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A Universal Prior for Galaxy Morphologies: Building a Diffusion Model from All the Observations

A major challenge in both simulation and inference within astrophysics is the lack of a reliable prior model for galaxy morphology. Existing galaxy catalogs are heterogeneous and provide an impure representation of underlying galaxy structures due to instrument noise, blending, and other observational limitations. Consequently, priors on galaxy morphology typically rely on either simplistic analytic models or more complex models trained on a limited subset of high-resolution observations. Building on previous work that leverages diffusion models to learn priors from incomplete data, we extend this framework to jointly learn two priors: one for uncorrelated light along random sightlines and another for light associated with galaxies. This approach enables us to learn a cleaner prior on galaxy morphology and to sample from the deblended posterior of an observation. We demonstrate our method's ability to robustly infer both distributions through empirical validation. We apply our framework to build a galaxy morphology prior using images from both the Legacy Survey and the HST COSMOS catalog, showcasing its adaptability across heterogeneous datasets. Finally, we illustrate the power of this learned prior for simulation-based inference by using it to significantly tighten dark matter constraints derived from strong gravitational lensing observations. Our results highlight the potential of data-driven priors to improve astrophysical modeling and inference in the era of large-scale sky surveys.

AI keywords

Diffusion models; Generative models; Simulation-based inference

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