X06a Accelerated Inference of Empirical Galaxy-Halo Connection Models

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The UniverseMachine (UM; Behroozi et al. 2019) provides a robust empirical framework for connecting galaxy properties to dark matter halo assembly histories through cosmological N-body simulations. A key feature of UM is its parameter posteriors given calibrating observations, enabling uncertainty quantification in galaxy-halo connection models. The model's 44-parameter space required extensive sampling and the original DR1 posterior inference consumed over a million CPU hours. With new observational constraints from JWST and other surveys, traditional MCMC sampling becomes computationally prohibitive for model recalibration. To address this computational bottleneck, we implement simulation-based inference to accelerate UM parameter inference by orders of magnitude. This approach trains neural networks on forward model realizations to directly estimate posterior distributions, reducing inference time from months to seconds while preserving full uncertainty quantification across the high-dimensional parameter space. Our method enables rapid recalibration of galaxy-halo connection models as new data becomes available, facilitating real-time constraints on galaxy formation physics. We demonstrate the technique's accuracy against traditional sampling methods and present updated UM calibrations incorporating recent observational datasets. This accelerated inference allows for live galaxy formation constraints, where the models can be updated in real-time as observations accumulate, fundamentally transforming empirical galaxy formation modeling in the era of large astronomical surveys.