

NEXT-GENERATION MHD MODELING OF SOLAR WIND USING NEURAL OPERATORS

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Traditional magnetohydrodynamic (MHD) solvers remain indispensable for modeling heliospheric plasma dynamics, yet their high computational cost and limited scalability hinder ensemble simulations and real-time forecasting. In this study, we propose a new framework employing neural operators to efficiently emulate 3D solar wind conditions learned directly from MHD simulation data. Our approach integrates observationally-derived multi-channel inputs and utilizes a hybrid training scheme, combining data-driven supervised learning with physics-informed constraints through embedded conservation laws. The neural operator demonstrates robust generalization capabilities, capturing complex heliospheric structures such as stream interaction regions and heliospheric current sheets.

By ensuring both physical consistency and fidelity to simulation data, our model offers a scalable and computationally efficient alternative to traditional MHD codes. This enables almost instantaneous generation of full 3D solar wind solutions with orders of magnitude faster than conventional codes. We will discuss challenges related to training stability, resolution of sharp structures, and ensuring physical realism, along with strategies such as coordinate-aware inputs and gradient-based diagnostics. This work demonstrates the transformative potential of neural operators as next-generation simulation tools in computational astrophysics and space weather forecasting.