Microturbulence within the foot of quasi-perpendicular supercritical shocks: Poynting flux analysis of whistler instabilities with PIC simulations

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Extended Abstract

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 magnetic foot upstream of the shock 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, the speed of the reflected ions is mostly directed at 90° to the magnetic field $\mathbf{B_o}$ in the normal incidence frame (NIF). 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 with frequencies in the lower-hybrid range are excited :

1. Oblique waves with wavelengths equal to a fraction of the ion inertia length which propagate toward upstream at angles $\theta_1 \approx 50^\circ$ to $\mathbf{B_o}$.
2. Quasi-perpendicular waves with wavelengths several times the electron inertia length which propagate toward downstream at angles $\theta_2 > 80^\circ$ to $\mathbf{B_o}$.

We point out that our plasma is characterized by a double anisotropy: one defined by the direction of $\mathbf{B_o}$, the other by the drift of the reflected ion beam $\mathbf{V_d}$. Let $\psi = (\mathbf{B_o}, \mathbf{V_d})$ be the plane that is defined by these two directions. We perform electromagnetic pseudo-oblique 1D PIC simulations where the direction of unstable wavevectors $\mathbf{k}$ is set to lie within the plane ψ. Coordinates are chosen such that the x-direction is given by $\mathbf{k}$, the y-direction is perpendicular to ψ and the z-direction is orthogonal. Field data issued from the simulations have components along the three x,y,z directions, which are used to construct hodograms and compute the components of the Poynting flux:

$$
\begin{aligned}
S_x &= \Gamma < E_y B_z - E_z B_y > \\
S_y &= -\Gamma < E_x B_z > \\
S_z &= -\Gamma < E_x B_y >
\end{aligned}
\tag{1}
$$

where $<>$ means an averaging over some periodicity in the fields and $\Gamma \equiv c/(4\pi)$. Results show that the complex polarization of the waves includes an electrostatic component E_x, so that the Poynting vector needs not be parallel to $\hat{x}$. In fact, whereas $< E_x B_z >$ averages to zero, $< E_x B_y >$ does not. Hence, the Poynting vector lies in the plane ψ. Two series of simulations are carried out for, respectively, θ_1 and θ_2. The outcome is discussed and compared to previous simulations [1] and to measurements at Earth's bow shock from Cluster [2]. Moreover, the high resolution experimental data of the recent multi-satellite MMS mission could be a very powerful tool in order to analyze/verify the present results in detail.

References

[1] H. Comisel, M. Scholer, J. Soucek, and S. Matsukiyo, *Ann. Geophys.*, **29**, 2011, pp. 263–274.

[2] D. Sundkvist, V. Krasnoselskikh, S.D. Bale, S.J. Schwartz, J. Soucek, and F. Mozer, *PRL*, **108**, 2012, 025002.