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Physics-Informed Neural Networks for solving cosmological background equations in standard and extended cosmological models

Modern cosmology is grounded in the solution of the cosmological background equations, a system of differential equations obtained by applying Einstein's field equations to a homogeneous and isotropic Universe. These equations describe the large-scale evolution of the Universe and form the basis of modern cosmological models and the interpretation of observational data. Although analytical solutions exist for simplified scenarios, the inclusion of additional components, such as massive neutrinos and dynamical dark energy parametrizations, enlarges the cosmological parameter space and requires numerical methods to obtain accurate solutions. In recent years, Physics-Informed Neural Networks (PINNs) have emerged as an alternative approach for solving differential equations by incorporating the governing physical laws into the training process. This work proposes the use of PINNs to solve the background equations for the standard ΛCDM model and parametric dark energy models described by the Chevallier-Polarski-Linder (CPL), Jassal-Bagla-Padmanabhan (JBP), and Barboza-Alcaniz (BA) equation-of-state parametrizations, evaluating their performance in scenarios with a higher-dimensional parameter space by the inclusion of neutrinos and dynamical dark energy. The methodology will be validated through comparison of the predicted solutions with analytical and numerical solutions, using approximation error and computational cost as performance metrics. The expected outcome is a precise and computationally efficient framework for solving cosmological background equations, providing an alternative computational method for the study of both standard and extended cosmological models. Finally, since the temporal evolution of the Universe follows an inherently causal structure, where the state of the system at a given epoch depends on its state at earlier times, we discuss how incorporating causality into the PINNs framework affects convergence, accuracy, and computational efficiency in solving the cosmological background equations.

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