Excitation of high frequency waves in non-linear 6D kinetic Vlasov simulation at tokamak conditions

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This contribution presents first of a kind 6D-Vlasov simulations focusing on high-frequency ion Bernstein wave turbulence for parameters relevant to the tokamak edge, showing transport levels comparable to sub-Larmor-frequency gyrokinetic turbulence. We demonstrate the destabilization of these waves in the presence of steep temperature and density gradients. The growth rates can exceed those of the ITG instability, especially with the presence of a density gradient. Our simulations accurately reproduce the predicted growth rates in both local gradient setups and when applying a non-linear treatment of the gradients [4].

With the increased computational capabilities in recent years, it has become possible to simulate increasingly complex and accurate physical models. Gyrokinetic theory was introduced in the 1960s and 1970s to describe plasmas with more accuracy than with fluid models, while eliminating the complexity of the fast gyration of the particles around magnetic field in 6D kinetic models. Although current gyrokinetic simulations show fair agreement with experimental results in core physics, crucial assumptions made in the derivation make it unreliable in regimes with higher fluctuations and stronger gradients, such as the tokamak edge.

Experimental results from the PLT (Princeton Large Torus) tokamak at the Princeton Plasma Physics Laboratory (PPPL) have demonstrated the suppression of fluctuations by injecting high-intensity ion Bernstein waves (IBWs). These studies focus on the observed effects of externally induced IBWs but do not fully explain the underlying mechanisms. IBWs disrupt the gyrokinetic approximation, making current gyrokinetic turbulence and stability codes inadequate for studying their intrinsic stability or their impact on energy and particle transport. Simulating the excitation of IBWs would be a crucial step towards a more comprehensive understanding of the high-frequency regime at the plasma edge.

We have developed an advanced and scalable semi-Lagrangian solver tailored for the 6D kinetic Vlasov system. This solver incorporates a highly efficient scheme to address the $\boldsymbol{v} \times \boldsymbol{B}$ acceleration resulting from the strong background magnetic field [1, 2]. This allows us to simulate the excitation of plasma waves and turbulence with frequencies extending beyond the cyclotron frequency, without being limited by gradient strength or fluctuation levels [3]. The solver has undergone rigorous testing in the low-frequency regime, consistently providing accurate results for dispersion relations and energy fluxes in both linear and non-linear scenarios [5]. Having a tool that precisely captures turbulent transport is crucial, given the significant influence of edge turbulence on the confinement properties of magnetically confined plasmas. Despite the associated high computational costs, considering 6D kinetic effects becomes indispensable for a comprehensive understanding of edge physics.

References

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