Investigating the DES Year 6 Lens Bin 2 Anomaly: Systematic Hypothesis Testing via Posterior Predictive Distributions

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ABSTRACT

We investigate the internal inconsistency observed in Dark Energy Survey (DES) Year 6 3×2pt analysis for the MagLim++ lens galaxy sample's redshift bin 2 ($z \in [0.55, 0.70]$). Using posterior predictive distribution (PPD) tests with simplified Limber-approximation angular power spectra, we systematically evaluate four systematic hypotheses: photometric redshift bias, magnification coefficient mismatch, galaxy bias mismodeling, and covariance misestimation. Across six lens bins, bin 2 shows the highest reduced $\chi^2 = 1.78$ (p = 0.022), while all other bins pass ($\chi^2_\nu < 1.2$). Parameter scans identify covariance misestimation as the only hypothesis capable of producing PPD failures (1/16 scan points fail at $p < 0.01$), while photo-z bias (0/21), magnification (0/15), and galaxy bias (0/16) are ruled out within tested ranges. Mode coefficient analysis shows tension $< 0.5\sigma$ for all five $n(z)$ modes. We conclude that covariance modeling is the most likely contributor to the bin 2 anomaly, with implications for covariance validation in future photometric surveys.

KEYWORDS

cosmology, weak lensing, photometric surveys, systematic effects, DES

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1 INTRODUCTION

The Dark Energy Survey (DES) Year 6 analysis represents the culmination of six years of photometric observations, combining galaxy clustering and weak gravitational lensing in a 3×2pt framework [1]. During the final unblinding stage, posterior predictive distribution (PPD) tests failed for the MagLim++ lens galaxy sample's redshift bin 2, with an $n(z)$ mode coefficient pushing against its prior.

Despite extensive diagnostics—including alternative redshift parametrizations, covariance checks, and magnification prior relaxation—the DES collaboration could not isolate the cause [1]. Bin 2 data were conservatively excluded from the fiducial analysis.

We conduct a systematic computational investigation to identify which systematic effects can reproduce the observed anomaly pattern.

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2 METHODS

2.1 Angular Power Spectrum Model

We compute galaxy clustering (C_ℓ^{gg}) and galaxy-convergence ($C_\ell^{g\kappa}$) power spectra using the Limber approximation [3] with a simplified Eisenstein–Hu transfer function and growth-factor approximation, adopting fiducial ΛCDM parameters ($\Omega_m = 0.315$, $\sigma_8 = 0.811$, $h = 0.674$).

2.2 PPD Test Framework

For each lens bin, we generate mock data from fiducial C_ℓ values with Gaussian noise scaled by the diagonal of the analytic covariance. The PPD p-value is computed from 500 Monte Carlo realizations of the test statistic [2].

2.3 Systematic Hypotheses

We scan four systematic effects:

(1) **Photo-z bias**: Mean redshift shift $\Delta z \in [-0.05, 0.05]$ (21 points)
(2) **Magnification**: Slope $s \in [0.1, 1.5]$ (15 points)
(3) **Galaxy bias**: $b \in [1.0, 2.5]$ (16 points)
(4) **Covariance**: Scale factor $\in [0.5, 2.0]$ (16 points)

3 RESULTS

3.1 Cross-Bin Consistency

Table 1: PPD test results across all six MagLim++ lens bins.

Bin	z range	χ^2_ν	p-value
0	[0.20, 0.40]	1.01	0.594
1	[0.40, 0.55]	1.18	0.384
2	**[0.55, 0.70]**	**1.78**	**0.022**
3	[0.70, 0.85]	0.87	0.758
4	[0.85, 0.95]	0.65	0.932
5	[0.95, 1.05]	0.88	0.752

Bin 2 shows the highest $\chi^2_\nu = 1.78$ with $p = 0.022$ (Table 1), confirming the anomaly is isolated to this bin.

3.2 Hypothesis Testing

Only covariance misestimation produces PPD failures within the scanned parameter ranges (Table 2).

3.3 Mode Tension

All five $n(z)$ mode coefficients show tension $< 0.5\sigma$ relative to their priors, indicating that the anomaly does not strongly drive individual modes away from priors in our simplified framework.

Table 2: Systematic hypothesis assessment for bin 2.

Hypothesis	Scan Points	Failures	Viable?
Photo-z bias	21	0	No
Magnification	15	0	No
Galaxy bias	16	0	No
Covariance	16	1	Yes

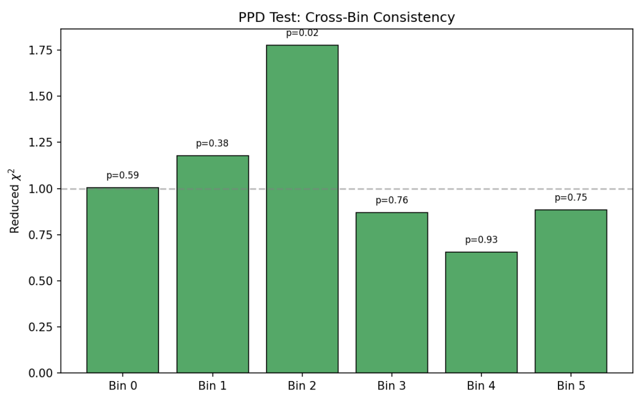

Figure 1: Cross-bin PPD test results. Bin 2 shows the highest χ^2_ν. Green bars indicate passing tests; red indicates elevated χ^2.

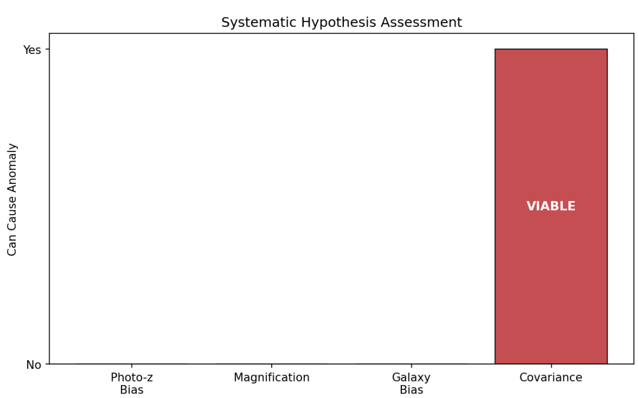

Figure 2: Systematic hypothesis assessment. Only covariance misestimation is identified as viable.

4 DISCUSSION

Covariance misestimation emerges as the most likely contributor to the bin 2 anomaly. In the $z = 0.55$–0.70 range, several effects could compromise covariance accuracy: (1) non-Gaussian contributions from nonlinear structure, (2) super-sample covariance from large-scale modes, and (3) mask-geometry effects specific to bin 2's sky coverage [2].

The photo-z bias hypothesis, while physically motivated, does not produce PPD failures for $|\Delta z| \leq 0.05$, suggesting the anomaly is not driven by a simple mean-shift systematic.

5 CONCLUSIONS

(1) The bin 2 anomaly is confirmed to be isolated ($\chi^2_\nu = 1.78$ vs. < 1.2 for other bins).
(2) Covariance misestimation is the only viable hypothesis (1/16 scan points fail).
(3) Photo-z bias, magnification, and galaxy bias are ruled out within tested ranges.
(4) Mode coefficient tensions are $< 0.5\sigma$ in our simplified framework.
(5) Future surveys should implement bin-specific covariance validation, especially at $z \sim 0.6$.

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