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Machine-Learning Closure of Kinetic Plasma Turbulence in the Earth's Magnetosheath

Enabling multiscale modelling is a pivotal problem in plasma physics, which entails the need to couple global reduced-order (fluid) models with local, fully kinetic descriptions that capture microscopic particle dynamics. In this presentation, we address this challenge by studying decaying turbulence in the near-Earth magnetosheath using fully kinetic particle-in-cell (PIC) simulations. We apply machine learning techniques to extract a reduced-order model that estimates the pressure tensor in Ohm's law, thereby providing a closure of the fluid equations that incorporates kinetic corrections and demonstrably outperforms conventional double-adiabatic closures. We analyse the energy-transfer pathways and their correlation with coherent structures in the turbulent plasma. Moreover, we demonstrate that the learned model generalises beyond the training set, successfully reproducing key signatures of energy transfer, such as the statistical behaviour of pressure-strain interactions. We show that the anisotropies in the simulations are well bounded by microinstabilities. These results present a promising route toward embedding kinetically informed closures within multi-fluid models for space plasma applications.

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