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DE-VAE: a representation learning architecture for a dynamic dark energy model

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We present DE-VAE, a variational autoencoder (VAE) architecture to search for a compressed representation of beyond-ΛCDM models. We train DE-VAE on matter power spectra boosts generated at wavenumbers $k \in (0.01 - 2.5)$ h/Mpc and at four redshift values $z \in (0.1, 0.48, 0.78, 1.5)$ for a dynamic dark energy (DE) model with two extra parameters describing an evolving DE equation of state. The boosts are compressed to a lower-dimensional representation, which is concatenated with standard CDM parameters and then mapped back to reconstructed boosts; both the compression ("encoder") and the reconstruction ("decoder") components are parametrized as neural networks. We demonstrate that a single latent parameter can be used to predict DE power spectra at all k and z within 2σ, where the Gaussian error includes cosmic variance, shot noise and systematic effects for a Stage IV-like survey. This single parameter shows a high mutual information (MI) with the two DE parameters, and we obtain an explicit equation linking these variables through symbolic regression. We further show that considering a model with two latent variables only marginally improves the accuracy predictions, and that a third latent variable has no significant impact on the model's performance. We discuss how the DE-VAE framework could be extended to search for a common lower-dimensional parametrization of different beyond-ΛCDM models, including modified gravity and braneworld models. Such a framework could then both potentially serve as an indicator of the existence of new physics in cosmological datasets, and provide theoretical insight into the common aspects of beyond-ΛCDM models.

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