Prediction on cosmological parameters using weak gravitational lensing

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Abstract

The Euclid mission aims at understanding the accelerated expansion of the universe and what is the nature of the source responsible for this acceleration. Based on the work done on *Euclid Preparation*, we aim to obtain estimates on the uncertainties of the cosmological parameters $\Omega_{m,0}$, h, n_s, σ_8, using fisher matrix forecasts, applied to weak lensing phenomenons.

Introduction

Assuming the spatially flat Λ**CDM** model as a baseline of this work, we can describe our model by a minimal set of parameters:

- $\Omega_{m,0}$, the total matter energy densities at present time.
- h, the dimensionless Hubble parameter.
- n_s, the spectral index of the primordial density power spectrum.
- σ_8, the rms of present-day linearly evolved density fluctuations in spheres of $8h^{-1}$Mpc.

The Hubble parameter can be expressed as a function of redshift $H(z) = H_0 E(z)$, where is the Hubble parameter today and the proper distance function $E(z)$ can be expressed as:

$$E(z) = \sqrt{\Omega_{m,0}(1+z)^3 + \Omega_{\Lambda,0} + \Omega_{K,0}(1+z)^2}$$

where $\Omega_{\Lambda,0} = 1 - \Omega_{m,0}$, since for spatially flat cosmology the effective curvature density is zero. In addition we define the comoving distance to an object at redshift z as:

$$r(z) = \frac{c}{H_0}\int_0^z \frac{dz}{E(z)}$$

which factors out the expansion of the universe today, providing a distance that does not change in time due to the expansion of space.
Finally, the matter power spectrum (mps) describes the density contrast of the universe as a function of the wave number and the redshift. It's depicted as:

$$P_{\delta\delta}(k,z) = \left(\frac{\sigma_8}{\sigma_N}\right)^2 \left[\frac{D(z)}{D(z=0)}\right]^2 T_m^2(k) k^{n_s}$$

Weak Lensing

We model the first of the five quantities that comes from the W.L observable; **The cosmic shear power spectrum**, i.e is the change in the ellipticity of the image of background galaxy, caused by the lensing effect of large-scale structure along the line of sight. The correlation function that describe this phenomenon is:

$$C_{ij}^{\gamma\gamma}(\ell) \simeq \frac{c}{H_0}\int dz \frac{W_i^{\gamma}(z) W_j^{\gamma}(z)}{E(z) r(z)} P_{\delta\delta}\left[\frac{\ell + 1/2}{r(z)}, z\right]$$

where i and j identify pairs of redshift bins, the mps is evaluated at $k = k_\ell(z) \equiv (\ell + 1/2)/r(z)$ (Limber approximation), and the weight functions $W_i^{\gamma}(z)$ are defined as

$$W_i^{\gamma}(z) = \frac{3}{2}\left(\frac{H_0}{c}\right)^2 \Omega_{m,0}(1+z) r(z) \int_z^{z_{max}} dz' n_i(z') \left[1 - \frac{\tilde{r}(z)}{\tilde{r}(z')}\right]$$

where the integral is also known as the window function ($\tilde{W}_i(z)$). The term $n_i(z)$ corresponds to the number density distribution of the observed galaxies in the ith bin.

Fisher Matrix

Assuming the signal is the mean power spectrum, the Fisher matrix reads

$$F_{\alpha\beta} = \sum_{\ell=\ell_{min}}^{\ell max} \sum_{ij,mn} \frac{\partial C_{ij}^{\epsilon\epsilon}(\ell)}{\partial \theta_\alpha} \mathrm{Cov}^{-1}[C_{ij}^{\epsilon\epsilon}(\ell), C_{mn}^{\epsilon\epsilon}(\ell)] \frac{\partial C_{mn}^{\epsilon\epsilon}(\ell)}{\partial \theta_\beta}$$

and corresponds to the curvature of the logarithmic likelihood, describing how fast the likelihood falls around the maximum.

The covariance matrix is depicted as:

$$Cov[C_{ij}^{\epsilon\epsilon}(\ell), C_{kl}^{\epsilon\epsilon}(\ell')] = \frac{C_{ik}^{\epsilon\epsilon} C_{jl}^{\epsilon\epsilon}(\ell') + C_{il}^{\epsilon\epsilon}(\ell) C_{lk}^{\epsilon\epsilon}(\ell')}{(2l+1) f_{sky} \Delta\ell} \delta_{ll'}^K$$

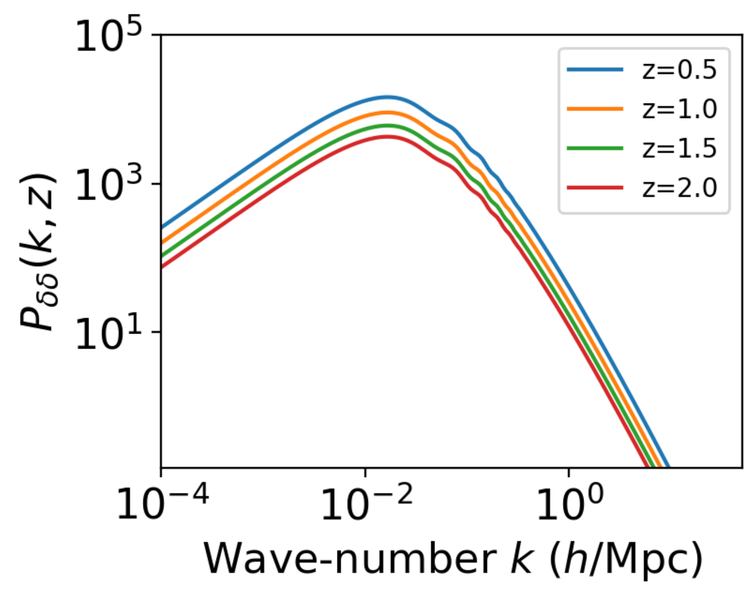
where f_{sky} is the fraction of surveyed sky and $\Delta\ell$ is the multipole bandwith. Finally it's possible to calculate the expected marginalized $1 - \sigma$ error on the parameter θ_α (left) and the unmarginalised expected errors (right)

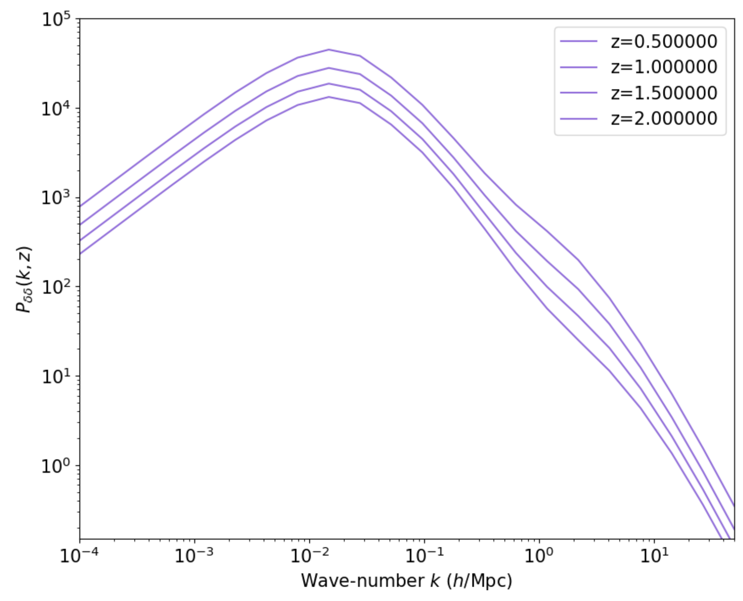
$$\sigma_\alpha = \sqrt{(F^{-1})_{\alpha\alpha}}, \quad \sigma_\alpha = \sqrt{1/F_{\alpha\alpha}}$$

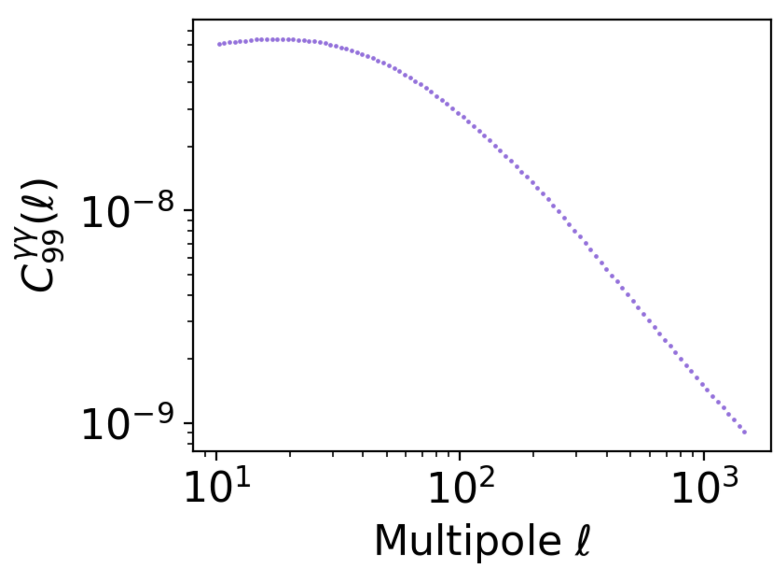
accomplishing our main goal: the estimation of the uncertainties of the cosmological parameters.

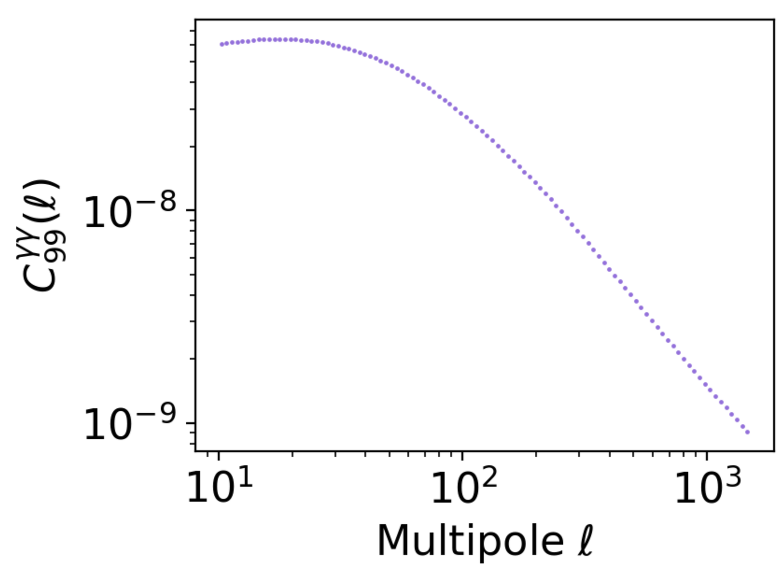
Results

In order to obtain the cosmic shear power spectrum the mps is needed, which was obtained with CAMB (3) in two ways: by calling the CAMB interpolator directly (left) and by calling camb to obtain points of the mps and interpolate manually (right).

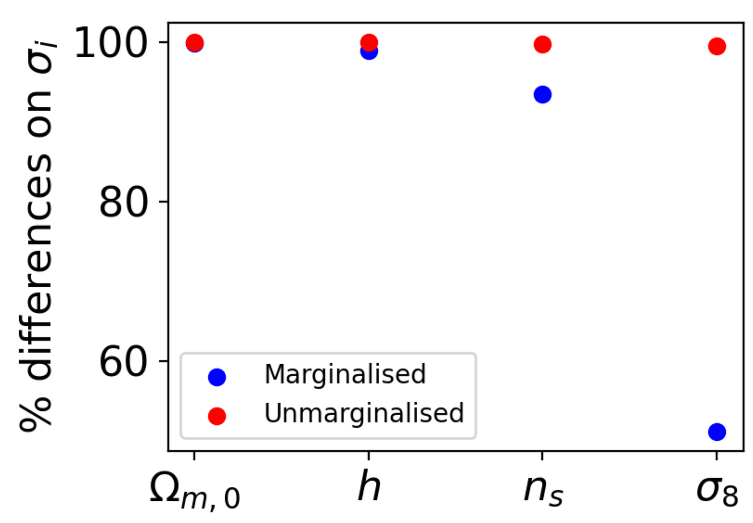


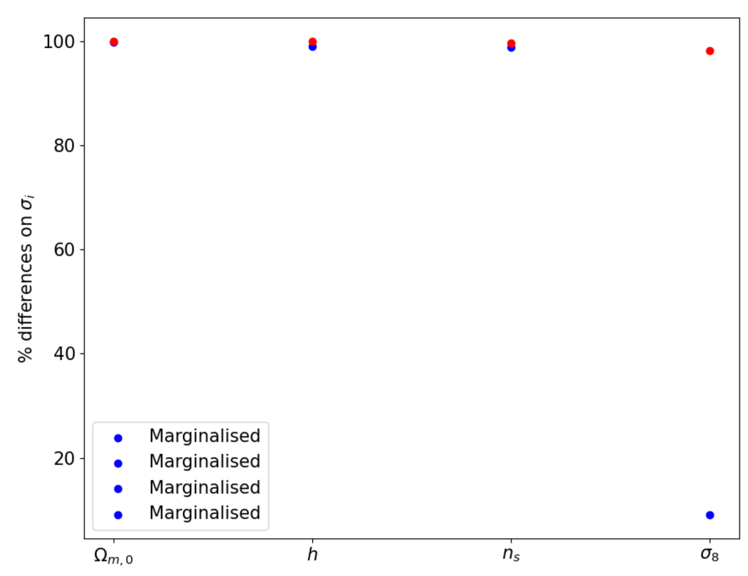






The following is a comparison of the errors on the marginalised and unmarginalised cosmological parameters.





Discussion and Conclusions

There are some minor differences in the mps fits. It is easy to notice that the mps obtained by manual interpolation decays more abruptly than the interpolation made by CAMB. However, the behaviour of the cosmic shear power spectrum is really similar for all the bins, since integration over redshift was performed.
When comparing to the errors obtained by the *Euclid Collaboration*, we found that our errors were up to two orders of magnitude smaller. This could be explained by the fact that our covariance matrix had between 15 and 20 orders of magnitude more than expected. In the future, this will be studied carefully, along estimating other cosmological parameters (such as $\Omega_{b,o}$ w_a), consider the intrinsic alignment power spectrum, finding the appropiate shot noise and improving efficiency.

References

[1] Rachel Mandelbaum. (2017). Weak lensing for precision cosmology

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