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Data-driven models for anomalous resistivity in collisionless plasmas

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Plasmas compose most of the visible universe. Understanding their dynamics could lead to advances in fields such as nuclear fusion and particle acceleration, but this is not a trivial task. The multi-scale nature of plasmas makes studying them extremely difficult since behavior at microscopic scales can influence the macroscopic dynamics of the system, and the opposite can also happen. This is a long-standing challenge in plasma physics given the lack of good analytical models to describe the interplay between the different scales, and the difficulty of modeling these systems computationally while capturing the nonlinear relations of phenomena at different scales.

The wide-scale range of plasma dynamics has led to the compartmentalization of plasma studies by either taking a fully kinetic approach to model microscopic behaviors or using fluid models to describe large-scale phenomena. Therefore, reduced models that can encapsulate the impact of microscopic physics on the macroscopic behavior of plasmas are crucial for accurately modeling them at various scales.

In this work, we will focus on collisionless plasma shocks, which are a quintessential multi-scale problem in plasma physics. In these scenarios, instabilities induce microscopic fluctuations that are manifested as an anomalous resistivity that affects the macroscopic behavior of the system.

In this PIC2, we aim to develop a foundational understanding of the physics and tools to be explored in the Thesis. In particular, to get a better grasp on collisionless plasmas and their multi-scale nature, we study in this work a mean-field fluid description of collisionless plasma shocks to obtain a relation between the average quantities of the system and the small-scale field fluctuations that create the anomalous resistivity observed in shocks. We also investigate the physical interpretation of the kinetic fluctuations that have more impact on the macroscopic behavior of the system. This method is evaluated on fully kinetic PIC simulations of collisionless shocks. This allows us to verify if the mean-field description retains relevant information about the shock that can be used to extract a reduced model of anomalous resistivity from simulation data using machine learning tools, which will be done as part of the Thesis.

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