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Beyond Summary Statistics: Leveraging Generative Models for Robust and Optimal Field-Level Weak Lensing Analysis

Deep learning (DL) methods have demonstrated great potential for extracting rich non-linear information from cosmological fields, a challenge that traditional summary statistics struggle to address. Most of these DL methods are discriminative models, i.e., they directly learn the posterior constraints of cosmological parameters. In this presentation, I will make the argument that learning the field-level likelihood function using generative modeling approaches such as Normalizing Flows usually leads to more effective extraction of cosmological information. This approach also enables anomaly detection to improve the robustness of the analysis. To scale the modeling to high dimensional data and improve its generalization capabilities, we further incorporate physical inductive biases, such as symmetries and multiscale structure, into the architecture of the normalizing flow models. On mock weak lensing maps, I will show that the model leads to significant improvement in constraining power compared to power spectrum and alternative DL models. I will also show that it is able to detect domain shifts between training simulations and test data, such as noise miscalibration and baryonic effect, which, if left unaddressed, could introduce systematic biases in parameter constraints. Finally, I will also show some preliminary results of our ongoing work on applying this model to the field-level cosmic shear analysis for HSC.

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