Nonadiabatic electron heating in a high Mach number collisionless perpendicular shock : Vlasov simulations.

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We have performed Vlasov simulations of collisionless perpendicular shock waves. Vlasov simulations provide a precise description of plasmas because of the absence of the numerical noise which is intrinsic in the hybrid and the particle codes. This excellent property of the Vlasov simulations enables us to describe the nonlinear processes more accurately.

First, the basic structure of perpendicular shock which was found by early numerical studies is confirmed. The reflected ions are observed at the shock front and the foot is formed in front of the magnetic overshoot because of the accumulation of the reflected ions.

In a low Alfven Mach number and moderately high plasma beta shock, the shock structure is quasi-stationary and the shock front is almost stable. In addition, the magnetic field strength varies smooth in the ion dynamics scale without any fluctuation of electron inertia scale. On the other hand, in a high Alfven Mach number and/or low plasma beta shock, the dynamic behavior of the shock front is observed. The main characteristics of the shock structure (foot, ramp, overshoot) remain the same as the low Mach number shock, however, the magnetic field strength at the overshoot oscillates in time. Hence the density of the reflected ions also oscillates at the same cycle of the overshoot.

The behavior of this cyclic self-reformation process is consistent with previous hybrid and particle-in-cell code studies.

Next, we have found the nonadiabatic electron heating which is associated with the electron inertia scale electrostatic waves excited by the reflected ion beam in the foot region of the low beta shock. Unlike the conventional particle codes, our noiseless Vlasov simulation code enables us to find out this weak waves which amplitude is of the order of the upstream motional electric field. We also find a clear dependence on the upstream plasma beta of this nonadiabatic heating. We have identified that the observed electrostatic wave is ion acoustic wave by the dispersion analysis. The beta dependence of the growth rates is also confirmed, which is consistent with the observed dependence of the nonadiabatic heating.