Data-driven multi-species heat flux closures for two-stream unstable plasmas

Emil Raaholt Ingelsten*[1], Madox Mcgrae-Menge[2], Paulo Alves[2], and István Pusztai[1]

[1]Chalmers University of Technology [Gothenburg, Sweden] – Sweden
[2]University of California [Los Angeles] – United States

Abstract

Satisfactory modelling of multi-scale collisionless plasma phenomena requires both physical accuracy and computational efficiency. While fully kinetic models are highly accurate, they are also computationally expensive, making large-scale full-system modelling infeasible. On the other hand, fluid models are significantly more computationally tractable, but finding accurate and sufficiently general closures for nonlinear phenomena has proven challenging. In recent years, however, data-driven methods like neural networks and sparse regression have started to pave the way for systematic construction of accurate and robust closures. In particular, sparse regression was recently used to identify an interpretable six-term model of the heat flux for the combined electron population in a two-stream unstable plasma (E.R. Ingelsten et al (2025), JPP). Here, we demonstrate how the same type of closure, with minor modifications, can be leveraged to model the two counter-streaming populations separately, allowing the fluid model to resolve the instability without manually inserting it through the closure. We also illustrate how nonlinear sparse regression can be used to determine the unknown coefficients for the three most important terms in the model with neural-network-equivalent accuracy, making the closure applicable over a range of relevant parameter values.

*Speaker