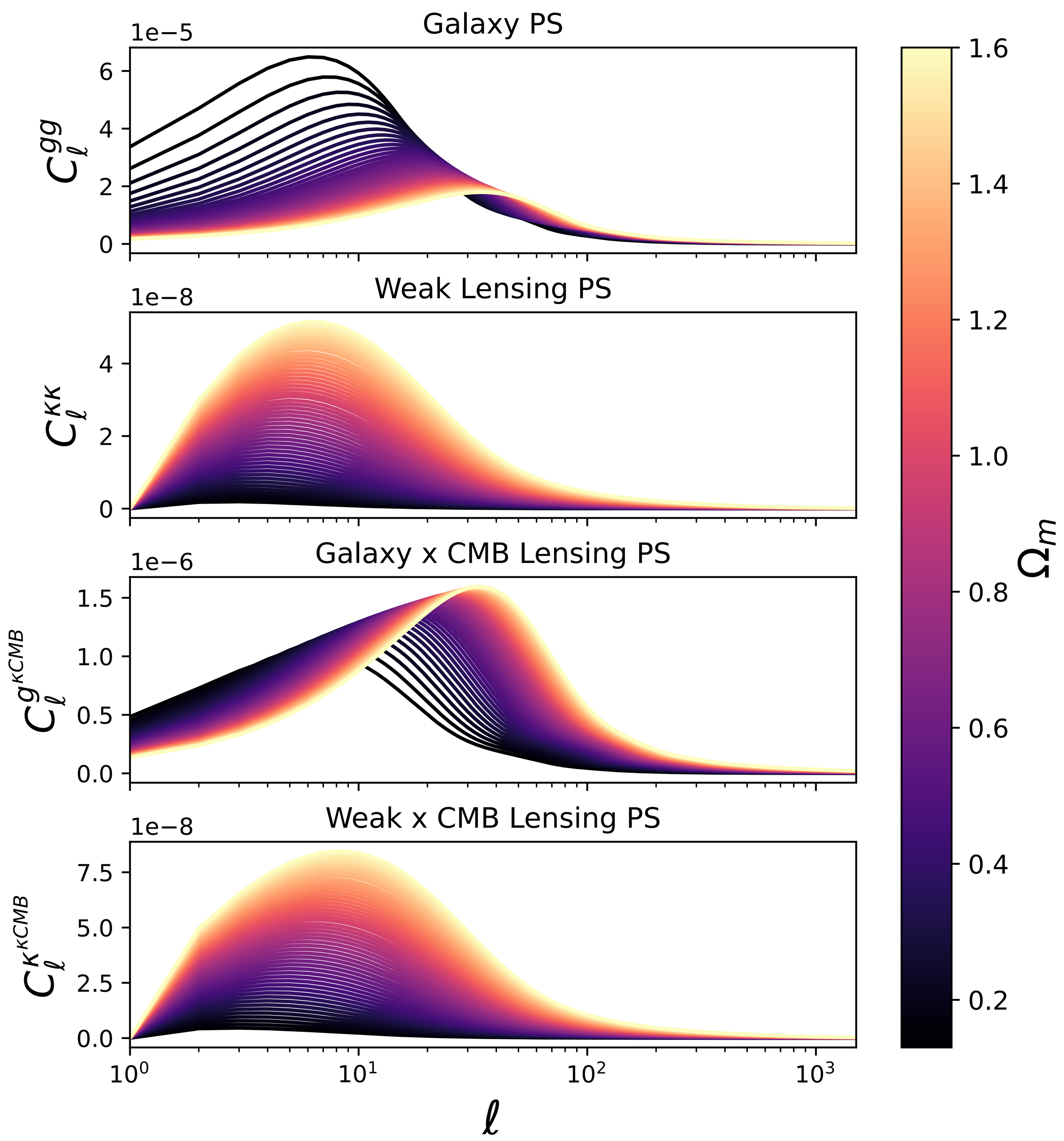


Figure 1. Theoretical power spectra of the four probes varied on the prior range of the matter density of the universe ($\Omega_m = \Omega_b + \Omega_c$). In this figure, we consider the power spectra corresponding to the first redshift bin of the lens and source galaxies. Our first step was generating these plots for all redshift bins and probes to gain intuition about which parameters were most sensitive to which probes.

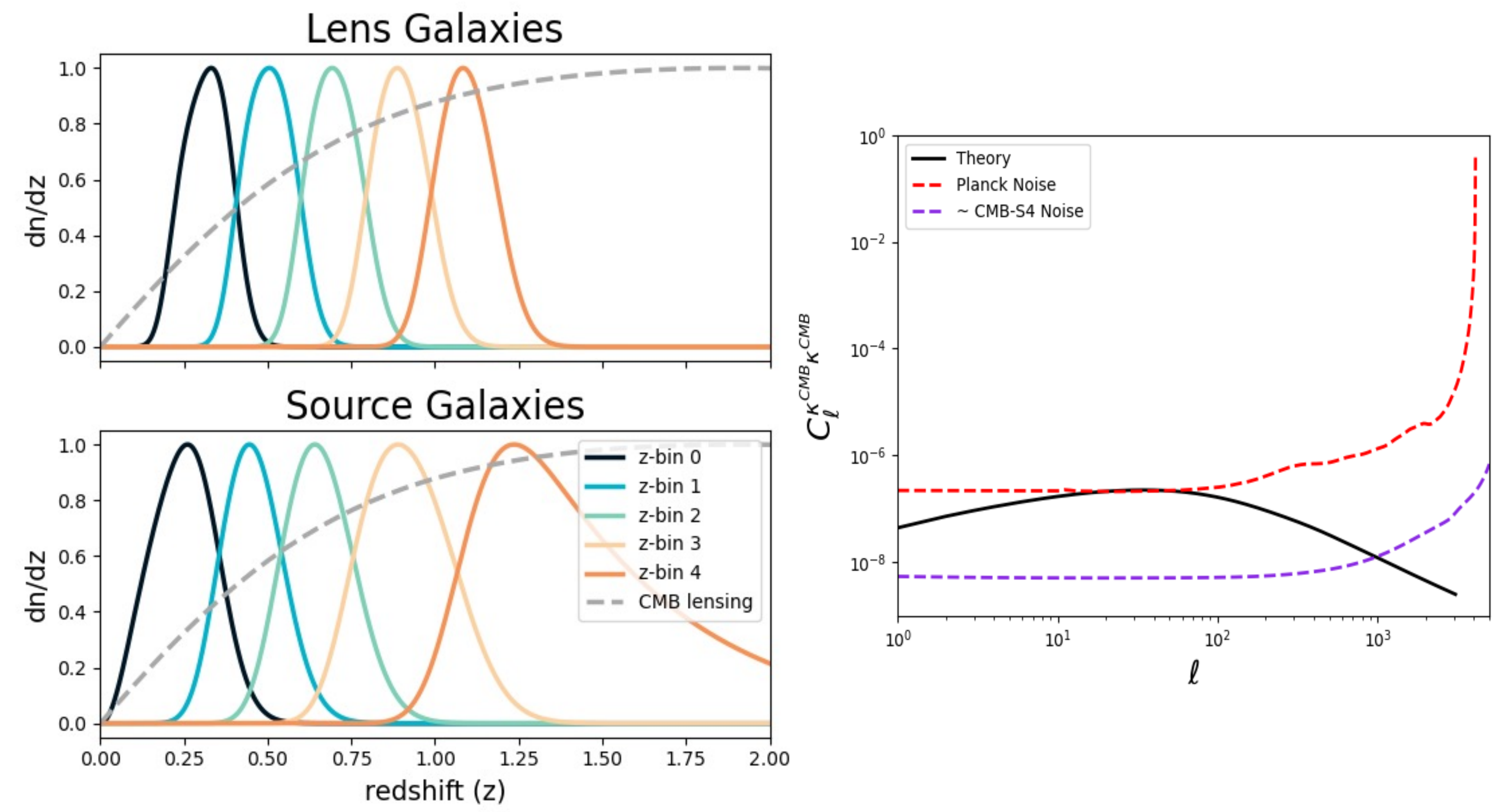


Figure 2. (Left): Redshift distributions of the tomographic bins for the lens (top) and source (bottom) samples as specified in the LSST-DESC SRD for the first year of LSST operation and for the samples we considered in our study. The dashed black line denotes the CMB lensing kernel, and all distributions are normalized to a unit maximum.
(Right): Theoretical CMB lensing power spectrum (solid black line) compared to the noise power spectrum of the CMB lensing map from the Planck satellite (dashed red line) and the expected noise level of the CMB-S4 lensing (dashed purple line).

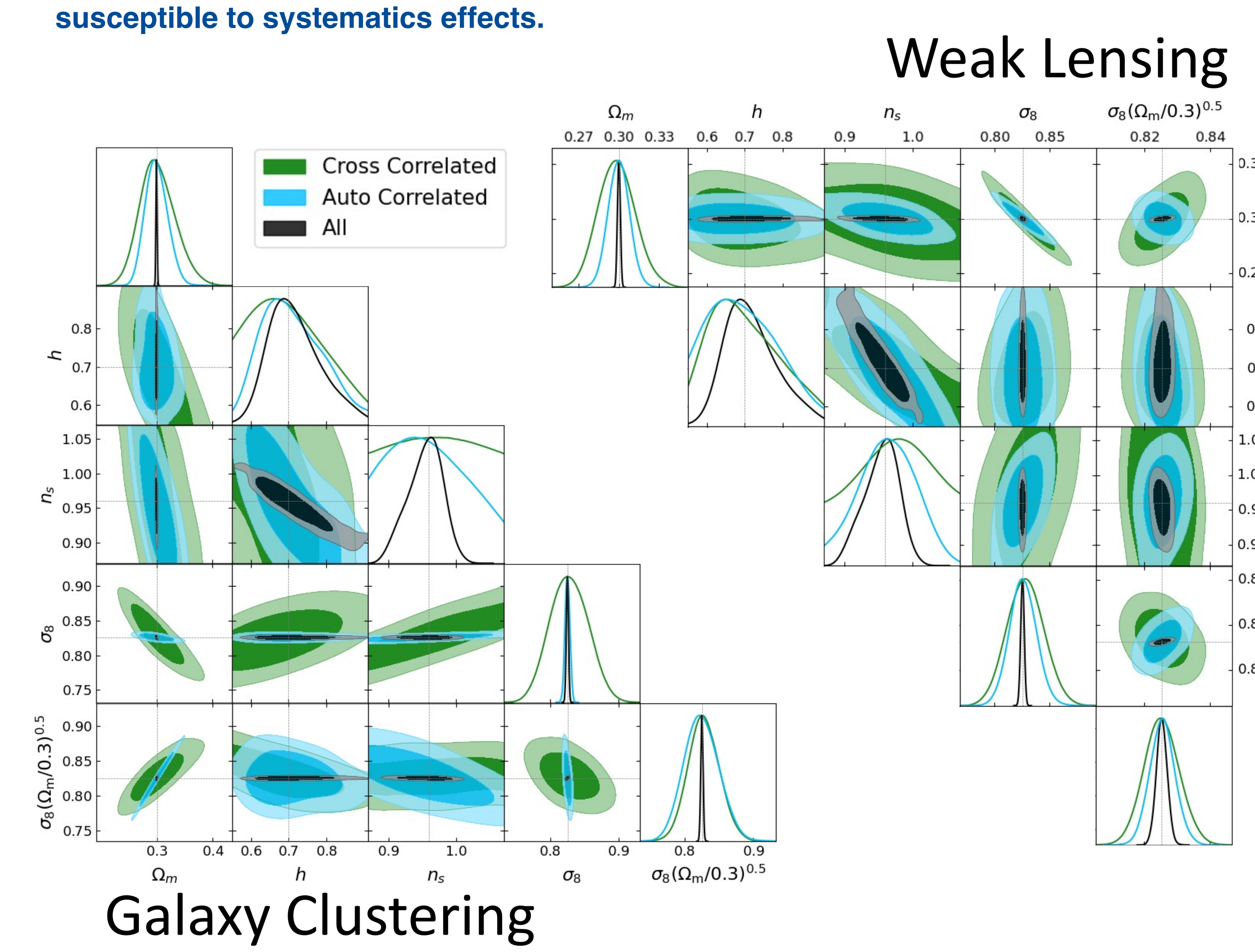
Purpose & Methods

- We aim to understand the expected cosmological sensitivity of each of the probes, including galaxy positions, galaxy weak lensing, CMB lensing, and the cross-correlation of these probes, for a survey like LSST and CMB-S4. Why cross-correlate?
  - Cross-correlation of different experiments is less sensitive to additive bias and removes large amounts of noise, as most systematics are uncorrelated.
  - It additionally breaks degeneracies associated with nuisance parameters contaminating single-survey constraints.
- We use Pyccl[1] to perform the theoretical prediction of the power spectra (Figure 1) including respective redshift distribution and noise levels illustrated in Figure 2.
- We examine the constraining power of different probe combinations, including the power spectrum of galaxy positions (lens galaxies), galaxy weak lensing (source galaxies), and their cross-correlation with CMB lensing, by running an MCMC likelihood analysis using a set of simulations with LSST and CMB-S4 specifications.

Conclusions

- Figure 3 shows the constraining power of the individual and combined probes. Focusing on the Ω_m and $\sigma_8\sqrt{\Omega_m/0.3}$ parameters:
  - The galaxy weak lensing auto correlation has a 43.6% stronger constraint on Ω_m and 27.8% strong constraint on S_8 than weak cross CMB lensing.
  - A joint analysis provides much tighter constraints on the major cosmological parameters.
  - Future analyses that incorporate more realistic effects will enable us to better understand the expected errors of the parameters constrained with these probes.

Figure 3. Contours of the output cosmology from the MCMC. Auto correlated probes are shown in blue and probes cross correlated with CMB lensing are shown in green. Black contours show the result of an MCMC run with all probes to maximize constraint. Weak lensing has strong constraints on many parameters, but the cross correlated probes (e.g., WL x CMB) have comparable strength and are expected to be less susceptible to systematics effects.



References

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2. Fang, Xiao, et al. "Cosmology from clustering, cosmic shear, CMB lensing, and cross correlations: combining Rubin observatory and Simons Observatory." *Monthly Notices of the Royal Astronomical Society* 509.4 (2022)
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