Geophysical Research Abstracts
Vol. 19, EGU2017-8780, 2017
EGU General Assembly 2017

Identification of two types of whistler instabilities excited in the foot of quasi-perpendicular supercritical shocks: a Poynting flux analysis

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Supercritical shocks in collisionless plasmas are characterized by the presence of a noticeable fraction of ions that are reflected off of the shock front and form a foot upstream of the ramp. These ions carry a significant amount of energy; they are the source of microturbulence within the shock front itself and play a key role in transforming the directed bulk energy (upstream) into thermal energy (downstream). For quasi-perpendicular geometries and as seen in the normal incidence frame (NIF), the velocity of the reflected ions is mostly directed at 90° to the magnetic field $\mathbf{B_o}$. Streaming instabilities can develop, which are excited by the relative drifts between the populations of incoming ions, reflected ions, and electrons across $\mathbf{B_o}$ in the shock's foot. Two types of waves from the whistler branch and with frequencies in the lower-hybrid range are shown to be unstable:
1) Oblique waves with wavelengths a fraction of the ion inertia length which propagate toward upstream at angles about 50° to $\mathbf{B_o}$.
2) Quasi-perpendicular waves with wavelengths several times the electron inertia length which propagate toward downstream at angles larger than 80° to $\mathbf{B_o}$.
For each type of whistler we perform electromagnetic pseudo-oblique 1D PIC simulations. These are carried out in the proper frame where the total momentum density vanishes. Field data issued from the simulations are used to construct hodograms and compute the Poynting fluxes. We apply the Lorentz transformation in order to express the results in the shock frame, specifically the normal incidence frame. The outcome is then discussed and compared to previous simulations *[Comisel et al, Ann. Geophys. 29, 2011]* and to measurements at Earth's bow shock from Cluster *[Sundkvist et al, PRL 108, 2012]* and more recently from the MMS mission .