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Transition of dominant ion-scale instabilities and conditions for magnetic reconnection in strong perpendicular shocks

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It is well known that the energy distribution of particles in space is usually not represented by a thermal Maxwellian distribution but has a high energy power-law tail called "non-thermal particles". Collisionless shock waves, generated by supernova remnant shocks and solar flares, are considered to contribute significantly to the generation of such high energy particles. The first order Fermi acceleration is thought to be the primary particle acceleration mechanism, which requires some mechanisms that pre-accelerate from thermal to an intermediate energy. Extensive studies on the pre-acceleration mechanisms have been conducted over the years. In high Alfven Mach number shock waves, ions are partially reflected by the shock front, various instabilities can be excited by the velocity difference between three particle species, i.e. the incoming electrons, ions and reflected ions. Some of these instabilities play a crucial role in electron pre-acceleration.
In this study, we investigate plasma instabilities in the perpendicular shock transition region. 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. The AIC instability via the ion cyclotron resonance generates a rippled shock surface, while the Weibel instability has been shown to generate folded current sheets, which eventually dissipate via magnetic reconnection to accelerate electrons (Matsumoto et al., 2015). Qualitatively, the Weibel instability will be the dominant mode at very high Mach numbers (or weak magnetic field), and otherwise, the AIC instability should dominate. However, the exact relation between the two instabilities has not been fully understood.
In our study, we adopted a local model focusing only on the transition layer and investigated the dependence of instability on upstream physical parameters such as Alfven Mach number, cyclotron frequency/plasma frequency ratio, electron/ion mass ratio. We consider a homogeneous plasma in the upstream rest frame and as the initial distribution, incoming electrons and ions have a Maxwellian distribution, while reflected ions have a ring distribution. We performed linear analysis for the three-component plasma model and found that the AIC and Weibel instabilities both appear from a single dispersion relation in different limiting cases. We found that the maximum growth rate of waves propagating parallel to the ambient field depends largely on Alfven Mach number, ring ion plasma beta and ring ion ratio among the upstream parameters. We also examined Particle-in-cell simulations and confirmed that the growth rates are in agreement with the linear theory. The result of our parameter survey has shown that (1) the transition between the AIC and Weibel instabilities is around where the maximum growth rate reaches about ~7/ion cyclotron frequency, (2) Magnetic reconnection is observed in the ring distribution model, but only for extreme conditions (M_A ? 100, n_r/n_0 ? 0.5), (3) when the reflected ions are represented by a beam distribution, magnetic reconnection is more active than the ring model under similar conditions. In this presentation, we will report linear analysis and simulation results especially focusing on the transition between the AIC and Weibel instabilities, the conditions for the magnetic reconnection and the difference between the ring and beam distribution models.