

Development of a Neural Operator-Based Surrogate Model for Accelerated Gyrokinetic Transport Calculations

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The accurate prediction of turbulent transport in magnetically confined fusion (MCF) plasmas relies heavily on first-principles gyrokinetic simulations. However, the high computational cost of these calculations—often requiring weeks to months on high-performance computing platforms, presents a significant bottleneck for their inclusion in integrated modeling workflows and the rapid analysis of tokamak experiments. Consequently, the fusion community often relies on reduced-order transport models, such as TGLF, which necessarily trade some physical fidelity for computational tractability.

This work presents our progress in developing a machine learning (ML)-based surrogate model for δf flux-tube gyrokinetic simulations, aimed at overcoming this computational barrier. We leverage physics-informed neural operators, a class of deep learning models adept at learning the solutions to parametric partial differential equations, to create a fast and accurate surrogate. Our approach involves training the model on a database of high-fidelity gyrokinetic simulations spanning a wide range of physical input parameters.

In this presentation, we will detail the architecture of our neural operator model, the training methodology, and the current status of its development. We will showcase validation results against unseen gyrokinetic simulation data and discuss performance metrics, focusing on both accuracy and computational speed-up. The ultimate goal of this research is to create a surrogate capable of providing near real-time turbulent transport predictions. Such a tool could be a transformative component for advanced control strategies, experimental planning, and the eventual development of high-fidelity digital twins for fusion devices, thereby contributing to the international effort to accelerate fusion development.

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