SURROGATE MODEL FOR TURBULENT TRANSPORT USING DEEP LEARNING AND PLASMA PROFILE PREDICTION IN TOKAMAK PLASMAS

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Turbulent transport is a key factor in determining tokamak plasma confinement, directly impacting fusion energy efficiency. While first-principles gyrokinetic simulations provide high-fidelity predictions, their high computational cost limits their use in real-time optimization and control. Artificial intelligence (AI), powered by large-scale data, is increasingly shaping magnetic fusion research.

In this work, we develop a deep learning-based AI surrogate model to predict turbulent transport and plasma profile evolution under various operational scenarios. Our model is trained on high-resolution gyrokinetic simulations performed with the GTC code, as well as experimental data from the HL-2A tokamak. We explore plasma gradient space for the Cyclone Base Case and HL-2A parameters using nonlinear gyrokinetic simulations to generate datasets for typical electrostatic drift-wave turbulence. The primary electrostatic modes—ion temperature gradient (ITG)[1] and trapped electron mode (TEM)[2]—are classified and labeled using conventional methods.

To classify drift-wave turbulence types, we apply a support vector machine (SVM) with plasma gradients as input, achieving an accuracy of up to 98%. Additionally, we derive simple distance-based formulae for transport coefficients, enabling rapid turbulence classification and validating their effectiveness against gyrokinetic simulations [3]. Deep learning techniques, including neural networks, are then employed to develop surrogate models for turbulent transport across a broad range of tokamak parameters [Fig. 1]. Our models achieve R^2 values of up to 0.85 for nonlinear transport and 0.95 for linear growth rates [4].

Finally, we integrate our turbulence surrogate model into a transport model to predict plasma profile evolution in real experiments. These results demonstrate that AI-driven models can serve as efficient alternatives to conventional gyrokinetic simulations, enabling faster scenario modeling and facilitating real-time plasma control in future tokamak experiments. the information given in this template should enable to select the correct format for each section.

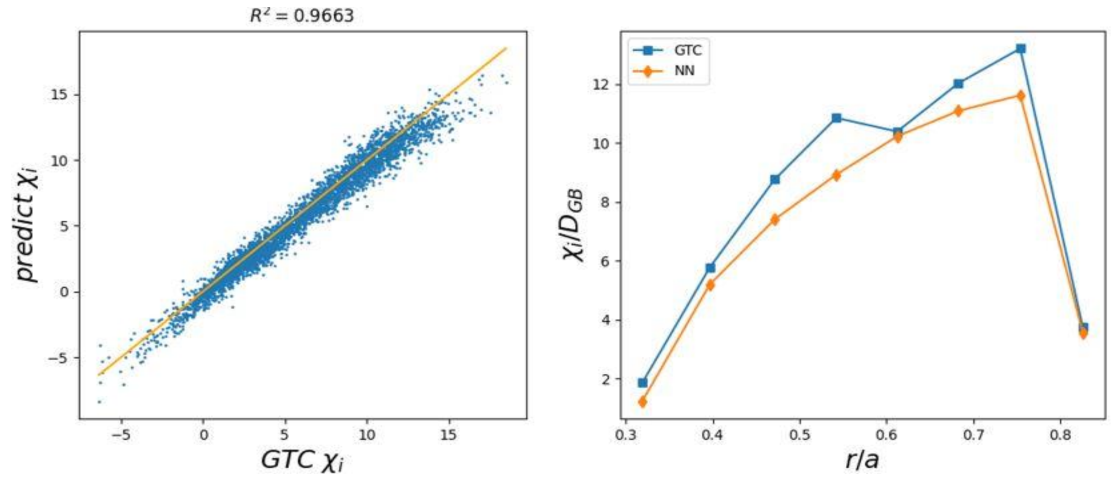

Figure 1: AI surrogate mode for turbulent transport using GTC data based on HL-2A parameters and deep learning

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