Relation between Alfven-ion-cyclotron and Weibel instabilities in the collisionless perpendicular shock transition region: Upstream plasma parameter dependence

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One of the most important problems in space physics is the mechanism by which charged particles accelerated to non-thermal energies. The collisionless shocks in plasmas have been studied extensively observationally, numerically, and theoretically, since they are believed to be the major sources of non-thermal high energy particles through the first-order Fermi acceleration. In this study, we investigate plasma instabilities in the collisionless shock transition region. In a collisionless shock wave having a sufficiently large Alfven Mach number, some of the upstream ions are reflected by a potential barrier in the shock. A variety of instabilities excitedby the velocity difference between the reflected ions and the upstream ions play a crucial role in the dissipation at the shocks.

Low-frequency and long-wavelength instabilities generated in the transition region may have large saturation levels, and can affect the entire shock stricture. In particular, we focus on Alfven Ion Cyclotron (AIC) instability and Weibel instability, both of which are excited by an effective temperature anisotropy generated by the reflected ions. It is well known that the AIC instability generates a rippled shock surface (Winske & Quest, 1988). On the other hand, the Weibel instability dominates at very high Mach number shocks as seen in supernova remnants. Large-scale Particle-in-Cell simulations have found electron acceleration in spontaneous magnetic reconnection generated in the amplified magnetic field and dense current filaments (Matsumoto et al., 2015). This electron acceleration may play an important role in pre-acceleration required for the Fermi acceleration. Qualitatively, the Weibel instability will be the dominant mode at very high Mach numbers (or weak magnetic field), and otherwise, the AIC instability should be dominant. However, the relation between the two instabilities has not been understood.

In this study, we adopt an idealized model for describing the dynamics in the shock transition layer. We consider a homogeneous plasma in the upstream rest frame, which consists of three particle species: the upstream ions, upstream electrons, and reflected ions. The initial velocity distributions are assumed to be Maxwellian distributions for the upstream ions and electrons while the reflected ions form a ring distribution in the direction perpendicular to the ambient magnetic field. Under these conditions, we performed linear analysis for a wavenumber parallel to the ambient magnetic field using the cold plasma approximation. We found that the AIC and Weibel instabilities both appear from single dispersion relation in different limiting cases. In other words, the AIC instability changed to Weibel instability in the limit of no magnetic field (or infinite Mach numbers). Two-dimensional Particle-in-Cell (PIC) simulation also shows that, as the Alfven Mach number increased, the generated mode structure changes from AIC-like to Weibel-like. In this presentation, we will report simulation results on the transition between the two different regimes and how it depends on upstream physical parameters such as the Alfven Mach number and ion-to-electron mass ratio.

Keywords: collisionless perpendicular shock, Alfven-ion-cyclotron instability, Weibel instability

