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Large-Scale Gravitational Lens Modeling with Bayesian Neural Networks for Accurate and Precise Inference of the Hubble Constant

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We investigate the use of approximate Bayesian neural networks (BNNs) in modeling hundreds of time-delay gravitational lenses for Hubble constant (H0) determination. Our BNN was trained on synthetic HST-quality images of strongly lensed active galactic nuclei (AGN) with lens galaxy light included. The BNN can accurately characterize the posterior PDFs of model parameters governing the elliptical power-law mass profile in an external shear field. We then propagate the BNN-inferred posterior PDFs into ensemble H0 inference, using simulated time delay measurements from a plausible dedicated monitoring campaign. Assuming well-measured time delays and a reasonable set of priors on the environment of the lens, we achieve a median precision of 9.3\% per lens in the inferred H0. A simple combination of 200 test-set lenses results in a precision of 0.5 km s−1 Mpc−1 (0.7%), with no detectable bias in this H0 recovery test. The computation time for the entire pipeline – including the training set generation, BNN training, and H0 inference – translates to 9 minutes per lens on average for 200 lenses and converges to 6 minutes per lens as the sample size is increased. Being fully automated and efficient, our pipeline is a promising tool for exploring ensemble-level systematics in lens modeling for H0 inference.

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