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Probabilistic Mapping of Dark Matter by Neural Score Matching

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We present a novel methodology to address ill-posed inverse problems, by providing a description of the posterior distribution instead of a point estimate solution. Our approach combines Neural Score Matching for learning a prior distribution from physical simulations, and an Annealed Hamiltonian Monte-Carlo technique to sample the full high-dimensional posterior of our problem.
In the astrophysical problem we address, by measuring the lensing effect on a large number of galaxies, it is possible to reconstruct maps of the Dark Matter distribution on the sky. However, presence of missing data and noise dominated measurement makes the inverse problem non-invertible.
We propose to reformulate the problem in a Bayesian framework, where the target becomes the posterior distribution of mass given the galaxies shape observations. The likelihood factor, describing how light-rays are bent by gravity, how measurements are affected by noise, and accounting for missing observational data, is fully described by a physical model. The prior factor is learned over simulations using a recent class of Deep Generative Models based on Neural Score Matching and takes into account theoretical knowledge. We are thus able to obtain samples from the full Bayesian posterior of the problem and can provide Dark Matter map reconstruction alongside uncertainty quantifications.
We present an application of this methodology on the first deep-learning-assisted Dark Matter map reconstruction of the Hubble Space Telescope COSMOS field.

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