

Reconstructing the Type Ia Supernova Absolute Magnitude with Two-Probe Physics-Informed Neural Networks

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We apply two variants of Physics-Informed Neural Networks (PINNs) to reconstruct the Type Ia supernova absolute magnitude $M_B(z)$ from joint BAO and supernova data under four cosmological models (Λ CDM, CPL, GEDE, Λ sCDM) and two DESI DR2 fiducial sets. A heteroscedastic single-network method tested across four constraint configurations establishes that the Etherington distance duality relation is more fundamental constraint than cosmological model priors, with DDR violations of 30–52 mmag under physical constraints versus 85–2330 mmag without. Under full constraints all models recover $M_B \approx -19.3$ mag with biases below 0.05 mag. A Fisher information-weighted two-network variant trains independent networks on BAO and SN data, providing clean probe separation and finding no significant M_B evolution in $z \in [0.3, 1.5]$. The heteroscedastic method identifies a persistent $2\text{--}3\sigma$ residual at $z \sim 0.4\text{--}0.5$ that is consistent across all four models and both fiducials; the Fisher method finds no significant pointwise deviation in $z \in [0.3, 1.5]$ but shows a systematic separation of redshift-binned M_B distributions consistent with the same underlying tension. While the origin of this feature remains ambiguous, its model-independence and cross-method consistency warrant further investigation with forthcoming data.

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