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Electron scale current sheets in kinetic Alfvén wave turbulence

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Kinetic Alfvén waves (KAWs) are simulated using 3D particle-in-cell(PIC) simulations by using the eigenvector relations of electric, magnetic, velocity, and density fields of KAW from two fluid model[1,2]. The 2D two-fluid model eigenvector relations are converted into 3D using the rotation of the reference frame before using them in 3D PIC simulation. A superposition of several KAWs at scales larger than ion-skin depth is used to initialize the simulation. Similar method is used to simulate whistler waves[1] in the PIC simulation. The magnetic, velocity, and density perturbation ratios for both the wave modes obtained analytically and from simulations are compared. We find that both the simulations, i.e., either initialized with KAWs or whistler waves, show perturbation ratios that are close to KAWs at later times of simulation. This indicates the dominance of KAWs in comparison to Whistler waves at these scales. The perpendicular wavenumber magnetic spectrum also matches the ion-transition range of the solar wind power spectrum.

We investigate the dependence of intermittent current sheet structures at kinetic scales. For this we run simulations with three different mass ratios, keeping the same ion and electron temperatures $(T_i/T_e \sim 1)$ and also the same plasma beta. This is achieved by adjusting the thermal velocities of electrons and ions accordingly. Time evolution of $\delta B_{rms}/B_0$ is obtained, which shows the same behavior for all three simulations, indicating the same level of turbulence in these simulations. Looking at the current density for these three simulations, we find current sheets being formed at later times, as shown in the figure below. Two methods, namely the Breadth First Search(BFS) clustering algorithm and the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm, are used to identify the current sheet structures. We identify current sheets in the 2D x-y plane and also in full 3D. We find that in 2D and 3D, both algorithms identify similar current sheets, with some differences where these two methods complement each other. In 2D, we find that the thickness of current sheets decreases with increasing mass ratio. In 3D, we find this behavior is more pronounced, and the average thickness of the current sheets scales as the inverse mass ratio. Since increasing the mass ratio pushes the electron scale to smaller values, this indicates that the electron scale current sheets are being formed in these simulations. We also obtain the variation of second and higher-order structure functions with length l. The slope of structure-function decreases with decreasing l indicating the presence of sharp gradients and structures at smaller scales. Scale-dependent Kurtosis is calculated which shows the presence of sub-proton and electron scale intermittency in the simulations, which is similar to observations in magnetosheath and solar wind turbulence.

References

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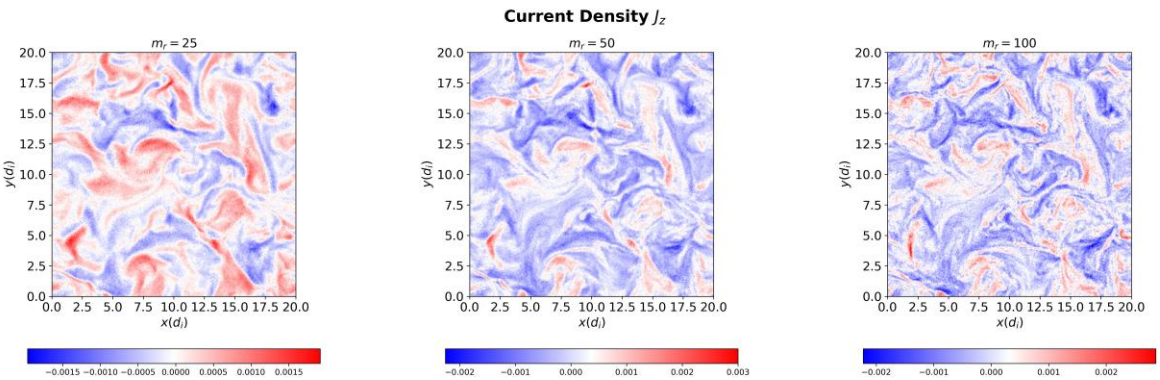

Figure 1. Current density J_z in plane perpendicular to mean magnetic field from three simulations with mass ratios 25, 50, and 100 (from left to right) at time $\omega_{p,i}t = 600$.