Fisher Forecasts for Cosmological Yields from 3×2pt Analysis of the Roman Space Telescope High Latitude Imaging Survey

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Abstract

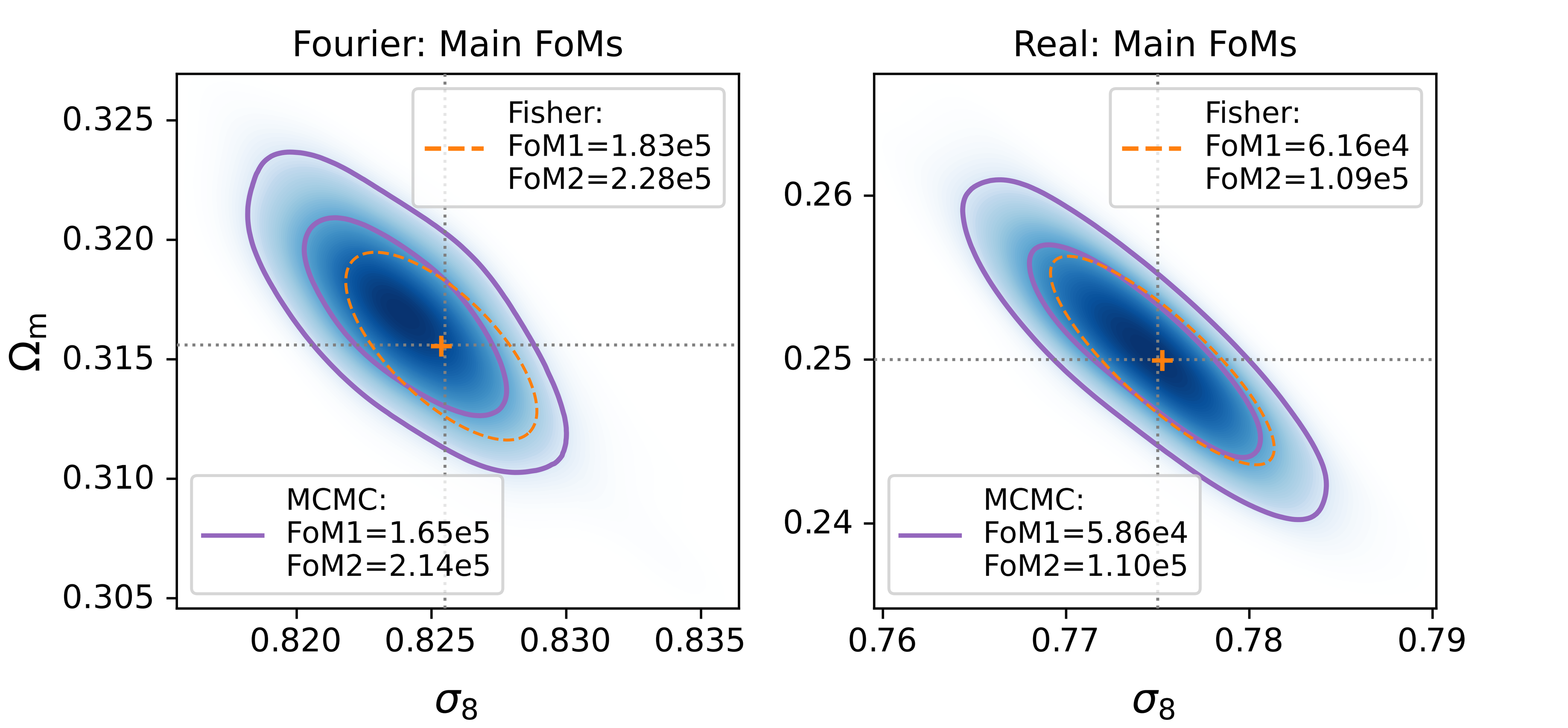
The High Latitude Imaging Survey (HLIS) of NASA's Nancy Grace Roman Space Telescope will provide powerful tests of cosmological models through sensitive measurements of cosmic shear, galaxy-galaxy lensing (GGL), and galaxy clustering. As part of the HLIS Project Infrastructure Team's Data Challenge 1 (DC1), we carry out Fisher forecasts of cosmological parameter constraints from combinations of these probes, focusing on inverse-variance figures of merit (FoMs) for the parameters σ_8 and Ω_m, which scale the amplitude of weak lensing signals. We find good agreement between Fisher analysis and Markov chain Monte Carlo (MCMC) analysis of the DC1 baseline data vector, and we exploit the flexibility of Fisher analysis to investigate varied priors on cosmological parameters and on nuisance parameters describing unknown biases in photometric redshifts or shear measurements. Given the benchmark DC1 priors, the forecast constraints from GGL+clustering are substantially stronger than those from cosmic shear, with the combination of all three probes ("3×2pt") providing modest further improvement. Adding tight external priors on the power spectrum shape parameters n_s, Ω_b, and h_0 can improve the $(\sigma_8, \Omega_\mathrm{m})$ FoMs by factors of 1.2–3.5. The smallest scale angular bins provide much more information than the largest scale bins, and the highest redshift tomographic bins provide more information than the lowest redshift bins. Factor-of-two changes in the priors on photo-z and shear biases, relative to the benchmark values based on anticipated calibration accuracy, produce changes of $\lesssim 20\%$ in FoMs, implying robust cosmological performance if this demanding level of accuracy can be achieved.

Methods

1. Cobaya-CosmoLike Joint Architecture (CoCoA) — predicting two-point correlation functions (2PCFs) in real space and/or the corresponding power spectra in Fourier space
   - Cosmic shear: autocorrelation of cosmic shear; $\xi_\pm(\theta)$ in real space and $C_\mathrm{ss}(\ell)$ in Fourier space.
   - Galaxy-galaxy lensing (GGL): cross-correlation of cosmic shear and galaxy distribution; $\gamma_\mathrm{t}(\theta)$ in real space and $C_\mathrm{gs}(\ell)$ in Fourier space.
   - Galaxy clustering: autocorrelation of galaxy distribution; $w(\theta)$ in real space and $C_\mathrm{gg}(\ell)$ in Fourier space.
2. Cosmological Parameters Inference Pipeline (CPIP) Data Challenge 1 (DC1) — providing blinded data vectors, suggested masks, and covariance matrices
3. Finding Best-fit Parameter Values — maximizing either the likelihood $\mathcal{L}(\boldsymbol{\theta})$ or the posterior probability $\mathcal{P}(\boldsymbol{\theta})$ using a modified version of the coordinate descent algorithm
4. Fisher Information Analysis — computing precision matrix of parameters

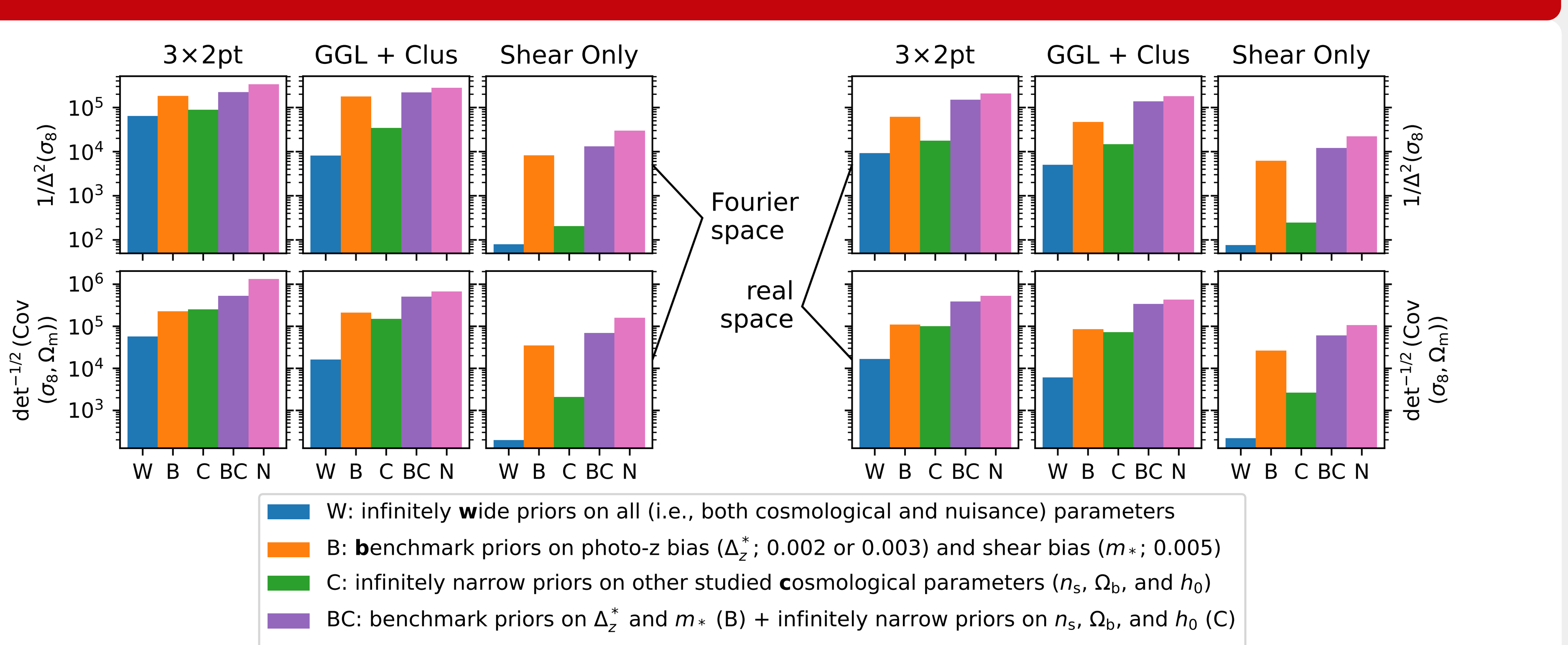
$$\boldsymbol{\Sigma}_\mathcal{L}^{-1} \equiv F_{\alpha\beta} = \boldsymbol{m}_{,\alpha}^\mathrm{T}\mathbf{C}^{-1}\boldsymbol{m}_{,\beta}, \quad \boldsymbol{\Sigma}_\mathcal{P}^{-1} = \boldsymbol{\Sigma}_\mathcal{L}^{-1} + \boldsymbol{\Sigma}_\mathrm{Prior}^{-1}.$$

Forecasts for the DC1 Baseline Case



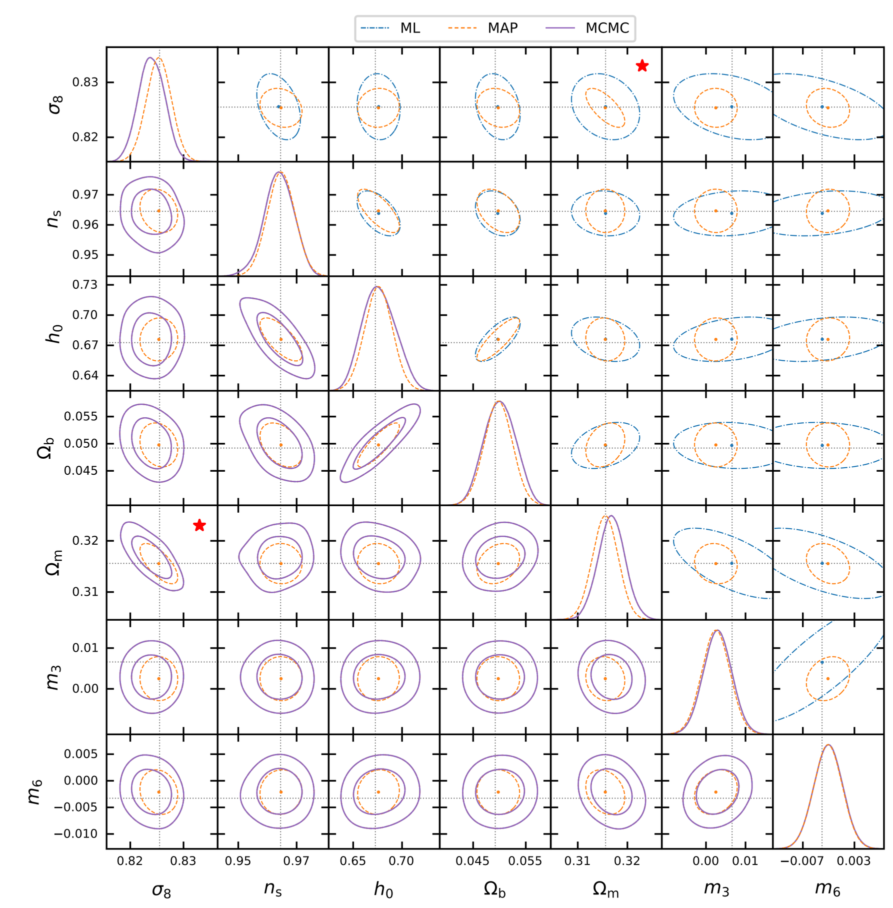
The subspace of σ_8 and Ω_m, in which our two figures of merit, FoM1 $= 1/\Delta^2(\sigma_8)$ and FoM2 $= \det^{-1/2}(\mathrm{Cov}(\sigma_8, \Omega_\mathrm{m}))$, are defined. The two panels present results in Fourier space and real space, respectively. In addition to elements from corner plots below, the (weighted) densities of parameter values sampled by MCMC are visualized in blue.

Marginalization Choices, Probes

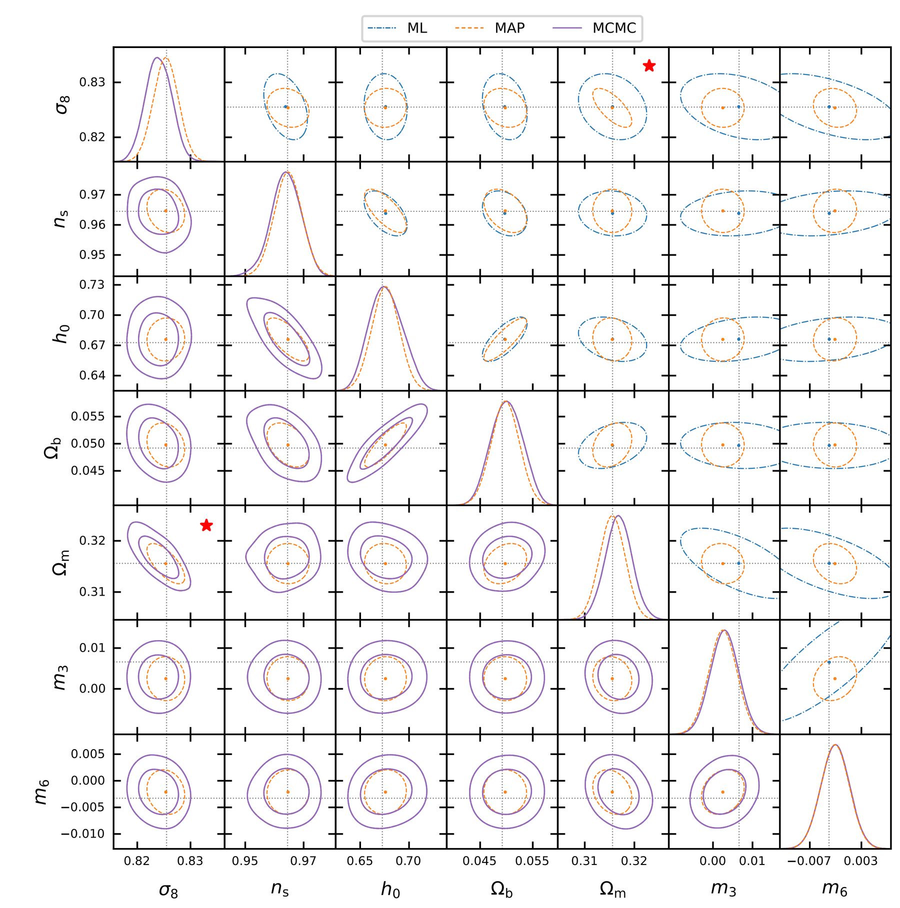


Constraining power of different combinations of probes: the combination of all three probes ("3×2pt"), the combination of galaxy-galaxy lensing ("GGL") and galaxy clustering ("Clus"), and cosmic shear ("Shear") only. In each panel, different colors correspond to different marginalization choices.

Fourier Space



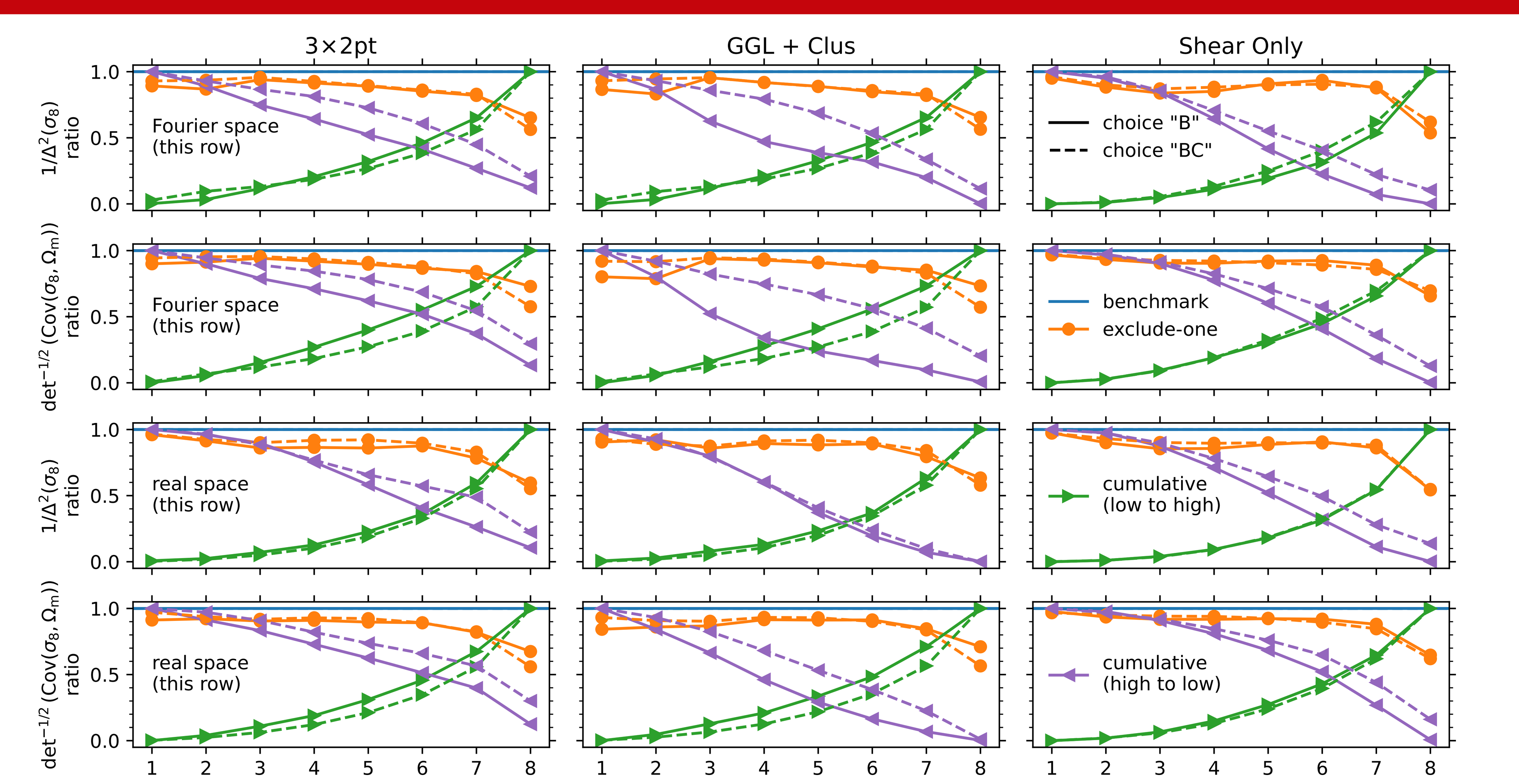
Real Space



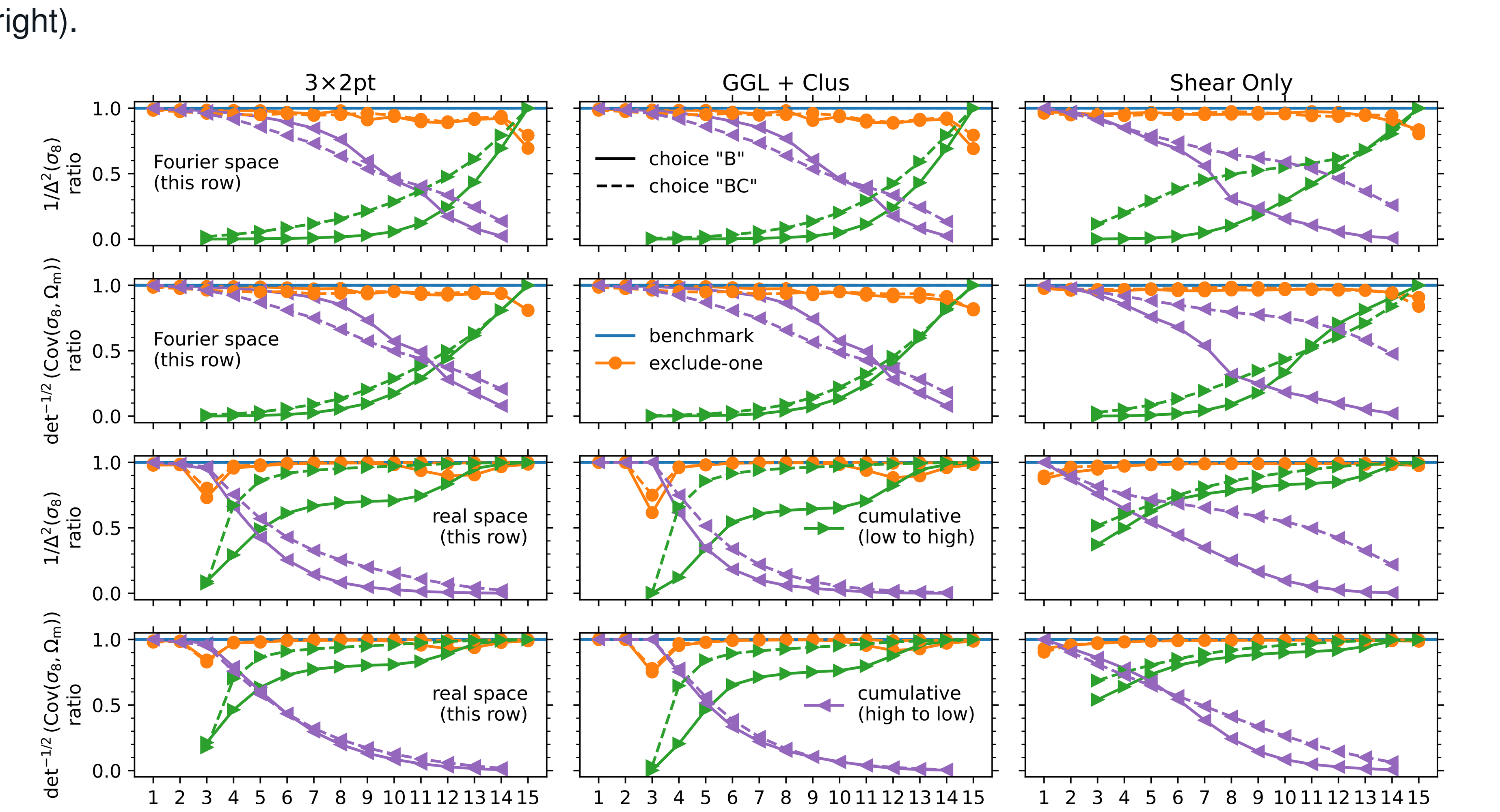
Corner Plots for Representative Parameters

7 parameters are shown in the corner plots above: all cosmological parameters studied in this work (σ_8, n_s, h_0, Ω_b, and Ω_m), as well as multiplicative shear biases (m_3 and m_6) in the 3^rd and 6^th tomographic bins. In the panels above the diagonal, the maximum likelihood results ("ML"; blue) and maximum a posteriori results ("MAP"; orange) are compared. Peak values are shown as dots, and boundaries of 1σ credible regions are shown as ellipses. In the panels below the diagonal, the MAP results are compared to MCMC results, which are shown in purple, with both 1σ and 2σ regions. The diagonal panels show the 1D marginalized distributions from MCMC results and Fisher results. The truth parameter values (i.e., those used to make the "observed" data vector $\boldsymbol{d}$) are marked as gray dotted horizontal and vertical lines. We mark the panels corresponding to $(\sigma_8, \Omega_\mathrm{m})$ constraints, which are the focus of this paper, with a star.

Tomographic Bins, Angular Scales



Breakdown of contributions from tomographic bins. The ratios are computed by dividing figures of merit in variant cases (with a subset of tomographic bins) by the corresponding ones with all tomographic bins included. Blue represents the benchmark case, orange represents the variant cases with all-but-one tomographic bins, and green (purple) represents the combination of the labeled bin and those on its left (right).



Breakdown of contributions from angular scales. Note that in real space, the angular scale bin index runs from small scale ($\theta \simeq 2.97\,\mathrm{arcmin}$ for the 1st bin) to large scale ($\theta \simeq 219\,\mathrm{arcmin}$ for the 15th bin), while in Fourier space, it runs from large scale ($\ell \simeq 35.31$ for the 1st bin) to small scale ($\ell \simeq 3398$ for the 15th bin).