SOUTHWEST RESEARCH INSTITUTE

Charged particle dynamics at very high Mach number Quasi-perpendicular shocks

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MMS Science Working Team Virtual Meeting

April 2020

Introduction: We surveyed MMS data for instances of quasi-perpendicular bow shock crossings, and when the upstream Alfvèn Mach number is greater than 25. This type of highly supercritical shocks is rarely observed in near Earth space environment. We found four events that met the criteria. In the following slides we present some details of ion dynamics and wave activities during one of these events. Although each event has its unique characteristics, what we discuss here are, with varying degrees, also observed at other events.

Overview of the shock and background

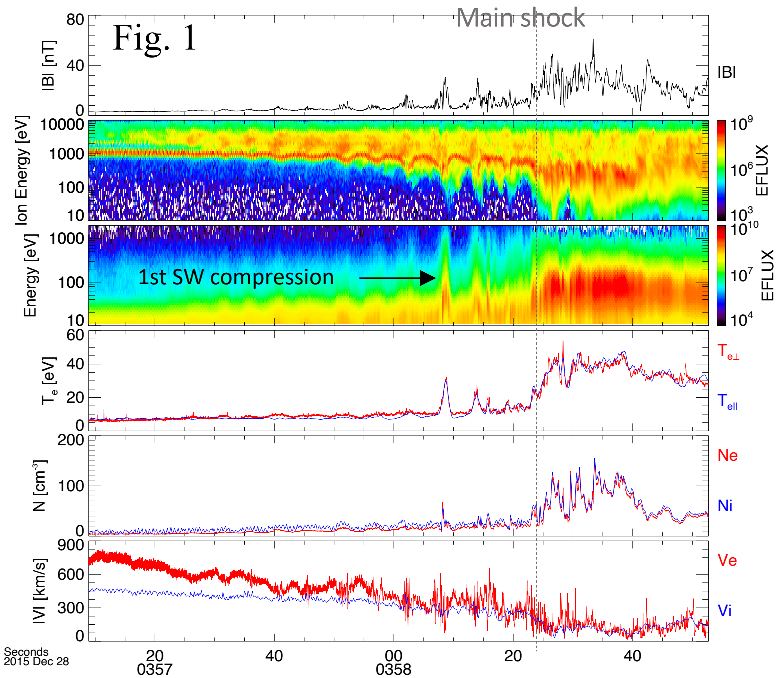
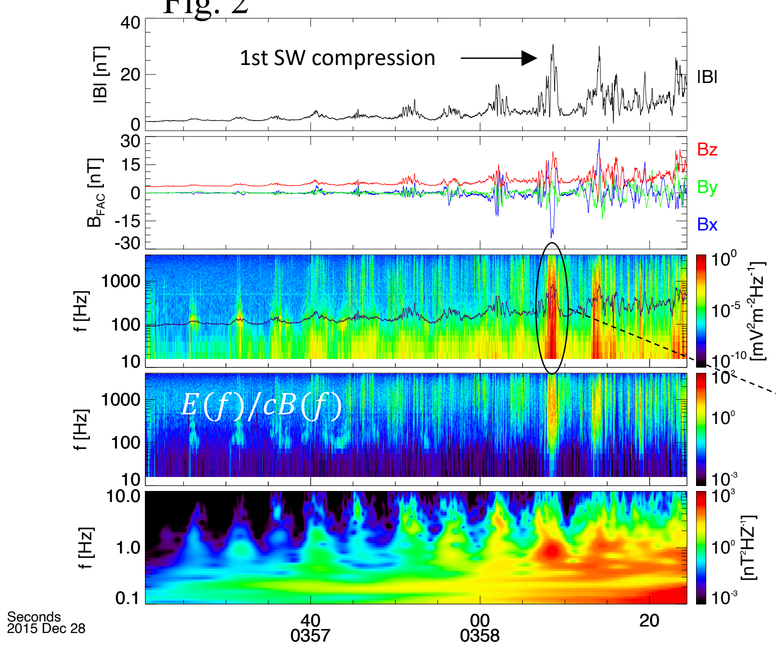


Fig.1 shows a non-stationary quasi-perpendicular shock, characterized by modulated enhancements of B and N in the foot region of the shock. Periodic wave activities in the upstream change into episodic compressions closer to the shock (Fig. 2). The Mach number for this shock far exceeds the nonlinear Whistler critical Mach number, and Whistler waves cannot propagate upstream. Significant isotropic electron heating is observed in the foot with broadband ESWs (electrostatic solitary waves), associated with unipolar structures in the electric field (Fig. 3).

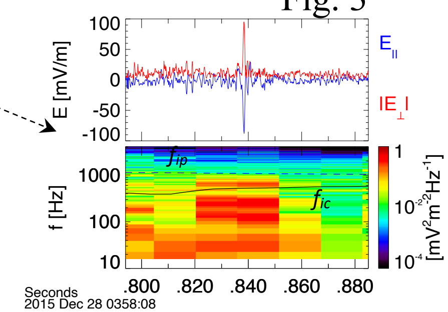
Upstream wave properties:

Waves have an average period of ~5 s, or 0.2 T_{ic} , enough time for reflected ions to gyrate in the upstream and return to the shock.

Events:	28 Dec 2015, 03:58:25
V_{SW} [km/s]	465
β	9.6
M_{Alf}	28.37
M_{ms}	9.3
θ_{bn}	79.87
T_{ic}	25 s
B_{IMF} [nT]	2.66
n_{SW} [cm^{-3}]	4.49
V_{shock} [km/s]	83.6
$\vec{n}_{shock}$ (GSE)	(0.94, 0.23, -0.21)

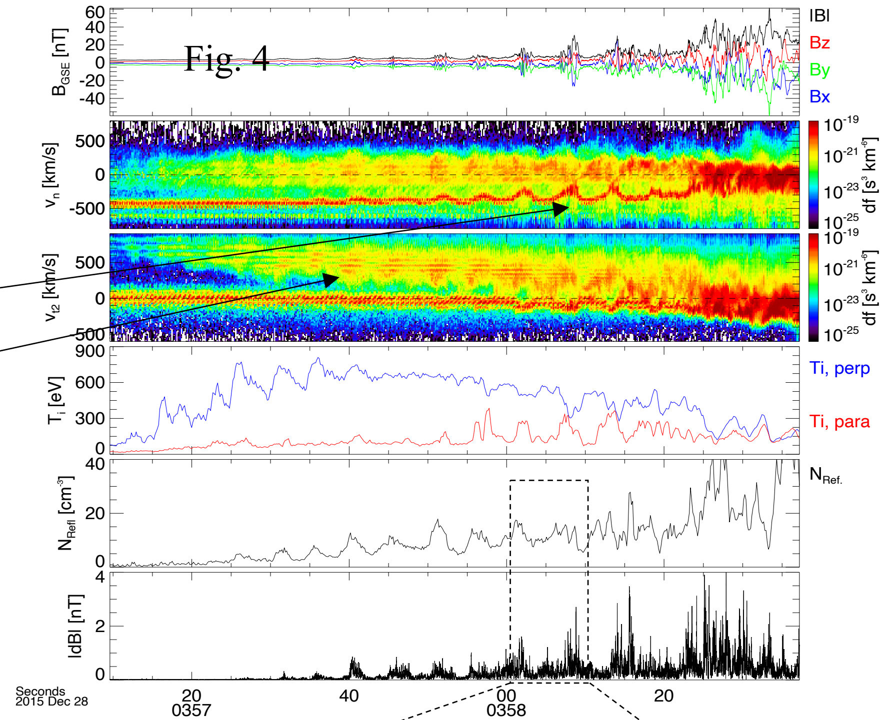


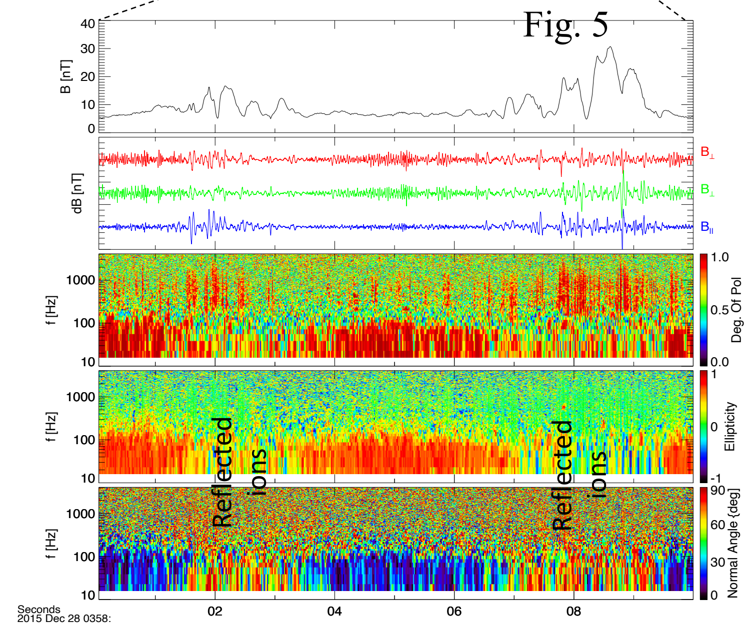
The red colors in Ratio of power spectral densities $[E(f)/cB(f)]$ indicate purely electrostatic wave activity (typical for the shock ramp).



Ion reflection

- In Fig. 4 we present ion data in the normal incidence frame (NIF), $\hat{\mathbf{n}}$: shock normal, $\widehat{\mathbf{t_2}}$: motional electric field.
- Ion phase space density holes in the foot are seen due to interaction with the wave packets.
- Ions accelerated by the motional electric field.
- Ion temperature anisotropy in the foot is due to reflected ions.
- Correlated increases in |B| fluctuations with reflected ion density (last two panels, Fig.4).





Conclusions:

- The upstream region is stable to ion acoustic waves. Ion Weibel instability can be excited in plasmas with magnetized electrons and unmagnetized ions.
- Coupling between reflected ions and ion Weibel instability can result in non-propagating linearly polarized magnetic waves (Burgess et al. 2016; Sundberg et al. 2017). What we observe upstream of this shock can be attributed to the ion Weibel instability.
- This instability is exited near the upstream edge of the foot due to the cross-field current of the reflected ions. During the interaction with reflected ions, the wave polarization changes (Fig.5).

Next steps: Quantify the ion Weibel instability (prop. direction, wave speed, etc.), identify the condition and threshold when broadband electrostatic waves emerge