Data-driven discovery of a heat-flux closure in a two-stream unstable plasma

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Global modeling of multi-scale collisionless plasma phenomena is a long-standing computational challenge. Even with state-of-the-art machines it is computationally infeasible to resolve the smallest scale kinetic effects within large scale, global domains relevant for fusion and astrophysical systems. Collisionless fluid models offer a more tractable alternative, calling for a systematic approach to constructing accurate closures – tailored to the phenomena in question – which capture the essence of the kinetic physics.

Here, we employ data-driven methods based on the SINDy algorithm [1, 2] for sparse symbolic regression to obtain a closure – an expression for the heat flux in terms of lower order moments – in a two-stream unstable plasma. Similar methodology for discovering governing equations of dynamical systems has been applied previously over a broad range of fields, but it has only recently been introduced in plasma physics [3].

Using particle-in-cell simulation data created with the OSIRIS code [4], we search for optimally accurate expressions for the heat flux at each given model complexity. We follow the time evolution of the closure across the evolution of an electrostatic two-stream scenario, from growth through saturation via the formation and merging of phase space holes. The expressions are interpreted in the context of the local approximation [5] of the Hammett-Perkins closure [6] that is constructed to capture Landau damping.

References

[1] S. L. Brunton et al., PNAS **113** 3932 (2016).
[2] S. H. Rudy et al., Science Advances **3** e1602614 (2017).
[3] E. P. Alves and F. Fiuza, Phys. Rev. Res. **4** (2022).
[4] R A. Fonseca et al., Comp. Science - ICCS 2002, 342–351, Springer Berlin Heidelberg (2002).
[5] J. Ng et al., Phys. Plasmas **27** 082106 (2020).
[6] G. W. Hammett and F. W. Perkins, Phys. Rev. Lett. **64** 3019 (1990).