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Ion-driven and electron-driven waves in Earth's bow shock

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The collisionless shock involves various kinds of plasma instabilities in its transition layer, ranging from the smallest Debye scale to the magnetohydrodynamic (MHD) scale. Understanding the instabilities and the generated wave properties is crucial for the physics of collisionless dissipation at the shock. The acceleration of non-thermal particles through the standard diffusive shock acceleration (DSA) and the more recently proposed stochastic shock drift acceleration (SSDA) require a certain level of electromagnetic fluctuations, most likely driven by plasma instabilities.

While there has been a long discussion of kinetic instabilities in and around the shock transition layer, instability analyses have typically been performed on a case-by-case basis under simplifying assumptions such as spatial homogeneity. The actual transition layer of the shock is much more complicated, with highly inhomogeneous density and magnetic field structures. It is also likely that waves of different types interact nonlinearly with each other. Although in-situ observation at Earth's bow shock provides valuable information for understanding complicated nonlinear phenomena, it is often difficult to disentangle physics from observation alone.

We present the result of Particle-In-Cell (PIC) simulations of collisionless quasi-perpendicular shocks for the parameter regime relevant to Earth's bow shock. We find various wave activities, including electrostatic ion-acoustic-like waves, quasi-parallel and oblique whistler waves, and Alfven-ion-cyclotron waves. We compare shocks of different ion plasma betas with all the other parameters being fixed. The intention of this comparison is to separate the sources of waves, i.e., either ion-driven or electron-driven. The higher ion beta shocks are more laminar and dominated by whistler waves likely generated by electrons. On the other hand, large amplitude and low-frequency magnetic fluctuations dominate the shocks of lower ion beta, suggesting that the reflected ions are the source of instability. We discuss the impact of the ion-driven waves on the electron-driven waves and possible ways to distinguish the waves of different origins.