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Neural network based closures to fluid systems trained with kinetic simulations

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We develop a neural network based closure to the one-dimensional fluid moment equations derived from the Vlasov equation. This closure makes it possible to carry out plasma simulations in intermediate collisional regimes (Knudsen number ranging between 0.01 and 1) with a fluid model, cheaper than the kinetic model, and with more accuracy than the standard Navier-Stokes closure. Figure 1 shows examples of such simulations [1].

The neural network is trained to predict the heat flux of the plasma from its density, mean velocity and temperature, using data produced with kinetic simulations of the Vlasov-Poisson equation. We use a convolutional neural network with a V-Net like architecture, which allows it to capture non-local dependencies, and results in a global closure. Data generation and data processing are designed with the aim of ensuring uniform accuracy on a wide range of Knudsen numbers and initial conditions. We carry out numerical experiments to assess the accuracy and generalization ability of the neural network based closure.

Other papers have been published on using machine learning with kinetic models. For example in [2], the authors also make use of kinetic simulations to construct a reduced model. In [3], the authors evaluate the ability of several parameterized models to learn a given closure like the Hammett-Perkins closure. By comparison, our method leverages data from kinetic simulations to give the network the ability to learn a new closure.

References

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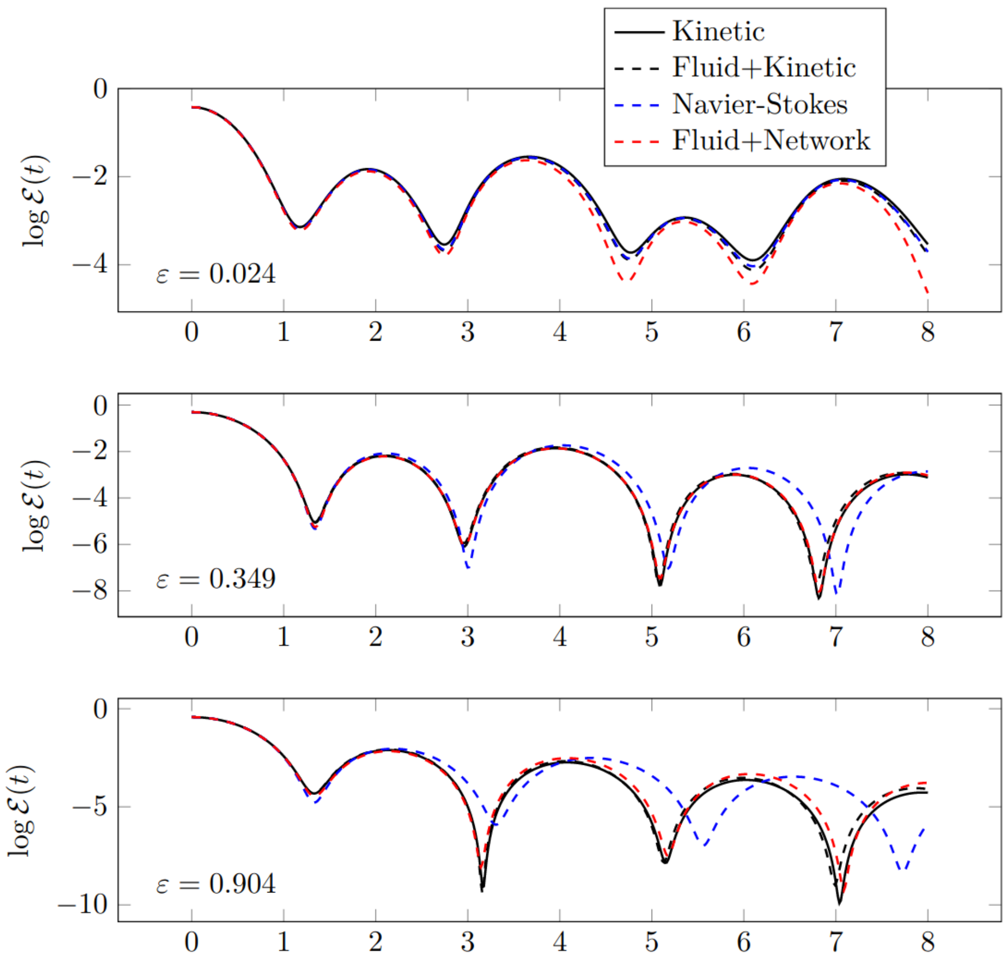

Figure 1: Electrical energy of the plasma in function of time, for different models: the kinetic model (Kinetic), and the fluid model using either the exact closure (Fluid+Kinetic), the Navier-Stokes closure (Navier-Stokes) or our network based closure (Fluid+Network). ε denotes the Knudsen number.