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Contributory: Testing Sub-Horizon Approximations in Interacting Dark-Sector Cosmology

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Sub-horizon and quasi-static approximations are widely employed in cosmological simulations to efficiently model the evolution of perturbations in theories beyond Λ CDM. However, their validity can depend on the underlying dark-sector physics and the scales being considered. In this work, we investigate these approximations in an interacting scalar-field dark-sector model, where dark matter and dark energy are coupled. We derive the full linear perturbation equations and obtain their sub-horizon and quasi-static limits, allowing a direct comparison between the approximate and full dynamics. We study the resulting evolution of matter perturbations and compare the interacting model with Λ CDM and a non-interacting scalar-field scenario. This provides a systematic assessment of when the approximations accurately capture the underlying perturbation dynamics and how dark-sector interactions can modify their validity. Our results are relevant for interpreting and improving the treatment of interacting dark-sector models in cosmological simulations and large-scale-structure studies.

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