CMBXc mocks: simulations and covariances

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Abstract

This work describes the end-to-end lensing pipeline developed in CMBXc .
The pipeline starts from N-body numerical simulations, the DEMNUnii and DUSTGRAIN suite. These cover standard LCDM, dynamical dark energy scenarios, and other cosmological models as modified gravity, all in the presence of neutrinos.

The pipeline simulates different lensing observables, starting from the same realization of the Universe. We produce CMB-Lensing (kCMB convergence) and Weak Lensing Convergence maps which follows Euclid specifications. Besides, galaxy maps can be obtained from the same simulations, exploiting SHAM (SubHalo Abundance Matching) techniques applied in different cosmologies but fitted on observations. We exploit the use of the Quadratic Estimator (QE) to reconstruct lensing potential maps from lensed-CMB mocks, including Gaussian noise for the Simon Observatory (SO) experiment. Finally, we estimate covariances from full-sky maps to include the cross-covariance between CMB-lensing and the Euclid WL and GC_{ph} observables, needed for the full Euclid likelihood pipeline.

Another goal of this work is to compare cross-correlation between several lensing observables and matter tracers (WLxCMB-L, WLxISWRS, halosxWL, GCxCMB-L, GCxISWRS, GCxRecPhi, etc.) and quantify the impact of a different cosmological scenario on these cross-correlation signals.

Lensing simulations

This work is based on two suite of N-body cosmological simulations: the XL-DEMNUnii [1] and XL-DUSTGRAIN [2]. Both suite employ the same initial conditions and share the same setup, ie. number of particles and box size. In this work we consider only the DEMNUnii simulations with massive neutrinos and cosmological constant, while for the DUSTGRAIN we consider two different f(R) scenarios, again in the presence of massive neutrinos.
The maps of the different lensing observables are extracted with a post-processing procedure acting on the N-body snapshots to create a full lightcone. This procedure was developed to perform high-resolution CMB lensing simulations [3,4] in order to implement both a single and multiple lens ray-tracing algorithm in spherical coordinates on the full sky. In Figure 1 a schematic description of the pipeline.

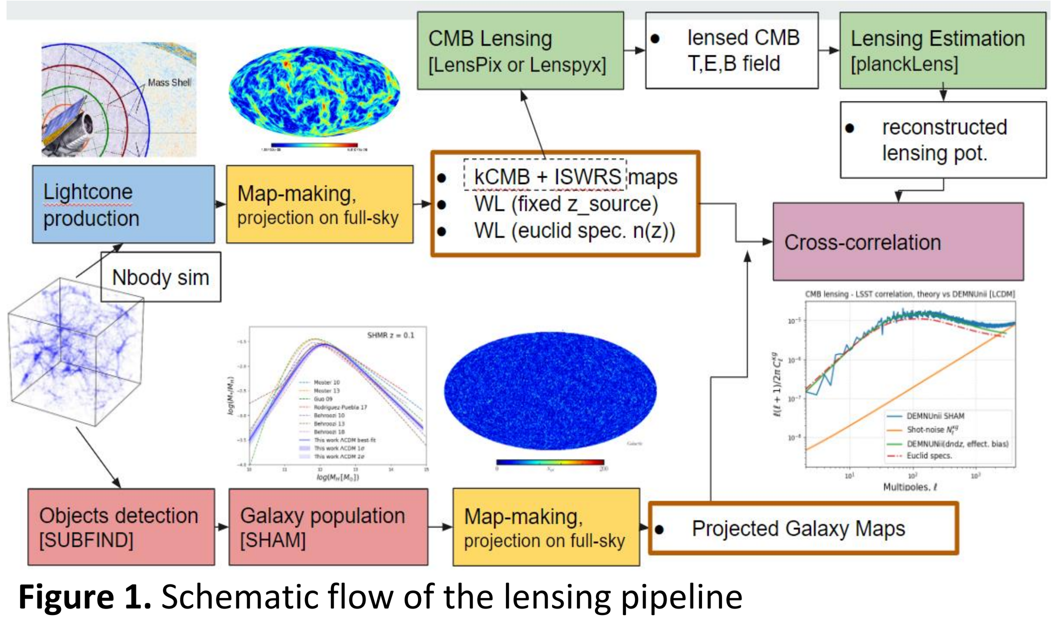

Figure 1. Schematic flow of the lensing pipeline

Results and validation

Lensing maps are compared with respect to semi-analytical realizations by pyCAMB, see Figure 2 for the case of the angular power spectra from CMB convergence maps, both in terms of absolute spectra (top panel) and ratio w.r.t. the ΛCDM case for all the different neutrino cosmologies considered. The pipeline is able to simulate the effect of the noise from a CMB experiment, as for the Simon Observatory [5] (see Figure 3) with high accuracy.

We include galaxy maps in our analysis by exploiting SHAM techniques to populate halos in the simulation [6,7]. Figure 4 shows the cross-correlation a.p.s. between the SHAM galaxy distribution and the reconstructed lensing potential. This signal is constructed following Euclid specifications in terms of effective galaxy bias and their redshift distribution [8,9], while correlating with a CMB lensing field reconstructed with a QE [10] estimator considering SO noise recipe.

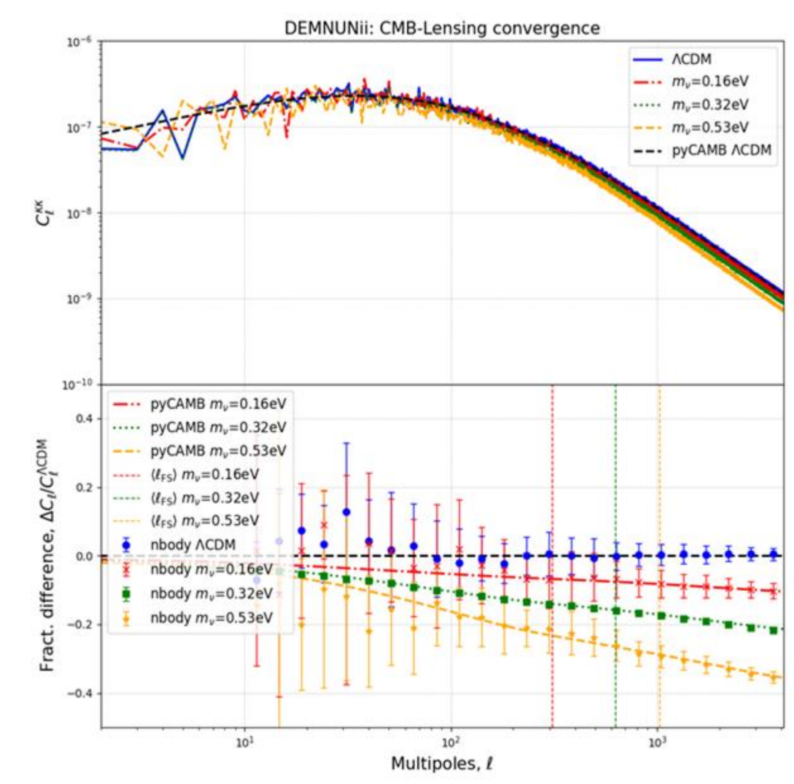

Figure 2. kCMB maps angular power spectrum; bottom panel fractional ratio with ΛCDM and comparison with pyCAMB. Different line colours for different neutrino mass.

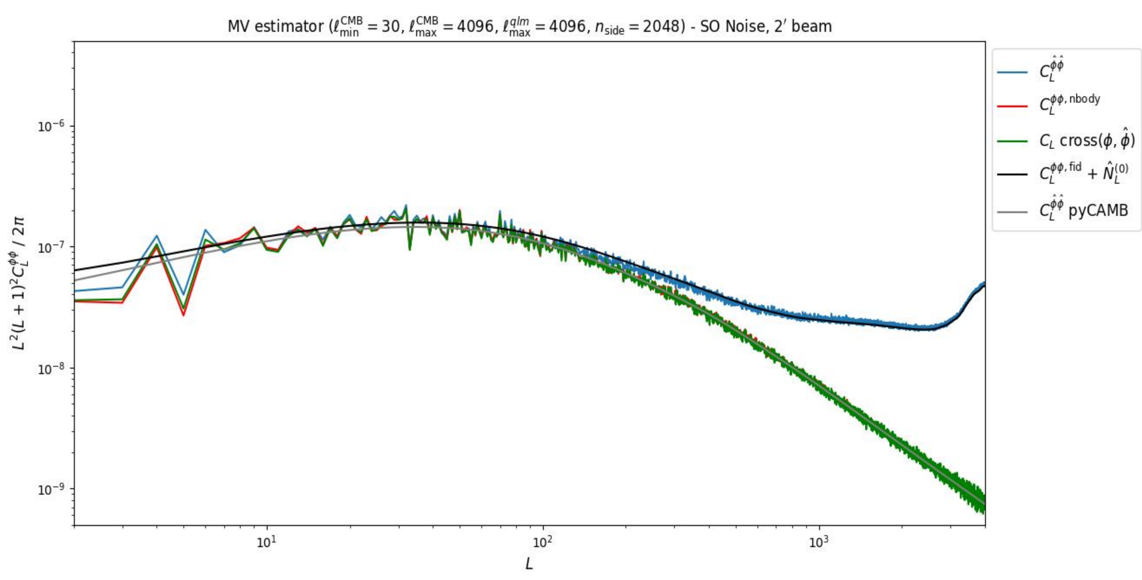

Figure 3. CMB lensing angular power spectrum, compared with semi-analytical signal. Blue line is the reconstructed lensing potential, green line is the cross between reconstructed ϕ and real-ϕ, compared with semi-analytical expectations (pyCAMB).

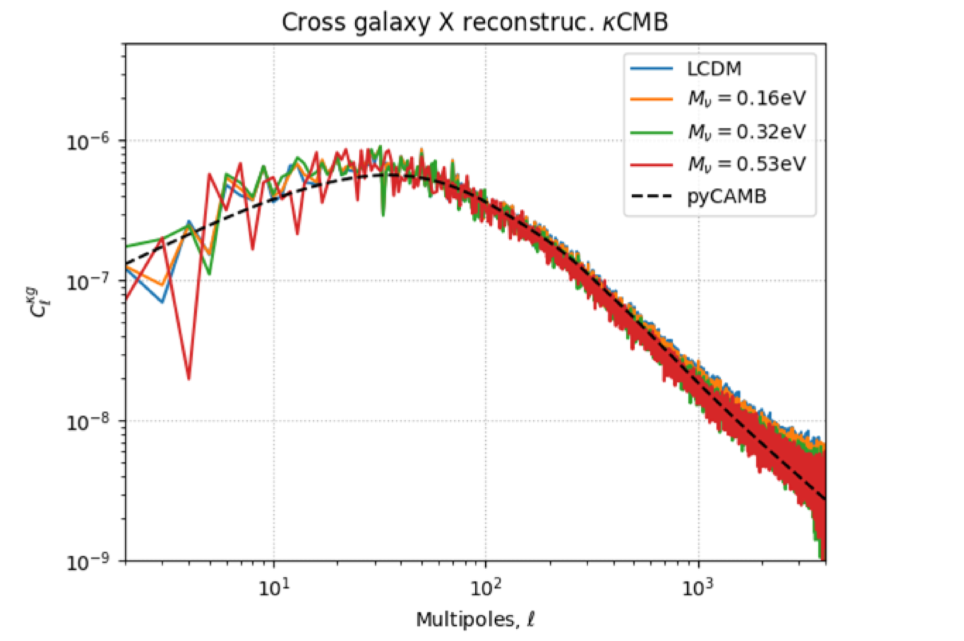

Figure 4. Cross angular power spectrum between the reconstructed lensing potential and galaxies, from different cosmologies. ϕ is reconstructed by the QE with a SO noise. Black line is the comparison with semi-analytical expectations.

Covariances simulation

We design a concurrent pipeline to compute full-sky maps exploiting the Flask [11] code. These maps, which are generated throughout a log-normal distribution, can be used to create a similar set of lensing observables as in our end-to-end pipeline.

These realizations are crucial to compute the cross-covariance of the primary Euclid probes with CMB-lensing, and to account for CMB lensing observable in the final Euclid cosmological parameter inference. We plan to include the QE in this pipeline as well, to account for the noise and specifications of the CMB experiment. In Figure 5 we show the comparison for two moments (skewness and kurtosis) of the distribution of Flask maps with a set of 50 maps extracted from 50 different N-body simulation (DEMMUni-cov). Finally, in Figure 6 we report the full (3x2pt)-CMB-L cross-covariance matrix for the ℓ=11 case.

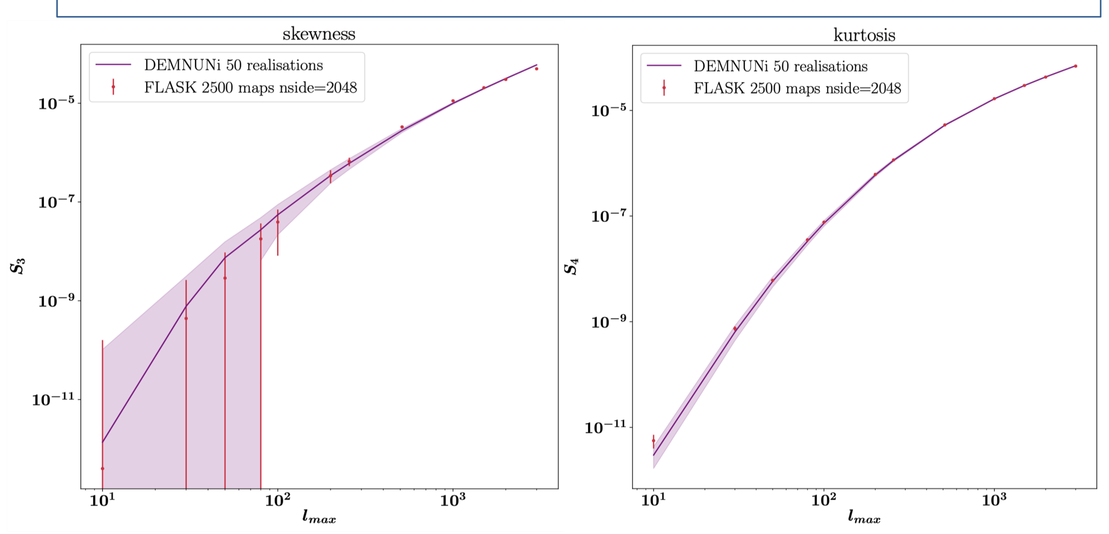

Figure 5. Skewness and kurtosis extracted as a function of ℓ_{max}, Flask maps compared with 50 DEMNUni-cov numerical simulations.

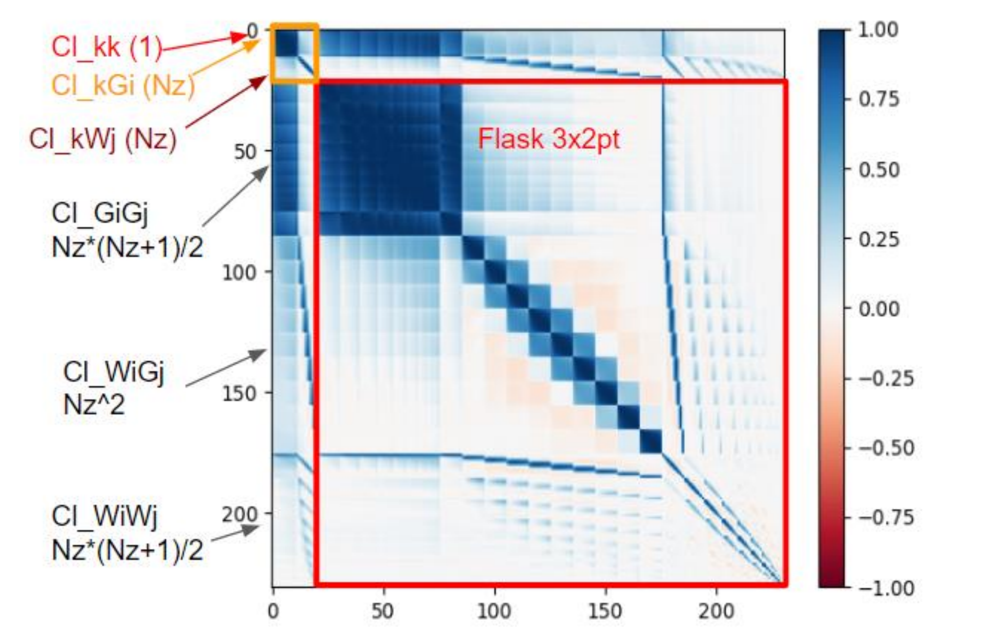

Figure 6. CMB lensing and (3x2pt), (3x2pt)-CMB-L cross-covariance matrix, computed with Flask maps.

Conclusions

In this work we have presented our end-to-end pipeline, which is able to simulate different full-sky lensing observables starting from a N-body simulation in several cosmological scenarios.
The pipeline computes different cross-correlation signals with matter tracers (SHAM galaxies): WLxCMB-L, WLxISWRS, halosxWL, GCxCMB-L, GCxISWRS, GCxRecPhi, etc., resulting in a full pipeline which can simulate both GC_{ph} e WL according to Euclid specifications. Besides, we have performed the map-based CMB lensing reconstruction with a QE, allowing to simulate the CMB lensing reconstruction noises for SO. Finally, we have developed a concurrent pipeline to generate many realizations of the Universe and numerically simulate an extended (3x2pt)-CMB-L cross-covariance matrix.

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References

1. Carbone, C., Petkova, M., & Dolag, K. (2016) J. Cosmology Astropart. Phys., 7, 034
2. Giocoli, C., Baldi, M., & Moscardini, L. (2018) MNRAS, 481, 2813
3. Fabbian G. et al, (2018) J. Cosmology Astropart. Phys., 2, 050
4. Calabrese M. et al, (2015) J. Cosmology Astropart. Phys., 3, 049
5. Simons Observatory Collaboration, JCAP 1902 (2019) 056. arxiv:1808.07455
6. E. Carella, C. Carbone et al., The galaxy-halo connection in the presence of dynamical dark energy and massive neutrinos (in prep.)
7. G. Girelli et al, A&A 634 (2020) A135
8. I. Tutusaus et al, A&A 643 (2020) A70
9. R. Laureijs et al. "Euclid definition study report." (2011) arXiv preprint arXiv:1110.3193
10. W. Hu and T. Okamoto, (2002) ApJ 574 566
11. http://www.astro.iag.usp.br/~flask/