Microturbulence in the foot of a supercritical shock: evidence of cyclotron instability

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We have performed one-dimensional full particle simulations of perpendicular shocks and found that an electron cyclotron microinstability can develop in the foot of supercritical shocks. For such shocks, a certain percentage of incoming ions are reflected and are responsible for the cyclic self-reformation of the shock front in low-β plasmas [1,2]. One surprising result is that this instability arises even when the supercritical shock has a relatively low (but still supercritical) Mach number. The instability is periodically excited by the beam of reflected ions interacting with the electrons during each self-reformation cycle. It exhibits a rapid growth, and propagates along the shock normal towards upstream. As its phase velocity is close to the beam velocity, it has a noticeable impact on both the populations of reflected ions and electrons, but does not interact with the incoming ions. This instability has a frequency comparable to the electron cyclotron frequency and a wavelength shorter than the electron inertia length. It is mainly electrostatic and basically results from the coupling of electron Bernstein waves with an ion beam mode carried by the reflected ions. Fig.1 shows a snapshot at a time when the microinstability is well developed. The latter is visible ($x \sim 65\, c/\omega_{pe}$) in the electron density N_e and the electrostatic field E_x.

Dispersion properties encountered in the foot are analysed and are found in very good agreement with results obtained self-consistently from the present simulations. A theoretical model is developed in order to get an estimate of the instability wavelength versus the main plasma parameters. From this model, we analyze the effects of varying simulation parameters, as the fake ion-to-electron mass ratio and the reduced electron plasma-to-gyro frequency ratio used in the simulations converge to more realistic values. In particular, it is shown that raising the ion-to-electron mass ratio alone shortens the wavelength , while raising the other ratio alone elongates the wavelength. These theoretical results are found in good agreement with those issued from two complementary simulation runs. As a consequence, increasing both ratios towards more realistic values compensates each other, which makes the electron cyclotron instability a promising candidate to account for the electrostatic microturbulence in the shock front. At least, criteria for evidencing this instability are clearly identified. Present results are quantitatively compared with old/recent full particle simulations of shocks in order to clarify why the electron cyclotron instability had not been evidenced previously within a self-consistent approach [1,2].

REFERENCES

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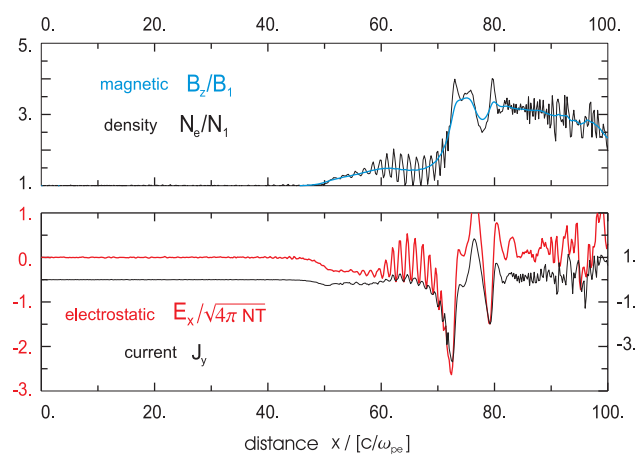

Figure 1: Snapshot at a time when the instability is well developed. Top: magnetic field B_z and electron density N_e normalized to their upstream value. Bottom: electrostatic field E_x and diamagnetic current J_y.