P1 Field-level inference for weak lensing

Background

Standard cosmological analyses compress galaxy survey data into summary statistics — but this compression inevitably discards valuable cosmological information. Recent advances in differentiable simulations, Bayesian statistics, and machine learning now make it possible to analyse the *full field* directly, potentially improving cosmological constraints by a factor of 2-5. This project will apply these cutting-edge field-level inference techniques to real weak gravitational lensing data from the Dark Energy Survey (DES).

Project Goal

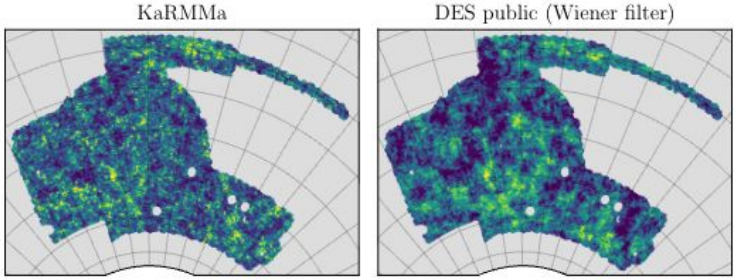
We will build a Bayesian field-level inference pipeline for analyzing weak lensing data and use it to reconstruct maps of the invisible (dark) matter distribution and infer cosmology at the field-level. Along the way, participants will develop hands-on experience with differentiable cosmological simulations and high-dimensional posterior sampling using Hamiltonian Monte Carlo (HMC). We will also explore how machine learning can be used to improve analytical models of the matter distribution. The central question we aim to address: *How much more cosmological information can field-level inference methods extract from Stage-IV weak lensing surveys compared to standard analyses?*

Necessary Concepts

Basic cosmology and weak gravitational lensing, Non-Gaussianity of cosmological fields, Markov Chain Monte Carlo (MCMC) methods, machine learning

Computing Need

Most of the analysis can be run on laptop, but will need access to a cluster for the later FLI runs.



Comparison of the mass map created using the Bayesian forward-modeling approach KaRMMa (left) and one of the publicly available maps. As you can see, the field-level method extracts more information from the same data and reconstruct smaller structures.

Background Resources

- FLI pipeline: 2204.13216,
- Bayesian mass maps from DES-Y3: 2403.05484,
- Machine-learning for fast WL maps (GANSky): 2406.05867
- *Weak lensing review*
- Data analysis recipes: *Fitting model to data*, *Markov Chain Monte Carlo*
- Lecture notes on *Field-level inference in cosmology*

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